coating. In addition, the formulation of Nukote HAR and HTD coatings significantly improved their cathodic-disbondment resistance in comparison with other types of polyurea coatings.

In the current Phase 2 initiative, these Nukote coatings will be further tested through long-term field trials in several applications.

Deliverables

Deliverables will include a report on the application of the coatings at various field sites. The report will also provide guidance for the polyurea applications method and process.

Benefits

This research will provide utilities with the comparative, sound engineering data necessary to make decisions regarding the use of polyurea coatings.

Technical Concept & Approach

Specific tasks include:

- **Identification of Field Test Sites and Coating Applicators**

  The research team surveyed project sponsors to determine/verify potential applications in the natural gas distribution system, identify coating applicators, and secure sponsors and sites for conducting field tests of the polyurea coatings.

- **Establishment of a Field Testing Matrix**

  This includes:

  - Selecting the coating for the typical application
  - Determining coating application methods and processes based on the field application, and
  - Determining the total test duration and coating evaluation frequency over the entire field-test period.

- **Evaluation of Field-Coating Applications**

  Technical staff will witness the coating preparation and application process and document the application parameters, field conditions, and completed installation.

- **Coating Evaluation**

  Evaluations of the in-field coatings will be conducted after one year of in-service conditions. Investigators will then re-evaluate the in-field coatings after three and five years of in-service conditions. The inspections will include visual and nondestructive coating evaluation to locate coating color change, blisters, peeling, rust, holidays, and adhesion.

- **Guidance for Polyurea Applications**

  Based on the field-test results, the research team will recommend the applications in the natural gas distribution system where polyurea coatings could be used. A guidance document on coating application methods and processes related to the specific applications will be developed.

Results

Initially, the research team conducted a survey with sponsoring companies to collect information about the potential applications and requirements for polyurea coatings. A test matrix was developed for a complete evaluation of the polyurea coatings.

The performance of polyurea coatings was evaluated using ASTM standard tests. The overall performance of polyurea coating was evaluated and compared with a benchmark liquid epoxy coating. A Final Report detailing testing results was issued in 2013.

A follow on project was recommended to conduct long-term field trials in several potential applications where polyurea coatings could outperform the traditional coatings, such as vaults, buried pipes, and pipe on bridge crossings. In addition, it was recommended that the coating-application method and process be evaluated in the follow-on field trial project to determine a cost-effective solution for each application.

In 2013, an effort focusing on Nukote coatings was initiated. A project survey was prepared to assist in identifying the sponsors and the sites for conducting field tests. The team identified a potential site in New York City for field installation and testing.

Status

Current activities are focused on establishing a field-testing matrix and preparing for field tests in 2015.

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Development of a System for Repair of Aboveground Leaks

Researchers are conducting a thorough evaluation of repair methods for leaks on aboveground piping in an effort to establish a basis for choosing the right repair method for a specific leak, establishing levels of adequate preparation, and providing the proper installation for increased reliability.

Project Description

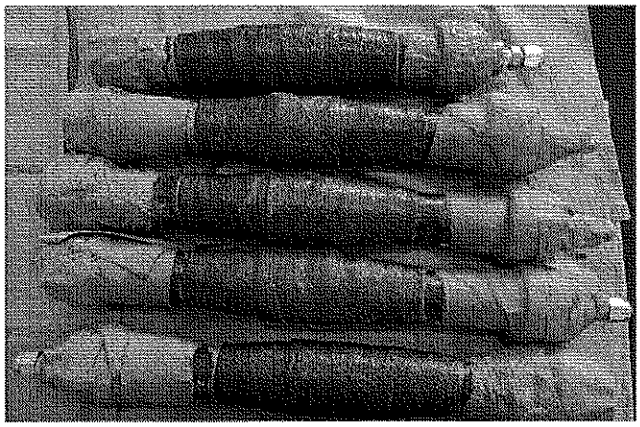
Utilities are now classifying and logging leaks on aboveground piping, and many have established that a significant number of the leaks occur due to pitting corrosion or through threaded joints between components. Removal or replacement of leaking components is not desired due to customer downtime, relights, and the time involved in conducting the repair. Additionally, many of the components (other than the thread area) may be in good working condition and do not require replacement.

Although many leak-repair systems are available, very few gas utilities are using these systems and, if they do, most use them only as a temporary repair.

Several of the most popular mechanical and composite -wrap systems in use today can be complicated and difficult to consistently install. Strict requirements for surface preparation, cleanliness, installation alignment, installation tension, torque requirements, and cure time all create variability in the final repair integrity.

Research found that there are several key factors that have resulted in large numbers (>10%) of these repair systems to leak within weeks or months of installation.

In this project, researchers are conducting an evaluation of repair methods for leaks on aboveground piping in an effort to establish permanency of the repairs and determine their life expectancy.



Repaired specimens prepared for accelerated corrosion testing.

Deliverables

The deliverable will be an analysis of the permanence of tested aboveground leak repair systems. The evaluation will provide extrapolated estimates of the long-term life expectancy of these repairs based on the long-term tests at elevated temperatures.

Based on the results of this effort, an additional task may be initiated to enhance current leak-repair systems and possibly begin the development of a new leak-repair system to allow for greater repair flexibility and reliability.

Benefits

Through a long-term evaluation of aboveground leak-repair installations, a basis will be established allowing utilities to determine the long-term performance of the repair methods for varying types of conditions. Benefits include improvements in the efficiency of utility personnel at resolving leaks, the quality of leak repairs installed, and the longevity of the repairs.

Technical Concept & Approach

This project currently consists of two main technical tasks:

- **Determination of Design Parameters**

  The project was initiated with an in-depth review of current repair systems for aboveground leaks. This was performed by reviewing current industry standards and practices, as well as conducting surveys of sponsoring utilities. Hydrostatic burst tests were also performed on leaky joint and pinhole repair samples.

  This was performed by reviewing current industry standards and practices, as well as conducting surveys of sponsoring utilities. Hydrostatic burst tests were also performed on leaky joint and pinhole repair samples.

- **Testing & Analysis of Available Repair Methods**

  Researchers will conduct a thorough evaluation of specific systems to establish their long-term life expectancy for use as permanent repairs.

  Test samples will be prepared, and the testing platforms fabricated. The samples will be constructed to represent leaking joints and pinholes in the field.

  Samples will be evaluated in long-term hydrostatic pressure tests. The method consists of testing sets of specimens at three different temperatures. The samples at each temperature are held under various pressures to create failures in the desired timeframe.

Results

Initial activities involved the establishment of the testing platform, procedures, and parameters for the evaluation of two aboveground leak-repair systems.

Following initial contact with the system manufacturers, test results from the manufacturers were gathered, and initial product orders were completed. Prototype test samples were then constructed to simulate aboveground leaks from varying levels of corrosion (pin holes) and from threaded joints. The test samples were then fabricated, fitted with the corresponding repairs, and hydrostatically tested to failure.

Following hydrostatic initial burst testing, a series of short-term samples were constructed to aid in establishing the long-term test pressure.

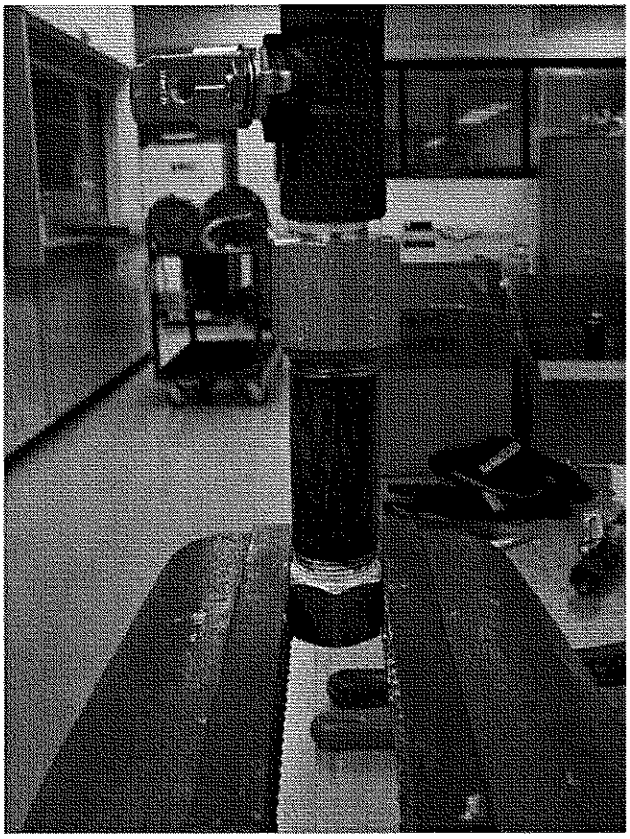
A test apparatus was constructed to determine both leak and burst failures and to condition the test samples to temperatures ranging from 23°C-60°C.

In 2012, a total of 30 samples from two manufacturers were evaluated. Following completion of the short-term test evaluation, an initial analysis was performed. Results are detailed in a report to project sponsors.

Activities for 2013 included the development of a procedure for pipe-sample preparation and repair, followed by the initiation of long-term testing.

The scope of the program was revised to include an updated testing matrix and another product to add to the testing program. Based on the revised project scope, the project team requested that the sponsors provide 10-15 vertical lengths of 12-inch pipe cut from a riser. A total of approximately 100 field samples are required for the revised testing program.

The project team met with representatives from the manufacturers of the fourth repair product who provided 40 of their repair kits as in-kind material contribution towards the project.



Repair on a leaking joint.

Testing continued throughout 2014.

Status

Testing is ongoing.

Unfortunately, the project team did not receive the required amount of samples to fully execute the testing program. Due to the shortage of field samples, researchers planned to initiate the test program based on what had been received and make up the remainder with new (standardized) samples. However, most of the field samples received were severely corroded and were not in a condition that could be used for testing. As a result only eight field samples were used for testing. Consequently, a schedule extension through July, 2015, was requested.

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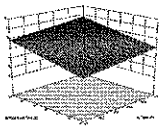
OTD Operations Technology Development

Integrated Expert Monitoring and Training System for Butt Fusion



A set of critical fusion variables is being developed in an effort to provide the gas industry with an integrated technology package for use in pipe-fusion training and field operations. The goal is to produce a system capable of flagging marginal fusions in all operating conditions.

Project Description

In this project, researchers are investigating technology that could be used to help reduce the likelihood of human error in the plastic-pipe fusion process.

Currently, data-logging systems for butt-fusion machines reflect an operating window that captures common practice and, on average, ensures a reliable butt-fusion joint. Inspection protocols rely mainly on visual cues (e.g., bead size and shape) that reflect a large body of experience with historic materials. It is possible to produce sub-standard joints while following the existing procedure and complying with all visual-inspection criteria. (These uncommon circumstances arise when the polymer state at the interface does not meet the minimum requirements to ensure successful co-crystallization across the interface.)

The technology being applied in this project relies on polymer physics and accurate displacement and temperature control to derive a variable that is directly driven by proper displacement of the interface. Using pressure as the primary control variable, as is the case with current technology, does not ensure optimal interfacial end states in all circumstances. Unusual interactions of drag, materials, heater-plate temperature, and ambient conditions can fool a pressure- and visual-cue controlled system. These unusual combinations will be specifically addressed in the design and control approach of the new technology.

The method was used in a NYSEARCH project that evaluated the integrity of butt-fused joints. This same project utilized a full pipe creep-rupture test to evaluate the robustness of joints fused under different conditions. The full pipe creep-rupture test proved to be sensitive to joint-quality variation, but the project did not develop sufficient quantitative data to attach a reliable quality score to joints fused under different conditions. In this new project, researchers will use this experience with the full pipe creep-rupture test in conjunction with the rate-process method and standard ASTM test methods to fill this knowledge gap.

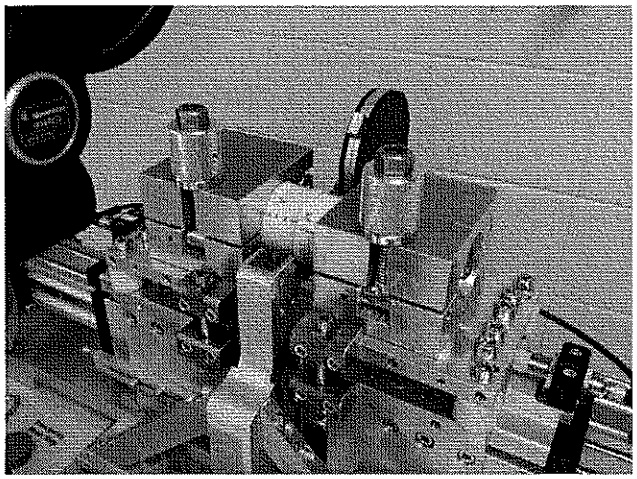
The goal is to produce a system capable of flagging marginal fusions in all operating conditions and provide guidance on how to adjust the process to achieve a good fusion, or instruct the operator to abandon a joint that is not within prescribed limits.

The short-term objective is to develop a well-defined set of critical variables and their bounds that will ensure robust butt-fusion joints under widely varying fusion conditions. A longer-term objective is to assemble a complete integrated expert monitoring and training system technology package that can be licensed to butt-fusion-equipment manufacturers and allow them to develop their own implementations of the concept.

Deliverables

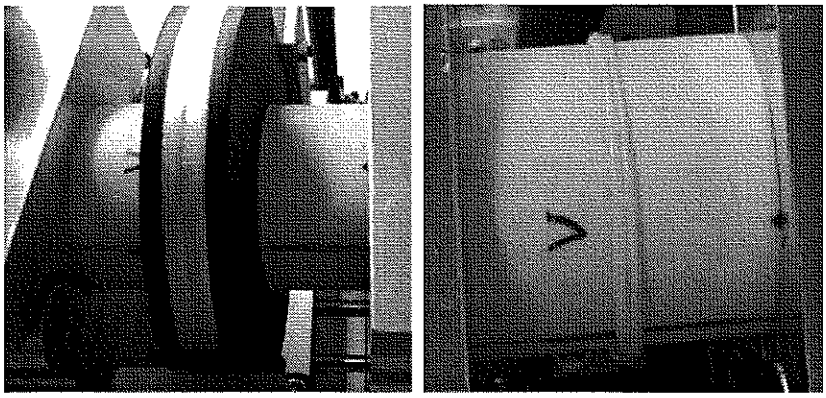
The deliverables for this project include:

- A list of essential variables and their acceptable limits for the butt-fusion process
- A set of procedures and protocols for realizing a robust butt-fusion process
- A comprehensive data set validating the effectiveness of the preferred processes
- A set of quality-control parameters that will be logged with each fusion and will provide an acceptable confidence level that the fusions were performed in the optimal process window



Custom-designed butt-fusion machine.

- A set of utility specific data that will be logged by the data logger and uploaded to GIS or other databases for integrity management
- A pre-commercial prototype that demonstrates the viability of the method.



Butt-fusion joint during heat soak (left) and cooling (right) phases.

Benefits

Intelligent monitoring and logging of the butt-fusion process will enhance safety, help ensure compliance with Distribution Integrity Management regulations, and minimize risk to the gas utility.

Integrated and interactive expert guidance during the butt-fusion process will be a valuable aid to field operators as well as an excellent training system for novice fusion operators. Installation crews will need less specialized training to achieve reliable and robust joint quality in the field under a wide range of ambient conditions. An expert system would ultimately help to reduce the risk of fusion joints susceptible to long-term failure due to improper fusion.

Technical Concept & Approach

- Analysis of the Fusion Process and Identification of the Preferred Butt-Fusion Process
- Specification of the Butt-fusion Machine and Manufacture of Equipment
- RPM Testing and Assembling Data Package
- Technology Package and Final Report.

Results

This project began in 2012 with a cataloging of pipe samples and baseline testing of material properties. A prototype butt-fusion machine was developed and modified.

In 2013, a butt-fusion testing matrix was developed. Preliminary butt fusions showed a need for fusion-process modifications (to closely replicate field procedures) with software changes and optimizations related to datalogging. Machine software modifications were completed as well as a testing procedure for the extraction of time-temperature shift factors, ultrasonic inspection of two-inch IPS butt-fusion joints, and infrared video capture of fusions. A fusion and testing workflow was also developed for execution of the Design-of-Experiment test matrices.

The detailed information gathered on actual fusion conditions and the test results will become the input for the models needed to develop an expert system that can be used for monitoring butt-fusion joints.

In 2014, an exploration of the range of acceptable interfacial pressures was initiated. Bend-back tests were carried out on joints made at the highest interfacial pressure the butt-fusion machine is capable of performing (150 psi), as well as at extremely low interfacial pressures (1 psi), at 400°F, 450°F, and 500°F plate temperatures. The fusion process was explored further, specifically focused on a motorized R&D butt-fusion machine can mimic the fusion process of both manual and hydraulic machines.

A number of fusions were executed to explore the dependency of weld displacement on plate temperature, heat soak time, and interfacial pressure. The major objective of these exploratory tests is to ensure that the final test matrices are correctly designed to match field conditions and fusion procedures. The preliminary tests demonstrated the ability to gather all relevant data for creating a butt-fusion expert monitoring system.

Status

The fusion process envelope limits continue to be explored. This includes more mechanical testing of fusions to obtain quantitative and qualitative fusion evaluations.

Fusions are expected to be completed by year-end 2014, with testing of the joints occurring in parallel with the fusions.

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Liners/Composites for the Rehabilitation of Distribution and Transmission Lines

This project focused on creating an implementation roadmap for the development, testing, and regulatory-approval process for new composite materials and technologies that allow for the rehabilitation of distribution and transmission pipelines through the trenchless insertion of composite pipe and/or structural liners.

Project Description

The overall objective of this program was to implement new composite materials and technologies that allow for the rehabilitation of distribution and transmission pipelines through the trenchless insertion of a composite pipe and/or structural liners.

Some pipeline operators have obtained special permits to use composite-material piping systems – such as Smart Pipe®, Fiberspar®, and FlexSteel® – to rehabilitate their pipe infrastructures. These special permits were for natural gas distribution and transmission lines that operate in Class 1 and 2 locations.

Discussions with the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) indicated that the administration is open to continue considering the acceptance of new materials through the special-permit process, providing that testing and evaluation is completed according to the appropriate material standards.

A composites workshop held in 2012 – which included pipeline operators, regulators, and other industry experts – identified several concerns over the development needs for long-term implementation and the long timeline required for regulatory acceptance. Significant findings included the following:

- **Composite Pipe Material Development, Testing, and Evaluation**

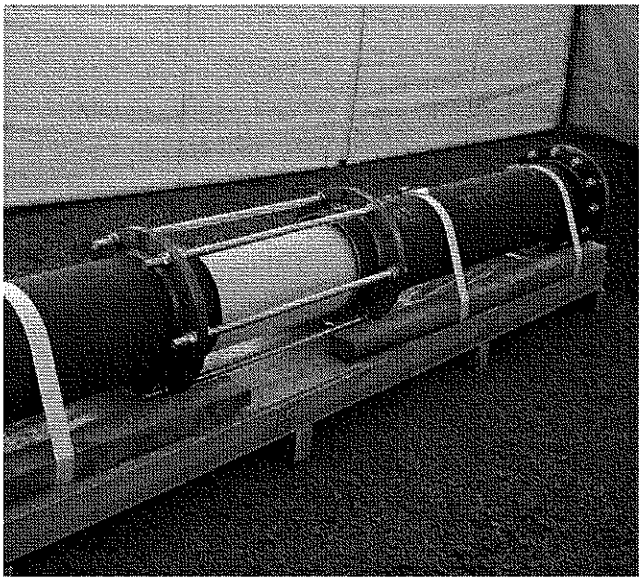
  Composite pipe systems are currently being used in upstream applications such as gas gathering and oil-field production. The application to existing pipeline infrastructure introduces challenges which include the evaluation of the long-term performance and the development and evaluation of the necessary fittings and appurtenances for certain natural gas applications (e.g., service taps and transition fittings).

- **Regulatory Approval**

  The special permit process appears to be the appropriate path forward for regulatory approval until full regulatory acceptance is achieved. Based on recent experiences, the timeline for obtaining regulatory approval of composite materials through the special permit process is approximately one year. The timeframe for full acceptance within the federal code is not well defined due to the lack of comprehensive standards for these materials and an ambiguous regulatory approval process. Past experience suggests that a minimum of three to five years is needed for standards development and that regulatory acceptance on the basis of these standards can take longer and include field trials installed under a special permit. Composite pipe special permit applications submitted to date for transmission applications have been in Class 1 and 2 locations and, therefore, have not addressed the significant pipeline integrity requirements. One key goal of this project is to perform a detailed analysis of all federal and state regulatory requirements and outline the pipeline-integrity implications of utilizing any of the commercially available composite pipe/liner technologies.

Deliverables

The deliverable for this project will be an implementation roadmap for the selection of the composite pipe materials and rehabilitation techniques, testing, and permitting requirements.



View of the pipe sample during pressure test.

Benefits

Modernization of the gas infrastructure is a challenge to distribution and transmission pipeline operators and it is particularly problematic in urban areas with very limited right-of-way space and high excavation and restoration costs. The trenchless installation of composite materials can potentially provide cost-effective means of restoring aging pipelines to full capability.

Technical Concept & Approach

This project focused on the development of an operator-specific implementation roadmap for composite-pipe rehabilitation technologies (e.g., cured-in-place liners, structural liners, and composite pipe for insertion) installed using trenchless techniques for both distribution and high-pressure systems (e.g., 350 psig). The project focused on existing technologies that can meet the business, engineering, and regulatory requirements for high-priority pipe.

The research team will develop an implementation roadmap for each of the composite-pipe-rehabilitation-material options. The implementation roadmap will include the following:

- Technology Selection Criteria
- Installation Considerations
- Operating and Maintenance Consideration
- Integrity-Management Considerations
- Regulatory Acceptance Strategy.

Results

In 2013, researchers investigated the use of liners in the rehabilitation of medium-pressure mains and high-pressure distribution line systems. A report was developed that covers:

- Properties and characteristics of available structural liners for the rehabilitation of transmission pipes
- An evaluation and selection of the composites in the external repair of mechanical damage in gas transmission lines
- An evaluation of the operating pressures of pipes with known toughness and yield strength.

Three potential rehabilitations systems were selected for study: starline® HPL-250, Smart Pipe®, and Primus Line®.

A laboratory test for the installation of Primus liners was conducted. The Primus Line is a multi-layered composite structure for the rehabilitation of gas pipelines. The system is planned for use in the rehabilitation of coated steel gas distribution lines with typical operating pressure of 220 psig and maximum operating pressure of 250 psig. The test consisted of testing one size of the Primus flexible high-pressure lines installed into a typical 12-inch pipe. The pipe had an open section to simulate a 36-inch free span. The system was pressurized to twice the pipe operating pressure using water pressure. Strain gages were installed to monitor the strains at the free-span section. A report on the results of the testing of Primus liners was submitted to project sponsors.

In field installations, the Primus Liner is inserted into the host pipe from small construction pits. The liner is not attached to the host pipe and an annulus space remains between the liner and the host pipe. A high-pressure connector is used at each end of the pipe to connect to the host pipe (steel, cast iron, or PE).

Status

This project was completed in 2014. A Final Report was prepared for this project and submitted to project sponsors.

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Guidelines for Special Permits for Structural Composite Rehabilitations

In many cases, the use of composite materials for pipe rehabilitation may be a cost-effective alternative to open-trench operations. However, special permits are required for the use of composites. In this project, guidelines are being developed for facilitating the process for submitting special permits to use composite materials for structural pipe rehabilitation.

Project Description

The need for new techniques to repair and replace gas distribution piping will continue to increase as the natural gas infrastructure continues to age.

While open-trench replacement will be the most cost-effective technique for many applications, some situations will require the use of trenchless or alternative techniques that use the host pipe as a conduit for installing a new pipe.

Research is finding that composite materials hold much promise for use in pipeline rehabilitation. Composite materials can have properties that are superior to steel and can be installed in flexible configurations.

The U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) suggested that the industry undertake a program that includes special permits, testing, standards development and pilot projects to obtain regulatory acceptance.

In response, this project is focused on developing information on the approval process and guidelines for submitting special permits for approval to use composite materials for structural pipe rehabilitation.

Current regulations do not prohibit the use of composites; however, special permits are required because they are not specifically approved. Furthermore, some sections of the regulation are not applicable or difficult to apply to composite pipes. (For example, the design requirements and pressure limitations for plastic and steel are not directly applicable to composite materials.)

Deliverables

The deliverable for this project will be a set of guidelines to assist operators in filing special permit applications to allow for the use of composite materials for structural pipe rehabilitation.

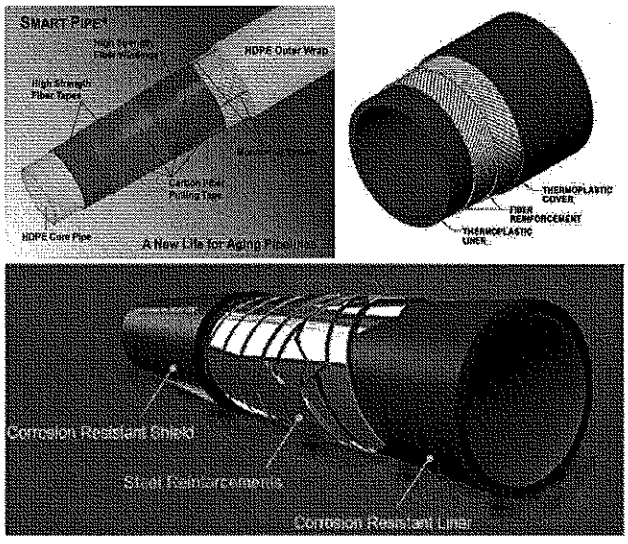
Benefits

Guidelines for submitting special permit requests will reduce the cost and time associated with filing the application. Guidelines will also improve the likelihood of obtaining approval through a special permit by ensuring that permit applications are complete and address issues of interest to state and federal regulators.

Technical Concept & Approach

A research team is developing special permit guidelines that include the following information:

- Sections of the regulation for which the waiver is requested
- Pipe segment characteristics
- Environmental conditions
- Technical properties of the composite material
- Compliance with industry standards



Through a previous OTD project, researchers identified several candidate technologies for both low-pressure distribution mains and high-pressure transmission lines.

- Performance history of the composite material
- Lessons learned from previous installations
- "Best Practices" for design, installation, testing, monitoring, operations, and maintenance.

This project involves a review of accepted and denied special permit applications to identify the information that must be included in an application. Federal and state regulators will also be engaged in developing the guidelines.

Results

This project was initiated in early 2013 with an investigation of previous accepted and denied special permits related to composites and rehabilitation techniques.

Special permit language for the use of a brand of semi-structural cured-in-place liners was drafted.

The guidelines include the following sections:

- Wavier Request
- Situation
- Material Description
- Benefits
- Past Experience
- Engineering Design
- MAOP and Design Strength
- Design Life and Long-Term Performance
- Gas Permeation
- Installation
- Operator Qualifications
- Post-Construction Testing
- Operations and Maintenance
- Monitoring
- Integrity Management
- Regulatory Oversight.

The project team reviewed candidate pipe segment information from one of the project sponsors. The team will present the recommended liner/composite to the sponsor/utility for approval. Investigators will subsequently write special permit language for the specific line segment and the selected technology for the sponsoring utility to submit to its public utility commission.

Status

In cooperation with participating operators, the project team will select a candidate pipe segment and one or more potential technologies for consideration. Upon selection of the pipe segment and the structural liner/composite, special permit language will be drafted.

Potential structural liner/composite system information will be gathered and shared with sponsors. Backyard installations may even be considered for some of the technologies.

The PHMSA recently added a category called "Reconditioned Cast Iron Pipe" to its annual report. This new category could potentially eliminate the need to submit a special permit for cured-in-place liners. Efforts are under way to determine how this new category will impact this project, as well as special permits in general.

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OTD Operations Technology Development

Accelerated Dynamic Testing for Long-Term Evaluation of Liners & Composite Pipe Materials

Research is under way for predicting the long-term performance of liners and composites in accelerated pressure tests. These liners are used in the rehabilitation of aging gas distribution and transmission lines.

Project Description

The trenchless installation of liners and composite materials can potentially provide a safe and cost-effective way for restoring aging pipelines to full capability.

While some pipeline operators have obtained special permits to use composite-material piping systems, the requirements for these special permits include providing supporting test data regarding the long-term performance of the composite materials. The objective of this project is to establish an accelerated testing procedure for the long-term prediction of the performance of liners and composite pipe materials. The procedure will provide an engineering assessment of the long-term performance (20 to 30 years) of the liner/ composite materials from relatively shorter hydrostatic cyclic tests at elevated temperatures.

Major funding for this project is provided by the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) and OTD matching funds.

Deliverable

The deliverables of the project are:

- Testing protocols for long-term tests
- The distribution of guidelines and "Best Practices" to aid pipeline operators in selecting, designing, and installing the composites based on their performance and operation characteristics.

Benefits

The rehabilitation of the natural gas distribution and transmission infrastructure is particularly problematic in urban areas with congested pipeline systems, very limited right-of-way space, and high excavation and restoration costs. The use of composite pipes, structural liners, and composite repairs in the rehabilitation of these systems can be an economically attractive alternative to the open-trench replacement option.

Test results from this project will provide the service-life predictions of composite pipes and structural liners used in the rehabilitation of distribution and transmission pipelines by trenchless insertion.

Technical Concept & Approach

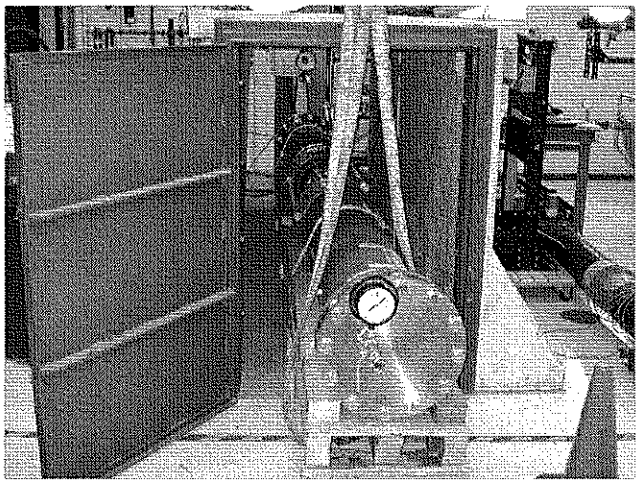
Current procedures for predicting the service life of liners and composites consist of performing several 10,000-hour (i.e., 14 months) hydrostatic pressure tests and extrapolating the material performance to longer times. Cyclic tests at elevated temperatures provide an accelerated procedure to identify the critical parameters which are used to establish the creep performance of the material at the desired operating condition.

In this project, researchers are testing liners and composites installed by insertion into the original carrier pipe using trenchless techniques. The selected products in the testing matrix can be used in distribution and high-pressure piping systems up to 350 psig.

The project consist of the following tasks:

- **Establishing Testing Requirements**

  This task consists of a detailed procedure involving the testing program, including the selection of the liners and composites for testing, cyclic equipment requirements and capabilities, instrumentation and monitoring, and the initial layout of the prediction approach.



Accelerated pressure testing.

- **Testing Setup and Calibration**

  This task includes the modification of testing equipment to be able to apply pressure cycles at various ranges of pressures, loading frequencies, and elevated temperatures.

- **Performing Accelerated Cyclic Tests**

  This task includes the sample preparation, instrumentation and testing setup, and performing the cyclic pressure tests. Pressures will be applied at various loading frequencies and loading levels from 0.10 to 0.75 of the maximum strength of the rehabilitated system. The tests will be applied at various temperatures to provide the strain temperature curves needed to establish the creep performance of the material.

- **Prediction and Validation Procedures**

  The analytical procedure for the prediction of the long-term performance will be developed in this task. The procedure will be based on established rheological models that relate the load, frequency, and temperature to construct a prediction curve for the long-term deformation of the material. Hydrostatic pressure tests will be performed at longer time intervals of 1,000 hours to validate the predictions from the cyclic tests at this duration.

Results

Researchers initially reviewed current standards and testing procedures (e.g., ASME, ASTM, ISO) to identify the requirements for the qualification of the composite systems and define a roadmap for their standardization and implementation.

A report was developed that presents a summary of current structural liners and composites that are installed using horizontal directional drilling techniques.

Full-scale hydrostatic pressure tests were performed to evaluate the strength basis of a structural liner. These tests were performed on a 12-inch-diameter, 13.5-foot-long steel pipe section with a liner installed inside the pipe. The liner was designed to carry the internal pressure of the pipe up to 450 psig.

Researchers concluded that the following steps need to be achieved to accelerate the use of composite liners and pipe in the rehabilitation of transmission lines:

- **Composite Pipe Material Development, Testing, and Evaluation**

  It is expected that currently available composite materials can be adapted to pipeline transmission in a short timeframe. Challenges include the availability and acceptance of the necessary fittings and appurtenances for certain applications (e.g., end connections, service taps, transition fittings, etc.).

- **Regulatory Approval**

  The special permit process appears to be the appropriate path forward for regulatory approval until full regulatory acceptance is achieved.

- **Full Regulatory Acceptance**

  The timeframe for full acceptance within the federal code is not well defined due to the lack of comprehensive standards for these new materials and the gaps in their quality control and integrity-management implementation.

A testing procedure was established to assess the long-term performance from relatively short hydrostatic and cyclic loading tests. The results from tests at elevated temperatures will be implemented based on the load-time-temperature superposition principals. A report was prepared to present the procedure for testing full-scale composite pipe samples under cyclic loading.

Long-term tests are carried out on pipe samples consisting of the basic pipe body and end fittings at both sides of the pipe. Tests at elevated temperatures are conducted in a thermostat-controlled water bath. Tests at room temperature are performed in the air with the specimen inside a concrete enclosure for safety.

A cyclic loading test at room temperature was completed on a composite pipe specimen.

Status

Testing is ongoing.

The project team identified research needs for the implementation of composites as structural elements, including: integrity management of the composite pipes; establishing risk assessment and fitness-for-service approaches or practices similar to steel pipelines; nondestructive inspection methods (e.g., x-ray spectroscopy, electromagnetic, and microwave); construction guidelines; locating composite pipes and procedures for emergency response; connections and fittings with dissimilar pipes; and field repairs and the installation of flow control devices.

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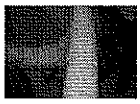
OTD Operations Technology Development

Composite Repair Wrap for Polyethylene Systems



Researchers are evaluating a new composite pipe wrap system for the repair of mechanically damaged polyethylene gas pipe. The repair system has the potential to lower repair costs, reduce repair times, and minimize service disruptions.

Project Description

The options that currently exist for the repair of polyethylene (PE) natural gas pipes, couplings, and joints are often nonexistent, costly, or unreliable.

With the few PE repair methods available, typically a short section of the distribution system is shut down and bypassed while the damaged pipe section is cut out and replaced. This approach is time consuming, expensive, and requires multiple excavations and complicated procedures. However, a new pipe wrap system for the repair of PE pipe components shows promise of being a fast, easy-to-use, durable, and cost-effective method for PE pipe repair.

This pipe wrap method provides direct bonding of composite materials to the PE pipe surface with minimal surface preparation. The composite material may be either resin pre-impregnated fiberglass cloth or field -impregnated fiberglass that adheres to PVC, fiberglass, concrete, and all metal pipes. According to the manufacturer, the PE pipe repair method and materials will also provide abrasion and impact resistance to the PE pipe. A single system can be used to repair pipes and/or fittings of various diameters, sizes, and shapes.

Although composites have been used for more than 20 years to remediate steel piping, the ability to repair PE pipe was limited due to the inability of composites to bond to the PE material. The patent-pending pipe wrap technology overcomes this limitation with minimal surface preparation. An initial test for bonding a composite directly to PE material resulted in average lap shear strength of 900 psi.

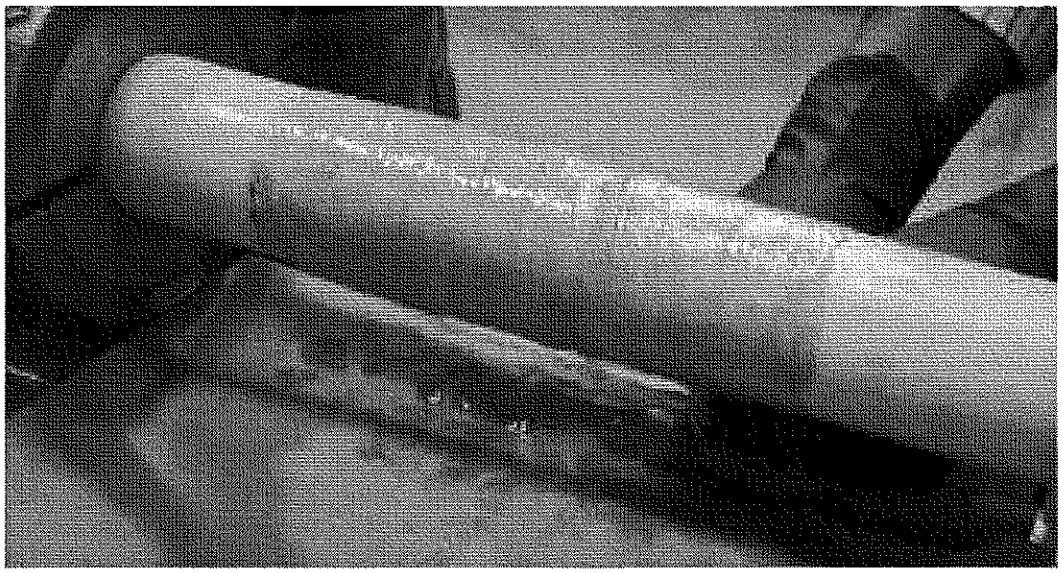
The objective of this project is to conduct a thorough evaluation of the pipe wrap system to develop information on the permanency of the repairs and determine the life expectancy.

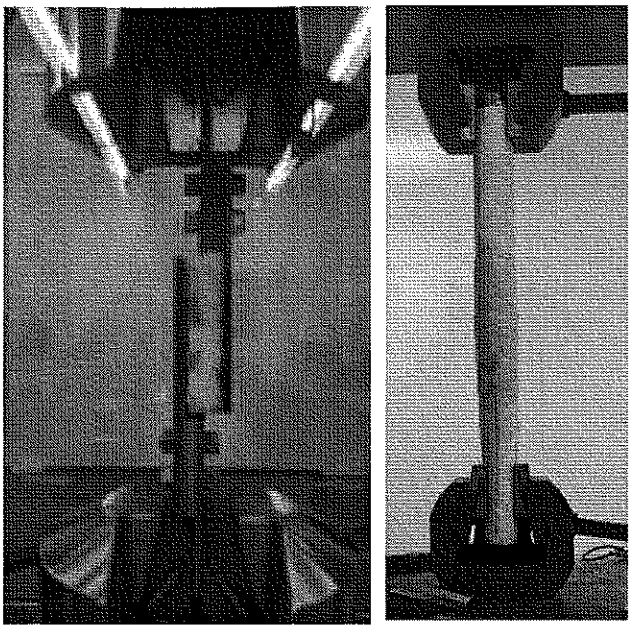
Deliverables

The deliverables for this project include testing reports detailing the performance of repairs made with the pipe wrap system.

Benefits

PE pipe systems experience two common types of damages. The first type is third-party mechanical damage that results in pipe wall loss that requires immediate remediation where the only available option is to remove and replace the damaged section. The second type is longer-term damage which manifests from either crimp-type fittings or the crimping operation required to conduct a cut-and-replace operation (which





Left: Composite to PE shear test.
Right: Tensile testing of repaired sample.

quired to conduct a cut-and-replace operation (which introduces micro-cracks into the pipe wall. These micro -cracks can become problematic and can be considered as deferred remediation projects. Both types of damage, if left in their natural state, will result in leaks and/or other hazards.

In some situations, the currently used repair systems were never designed for outdoor atmospheric exposure, and when used under these environments may prematurely degrade, leading to the reoccurrence of a leak. In addition, some of these repair systems are complex to install properly and their inherent designs produce a large degree of variability in the installation and, therefore, performance quality.

A practical PE permanent repair system will save time and money while minimizing service disruptions.

Technical Concept & Approach

The investigation of the pipe wrap PE pipe repair system focuses on applying the repair technique to different gas system components to evaluate effectiveness.

Simulated defects are machined in each pipe specimen. The mechanical properties of pipe wrap will be evaluated by determining lap shear strength in accordance with ASTM D3983 Standard Test Method for Measuring Strength and Shear Modulus of Non-rigid Adhesives by the Thick-Adhered Tensile-Lap Specimen.

Prepared samples undergo the following:

- Short-term hydrostatic burst testing.

"OTD works for the benefit of gas system operators and gas customers to create innovative solutions to address operational needs. This project to develop a repair wrap for damaged PE pipe is one such project to provide our field personnel an easily applied repair tool that will improve our operations by decreasing the time and the cost of repairs to our small-diameter PE distribution system."

- Richard J. Trieste, Jr.
Department Manager, Research & Development
Consolidated Edison Company of New York

- Rate Process Method (RPM) analysis by performing long-term hydrostatic pressure testing at elevated temperatures. Then, failure data obtained at all temperatures will be used to predict the performance of the repaired pipe samples at end-use temperature and pressure conditions.
- Impact testing in general accordance with ASTM D2444 Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (falling weight).

Results

This project was initiated in early 2014 with various interactions with the pipe wrap manufacturer to address concerns and options. Various pipe specimens were prepared with simulated defects and subjected to tensile testing and burst testing. Based on the limited number of specimens prepared and subjected to hydrostatic burst testing to date, it appears that the repaired two-inch-diameter pipe samples, irrespective of the pipe sample being heated or not during the repair process, are performing well. The peak load, stress values, and other information was provided in a report to project sponsors.

Status

Testing is ongoing. Efforts are also under way to establish the correct combination of adhesive and wrapping material by preparing additional specimens, some with simulated defects, and subject them to mechanical properties testing such as lap shear strength and tensile testing.

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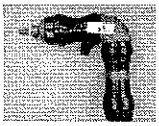
OTD Operations Technology Development

Pipe System Repair Techique

The objective of this project is to advance a novel repair method for live leaking steel-infrastructure applications. The goal is to have the repair method applicable to steel couplings, threaded joints, cast-iron bell joints, and service tees.



Project Description

In the natural gas industry, addressing the repairs of leaking infrastructure is a top priority. However, currently available options for the repair of leaking couplings, threaded joints, cast-iron bell joints, and service tees are often nonexistent, costly, or not reliable.

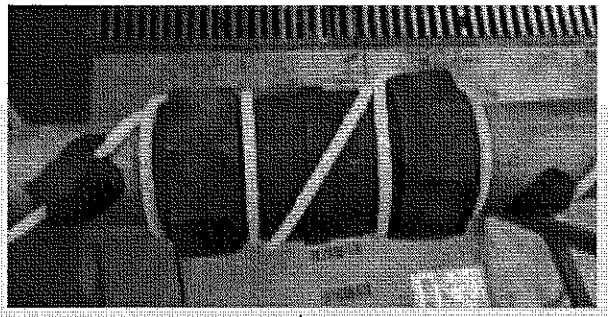
Available options involve line blow-down, bypass, cut out and replace, or encapsulation-type fittings. There are very few options for the live *in-situ* repair of leaking infrastructure components.

In this project, research is focused on addressing the need for a permanent leak-repair method that can be applied to many infrastructure components of various geometries without first stopping the leak. The project builds on the success of a effort supported by Gas Technology Institute's Sustaining Membership Program (SMP) in which a method was developed and tested that can seal a live leaking mechanical coupling up to 60 psig and provide axial restraint that exceeds that of a properly installed new Dresser Style 90 coupling.

This project includes the validation and application of this repair technique to various steel components.

Deliverables

Deliverables for this project include details on the performance of the repair technique applied to leaking steel pipe segments and leaking mechanical couplings. The intent is to have a set of procedures for application of the process to mechanical couplings, leaking steel pipes, cast-iron bell joints, and service tees.



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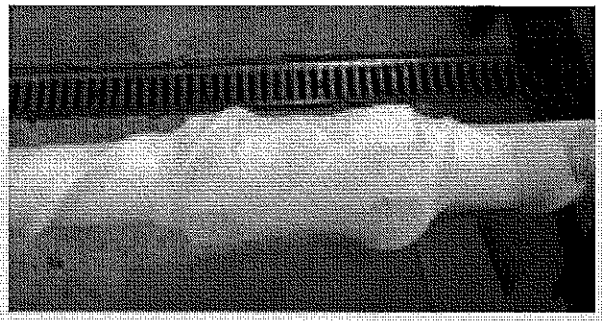

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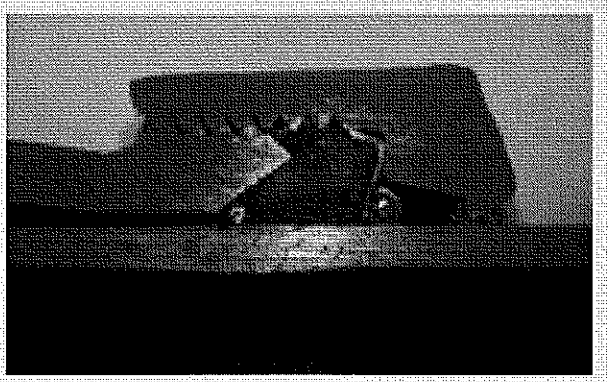

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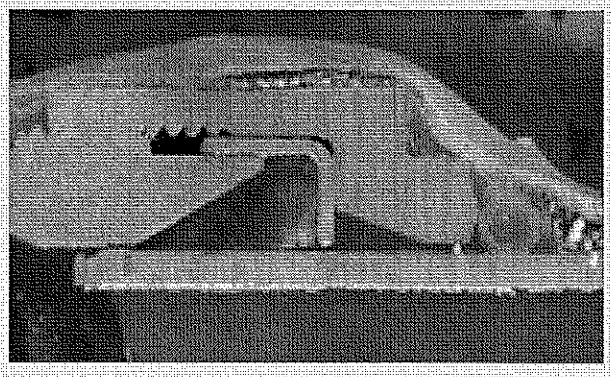

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The pipe-repair technique uses a perforated vent tube that is placed in contact with the leak (figure 1). This tube allows the escaping gas to be transported through the tube and into the atmosphere while the coupling is wrapped with a composite wrap (figure 2). The wrap cures in minutes and the leaking components' voids (figure 3) are filled (figure 4) by injecting sealant into the vent tube. The sealant is allowed to cure under pressure, completing the repair.

Benefits

The goal of this project is to advance the development of a permanent *in-situ* (i.e., without shutdown/bypass and cut out) method to repair leaking gas-system components and simultaneously provide axial pullout restraint for non-restraint type couplings. The commercial introduction of such a method would reduce operational costs and time, and improve the integrity of the gas piping systems.

This research will also provide utilities and potential commercializers with the sound engineering test data necessary to determine the permanence and effectiveness of this innovative *in-situ* repair method.

Technical Concept & Approach

In the initial SMP project, the repair technique was used to seal leaking couplings. This new project focuses on validating the technique on various steel gas-system components to evaluate its effectiveness and refine the process.

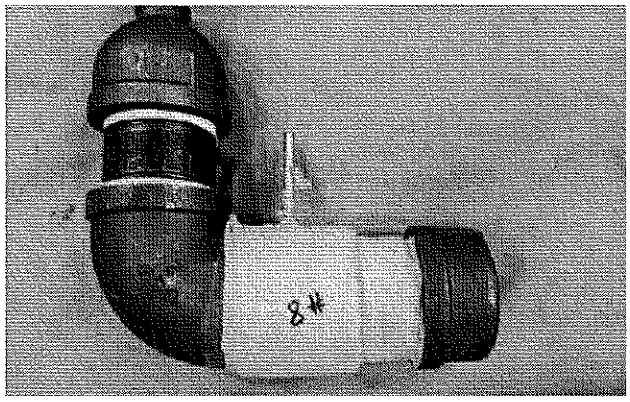
For testing, the research team acquired samples of 20 leaking steel-pipe segments and 20 leaking mechanical couplings. The samples were acquired from sponsoring utilities and/or simulated defects were created in the laboratory. Researchers also contacted composite wrap manufacturers to obtain materials and gain a better insight into options for improved performance.

The testing could include tensile, environmental, burst, or other types of tests.

Results

A survey was developed to gather information related to the size and types of fittings for the application of the leak-repair method.

Leak samples were prepared with two-inch-diameter pipe and coupling assemblies with composite wraps and adhesives applied. Attempts to replicate the leak repair that was performed in the SMP project were unsuccessful. It was difficult to get enough resin through the repair prior to it setting up, and technicians were unable to stop the leak. After several failed attempts, the team explored two different alternatives to successfully overcome the issue. Several alternative materials were investigated, including metallic-mold and condensed-tube wrap. Researchers investigated and used different resin systems, including room-temperature cure, low-viscosity resins, and heat-curable resins.



The option that was selected for further testing was a steel mold that the resin is injected into and allowed to cure. The mold is removed and then the composite wrap is applied.

Status

Researchers are proceeding with testing on the metallic mold design that was presented as an alternative. This testing is ongoing, and the prepared samples to date have shown the ability to repair the leak. Further temperature and pressure testing will continue.

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EXCAVATION & SITE RESTORATION

Excavation and site restoration are traditionally costly and time-consuming operations. In this area, research is conducted to lower those costs and improve efficiencies through investigations and developments in materials, construction procedures, and equipment.

Current efforts are focused on enhancing the operation of a soil-compaction-measurement device.

OTD Operations Technology Development

Soil Compaction Supervisor Enhancements

Efforts are under way to upgrade the capabilities of the Soil Compaction Supervisor to make it compatible with modern Geographic Information System data-capture practices as well as more user friendly through better data-logging and reporting capabilities.

Project Description

The current second-generation Soil Compaction Supervisor (SCS2) is a low-cost, easy-to-use instrument that assists with optimizing the compaction of backfill by eliminating inadequate compaction. The SCS2 also provides the ability to record compaction data for analysis, reporting, and quality control.

In use, a disposable sensor is placed in the bottom of an excavation and its cable is connected to the SCS2 handheld device. As each lift is compacted, the sensor sends a signal to the SCS2 for processing. When the maximum compaction is achieved, the SCS2 signals the user to stop compaction, and the data for that lift is recorded.

Industry practices in field-data collection have evolved considerably since the Soil Compaction Supervisor was first introduced. Currently, transferring data out of the SCS2 handheld device requires a "data key." This is an obsolete type of removable storage device that predates USB thumb drives or SD cards. The key and associated reader have become so difficult to procure that a hardware upgrade is required to conform to modern data-transfer methods.

This project focuses on enhancing the product with the ability to attach metadata (such as GPS coordinates and photos) to compaction data and make the data available via a Bluetooth® link. An Android device will be used to display and control the acquisition of data as well as provide extended data storage. Transferring compaction data from an Android device to a Geographic Information System (GIS) can be easily accomplished.

The additional capabilities available on Android devices (GPS, camera, connectivity, etc.) will be incorporated into the data acquisition. The data will be displayed graphically as it is acquired.

Initial investigations will also be made to determine the product's ability to be correlated to a standard proctor value or range.

Deliverables

The deliverables of the project are:

- An Android application that is compatible with the most recent SCS hardware
- The ability to attach GPS and other metadata to the compaction record prior to storing or forwarding
- Testing data on the complete hardware/software system
- In-ground test data for the SCS sensor cross-checked by a nuclear densitometer
- Field demonstrations of the new SCS system.

Benefits

By redesigning the SCS, a useful tool will continue to be available and have the enhanced ability for the data generated to be directly imported into utility GIS or other data systems. Capturing and archiving soil-compaction data will help ensure that compaction is being performed properly (quality control) and will enable a utility to validate proper compaction to jurisdictional and/or regulatory authorities.

The testing portion of the project seeks to obtain a better understanding of the correlation of the SCS data with that from a nuclear densitometer to provide a lower-cost alternative.

Technical Concept & Approach

Initially, project sponsors will be solicited for input on determining:

- The type of Android mobile devices in use by the utility workforce
- Metadata that would be valuable to capture with the compaction data
- The GIS or database schema that would be preferred by the project sponsors.

Based on the information gathered from project sponsors, field-user interface software will be constructed. The initial target will be an Android tablet device. The user interface is expected to provide (but is not limited to) the following:

- Graphical display of compaction data
- Methods to choose and attach metadata (such as location and photos) to the compaction record
- Methods to store and/or forward data records on the tablet.

Functional testing of various aspects of the combined hardware and software will be carried out prior to outdoor testing. The purpose of these tests is to verify the connectivity of components.

A series of in-ground compaction tests will be conducted to verify the operation of the updated SCS and to initiate the development of the ability of the SCS to provide standard proctor values or ranges. Testing is planned in three soil types: sand, a silt-clay mix, and granular- and stoned-based soil.

Excavation types for the in-ground testing include:

- 18-inch-diameter bell-holes
- Three-by-three-foot bell-holes
- Two-foot-wide trenches.

In all instances, the soil density will also be measured with a nuclear densitometer in order to provide a standard soil-density value. The soil moisture will be measured for each round of testing.

Following the in-soil testing, three demonstration tests are planned. One demonstration will take place with a local utility; two are planned for remote sites.

The data from the various testing tasks will be cataloged and analyzed. Conclusions and recommendations will be provided and initial indications as to the ability of the SCS to provide a standard proctor value/ range will be reported.

Results / Status

Various interactions were conducted with the manufacturer, including discussions to address formatting for the structure of the data, the sentence coming off of the Bluetooth module, and the type of Bluetooth profile available on the SCS to ensure compatibility with various mobile operating-system platforms.

The research team also prepared a proposal for a project focusing on using Esri technology for the application development so that the solution could be deployed on multiple mobile device platforms. Using Esri technology allows the application to be deployed on iOS and Android devices.

Activities are to be initiated on the develop and testing of the application to ensure that the device works correctly and that data can be stored and transmitted properly.

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PIPELINE INTEGRITY MANAGEMENT & AUTOMATION

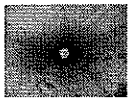
Projects in this area focus on the development of tools, techniques, and risk assessments to assist companies in meeting integrity requirements in a cost-effective manner.

To meet the challenges of pipeline integrity management, researchers are developing risk-assessment models, in-line pipe-inspection systems, and other technologies to improve the safety, efficiency, and reliability of gas delivery systems.

Through R&D in this area, pipeline and distribution system integrity can be maintained and improved based on sound, scientific developments related to inspection, testing, and other activities.

OTD Operations Technology Development

Evaluating Assessment-Technique Effectiveness



Researchers are developing a body of knowledge and a methodology to enable operators to determine the effectiveness of various pipeline-assessment techniques and select the most appropriate methods for particular conditions.

Project Description

Current regulations allow operators to use three specific methods to inspect/establish pipeline integrity of transmission piping segments in high-consequence areas: 1) in-line inspection (ILI), 2) hydro-pressure tests, and 3) direct assessment (DA).

To select the most optimal method to use, operators need to have knowledge on how effective each option is at ensuring the safety and integrity of the system and reducing risk. Each of the three main methods provides different data and information on pipeline-system integrity. As noted in the applicable standards:

- ILI provides 100% axial coverage of wall thickness (at a particular resolution) but does not directly provide coating damage sites and/or sites of "active" internal or external corrosion.
- Pressure testing provides a 100% system validation of pressure integrity but does not directly provide wall thickness, coating quality, or active corrosion locations.
- DA provides a coarse coverage of all or some of the system as to areas of coating damage and active corrosion hot spots, but does not provide wall thickness or pressure-carrying ability (integrity).

For this project, research team is developing a body of knowledge and a methodology to enable operators to determine the effectiveness of various assessment techniques and facilitate the selection of the most appropriate technique under different operating conditions.

Deliverables

The deliverables for this project will include:

- Definitions and methodologies to analyze assessment-technique effectiveness
- An assessment-effectiveness database
- A report providing an analysis of assessment-technique effectiveness.

Benefits

Selecting the most appropriate and effective assessment-technique, tool, or combination of tools for an integrity management program will reduce an operator's risk to incidents. This also helps to ensure the safe operation of the delivery system and improve the ability of the operator to meet regulatory compliance.

A	B	C	D	E	F	G	H	I
Inspection date	Segment ID	Inspection cost	Pass/fail	Corrective action?	Corrective action cost	Subsequent inspection scheduled/performed	Incident date	Incident/damage cost
1/1/1980	837147	$ 4,646	Pass	NA	$ -	11/19/1991	NA	NA
1/2/1980	174187	$ 4,993	Fail	Yes	$ 16,794	1/19/1991	NA	NA
1/3/1980	131417	$ 3,770	Pass	NA	$ -	8/4/1991	3/5/1982	$ 60,101
1/4/1980	315310	$ 4,587	Pass	NA	$ -	2/28/1991	NA	NA
1/5/1980	597542	$ 4,373	Pass	NA	$ -	11/29/1992	NA	NA
1/6/1980	915838	$ 4,084	Pass	NA	$ -	7/8/1991	NA	NA
1/7/1980	745861	$ 3,608	Pass	NA	$ -	6/19/1992	NA	NA
1/8/1980	416412	$ 4,553	Pass	NA	$ -	8/26/1991	NA	NA
1/9/1980	649214	$ 3,779	Pass	NA	$ -	1/26/1991	NA	NA
1/10/1980	935952	$ 4,867	Fail	Yes	$ 5,240	9/6/1991	NA	NA
1/11/1980	718900	$ 4,309	Pass	NA	$ -	10/16/1992	8/1/1988	$ 186,267
1/12/1980	535348	$ 4,244	Pass	NA	$ -	6/25/1991	NA	NA
1/13/1980	653177	$ 5,166	Pass	NA	$ -	5/29/1992	NA	NA

ThrAssess | ILI | Hydrostatic | DA

Portion of synthetic ILI database

Information on the appropriateness and effectiveness of various assessment techniques in different operating conditions will also allow operators to make better informed life-cycle decisions for managing their facilities.

Technical Concept & Approach

The results of this project will provide an analysis based on the best information available today, and will also provide a technique for continued industry data collection to enhance the level of understanding.

Specific tasks include:

- **Project Scoping**
  - Developing a definition of a methodology for measuring effectiveness
  - Defining data needed to be collected
  - Identifying and listing potential sources of data
  - Selecting assessment and inspection technologies to be included in the analysis
  - Developing a database design.
- **Collection, Assembly, and Organization of Data**

  Data will be collected through interviews, surveys, records, integrity management program documents, research reports, and other methods and sources.
- **Prepare Searchable Database**

  Commercial database products will be examined for their capability in meeting the needs of the design. The database will be built specifically for use in this project, and will also be designed for further use by individual companies to continue data collection after the project.
- **Analysis of Assessment-Technique Effectiveness**

  A detailed process for using the database and performing the analysis/comparison will be created. Similar to the database design, the comparison process will be developed for use in this project but with the understanding that it could be adopted by operators after the completion of the project.

  Fault Tree Analysis (FTA) is being employed as the primary method to analyze and compare the collected data. Tracking of pipeline failures would be the ideal way to measure effectiveness; however, pipeline failures are relatively rare. FTA allows one to track and analyze the causes that act alone or in combination to cause a pipeline failure. FTA starts with the top undesired event and then graphically develops all potential causes of that event. Probabilities can be assigned to each individual cause. This ability to identify combinations that can induce the top undesired event is a major FTA advantage.

  FTA was developed by Bell Laboratories, Boeing, and the U.S. Air Force to identify single-point causes and combinations of causes that could result in an unintended nuclear missile launch or unacceptable event or risk.

Research results will be disseminated through a Final Report and webinar. Potential follow-on work could include the development of a long-term industry data collection effort and incorporation of the developed methodology into a standard.

Results

For this project, a variety of data was collected, including a set of pipeline incidents obtained from the U.S. Department of Transportations Pipeline and Hazardous Materials Safety Administration records of transmission pipe incident data.

Researchers are developing a probabilistic methodology for maximizing each assessment method's utility function.

A database was populated with simulated inspection and incident data. These were processed and presented in a spreadsheet interface ("front-end"). Simulated data was used as the project team received limited data from sponsors. (To improve the accuracy of the model, additional data is needed.)

The project team improved the methodology previously developed and started adding constraints that would assist in assessing the effectiveness of each method and selecting the optimal method for each circumstance.

Status

Efforts are under way to populate the database with real data, expand its fields and attributes, and present the results in terms of a well-defined assessment effectiveness measure.

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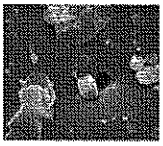
OTD Operations Technology Development

Probability-of-Failure Model for High-Risk Pipe Segments (Vintage Pipe)

Researchers are developing a methodology and risk protocol to provide likelihood-of-failure distributions for specific high-risk pipe materials and threats. The methodology uses sampling, operating conditions, and advanced risk-modeling techniques to quantify risk and allow mitigation techniques to be effectively applied.



Project Description

Various legacy materials, including some vintage polyethylene (PE) and cast-iron pipe, are known to have higher-than-average risk profiles. Currently, most available risk models are simplistic in their analysis of these materials and do not have the ability to modify risk profiles as new information becomes available.

The objective of this project is to develop a methodology and risk protocol that provides likelihood-of-failure distributions for specific high-risk pipe materials and threats.

The methodology uses sampling, operating conditions, and advanced risk-modeling techniques to provide a targeted approach for quantifying the risk of specific pipe segments to allow mitigation techniques to be effectively applied. A generic methodology will be developed and then applied to vintage PE and cast-iron pipe to demonstrate the use of the methodology.

Specific attention is being placed on the analysis of vintage Aldyl-A plastic pipe and cast-iron pipe.

Deliverables

Deliverables include:

- A general probability-of-failure methodology
- Demonstration of the methodology applied to Aldyl-A and cast-iron materials.

Benefits

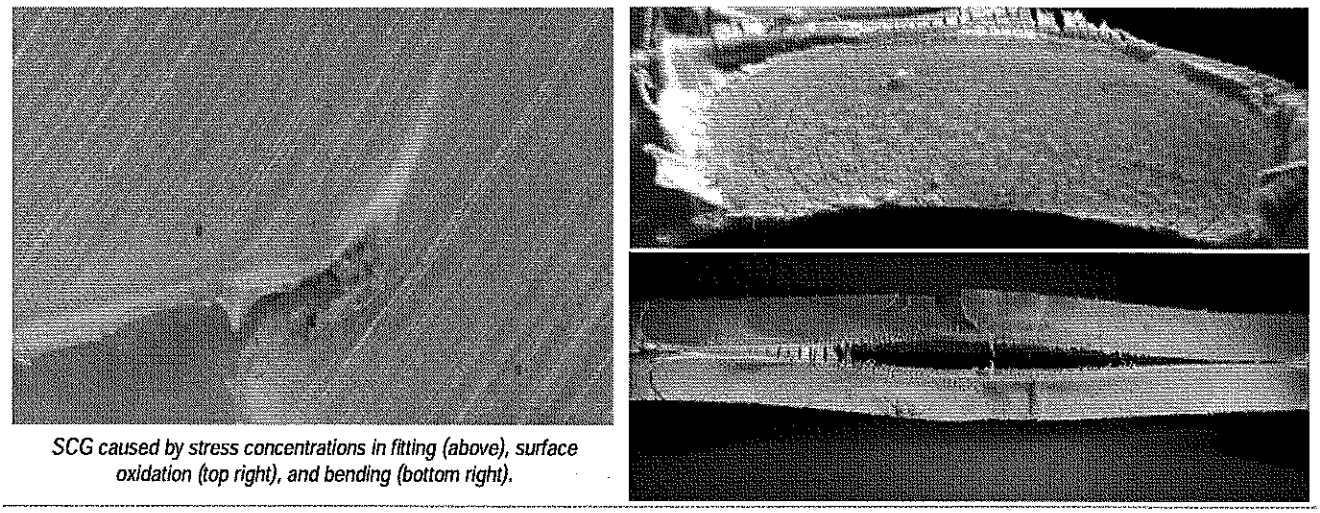
The results of this project will provide operators with a tool that can quantify the risk of failure using a systematic and probabilistic method that is able to isolate problematic segments. These methods can support a highly targeted approach to identify and mitigate risk.

This methodology will not only improve system integrity but will also provide operators with tools to improve pipe-replacement-prioritization and resource-allocation decisions.

Technical Concept & Approach

Specific project tasks include:

- Project scoping and literature review
- The development of risk-profiling methodology that can be applied for various threats
- Sample collection and analysis using microstructure analyses techniques such as Scanning Electron Microscopy (SEM) and Cross-Polarized Light Microscopy (CPLM)



SCG caused by stress concentrations in fitting (above), surface oxidation (top right), and bending (bottom right).

- Application to Aldyl-A and cast-iron materials.

Results

In 2012, researchers investigated vintage pipe specimens, using CPLM and SEM to catalog microstructures and internal surfaces. A database was designed to allow for easy correlation of microstructures to physical test results and will form the basis of a knowledge base collating the project research results for future reference.

A test protocol was developed based on Dynamic Mechanical Analysis (DTMA). This testing allows for the proper constitutive models of the materials to be extracted and will also provide accurate bi-directional shift factors for the individual pipe materials. These shift factors will be the basis for residual life estimates for pipes installed under known conditions.

CPLM and SEM microscopic analyses of Aldyl-A specimens were conducted in 2013.

Researchers are developing the Finite Element Analysis (FEA) damage-propagation models. This element of the project is essential to developing likelihood-of-failure of pipe segments under known conditions. Test methods for generating detailed constitutive models of polymeric materials that can be incorporated into FEA models were refined, specified and detailed cost information was obtained.

A literature review was completed for the cast-iron portion of the project and an experimental test plan was developed for cast-iron coupons.

A method for calculating the conditional probabilities of SCG in the presence of root causes was developed and a coupon sampling method was proposed. The ways to combine coupon data with leak data is understood, and the combination of these two data sets will provide a reasonable risk model.

DTMA testing was completed in 2014 and correlation with long-term hydrostatic testing, microscopy, and pipe vintages will be conducted as the project progresses.

Constitutive models for the Aldyl A are being integrated into the FEA modeling process. Some convergence issues were experienced with extremely large pipe deflections (e.g. pipe squeeze-off). The output will greatly enhance our ability to determine the true stress levels in field installations under widely varying conditions. This is important information for the risk models to function optimally.

Cast-iron corrosion testing was initiated. Data from the macro-corrosion wall loss and micro-corrosion pit depth measurements were analyzed using multivariate linear regression. The preliminary results indicated that a moderate correlation exists between microstructure and the micro-corrosion results. A weak correlation exists between the microstructure of the cast iron and the macro-corrosion results. The strength of the correlations compare favorably with those for soil type, resistivity, and other factors that are reported in the literature, indicating that the addition of microstructure as a variable in the models could significantly enhance the predictive power of the existing models.

In 2014, papers related to this project were presented at the American Gas Association's Operations Conference in May and at the Plastics Pipe XVII conference in September.

An effective fitness-for-service analysis strategy and several working risk models were developed for assessing the risk in Aldyl A gas distribution piping systems. The approach focuses on identifying problematic stress risers in the system that are the drivers of slow-crack-growth failures while taking credit for the fact that the core properties of Aldyl A do not deteriorate over time, and in the absence of stress risers replacement programs can be spread over a reasonable timeframe. The outputs are presented in clear engineering guidelines to help determine the optimum approach to managing the gradual replacement of Aldyl A piping systems that are nearing the end of their design life. The methodology enables the operator to target the highest-risk systems for immediate action while deferring the replacement of lower-risk sections of the system to a later date.

Status

Ongoing activities include:

- Incorporating data into correlations for the risk model
- Incorporating FEA analysis results with enhanced constitutive models into risk model
- Completing the risk model for Aldyl A pipe.

Several utilities are working with the project team to carry out targeted sampling of Aldyl A pipe.

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OTD Operations Technology Development

Correlating Pipeline Operations to Potential Crack Initiation, Growth, and Arrest

The objective of this project is to develop and validate a model for pipeline operations that correlates pressurization to pipe crack-growth rates, crack initiation, and crack arrest. The model will help to reduce risks associated with vintage transmission pipeline materials.

Project Description

Based on recent recommendations from the National Transportation Safety Board and other regulatory actions, the natural gas industry is expected to be required to increase hydro-testing and spike testing on vintage pipes. While there are many advantages to hydro-testing, there are concerns about the impact of this testing on pipe crack initiation and growth. Additionally, current practices allow operators to use spike testing every five years to maintain maximum allowable operating pressure status.

To address these concerns, this project is focused on the development of a model that can provide operators with information on the predicted effect of pressure-based testing.

Researchers are investigating a variety of gas transmission line crack types, including:

- "Cold Spots" (high hardness, Martensitic microstructure) in weld zones
- Stress risers from steel inclusions (defects at the steel and rolling mill)
- Stress risers from construction (partial DSAW welds, lap welds)
- Defects from pipe mill, field construction, and fabrication
- Knife-line corrosion defects from selective seam corrosion that continue to grow
- Propagation of pre-existing cracks from hydrogen and stress cracking
- Growth of mechanical damage, gouges, and arc strikes.

Deliverables

The primary deliverable of this project will be a predictive model that relates the historical and planned pipeline operational pressure envelope to time for crack initiation, crack growth rates, and the potential for crack arrest.

Benefits

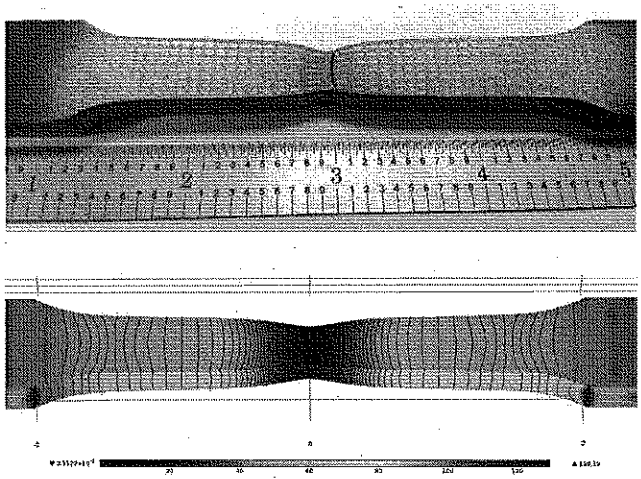
The model will allow operators to identify high-risk pipe segments based on historical pressurization records. The model will also allow operators to predict the impact on pipe integrity of hydro-testing and spike testing as well as select the optimal operating pressure.

The results of this project will reduce systemic risk associated with vintage transmission pipeline materials. The model will assist in targeting inspections of vintage pipe segments with the greatest risk of propagating cracks due to hydro/spike testing.

Technical Concept & Approach

In the first phase of this project, researchers will develop the predictive model and will then use small pipe samples for model validation. If necessary, a second-phase project will be conducted using full-size samples for further model validation.

A Design of Experiments (DoE) approach will be used to develop the model. Inputs include factors such as steel type, chemistry, toughness, manufacturing methods (welded or seamless), and operating conditions



The simulation captures the essential behavior of the material. Top image: ASTM A370 test sample after failure (typical). Bottom image: Simulated ASTM A370 tensile test, von Mises Stress plot (in ksi) with effective plastic strain contours.

(temperature and stress levels). These will be correlated to crack growth initiation time and rates from physical testing. The DoE will provide the necessary structure for establishing the most efficient data set; completing a full sensitivity analysis for all input factors, and deriving the model for crack-initiation stress, growth rate, and arrest stress with confidence intervals.

Small-scale, center-notched specimens will be fabricated from vintage pipeline steels provided from Gas Technology Institute's (GTI) historic steel pipe library. The pipe library contains vintages from the 1950s through 2000. GTI will perform fatigue and toughness testing in its laboratory. Fatigue testing will be conducted with center-notched specimens prepared from the pipe library. This testing will be performed at very low frequency, but still allow for decades of spike testing to be compressed into hours. The results will include cycles to failure, as well as arrest and propagation stress levels at various crack geometries.

Results

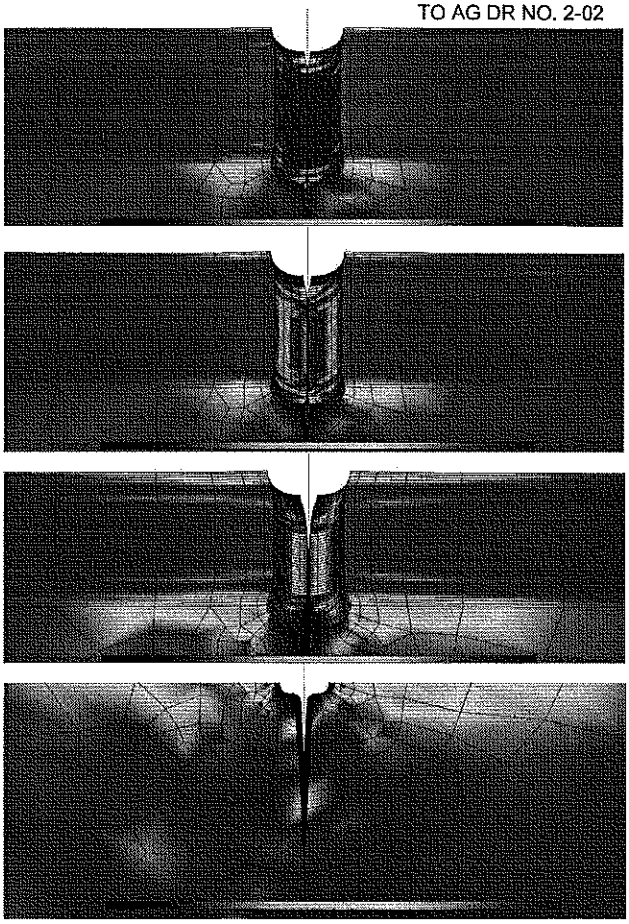
In 2013, researchers conducted tensile and fatigue testing on an ASTM A36-grade steel plate sized 0.312"x12"x36". This grade was specified because its chemistry limits and physical specifications are similar to that of plain carbon steel pipe grades at lower strength levels. Tensile tests using this material were used to identify integration issues between the video extensometers and the tensile test machine.

Test data was analyzed and the conversions from engineering stress/strain to true stress/strain were validated. Video extensometers produced reliable true stress/strain information beyond the necking point of the material. This information will be very useful in the full 3D finite element modeling of the crack propagation process.

The finite element model was adapted for full 3-D modeling of dynamic crack propagation.

In 2014, a literature review on developments in the field of damage propagation models was initiated, with the focus on information published in the 2009-2012 timeframe.

A unique method was developed to properly model damage-propagation modes in COMSOL (a finite element analysis simulation software package) in an automated method. This level of automation is key to enabling the simulation of the large number of configurations needed to feed the model. COMSOL formulations are operating correctly; however, each analysis runs for approximately 36 hours. A workstation capable of running six analyses in parallel has been acquired. This will allow an average of four analyses a day to be completed.



From top to bottom, stress plots indicate an initial crack at the corners of a round notch, the crack propagated through the thickness of the specimen, continued full-thickness crack propagation, and the crack at end of the simulation.

Status

A 3D Finite Element Analysis (FEA) model capable of capturing dynamic crack initiation, propagation and arrest has been developed. Next steps are to 1) validate the model with small-scale specimens extracted from actual pipe in the GTI library and 2) use the model process in pipe.

The test specimens are being machined – approximately 50% have been delivered.

The Final Report will include an analysis of how predefined flaws in pipe react to periodic pre-spike and hydro-tests based on the calibrated FEA model.

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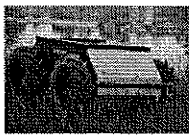
OTD Operations Technology Development

Tool for Detection of Cathodic Disbondment and Metal Loss



This project focuses on the development of a practical tool for detecting cathodic disbondment and metal loss. The technology will enhance the safety of steel gas piping systems by providing the ability to locate potential pipe-corrosion sites before leaks or serious metal loss occurs.

Project Description

A significant amount of the steel pipe used in gas distribution systems is more than 50 years old. To ensure system safety, these older pipes are often assessed for corrosion. Current corrosion-assessment methods generally require exposing the pipe for inspection, often requiring the removal of a coating. Since exposing the entire pipe is prohibitively expensive, these inspections assume that a statistical sampling of an area is representative of the pipe condition

Corrosion can be severe under a coating disbondment when the fusion-bonded epoxy, coal-tar enamel, or field-applied tapes separate from the steel. Water can migrate under the coating, forming an active corrosion cell that is shielded from cathodic protection (CP). Uncoated steel pipes may develop general corrosion or localized pits if CP is compromised.

The objective of this project is to develop, test, and commercialize a mobile platform for detecting coating disbondment and external corrosion by measuring magnetic fields from above ground. The tool will include sensors to detect magnetic fields, sensors to determine the orientation of the pipe, and computational means to extract coating disbondment and corrosion locations from this data. In operation, the multi-axis magnetometer will move over the pipe semi-autonomously, stopping at regularly spaced locations to capture data. The GPS coordinate of the reading point is captured along with the data. The intent is to have the platform perform some of the repetitive and potentially fatiguing aspects of the survey. Automating the survey can reduce the possibility of error in recording the data and improve the uniformity of the distance interval between readings.

The project builds on several projects funded by U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA), OTD, and Gas Technology Institute's Sustaining Membership Program. These project include the development of a tool to detect perturbations in magnetic fields caused by cast-iron joints and services and the development of cathodic disbondment detection. In this project, PHMSA is providing cofunding for field tests and other developments.

Deliverables

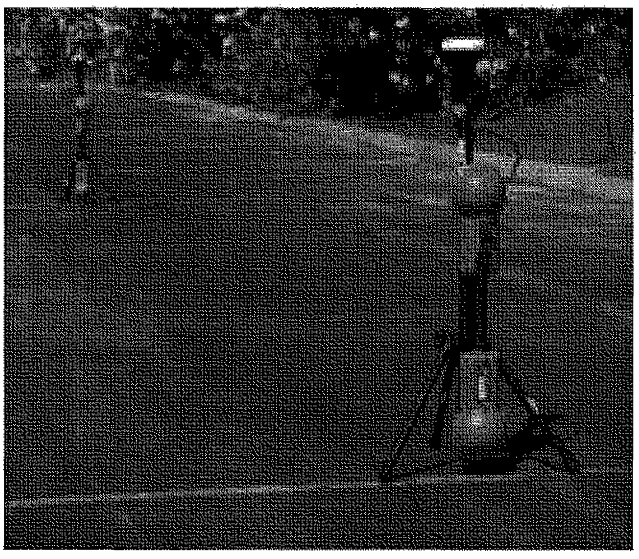
Deliverables will include a field-tested beta prototype, results of three field tests, and a report summarizing the findings of the field tests and containing recommendations for commercialization steps.

Benefits

Accurate assessment is needed to identify pipe in good condition and to distinguish it from pipe that should be replaced. Replacing pipe past its useful lifetime will improve the safety of the system.

The ability to locate potential corrosion sites before serious metal loss or leaks occur will improve public safety, corrosion-mitigation strategies, and the life-cycle of steel pipelines.

Currently, there is no tool to identify external corrosion from above ground and most gas-distribution mains are not accessible to in-line inspection tools. Exposing large lengths of main for inspection is cost prohibitive. Record keeping and direct assessments are the currently used tools for predicting pipe conditions. However, direct assessment is limited because pipe condition can vary dramatically within feet.



Magnetometers used in testing.

A tool able to assess a high percentage of pipe from the surface of the ground has the potential to save millions of dollars of inspection costs annually. Savings will also result from prioritization of pipes needing repair in a timely manner and those with substantial remaining lifetimes.

Technical Concept & Approach

The approach is to directly inject an alternating current signal into the pipe, generating magnetic fields around it. For a long straight steel pipe in good condition, these magnetic fields are perpendicular to the axis of the pipe – the basic principle of electromagnetic pipe locators. Coating flaws and corrosion will distort the magnetic field around the pipe by the increased attenuation of the current along the pipe and by creating current flows not parallel to the pipe axis. The challenge is to map these field distortions to features on the pipe.

A manual version of a cathodic disbondment detector will be tested at several utility sites. These early field tests will establish a baseline for the current capabilities of the technology. They will also provide an opportunity to test some of the additional candidate sensor packages under field conditions before integrating them with a self -propelled system. The data from the field tests will be reported to the sponsors with recommendations on features that may require investigation.

In order to facilitate a self-propelled platform to carry the sensors, a chassis and drive mechanism will be required. The expected outcome is a wheeled platform of moderate size, possibly with sensor trailers to isolate magnetic sensors from interferences such as large masses of metal. Initial testing will verify the ability of the chassis to be remotely controlled by an operator. It will also verify the load-carrying capacity, battery life, and ability to traverse unpaved areas.

To facilitate the rapid and accurate collection of pipe-condition data, the sensor platform will need to navigate in a semi-autonomous manner. An algorithm will be developed that allows the platform to follow the pipe route by using the on-board sensors and tracing signal.

The project team will design and construct a data-acquisition and processing system and develop software to capture the data from multiple, orthogonal sense coils and orientation sensors to extract the field phase and magnitude data. This data will be processed in order to maintain the course of the platform within reasonable alignment of the pipe route. The on-board sensors will provide sufficient data to correct for minor misalignment of the platform with the pipe.

In addition to collecting the magnetic-field signature data, it will be necessary to store this data properly correlated with platform attitude, GPS location, and a time stamp for every point in the survey. The stored data will need to be formatted such that it will be compatible with a utility geographic database.

The entire system will be subjected to testing to verify the proper integration of the chassis with data collection and data storage. The first round of testing will take place at a buried pipe test bed with known flaws. This facility will be used in the initial shake-down testing and refinement of the pre-prototype instrument. Once the pre-prototype equipment is functioning correctly, it will be tested at three natural gas utility sites.

Results

Initially, the project team identified several upgrades for the prototype instrument to prepare it for more extended field testing. The primary improvements are the inclusion of GPS data with the cathodic disbondment survey data, the ability to vary the frequency of the signal injected into the pipe to suit field conditions, and the ability to store greater amounts of survey data.

In March, 2014, field testing was performed with a local utility. The GPS location of the magnetometer system and the offset and depth to the pipe were captured along with the raw field data from a single magnetometer. The line that was surveyed was a 42-inch-diameter high-pressure steel line that had previously been surveyed by the utility. The testing was useful in determining the operating characteristics of the sensors over a live piping system. Additional field sites were surveyed during the August through November time frame. Some of these sites were subsequently excavated by the utilities and reports were sent to the research team.

Two significant improvements were made to the Spar system: 1) Custom firmware was created to provide the data in a format specific to the requirements of this project, and 2) the implementation of real time kinetic correction for the GPS.

Status

Field-testing activities are ongoing. Data is being analyzed. Activities have also been expanded to investigate graphitization on cast iron. All work up to this point has been on coated steel pipe.

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Continuous Threat Identification Program

The Continuous Threat Identification Program (C-TIP) is being developed to collect, analyze, and disseminate information on new and previously unidentified pipeline threats. This program will provide information to operators for their use in enhancing the safety and operation of their systems.

Project Description

As gas-system operators initiate Distribution Integrity Management Programs (DIMPs), information on new and previously unidentified threats is expected to become available. The objective of this project is to develop and implement a program to collect, analyze, and disseminate this information.

The program – called the Continuous Threat Identification Program (C-TIP) – focuses on threats specific to distribution systems and will provide information on existing and emerging system threats to operators for their use in identifying and assessing risks to their system.

The C-TIP, led by an independent third-party organization, will also facilitate the collection and further investigation of information that would lead to meaningful and transparent analysis.

Analysis by an independent organization will provide regulators and the public with assurance that the results are nonbiased and based on a rigorous scientific processes.

Deliverables

Information developed through this project will be disseminated through semi-annual webinars and annual reports.

Benefits

The C-TIP will help reduce operator risk for both distribution and transmission systems by improving system integrity and safety.

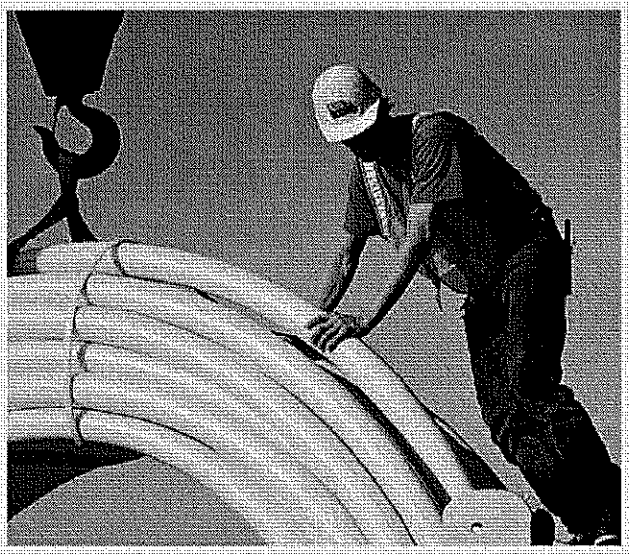
Risk will be reduced by providing comprehensive industry information to assist in identifying threats and quantifying the associated risk.

The C-TIP will also help to:

- Demonstrate to regulators and the public that the industry is pro-actively identifying new and emerging threats
- Standardize the data sets that operators use when developing and executing integrity management plans to further increase confidence in the results

Threats being investigated include:

- Corrosion
- Natural Forces (e.g., flooding and earth movement)
- Excavation Damage
- Other Outside Force Damage (e.g., vehicular damage or vandalism)
- Material, Weld, or Joint Failure
- Equipment Failure
- Incorrect Operation.



- Improve the efficiency of data collection, threat identification, and risk analysis by providing a collaborative mechanism for sharing information.

Technical Concept & Approach

Researchers will define the potential sources of data and create a data-collection template and form. A database will be designed and developed to store the collected data.

The C-TIP will systematically collect new and emerging threat information from operators and regulators.

Results

Initially, data was collected from OTD operators to identify threats and determine how each company identifies threats. Additionally, state regulators were contacted to obtain data on their findings related to new and emerging threats.

Interviews were conducted with various natural gas utility DIMP managers or a representative familiar with the company's DIMP. A summary of the responses was compiled. Threats and sub-threats from the DIM plans of those companies interviewed were compiled into tables.

Data was analyzed and webinars were held to discuss the results. A DIMP workshop was held in 2013 as part of the DIMP Risk Model project. Many operators requested standard definitions for all sub-threats in order to facilitate improved identification/categorization.

In 2013, the project team completed the initial version of the C-TIP database that combines the threats and sub-threats from the operator and regulator interviews as well as the information from 15 DIMP plans. Definitions, examples, contributing factors, and commentary was provided for each threat and sub-threat. Data was consolidated and reorganized to focus on the true threats and minimize confusion. Information was added to the threat database to provide further explanation and information about each threat to help improve categorization. Additional information/responses from regulators were collected with feedback on reviewed operator DIMP plans.

In 2014, the project team continued to monitor industry threats.

Status

The research team continues to review, refine, and add information to the threat database.

Plans are to create an online database that is searchable and allows users to add and modify information.

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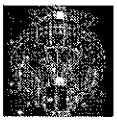
OTD Operations Technology Development

Pipecrawler Market Assessment & Demonstration

Researchers investigated a pipeline-inspection system used in subsea and offshore applications for its potential development for use in onshore gas-pipeline segments that currently can not be inspected with conventional equipment.



Project Description

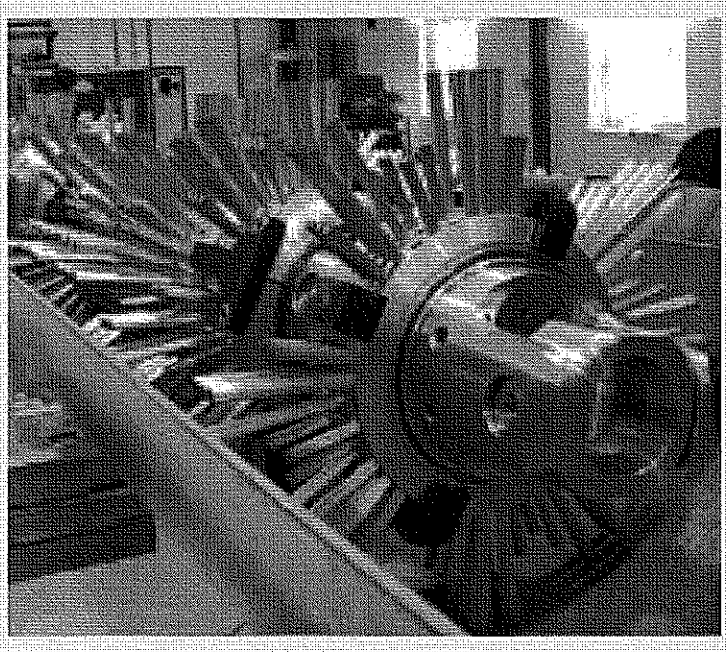
The natural gas pipeline infrastructure contains a considerable amount of "unpiggable" pipe segments that can not be inspected with conventional devices. Through this project, researchers investigated technology with the potential to inspect long segments of unpiggable pipe and thus reduce an operator's exposure to integrity threats and unknown pipe defects.

Specifically, research focused on Pipecrawler systems available through the Genesis Group, an engineering and technical services company for the upstream oil and gas sector. Currently, the technology is being deployed in subsea and offshore applications for inspecting unpiggable pipe segments.

Pipecrawler is a tethered inspection platform that uses brush-drive units that are powered by electric linear-drive motors for propulsion. The Pipecrawler has a modular inspection platform that can be integrated with multiple sensors. The current version is available with magnetic flux leakage (MFL) sensors, but the company is in the process of integrating a variety of other sensors as well. The Pipecrawler has been shown to be able inspect up to 3,000 feet of pipe in pressures up to 700 psi. Current models can inspect pipe 10 to 12 inches in diameter.

The brush drive and suspension system gives Pipecrawlers the ability to access a pipeline from a single location. Motion, control, and data transmission is managed from a topside console via an umbilical tether which enables the tool to be run at any speed from zero to maximum. The ability of the crawler to stop and secure itself in position anywhere in a pipeline (including risers) is particularly useful for many inspection tasks. By incorporating the speed control and the product flow bypass capability of the tool, controlled quantities of pipewall deposits can be removed while the pipeline is still operating. Once clean, the system can return to the launch position

Genesis is interested in bringing this technology to the natural gas distribution and transmission industry and partnered with Gas Technology Institute in this project to perform a market assessment and coordinate a field demonstration. The objective of this project was to provide the technical requirements needed to guide technology development for Pipecrawler technology and to demonstrate the size of the U.S. market.



Pipecrawler

Features:

- Patented "brush drive" technology
- Single entry and recovery point
- Fully bi-directional travel
- Can operate "with" or "against" the flow
- Can operate in no flow
- Can stop at any point in the pipeline system
- Multiple 3D bend passing
- Powered deployment and powered recovery
- Onboard internal and external temperature sensors
- Onboard internal and external pressure sensors
- Variable speeds from 0 to 900 meters/hour
- Emergency recovery via tether.

Deliverables

Research results will be presented in a Final Report to sponsors.

The market analysis will be used to justify further investment in the technology that may be required to serve gas-industry markets.

Benefits

Pipeline system safety can be enhanced through the introduction of a system capable of inspecting unpiggable pipelines and navigate through pipe bends, debris, rotated fittings, reduced-port ball valves and gate valves, plug valves, tees, and intersection points.

Technical Concept & Approach

For this project, a market assessment was conducted to gather information on the technical requirements, regulatory drivers, and market size of the onshore natural gas distribution and transmission industry in the U.S.

A laboratory demonstration of the Pipecrawler technology was also performed.

Results

The Pipecrawler market assessment, which was completed in 2012, provides information on the current gaps in inspection technologies for unpiggable pipe and the ability of Pipecrawler to meet the needs of the market.

In 2013, a successful Pipecrawler demonstration was conducted in a 10-inch-diameter laboratory test loop with 3D bends.

Research found that the Pipecrawler has many of the features required by operators to meet the market needs for inspecting unpiggable pipes:

- Operates live in low and no-flow conditions
- Allows for single entry and exit points
- Navigates some bends and reduced-diameter fittings
- Passes through debris and contaminants
- Accommodates up to 30% change in diameter
- Able to inspect dead legs.

The Pipecrawler is able to negotiate the most frequent and important pipe configurations and operating conditions that make segments unpiggable, including low-flow conditions and lack of launchers and receivers. However, some features (such as plug valves and tight-diameter bends) can not be accommodated with Pipecrawler and will therefore limit the size of the market.

Status

The market assessment and laboratory demonstrations are complete. Based on the cost, market, and industry-trend data collected in this assessment, the following conclusions can be drawn:

- If Direct Assessment (DA) is a feasible assessment technique in rural or suburban areas, operators will continue to use DA because costs are significantly lower (up to 50% less expensive) than a Pipecrawler inspection.
- If converting a line to be piggable only involves installing launchers and receivers and/or minor modifications, operators are likely to choose this option because it will allow traditional lower-cost inspection tools to be used.
- Pre-1970s pipe accounts for up to 60% of the regulated transmission pipe in the ground and represents a potentially strong market for Pipecrawler.
- The distance that can be inspected in between access points with Pipecrawler will have a significant impact on the cost competitiveness compared with other options. Pipecrawler will be a viable alternative in areas with high excavation and restoration costs, such as urban areas and crossings, if longer distances can be inspected between access points.

In 2014, a Guided Wave Ultrasonic Testing (GWUT) sensor was added to the Pipecrawler and the development of a testing program for the new GWUT sensor was initiated.

The research team is monitoring the development of a joint industry project to determine qualification requirements for the Pipecrawler and to perform testing to verify performance according to the qualification requirements.

The project team may join the project when it gets started. The project team also identified a potential demonstration site for the Pipecrawler with the MFL sensor.

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OTD Operations Technology Development

Distribution Integrity Management Plan Consequence Model

Researchers are developing a model to quantify the consequence of failure for natural gas distribution systems based on a wide variety of factors, including population density, proximity of critical infrastructure and business districts, and failure mode.

Project Description

Federal regulations for natural gas system operations provide specific requirements for determining the consequence of a system failure, including calculations for the Potential Impact Radius (PIR) and High Consequence Areas (HCA).

Distribution Integrity Management (DIM) regulations do not mandate a specific method for modeling the consequence of failure; however, the regulations require operators to consider the consequence of failure when assessing risk. Regulations imply that a risk model cannot be considered final and complete without proper consequence quantification.

Through OTD sponsorship, a comprehensive risk model for DIM was developed and is now commercially available through GL Noble Denton. This model provides a methodology for calculating the likelihood of failure for eight threats for various asset classes. However, this model does not provide a methodology for calculating the consequence of failure.

Some risk modeling software tools have built-in functions that assist operators in determining the consequence of failure for specific line segments. Some operators have developed their own methods for modeling consequences based on factors such as pressure and population density, while other operators use an SME approach to assign relative consequence scores. The goal of this new effort is to develop a model that quantifies the consequence of failure for distribution systems based on factors such as population density, proximity of critical infrastructure and business districts, failure mode, gas migration patterns, soil and surface conditions, pressure, and potential energy.

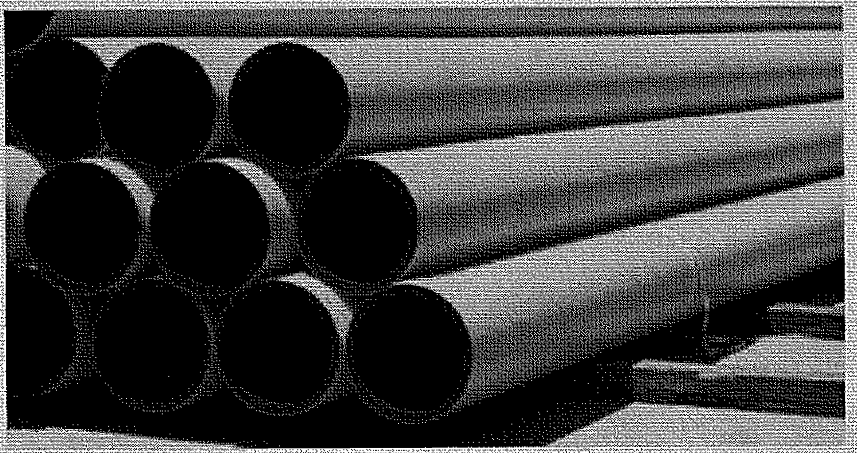
Deliverables

The deliverable of this project will be a DIM plan consequence model that operators and software vendors can incorporate into existing risk-modeling tools.

The model will be provided to OTD companies and licensed to software vendors and non-OTD companies.

The DIMP Consequence Model takes into account a wide range of pipeline variables, including:

- Pipe material
- Outer diameter
- Wall thickness
- Depth (of cover)
- Pressure
- Location
- Local population density
- Soil and surface conditions
- Threats (corrosion, natural forces, excavation damage, etc.)
- Repair costs
- Litigation and liability.



Benefits

A DIM plan consequence model will enhance the ability to comply with regulations while reducing system risk by assisting operators in understanding the risk of specific pipe segments based on the consequence of failure.

This risk-based model will assist in prioritizing replacements and the deployment of other mitigation techniques.

Technical Concept & Approach

Specific tasks in this project include:

- **Industry Review**

  This activity included a survey of sponsors and a literature review.

- **Development of a Modeling Approach**

  This task included the analysis of several existing risk-modeling approaches for compatibility with potential consequence-modeling approaches. Several distinct units of consequence measurement (e.g., volume of gas release or value of property damage) were considered.

- **Model Development**

  The model will be modular in order to integrate with a variety of existing risk-modeling approaches and flexible enough to allow for the use of different consequence units.

- **Model Testing**

  This task involves testing the consequence model with simulated and real data.

Results

In 2013, the consequence literature review was completed to assess the current state of the art. The investigation included reviews of regulations, templates, guides, and surveys, examples from operator DIM plans, academic papers, and government reports.

The modeling approach was developed and consists of the following steps :

1. Develop a set of consequence categories
2. Develop a list of affecting factors and quantify (or parameterize) their contributions.
3. Quantify consequence.

Several important equations were introduced into the model to account for various possible consequences on structures and people, under various conditions. Thermal radiation, gas ingress, and ignition formulas were introduced into the model, as well as various receptors (i.e., buildings and people), distributed according to class location and additional parameters.

Development of the model continued through 2014. Equations pertaining to the different consequence model components were developed, as well as the corresponding "sub-model" which allows for the quantification of consequences. The classification scheme for consequences, which was developed earlier, was modified to better match the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) Incident Database, from which many parameters were extracted.

Simulations were conducted to develop more realistic probability distributions.

The model was validated with PHMSA and National Transportation Safety Board incident reports by overlaying the reported damage on those incident reports on consequence histograms derived from the consequence model.

A webinar was presented to the sponsors to solicit feedback and steer the remainder of the project.

Status

Current activities include:

- Development and testing of a gas ingress submodel.
- Integration of the consequence model into a simple risk model for demonstration purposes
- Development of a Final Report.

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EMAT Sensor for Small-Diameter and Unpiggable Pipe

This project focuses on the development, testing, and demonstration of Electromagnetic Acoustic Transducer (EMAT) sensors for the inspection of smaller-diameter distribution pipelines and lines with features that prohibit the use of conventional in-line-inspection devices.

Project Description

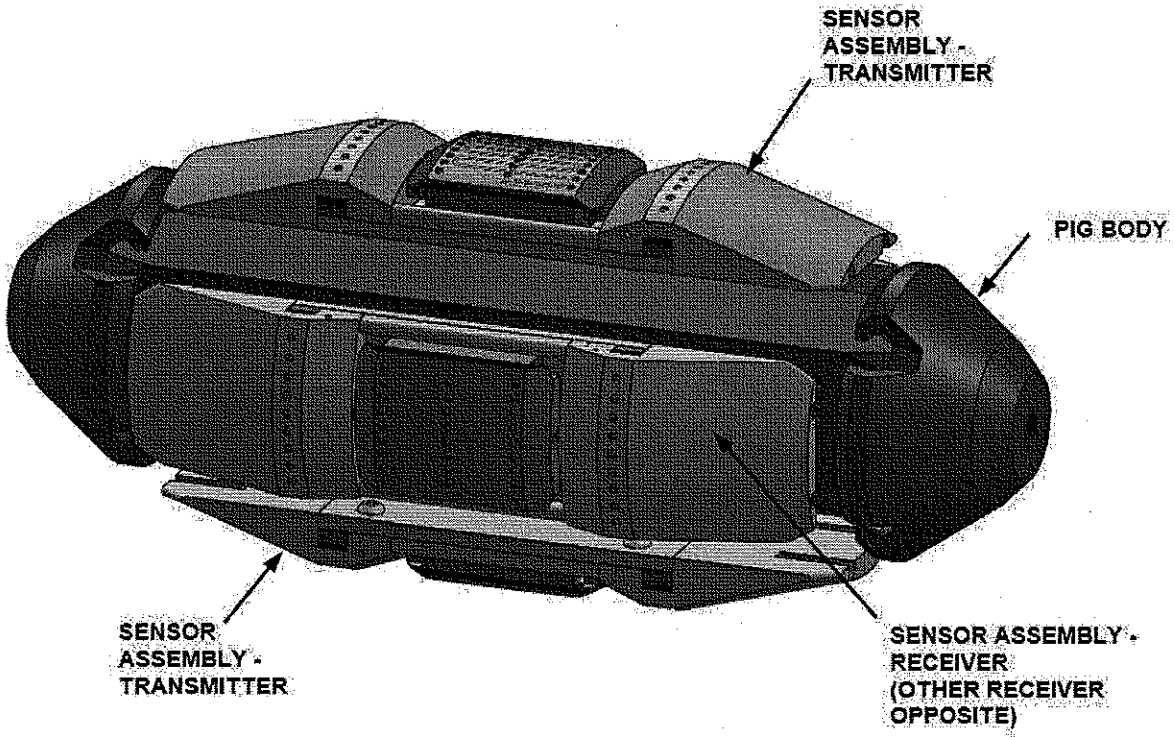
Many natural gas distribution companies operate segments of pipe that are classified as transmission lines, and, therefore, fall under specific integrity-management regulations. However, these pipe segments cannot always be inspected with traditional in-line tools designed for high-pressure transmission lines.

In previous research, EMAT (Electromagnetic Acoustic Transducer) technology was identified as a promising technology to address this issue. EMAT technology has the ability to detect and characterize corrosion, stress-corrosion cracking (SCC), cracks (including longitudinal fatigue, toe, and long seam-weld cracks), mechanical damage, laminations, coating disbondment, and lack of fusion. While third-generation EMAT tools are available for conventional in-line inspections, they have limited applicability for smaller-diameter, lower-pressure lines or lines that have reduced-diameter features, bends, valves, or other factors that restrict the use of conventional in-line-inspection devices.

For this project, a research team was assembled that includes one of the industry's leading companies in the development and deployment of EMAT sensors for the liquid and steam industries. The company developed a bi-directional pipe-inspection system that has been used to inspect pipes from three to 16 inches in diameter for distances up to two miles. The collapsible tool can traverse multiple back-to-back bends and navigate through features such as port valves and unbarred tees.

EMAT is a dry-coupled (can be used in live natural gas pipelines without a liquid slug) sensor that uses alternating current in a wire to induce an eddy current that can identify and characterize many defects that traditional magnetic flux leakage technology cannot. While this technology has been available for decades, recent advancements have significantly enhanced performance.

The objective of this project is to transfer EMAT technology for integrity-management inspections with a



specific focus on smaller-diameter and "unpiggable" pipe.

The EMAT sensor will be designed to find and characterize cracks in welds and pipe walls. The sensor will also be platform independent, allowing integration with multiple piggable and unpiggable pipe-inspection platforms.

Major funding in being provided by the U.S. Department of Transportation's Pipeline Hazardous Materials and Safety Administration (PHMSA).

Deliverables

The deliverables for this project include the development of a field prototype, testing, demonstrations.

Full design information will provide the physical, mechanical, materials, and operational design considerations necessary to manufacture the sensor.

Benefits

The goal of this project is to enable natural gas pipeline operators to identify traditionally difficult-to-find-and-assess defects and, therefore, improve system integrity and public safety.

Technical Concept & Approach

Activities in Phase 1 involve the development of a prototype bench-scale integrated EMAT sensor that is bi-directional and collapsible. The prototype will be tested for sensitivity and wear resistance. A transport platform will also be designed; however, the sensor will be able to be used on other available platforms.

Designs will be implemented in a complete prototype tool (8-to-12-inch-diameter range). It is anticipated that this tool will consist of one or more sensing modules with integrated storage devices similar to that of existing tools. It would be designed so that it could be operated with a variety of delivery methods such as coiled tubing, wire-line, or other compatible locomotion.

Future refinements of the tool will be iterative based on future demonstration as well as funded field jobs.

The ability to address the three challenges with EMAT – sensitivity, collapse factor, and wear – will be assessed. Testing on simulated and real defects in pipe samples will be performed.

The sensor design and testing results will be disseminated through a variety of industry avenues, including the PHMSA website and presentations at industry events.

Results / Status

Initially, the research team created a detailed survey which was sent to operators with smaller-diameter, high-pressure transmission lines to establish technology needs and operator requirements. The survey results were combined with the results of an in-depth literature search on EMAT technology to establish the design requirements for the sensor.

A sensor geometry design and operating points were selected. Initial laboratory testing is in process with a completed bench-scale prototype.

A verification of a 2D model against published work was completed. Also, 3D modeling was used to confirm 2D results.

A motion-control and data-collection system was developed to automatically scan the bench-scale prototype through the pipe. It will also be used to scan a sensor pair across test plates with defects. The motion-control system simultaneously collects, displays, and saves data to a file. This system will also be used for wear testing. A high-performance linear motor slide was configured to move the prototype through the pipe. This allows automated and semi-automated cycling of the prototype. The linear motor has a 28-inch range of motion and, although not necessary for this application, can operate at high speeds.

The system as currently configured is capable of acquiring and displaying averaged samples at a rate of approximately 1 Hz. In a fielded system, there may be some optimization through impedance matching when a detailed design of an integrated amplifier is completed.

The project commercializer plans to take the EMAT technology to market within 24 months of project completion.

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OTD Operations Technology Development

Hydro-Testing Alternative Program

In this project, research is being conducted to identify and validate alternative technologies that could provide inspection methods that are equivalent to or better than a hydro-test for regulatory-acceptance purposes.

Project Description

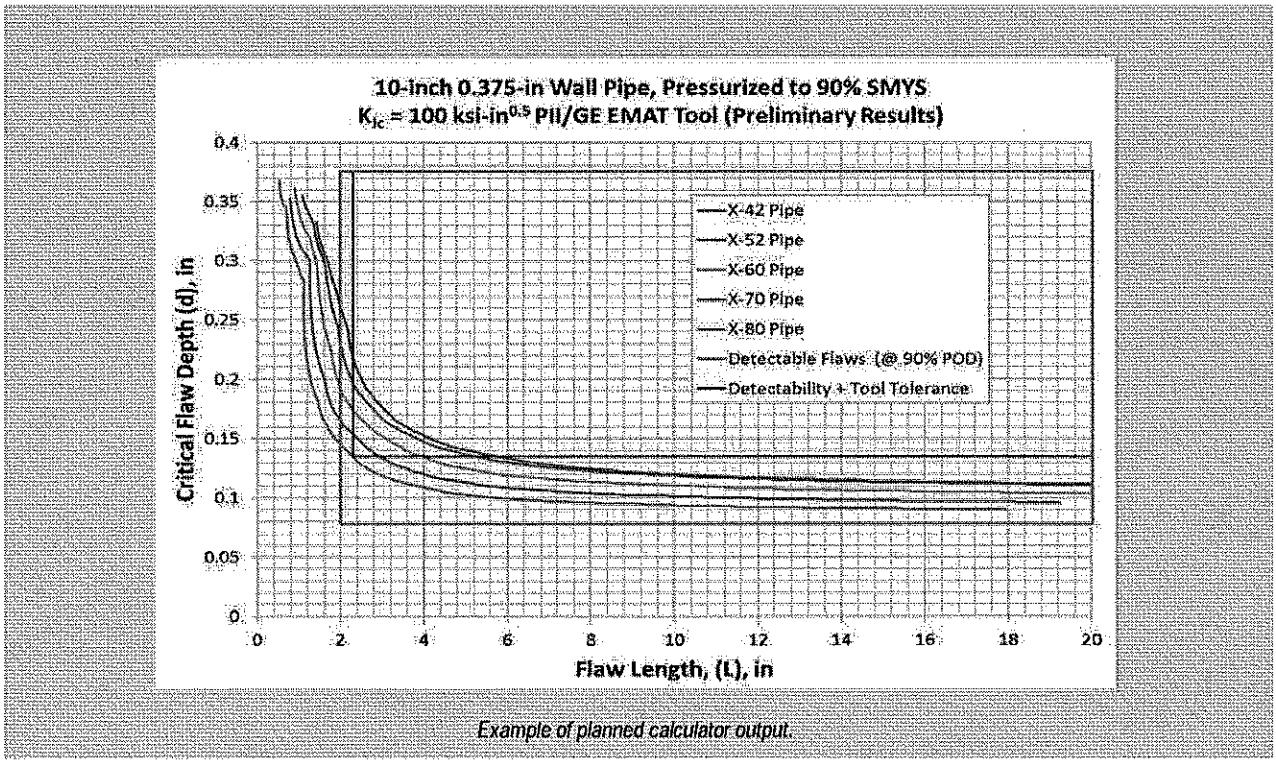
Hydrostatic testing is universally known and accepted as a means of demonstrating the fitness of a pressurized pipe or component used in the delivery of natural gas.

After a hydro-test, a pipeline or pressure vessel can be expected to safely contain its intended operating pressure. In addition, hydro-testing can be used as a re-validation test after a component has been out of service after a period of time.

Currently, the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) is considering new regulations that would require operators to perform hydro-testing on pipes that do not have hydro-test records. The new regulations would require many operators to take segments of a pipe out of service. However, the PHMSA is considering alternatives to hydro-testing that could provide an equivalent assessment. In this project, research is being conducted to develop such an alternative.

The most important step in this project was the definition of critical flaws that would fail a hydro-test. For this project, researchers developed a methodology to generate critical flaw curves for the variables including: diameter, wall thickness, toughness, and yield strength. Finite Element Analysis (FEA) and other research was conducted to obtain data on inspection technologies found to be potentially lower-cost alternatives to hydro-testing.

In the current phase of the program, a calculator will be developed that operators can use to determine the ability of a specific in-line inspection (ILI) tool to provide a hydrotest alternative for a specific pipe segment. This calculator will take uncertainty into consideration and be designed in a way to provide a conservative estimate of equivalence with confidence intervals.



Example of planned calculator output.

Deliverable

The deliverable for the current phase of the project will be a calculator that operators can use to determine the ability of a specific ILI tool to provide a hydro-test alternative for a specific pipe segment. Operators will input pipe-segment information (diameter, wall thickness, etc.) to generate a critical flaw curve to identify the size of the flaws that would fail a hydro-test and/or a spike test. The calculator could be used for a wide range of pipe configurations.

Benefits

The ability to use internal and/or external inspection tools to perform an integrity assessment as a regulatory-acceptable alternative to hydro-testing would ensure the operator of the safety of the pipeline and provide significant cost savings in complying with new regulations.

Technical Concept & Approach

To provide a proper comparison between hydrostatic testing and alternative means to ensure pipeline integrity, it is necessary to obtain *accurate* estimates of critical flaw sizes that would fail a hydro-test. Traditional pipeline failure models tend to underestimate critical flaw size, which leads to an over-optimistic impression of the effectiveness of a hydrostatic test (i.e., sizes that would fail a hydro-test). Traditional pipeline-failure models tend to underestimate critical flaw size, which leads to an over-optimistic impression of the effectiveness of a hydrostatic test.

A "virtual burst test" methodology has been developed that entails using 3D FEA to simulate pipeline rupture. This method is being applied to quantify flaw sizes that would be identified in a hydrostatic test. The flaw sizes computed with the virtual burst test method will be compared with the sensitivity of various nondestructive evaluation methods.

In the current phase of the project, researchers will develop and execute a tiered numerical solution (computer program) which narrows all solutions to those that contain the possible combinations of toughness, diameter, thickness, yield strength, hydro-test pressure, and other factors. The program will be used to create a calculator that takes user-defined inputs and provides critical flaw and wall-loss plots with inspection tool data overlays to define the areas equivalent to a hydro-test.

A draft (beta version) of the calculator and training manual will be circulated to sponsors for testing and feedback for a second beta version.

Results

This project is being conducted in three phases.

Initial research found that of the pipe that would be subject to new hydro-testing regulations:

- 3% have weld records
- 16% are piggable
- Very few mechanical couplings exist
- More than 70% was installed prior to 1970
- Almost all girth welds are from the 1950s and-more modern welds and are open root butt weld
- Valves, tees, and elbows are the most prevalent fittings/features
- Most operators do not know if they have mill records.

In Phase 1 (now complete), the project team identified and selected inspection tools for validation as a hydro-test equivalent.

In Phase 2, researchers completed the development of a methodology to generate critical flaw curves for the following variables: diameter, wall thickness, toughness, yield strength, and % Specific Minimum Yield Strength (SMYS).

Status

Phase 2 created the FEA critical flaw data and collected Probability of Detection data for Electromagnetic Acoustic Transducer and Acoustic Resonance Technology sensors.

In Phase 3 (current phase), researchers will create the critical flaw curves that will allow a comparison to ILI tool detection capabilities. The deliverable for Phase 3 will be a tool that operators can potentially use to demonstrate equivalence to a hydrotest for a specific pipe segment.

The research will work with the American Gas Association and/or the appropriate standards organizations to implement the results of this project.

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OTD Operations Technology Development

Surface Indentation for Material Characterization

Efforts are under way to develop a technique that allows pipeline operators to determine the material properties of in-service pipe with minimal disruption to system operations. Specific activities focus on the development of correlation factors to relate surface properties to actual material properties to allow surface-indentation techniques to be used for material characterization.

Project Description

Current regulations require pipeline operators to either assume a pipe yield strength value of 24 ksi or perform testing in accordance with American Petroleum Institute guidelines, with a sampling rate of approximately 10% for undocumented pipe.

For operational reasons, some operators may choose to assume 24 ksi instead of performing testing; however, this may result in pipe segments being classified as transmission lines because they are being operated above 20% SMYS (Specified Minimum Yield Strength). Operators, therefore, must perform specific integrity-management activities on pipe segments that may actually operate at lower stress levels.

Pending Integrity Verification Process (IVP) regulations may require operators to perform material testing for all transmission pipe that does not have validated and traceable material-property records. Compliance with this regulation using currently allowed techniques could be extremely expensive.

This project focuses on addressing the need for a technique that allows operators to determine the material properties of in-service pipe with minimal disruption to system operations.

In 2007, research supported by OTD was initiated to identify and validate alternative techniques to determine yield strength. Two surface-indentation techniques that used a probe for local interrogation were evaluated by comparing results to full-size samples. The results of the testing showed that the surface-indentation techniques could not be used to accurately determine the yield strength of in-service pipe through surface interrogation because some pipes have inner-wall yield strengths that are lower (or higher) than the outer, thereby reducing the overall yield strength of the pipe. One pipe sample had a discrepancy between surface and through wall yield strength of over 20%.

The American Society of Mechanical Engineers (ASME) conducted extensive research to correlate surface hardness values with yield strength. However, this approach is subject to the same constraints as the probe because it is only able to interrogate the surface of the pipe that may or may not represent the through-wall material properties. That particular study did not determine how much of the pipeline population might have non-uniform material properties through their thickness and if the sample set used to develop the method properly takes this into account.

To address the issue of non-uniformity, researchers developed a technique that removes a full-wall thickness, sub-sized sample from a standard six-inch hot-tap coupon to allow yield strength testing to be performed. An extensive testing program validated the equivalence of the sub-sized samples to the full-size samples. One operator has received a special permit to use the sub-sized samples for determining the yield strength of an undocumented pipe.

The sub-sized sample technique was developed because it extracts a *full-wall* thickness sample and uses standard hot-tapping equipment that has been in use in the industry for decades. However, the use of this technique to test extensive amounts of in-service pipe, as would be required with IVP, may not be optimal since operators and regulators may not want to subject thousands of miles of pipe to extensive hot-tapping operations and the subsequent repairs.

The objective of this project is to develop correlation factors to relate surface properties to actual material properties to allow surface-indentation techniques to be used for material-property validation for pipelines. The correlation factors will be based on pipe vintage by decade. Researchers will develop probabilistic confidence intervals that will allow operators to use surface-indentation techniques by applying correlation factors to pipe materials that may have through-wall variability.

Deliverable

The deliverable of this project will be a database of through-wall properties by vintage for typical pipelines in service in the natural gas industry. The probability distributions of these properties will be used to correlate existing and future surface based measurement techniques to an aggregate through-wall property to comply with IVP and pipeline safety and integrity requirements.

Benefits

The ability to characterize material properties – particularly yield strength – of in-service pipelines without taking the line out of service or removing samples will significantly reduce the cost of complying with existing and pending federal regulations. Backfiling records with material-property information (such as yield strength and toughness) also improves integrity management through system knowledge that allows for enhanced modeling and analysis.

It is anticipated that the results of this research will facilitate the regulatory approval of microprobes and hardness testing to characterize material properties of in-service pipe. It will also enable the use of internal inspection tools for surface readings from the inside of the pipe to be applied to the entire pipe wall.

Technical Concept & Approach

The scope of this project includes the development of factors that will correlate surface properties with through-wall material properties based on vintage. Researchers will identify the manufacturing processes and related pipe vintages that resulted in non-homogenous pipe and will develop correlation factors that account for the potential through-wall variations.

This project includes the development of correlation factors for four out of eight vintages of pipe. The four vintages to be included in this scope will be selected by project participants. Correlation factors for the remaining four vintages can be developed in a second-phase project.

The research team will define the type and amount of pipe samples needed to develop correlation factors for the four selected vintages. A request for pipe samples will be issued to operators, universities, and other research organizations. The 40 samples that were received for the previous projects will also be used.

Testing of 25 to 30 pipe samples from each vintage category will be performed. Testing will include cut-out and preparation of samples to conduct full-size tensile, probe, Charpy V-notch toughness, metallography and microstructure, hardness, and other metallurgical and mechanical tests as warranted.

All project data will be logged into a database for future use. Data will be analyzed to establish the uniformity or non-uniformity of metallurgical and mechanical properties across the pipe wall by vintage and manufacturing process.

Results / Status

A literature search and sample collection is under way. More than 50 key published papers were identified, as well as published books on or related to the project subject. The papers have been sorted and ranked to their relevance and value in the research. Information is being cross-referenced and summarized.

Emphasis is placed on mechanical, chemical, and physical data. Information is being gathered on hardness, micro-indentation, microstructure, vintage variability, chemistry trends, yield strength, tensile strength, and other factors.

Researchers are also investigating primary steel-making and thermo-mechanical pipe-forming trends.

Plans are to categorize the pre-1970 pipeline steels into groups based on the literature findings and how this relates to non-isotropic/homogeneous properties across the pipe wall.

A model was identified relating chemistry and grain size to yield and tensile strength. Initial validations show promise and could lead to model incorporation into the surface correlation method.

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OPERATIONS INFRASTRUCTURE SUPPORT

Addressing issues often beyond the traditional areas, this research involves the development of tools and techniques for metering, gas shut-off, vault maintenance, remote monitoring, cathodic protection, data collection, and other applications.

Developed technologies are subjected to a regimen of laboratory and field evaluations to ensure their safety and efficiency.

New efforts include evaluations of PE pipe splitting and excess flow valves.

OTD Operations Technology Development

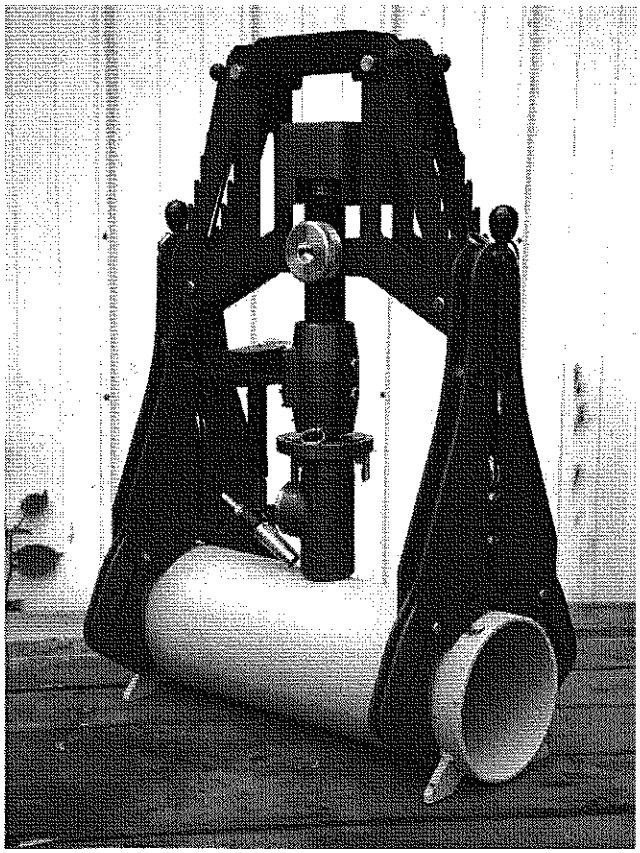
Development of an Automated Welding Unit for Installing Laterals

An alpha prototype of a portable automated system was developed for welding steel service tees onto steel mains. Current efforts are under way to develop a beta system for performing welds on various types of tees and nipples in steel gas piping systems and to identify a manufacturing partner to bring the system to market.

Project Description

The prominence of polyethylene (PE) pipe for natural gas distribution has led to industry concerns with the reduction in the amount of experienced welders in the utility workforce. While PE systems dominate the natural gas distribution system, most utilities still have a significant amount of steel distribution pipes in operation that need to be properly maintained. When these steel systems require servicing (planned and emergency work), scheduling a welder is often a critical path in completing the job.

Recognizing the issue, in 2011 Gas Technology Institute's Sustaining Membership Program sponsored a program that produced a working concept alpha unit to weld steel service tees to steel gas mains in keyhole applications. Subsequently, OTD supported testing and modifications and developed an alpha prototype portable welding unit for use in traditional excavations to automatically weld steel service tees onto steel mains.



Prototype from Phase 1.

In a continuation of the project, a new effort was initiated in 2013 to design an advanced automated welding unit with an emphasize on quality control and consistency of welds on service tees and nipples in steel distribution systems. The system is also designed to expedite the training and qualification process to perform these welds and at the same time increase the labor pool qualified to perform this type of procedure.

The automated welding unit for steel may be seen as analogous to what electrofusion PE fittings did for the PE piping systems, which resulted in increased quality, reduced training needs, greatly reduced user-to-user variability, and reduced failures in the piping systems.

The objective of the current Phase 2 of the project is to assess the status of the alpha prototype, identify a commercial partner, and develop a beta prototype of the automated welding unit. Once the partner is identified, the project team will move forward with developing a manufactured prototype.

Deliverables

Efforts in this project focus on the identification and selection of a manufacturing partner, development of a beta prototype automated welding unit, and the creation of procedures to perform welds on various types of tees and nipples. Throughout the project, researchers will team with the selected manufacturer to assist with the implementation of the unit as a commercially viable product for the industry. A Final Report will document these efforts.

Benefits

The benefits of an automated welding system for steel service tees and nipples (laterals) range from improved weld quality to decreased variable labor rates. These include:

- **Improved Weld Quality** - Mechanized welding improves weld integrity and repeatability
- **Simplified Training Needs** - Similar to electrofusion welds on PE, operators will be trained to prepare the parts, understand the process, perform the necessary steps, and visually inspect the welds
- **Decreased Labor Costs** - Reliance on human welders increases the labor costs (i.e., time for welder to get to job site, crew time waiting for welder, etc.)
- **Increase Labor Pool** - To install steel service tees and nipples
- **Safer Work Practice** - No person will be in the excavation during the welding operation (crews set up the unit and exit the excavation prior to welding – similar to electrofusion of PE fittings)
- **Enhanced Operating Efficiency** - No waiting for welders to at the job site and welders do not have to wait for the crew at the job site.

Technical Concept & Approach

Tasks in this project include:

- **Review of Current Prototype Unit**

  Researchers will review the status of the current prototype to obtain a better understanding about the remaining issues with the prototype unit. The research team will also initiate efforts to identify potential commercializers and/or manufacturers to partner with to develop the next-generation prototype unit.

- **Design, Development, and/or Enhancements of Beta Welding Unit**

  Researchers, project sponsors, and a manufacturing partner will develop a path for the design and development of a beta unit.

- **Fabrication and Evaluation of Beta Welding System**

  Once the unit is finalized, various welds will be created and each of the welds will be destructively tested to ensure quality and repeatability. Results of the tests will be used to modify the welding system to meet any requirements necessary for approval or success of the project. Field testing will highlight any necessary changes before the final designs are handed off to the manufacturer for production.

Results / Status

Efforts are under way to formalize an agreement with a commercialization partner for the automated welder. Once the manufacturing/commercialization agreement is in place, further enhancements of the beta welder will be made in collaboration with the manufacturer.

Surveys were sent to prospective manufacturing partners to evaluate their fit for this project.

An entirely new beta prototype design concept was developed in response to the evaluation of the alpha prototype developed in Phase 1. This redesign addresses concerns raised about the complexity and reliability of the alpha prototype and re-focuses emphasis on ease of use and portability for this field tool.

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Tool for the External Classification of Pipe Contents

Research is being conducted to develop a practical tool that can enhance operations safety by being able to distinguish the contents of a buried utility pipe without breaching the pipe wall. The ultimate objective is to develop an affordable tool that could be carried in each crew truck.

Project Description

Natural gas pipelines, water lines, electric cable, and other underground facilities can be buried near each other, often making it difficult to distinguish one utility from another. Compounding the difficulty is the fact that gas pipelines can be at a variety of pressures, and electric lines can be pressurized with mineral oil or nitrogen. Misidentifying an electric line for a gas line or tying a low-pressure gas main to a high-pressure gas main can cause potential hazards for utility workers and the general public.

In this project, research is focused on the development of a practical tool that can distinguish the contents of a utility pipe without breaching the pipe wall. Current activities are aimed at developing the ability to detect "live" three-phase electrical cables.

Deliverables

In Phase 1 (now completed), the research team identified potential technologies, performed a system design, and developed a work plan. In Phase 2 (completed in 2013), the research team developed and tested an alpha prototype device. The current Phase 3 focuses on the development of a pre-production model with the ability to detect electrical cables.

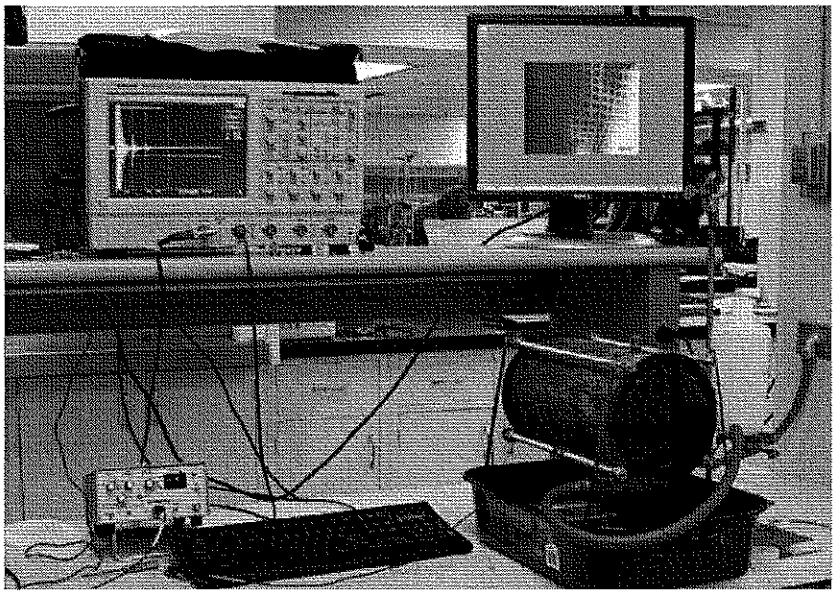
Benefits

The successful development of a tool for externally classifying pipe contents would help to prevent accidents that can occur when steel pipe containing high-voltage electrical lines are drilled into because they are assumed to be natural gas lines. The tool could also identify standing water in mains and measure the water depth in these areas of standing water. The tool would minimize costs associated with water removal from gas mains by being able to detect and measure fluid depth from outside of the pipe.

Technical Concept & Approach

This project is being conducted in three phases:

- Phase 1: Selecting technologies to be used, performing a system design, assessing the market, and developing a work plan.



Experimental set-up to test the ability to measure water and oil depth.

- Phase 2: Develop a fully tested (laboratory and field trials) alpha prototype device suitable for applications for 3- to 10-inch pipe diameters for steel, cast-iron, and polyethylene pipe.

  Operator input will be limited to preparing the pipe surface and holding the sensor. Additionally, the operator will not have to enter the pipe diameter or material. Signal processing techniques will be designed to measure water depth and to identify the presence of water and three-phase electric cables. Measurement techniques will be programmed into the prototype tool.

- Phase 3 focuses on product enhancements and the search for a manufacturer to commercialize the tool.

Results

Phase 1 demonstrated that it is possible to:

- Accurately measure water depth with an ultrasonic sensor on the bottom of pipe
- Determine if the water level in a pipe is above a certain level
- Determine if a main is completely full of water – either a water main or a gas main filled to the top with water – versus a gas-filled main (natural gas or air)
- Detect the presence of electrical cables in dielectric oil-filled steel pipe
- Detect live, three-phase electrical lines at voltages as low as 1200V with an acoustic sensor.

Phase 1 also demonstrated that estimation of gas pressure inside a conducting, non-ferromagnetic pipe is possible using an Electromagnetic Acoustic Transducer (EMAT). Measurement of gas pressure inside a steel pipe would be possible if an EMAT that efficiently generates longitudinal waves in ferromagnetic material existed. However, substantial development work is required before such a sensor is viable.

A survey on the technology needs/market size found a viable market for a practical pipe contents tool. The market survey also found making measurements of water depth from the bottom of the main and the amount of pipe preparation required are both acceptable.

In Phase 2, an ultrasonic tranducer (UT) was used to generate waveforms that can yield water depth and the presence of electrical cables from the outside of the pipe. A large number of waveforms were collected from pipes of different materials, diameters, and water depths. Using this data, an algorithm was developed to recognize the appropriate reflections automatically, and calculate an estimate of the water depth. Algorithms were developed that determine the depth of water to +/- ⅛ inch. The appropriate depth information is displayed without the operator viewing or analyzing waveforms or data.

An algorithm was also developed to identify the vibrations created by three-phase electrical cables and alert the operator. The sensor used for live cables can be used on the surface of the pipe or the surface of the ground.

A prototype sensor holder was designed and built to hold the UT sensor against the bottom of the pipe.

Alpha prototype hardware was designed and an operator interface was designed and implemented. A LCD display is used to guide the operator through the measurement process in logical steps. The operator reads a menu and enters choices via a 16- key pad.

Various modifications were made, including improvements to the pulser. With a redesign of the pulse circuitry for the ultrasonic transducer and new components, the pulse circuitry is performing as expected, and transducer signal transmission is propagating in the material correctly.

Phase 2 activities were completed in 2013 and the system was demonstrated in the laboratory.

Status

The current Phase 3 involves the construction and demonstration of a pre-production prototype tool capable of detecting "live" electrical cables by the current flowing in the cables.

The objective is to detect three-phase cables at several locations: at the surface of the ground, in the excavation before the pipe is exposed, and in contact with the pipe.

In 2014, the project team reviewed transducer options in terms of frequency range, sensitivity, low noise floor, and durability. Testing of hardware and software is under way.

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OTD Operations Technology Development

Development of Standardized Algorithms and Identifiers for Enhanced Material Tracking and Traceability

Efforts are under way to develop a series of protocols that can be used as a method for utilities to track their facilities. Current efforts build upon a standardized classification system developed in this program for underground utility assets to include meters, regulators, and transmission pipeline components.

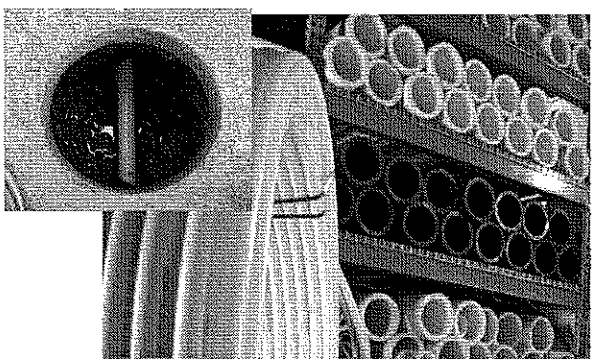
Project Description

The precise identification of underground assets and other gas-system facilities is critical to utility infrastructure planning, risk management, and a wide range of other company activities.

Currently, there are various tools available and under development to aid gas utilities in locating buried pipe and facilities. However, even with the latest technologies, the data obtained is not standardized and may be insufficient for appropriate planning purposes. Adding to the issue are pending distribution integrity management initiatives that emphasize the need for identifying buried underground assets and mitigating risks. While ASTM standards address marking, the guidelines lack the specificity needed to be able to accurately track materials and products throughout the entire supply chain.

In response, project researchers developed a series of standardized algorithms and unique identifiers (standardized nomenclature or "language") to more accurately characterize gas-utility assets. These "identifiers" can subsequently be used as building blocks to track materials (e.g., subcomponent fabrication, manufacturing, assembly, distribution, storage, and installation) both from an individual gas-company perspective and from an industry-wide perspective.

In Phase 1 of the project (now complete), a standardized classification system (base-62 encoding system) was developed to provide the basis to codify key attributes of a given component in discrete sizes and format to facilitate more effective tracking and traceability. Specifically, the 16-digit alpha-numeric code consists of datasets that provide information related to the manufacturer name, characterization of the component (size, material type, and component type), and product logistics (lot number and date of production).



With a standardized set of protocols, utilities will be better able to manage their assets and respond to critical situations.

The objective of the program is to advance the standardization activities to promulgate the 16-character code schema and methodology within the marking requirements of various applicable code and industry standards related to meters, regulators, and transmission pipeline systems (pipe and components) and to promulgate the newly developed ASTM F2897 methodology within the marking-requirements sections of various ASTM and other industry standards.

Deliverables

The Phase 1 deliverable included a validated series of algorithms to assist in the identification of the 20% high-use gas-distribution products; a set of validated "modules" (e.g., spreadsheets and database libraries) which can be integrated within gas utility company operations; and a draft standard for inclusion within ASTM standards and specifications.

Phase 2 deliverables include a petition to the U.S. Department of Transportation to reference the use of the algorithms and technical guidelines for each sponsoring company with respect to implementation options and requirements specific to their operations.

Benefits

Inaccurate or insufficient information related to buried assets during a critical time (such as a product recall, problematic pipe and fittings, etc.) can result in significant expense, lost time, and productivity losses. The development of standardized language at a national level would provide an effective method for tracking the assets of the overall gas distribution piping system throughout the entire supply chain. A standardized ap-

proach also provides the appropriate framework for the implementation of new techniques and technologies.

Technical Concept & Approach

A database was developed in a relational database management structure to address relationships and identify commonalities among various components and respective suppliers. The results were then used to create the necessary construction of identifiers. Identifiers provide a means to develop sufficient marking requirements that establish the uniqueness of the various components.

The Gas Distribution Component Traceability Identifier includes pertinent information such as: part manufacturer, attributes of a given part, and the pedigree of the part.

To date, all facets of the initial program are complete and a Final Report was prepared. Leveraging this momentum, in 2013 additional tasks were added to extend the base-62 encoding system methodology to transmission pipeline components, meters, and regulators. The research team will:

- Document current procurement practices for steel pipes and components, meters, and regulators
- Review applicable code and ANSI certified standards governing the physical, traceability, and marking requirements for steel pipe and components, meters, and regulators
- Document and finalize the key items of interest that need to be encoded through the base-62 encoding system for the vast number of gas transmission pipeline components (pipe, fittings, and appurtenances), meters, and regulators
- Develop a standardized 16-character identifier to encode key characteristics of transmission systems.

Results

Since 2008, researchers have been engaged in a comprehensive effort to establish a standardized means of marking various components used to construct the gas delivery network. To date, the project team has successfully developed a unique base-62 algorithm to encode key characteristics (attribute and pedigree information) for various types of gas distribution system components and integrate the information within various ASTM product specifications. The objective of this program was to leverage the base-62 algorithm and extend a similar methodology for transmission pipeline systems (line pipe and components).

Following a comprehensive review of requirements within industry standards/specification and input from OTD sponsor companies, two working models were developed for possible integration within industry standards.

A web-based application – www.componentid.org – was developed to establish a national registry of manufacturer identifiers.

To provide guidelines for the use of the base-62 traceability encoding system, researchers established a consensus-based stand-alone ASTM specification – ASTM F2897-11 *Standard Specification for Tracking and Traceability Encoding System of Natural Gas Distribution Components (Pipe, Tubing, Fittings, Valves, and Appurtenances)*. The specification will provide a path forward for manufacturers to mark their respective products in a uniform and standardized manner and for gas utility companies to address recent regulatory initiatives and reporting requirements.

Activities in 2014 focused on developing and implementing the 16-charcter code schema(s) for meters/regulators and transmission pipeline components within respective industry standards. Based on discussions within industry stakeholders, the consensus opinion was to start with ASTM 2897 and strengthen the standard as it relates to various "other" pipeline components. The ASTM F2897 standard could then be referenced within other industry specifications without the need to develop additional verbiage. It is hoped that this strategy will streamline acceptance timeframes and also subsequent modifications only need to take place in a single standard.

Status

In the current Phase 2, research is addressing the need to implement the 16-charcter code schema(s) developed for meters/regulators and transmission pipeline components within respective industry standards. Specifically, it was recommended that there be a concerted effort to include the proposed 16-character code schema and developing suitable verbiage to incorporate within applicable industry standards (e.g., API 5L and ANSI B16 committee for various components). Modifications were made to ASTM F2987 to include respective meters and regulator information. The revision was submitted for consideration and acceptance by ASTM.

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Mitigating Electrical Interferences on Cathodic Protection Systems

To enhance the safety and lower the maintenance costs on steel gas-piping systems, research was conducted to identify or develop practices that mitigate the effects of electrical interference on cathodic protection and telemetry systems.

Project Description

Electrical interference can impair or entirely negate the effectiveness of cathodic protection (CP) systems used to prevent corrosion on steel pipelines.

Power-line surges, lightning strikes, and other transients will follow the path of least resistance from exposed points into the CP system. Examples of exposure points include: instrumented regulator vaults, meters and custody-transfer points, parallel high-tension lines, facility crossings, and rectifier stations.

Current electrical-mitigation practices address the steady-state levels of interference seen under normal conditions; however, the performance of these systems under extreme conditions, such as lightning strikes or power-line faults, is not well understood. A remote CP system that is disabled may go undetected for a long period. In addition, there is some evidence that AC interference can cause corrosion on gas pipelines, even with CP, but it is unclear whether this is caused by steady-state or transient events. (A transient or fault that does not disable the CP system may still leave some cumulative damage.)

While National Association of Corrosion Engineers (NACE) guidelines (e.g., RP1077) establish acceptable limits of induced AC or the interference from other facilities, these guidelines assume that the other facilities are operating normally.

In this project, research was conducted to identify practices that mitigate the effects of electrical interference on CP and telemetry systems.

Deliverable

Investigations will result in the development of detailed information on CP-interference issues, practices to address these issues, and recommendations for improvements.

Benefits

This project is being conducted to improve the reliability of remote CP and telemetry systems – equipment that must operate unattended in order to be cost effective.

Application of research results can be used to assure that CP and telemetry systems can withstand transient events and continue operating safely and efficiently. In addition, research could lead to a reduction in the need to repair or reset equipment in remote locations.

In the case of CP systems, research results can be used to initiate practices to prevent possible AC corrosion. This will avoid future costs of repair to both the CP system and the infrastructure itself.

Technical Concept & Approach

- **Review of Utility Experiences**

  Representative site data from participating utilities was used to better direct the investigation. Researchers also reviewed interference-mitigation practices in the gas industry.

- **Instrument Field Sites**

  Selected field sites were instrumented to capture data on steady-state and transient interferences on CP systems. The instrumentation consists of battery -powered data-loggers and appropriate sensors. In addition to the normal sensors for CP parameters, the sites are instrumented for the detection of lightning strikes and power-line surges.

- **Investigation of AC Interference**

  Investigators interact with corrosion departments of the participating utilities to review the existing survey data and to collect additional field data.

- **Investigation of Transient Interference**

  Researchers note that currently there is little data in this area and that lightning and power-line events may be occurring unnoted. The data-loggers will record both the standard CP data and transient events. The records from the data-loggers will be examined periodically to determine if significant transient events, such as lightning strikes or power-line surges, have occurred. These events would be cross-referenced with the standard CP data to determine if the two can be correlated.

- **Development of Conclusions and Recommendations**

  Investigators will produce a report that details the project results and provides recommendations on practices and equipment that can protect CP and telemetry systems from interference damages.

Results

Initially, an extensive search of CP data-logging systems was performed to identify equipment capable of performing the measurements required for this study. A commercial unit (the WatchDogCP P2S-AC CP test station monitor and data logger) was chosen for field studies initiated at utility test sites in Idaho, Missouri, and Utah.

Technicians installed New Power Technologies' Sensor Guard systems to monitor the condition of the AC power line for over and under voltage conditions. The systems also monitor the ambient electric field to determine if a lightning strike is imminent.

There was significant turnover in the equipment at two of the sites. The lightning and AC interferences at these locations was more severe than anticipated. The research team worked through these problems and all of the deployed instrumentation was brought back on line. Data was collected at all three sites in 2012 and at one site in 2013 (the site with the most severe AC interference problem).

During the course of the experimental investigation and collection of data, it became apparent that both AC interference and transient events caused by lightning are distributed threats to cathodic protection integrity. A typical cause of AC interference is the parallel installation of power lines and gas lines that is becoming more common in congested utility corridors. The project also added to the empirical evidence that lightning strikes can couple into long runs of pipe. There is also the possibility that the local potential between the pipe and the soil in the immediate vicinity of the strike can be, momentarily, high enough to break down the coating.

These observations lead to the conclusion that a distributed mitigation may provide superior results to those located at a single point on the pipeline.

An additional observation is that in every instance that a rectifier sustained damage, the current causing the damage appeared to have originated from the pipe.

A distributed approach was put through some early testing, placing anodes in boreholes at regular intervals along the pipe. The anodes are connected to the pipe through an electronics package that drains off AC currents from the pipe while leaving the negative DC levels required for CP undisturbed. The approach can be thought of as "micro-wells" or a distributed ground bed. Two of the micro-wells were installed at a site with little impact on the AC level. Rather than add additional micro-wells, the utility chose to follow a more aggressive program of installing a series of conventional wells connected to the pipe through AC decoupling devices. The wells were added one at a time and the impact of each observed using the data logging equipment installed earlier in the project. These wells have also had small impact on the AC levels on the pipe.

Status

The Final Report is in the process of being prepared. This was on hold pending the outcome of the mitigation at one site and the anticipation of receiving additional power-line data from another.

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Cathodic Protection Monitoring Technology Deployment

In this project, a research team is providing training and data gathering to support the deployment of cathodic protection (CP) technology. The focus of the project is on a low-cost CP monitor to provide more rapid and improved data collection to maintain safe operations.

Project Description

To maintain safe operations, gas utilities are required to take periodic pipe-to-soil readings on their infrastructure.

The current method for obtaining the necessary data requires that the utility maintain cathodic protection (CP) test stations that are routinely visited by corrosion technicians. It is required for some structures to obtain at least one reading per calendar year.

The focus of this project is on the deployment of a CP monitoring product that could greatly accelerate data collection and eliminate the maintenance of the test stations.

The monitor is a wireless, permanently buried device developed in a project co-funded by the Gas Technology Institute (GTI) Sustaining Membership Program and National Grid. Beta units were tested at several locations and found to be effective. A further development phase was conducted by 3M Dynatel that produced engineering prototypes that are compatible with the same Dynatel handheld reading devices used for ID marker balls.

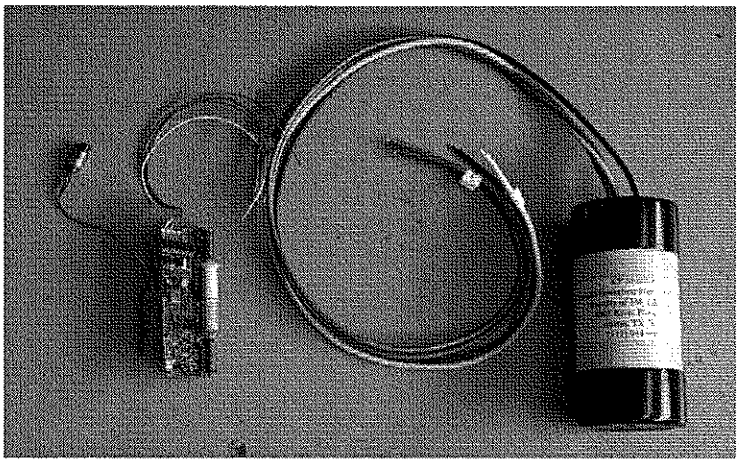
Once in place, the CP monitor can be located and read using off-the-shelf devices from 3M Dynatel. The locating and reading process is very rapid and can be done by an operator with minimal training.

In Phase 1 of the project, a modified CP monitor prototype was developed and tested in a field trial. Phase 2 focuses on modifications and further testing activities.

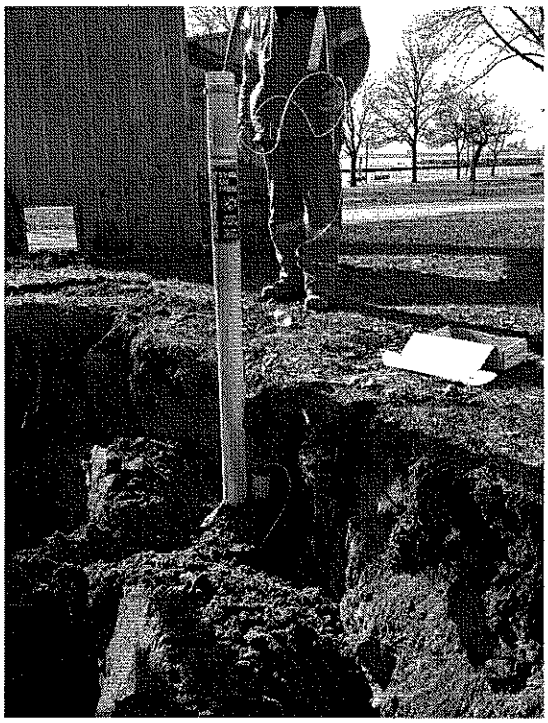
Deliverables

Deliverables include:

- A modified CP monitor prototype with enhanced features
- Locating devices and training for participating companies
- A commercialization plan.



The current version of the wireless CP monitor consists of a sealed transponder that is connected to a buried reference cell. The monitor is placed in an excavation adjacent to the facility to be monitored. A wire from the monitor is attached to the main, with the reference cell attached to the monitor placed near the main. An exposed station above ground is not required.



Benefits

The buried wireless CP monitor eliminates the need to maintain test stations between readings. It allows the routine readings to be taken rapidly by less skilled personnel, allowing the corrosion technicians to concentrate on more critical work. Monitoring of high-consequence areas can be recorded monthly and collected at the utility's convenience.

Technical Concept & Approach

Efforts are under way to develop a completely encapsulated, direct-burial monitoring device. A handheld locator/reader is used to retrieve the readings electronically from above ground without requiring a direct connection. The data can be downloaded from the handheld devices as tabular data. The monitor records and stores a pipe-to-soil potential reading once every 30 days. When an operator takes the reading, 12 months of data is recovered. This helps assure that the requirement of one read per calendar year can be met. In high-consequence areas, monthly reads can be obtained without monthly visits.

The first version of the CP monitor was successfully tested in Phase 1. As a result of testing, additional product requirements were identified.

The objective of Phase 2 is to develop and test a modified CP monitor prototype with some or all of the following features:

- Ability to record AC potential readings to detect stray currents
- Increased data storage
- Programmable data recording intervals, and
- Ability to transfer data to other handheld devices via Bluetooth™ for direct GIS integration.

Results

In Phase 1, four experimental units were installed near GTI facilities for long-term monitoring. Subsequently, four additional units were installed in the field and training was provided to utility personnel. The schematics for the CP monitor were revised in preparation for a production run of prototypes. There was also a need to upgrade the internal software of the handheld device that is used to locate and read the CP monitor.

The research team collaborated with 3M in the production of 100 beta samples for distribution to host utilities for testing.

In 2013, qualification testing of the CP monitor was completed and the first set of samples were sent to a project sponsor. A second field deployment and training trip occurred in April of 2014.

The reader and PC software required several iterations.

In-house testing of the CP monitor at GTI was completed. This included both indoor testing and testing on the GTI Pipe Farm.

GTI and 3M collaborated in producing a manual for the CP monitor.

GTI received 100 of the buried modules and six of the handheld readers, some of which were deployed to utilities. GTI visited all of the test sites to provide training and to obtain feedback on the user experience.

The user experience has generally been positive. All of the testers in the program have a need for low-profile, or "stealth" installation. Solutions that involve above-ground or visible data loggers are not acceptable. The users can typically locate and read out the loggers reliably with a minimal amount of practice. One of the testing utilities expressed an interest in moving the system towards commercialization and adopting it as a practice.

Status

A total of three test sites were fitted with the 3M CP monitor prototypes and associated readers. Data was collected from two out of three sites. There have been IT issues gathering data at the third; this may be resolved during 2015 but this will be after the Final Report has been issued.

The results overall are positive and the companies have been applying the CP monitors to known trouble spots in their systems. One of the testing companies has expressed interest in a full commercial deployment and adoption of technology.

The research team is gathering information on installation costs and other operations from the test sites. The business case for using a buried CP monitor in place of a permanent test box in the street will be addressed in the Final Report.

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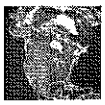
North American Manufacturer Outreach Program



Research was conducted to identify promising technologies that could provide significant benefits to the North American natural gas industry and its customers. Efforts are directed at potential development opportunities in various gas-operations areas.

Project Description

The North American Manufacturer Outreach Program is an effort to identify new gas-operations-related technologies that are not currently available from North American manufacturers, facilitate development, and accelerate the introduction of new products into practical applications.

The intent is to find technologies that are promising but not currently in full development due to a lack of financial resources or for other reasons.

In this project, market research was conducted to identify technologies through a formal program of interaction with technology developers and manufacturers. This program solicits proposal ideas for new or improved technologies from manufacturers and assists with the proposal development for projects of interest in an effort to facilitate and accelerate the development and introduction of new technologies to meet gas industry needs.

Deliverables

The results of this research will be a collection of ideas for consideration for OTD support.

Reports will be assembled to provide company-by-company summaries of the responses gathered from the manufacturers.

Benefits

The results of this project will be used to guide further implementation of technologies that reduce operational costs, improve safety, or reduce risk. Through this program, new and innovative ideas and product concepts are identified through a streamlined process designed to shorten product-development times.

Technical Concept & Approach

This project focused on identifying technologies for potential further investigation and demonstration.

OTD participants will have the opportunity to sponsor further development efforts, laboratory testing, field tests, and/or commercialization efforts.

The types of technologies reviewed included:

- Products from manufacturers' product development roadmaps

Interactions with various organizations identified promising products and opportunities.

REMOTE ORBITAL INSTALLATIONS LLC

DCI Digital Control Incorporated

elster American Meter

California Polytechnic State University — Discere Faciendo — 1901

Mueller Co.

HEATH CONSULTANTS

TDW

Timberline Tool

Information was developed on:

> Application of Equipment
> Stage of Development
> Potential Benefits
> Economics and Costs
> Safety Considerations
> Market Readiness
> Training Needs
> Patent and License Issues
> Potential for Adapting to the North American Market

- "Second-best" ideas from manufacturers that may be a higher technology risk
- Technologies that need field trials during the development stage.

Manufacturers were contacted to determine their interest in participating with OTD in new product development and exploration activities.

Information was gathered through literature searches, conferences, patents, and various websites. Phone interviews were conducted with personnel representing consultants and manufacturers.

Results

Through this project, many manufacturers were identified and informed of the opportunities through OTD. Several manufacturers submitted quality ideas for proposal considerations; others submitted ideas for review, but were not ready to submit them for proposals.

A page on the OTD website was developed to assist in the dissemination of information to interested manufacturers.

Some of the proposal ideas that were submitted are:

- A spray-on coating system for 12-inch-diameter pipe rehabilitation (the system currently exists for 24-inch and above)
- Robotic internal pipe-coating equipment that meets the requirements of natural gas distribution operations
- Tension and pressure monitoring with data logging for small-diameter horizontal directional drilling applications
- A cured-in-place liner system to reconstruct or repair existing gas distribution and service pipe.

Through 2013 and 2014, project team representatives attended various industry conferences and exhibitions, including conferences sponsored by the Southern Gas Association, the Midwest Gas Association, the Western Regional Gas Association, and the American Gas Association.

Several companies indicated that they have project ideas they plan to submit for review. Selected companies were contacting regarding specific technologies, including:

- Learning and knowledge transfer platforms using virtual and augment reality platforms in addition to game-based learning.
- Right-of-way monitoring using a private satellite constellation
- GPS-simulating location technology.

Status

The research team continues to contact previous companies that indicated there was a potential for a project idea and identify new companies with potential project ideas.

Investigators are also providing assistance to companies in submitting proposals.

The Final Report is being prepared for release in early 2015.

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Enhancing the EZ Valve by Developing a Weld-On Steel Housing for Gas-Distribution Use

In a follow-on project to a previous project, efforts were made to develop a steel-bodied version the EZ Valve for natural gas applications that could be welded on after installation to allow for a more permanent, leak-free system.

Project Description

The EZ Valve from Advanced Valve Technologies, Inc. (AVT), is a versatile fitting designed to perform multiple flow-stopping tasks on water- and gas-distribution pipes. It is mounted (bolted on) as an encirclement pipe fitting after a slot is milled in the top portion of the pipe. The operation does not interrupt the flow of gas and can function as a temporary line stop or as a permanent mainline valve.

This project focused on modifying the EZ Valve housing design so that the valve can be welded onto the pipe after its installation to allow for a more permanent, leak-free fitting. The goal was to develop and test a weld-on housing to provide the ability to use the valve on natural gas distribution systems at pressures of 125 psig without leaking.

Deliverables

The deliverables for this project included a prototype, weld-on steel EZ Valve fitting in one size (size to be determined). Based on the results of the beta prototype EZ Valve, a follow-on project may be recommended to perform field evaluations of the EZ Valve.

Benefits

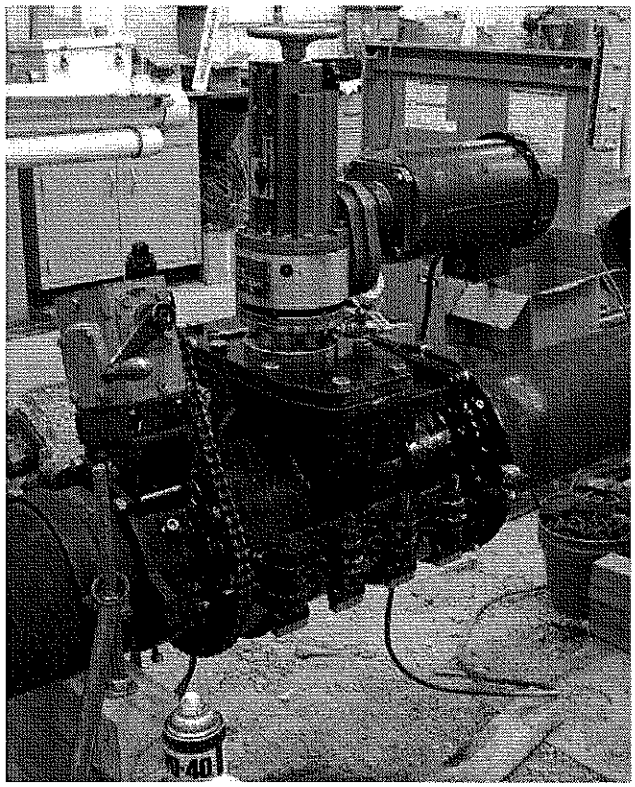
The gas distribution industry would benefit from a lightweight valve or line-stop fitting that can be quickly installed and operated to control the flow in gas mains. Current line-stopping equipment and fittings are large, expensive, and time consuming to install. The EZ Valve can benefit the industry if used as a line-stop fitting for cut offs or stopping the flow in gas mains when a bypass is not required.

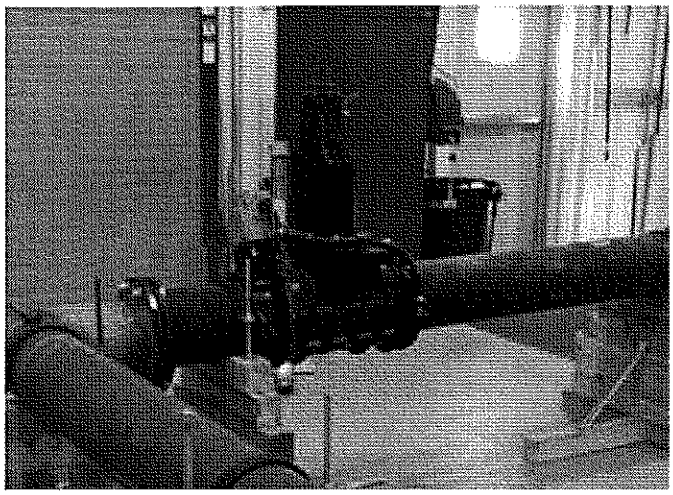
The benefits for an enhanced EZ Valve include the following:

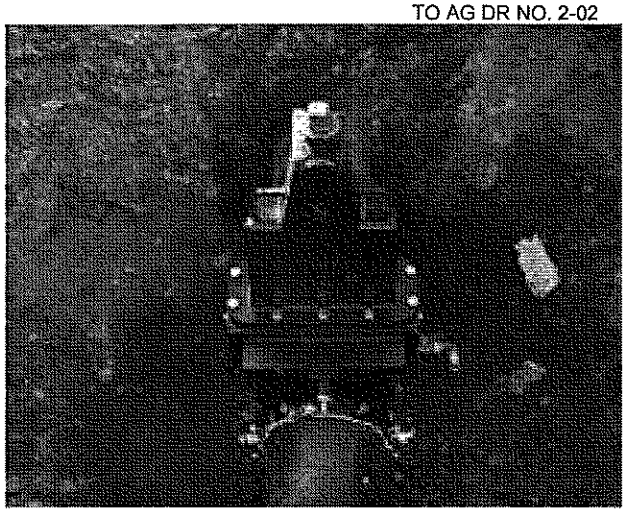
- The EZ Valve can still be used for emergency shutdown with greater efficiencies and can then be welded in place after the situation has been addressed.
- A boom or backhoe is not necessary to install the fitting. A two-person crew can lift all the parts and perform the installation and tapping of the valve in under an hour.
- The EZ Valve can be welded onto the pipe by a certified welder after the valve has been installed.
- The EZ Valve can be used as a typical line stop or it can be used as a permanent mainline valve.

The EZ Valve has the potential to make an impact on how the gas industry controls the flow of gas in pipelines. It can replace a portion of today's older, much heavier flow-control equipment that can be more time consuming to install.

The EZ Valve can be installed in strategic locations in the distribution system without the need to shut off the flow of gas, therefore resulting in smaller excavations, less time for installations, and lower costs.







Technical Concept & Approach

The scope of this project was to jointly develop an EZ Valve weld-on housing for the natural gas industry. AVT will manufacture prototypes for laboratory testing and evaluation. Gas Technology Institute (GTI) assisted with the functional specifications of the components

Specific tasks included:

- The generation of concepts for the steel-bodied housing for the EZ Valve
- The development of manufacturing drawings
- The creation of an alpha prototype housing made of steel
- Alpha prototype evaluation and testing
- Modification of alpha prototype housing.

The basic installation and operation of the current EZ Valve is displayed in a six-minute video on the AVT website: *atvfittings.com.* The installation includes bolting the fitting, milling out a slot across an arc of the circumference of the pipe, cleaning out the chips, and installing a flat gate valve. The EZ Valve is currently available in 4-inch to 16-inch sizes (maximum pressure is 250 psig). The valve can be applied on both steel and cast-iron pipe

Results

A set of design assumptions (based on an initial survey and other input from sponsors) was used in developing an initial conceptual design.

The concept allows the user to bolt on the fitting, mill the slot in the top of the pipe, and either perform the stopping operation and then weld it in place or weld it in place first and then perform the stopping operation.

These needs were considered when creating the conceptual designs:

- Applications for both line stopper and line valve (for emergency and scheduled maintenance situations)
- Applications for steel pipe
- Diameter ranges: four inch to eight inch
- Pressure ranges – up to 60 psig (100 psig desired)
- Bolt on fitting which can then be welded on after tapping/cutting
- Material costs less than $3,000 - $4,000.

Being able to operate the EZ valve and then weld it in place would allow for fast deployment and flow-stopping operations during emergency situations.

Status

AVT investigated products from past fittings with similar designs to incorporate into a weld-on product. However, the project was terminated in early 2015 due to issues involved with the costs for casting the steel-bodied design.

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Evaluation of Static Suppressors on Existing Polyethylene Piping Systems

To maintain safe operations, utilities use a variety of products and methods to reduce or eliminate static associated with plastic pipes. In this project, researchers tested different types of suppressors that may prove to be more effective and efficient than conventional static-suppression methods.

Project Description

The reduction or elimination of static in and on polyethylene (PE) gas distribution systems is critical to safe utility operations. When PE pipe is charged by particulates (dust, rust, etc.) flowing in the gas stream, charges are generated initially in the interior of the pipe. The electric field resulting from the interior charge induces an exterior charge on the pipe via conducting paths through moist atmosphere and contamination effects.

Standard safety procedures involve wrapping the pipe with wet, soapy burlap. This procedure is effective for neutralizing exterior charge accumulations, but does not affect the interior charge and may even increase the likelihood of a static-through-wall discharge event.

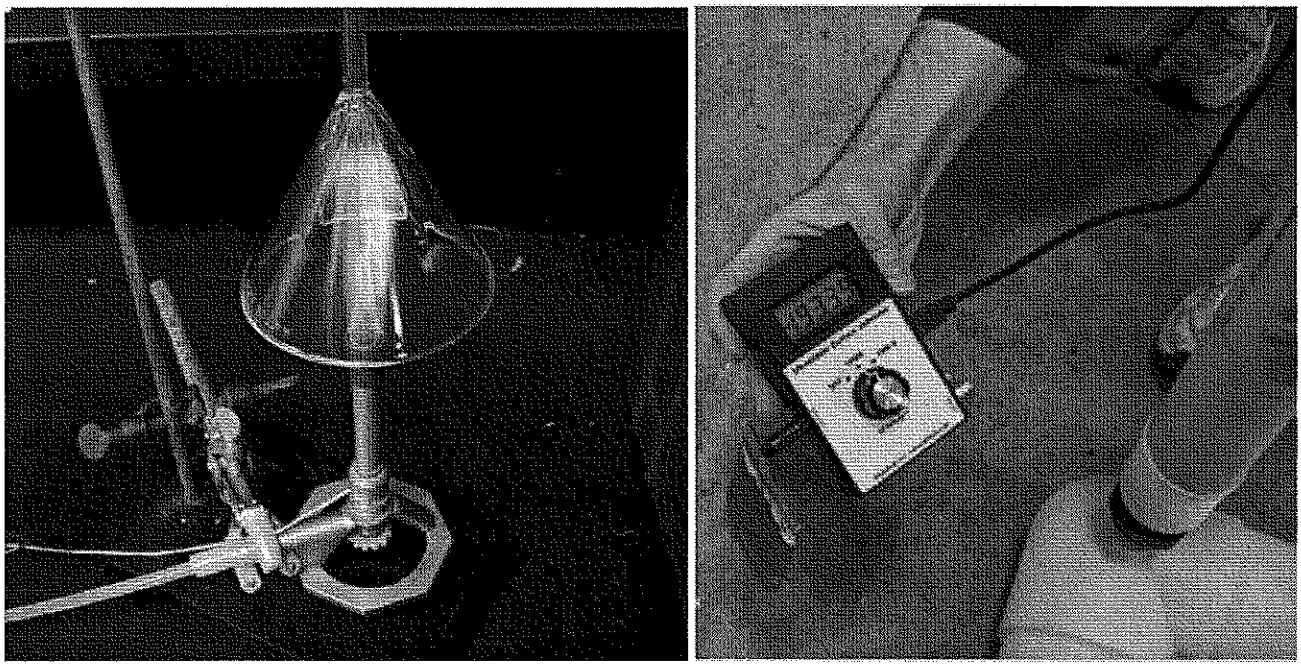
To reduce static, some utilities are using or considering the use of aerosol static suppressors and other products. The manufacturers claim that these are true anti-static products and therefore superior to soapy burlap.

This project focused on an evaluation of the effectiveness of the three commercial products:

- **Ionix Aerosol Static Suppressor** (also available as IGT Static Suppressor) – According to the manufacturer, the Ionix spray is less expensive, more effective, and easier to use than soapy-burlap or plastic-film techniques.
- **Ionix MA** (a chemical additive to mercaptan) – According to Ionix, when added to the mercaptan tank, Ionix MA is carried off through the gas distribution system with the mercaptan and eliminates any static inside the gas system downstream of odorizing.
- **Statikil PE** – According to the manufacturer, the Statikil PE spray effectively eliminates static charges on PE gas pipe by increasing surface conductivity. It also eliminates the need for bulky burlap or pipe wraps.

Deliverable

Testing results are presented in a detailed report to project sponsors.



Laboratory testing of Ionix MA (left) and Statikil (right).

Benefits

Reducing the risk of static discharge can help to assure the safe operation of PE piping systems. The products under evaluation may provide a greater level of safety during PE pipeline repair operations and the integrity of the PE pipeline will not be compromised.

Products under evaluation.

Technical Concept & Approach

Research included:

- In-depth discussions with manufacturers and others to obtain detailed information regarding the products and product performance
- A thorough literature review
- A survey of OTD members regarding current practices
- A static-flow-loop evaluation to review product performance
- The development of a business-impact study.

To frame testing activities, researchers performed chemical analyses to identify the constituents of the products.

The project includes short- and long-term testing on both control and in-field piping specimens removed. In addition, various butt-fusion and lateral-joint-fusion tests will be conducted on PE pipe specimens that have been exposed to the Ionix products.

Positive results may lead to future investigations into use of the products to eliminate static from the inside of pipes by directly injecting it into the gas stream.

Results

A flow loop for product testing was devised based on technical operation of the products and previous flow-loop experience. A test procedure was also developed.

Ionix Aerosol Static Suppressor was evaluated with respect to external static-charge-induced electric field neutralization and its effects on PE heat fusion joints. Fusion tests showed no adverse effects caused by the product. Flow-loop tests showed effective static charge equalization. Chemical formulation analyses did not reveal any compatibility concerns with PE.

Ionix MA was evaluated with respect to effectiveness of internal static charge dissipation, compatibility with PE pipe, and its effects on natural gas combustion. Flow-loop tests showed a significant reduction in static charge levels as long as a grounding mesh was used (grounding mesh inside the pipe that is grounded to the outside of the pipe), albeit with concentrations much higher than those specified by the manufacturer. Ionix MA does not completely eliminate static charge – it only limits the charge level. Evaluations of excavated pipe from a natural gas utility system used with Ionix MA for approximately two years showed no oxidation on the inner diameter of the pipe wall. The chemical composition of Ionix MA was determined to be benign to plastic and metallic pipe materials. Direct combustion of pure Ionix MA in a natural gas flame produces higher NO_x emissions, compared to natural gas alone, due to its nitrogen content, but no other emissions differences were detected.

Statikil PE was evaluated in the same manner as Ionix Aerosol Static Suppressor with respect to external static-charge-induced electric field neutralization and its effects on PE heat fusion joints. Fusion tests indicated that surfaces treated with Statikil PE should be scraped before fusion operations. Flow-loop tests showed effective static charge equalization. Chemical formulation analyses did not reveal any compatibility concerns with PE.

Status

This project was completed in 2014. A Final Report detailing project results was issued April 2014.

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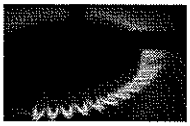
OTD Operations Technology Development

Indoor Air Quality and Safety Issues

Through this project, a website of vital information on indoor air quality and safety issues was developed for OTD members. The site provides a center of expertise and a single-point access to scientific data, performance information, and natural-gas-related issues.



Project Description

When seeking to determine causes for an indoor-air-related incident or health trend, products of combustion are often assumed to be the culprits, when other conditions could be responsible.

Experts contend that to address the issue considerable information needs to be developed – and existing information needs to be more readily available.

The natural gas industry has long supported R&D to generate data and advance technologies to address indoor air quality and related environmental and safety issues. Also, in recent years a variety of information on air-quality issues has been developed by various other organizations, including the American Lung Association and the U.S. Consumer Products Safety Commission. Among other issues, research has focused on the efficacy of carbon monoxide (CO) alarms under varying indoor temperature and humidity conditions, emissions from unvented space heaters and residential ranges, and nitrogen dioxide (NO_2) emissions from several forms of burners used in gas appliances. Research findings have been used to provide a sound basis for government regulation and a response to other audiences seeking solutions to large and complex issues.

A website for OTD members provides easy access to pertinent information from a wide range of sources.

Cause for particular industry concern is the widespread recommendation of the use of CO alarms in manufacturers' installation instructions. The general association of CO alarms with gas-fired appliances further emphasizes a need for the industry to provide an ongoing technical resource.

Through this project, a research team developed a website as an industry resource for responding to indoor CO, NO_x, and other issues.

Deliverables

The deliverables for this project are:

- An organized database of indoor-air-quality and related safety information generated over the last 30 years
- Information from gas industry experts in the field of residential appliances and indoor air quality
- Development of a consortium to advise, fund, and establish priorities for the effort
- The establishment of a center of expertise on indoor air quality and related safety issues.

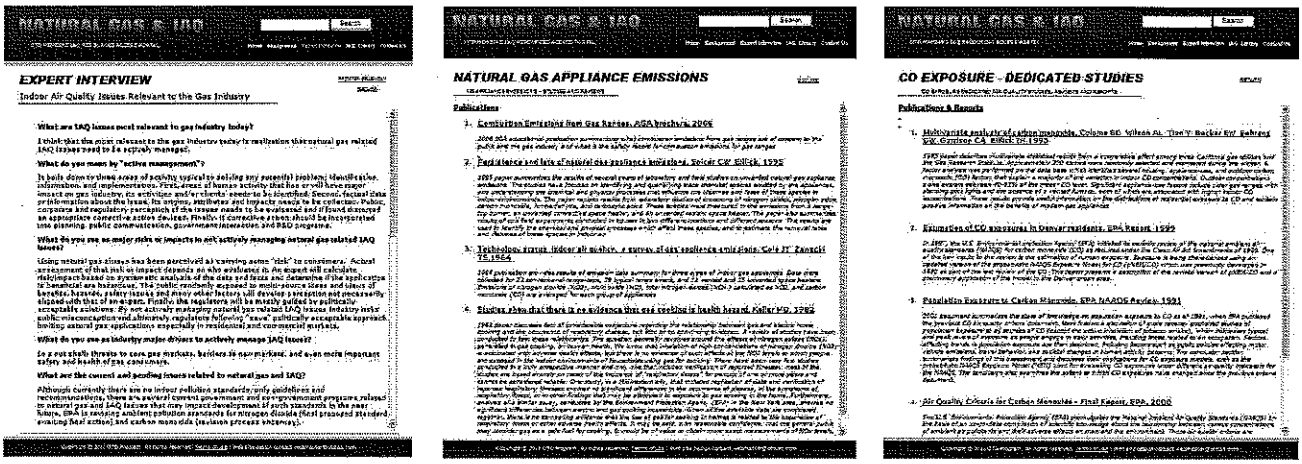
Benefits

Through the development and dissemination of information on indoor air quality, the natural gas industry can enhance customer and worker safety while providing operational savings.

Technical Concept & Approach

- **Data Search and Organization**

  A significant amount of literature from Gas Re-



The Natural Gas & IAQ website provides answers to some of the gas industry's most critical questions.

Search Institute – beginning in the 1980s and continuing past 2000 – provided a foundation of published literature for this effort.

- **Sponsor Involvement**

  Initially, sponsors reviewed records provided by experts, were involved in interviews, and assembled a consortium to support the effort into the future.

Results

An extensive literature search generated a list of more than 270 publications related to natural gas appliance indoor air quality. The publications were reviewed to eliminate redundant or less relevant materials.

In 2011, a website titled *Natural Gas & Indoor Air Quality* was developed and made available to OTD members through the OTD website (otd-co.org).

The website includes an extensive indoor-air-quality library, providing on-line access to:

- Gas Research Institute Reports
- Information on Natural Gas Appliance Emissions
- Indoor Pollutants Exposure Studies
- Dedicated Studies on CO Exposure
- Information on CO Detection and Prevention
- Dedicated Studies on NO_2 Exposure
- NO_2 Measurement and Mitigation Information

The site also provides links to information on industry programs and activities related to natural gas and indoor air quality.

Interviews with industry experts were consolidated into a Q&A format to address the most pertinent issues for the natural gas industry.

Since the introduction of the website, researchers have been adding data to the website, performing analyses, and responding to industry requests.

Status

This project was completed in 2014, with final activity focused on the development and evaluation of draft field data protocols for targeted IAQ parameters of interest, including NO_2, CO, CO_2, VOCs, and radon.

Monitoring of indoor and outdoor conditions allowed comparison to standard outdoor environment levels. Equipment was purchased and testing was conducted on two Chicago area homes. The testing allowed GTI to determine the best method of test and instrumentation for each of the parameters being studied for use in future field-data-collection efforts.

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Dewatering Systems for Mains and Services

In this project, investigators studied novel and commercially available dewatering technologies in an effort to develop a new system for the removal of residual water from gas mains and services. Current research focuses on an evaluation of chemical surfactants and the development of guidelines for product use.

Project Description

The presence of residual water in intermediate- and low-pressure natural gas lines can increase the potential rate and extent of corrosion, create hydrate formation, and cause outages during months of high demand.

Residual water presents a particular concern in cold-weather climates as gas velocity increases with demand. Water can migrate to meters and regulators and freeze, causing failures and service interruptions.

Currently, dewatering intermediate- and low-pressure mains and services can be an expensive and time-consuming process.

In Phase 1 of this project, researchers investigated two water-removal methods: 1) foam lifting products to move the water out of the low areas, and 2) fixtures, such as separators and desiccant filters, which can be strategically placed throughout the piping system.

Phase 2 includes: 1) further research and evaluations of chemical foaming surfactants that demonstrated good promise in the first phase of the project; 2) analysis of the potential safety issues and impact of these products when used to remove unwanted residual water in natural gas piping systems; and 3) the establishment of guidelines for the products' use based on the research and evaluations.

Deliverables

The deliverables for this project include reports detailing the results of the investigation into current water-removal systems, information on the use of surfactants for dewatering mains and service lines, and a set of guidelines on applying this technology to assist in the removal of residual water from natural gas distribution systems.

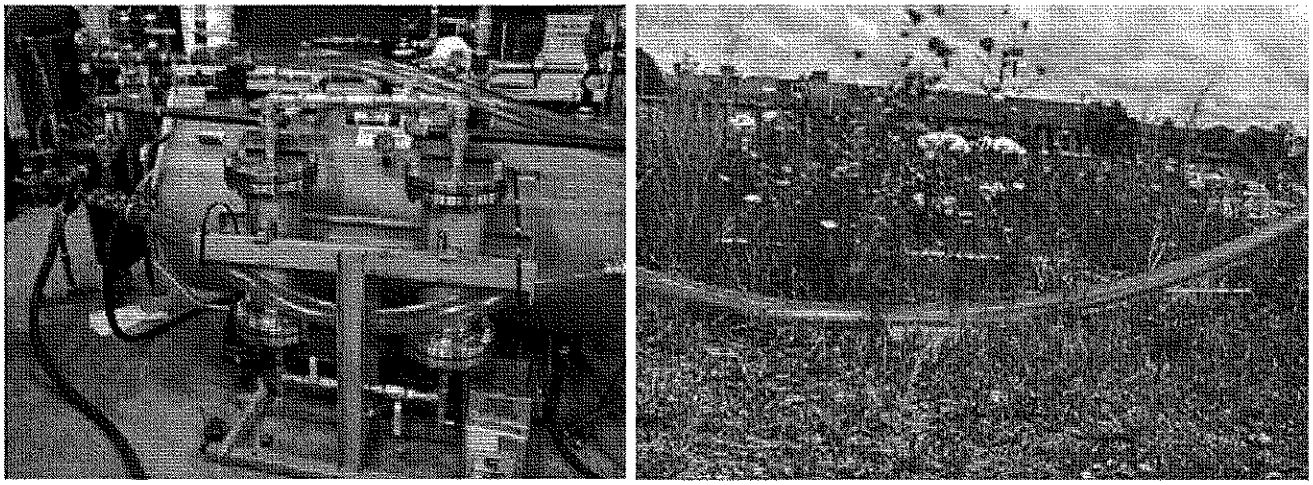
Benefits

Direct benefits of an enhanced dewatering system include: lower utility operations costs; reduction in pavement restoration due to fewer road cuts; fewer operational failures; fewer customer outages; and enhanced system integrity and reliability.

Technical Concept & Approach

Phase 1 included:

- An Investigation of Industry Standards and Current Market Solutions
- Evaluation and Transfer of Technologies
- Evaluation/ Design/ Modification of Solutions.



Left: Testing configuration for foaming agents. Right: Testing in the field.

A Final Report detailing Phase 1 testing results was issued in October 2012. Three videos of field-testing operations are available at the OTD website.

Phase 2 of the project focuses on foaming surfactants, one of the promising technologies identified in Phase 1. The objective is to more fully understand the process and implications of adding surfactants to the gas stream, and how their use may degrade pipeline materials or impact regulators, meters, and appliances during high-flow dewatering operations.

Specific tasks include:

- An evaluation of chemical foaming surfactants and their effective use and limitations in dewatering of mains and service lines
- An analysis of the potential safety issues and impact of these products when used to remove unwanted residual water in natural gas piping systems
- Establishment of guidelines for the products' use based on the research and evaluations.

Results

Researchers initially evaluated two water-removal methods: 1) a method for the removal of water from low points in the gas distribution system using foam surfactant products and 2) a method that included an examination of the devices installed on the pipeline that are designed to remove the water from the system (e.g., drip pots, separators, and filtering devices).

In Phase 2, further research was conducted into the chemical makeup of foaming agents and their use on natural gas systems. Research found that makeup varies across industry and function with different ingredients added for specific applications.

Research indicates that:

- Filtration membranes may be used to cheaply generate N_2 in the field. This can then be used to introduce a slug of dry N_2 to reduce the dewpoint in a line to near zero for effective drying or to push dewatering pigs through lines.
- Foaming/defoaming agents could potentially be a useful option for eliminating water in low gas-flow-rate regions of a distribution system, provided a correct dose can be ascertained.
- Dehydrators do not appear to be suited to best practices. The expense, maintenance requirements, and use of flaring all make this approach unattractive for use on gas distribution systems.
- Pigging is an attractive option for use on straight runs of pipe where lateral branch lines are absent.
- Portable jet (venture) vacuums may be used in distribution pipes as a less expensive solution to vacuum trucks, although they face some of the same technical limitations as vacuum trucks.
- Autodumps can be added to existing or new sump installations to reduce frequency of maintenance.

In 2013-2014, research was conducted on membranes, foaming agents/defoaming agents, dehydrators, dissolving pigs, portable jet-extraction systems, and autodumps for sumps.

A variety of information – including a report on industrial surfactants and their use – was provided to project sponsors.

While several promising avenues for physical extraction of water from distribution piping have been identified to date, foaming agents that meet safety requirements have yet to be identified. Silicon-based surfactants may well present low safety risks in terms of material handling and anticipated by-products during gas combustion, yet these agents appear to require precise application. Failure to correctly assess the volume and chemistry of the water entrained in treated distribution piping can lead to overdosing issues such as the creation of thick sludge. Silicone-based foaming agents require further investigation for use in plastic gas mains and services. Researchers were unable to procure small quantities of several silicone-based foaming-agent formulations for the purpose of conducting in-house material-degradation tests. For this reason, exposure testing was performed on three alternative, alcohol-based surfactants that are not deemed likely to pose safety hazards to personnel.

Status

Surfactant exposure testing and analysis have been completed.

A Final Report detailing findings from this phase of the project is expected to be available in 2015.

Researchers continue to search for suitable chemical agents. Should this search prove unproductive, a change of scope is likely to be proposed to enable further investigation of promising physical extraction technologies.

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Intelligent Utility System

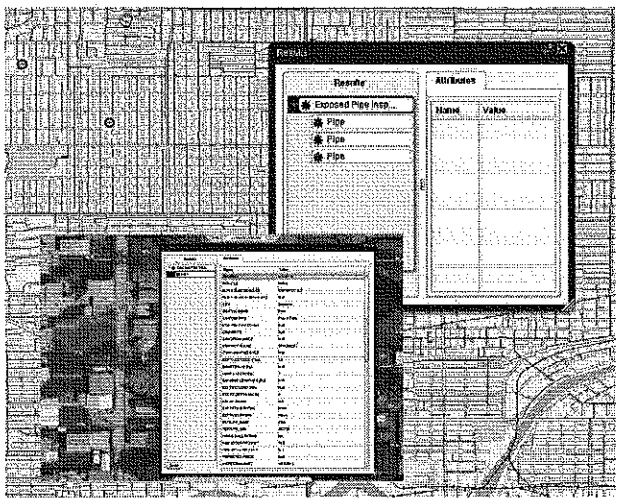
Research is under way to develop a low-cost, user-friendly Intelligent Utility System that reduces the cost of collecting and managing operational data and improves the quality of field-collected data.

Project Description

In recent years, an Intelligent Utility System (IUS) was developed as a commercial product designed to streamline field data collection using consumer-grade mobile devices in conjunction with geographic information system (GIS)-based software.

A key feature of the IUS project is disconnected editing, which allows for the collection of data in the field when a network connection is not present. The software was developed on Google's Android platform to have an interface that allows users in the field to easily collect data on gas features and installations, which is then transmitted to a server platform once a network connection is present.

The IUS is designed to help automate detailed data collection in the field utilizing Bluetooth™ technology to connect to hand-held scanners and high-precision global positioning system (GPS) devices. Hand-held barcode scanners can be used to record detailed attributes by scanning barcodes for vendor-supplied American Society for Testing and Materials (ASTM) F2897-11a plastic pipes and pipe fittings. High-precision GPS devices can connect to the IUS to record accurate location information. In addition, the IUS can record and document installation procedures, such as an electrofusion joining of plastic pipe and components. Data from installation and maintenance procedures can also be entered manually in the absence of a direct connection from the machine to the mobile device.



In this project, researchers are teaming with utility companies and using smartphones, cloud computing, and other technologies to provide a low-cost, easy-to-use system that can be extended to a variety of operations. Two pilot projects were conducted to help identify issues, troubleshoot compatibility with external devices, and obtain feedback on how the system works in the field.

Several current research projects are focused on the development and investigation of emerging technologies to automate the data-collection and management process. The objective of the IUS project is to combine the results of these individual projects into one comprehensive program.

In addition, researchers are working with individual sponsoring companies to develop specific applications as part of the IUS. These include:

- Applications for collecting new service-installation data utilizing mobile devices
- A pilot project to demonstrate the procedures and technologies for implementing a radio-frequency identification (RFID) tag marker-ball asset-locating system to reduce excavation damage
- An investigation on the use of smartphones and mobile GIS to automate field data collection for exposed pipe surveys.

Software is being developed to provide automated, real-time validation of components and equipment installed during construction.

Deliverables

The initial deliverable will be a forms-based and a map-based application for two utility operations. Pilot projects will be conducted to test and demonstrate the use of the developed applications. The deliverables for two sponsors will be smartphone/tablet devices with the new mobile service-installation application.

In addition, the research team will develop a prototype software system that provides automated, real-time validation of components and equipment installed during construction.

Benefits

Data collection and management is labor intensive and represents a large cost to gas utilities and their customers. Adoption of the IUS will provide value in both the short and long term. Short-term value will result from reducing the cost of collecting field data as part of routine operations and compliance activities. Long-term value will result from reducing system risk and optimizing maintenance, repair, and inspection activities.

Automated and electronic data capture will lead to a reduction in data-entry errors, eliminate labor costs due to back-office processing, and improve overall data quality. Enhanced data will allow for the optimization of various activities including surveys, inspections, work order dispatching, and repair/replace decisions.

Technical Concept & Approach

The IUS research program is being conducted in three phases:

Phase 1 (now completed) focused on reducing the cost of data collection and management using smartphones, smart tags, and cloud computing.

Phase 2 (now under way) focuses on automating the collection of inspection and survey data to reduce (or even eliminate) the time required for on-site collection.

Phase 3 will focus on developing analysis tools to improve operating knowledge, recommend specific actions, and provide logistical support functions for optimizing the dispatch, warehousing, and deployment of field resources.

Results

Through the Intelligent Utility System project, a computing infrastructure was developed to deliver data from the field for verification and validation. Commercial GIS software was customized to fit the scope of the IUS project.

As part of Phase 1 of the program, several pilot projects with sponsoring utilities were initiated that resulted in:

- Deployment of an iPad application for exposed pipe
- A study of devices and training for an RFID marker-ball locating system
- Deployment of marker balls using a high-accuracy GPS receiver
- The deployment of an application for high-consequence areas
- The development and deployment of an Esri ArcGIS-based web-mapping application for data visualization and data sharing.

Phase 2 activities included the development of disconnected editing to alleviate some of the connectivity issues experienced in pilot projects. Researchers developed a more stable set of editing tools, providing the ability to create and edit features locally with little difficulty. In all cases, the new software was able to read the data from the receiver and create a mapping or survey-quality point feature.

In 2013, a Native Android application was completed and readied for commercial release. The configuration components of the application were extensively tested and the configuration processes (barcode reading, external GPS, selecting different map layers, etc.) are performing as expected.

The project demonstrated the software and its disconnected editing capabilities at several industry events and webinars. Once the software was sufficiently stable, it was deployed at two pilots as part of different projects. Based on user feedback from the pilot projects, a number of enhancements were made and tested.

A Final Report on Phase 2 of the project was issued in June 2014.

Status

The research team continues to support the ongoing pilot projects and will make updates and improvements as necessary.

Phase 2 of the project was successful in creating a disconnected editing environment on mobile devices that can connect to tools to automate data collection. To accommodate corporate policies of partners and potential clients, the IUS will be developed for the Windows 8 platform.

Further enhancements could include the integration of higher-accuracy GPS locating techniques, including laser range finders, IP-based correction, and the use of multiple GPS units.

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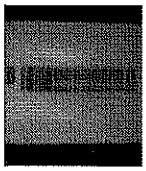
Intelligent Utility Installation Process (Asset Tracking)



A research team developed an Intelligent Utility Installation Process to provide a methodology, field process, and a data model for capturing data during new utility installations. The focus of the current phase of the project is on providing operators with the ability to track assets from manufacturing through replacement while geospatially associating engineering and operational data to specific assets.

Project Description

New installations, replacement programs, and extension projects are ideal opportunities for capturing and documenting asset and related gas-system information. However, many operators are using outdated methods to collect this information or are not collecting it at all.

Existing and future requirements obligate local distribution companies to maintain complete and accurate data that will be important for Distribution Integrity Management (DIM) compliance, risk analysis, and future system use considerations.

In Phase 1 of this project, an Intelligent Utility Installation Process was developed that provides a methodology, field process, and a data model for capturing data during new installations. The process is used to capture information regarding the location, materials, installation process, environmental considerations, and other factors.

The current Phase 2 of the project is focused on providing operators with the ability to track assets from manufacturing through replacement while geospatially associating engineering and operational data to specific assets. This project supports the implementation of ASTM F2897-11a *Standard Specification for Tracking and Traceability Encoding System of Natural Gas Distribution Components (Pipe, Tubing, Fittings, Valves, and Appurtenances)* by developing field-data-collection software, conducting pilot projects, developing best practices, executing a testing program, and coordinating a working group.

Deliverables

Deliverables for this project include data-collection guidelines; a data model; field-data-collection procedures for GPS; smart tag programming protocols and installation procedures; a methodology for determining and documenting data quality; technology recommendations; and regional workshops.

Pilot project in Illinois.

Benefits

There are many existing and future beneficial uses for the Intelligent Utility Installation Process, including:

DIM Compliance – New DIM regulations will require operators to collect information during new installations and exposures to facilitate the execution of a DIM program.

Analysis – Increased and improved data will facilitate a full and proper risk analysis and optimization of risk management efforts.

Industry Standardization and Adoption – The development of industry standards in data collection will enable widespread adoption and use by utilities and their contractors.

Future Considerations – Gathering information during construction will ensure that future issues or opportunities can be evaluated with quality data without incurring the cost of collecting it.

Technical Concept & Approach

Examples of information being collected include:

- Location
- Changes in direction
- Location of abandoned facilities
- Material properties
- Installation method
- Environmental conditions
- Supporting assets (e.g., tracer wire, marker balls, and warning tape)
- Coupling and joining information
- Contractor and field personnel information
- Pressure test records
- Inspection records.

Results

In this project, data-modeling development progressed in parallel with the development of the data-capture process – with the model becoming more complex and detailed, transitioning from a conceptual data model to a logical model.

Barcoding technology integrated with high-accuracy GPS and a hand-held field-data-collection device was chosen as the first combination of technologies to demonstrate.

In 2013, the *Purchasing Specification Guidelines for Marking Polyethylene Gas System Components* was published. The guidelines address the issues related to the permanency and durability of the barcode markings, how frequently the markings should be made, how the various fittings and appurtenances should be marked, and what type of marking techniques should be used. Barcode testing was also initiated to verify scanning and decoding barcodes per ASTM F2897-11a.

Pilot projects were initiated with four utilities. For each test, barcodes are scanned before and after installation to determine the change in barcode readability. Field demonstrations were conducted with a prototype system that uses barcode scanners, high accuracy GPS, and GIS-enabled software that runs on smartphones and tablet computers.

Taber abrasion testing was performed to test the durability of the ink-printed barcodes on plastic pipe.

The project team tested the final version of the barcode-decoding application to allow mobile software the capability to scan, decode, and create features within a GIS by scanning the ASTM barcode on plastic pipe and components.

In 2014, marking testing activities continued. UV testing was also conducted.

In a pilot project in Illinois, the project team successfully automated the process of mapping and documenting new pipe installations through the use of mobile GIS, GPS, and barcode scanning.

The following attributes were populated automatically when the barcode was scanned:

- Feature (pipe, fittings)
- Material
- Manufacturer
- Sub-type
- Size
- Component barcode
- Component description.

The pilot project provided valuable feedback that led to identifying solutions for issues encountered during the piloting of the mobile GIS solution developed under OTD projects to create spatially accurate GIS features in real time.

Status

Phase 1 of the project is completed. Phase 2 testing and pilot projects are ongoing.

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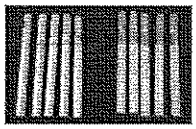
OTD Operations Technology Development

Quality-Control Procedure for High-Potential Anodes

A series of laboratory tests were conducted in an effort to develop a quality-control procedure for high-potential magnesium anodes used in cathodic-protection systems. The goal is to develop a method that verifies the potential, current, and efficiency of the anodes.



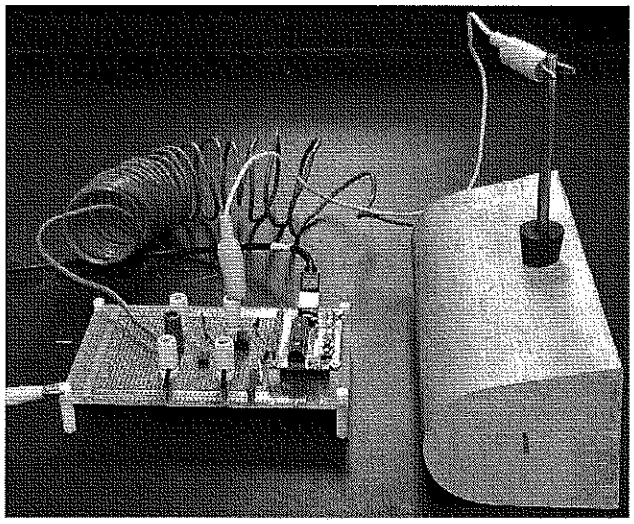
Project Description

Utilities apply high-potential (HP) magnesium anodes to challenging locations that need a maximum of cathodic protection (CP). However, there is a growing concern about the efficiency and service life of these anodes.

A simple and common method for testing an anode is performed by wetting the anode and reading its potential with a digital multi-meter referenced to a copper-copper sulfate electrode. However, this test only addresses the open circuit potential (OCP) and *not* the current or efficiency performance of these HP anodes – both key parameters for the anode's ability to protect assets and meet expected service life.

Utility anode purchases are typically from a variety of suppliers, some of which are offshore. The ability to acquire HP magnesium anodes from multiple sources and at competitive prices is desirable; however, a simple and effective quality-control (QC) procedure is needed to verify the efficiency of anodes. The current verification test (ASTM G97) is expensive, requires extensive machining of the magnesium, and the actual test requires 14 days.

The objective of this project is to develop a QC procedure for HP magnesium anodes that verifies the potential, current, and efficiency of the products.



Coupon-in-Bore Test Set-Up.

Deliverables

The deliverables include:

- A complete analysis and test reports for all processed samples
- A recommended QC procedure that can quickly provide a determination of the quality of an HP magnesium anode.

Benefits

There is a risk involved with installing off-spec anodes in challenging locations where high performance is needed: the asset that needs CP may not receive it. Even anodes that initially perform well may have lower-than-stated efficiency, causing the anode to have a shorter-than-expected service life. Information developed through this research project will help utilities provide adequate protection for their buried assets and maximize the benefit CP systems.

Technical Concept & Approach

The working hypothesis developed in Phase 1 is that the OCP collected near the end of the standard G97 test is a reasonable metric of the anode efficiency. However, a technique called the Coupon-in-Bore (CIB) method may provide a lower-cost means of obtaining the OCP of the anode after it has been aged. The CIB method exposes the interior surface area of the anode by drilling a hole and then using a hand-reamer to further polish the interior surface of the bore. The bore is then filled with a salt solution and a steel coupon with a known surface area is inserted. Instrumentation is connected between the coupon and the magnesium.

Phase 2 of this project included the following tasks:

- **Sample Testing**

  Samples were tested using the CIB method. One feature of the testing is that the anode must be used or aged for some period in order to determine if it can maintain sufficient potential over time. Establishing the minimum period of testing that can de-

lishing the minimum period of testing that can determine the efficiency with confidence is one goal of this task.

Two different methods of putting wear on the anode were tested: self-potential and constant current. The self-potential method uses the magnesium-to-steel coupon potential to drive current through a salt solution. For the constant-current method, an additional voltage source is added to maintain a fixed current through the salt solution. In both cases, the current was monitored and recorded continuously. At fixed intervals, the magnesium-to-steel circuit were opened and a potential measurement recorded. In this way, the OCP value can be tracked as the anode is aged.

The measurement cycle for each test was approximately three weeks in order to obtain trend data. The reason for this duration is to exceed the time for the standard G97 and determine if the rate of change of the OCP so the technique can be rapidly moved.

- **Data Analysis and Reporting**

  Data was correlated with the data gathered during Phase 1 of the project. The CIB method was compared with ASTM G97 efficiency measurements.

- **Optional Testing**

  At the sponsors' discretion, new anodes may be introduced for testing.

Results

During Phase 1 sponsor-provided sample anodes underwent basic characteristic measurements, ASTM G97 testing, Electrochemical Impedance Spectroscopy testing, and CIB testing. Testing in Phase 1 was to corroborate earlier work that indicated that the OCP at the end of a G97 test correlated well with the efficiency of the anode.

In Phase 2, CIB testing was performed on the anode samples already in hand. This allowed for the alternative test results to be related to the efficiency calculated from the G97 test results during Phase 1. Replicate anodes from the same manufacturers' heat were provided during Phase 1 to allow for the possibility of additional testing. This allowed some level of confidence that the magnesium under test had uniform properties for samples drawn from the same heat.

Two additional ASTM G97 tests were performed during Phase 2 in order to fill in gaps in the data set. To gain a better insight into the behavior of the test specimens, the data was reevaluated by analyzing the G97 data at the level of the individual pencil samples. Using the population of 60 samples rather than 12 allows the different anodes and heats to be statistically evaluated.

The following conclusions were drawn from the experimental observations and test data:

- The efficiency of the anode shows a positive correlation with the OCP observed on day 14 of the ASTM G97 test. This finding correlates with previous studies of this issue. Both the efficiency and the OCP are currently captured using the G97 test.
- The CIB method is a less expensive means of capturing data related to the post-G97-test OCP value that would provide a measure of the efficiency.
- The CIB method will require further testing. Initial testing focused only on current measurements and limited replicates. Future testing would capture both current and OCP during the test.
- There is variation of the measured anode parameters between samples drawn from the same heat. This is true of both the G97 and the CIB methods. Scatter (anode-to-anode variation in test parameters) was smaller for one of the three suppliers included in this testing than the other two. This implies that the anodes from this supplier are manufactured to a tighter tolerance.
- The G97 tests show a higher scatter for a given five-pencil than those performed by the laboratory.
- There was no clear correlation between the ASTM G97 efficiencies and the parameters measured with the CIB method.

Status

This project is complete. A Final Report was issued in February 2014.

The research team has proposed to further test two anodes. Testing would consist of drilling between three and five holes in each anode and repetitively performing the CIB test to determine if consistent results are seen at different sites on the same anode.

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OTD Operations Technology Development

Smart-Grid Initiative Standards and Regulations

This project is focused on the development and operation of a Working Group to support specific activities designed to represent the technology needs for the natural gas industry in current and future smart-grid initiatives.

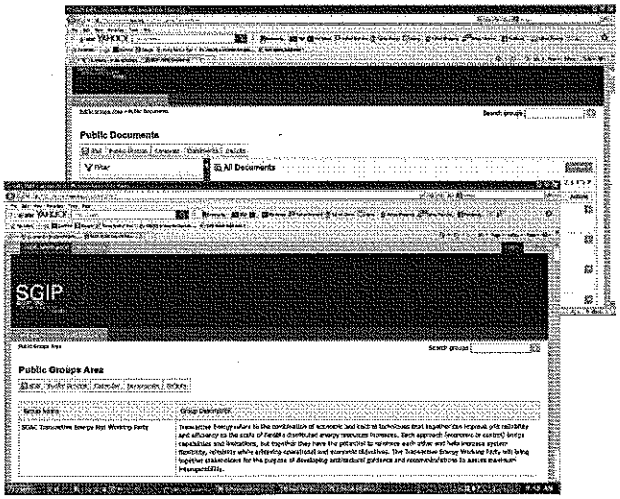
Project Description

The overall objective of this project is to provide information and representation to support the infrastructure requirements that are specific to the natural gas industry in technology, standards, and regulatory initiatives currently focused on electric smart-grid initiatives.

One of the goals is to develop and deploy technologies and processes that effectively use two-way communications and intelligent field devices to enhance the safety and efficiency of the natural gas infrastructure to serve new demand and supply sources and integrate with other infrastructure grids.

Industry experts note that technology can help to address a variety of issues:

- New sources of demand for natural gas (e.g., power generation, direct end use, and vehicles) and new sources of gas supply (renewable and shale gas) are having an impact on the industry. As a result, load monitoring, load balancing, and the need for real-time information on supply and demand become increasingly more important.
- Energy efficiency and emissions-reduction targets could place new requirements on natural gas operators to provide real-time usage information to customers through smart meters.



Public information is maintained at the Smart Grid Interoperability Panel: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid.GasTechWG

- Regulations for increased integrity management and enhanced system safety and functionality could effectively be achieved through sensors and remote controls capable of detecting excavation encroachment, corrosion, and leaks, and providing remote controls to shutoff valves.
- Operators are under increasing pressure to reduce operational costs. A sensor-enabled infrastructure could reduce the need for manual data collection and reduce the labor costs associated with surveys, inspections, and other manual data-collection activities.

This project provides the natural gas industry with a focal point where the overlap of technology, standards, and regulations is known and understood, reference materials can be accessed, issues and concerns can be discussed, and enhancements and/or new or novel capabilities can be addressed.

In Phase 1 of this project, the research team established: active participation in standards development for sensors, automation, and smart-grid connectivity; representation at organizations recognized for their efforts to create an open forum for technology development and deployment; and an on-line source for standards, documents, reference designs, testing results, and case studies.

The objective of Phase 2 is focused on efforts to ensure that standards and regulations governing sensors, controllers, and communications devices are compatible with natural gas distribution operations while ensuring that cyber-security standards are integrated into each device capable of communications.

Deliverables

The deliverables for this project include newsletters, the results of standards activities, a White Paper providing recommendations for regulatory interactions, and an on-line reference system.

Benefits

Through this effort, the interests of natural gas customers and suppliers can be better positioned to demonstrate the benefits of natural gas technologies and incorporate gas-related products into smart-grid initiatives. The goal is to provide the gas industry with a focused, unified voice in emerging technology forums.

Technical Concept & Approach

Project Tasks:

- **Participation in Industry Standards Development Organizations**

  On behalf of the Smart-Grid Initiative, Gas Technology Institute (GTI) established and maintains memberships in organizations with the potential to influence the technologies and standards in use or being developed that could optimize the natural gas delivery infrastructure.

- **Examination of Regulatory Issues**

  In this task, a White Paper will be developed to provide guidance and recommendations for coordinating infrastructure development between electric and gas smart grids from a regulatory perspective.

- **Establishment of an On-line Reference System**

  GTI developed an on-line reference system to include technology, standards, and regulatory information related to smart-grid topics.

- **Investigation of Sensors, Controllers, and Communications Devices**

  Studies focus on automatic flow monitoring and control, load balancing, feeder reconfiguration, switching of gas sources, meter reading, leak detection and locating, and remote meter shut-off.

- **Develop Interoperability Standards for the Integration of Gas Systems into the Electric-Centric Smart Grid**

  The standards will address both the commonalities and the interdependency of electric and natural gas grids.

Results

During Phase 1, the research team coordinated with the Smart Grid Interoperability Panel (SGIP) – organized and managed under the leadership of the National Institute of Standards and Technology – to create a Gas Technology Working Group (GTWG) under the SGIP.

In Phase 2, activities have focused on cyber security and pressure monitoring. The pressure-monitoring case provides an application-use case of interest to gas utilities that is distinct from electric grid issues. The SGIP catalog of standards should provide methods of capturing and transporting this data in a secure manner. This particular test case will allow the Working Group to test the SGIP process and determine its value to the gas community.

In 2014, efforts initially focused on the preparation of a Program Action Plan (PAP) proposal for submission to the SGIP management. The purpose of this PAP was to develop the specifications and requirements for a Smart-Grid-enabled pressure-monitoring device. A Request for Information (RFI) on the current and future pressure monitoring-practices in the gas industry was prepared and circulated to both the project investors and through the American Gas Association. When the results from the RFI were tallied, it was determined that sufficient requirements were in hand to move forward without a PAP. The path forward is to work with the AGA Distribution Measurement Committee and the AMI Sub-Committee to construct a recommended practice from the requirements information captured so far. The follow on step would be to promote the recommended practice through ANSI or another standards-making body.

Status

Researchers determined that the best path forward will be to shift emphasis to working directly with the AGA rather than through the SGIP. The participation in the SGIP-based working group never achieved the levels desired. A policy shift by the SGIP during 2013 excluded non-members from participating in working group calls, further lowering participation.

The RFI on pressure monitoring circulated through the AGA drew survey responses from 28 companies, demonstrating a good level of interest. The regular participants in the past SGIP work were also members in the AGA. A White Paper describing the GTWG goals and activities has beeen prepared to provide insight into gas industry practices to other stakeholders. The paper is being expanded and will be presented at the May, 2015, AGA Operations Conference.

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OTD Operations Technology Development

Integrating Sensors with Existing Automated Meter-Reading Systems

Research was conducted to demonstrate the feasibility of adapting sensors to existing automated meter-reading (AMR) and advanced metering infrastructure (AMI) systems in order to acquire additional information about specific distribution systems.

Project Description

Many operators of gas utilities have implemented automated meter-reading (AMR) systems. These systems represent an existing data communication and database infrastructure that could be used to capture additional operational and engineering information – beyond meter readings – to enhance system monitoring and control.

In this project, a pilot program was conducted to evaluate and demonstrate the integration of pressure and other sensors into legacy AMR and AMI systems. In tests, AMR systems were equipped with additional sensor technology to record pressure readings at select locations.

Pressure sensors were identified as beneficial to integrate with existing AMR infrastructures. However, AMR systems could be adapted to work with other sensors to provide information on:

- Cathodic protection (CP) potentials
- Rectifier currents
- Water and methane levels in vaults, and
- Entries and exits from secure areas.

Deliverables

The deliverables for this project included:

- A set of AMR-enabled sensors that are compliant with the operator's AMR system
- A defined format and collection methodology that allows the sensor data to be extracted from the meter-reading database
- A pilot project that demonstrates the capability of providing existing AMR systems with additional sensors.

Benefits

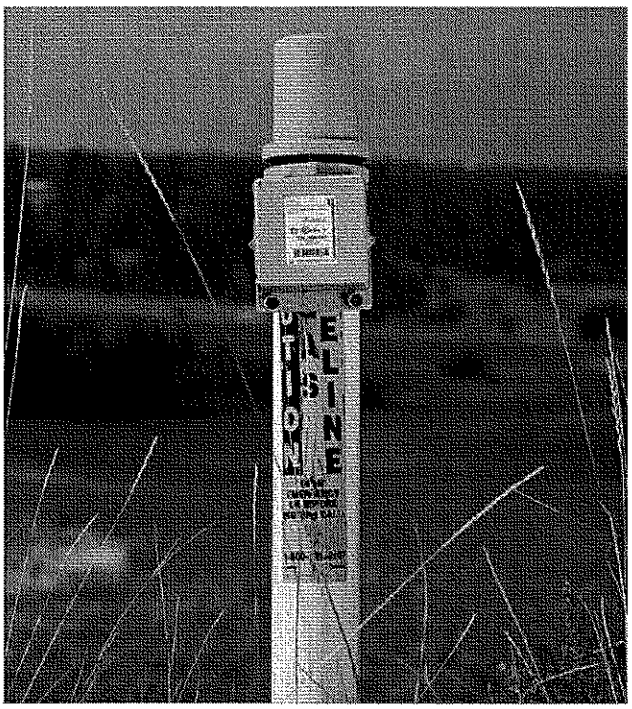
The results of this project will facilitate the use of existing AMR systems to gather operational data (e.g., pressure and corrosion readings) and help to lower operating costs and reduce risk. Technical success in this project will enable utilities to collect significantly more system data in a cost-effective manner.

Cost reduction will be achieved by decreasing the labor requirements for field-data collection. Risk reduction will result from receiving more frequent access to operational data that could alert operators of a potential issue. Leveraging existing AMR systems will reduce the cost of implementing a sensor network.

Technical Concept & Approach

This project initially focused on using an operator's existing AMR system with additional sensor technology to capture pressure readings at select locations.

Most AMR product lines have generic radio "heads" that allow data to be transmitted to a handheld unit, reading truck, or stationary tower. The goal is to provide an interface between the generic AMR radio and pressure sensors.



Specific project tasks included:

- **Technology Review and Selection**

  This task involved a review of currently available sensors and AMR devices in order to make recommendations for the pilot project. Sensor and AMR vendors were engaged to participate.

- **Pilot Project**

  Sensors were placed at specific locations selected by the operator.

Itron radios were selected to be used since the majority of the project sponsors used Itron as their AMR provider. Researchers modified a communication protocol using Itron water meters to establish interconnectivity.

Results

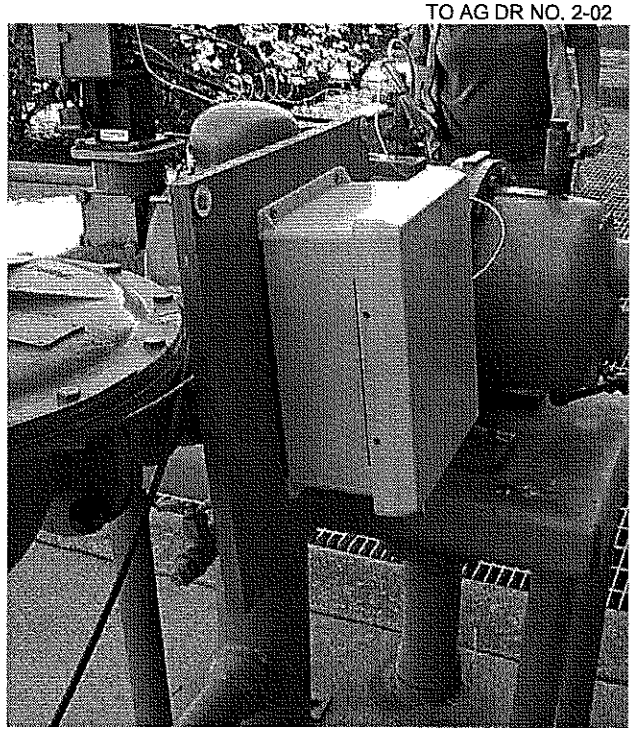
In 2012, an off-the-shelf Itron radio product was interfaced to pressure loggers to transmit a current pressure reading to a standard handheld meter-reading device. The monitors were placed at two sites to measure low-pressure points on a gas distribution system. The monitors recorded pressure data on a secure digital memory card on a minute-by-minute basis.

The AMR-enabled pressure monitors were located near existing utility pressure sensors, allowing for an independent verification of their accuracy. The new pressure-monitor readings have tracked accurately with the pre-existing equipment. The pressure monitors are periodically read by utility personnel using the same model of handheld device that is currently used to read gas meter AMR end points.

Three prototypes were constructed, bench tested, and demonstrated to provide pressure readings for the 0 to 30 psig range.

The utility personnel supporting the pilot used a standard Itron FC300 handheld device to capture pressure readings. This is commonly used by meter readers performing walk-by reads. They are also used by technicians who set up and service the meters. The only modification required to the handheld was the installation of a custom configuration file on the device.

In 2013, long-term testing of the Itron 100T-CP device was conducted. This device is a CP data logger that is readable using the Itron AMI infrastructure. The current version can be read using either a fixed tower network or a handheld reading device. The 100T-CP can acquire and store daily readings of the DC and AC pipe-to-soil potential for 480 days. Testing of sample devices indicated that they are accurate and stable. Samples of the 100T-CP product were made available to project sponsors in lots of 10 pieces.



Prototype deployed at utility site.

Throughout the project, a number of technical issues were encountered and subsequently resolved. In May, 2013, activity with the pressure monitors was discontinued due to communications issues.

Status

Additional field testing of the 100T-CP modules can begin at the utilities' discretion. Sample quantities are available from Gas Technology Institute.

The efforts on the AMI-enabled pressure logging device remain suspended. These had been stopped due to technical difficulties and the effort focused on advancing the CP sensor.

A Final Report on the project was issued in November 2014.

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Breakaway Disconnect/Shut-off for Meter Risers

To enhance gas-system safety, a breakaway disconnect/shut-off fitting for meter risers and other above-ground gas facilities is being developed and tested. In the event of an impact to a meter assembly, the device would automatically stop the flow of gas to the environment.

Project Description

Meter Set Assemblies (MSAs) and other above-ground gas facilities are often damaged by various outside forces, primarily vehicular damage. To reduce the risk of gas leaks, fire, explosion, property damage and possible injury from an MSA impact, research is being conducted to develop a breakaway disconnect/shut-off fitting for MSAs.

Currently, many industries use breakaway disconnects. For example, vehicle fueling stations use them on their fuel pumps. If a car accidently drives away with the fuel nozzle still in the gas tank, the breakaway disconnect shuts off the fuel line and eliminates the leak and possible hazard. Portable gas grills use similar disconnects, which are designed to be pulled apart manually. The liquid- and compressed-fuels industries also use disconnects in filling and recharging cylinders, tanks, and vehicles.

The objective of this project is to develop a breakaway disconnect/shut-off fitting for MSAs so that if an external force is large enough to sever the meter riser connection (e.g., a vehicle collision or impact from falling ice or snow), the breakaway disconnect will release from the riser and close, preventing natural gas from leaking to the surroundings.

Deliverables

Prototypes for field testing were developed. Reports will be issued documenting the findings and results of the program.

Benefits

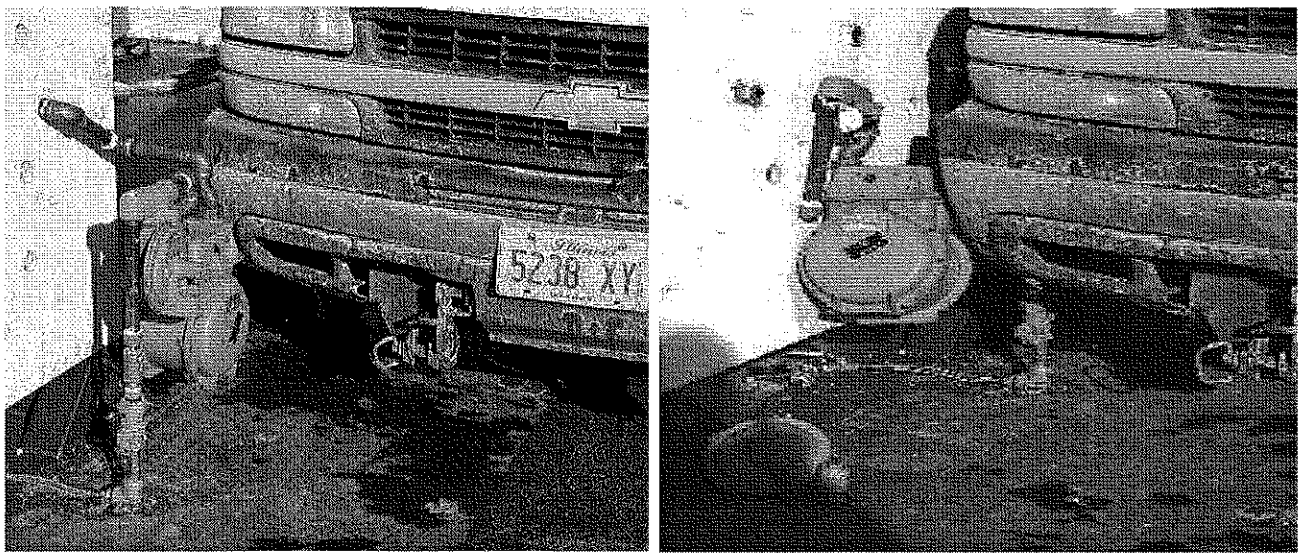
The introduction of a new breakaway disconnect/shut-off fitting will reduce potential hazards and enhance the overall safety in the delivery of natural gas.

Technical Concept & Approach

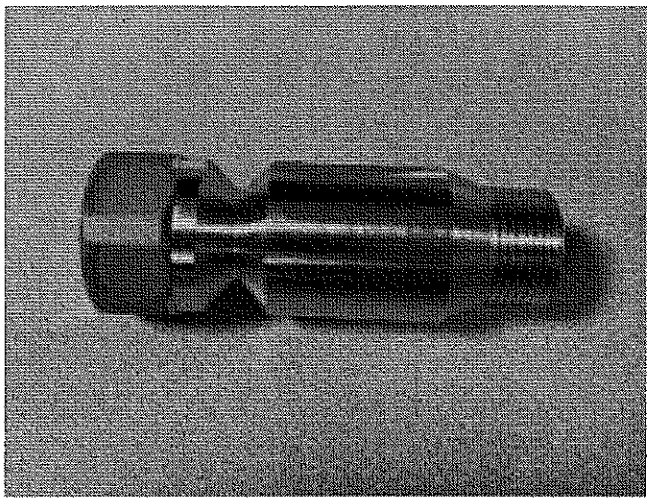
For this project, the research team is partnering with a manufacturer to create a prototype breakaway disconnect/shut-off fitting, which was tested in a variety of conditions under Phase 1 of the project. Upon successful field trials, a production model will be manufactured and tested in Phase 2.

Results

In Phase 1 of the project (now complete), a manufacturer was selected to team with researchers in develop-



Crash test before and after the vehicle impact.



ing initial concept designs and planning. The project team created a series of breakaway fitting design concepts. The fittings are designed with weak points that break when an external force acts on them. When the weak point breaks and the fitting separates, a check valve is activated inside the fitting, shutting off the flow of gas from the service line.

Numerous destructive-pipe and riser-fitting tests were conducted to determine the failure forces as they relate to meter sets. The results of Phase 1 research were presented in a report issued in June 2012.

In 2012-2014, the project team created, tested, and modified two working prototypes.

Testing equipment was developed to specifically test the fitting and simulated field evaluations were conducted within a controlled laboratory environment.

Initial testing showed moderate results with the initial design. The fitting was subsequently redesigned, providing improved flow and pressure through the fitting (less pressure drop).

A series of impact tests were conducted on various-size (wall thicknesses at the machined weak point) breakaway fittings. The fittings were tested both above the meter valve and below. The results of the impact and static load testing were used to assist with identifying the appropriate dimensions of the valve.

Researchers initiated a field-simulated crash test by impacting meter sets with and without the breakaway with vehicles moving at five mph. All breakaway fittings sized appropriately broke upon impact no matter if the fitting was installed above or below the meter set valve. The breakaways sized above this critical design level did not break when installed above the meter set valve. However, all broke as designed when installed below the meter set valve.

The breaking point of the breakaway fitting was fine tuned through a series of simulated impact and static load tests. Based on these laboratory tests, the appropriate breakaway fitting design and groove size were determined.

A crash-test platform was built and various meter sets were constructed of various designs – some with prebent piping some without; some with meter bars and some without. A series of crash tests with a Chevy 2500 pickup truck were conducted with and without the breakaway fitting incorporated into the meter set. A pressurized nitrogen tank was used to provide 60 psig pressure to the inlet of the meter set. All meter sets were easily damaged to the point of multiple complete breaks on the meter set piping, even at speeds around 4-5 mph.

Following testing, the potential for improvements were investigated, including:

- Making a slight change to the engineered break point
- Changing the breakaway from female/female to female/male (bottom) unit to minimize the fittings needed to incorporate into existing meter sets
- Changing the length of the breakaway unit to meet standard lengths of pipe nipples to fit into meter set systems
- The concept of having a heat-sensitive stem and a fire-rated ball to allow the valve to close during a fire condition
- Application of the breakaway for first-stage regulators (farm taps).

Status

The project team is now moving forward with pilot installation trials to further evaluate the breakaway fittings – from ease of installation to providing protection in case of impact. Researchers are seeking additional sponsors to assist in the pilot installation.

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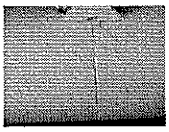
OTD Operations Technology Development

Essential Data Capture for PE Fusion Operations



Researchers are developing a methodology to automate the data-capture process for PE fusion operations. Currently under development are a model to standardize the type and format of data, protocols for data transfer to a handheld device, and an assessment of supporting technologies.

Project Description

In this project, research is focused on developing a methodology to automate data capture during polyethylene (PE) pipe-joining processes to help determine the root cause of a pipe-joint or fitting failure and provide added information for Distribution Integrity Management (DIM) programs and other company activities.

Currently, when operators examine failed joints or fittings, they are often inhibited with a lack of information on how these fittings were assembled, the weather conditions during the joining process, equipment used to assemble the fittings, procedures followed, employee performing the fusion, and other factors. Even when failures do not occur, there is a need to have this data readily available so that quality audits can verify that proper processes and procedures were followed.

Plastic-pipe fusion processes (e.g., electrofusion and heat fusion) have remained the same for many years. Only minor technological upgrades have been incorporated into the electrofusion process, such as the use of barcodes to assist with fitting recognition. Also, data-logging technologies have recently been made available for use with some of the hydraulic butt-fusion equipment. The development of fusion data protocols will allow some of these technological advances to provide more meaningful information to the operator.

System knowledge is also essential to improved DIM efforts. One of the needs of the industry is to better monitor and control who is qualified to perform the various PE joining processes during the assembly of the PE piping system. A need exists to allow fusion systems to manage operator qualifications and restrict users (company and contractor personnel) that are not properly qualified and/or with expired qualifications. New technologies could facilitate the implementation of a system that requires employees to be "approved" before using a specific piece of equipment or performing an operation.

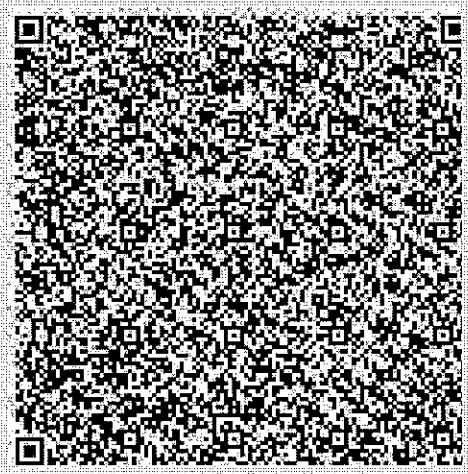
The objective is to develop a methodology for capturing data on: process parameters during the fusion; environmental conditions during the fusion process; employee and contractor information and status of operation qualification (OQ) certification; and material and fitting information.

Deliverables

The deliverables for this project will provide the industry with a standardized methodology to capture information during the PE fusion process. Deliverables will include a software application that captures fusion and weld parameter data from Bluetooth™ and/or barcode-enabled equipment and incorporates this data as asset attributes in the GIS or other asset management system.

Benefits

A data model and data transfer protocol will assist manufacturers in incorporating automated data capture into PE fusion equipment. A standardized methodology will create an interoperable system to allow operators to utilize different fusion equipment and handheld devices without the need to modify data-collection procedures.



This barcode is an example of the capture of electrofusion data as suggested by the project's data model. Scanning this bar code will provide a variety of data, including information ISO 12176 requires, some additional data, and 30 fusion process data points.

Capturing this information during routine operations will reduce operator risk and will demonstrate proactive DIM compliance. Collecting parameter information during operations will allow an inspector, in the office or in the field, to verify that the process was completed according to company specifications. The operational parameters can also be stored and later compared against leak records and other inspection results to identify trends.

Technical Concept & Approach

This project includes the following tasks:

Phase 1

- **Capture Project Requirements and Communication with Industry**

  This task included a review of existing electrofusion control boxes and butt- and heat-fusion data loggers.

- **Develop Standardized Data Model**

  Essential variables and their limits (e.g., operator, ambient temperature, etc.) will be established.

- **Identify Operator Qualification Parameters**

  The research team will develop recommendations for utilities and manufacturers.

- **Identify Data Transfer Protocol**

  Researchers will identify existing data-transfer technologies that can be used to collect information during the fusion process.

- **Develop ASTM Standard or Other Industry Accepted Practice**

  The research team will draft a new ASTM standard or industry practice to formalize a standard data structure and define standard codes of practice.

Phase 2

- **Equipment Selection**

  The research team will identify existing equipment that provides the required functionality.

- **Software and Process Development**

  Software will be expanded to include an application that captures fusion and weld parameter data from Bluetooth-enabled equipment.

- **Testing and Demonstrations**

  Demonstrations with operators will be performed.

Results

Initially, researchers at Gas Technology Institute (GTI) investigated various potential methods of capturing PE fusion data and transferring information into existing GIS databases, finding 2D barcodes well suited for this purpose.

In 2013, the project team solicited the support of manufacturers for the development of an ASTM standard to standardize the output of the fusion data for the various PE fusion operations. Efforts were made to incorporate all three fusion data-capture standardizations (butt, saddle, and electrofusion) into the same standard. Subsequently, GTI teamed with Nortec, a leading Israeli-based manufacturer, to develop and manufacture an innovative barcoding solution for underground asset lifecycle tracking.

In 2014, Nortec and GTI developed a data model to capture the data collected during a fusion process that will be used to structure the data from a fusion machine.

A list of all collectable parameters from the various fusion machines (during or after the fusion process) was compiled. Research to identify the different kinds of barcodes available for the purpose of converting fusion parameters into barcode format was also performed. The essential parameters that will be contained in the barcode were identified based on feedback from utility companies that were interviewed.

Initial development of the fusion integration with the native Android disconnected application was also completed. The application walks the user through the scanning of a Nortec barcode and either creates a weld feature for a butt fusion or appends a related record housing all of the fusion data.

Several industry demonstrations were made using an electro-fusion machine and an integrated ASTM/fusion barcode.

Status

GTI continues to work with Nortec on determining the best way to validate operators qualifications. Efforts are also under way to develop pilot projects to test the mapping technology and integration with fusion machines.

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Development of an Intelligent Shut-Off Device for Commercial and Industrial Customers

Efforts are under way to develop an intelligent gas shut-off device with the ability to detect third-party damage to facilities and, in response, limit the flow of natural gas to minimize the potential hazard from the incident.

Project Description

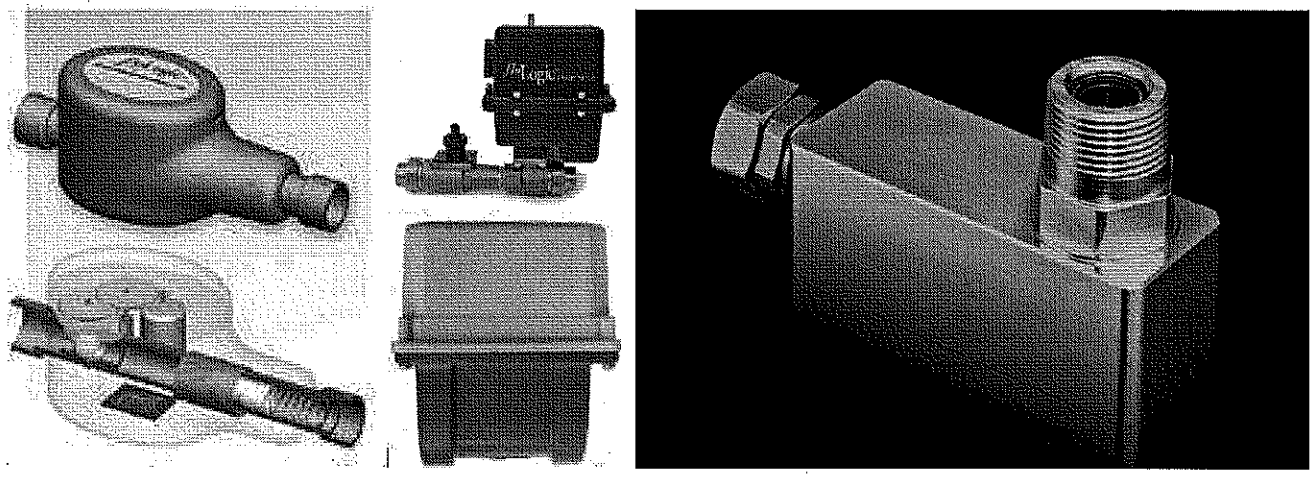
Recent gas-industry distribution integrity management program standards are expanding the requirements of excess flow valve (EFV) installations from solely single-family residential locations to multi-family, commercial, and industrial gas customers. Consequently, the large-scale implementation of EFVs in the commercial and industrial market requires long-term planning to be effective.

The application to commercial and industrial customers presents several issues:

- From a safety standpoint, multi-family, commercial and industrial customers expect a highly reliable gas supply. An inadvertent shutoff of commercial or industrial facilities (e.g., such as hospitals, manufacturing, or chemical plants) could create a greater hazard than the gas leak it was intended to address. For other businesses, the financial implications of a false EFV closure could, at a minimum, temporarily close a business, resulting in high associated financial losses.
- The challenge of load variability is inherent to commercial and industrial locations as customers who occupy these spaces frequently change based on rental agreements (such as from a small retail clothing store to a restaurant), which can significantly change the required loads. Due to this variability, life-cycle loads (50-100 years) often differ considerably compared to that at the time of service installation. As a result, pre-installed EFVs with a set flow rate tend to be sized either too small (creating false trips) or too large (rendering the EFVs ineffective at times when they are needed).
- As the cost to replace an incorrectly sized EFV may vary from $5,000 to $50,000 (if the municipality allows the street to be cut), replacing improperly sized EFVs can become a costly endeavor.

In response to these issues, this project is focused on the development of an intelligent shut-off device (ISOD) to address regulations and risks associated with service and meter-set-assembly (MSA) damage and associated leaks. The device will be designed to have the ability to detect third-party damage to the service or MSA and, in response, limit the flow of natural gas, thereby reducing the hazard from the incident.

Several commercial systems exist for use within the natural gas infrastructure as remote shut-off devices. These devices can automatically shut off gas flow by control of a wireless device. Through prior evaluations, it was discovered that some of these wireless remote shut-off devices were able to communicate even through structural materials such as concrete walls and soil to a handheld device at distances of several hundred feet.



Researchers are investigating various remote shut-off devices.

Other possible transfer technologies have been found in use in the water industry. One system continuously monitors water flow and can automatically shut off the service if it detects low- or high-flow conditions. A system similar could be constructed with the ability to sense gas flow rate and compare it with a reprogrammable set of flow parameters. If the sensed flow rate or rate of change of flow rate is not within set parameters, the device automatically closes. Then, if the required load changed at the building, the system could simply be reprogrammed.

Deliverables

Deliverables include a working prototype ISOD and supporting documents providing details on the development of the system.

Benefits

Third-party damage is the number one threat to natural gas distribution systems. Service lines and MSAs are particularly vulnerable to damage from third-party excavators and vehicular traffic. The goal of this project is to develop technology to minimize this risk by limiting the volume of gas released from such incidents.

Technical Concept & Approach

Tasks for this project include:

- **Market Review and Development of Design Parameters**

  This task included a review of historical data to help to determine the influential design constraints of the ISOD.

  Items addressed during this task included:

  - Best location of ISOD (e,g, on a service connection, tee, or the service line)
  - Common system sizing
  - Pressure and flow range for normal or alarm conditions
  - Wireless transmission requirements (range, penetration ability, and frequency limits).

- **Development of Evaluation Methods**

  This task involves the development of a testing strategy for the prototype ISOD systems.

  In addition, any systems found to show promise for use with the ISOD will be sourced and used to help develop the testing protocol.

- **Development and Evaluation of Prototype System** *(potential follow-on phase)*

  This task focuses on the development of a prototype system based on the set of design constraints developed in an earlier task. This task could proceed in two directions: 1) aiding manufacturers in modifications to existing systems, or 2) developing a prototype in house.

Following the development of prototype devices, the testing protocol will be used to ensure that the systems adhere to the original design parameters.

Results

Phase 1 activities focused on:

- Developing the initial design constraints with which to find possible market-ready devices
- A review of possible market-ready devices
- Contacting manufacturers
- Initiating development of the initial test parameters which would be used to evaluate the devices.

As no device exists that currently fits the desired application, proposals were solicited from manufacturers that produce a product that has potential for modification. Several companies expressed interest in participating in development of an ISOD for commercial and industrial customers that is installed on the service line at the tee. The research team subsequently developed a proposal for the development of a prototype of ISOD.

In 2014, researchers evaluated a remote shutoff system concept to determine if it is able to meet the needs of the natural gas industry and to identify areas for enhancements and modifications.

Status

The project team is subcontracting with Lorax Systems Inc. to design and build a prototype of the shut-off device. The valve will be compatible with PE service lines and will be entirely mechanical, requiring no electrical power in order to function.

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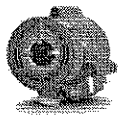
Development of a Portable Flash-Fire Suppression System

Research is being conducted to advance the development of an automated, portable flash- fire suppression system for use in confined spaces and excavations during gas maintenance and repair operations.



Project Description

Currently, utility procedures for combating flash fires involve a combination of preventative and reactive methods, including the use of oxygen sensors, fire suits, breathing apparatus, and manual fire extinguishers.

While these systems help to improve safety, they are still limited in effectiveness. Preventative methods of gas detection are not consistently used, which leaves personnel unprotected when unexpected leaks occur. Once a flash fire does erupt, fire protective suits only provide protection for a limited period of time, and manual fire extinguishers are often used too late.

Development of a system that can detect a flash fire just after ignition and begin immediate suppression will allow workers the time needed to egress a worksite.

From 2010-2011, the Sustaining Membership Program (SMP) sponsored a project at Gas Technology Institute (GTI) to investigate technologies that have the ability to detect and suppress flash fires. Multiple detection systems (including optical flame detection, heat-sensitive wire, and thermocouple-embedded clothing) were evaluated for effectiveness, reaction time, and susceptibility to false alarms. Researchers also evaluated several fire-suppression systems with the ability to quickly react and adequately suppress or extinguish natural gas flash fires. As a result, several promising solutions – with varying capabilities – were found.

For this new project, a research team will establish which system is most acceptable to utilities, determine what situations it will most likely be used, and then fabricate, evaluate, and refine the system in order to make a versatile portable flash-fire suppression system for use in confined spaces and excavations during gas maintenance and repair operations.

Deliverables

The initial deliverable for the project will be a prototype of a portable flash-fire suppression system. The next step in the project will include interactions with potential manufacturers to determine interest and commercialization opportunities. In addition to the prototype, a report will be supplied including data on all system refinements and testing results.

Benefits

Although the likelihood of flash fires in excavations is remote, if one does occur, the consequences can be serious.

A "standby" system with the ability to automatically detect and then suppress a flash fire (without relying on human intervention) will significantly reduce the likelihood and severity of human injury from a flash fire.

Technical Concept & Approach

Tasks for this project include:

- **Refinement of Design Goals**

  During this task, a survey will be distributed to the sponsors to determine the expectations of the final product (e.g., response time, range of expected costs, and scenarios that require false alarm resistance).

- **Prototype Construction and Refinement**

  An operational portable prototype will be designed and fabricated, with necessary modifications to adhere to requirements.

- **System Evaluation**

  An evaluation of the prototype system will be conducted to ensure that proper progress towards design goals is achieved. Testing will be conducted in the GTI field-scale testing pit constructed during the SMP project.

Results

Activities in 2012 focused on establishing a solid evaluation system and the initiation of the design and construction of the flash-fire suppression system itself.

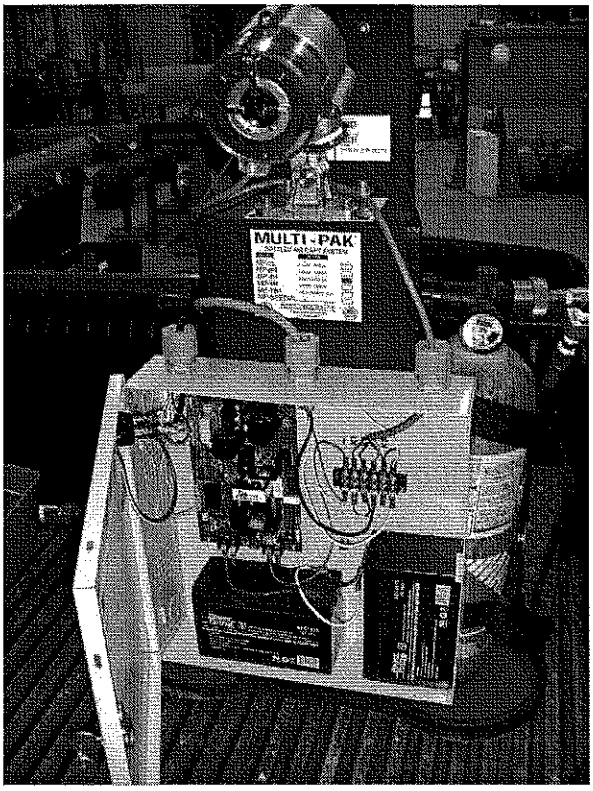
Modifications were made to the suppression nozzles to maximize the effectiveness of the system. In testing, the modified nozzles displayed high level of effectiveness, fully suppressing fire in less than half a second after receiving a signal from sensor. However, the flame-detection camera was responding 3-5 seconds after the ignition. Additionally, false signals were received from sunlight and movement of the camera. Consequently, the flame detector was replaced with a model from a different manufacturer. This flame detector should provide a response time less than 150 msec. A power supply with 24V DC battery was ordered to create system that can be used independently from an outside power source.

Testing of the full modified system was made in the laboratory to detect reaction of the flame detector on the following different radiation sources:

- *Indirect or reflected sunlight:* The detector did not alarm or react to the indirect or reflected sunlight.
- *Arc welding:* The detector did not alarm or react on distances more than 6 feet.
- *Flashlight:* The detector did not alarm or react.
- *Lit cigarette:* The detector did not alarm or react.
- *Propane welding torch:* The detector did not alarm or react on distances more than four feet.
- *Indirect vehicle headlights (low beam).* The detector did not alarm or react.
- *Bright safety orange clothing:* The detector did not alarm or react.
- *Radiation heater:* The detector did not alarm or react.

Status

Final testing of the system in the field test pit is under way. Plans for Phase 2 include partnering with a potential commercializer.



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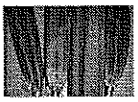
OTD Operations Technology Development

Large-Diameter, Medium-Pressure Inflatable Stoppers



Researchers evaluated a new flow-stopping system for use on gas pipe diameters up to 24 inches and pressures up to 60 psig. The system, which is manufactured in Europe, was investigated to validate its use in the U.S. gas industry.

Project Description

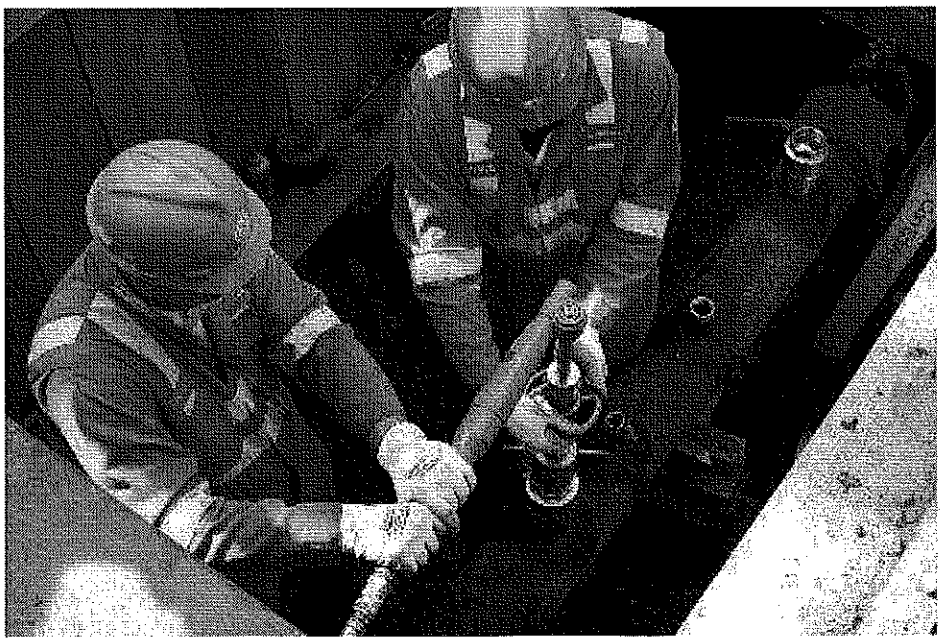
Line-stopping equipment used in the natural gas industry is usually heavy, takes multiple people or mechanical assists to maneuver, is costly to maintain, and is very time consuming when installing and tapping necessary fittings.

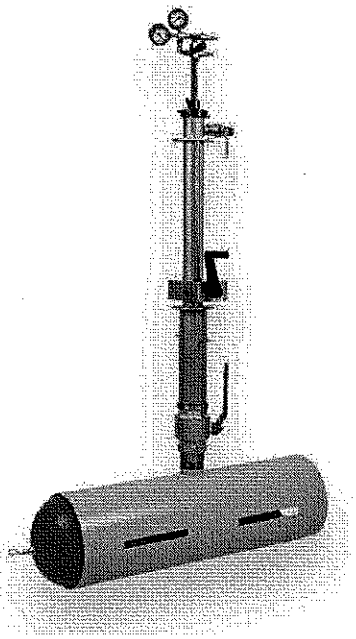
In response, researchers investigated new line-stopping equipment that has the potential to reduce these problematic issues while providing the same assurance of safety and performance.

Research is addressing several industry needs:

- One application is used on larger-diameter (12-inch to 24-inch) cast-iron and steel piping systems that operate at pressures greater than five psig and have limited options to control gas flow. Currently, bag stopping equipment can only be used up to five psig. Therefore, when cast-iron and/or steel systems that are operating at medium pressures (greater than five psig) the options for shutdown are either valves – which may negatively impact customers – or costly line stoppers.
- Another application is related to the natural gas industry's increasing use of larger-diameter polyethylene (PE) pipe. Hydraulic squeeze tools are manufactured to squeeze the PE pipe to stop the flow of gas, but an alternative is needed.
- New bag stopping equipment may have the potential to be used in combination with traditional line-stopping equipment to provide additional safety. The bag can act as a secondary stop with a vent (bleed) between the primary stop (traditional equipment) and the bag. This application can potentially be used on higher-pressure systems (greater than 60 psig). The traditional stopping equipment can be used to stop-off the majority of the flow of gas; however, at times complete flow stoppage cannot be obtained. The bag system could be used to completely stop off the gas flow while the "blow by" from the traditional stopper is vented to atmosphere. Therefore, the high pressures in the pipe will not be seen by the bag stopper.

In this project, researchers evaluated a system from a European manufacturer of equipment and materials, including several styles of flow-stopping products able to be used on gas pipes with diameters up to 24 inches and pressures up to 60 psig.





Deliverables

This project will result in a laboratory- and field-tested large-diameter, medium-pressure stop-off system(s) and some validation of smaller-diameter systems. An alternative line-stopping prototype system will be developed that can be used not only as an emergency response tool, but also as a routine stopper for use on PE, steel, and cast-iron piping systems.

Benefits

New bag-stopping technologies currently used overseas have the potential to provide the U.S. natural gas industry significant savings in day-to-day operations while increasing operational efficiencies and safety.

Technical Concept & Approach

This project will assist with the technology transfer and evaluation of currently manufactured flow-stopping equipment in Europe for the U.S. natural gas industry. Activities are being coordinated between Gas Technology Institute (GTI) and GDF SUEZ. GDF will focus its efforts on the bag system for pipe sizes eight inches and less in diameter; GTI efforts are on a system for pipe diameters of 12 inches and larger.

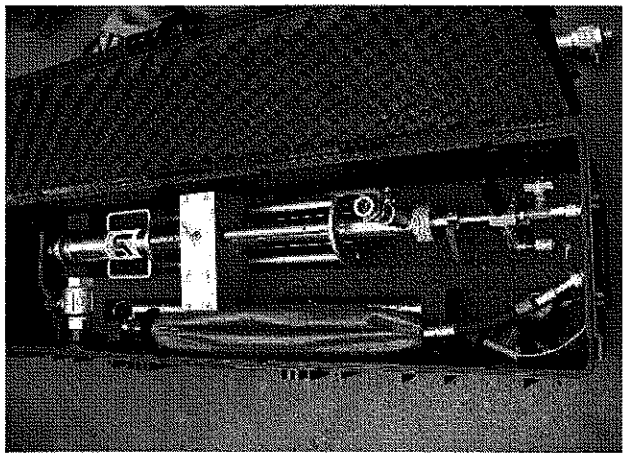
An investigation of fittings (or recommended fittings), tapping equipment, bag system, bags, and other associated components was conducted.

Results

This project was initiated in 2012 with efforts to identify the necessary equipment and piping components required to perform the evaluations on low- and medium-pressure natural gas systems up to 24 inches in diameter. In addition to identifying the bagging equipment needed, researchers reviewed past bagging projects to better understand the needs, applications, and fittings available. The majority of the past efforts focused on six-inch diameter and less. Therefore, project sponsors were surveyed to obtain additional information on larger-diameter stopping.

A test matrix was developed that included a variety of laboratory tests. Several modifications and improvements to the system were made.

In 2013, a live demonstration of the medium-pressure stopping system was conducted in Michigan on a 16-inch-diameter low-pressure cast-iron main. Overall the demonstration was successful and the system performed well. Various enhancements were identified.



In 2014, contact was made with several potential North American commercializers for the inflatable system. This included a range of companies which already supply and/or distribute products into the natural gas industry. Project representatives demonstrated the equipment to interested manufacturers/suppliers. An initial selection and agreement was made between the developer and a North American distributor for selling, servicing, training, and other necessary support for the products.

The 60 psig system was only able to be used in pipes up to eight inches in diameter. However, a new fitting allowed the new tapping and bagging system to be used on 18-inch PE pipe.

A demonstration of all the equipment, including the new large-diameter PE equipment, was conducted in Chicago using the new equipment to stop off the flow on an 18-inch HDPE pipe at 25 psig. In addition, another demonstration was performed on a six-inch steel pipe operating at 60 psig. In addition, a field deployment of the system was conducted in New York City.

Status

Testing is completed for all systems received to date. Field demonstrations were conducted and a Final Report is being prepared.

A commercialization agreement was put in place and the equipment is now available in North America through Mainline Control Systems.

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Advanced Tools for Improved AC Corrosion Prevention and Mitigation

To help operators reduce the risk of pipeline failures, researchers are developing a probabilistic model and calculator designed to predict AC corrosion rates in natural gas pipelines.

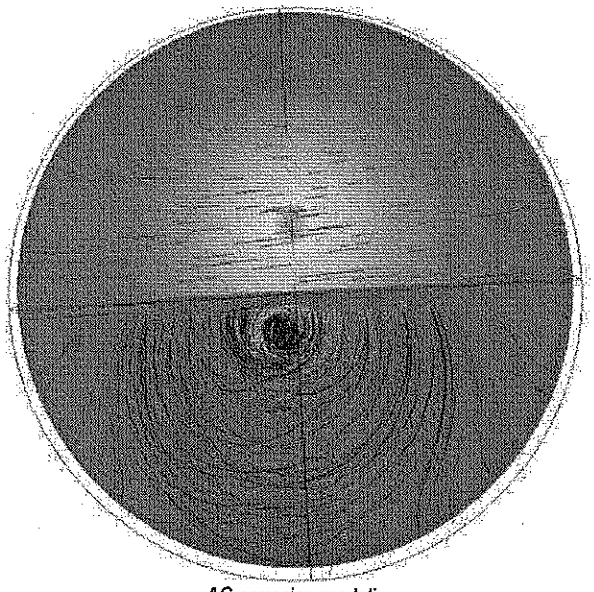
Project Description

Corrosion by alternating current (AC) is one of the threats to the integrity of the buried gas pipelines, which often share the right-of-way with high-tension electrical lines. Typically, AC interference sources are high-voltage transmission lines and AC traction systems.

To address the issue, this project focuses on the development of a probabilistic model and calculator to be used on gas pipelines to accurately determine AC corrosion rates and predict the effect of various mitigation efforts (e.g., coating rehabilitation) or changes in environmental factors (e.g., power line up rates).

AC-induced corrosion is not as commonly encountered as traditional, chemically based, external corrosion. However, when it does occur, it happens much faster than traditional corrosion mechanisms. AC corrosion rate is unpredictable for AC densities between 20 A/m^2 to 100 A/m^2, and there is conflicting guidance on what value of current density is needed to start AC corrosion.

The objective of this project is to develop clear and consistent guidelines on the current density required for AC corrosion, particularly in the "unpredictable" zone.



AC corrosion modeling.

Deliverables

The deliverables include:

- An **AC Corrosion Model** that:
  - Defines the likelihood of corrosion within the currently defined "unpredictable zone"
  - Accounts for uncertainty, allowing confidence intervals to be calculated on risk predictions
  - Is validated with a significant data set from operators and the public literature.
- An **AC Corrosion Calculator** that:
  - Provides operators with a tool to effectively select preventive and mitigation measures
  - Has an easy to use and flexible input process
  - Allows multiple mitigation strategies to be "tested" for effectiveness
  - Addresses current operator needs.

Benefits

The ability to accurately predict AC corrosion rates will reduce the risk of sudden pipeline failures due to AC corrosion by identifying specific pipe segments in need of additional preventive and mitigative measures.

Information on AC corrosion rates will allow operators to target validation excavations and other assessments towards segments of pipe with the greatest risk. The model/calculator could be used on existing lines, new lines, in the pre-construction stage, and to optimize proposed designs to reduce the threat of AC-induced corrosion.

Technical Concept & Approach

The scope of this project includes developing an AC corrosion-rate model and incorporating the model into a user-friendly software tool. The tool will allow inputs and mitigation techniques to be adjusted.

The research team will develop an AC corrosion model by performing the following:

- Collect and quality-filter publicly available and peer-reviewed data on AC corrosion criteria, rates, and severity levels
- Construct a model that accounts for uncertainty and provides the required confidence levels
- Conduct a statistical analysis (e.g., regression study) on all available corrosion rate data in the 20-200 A/m^2 region to provide relationships for the predictive corrosion model
- Define operator system knowledge needed to input into AC corrosion determination models
- Establish measurement uncertainty and variability of these inputs as typically encountered in practice.
- Validate and refine the closed-form solution with the physical data set.

The research team will use the model developed to create a software tool that allows operators to predict corrosion rates and run scenario analysis for various mitigation techniques. The calculator will be built specifically for ease of use and flexibility.

Results

This project was initiated in 2012 with the formation of an advisory committee and the preparation of an industry survey to collect information on AC corrosion, field conditions, corrosion data availability, and the requirements for the software tool.

The currently used Pipeline Research Council International (PRCI) AC corrosion model was reviewed as part of a comprehensive literature search of research studies and laboratory/field test results on AC corrosion.

Corrosion simulation using a corrosion/surface chemistry modeling module was initiated. However, researchers experienced technical challenges with constructing the corrosion model.

In 2013, the research team investigated options for adapting the capabilities of corrosion models to meet the objectives of this project. Researchers evaluated the software to determine the gaps and limitations of the model to meet the needs and objectives of this project. A business arrangement was pursued with the software developer to leverage this technology as the calculation engine behind the risk calculator; however, it was not possible to reach an agreement commensurate with the time and budgetary constraints of the current project. Consequently, efforts were focused on constructing the web-based interface for the risk calculator and for providing an alternative means of calculating the induced currents and the AC corrosion rate using the calculation methods that are available in the open literature. These methods have been shown to provide good agreement with the PRCI reference model.

In 2014, the web interface through which a user enters a particular site parameters was completed. The user web interface provides the "shell" through which the entered data is placed into the calculation model and through which the results of the calculation are presented to the user. The user interface also provides the ability to perform some basic what-if scenarios with different mitigation strategies. The amounts and types of mitigation equipment needed can be developed using this capability.

The project investors were solicited for test case data for locations where AC corrosion has been investigated in order to provide verification for the calculation models. This data includes measured induced currents and measured resulting corrosion on pipelines.

The methodology for calculating induction influences for the cases of parallel pipe and power lines and for angled approaches has been determined. The methodology for converting the induced voltages and into corrosion rate was also determined. For this iteration of the calculator, the corrosion rate calculation was simplified. It was determined that although some portions of the soil chemistry can contribute to long-term metal loss, the basic soil impedance dominates in the short run. The most rapid metal loss is regulated by soil impedance and the other effects are secondary. The second order effects could be factored into the model but will require a much higher level of field data collection on the part of the user.

Status

Database entities are being finalized (e.g., tables, stored procedures, and relationships) and specific modules are being developed to add the required functionality.

Efforts are under way to complete the development of closed-form calculations of the induced AC influences and the corrosion rate. Researchers will use available field data from several sites as calibration and verification for the calculation model.

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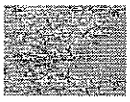
OTD Operations Technology Development

Guidelines for Cast-Iron Piping Winter Operations

To address concerns with cast-iron piping systems for natural gas distribution, researchers investigated the frost impact on a cast-iron system in New England and developed guidelines for initiating a leak-surveillance program for winter operations.



Project Description

Federal regulations require pipeline operators to have a procedure for continuing surveillance of their facilities, to identify problems, and take appropriate action for various situations, including leaks, breaks, and, for cast -iron (CI) piping systems, graphitization.

Incidents with cast-iron pipe have prompted state regulators in Pennsylvania to evaluate and modify the procedures regarding the frequencies of the CI winter surveillance. In response, a utility in the Northeast initiated a research program through OTD to provide an engineering-supported approach and procedure that can be used to identify the locations, durations, and frequencies of its CI winter surveillance.

In this project, a research team investigated the frost impact on the CI distribution system and provided guidelines regarding when to initiate and terminate a winter-surveillance program, and under what conditions.

Deliverables

The deliverables for this project include the research methodology, analysis of results, and user-friendly guidelines to assist in the condition assessment of the CI system and support a leak-surveillance program.

Frost heave formation at the pavement surface.

Benefits

The guidelines identify high-risk scenarios, pipe-condition ratings, and survey procedures for CI piping systems in winter operations. The analysis also provides indicators on the freeze effects which are tailored to the local characteristics and experience of each region in the study.

Technical Concept & Approach

The approach for this project involved:

- The establishment of a database of the leak-surveillance data, inspection and repair records, and historical data from participating utilities
- The correlation of existing CI leaks and breakage data due to frost impact with local site conditions, such as soil, weather, and construction practices
- The use of risk-analysis techniques for modeling the relationships between the various parameters and providing a risk-based assessment of the probabilities of failures (i.e., leak and breakage).

Specific tasks included:

- **An Assessment of the Utility CI Distribution System**

  Researchers investigated the characteristics of a cast-iron piping system in a utility's distribution network in terms of miles, location, and pipe properties (e.g., diameter, wall thickness, joint types, and age). Since soil data and environmental conditions change significantly within small areas, well-defined and discrete areas were selected to provide representative samples of the region and enable using manageable sets of weather and soil data.

- **Identification of the Parameters Affecting CI Performance**

  Researchers investigated the key factors that are associated with CI failures due to frost action. These factors include environmental conditions (e.g., soil temperature, freeze depth, and duration),

site characteristics (e.g., pipe and joint types, pipe size, and soil properties) and operation conditions.

- **A Risk-based Analysis for Condition Assessment**

  The technique for the assessment of the cast-iron pipes in frost conditions was based on the Fault Tree Analysis model and used the Isograph Reliability Workbench Program.

- **An Evaluation of Gas Migration Patterns**

  Investigators reviewed previous research on gas flow in soil and the effects of soil properties and leak characteristics on gas migration, followed by a study of available leak-surveillance data, inspection and repair records, historical data, and the operators' observations.

- **The Development of Implementation Guidelines**

  These guidelines will allow the utility to focus its leak-surveillance program on when and at what conditions it should initiate its response to frost impact on the cast-iron pipeline system.

Results

In 2013, investigators completed a statistical analysis of data sets of leaks and breakages of cast-iron pipes in the a major New England metropolitan area. The results established the basis for the evaluation of the frost impact on cast-iron pipes. Researchers established correlations of the pipe breakage with weather data and provided preliminary recommendations regarding the start and end dates for the winter leak survey.

In the project, researchers investigated CI winter leaks and breakage records of selected areas during the period from 2002 to 2012.

The cast-iron leak records during the winter months were mostly associated with joint leaks and main-line breaks. Very few records had other leak and break types (e.g., valves, fittings, and tap connections). Most of the broken mains occurred in small-diameter pipes. The database had negligible line breaks in pipe diameters at and above eight inches and almost no breaks occurred in pipes larger than 20 inches.

The rates of pipe breaks per mile varied during the period from 2002 to 2012 and ranged from 0.05 to 0.29 breaks per mile. These variations are mainly attributed to the various freeze conditions and durations during these years.

The soil properties in the region were obtained from the Soil Survey database of the U.S. Department of Agriculture. The soils were mostly gravely and loamy sand with low silt and clay contents. The correlations between the soil data and pipe breaks did not show a significant relationship. This is likely because the soil survey data did not fully represent the roadway and backfill materials around the pipes in the urban areas of the region.

Weather data was obtained from 10 weather stations in the region. The data was used to determine the correlation between pipe breaks and the freeze conditions in the various towns of the region. The occurrence of breaks correlated to the freeze conditions; and the prediction of the number of breaks is thus possible with the use of weather forecasts.

The duration of freeze during the winter season is the main parameter which affects the increase of pipe breakage rates. It is defined as "Freeze Days," which is the number of days per month with maximum daily temperature below or equal to 32°F. The Freeze-Days parameter relates to the "Degree-Days" parameter, which is commonly referenced in the literature as the difference between the average daily temperature and 32°F, multiplied by the number of the Freeze Days. The correlation between the Freeze Days and pipe breaks was evaluated in 18 towns in the region. The correlation showed that most of the winter breaks (90% of the cast-iron breaks) occurred after five days accumulation of the Freeze Days. This correlation can be used to establish a criterion for initiating winter patrols and to optimize the probabilities of detecting winter breaks.

The database shows that the major source for identifying cast-iron leaks in the winter months is the public notification of leaks; followed by company personnel and winter patrols.

The results show that the number of after-freeze breaks (i.e., during the thawing period) had a weak correlation with the total Freeze Days in the winter season. However, the records did not show after-freeze breaks when the duration of the freeze season was short (i.e., when all Freeze Days occurred in less than three months of the winter season).

Status

This project was completed with the release of a Final Report in January 2014.

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OTD Operations Technology Development

Evaluation of Commercial-/Light-Industrial-Sized Excess Flow Valves (EFVs)

For this project, researchers evaluated the performance of high-volume EFVs for commercial, multi-residential, and light-industrial applications in response to new regulations requiring an expanded use of EFVs.

Project Description

Since 2008, the natural gas industry has required the use of a safety device called an Excess Flow Valve (EFV) in all new single-family residential services. These devices are installed on the upstream portion of natural gas service lines, providing protection to the pipe downstream.

A properly installed EFV detects a reduction of pressure in the line compared to the upstream regulated supply pressure as a result of gas escaping through a severed or damaged line and shuts off product flow. In principle, these devices are highly valuable, reducing the risk of damages caused by catastrophic failure to the service line. However, incorrect selection, sizing, and installation of EFVs may lead to improper valve actuation. While EFVs are being increasingly used for commercial and light-industrial applications, there is little historical information on the use of these higher-capacity EFVs. Until this project, no studies had been performed on their performance and the only performance data available was from manufacturers of the devices.

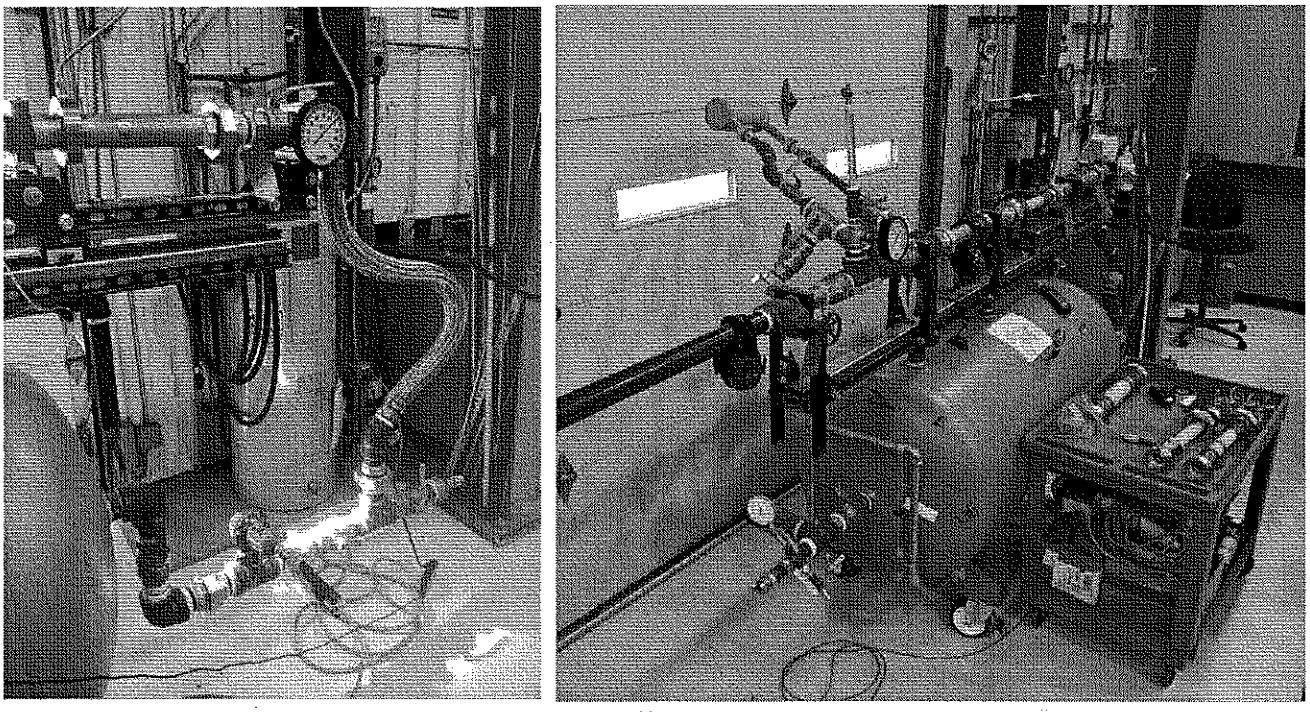
In this project, a third-party evaluation of the performance of high-volume EFVs was conducted to provide utility operators with a better understanding of high-volume EFV performance capabilities and limitations.

Some of the concerns regarding the installation of high-volume EFVs include:

- The transient nature of businesses
- Additional load without notification
- Breadth of capacity
- Size of service line requirements.

Deliverables

The deliverable for this project will be information to provide guidance for selecting commercial EFVs when considering the variables of commercial and light-industrial customers.



High-volume EFV testing apparatus.

Benefits

The Pipeline Transportation Safety Improvement Act (S.B. 275) – which addresses safety issues such as the use of automatic shutoff valves and EFVs – includes expanded requirements for EFVs to include multifamily buildings and small commercial/industrial facilities. With the new requirement, the number of higher-capacity, larger-sized EFVs installed will increase substantially.

This project will provide information to assist utilities in EFV selection, installation, and training. Additionally, this project is expected to lead to the commercial availability of standardized tooling packages for purchase by utilities and their contractors.

Technical Concept & Approach

The scope of this project was to evaluate high-volume EFVs from manufacturers.

Activities for this project involved the following:

Industry Input – A survey was conducted to address the use of commercial EFVs by manufacturer and type, occurrence of accidental or unwanted closures, service length range, and other issues.

Performance Evaluation – In order to evaluate these high-capacity EFVs, a flow-testing apparatus was upgraded by increasing the volume capacity to test EFVs up to two inches in diameter.

Test parameters included:

- Performance differences between manufacturers for closure (trip) and bypass flows
- Amount of gas released during EFV activation
- Effect of service length
- Instantaneous load (demand surge)
- Over loading.

Results

Various project utility sponsors and EFV manufacturers donated EFV samples. Six different commercial-grade EFVs of varying sizes, styles, and capacities were selected for evaluation based on popular use and interest. All acquired samples were equipped with a bypass mechanism. At least three samples of each EFV type were subjected to a testing regime which included two inlet pressures (10 psig and 60 psig) and totaled more than 600 individual tests.

Validation of EFVs were performed and compared directly to test data from one of the EFV manufacturers.

A subset of evaluated samples were subjected to various mixtures of contaminant material and re-evaluated. Polyethylene plastic shavings, metal shavings, and finely ground ferric oxide were mixed with kerosene to produce three separate contaminating mixtures. Three samples of each EFV type were submerged in their own contaminant mixture. The samples were allowed to dry for 24 hours before testing began. Contaminant testing was limited to capturing flow profiles, testing the trip flow rate, and determining the time to reset.

Findings:

- EFVs are effective to protect against major line breaks
- Larger-capacity EFVs are not a method of protection for minor breaks or leaks
- Affected service lines must be shut down and repaired to reset the EFV
- Contaminants do not have a great effect on the operating parameters of the EFV.

The parameters captured and presented indicate important information regarding the expected behavior of the EFV under typical operating conditions and how the device impacts product delivery.

Status

Testing has been completed and data has been analyzed. A Final Report detailing testing results was completed in 2014.

Recommended additional testing:

- Evaluation of maximum length of service lines
- Evaluation of multiple EFVs on a branched line
- Collaborations of best practices
- Autonomous testing.

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GPS-Based GIS Conflation System

The objective of this project is to develop and demonstrate a real-time GPS-based GIS system to increase the accuracy of a GIS using GPS data collected as part of routine operations. A process called conflation will be used to shift the GIS to match the GPS coordinates of assets collected with high-accuracy equipment.

Project Description

Many natural gas system operators have improved the accuracy of their geographic information systems (GIS) through conflation – a process that typically uses a commercial land base to shift the position of assets in the GIS to more accurate real-world coordinates. Use of a commercial land base allows the GIS to be blended with (or, conflated) to an existing data set with an accuracy of one to 10 meters.

Research suggests that GPS can potentially be used as an alternative data source for performing GIS conflation to provide a higher level of GIS accuracy. Conflation to GPS coordinates of features within the GIS will not only result in a higher level of spatial accuracy in relation to real-world features, but it will also potentially improve the underlying accuracy of the data because it will allow inaccurate "as-built" data to be corrected. Collecting the GPS coordinates of features when exposed or located would allow features to be conflated to a truly accurate position. Furthermore, conflation to centerline data is very difficult in rural areas where landmarks are not present and conflating to GPS may be the only feasible option for improving the accuracy of the GIS.

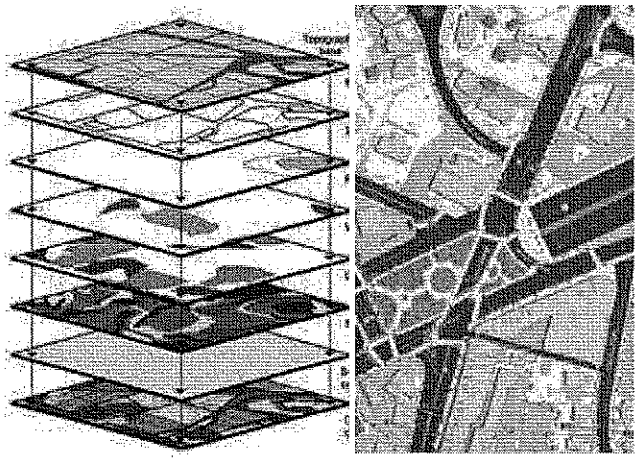
In 2010, research was conducted to compare the two different conflation techniques – conflating to a commercial land base and conflating to GPS coordinates. The results of the project indicated that conflating to GPS coordinates can provide superior accuracy compared to a commercial land base and, in some situations, may be the only feasible option for GIS conflation.

Through the OTD-sponsored *Intelligent Utility Program,* a system was developed that can efficiently collect field data using mobile technology such as smartphones and tablet devices. High-accuracy GPS receivers were incorporated to provide sub-foot accurate data without the need for post processing or access to base stations.

Building on these technologies, it is now possible to develop tools that can cost-effectively collect GPS data and perform real-time GIS conflation. The objective of this project is to develop and demonstrate a real-time GPS-based GIS conflation system to increase the accuracy of a GIS using GPS data collected as part of routine operations.

Deliverables

This project is being performed in two phases. In the current Phase 1, researchers will develop a proof-of-concept system to demonstrate the feasibility of the field-data-collection system and the server-based GIS conflation process. Upon successful completion of the proof of concept, Phase 2 will be conducted to develop a fully functional prototype system for testing in a pilot project, followed by commercialization activities.



Benefits

The value of a higher-accuracy GIS will be realized through increased operational efficiency and decreased risk. Less time will be spent locating assets during routine operations, one-call tickets will be reduced, and fewer field visits will be required for design and engineering analysis. Risk will be reduced through excavation-damage prevention and improved asset locating. Conflating to GPS data will also correct errors within the existing GIS data by verifying the spatial location of assets.

Higher-accuracy maps could be extremely beneficial in emergency situations where valves, meter sets, and other assets need to be located quickly.

Technical Concept & Approach

Activities include the following:

- A mobile field-data-collection application will be built that includes the development of 1) a conflation area polygon; 2) map displays to support the display of the conflation area polygon and features; 3) a process to adjust or create an adjustment feature to define the actual location of a feature defined in a sampling plan; and 4) a process to adjust or create features from a validation sample set to define the actual location of a feature defined in a validation plan.
- A server-based process will be developed that allows field-collected GPS data to be used to perform GIS conflation. The conflation system for Phase 1 will not be truly real-time and will involve manual processing to reduce the cost of development for proof-of-concept testing. The system developed for Phase 2 will be automated and real-time.
- Researchers will first perform integration testing of the systems, followed by a proof-of-concept demonstration. The proof-of-concept system will consist of a mobile data-collection device, real-time sub-foot-quality GPS receiver, a mobile data-collection application, and the conflation software.

Results

A workshop was held in early 2014 with the research team, contractors, and an industry sponsor to develop a sampling plan and discuss potential data-conflation scenarios to run for reporting and comparison purposes.

At a site in Boise, ID, all assets in the area were identified and marked. High-accuracy GPS data of the assets was collected using the mobile application developed under the *Intelligent Utility Systems* project.

Researchers also provided "what if" scenarios to use to determine how different data-collection procedures affect the accuracy of the conflation process. The scenarios provide information to help determine the amount of data needed in order to provide the most accurate data with the most efficiency.

Status

Upon delivery of the final conflated data, an analysis will be performed to determine the accuracy of conflated data using GPS.

Researchers will also analyze "what if" scenarios to determine the accuracy achieved by using different data-collection processes.

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PE Pipe Splitting – Technology Evaluations, Enhancements, and Standardization of Tool Kits

For this project, a research team will evaluate and refine existing PE pipe-splitting equipment and develop standardized commercially available tooling packages and operating procedures.

Project Description

In recent years, research organizations, manufacturers, and others have partnered to develop splitting systems to replace old, small-diameter plastic pipe with new polyethylene (PE) pipe for gas distribution. In these projects, pipe-splitting technology was used to simultaneously slice the existing service line or main, while pulling in a new pipe behind the splitter.

Past efforts proved successful in splitting and replacing gas distribution piping ranging from diameters as small as one-half inch to two inches. However, there were some shortcomings that this new project addresses.

Currently, splitting systems are pieced together by the manufacturer or the pipe contractor to meet the specific needs of the job at hand. The availability of a standard commercial system is the first step to allow this system to be accepted and used by the gas industry.

The focus of this project is on the evaluation and refinement of existing PE pipe-splitting equipment such that standardized tooling packages become commercially available along with operating procedures.

Deliverables

Demonstrations of pipe-splitting systems will be conducted at simulated field sites and at sponsor field sites.

Case Studies on the operation and application of the various splitting technologies will be developed to allow for a better understanding of the systems available and their operations.

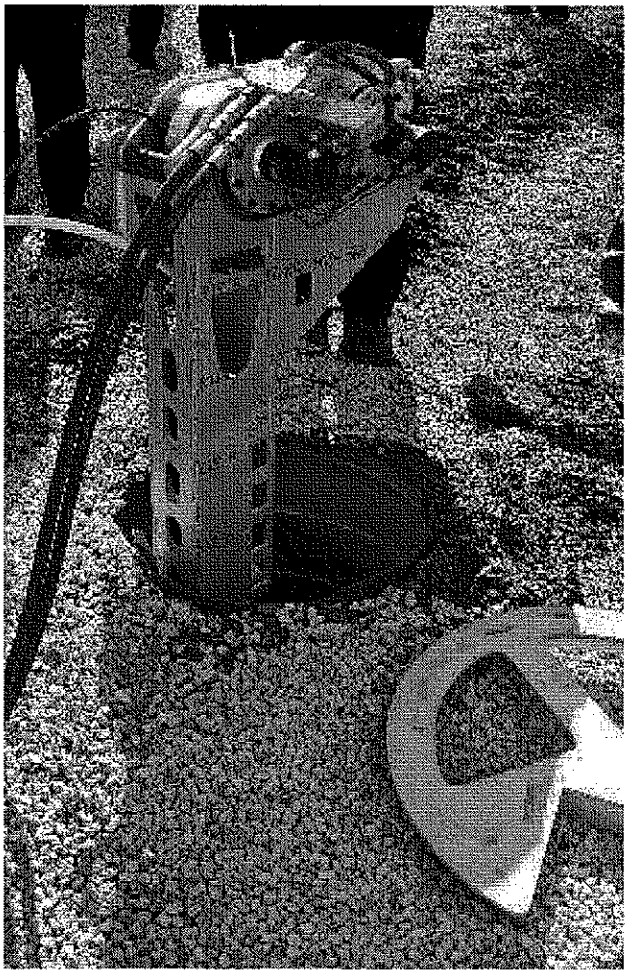
In addition, operating procedures for each standardized tool kit will be developed.

Benefits

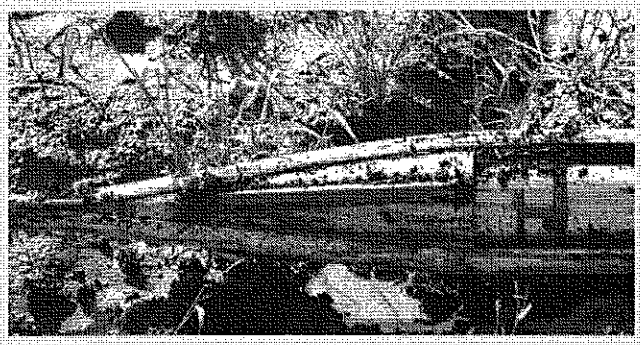
Utilities are becoming more aggressive in the systematic replacement of certain vintage PE piping systems. Pipe splitting can offer significant cost savings while performing the operation more efficiently with less disruption to traffic and the general public. One utility – measuring savings based on reductions in pavement restoration – reduced pavement restoration with pipe splitting by 2/3 vs. open-cut and by 1/3 versus horizontal directional drilling.

Participants will gain first-hand knowledge of the existing and enhanced splitting systems, the specific applications where these systems perform best, and system limitations.

Additionally, this project is expected to lead to the commercial availability of standardized tooling packages for purchase by utilities and their contractors.



Researchers are investigating a pipe-splitting technology that can be used in keyhole excavations.



PIPE SPLITTING ADVANTAGES

- New pipe can be equal to, greater than, or less than the existing diameter of the old pipe being split.
- Reduced disruption to traffic and local businesses.
- Reduced excavation and restoration costs.
- Using the same host pipe as a pathway for the new PE main reduces the risk of third- party damage within crowded right-of-ways.
- No need to remove the retired gas pipe.
- On segments that have few services, splitting pipe can save approximately 20% of the costs over traditional open-cut construction methods.
- Savings can increase to up to 35% for pipes under pavement and in heavy urban locations.
- Pipe splitting technology's capital costs are less than horizontal directional drilling rigs.

Technical Concept & Approach

Specific tasks in this project include:

- **Establishing Product Specifications, Requirements, and Capabilities**

  The research team and project sponsors will determine pipe-splitting application parameters and system requirements. In addition, the currently available splitting technologies and their applications and limitations will be identified.

- **Simulated Pipe-System Evaluation of Splitting Units**

  Field tests with selected trenchless-technology manufacturers will be conducted to evaluate the splitting systems and to verify the capability to perform the applicable operations.

- **Field Evaluations/Modifications of Splitting Technologies**

  Upon satisfactory simulated pipe evaluations and refinements of the identified splitting systems, field evaluations on sponsor system piping will be conducted. These evaluations of the various splitting systems will provide actual field assessments to determine the effectiveness of the splitting systems.

- **Reporting and Case Studies**

  Case Studies of successful systems will be developed from the demonstration projects.

Results

Initially in 2013, discussions were held with equipment manufacturers in order to gain a better understanding of the systems and also to gain their support for this project. The research team began assembling guideline documents to both identify the applications suitable for PE pipe splitting, along with equipment and practices of each manufacturer's equipment for service and mainline PE pipe splitting.

The project team identified two interested equipment manufacturers, who will provide equipment and support for the project. One manufacturer is partnering with the project team to advance its "low-profile" splitting heads that were used in a splitting demonstration. These "low-profile" splitting heads were created just prior to the demonstrations and enhancements were needed for durability.

In 2014, demonstrations of one of the manufacturer's PE main- and service-line splitting system were conducted. A utility installed approximately 40 feet of two-inch-diameter PE pipe with another two-inch PE pipe next to it to simulate joint trench and other potential adjacent utilities. Observations were made to determine if any damage was caused by the splitting head (blades) during the splitting process.

Status

Ongoing activities include:

- Continued identification of additional PE splitting equipment
- Obtain specifications on the various PE splitting equipment
- Development of procedures for both PE main and service splitting
- Identification of potential field-test sites with proj -ect sponsors.

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EZ Valve for Transmission Mains

The objective of this project is develop a concept for a commercially available valve to allow for its use on natural gas transmission lines. The design has the potential to provide a compact and fast alternative to traditional valve installation methods.

Project Description

This project is focuses on a the development of valve-system concept similar to the commercially available EZ™ Valve System, but designed for higher-pressure distribution and transmission pipes.

The current EZ Valve System is used in the water industry and bolts to the pipe to allow for the installation of an in-line valve without shutting off the flow. Advanced Valve Technologies, Inc., developed the EZ2™ Valve System that can be installed under pressure in one excavation, eliminating expensive multiple excavations.

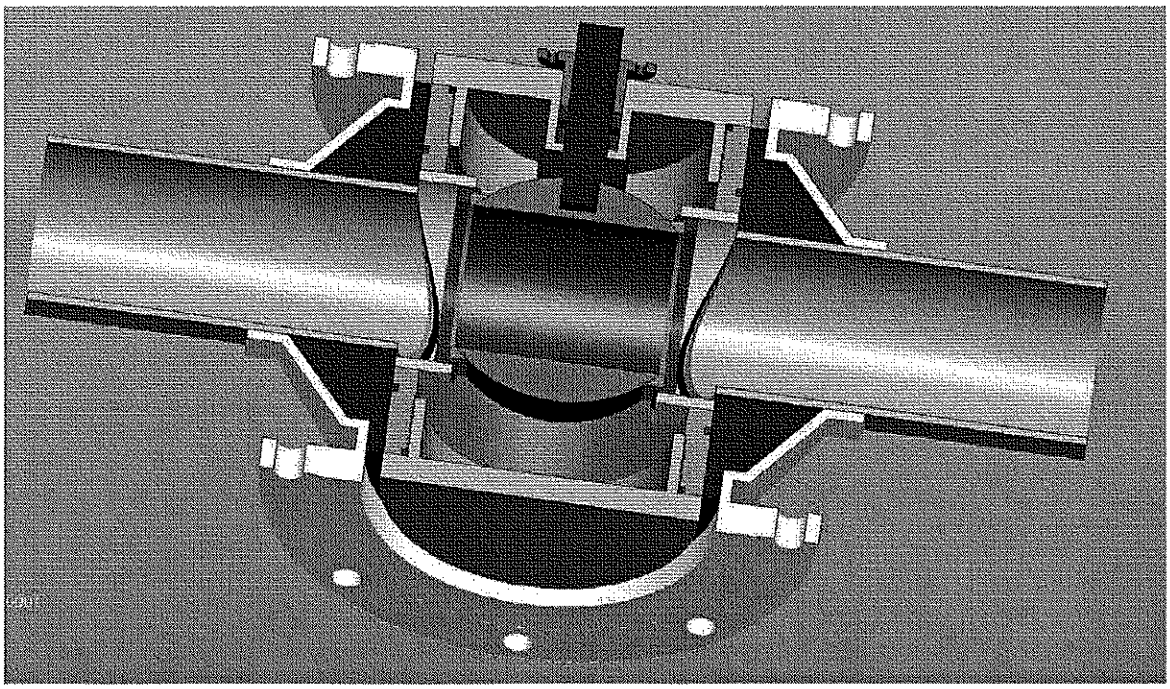
In a previous OTD project, R&D on the EZ valve was conducted to:

- Determine the desired operating characteristics and the benefits seen by its application in the water industry
- Modify the valve to address gas industry needs and to resolve an issue of the large number of chips (cuttings) generated during the milling process inside the gas pipe
- Test the EZ Valve to validate the operational parameters as they relate to the gas industry standards.

The current project involves R&D to allow the EZ Valve fitting to be permanently welded to a steel pipe after installation. This system will be a unique design that meets all material and performance expectations while delivering a compact and fast alternative to traditional valve installation methods. It will be developed to provide important performance and installation benefits to pipeline operators working under difficult conditions and with critical needs. Initially, researchers developed a concept for a transmission EZ Valve for sizes up to 12 inches in diameter with working pressures up to 300 psig. The development of an alpha prototype is currently under way.

Deliverables

Phase 1 deliverables included a conceptual design for the EZ valve. Deliverables from the current Phase 2 include the development of a working laboratory prototype.



Benefits

Issues with installing traditional valves on an existing pipeline include high costs, the need for large excavations, the need for the installation of several fittings to allow for flow stopping, and, in many cases, the need for by-pass of the pipeline.

The adaptation of the EZ valve system will give operators options for the placement of these valves, along with the benefit of greatly reducing the cost of installation.

Benefits of the valve concept include:

- Faster installation times, especially in urban environments
- No need for flow control and/or by-pass
- Only single excavations needed since there is no need to stop off the flow in the pipe and no need to install a by-pass
- Enhanced safety
- Lower cost of installation.

Technical Concept & Approach

Specific key tasks for Phase 1 of this project included an evaluation of the existing EZ Valve System and other current valve designs. Conceptual valve designs were created. Due to the operating conditions, the fitting will be required to be welded in place and therefore the fitting will not be able to be rotated during the cutting operation as with the current EZ Valve system.

Phase 2 activities include:

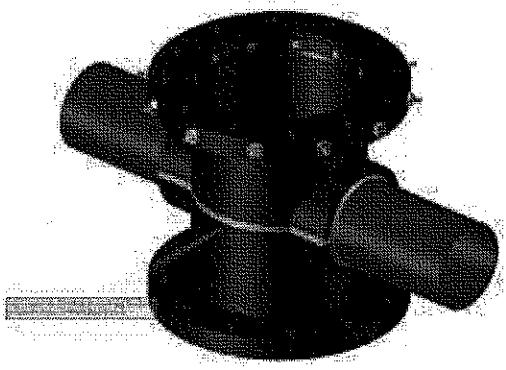
- **Construction of a Laboratory Prototype Transmission Cut-in Valve**

  The team will work with several manufacturers on the various components of the valve and the equipment necessary for installation. After development of the various components, technicians will assemble the fittings and install the valve on a pressurized (with air) six-inch-diameter steel pipe.

- **Testing and Evaluation of a Prototype Cut-in Valve**

  Testing includes all aspects of the installation and performance of the valve (including across the valve seats) and hydrostatic testing to confirm the pressure range per regulatory requirements.

At the conclusion of this effort, a Final Report will be issued providing an overview of the transmission cut-in valve and the testing results.



Results

Initially, concepts and initial designs for a live insertable transmission valve were generated. The designs focused on a valve that could be installed without shutting off the flow of gas on steel transmission (or high-pressure distribution) pipelines. The focus was on pipelines ranging from four inches to 12 inches in diameter and pressures up to 300 psig.

CAD drawings of the weld-on split sleeve fitting, insertable ball valve cartridge, and tapping and insertion tooling were created. In addition, Finite Element Analysis (FEA) modeling was created for the weld-on split sleeve. A series of reviews and modifications were also performed on the design and an invention disclosure was submitted for consideration.

Manufacturing detailed drawings were developed for both a six-inch cut-in valve and for the equipment to install/insert the valve. An animation simulation of the six-inch cut-in valve and the installation process was also created.

In 2014, the team prepared plans for a Phase 2 and the development of a prototype transmission valve by finalizing some of the drawings so they can be used as manufacturing drawings.

Status

A Phase 1 Final Report was completed and is currently in review.

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Low-Cost Collision-Avoidance System

To enhance safety in gas operations, efforts are under way to develop a low-cost, low-speed, collision-avoidance system that would provide gas industry utility vehicles the ability to provide driver alerts and, when necessary, automatic braking.

Project Description

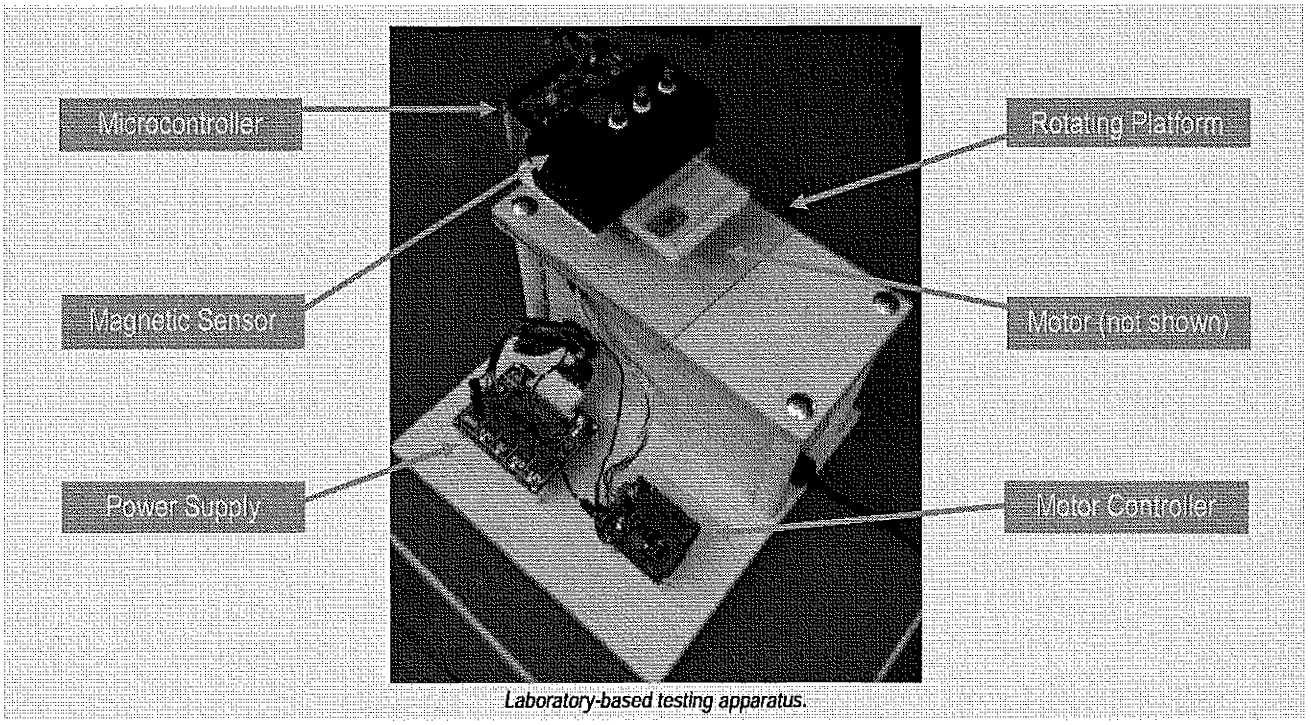
Common, low-speed collisions in utility vehicles can result in equipment damage and injury to both utility personnel and the public. While commercial systems are available to warn the driver or automatically apply the brakes, these systems use expensive sensor technologies. A high price in the $2,000 to $5,000 per-system range shifts the cost/benefit analysis when considering a large fleet of vehicles.

This project is focused on the development of a lower-cost collision-warning system that could be implemented in a large fleet of vehicles at a lower cost.

Ultrasonic sensors provide reliable distance measurement at a range of up to 10 meters and a rate of 10 to 20 measurements per second, which may limit their use in high-speed applications. They have the advantage over other sensors – such as radar, lasers, or digital cameras – in that they are much lower in cost ($10-$20 per sensor), so several sensors can be used on a single vehicle. However, an ultrasonic sensor only provides a single measure of the distance to the nearest object in its field of view. Also, they cannot discriminate between types of objects, thus a tumbleweed can appear the same as a steel railing.

To compensate for this limitation, an additional low-cost sensor – such as a magnetic sensor – can be integrated to the system to reject warnings of objects that are likely of no harm. The detection and distance to an object in front or behind a vehicle can be used in an algorithm that considers the state of the vehicle (e.g., speed, turning, and road conditions). The algorithm can combine the known information, reject false warnings, and warn the driver to apply the brakes, or, when necessary, automatically apply the brakes.

Previously, the Transportation Research Board of the National Academies sponsored a program to develop a low-cost collision-avoidance system for overland trucks. The project demonstrated a method that combined an ultrasonic and magnetic sensor with a software algorithm to produce a prediction of the presence of a potential collision. The use of two different types of sensors allowed the system to reject false warnings, which can render the data unreliable.



Laboratory-based testing apparatus.

Deliverables

Deliverables will include a field-tested prototype system with sensors, a computer, and an algorithm and human interface. An assessment of the effectiveness of the technology and recommendations for future product development for gas-industry fleets will be present in a technical report.

Benefits

Experts note that through the arrangement of ultrasonic and magnetic sensors, a collision-warning system could be developed that would reduce the number and severity of collisions for low-speed scenarios in utility vehicles and at a fraction of the cost of other commercial products. The new warning system could be especially cost-effective when implemented in large fleets.

Technical Concept & Approach

Tasks for this project include:

- **Developing Project Input** – Collaboration with gas industry field personnel to identify the specific vehicles, environments, driving patterns, and other constraints that may contribute to the effectiveness of the technology.
- **Field Visits and Tests** – Initial field visits and tests to identify specific needs and special conditions for the technology that are unique to the gas industry.
- **Laboratory Development** – Bench tests by simulating field conditions under a controlled laboratory environment.
- **Field-Test Evaluation** – Field deployment of an object-detection system in coordination with industry partners to assess the effectiveness in real-world environmental conditions.

Results

The project team visited a field operations facility to gather information on the various types of vehicles operated. An industry survey was developed to gather additional information.

Laboratory development included the acquisition of a microcontroller hardware platform and an inertial navigation sensor. The team integrated the magnetic sensor with the microcontroller, wrote computer code to initialize the system and record data, and made an initial assessment of the performance of these components.

A bench-top test apparatus was built and tested that allows the sensors to be tested under controllable conditions. The apparatus rotates the sensors at a precise rate so that researchers can simulate the turning motion of a vehicle. The purpose is to rotate the sensors at a known rate and compare the sensor output to the known value.

In 2014, an algorithm was developed to measure the sensor inputs and compute an accurate estimate of the presence of an obstacle near the vehicle. The algorithm filters out noise and compensates the magnetic data for the turning motion of the vehicle.

The laboratory-based development included completing the assembly and testing of the experimental apparatus, using it to generate sensor signals in a controlled environment, and using the signals to test and tune the computer algorithm. In addition, a wireless user interface design was initiated that will allow the developers to monitor the performance of the system from within the vehicle cockpit.

Initial field tests included recording raw sensor signals during various common driving maneuvers in an automobile driving on surface streets at low speeds. The system was able to successfully record and save the sensor signals for 23 driving scenarios (e.g., driving in a circle, lane change, left turn, U-turn, passing a truck, and other maneuvers). This data will be used to tune the collision-avoidance algorithm and to validate that the laboratory-based testing apparatus generates data that is similar to signals recorded in the field.

Status

A complete set of laboratory-based testing scenarios is being designed and implemented using the experimental test apparatus in order to generate datasets that represent typical driving maneuvers in the field.

Up to this point in the project, the focus has been on the compensation of the magnetic sensor. Next, the ultrasonic sensor will be added to the sensor system and the magnetic signal will be fused with the ultrasonic sensor to produce a prediction of the presence of an obstacle near the vehicle.

Full-scale field testing will be conducted to test the system. During testing, feedback from the test engineers will be used to improve the interface and add or remove software features.

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RFID Testing Program

A testing program is under way to compare the performance and features of multiple radio frequency identification (RFID) and related technology solutions for locating and tracking underground gas utility assets.

Project Description

A variety of below-ground RFID asset tags are marketed to the gas industry, with several new RFID or similar technology products having entered the market in recent years. However, these products have a wide spectrum of carrier frequencies, varied burial requirements, and other differences.

In this project, researchers are evaluating a selected group of RFID technologies for use in the gas industry to allow operators to select the optimal system for specific applications for locating and tracking underground assets.

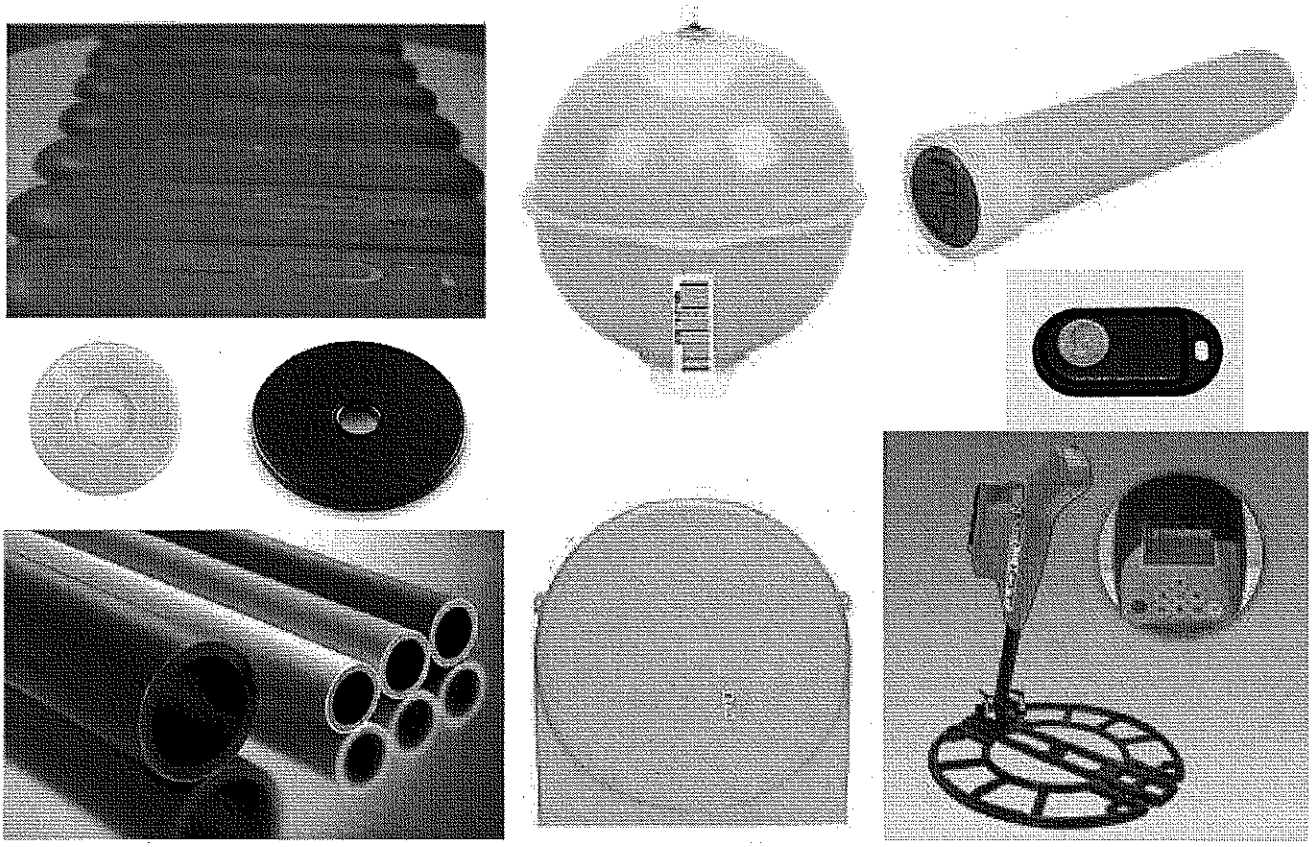
Testing will be conducted over a long time period to ensure inclusion of a wide range of field conditions and to assess degradation and weathering effects.

Deliverable

The deliverable of this project will be a report that presents the results of the comparative testing program of RFID technologies for tracking underground assets.

Benefits

As utility companies continue to increase the use of RFID marker balls, there is a need to understand the advantages and limitations of other technologies. The results of this project will provide operators with an understanding of the performance capabilities and functionality of various RFID solutions. Project results will allow users to select the most appropriate and cost-effective RFID technology for their applications.



A variety of RFID and related technologies are being evaluated.

Technical Concept & Approach

A technology search was performed to identify RFID technology providers that have solutions applicable for underground asset locating. Both domestic and international companies were included. Up to five RFID solutions will be selected for inclusion in the testing program.

A laboratory testing program will be designed to evaluate features such as distances of horizontal and vertical readability, impact of soil conditions, read/write speed, depth accuracy, data management and integration, and other capabilities.

Buried tests will be conducted to simulate expected field conditions as accurately as possible. Installation methods will be dictated by industry best practices and vendor guidelines. In an attempt to minimize variability in setups, a consistent level of backfill compaction will be applied in each scenario as guided by common industry practices.

A number of factors suspected to impact the performance of reading RFID markers will be examined during the testing program. These factors may include:

Device Specific:

- Carrier Frequency (brand specific)
- Battery condition (active devices only)

Installation:

- Installation depth and backfill material (sand or native soil) will be tested. All devices were installed in single vacuum-excavated holes and backfill was compacted as per standard industry practice.

Environmental:

- Soil conditions (moisture content)
- Temperature, humidity, UV exposure (for above-ground tags).

Tags will be tested on one or more dates separated by at least six months to determine if any noticeable signal degradation is observed.

Device performance and functionality will be evaluated under a range of realistic field simulations.

User impressions for ease of use of the various RFID tags and corresponding locate/reader equipment will also be important as few, if any, sponsors currently employ RF tags capable of storing unique serial numbers. Currently, RF tags without ID functionality are reasonably widely used by gas utilities, primarily for marking plastic gas lines.

Testing of RFID products to reader orientation will be performed in a laboratory setting in order to avoid an excessive number of excavations. The data collected during this testing can then be correlated to a smaller number of buried test cases.

The ability to evaluate multiple RFID devices in a small area will also be tested above ground. The manufacturers claim that several RFID devices can be placed close together and still be resolved and read individually. The minimum spacing that is called out by the manufacturer will be tested in an above-ground environment. The maximum number of tags that can be placed in a locale will also be tested.

Results / Status

In 2014, the majority of equipment required for the testing program was acquired and burial-site preparations were initiated. Devices have been installed at both above- and below-ground sites and testing is under way.

Consultations were conducted with product manufacturers. Recommended installation and operating instructions were reviewed and technicians practiced reading and writing to RFID tags.

Potential buried test sites were identified that include:

- 110-foot-long polyethylene pipes (two-, four-, and six-inch diameter) buried on an incline with one end roughly two feet below grade and the other at a depth of seven feet
- 60-foot-long steel pipe at fixed three-foot depth.

Early in the program, sponsors indicated a preference to also incorporate RFID tags designed for above-ground asset tracking.

The intention is to apply these to facilities such as surface valves, meter sets, regulators and other equipment.

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OTD Operations Technology Development

Improving Cybersecurity for LDCs – Needs-Identification Workshop

A workshop was sponsored to identify the short- and long-range needs for cyber-security-capability improvement for natural gas distribution companies. Through the workshop, researchers identified and prioritized the critical cybersecurity technology needs, assessment methodologies, and areas for improvement.

Project Description

Identity theft, theft of intellectual property, and system disruption and/or destruction are growing concerns for critical industry sectors, including the energy industry.

In 2011, the Energy Sector Control Systems Working Group issued an update to the Roadmap to Achieve Energy Delivery Systems Cybersecurity. The Roadmap provides a plan to improve the cybersecurity of the energy sector and identifies key challenges and barriers faced by the energy sector. The Roadmap points out that the need for solutions tailored to energy -delivery systems are still not well understood. The Roadmap further states that the energy sector must develop a strong business case to justify investments in cybersecurity.

In response, OTD sponsored a needs-identification workshop in April, 2014, to address cybersecurity issues for local distribution companies (LDCs) and identify the next steps needed to take to enhance the safety of natural gas operations.

Deliverables

The deliverables for this project include:

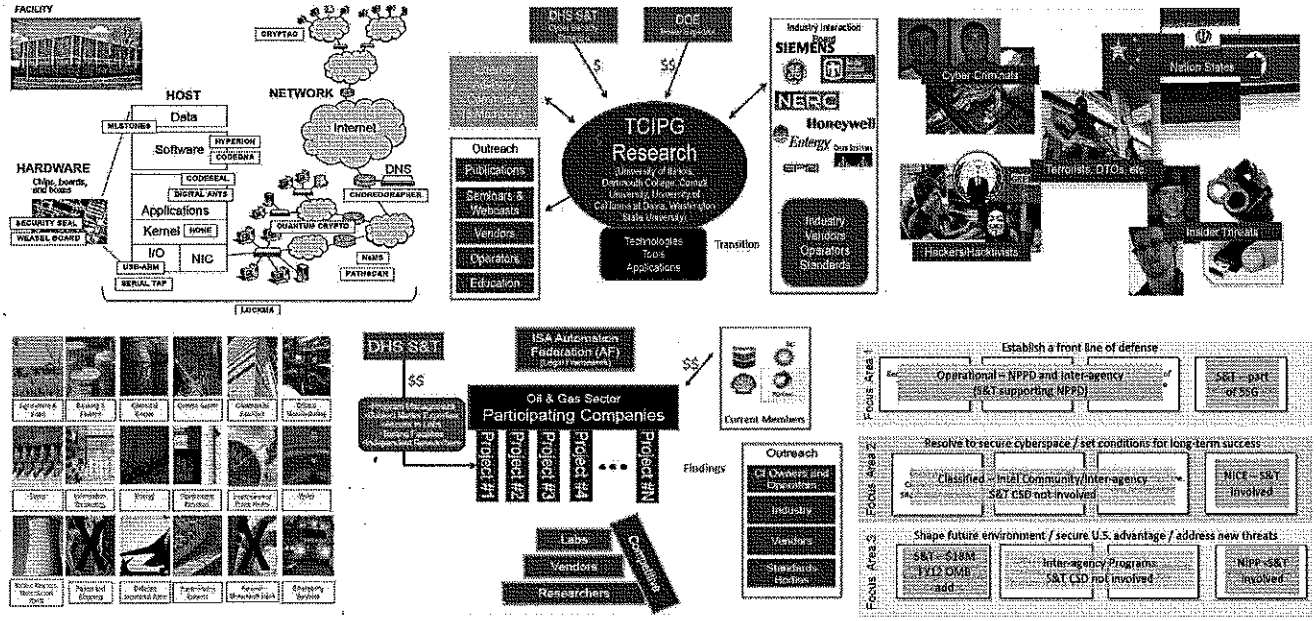
- A summary of cybersecurity lessons learned for the LDC community
- The identification of technical needs, areas for capability improvement, and potential next steps.

Benefits

This project will have the short-term benefit of allowing companies to establish a clearer understanding of their cybersecurity status and provide additional information to develop or strengthen a business case for a cybersecurity program.

Technical Concept & Approach

The needs-identification workshop was an invitation-only event bringing together the key operations, engi-



The needs-identification workshop provided attendees with a variety of critical information for improving the safety of gas distribution systems.

neering, information-technology, and research experts from the LDC community to identify and prioritize the critical cybersecurity technology needs and areas for capability improvement.

The workshop included presentations by representatives from the DHS, AGA, SRI International, and Gas Technology Institute (GTI).

The presenters provided information on the current status of cybersecurity for the energy sector as a whole, as well as actions being taken to address the needs of the LDCs. The presenters also provided information on best practices in other industries.

Results

The Improving Cybersecurity for LDCs – Needs-Identification Workshop was held on April 16-17, 2014, at GTI facilities in Des Plaines, IL.

Results and recommendations from the workshop include a six-step approach to immediately provide access to technologies available to transition to practice:

1. Attend a DHS Demonstration Day on technologies available to transition to practice
2. Develop a natural-gas-utility-specific cybersecurity training/education program
3. Evaluate regulations, standards, and organizations involved in cybersecurity
4. Develop a "roadmap" to address asset management
5. Evaluate partnerships with DHS, SRI, and others
6. Develop a proposal and program for cybersecurity R&D.

The following annotated list provides the top-priority items identified:

Training and Education

- Needs to be at all levels, start at the top, need buy in to be effective
- Use real examples and add criticality information to assets
- Cyber and safety should be considered together
- There is a need for education on data ownership
- Need a person in each area of business.

Asset Management

- Need to define what is an IT asset vulnerable to cyber attack and what is not
- Has to be active and automated with mapping
- Need the ability to track and trace assets through the use of a GIS
- In addition to inventory, relationships between devices are very relevant
- Updates for software odorizing could be compromised
- Life cycle management is challenging given that software needs to be updated at so many levels
- Current asset management is tied to financial valuation, not security.

Detection

- Differentiate between vulnerability vs. attack
- Need the ability to differentiate/prioritize attacks/ alerts as well as the need to know what to do about the event – reset, disconnect, isolate, etc.

Status

This project is complete. A detailed report on the cybersecurity identification-needs workshop was issued in May 2014.

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OTD Operations Technology Development

Tracking and Traceability for Transmission Pipe Materials

Efforts are under way to develop standards, guidelines, and software for the tracking and traceability of gas transmission pipeline assets. The results of this project will provide the industry with a standardized approach for capturing data through an electronic database and unique identifiers applied with barcodes.

Project Description

Today's gas pipeline operators are faced with the challenge of creating records that are traceable, verifiable, and complete.

In response, this project is focused on the development of a standard approach for collecting data from pipe and coating mills, storing this information in asset-management systems, and automating the capture of data in the field.

Through OTD's Intelligent Utility Program, a software platform was built to assist the industry in eliminating the use of paper-based data-collection methods. An application to capture new installation data – including tracking and traceability information through ASTM F2897 – through the use of barcoding and GPS was developed specifically for gas distribution assets. This software was tested through full-scale pilot projects. This new project builds off of the existing system and will create an application specific to gas transmission assets.

In another OTD initiative, an ASTM standard for an algorithm is being developed to create a unique 16-digit identifier for transmission assets though base-62 encoding. Since data captured in the 16-digit identifier will be limited and will not include all data necessary for complete tracking and traceability, this new initiative complements the existing project by facilitating the capture of *all* important pipe and mill data through an electronic database. Once the ASTM standard for transmission assets is published, purchasing specifications, barcode specifications, and software will be updated to require the inclusion of the ASTM identifier.

The results of this project will provide the industry with a standardized approach for capturing pipe and coating data from the mill through an electronic database and unique identifiers applied with barcodes. Software will be developed to automate the process of retrieving mill data through the unique identifier and incorporating select data into GIS feature attributes. The technology will automate the process of capturing essential pipe-material information in the field to create high-quality GIS records.

Deliverables

The deliverables for this project include:

- A data requirements report
- Purchasing specification guidelines
- An electronic data standard for vendors
- Barcode specifications
- A software application
- Webinars and demonstrations.

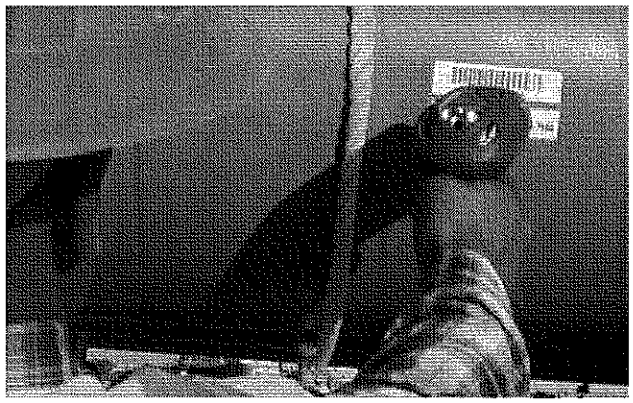
Benefits

The ability to automate the process of capturing and storing tracking and traceability information for transmission pipe will improve data quality and reduce risk.

Data quality will be improved by using electronic records and barcode scanning to capture data essential for integrity management. Eliminating manual, paper-based data collection will reduce the occurrence of human errors when capturing and transferring data into an asset-management system.

In addition, operators will have access to pipe and coating data that can be used for threat identification and risk modeling as part of integrity management.

The published standards will provide operators with consistent information in a consistent format from



manufacturers to reduce the cost and complexity of creating traceable, verifiable, and complete records.

Technical Concept & Approach

This project includes the following activities:

- The research team will develop a set of pipe and coating data requirements for vendors. This will including mill test reports, heat numbers, physical and chemical properties, and other attributes. Operators' existing data requirements for vendors and industry standards will be reviewed and used as a basis for the new requirements. Researchers will engage pipe and coating mills to jointly develop the data requirements and a template for reporting important coating information.
- The research team will develop purchasing-specification guidelines requiring vendors to publish data in an electronic database that operators can access remotely. The specifications will also include a requirement to create a unique identifier to link a pipe segment to the appropriate records in the database.
- Once data requirements are defined, a data standard will be developed to ensure that the definition and format of electronic databases published by vendors conform to operator accessibility requirements.
- A GIS data model for specific commercial platforms will also be developed and submitted to the respective organizations. The goal is to modify existing data models to include fields for the new data requirements so that tracking and traceability data can be directly integrated into GIS.
- The research team will develop specifications for pipe and coating mills for barcoding assets with unique identifiers. The unique identifiers will link to the electronic database published by vendors to retrieve pipe and coating information. Several barcoding placement options will be evaluated with vendors to select the most feasible for implementation. Examples include placing barcode labels on the interior of the pipe wall, exterior of the pipe wall near the end where coatings are not applied, or on an end cap. The barcoding methodology will address issues such as: barcoding under/over coatings, barcode durability, spacing and orientation, and format.
- Software will be developed to collect tracking and traceability data for transmissions assets during new installations. The application will be an extension of the Asset Lifecycle Tracking software developed in a previous OTD project. The software will read the barcode and retrieve select data from the vendor's electronic database. Select data will include yield strength, wall thickness, diameter, and other data. The retrieved information will be stored as GIS feature attributes.
- Researchers will perform testing and validation of the software's performance. Two demonstrations of the software will be performed.
- Efforts will be conducted to standardize forms and technology to capture field welding and field-applied coating data.

Results / Status

A preliminary set of data-collection requirements was created and updated based on feedback.

In Phase 1 of the project, interviews were conducted with pipe manufacturers and representatives from other industries to gather information on pipe tracking and traceability, including information about current practices for barcoding and labeling pipes and fittings designed for high-pressure transmission systems.

In the current Phase 2, researchers are investigating barcoding technologies that may be able to support the harsher environments of a steel-pipe manufacturing facility, including a method for placing permanent, individually traceable, public-domain data symbologies onto or into parts manufactured under harsh conditions. The process uses disposable, pre-encoded stencils to create permanent barcodes directly onto a part at the point of manufacture or afterward as a retrofit. The barcodes are resistant to abrasion, corrosion, UV, and can maintain their integrity through heat treatment and other aggressive manufacturing processes that would destroy paper- and Mylar-based barcodes.

Efforts are under way to combine a commercial technology that collects and stores pipe and component data in a web-based database with OTD's Intelligent Utility technology to provide a complete solution.

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OTD Operations Technology Development

Battery- and Electric-Powered Tool Evaluation

To help ensure the safety of routine gas industry operations, research is being conducted on battery- and electric-powered hammers, drills, and other devices to determine the safety of using these tools in locations where natural gas may be present.

Project Description

In this project, research is being conducted to determine the safety of using battery- and electric-powered tools in locations with the potential for natural gas concentrations in the flammable range.

The impetus for the project was a report of an electric drill igniting natural gas while drilling through a foundation wall. This project will help to determine whether the ignition was an isolated incident, or whether there are general safety issues with using battery- and/or electric-powered hand tools for natural gas operations.

Deliverables

The deliverables include:

- A report on the technical and safety issues of using battery- and electric-powered tools in potentially flammable conditions
- Recommendations on the next steps for research
- A Phase 2 research proposal (if applicable).

Benefits

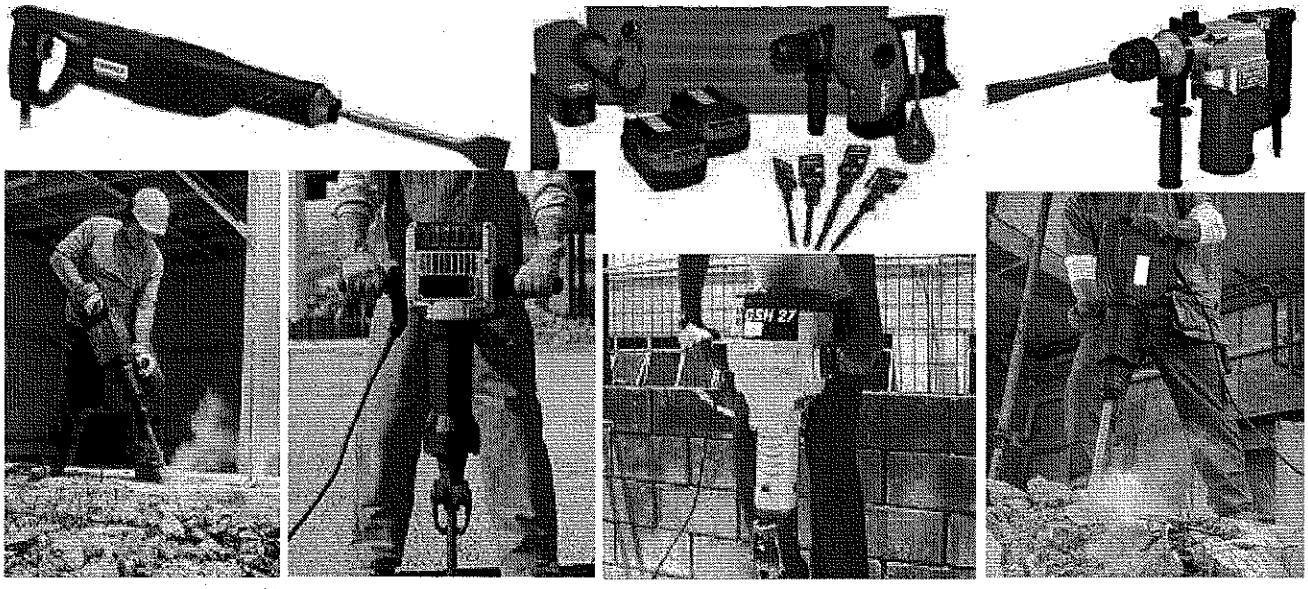
In routine operations, natural gas utility crews use a variety of battery- and electric-powered tools. Because there is no connection to a compressor, battery- and electric-powered hand tools are more convenient to use than pneumatic tools and can provide productivity improvements at a lower cost.

In recent years, new tools that require data-collection/ documentation (such as automated butt-fusion equipment) are powered with batteries or 110 volts.

Occasionally these tools must be operated at locations where natural gas in the flammable range is present. The industry needs to know if the use of these tools in these environments creates a safety risk to employees and the general public.

Technical Concept & Approach

Some electric hand tools use motors with brushes, while others use brushless connections. These designs pose different safety risks, especially as the tool wears/ ages, and both will be addressed.



Research seeks to answer a wide variety of questions, including:

- Are sparks created during normal operation?
- Does changing a battery pack or plugging into a 110-volt power source create hazards?
- Do battery packs with a built-in current limiter prevent ignition?

The technical approach divides the project into phases with go/no-go decisions at the end of each phase. Phase 1 will define the issues and recommend the best course of action. This will include:

- Surveying existing information on intrinsic safety and explosion-proof requirements
- Reviewing procedures published by organizations such as the National Electrical Code and The National Fire Protection Association.
- Contacting manufacturers to obtain feedback on potential hazards for using tools in flammable natural gas mixtures and to determine their willingness to certify their equipment in such situations.
- Collecting information on motor types and if sparks are generated
- Collecting information on battery types and built-in safety measures
- Collecting information on previous studies on tool safety.

These inputs will be analyzed to identify potential hazards and potential solutions.

Selected tools for research will be visually inspected for signs of sparking during normal operation. This includes sparks internal to the body housing and during battery-pack exchange and plugging/unplugging to a receptacle. Follow-on phases would address the issues raised in Phase 1. This may include testing tools in flammable environments.

Results

Research and testing of safety capabilities are being directed towards motor design, discharge methods, and electrode locations of tools commonly present on worksites.

A survey was generated to gather details regarding the tools used in the gas utility industry.

Safety requirements from several organizations were reviewed.

Initial Findings:

- Industrial electric-powered tools are not and cannot be declared intrinsically safe
- Spark gaps internal to the working motors of these devices can be sufficiently minimized to eliminate the possibility of natural gas ignition
- Utilities are interested in obtaining alternative devices to enhance their ability to complete work.

An investigation into spark-ignition requirements provided the experimental setup criteria necessary to safely test the spark-generation capabilities of power tools.

Status

Visual spark testing on a range of brushed and brushless hand-held battery-operated power tools is under way. Each product is utilized in a number of normal operation modes while carefully observing brush faces or other internal components capable of generating sparks. Where necessary, tool housings have been cut away to provide direct line of sight of spark sources.

Findings from current testing will establish which products, if any, should be subjected to additional testing in methane environments.

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OTD Operations Technology Development

Residual Gas Removal – Identifying Technologies, Limitations, and Best Practices

Several technologies are available to address the removal of potentially hazardous residual gas that can collect underground following gas leak repairs. In this project, research is under way to identify and evaluate the best technologies and most-effective industry practices.

Project Description

Underground gas leaks can result in substantial quantities of natural gas trapped in the soil surrounding the leaking buried gas pipe. Gas saturation of the soil near a leak creates a challenge to accurately pinpoint and repair gas leaks, and can migrate horizontally from a buried service into nearby homes and commercial structures, posing a considerable threat.

The time required for residual gas to naturally vent can be extensive and problematic in emergency situations. This is dictated by soil types in addition to the extent and duration of the leak prior to repair. Furthermore, the presence of residual gas can hinder the ability to accurately gauge if a leak has been adequately addressed.

The presence of residual gas may cause extended evacuations of residences and commercial establishments, and require further verification to ensure no additional leaks are present. The lingering odor may also generate continued leak reports from passersby.

A safe and timely means to extract in-place gas during leak pinpointing and subsequent to leak repair is required to comprehensively address leaks, improve repair status assessments, improve public safety, and reduce the likelihood of further leak reports from the general public.

A range of options for eliminating residual gas exist and some have been used for many years. The industry standard technique is to utilize a bar probe to establish two-to-three-feet-deep vent holes to allow the gas to vent naturally, the use of industrial air movers on the surface, or the use of a compressor-driven aspirator inserted into a bar hole to assist in the removal of the gas. Another option explored by a few utilities is the Vapor Extraction Unit (VEU), which essentially vacuums residual gas out of the soil, dispersing it in the atmosphere, and improving the rate of gas extraction above the traditional venting technique. The VEU incorporates sensors to automatically detect methane levels approaching the lower explosive limit (LEL). An alarm is sounded if methane levels approach within 25% of the LEL, and the engine is automatically shut off at 50% of the LEL. The issue raised by the VEU users is the reduced efficiency when fresh air is required to be mixed with the suction of gas to keep the methane levels from approaching 25% of the LEL.

Studies are being conducted into the possibility of using a natural gas engine to draw residual gas out of the ground and combust it, reducing greenhouse-gas emissions and avoiding the efficiency concerns with start/stop operation of the VEU when having to address high levels of methane.

This project is designed to identify technologies, assess their limitations, and document best practices for safe and effective dispersal of residual in-ground gas at leak sites. The impact of environmental conditions, such as the volume and area of gas requiring extraction, soil conditions (e.g., moisture content and type) and presence of pavement, etc., on choice of approach will be important.

Deliverable

The deliverable for this project will take the form of a final report summarizing the various residual gas-extraction methodologies identified, typical performance, along with information on limitations or safety concerns with their use in the field.

Benefits

A means to safely and quickly remove residual gas from leak sites provides improved public safety and ensures that leaks are comprehensively addressed.

Technical Concept & Approach

Utilities will be surveyed to determine current practices for removing residual gas at leak sites. Field trips to various utility leak-repair sites will be conducted in order to observe current residual-gas mitigation strategies in action. Procedures currently employed will be documented and evaluated for potential safety and/or efficiency improvements.

An additional task for controlled side-by-side evaluations of leading technologies may be considered following this Phase 1 effort.

Results

A technology survey was prepared for the project sponsors to obtain input on current practices for removing residual gas, equipment used, conditions which may impact residual-gas-removal efforts, extraction rates, time required to complete residual gas extraction, and other information. The responses appear to indicate that the residual gas issues are less frequently encountered than anticipated, and highly dependent on local geology and duration of leaks prior to discovery and repair.

Information on the VEU technology was obtained from the manufacturer and users. The VEU is designed as a less costly alternative to the dedicated vacuum truck for residual-gas-removal job. This unit's specificity and cost may explain the slower-than-anticipated uptake in the industry. Sporadic need for residual-gas-removal equipment often results in this device used for leak-pinpointing applications. Purgers and air movers are far more commonly used for residual gas extraction.

West coast utilities appear to face greater potential challenges due to wet soil and/or high permeability soils enabling larger quantities of natural gas to be contained below ground under pavement.

No single selection criteria was singled out as being highly influential when weighing various residual gas extraction options. It is apparent that despite high-extraction-rate options marketed for this application, most companies continue to use lower-cost methods such as bar holes, aspirators, and vented manhole covers.

One utility has encountered issues with high VOC content in extracted residual gas and mitigates this issue by burning gas in an internal combustion engine.

A field trip was conducted with assistance from an utility to view the residual gas removal operation in the field. Key findings were:

- Residual gas often migrates along buried utilities, especially telephone lines. The use of vented manhole covers was strongly advocated. Telephone lines can provide paths for gas migration hundreds of feet from the active leak, complicating pinpointing, and can be a means of ingress for gas into buildings and basements.
- The presence of steam lines near a gas repair necessitates use of high-temperature epoxy for long-term integrity of the repair.
- There is a potential risk that any gas extraction may draw gas from an active leak toward residential and commercial structures, posing potential hazards. It is therefore important to monitor gas during operation of the extracting equipment and shut-off the extraction device and relocate it should concentrations rise at monitoring points.
- Aerators can be a very efficient and low-cost gas-extraction technique. These devices can also effect quick extraction of water from manhole and gas-valve boxes.
- Aerators are not permitted for use in situations where extracted gas cannot easily disperse into the atmosphere. For example, locations below scaffolding erected to protect pedestrians from falling debris and tools while overhead construction is undertaken.

Status

Researchers are reviewing a variety of information gathered during the project and preparing a Final Report summarizing results.

A few project sponsors have confidentially disclosed their current written procedures for addressing residual gas mitigation. Opportunities to view alternate or novel extraction techniques have proven elusive to date. The infrequent usage of equipment and short-notice scheduling continue to hamper efforts. It is unlikely much of value can be learned from further first-hand observation compared to simply reviewing written procedural documents.

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ENVIRONMENTAL, RENEWABLES & GAS QUALITY

Research in this area provides technical solutions for various gas industry concerns.

Results from these efforts help companies to reduce operations costs, minimize environmental impacts, and more cost-effectively comply with regulations.

Significant initiatives are addressing greenhouse-gas issues, water cleanup technologies, and odorant fade issues. Additional efforts include the development industry guidance documents, improved methods for estimating pipeline leak emissions, and the investigation of trace constituents in fuel gases.

Natural-Gas-Quality Survey: Trace Constituents

This research project is aimed at developing information to help introduce renewable "green" sources of energy into the natural gas pipeline. Information on trace constituents will facilitate a utility's ability to assess the potential to use gas generated from wastes and other sources.

Project Description

Natural gas – as well as renewable gas from wastes and other sources – contains specific properties and compositions which are complex and a function of many factors, including: 1) resource supply characteristics, 2) level of gas processing, and 3) degree of gas co-mingling prior to and during transportation.

In recent years, significant research has been conducted to analyze and characterize renewable natural gas (RNG) from dairy-waste conversion, landfills, and wastewater-treatment facilities. Through these projects, natural gas utilities have developed a greater understanding of renewable gas products and the ability to engage in productive dialogs with potential vendors of biomethane (cleaned biogas or RNG).

In previous research, samples of RNG products were analyzed for major components as well as trace constituents. Results were used in the development of guidance documents for the purposes of assisting natural gas companies in evaluating RNG products. The profiling was extensive; however, the sample set was limited (less than 100 samples total for all RNG sources from a limited number of sites).

This project is aimed at developing an improved understanding of trace constituents in natural gas to make a meaningful comparison with renewable and unconventional fuels. Without this information, some companies have been hesitant to accept these alternative fuel products into their systems.

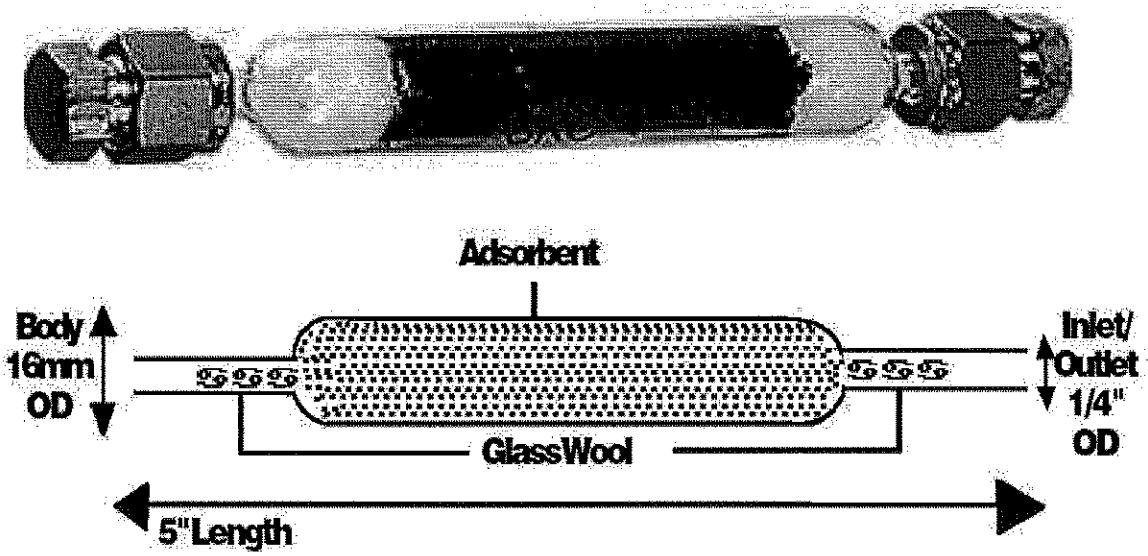
To address the issue, researchers are conducting an analytical survey of trace constituents in natural gas supplies throughout North America.

Through this research, the industry will develop an enhanced understanding of the variety and concentrations of organic, inorganic, and biological constituents in currently available natural gas supplies.

This survey entails sampling and analysis of natural gas samples only.

Activities are divided in two phases.

Phase 1 focused on data collection, information dissemination, and project development. Sample collection/analysis is being conducted in the current Phase 2.



Sorbent tube used for radon sampling.

Deliverables

The overall goal of Phase 1 of this project was to fully scope and understand activities to be executed in the Phase 2 sampling activities.

Phase 1 deliverables included: 1) a definition and consensus specific to the use of the information gathered as part of the overall project, 2) establishment of an oversight committee with responsibilities discussed and determined, and 3) detailed scoping and preparation for all Phase 2 activities, including a definition of the sampling sites, sampling sets, analytical profiling, field-crew assignments, data-reporting requirements, and Phase 2 costing.

Benefits

Results of the research will help increase the ability to employ "green" sources of energy and demonstrate an environmental commitment.

The purpose of the overall study is to more fully understand the trace constituent profile in natural gas so that more accurate comparisons of alternative fuels with existing natural gas supplies may be facilitated.

Technical Concept & Approach

Initial activities in Phase 1 involved interactions with project sponsors and others to develop a mechanism by which the data collected in this project can be effectively disseminated and shared throughout the natural gas industry and with other interested parties. To this end, an oversight committee was assembled to assist with industry communication and project planning.

In Phase 1, the project team developed plans for sampling activities in Phase 2. There are numerous options for natural gas sampling points, and efforts were made to determine the most appropriate natural gas sampling program (including variables such as the number of gas samples to be collected and the size and function of sampling teams).

Natural gas sample locations will be determined and access to sampling points will be arranged. The objective is to decide upon the most useful sources for natural gas testing at points which are most representative of the conventional and unconventional supply sources throughout North America.

In Phase 2, investigators will attempt to sample a wide variety of natural gas supplies from differing locations throughout the United States and Canada.

Results

Sampling was performed and all samples analyzed for the Marcellus and Devonian shale gas sites. Data sets were included in a report to project sponsors.

The research team experienced some difficulty in obtaining active field test sites, and some companies are reluctant to provide gas samples. In response, contact was initiated with several producers and pipeline companies to expedite sampling.

The radon collection media was modified to concentrate the samples and keep the sampling volume lower in order to eliminate potential interferences.

Several distribution companies offered access to collect gas samples, the only concern being able to identify the source of the gas.

Information on the project was presented at the Gas Processors Association meeting in San Antonio, TX, in April, 2013.

Sampling activities slowed in 2014 due to the difficulty in obtaining test sites. Contact was made with alternate producers and pipeline companies to expedite sampling.

Improvements were made to the mercury-analysis technique.

Several sponsors requested that researchers include hydro-fracturing chemicals in the trace constituents list. A number of these hydro-fracturing chemicals have significant vapor pressure at room temperature. Some of the chemicals are volatile enough that they could be present in the gas phase.

Status

The project team is targeting producer companies who seem to be more willing to grant access to sampling sites. In addition, discussions are ongoing with the Canadian Energy Partnership for Environmental Innovation to possibly share data and sampling sites.

Statistical analysis for the all collected gas samples is being performed.

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Development of a Practical Pipeline Operator Guide to Manage Odor Fade Issues

Research was conducted to help determine the variables that can contribute to odor fade in natural gas. The results will be presented in a guide to aid pipeline operators in managing their systems and maintaining safe operations.

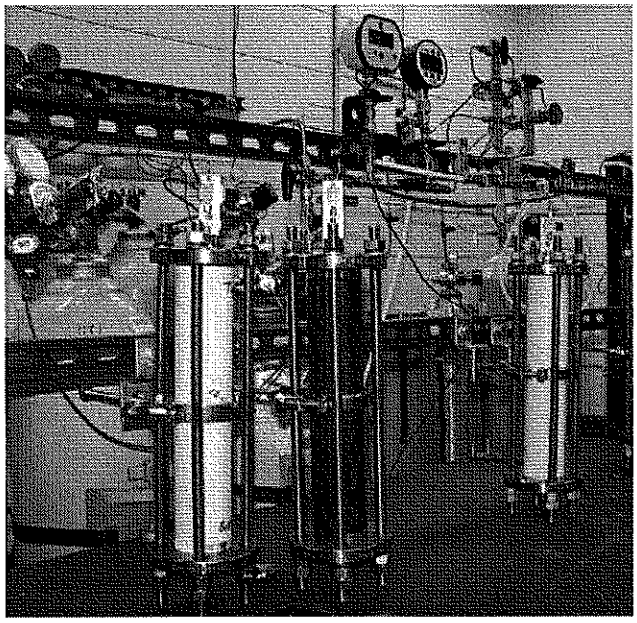
Project Description

Loss or change of odor in natural gas is usually attributed to two different causes: odor fade and odor masking. These are two distinct/separate issues requiring separate research efforts.

Odor fade is the actual loss of odorant by chemical or physical processes, including adsorption/absorption onto internal surfaces of metal or plastic pipe or the chemical reaction of gas odorants with pipeline contaminants and/or trace constituents in the gas stream.

Currently, supplemental odorant injection and control is, for the most part, based on a non-technical approach. Anecdotal information forms the basis of most current guidelines and the "Rule of Thumb" approach is also employed, where some pipeline operators use an odorizing "cookbook" with very mixed results.

This project focused on research, model design, and the validation of issues associated with natural gas odor fade in an effort to provide a "Practical Pipeline Operator Guide" to manage odor fade issues associated with typical gas system operating conditions and materials of construction.



Laboratory static testing of pipe specimens.

The research team developed a methodology to validate combinations of gas, system, and material scenarios. Ideally, the project results, guide, and validation data will also be incorporated into the next update of the American Gas Association (AGA) Odorization Manual. Although the AGA Odorization Manual highlights some potential fade causes, currently it does not provide specific guidance or solutions to manage the odor fade problem.

Odor masking (not the subject of this research effort) is the change in *perception* of the characteristic gassy smell of odorants present in natural gas.

Deliverables

Deliverables for this project include:

- **A Practical Pipeline Operator Guide** to manage odor fade issues for a particular number of subsets of the combinations of gas, system, and material variables
- **A Tested Methodology** to validate combinations of gas, system, and material scenarios.

Benefits

- Reduction in the number of odorant-related incidents and resulting litigation
- Improved safety, public relations, and regulatory compliance, including Distribution Integrity Management Program compliance
- An improved ability to promote the acceptability of renewable gas sources by quantifying the impact of trace constituents (if any) on odorants within gas supplies
- The assured continuity of safe pipeline operations as the loss of experience and expertise (due to the retirement of odorant experts) impacts the industry
- Reduction in operating costs for odorant programs through the optimization of supplemental odorant-injection rates.

Technical Concept & Approach

This project included the following tasks:

- Definition of Project Boundaries, Literature Search and Dissemination of Results
- Identification and Definition of Variables that Affect Odor Fade
- Prioritization of Variable Effects
- Development of a Simplified Odor Fade Model Based on Key Variables
- Validation and Refinement of the Model with Specific (Select) Physical Testing
- Development of an Operator Guide.

Results

A preliminary literature survey reviewed the availability of current and historical data. The review found that the primary causes of odorant fading are: 1) surface interactions of odorants with different pipe materials, 2) scrubbing or dissolution by condensates or cleaning fluids, 3) chemical reaction/oxidation of odorant with other components in the gas stream, and 4) other system state variables.

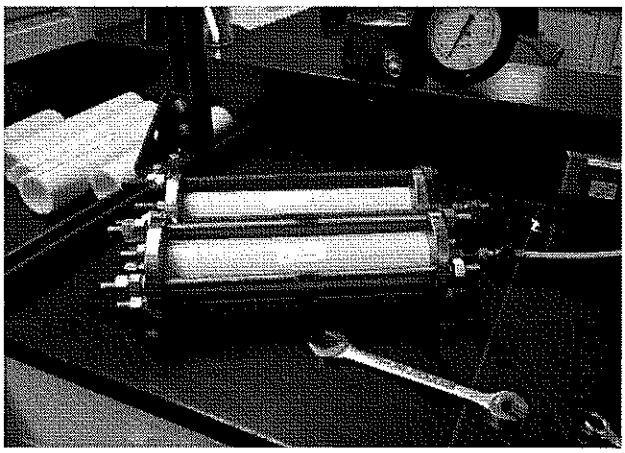
To obtain specific detailed data from project stakeholders, survey questionnaires were designed for pipeline odor-fade events, preconditioning, and supplemental odorization.

Laboratory batch or "static" testing was conducted to obtain data regarding odorant loss under various selected conditions of gas composition, temperature, and pipe material. Containers used for testing odorant loss consisted of sections of plastic and steel pipes and two inerted stainless steel sampling cylinders. Analysis of sulfur compounds was by gas chromatography with a pulsed flame photometric detector.

Results confirm expectations that the variable that most impacted t-butyl mercaptan concentration in the gas phase was the presence of rust on the pipe surface. The concentration of t-butyl mercaptan in a steel pipe fades very rapidly until active sites are quenched.

Testing with trace contaminants in the inerted reactor were reported with a statistical evaluation of the data.

Field data was used to obtain some correlations with system variables. An increase in gas pressure appeared to induce increased absorption and adsorption, and concurrently an increase in oxidation from surface rust induced odor fade. Pipe diameter also showed some correlation as would be expected, with larger pipes requiring more odorant to be added.



Plastic pipe test specimens.

Research found that there is the potential for a significant number of reactions to occur in an odorized pipeline gas system. In addition to forming disulfides and iron sulfides (mainly), mercaptans might also decompose or react with trace gas processing constituents. Results indicate that by using the technique of injection of highly odorized gas, some 0.2 to 0.4 mL/ft^2 of odorant addition was required to achieve full conditioning of six-inch-diameter pipe. Nearly double the odorant addition rate was required when using the continuous liquid addition technique.

Phase 1 of this project was completed in 2013. A Final Report was issued in December 2013.

Status

The information gained in this project was used to prepare a suggested revision to the AGA Odorization Manual, last revised in 2000. Although the current manual highlights some potential fade causes, it does not provide specific guidance or solutions to manage the odor-fade issue. The revisions provide information on chemical reactions, adsorption, and absorption. Practical field information on "pickling" (the addition of extra odorant), the interactions of trace constituents, soil adsorption, odor masking, and olcactory sensitivity and fatigue was also provided.

A Phase 2 for the project is being proposed to conduct laboratory testing, construct a set of flowing steel pipes to simulate additional field-test data, and validate a model.

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Improving Methane Emission Estimates from Underground Pipeline Leaks

In this project, research is being conducted to develop a technical approach to quantify methane emissions from gas mains and service pipelines. The new method will provide an increased level of accuracy and an improved ability for utilities to comply with future regulations.

Project Description

Due to the growing concern over climate change and greenhouse gas (GHG) emissions, the natural gas industry is developing more accurate emission-estimation methodologies.

In this project, research is addressing methodologies for quantifying fugitive and methane emissions.

In Phase 1 of the project (completed in 2010), researchers assessed existing methodologies and proposed a technical approach for measuring leak flow rates at their aboveground state. Measurements of aboveground methane flow rates were performed in controlled tests where gas leaks were captured at the surface and measured using the Hi Flow Sampler™. The results of the tests showed good correlation with the applied leak rates from the pipes.

Phase 2 of the research program (completed in 2013) included field tests at utility sites with known leaks to evaluate surface measurements in various site conditions. The measurements correlated to below-ground measurements in isolated pipe segments.

Phase 3 of the project (completed in 2014) focused on performing field measurements to establish the emission factors for emissions from cast-iron and unprotected steel pipes.

The current Phase 4 involves on the implementation of the project results and improving estimates for activity data.

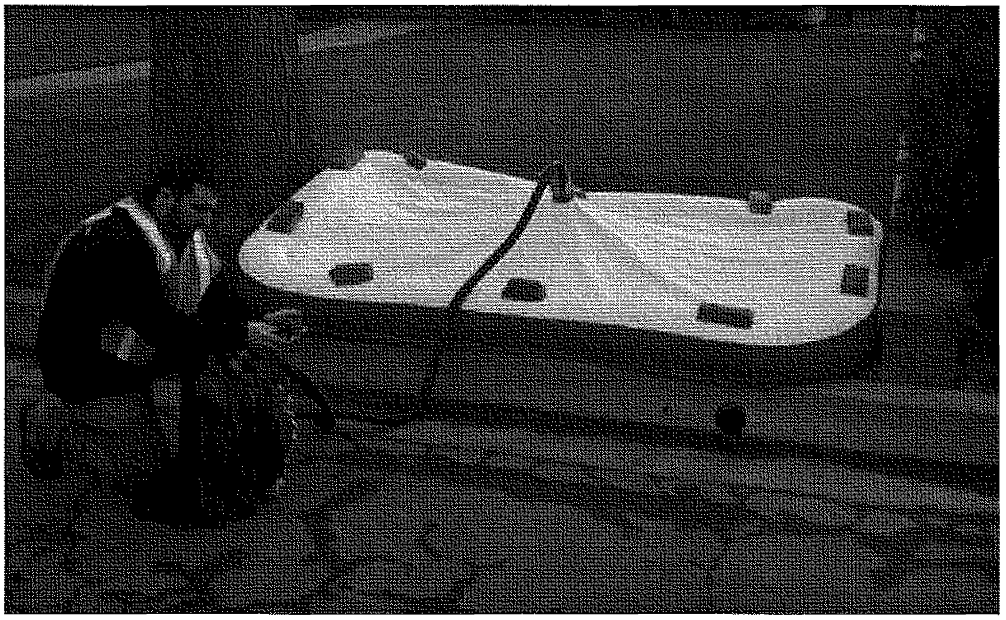
Deliverables

Deliverables include updated emissions factors for methane emissions from plastic, cast-iron, and unprotected steel pipes, and a new methodology for more accurate estimation of methane emissions using aboveground measurements of pipe leaks.

Benefits

Results from this project will directly improve a company's ability to:

- Provide accurate, cost-effective, and manageable emissions management



Capturing the gas leak area for rate measurements.

- Satisfy regulatory requirements
- Implement methodologies that can be integrated with existing gas-distribution software and system tools.

With the new methodology, records are updated regularly using a combination of various technologies to search, pinpoint, and classify leaks. The estimates of activity data from utility inventory will also allow for the development of custom-made emission factors that address company-specific infrastructure characteristics.

Technical Concept & Approach

This project is being executed in four phases:

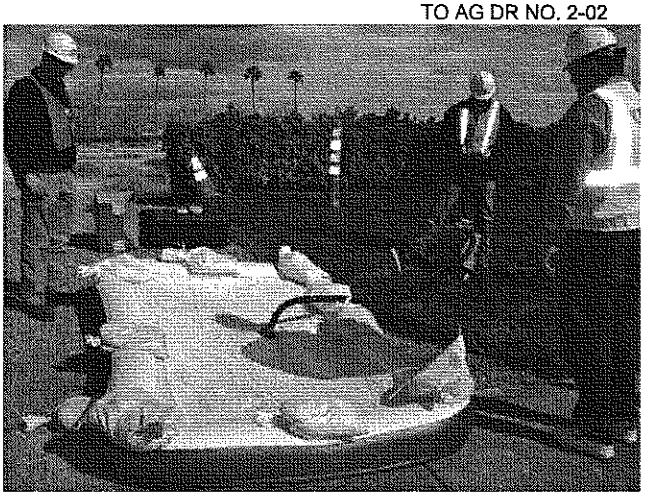
- Phase 1: Technical Approach and Methodology Assessment *(Completed)*
- Phase 2: Field Measurement of Emission Factors of Plastic Pipelines *(Completed)*
- Phase 3: Field Measurement of Emission Factors of Steel and Cast-Iron Pipelines *(Completed)*
- Phase 4: Implementation *(Ongoing)*.

Results

In Phase 1 of this project researchers assessed the previous methodologies used in estimating leak rates from below-ground pipelines and proposed a technical approach for surface measurements of the flow rates at leak sites. Above-ground measurements were performed in controlled tests where gas leak areas were covered and the leak rates were measured using the Hi-Flow Sampler device. The results of these tests demonstrated the applicability of using the Hi-Flow device to measure gas flow rates at the surface and provided a framework for the tests at utility sites in the subsequent phases.

Following the development of a testing methodology, 30 tests at utility sites and field-testing facilities were performed. Leak measurements were taken at each site to cover the various factors associated with leaks in polyethylene (PE) pipe. The field measurements consisted of identifying the leakage areas using the standard utility leak-detection tools and the Hi-Flow device in measuring gas flow rates in the covered leak areas at the surface.

The results validated the Hi-Flow surface measurements and provided an updated estimate of the Emission Factor for the PE mains. Most of the PE leaks at the utility sites were characterized by low gas-concentration readings at the surface and low emission-rate measurements.



The field measurements provided a representative distribution of the full range of the gas concentrations in the utility records.

Most of the leaks in the mains were characterized as joint leaks, located at the joints between the main lines and the service lines.

Phase 3 involved the application of the developed field-testing procedures to obtain similar emission factors for cast-iron and unprotected steel pipes. Leak measurements were performed in California, Alabama, and Illinois, and subsequently analyzed.

In 2014, additional testing was conducted at sites in New England. Surface measurements were taken on several cast-iron leaks and one unprotected steel leak was measured; and one below-ground measurement was taken.

Plans were made to conduct a field test in Texas.

Status

Phase 4 is under way to enhance the accuracy of fugitive methane emissions estimates from natural gas underground pipelines and integrate the results with current industry practices and regulations.

An analysis of data gathered from field tests will be presented in a Final Report.

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Gas Quality Resource Center

A web-based Gas Quality Resource Center is being established to provide information and expertise on issues surrounding gas quality, interchangeability, and potential implications from the introduction of new supply sources into gas transmission and distribution systems.

Project Description

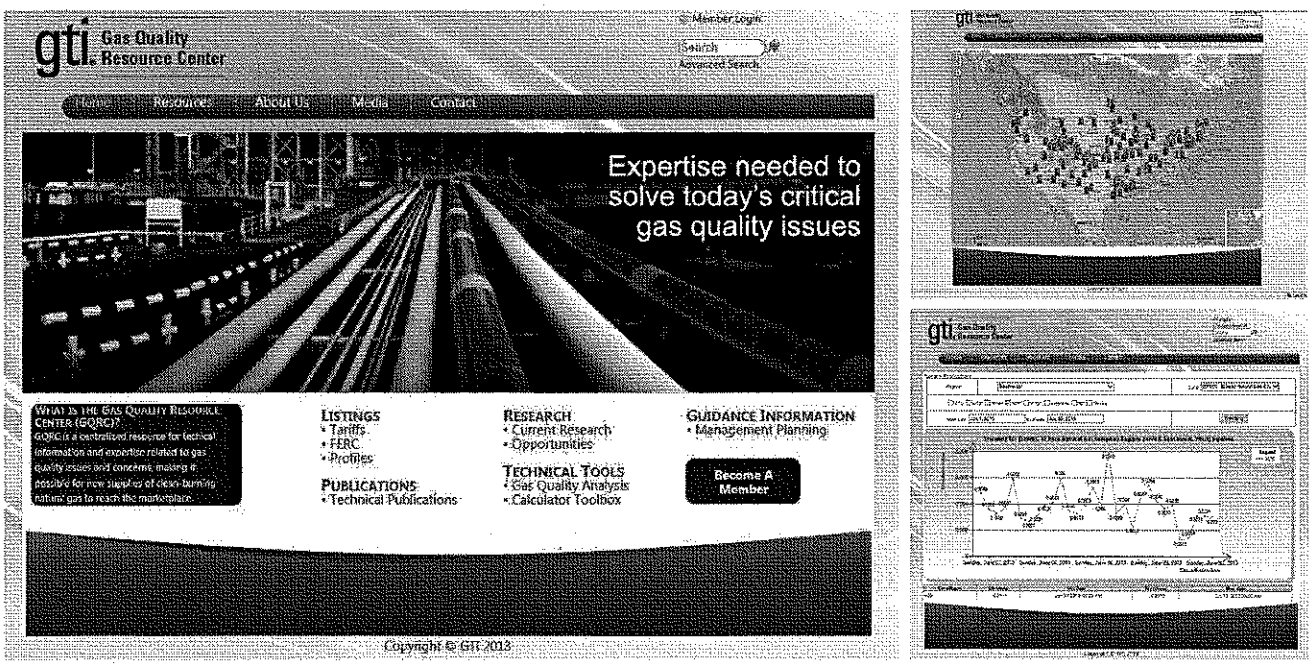
Natural gas transmission pipeline and distribution companies are increasingly being asked to evaluate opportunities and accept new supply sources into their systems. This situation has created a marked shift from traditional gas-supply flow patterns – a trend that is expected to continue as these new supply sources (e.g., shale gas production and the introduction of renewable gas) are brought to market.

Along with this change in supply comes a change in the gas composition. Traditional supplies and gas compositions that have been relatively stable and consistent for decades are now beginning to change, and stakeholders are looking to ensure that these compositional changes will not have an adverse effect on their gas-delivery infrastructure or their customers' end-use applications.

Foundational knowledge in gas quality and interchangeability is readily available. A study was conducted through an industry collaborative effort that resulted in the 2005 White Paper on Natural Gas Interchangeability and Non-Combustion End Use by the NGC+ Interchangeability Working Group. This document contains Interim Guidelines for Gas Interchangeability that have been widely used; however, the White Paper also recognized that there are significant informational or data gaps that require further research. Additionally, the NGC+ report does not address renewable gas at all.

Since the NGC+ report was published, the natural gas industry has generally taken a localized approach in understanding end-use performance and infrastructure issues through the initiation of isolated research efforts to address these increasingly global, systemic issues. Information generated from these research and development efforts is very useful and of great value, but generally fragmented and potentially proprietary.

For this project, a research team is developing a Gas Quality Resource Center (GQRC) to provide access to recent and historical information resources and provide expertise and guidance in this technically complex area. The Center will serve as a centralized clearing-



A web-based resource center is under development to provide for information on gas quality and unconventional/renewable sources of gas.

house for information related to gas quality, analysis of current flowing gas supplies in North America, identification of constituent trends across identified regions, analysis of current technical regulatory trends associated with pipeline tariff negotiations, and identification of research needed to help fill information gaps.

Deliverables

The initial deliverable for this project will be the creation of a dedicated Gas Quality Resource Center website and significant content.

Benefits

The Gas Quality Resource Center will help to allow for the safe introduction of new supply sources. The goal is to establish a common understanding and provide a sound technical basis upon which gas industry stakeholders can make informed decisions regarding new supply options. The GQRC will help to ensure continued system integrity and reliability, allow for an expanded use of clean-burning natural gas in growth sectors such as power generation and transportation, and help to reduce greenhouse gases through the addition/ substitution of renewable gas.

Technical Concept & Approach

For this project, a research team is interfacing with an industry advisory committee comprised of subject-matter experts to develop a subscription-based Gas Quality Resource Center.

Researchers are developing an on-line database on gas-quality-related information derived from publically published data as well as proprietary information garnered from various stakeholder groups.

Information focuses on renewable and unconventional gas. Within the renewable gas domain, the resource center will contain information on resource assessments, conversion options, clean-up systems, gas-quality expectations, and studies on potential concerns, implications. and mitigating measures. Within the unconventional gas domain, the resource center will contain information on historical and expected compositions from North American resource basins, gas-processing technology, gas-processing facilities and capabilities, blending capabilities, regional historic supply profiles, publicly available tariff requirements, and studies on known/potential implications to infrastructure and end uses as well as mitigating measures.

Phase 1 of the effort focuses on providing information and technical support.

In Phase 2 of the project, various GQRC research projects are expected to be initiated.

Results

With the major building blocks and the underlying database architecture completed (e.g., the design and implementation of basic functions and database schema), 2013 activities mainly involved populating various categories in the on-line data base. The overall interface was updated for functionality and ease of use.

The project team:

- Populated the Technical Publications module with more than 500 documents and articles pertaining to odorization, gas-quality measurement, and analysis
- Created packages for importing the gas constituent values for 68 pipelines
- Re-factored the data access layer and the search mechanism for Tariffs, FERC, Profiles, Current Research, Technical Publications, Management Planning, Gas Quality Analysis, and Advanced Search in order to improve the user experience
- Added the Password change and Password retrieve functionality
- Configured the production environment

In 2014, population of information and data continued for the various GQRC modules. The working prototype database is well established. A presentation was made at the AGA Gas Quality Workshop 11-14 in November 2014. Industry representatives from many different sectors were present, with positive feedback for the Resource Center. Interest in the final product was high.

Status

The first phase of the project is complete, with a working web-based prototype database established at: *gqrc.gastechnology.org*.

A Phase 2 effort was proposed to complete the GQRC Site and proposed functionality.

For more information:

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Next-Generation Water-Cleanup Technology

Activities in this project are aimed at supporting the development and implementation of technology to reduce the cost and complexity of water disposal associated with hydrotesting and other gas-industry operations.

Project Description

Proposed regulations will require operators to verify the integrity of transmission pipes without pressure test records. These regulations could potentially require the industry to hydrotest up to 90,000 miles of in-service pipe. Cleaning and disposing of the hydrotest water is a significant component of the overall cost of hydrotesting.

Cast-iron replacement and routine O&M activities also create large amounts of water that must be cleaned. This water can contain constituents such as hydrocarbons and PCBs that may need to be removed prior to disposal.

In response to these and other issues, new water-cleanup technologies are being developed which could be applied to cleaning wastewater from the natural gas piping infrastructure.

In this project, research is being conducted to assess the feasibility of using manganese dioxide (MnO_2) products to remove residual organic contaminants from various water streams that include post-hydrotest water and low-pressure gas-system water removal. The goal is to reduce the cost and complexity of water disposal associated with hydrotesting and other O&M activities.

Deliverable

In Phase 1 of this project, a technology review and business case will be conducted to quantify the cost of disposing water using current methods and the potential savings that could be achieved with new technologies. It is anticipated that development and implementation costs will be significant, thereby warranting a formal business case prior to pursuing technology development or technology transfer.

Benefits

Pending Integrity Verification Process (IVP) regulations for hydrotesting and accelerated replacement programs will increase the amount of wastewater that must be treated and disposed. Next-generation water-cleanup technologies in use in other industries may be able to significantly reduce the cost of water disposal for natural gas operators.

Technical Concept & Approach

Research is under way to quantify the costs associated with current water-cleaning and disposal techniques. Previous studies were reviewed. The research team is identifying new technologies that could be used to reduce costs. A manganese dioxide technology was identified as one potential candidate; however, technologies from other industries will also be investigated.

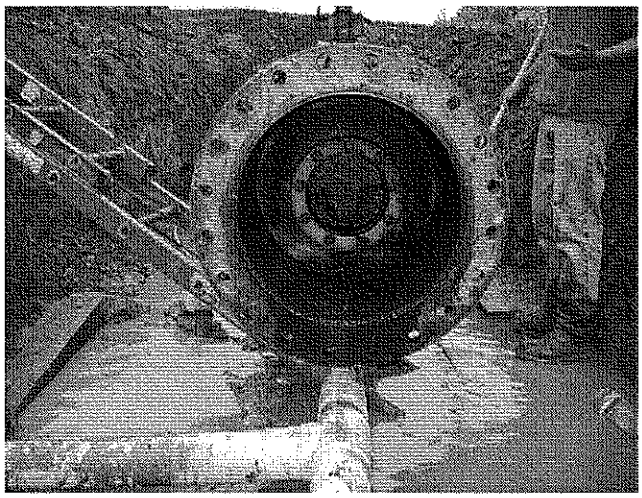
Efforts will be made to quantify the potential cost savings that could be achieved with the new technologies.

Additionally, the investments in R&D, capital equipment, and O&M activities will be quantified to assess the potential return on investment.

The ability of natural gas operators to realize value from this potential costs savings, given the fact that contractors usually perform water disposal services, will also be assessed.

Results

Initial activities included a review of the most recent literature followed by an industry survey regarding



water-management practices, including treatment goals for water effluents generated from the hydrostatic testing performed in the field.

Survey information was compiled and reviewed to address key questions on water volumes, water quality, and regulatory issues associated with the storage, handling, and disposal of wastewaters from hydrostatic tests and the maintenance of pipelines.

Discussions were held with commercial firms that market chemical oxidants for groundwater treatment. Companies were contacted to obtain important information on per-pound costs of oxidant formulations, the oxygen equivalents delivered per pound of oxidant product, and data from any treatability testing performed on BTEX and alkanes in water.

Some Key Findings

- The largest volume of water handled by the pipeline industry is associated with hydrostatic test water effluents. Several other water streams (such as washwater, rinse streams, and drips) are generated at smaller volumes.
- In water-stressed regions, many industries are searching for methods of reducing demands for freshwater thereby achieving a smaller water "footprint." The business case will take into account the potential value of achieving water-conservation goals.
- The amounts of water handled in the field seem to be manageable and could be handled with the use of several frac-tank structures.
- Cleaning solutions and rinse solutions amount to about 5,000 gallons per mile of pipe serviced.
- For companies that perform hydrotesting, the amount of pipe involved is about 5 to 50 miles per year. Another source of water effluent comes from wash and rinse water streams from pipe cleaning operations.
- Principal constituents of concern include PCBs, iron, and BTEX. If city water is used in hydrotesting, chlorine in the effluent can also be an issue.
- Current treatment methods include the removal of suspended solids using bermed areas that force water flows through strawbales, haybales, and filterpads and/or other filters at the discharge point. Carbon filters are used when soluble organic concentrations need to be reduced.
- Half of the respondent companies do not hydrotest their low-pressure distribution pipe.

"One major task required in the hydrotesting of existing lines is compliance with discharge limits. If this clean-up technology is successful, the multiple washing and rinsing of existing transmission lines with cleaners and pigs to remove contaminates could be eliminated."

- Jim Clark
Senior Engineer I
National Fuel Gas Distribution Corporation

- Wastewater that is generated is sent to disposal contractors and facilities.
- Most companies do not treat and discharge their water from low-pressure distribution pipe operations.

Status

Information obtained from the industry survey and the literature review is being used to determine the treatment needs and the types of treatment steps that will be needed to achieve the water quality required by regulatory permits for water management, surface discharge, and/or water reuse. The treatment needs will then be used to create flowsheets of treatment systems that implement chemical oxidation of organics and adequate removals of suspended solids. These flowsheets will be used to estimate the capital costs and operating costs for advanced oxidation treatment systems.

The research team is investigating advanced treatment systems capable of rapid removals of soluble organics and suspended solids. In particular, oxidant systems including manganese dioxide, persulfate, sodium permanganate, Fenton's Reagent, and other oxidant-based treatments are being reviewed.

The performance and costs of the advanced chemical treatment processes associated with highly mobile and low-footprint processing skids will be compared to current practices to determine whether a business case can be made for developing and implementing the next generation of water-cleanup technologies that utilize rapid chemical oxidation for in-field treatment and management of pipeline operations wastewaters.

For more information:

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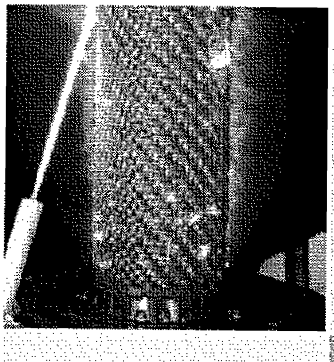
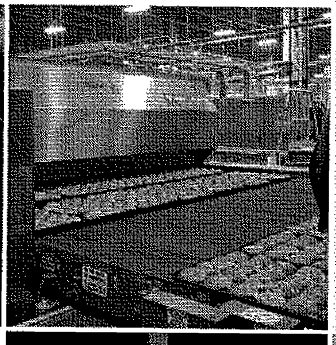
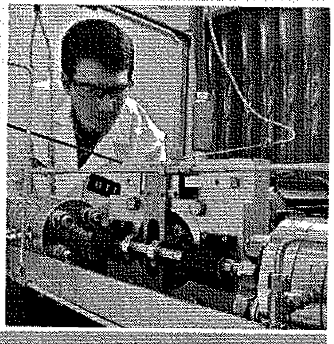
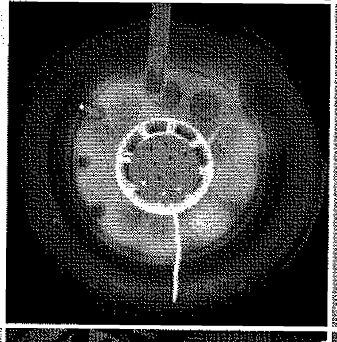
UTD.

Utilization
Technology
Development

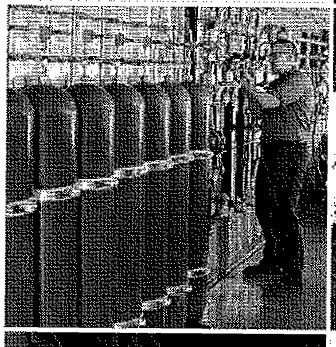


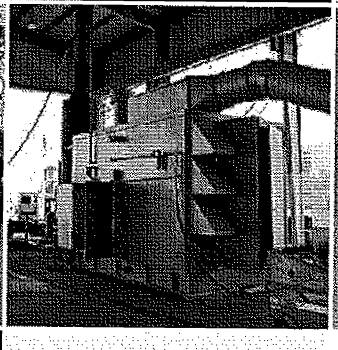


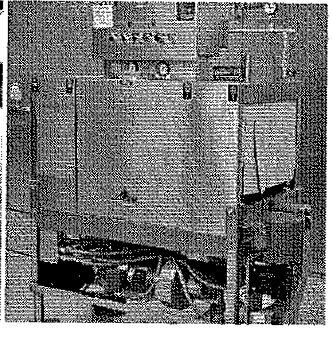


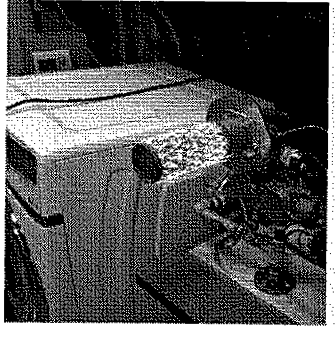


RESEARCH PROJECT SUMMARIES 2013-2014









Utilization Technology Development, NFP

RESEARCH PROJECT SUMMARIES

2013 - 2014

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Letter to Our Stakeholders

Utilization Technology Development (UTD) is shaping the energy future with new efficient end-use technologies that dramatically reduce greenhouse gas emissions and enhance energy security. As markets continue to evolve, there are new opportunities to lower energy intensity and consumption, provide significant economic and environmental benefits, and complement existing utility energy-efficiency programs.

UTD, led by our 16 member companies and representing over 22 million natural gas customers in North America, is looking to take advantage of these new opportunities. Our over-riding goal is to support the introduction of new technologies that help gas consumers save money, reduce emissions, improve efficiencies, and optimize the use of natural gas as a premium fuel.

UTD Members

> Alabama Gas Corporation
> APGA Research Foundation
> Atmos Energy Corporation
> Enbridge Gas Distribution Inc.
> Intermountain Gas Company
> Louisiana RDC
- Atmos Energy Corporation
- CenterPoint Energy, Inc.
- Entergy Corporation

> National Fuel Gas Distribution Corporation
> New York State Electric & Gas Corporation/ Rochester Gas and Electric Corporation
> NW Natural
> Oklahoma Natural Gas Company
> Peoples Gas Light & Coke
> Piedmont Natural Gas Company, Inc.
> Questar Gas
> Southern California Gas Co., a Sempra Energy Utility
> Southwest Gas Corporation
> TECO Peoples Gas

In 2013-2014, UTD managed a multi-million-dollar program that spanned all end-use market sectors, with a focus on taking projects from the laboratory to the field. UTD funding was leveraged with government and private industry funding, and through a combination of research, development, testing, and marketing activities, a number of our projects evolved into commercially available products.

With UTD support, Cummins Westport Inc. (CWI) developed a new 12-liter 400-HP NGV engine (ISX12 G) for the large truck and bus market segment that satisfies the most stringent California emission requirements. The engine became commercially available in 2013 after a field-test fleet of 20 trucks had accumulated almost 1.9 million miles.

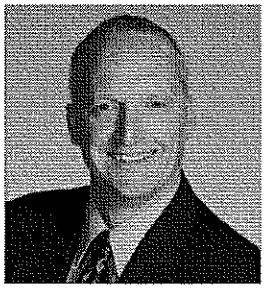
Engines, however, are just one specific element in a suite of UTD projects focused on breaking down barriers to the widespread adoption of NGVs. UTD has supported development of the Ultimate CNG FuelMule™, a mobile fueling solution offering rapid dispensing and large-volume onboard storage capacity. With UTD cost share, Gas Technology Institute (GTI), the University of Texas-Austin, and Argonne National Laboratory have also embarked on a novel new approach to a cost-effective home-fueling appliance that has the potential to significantly change the light-duty passenger NGV market.

To help ensure that the economic and environmental benefits of natural gas are fairly considered when codes and standards are being developed, UTD sponsors the development of unbiased, credible technical information for public stakeholder audiences. GTI helped author revised ASHRAE Standard 105-2014 so that it now includes a more comprehensive primary (or source) energy-based methodology for comparing building energy performance. This is a significant advancement over the prior standard that only included site energy metrics. Analytical tools and information like this have made a significant impact on business.

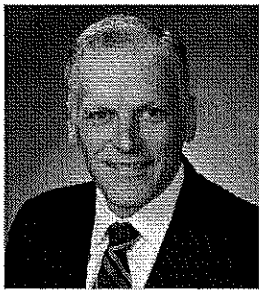
As you'll see throughout this report, these are just a few examples of meaningful initiatives being carried out by UTD. Our cooperative research is identifying emerging needs and solutions and showcasing the benefits of natural gas in residential, commercial, industrial, and power-generation markets.

Through UTD, many technology advancements are being made that provide overall cost savings, improvements in efficiency, and environmental benefits. Together, our members share experiences and exchange ideas that lead to stronger solutions.

Anthony Hills
Chairman



Ronald Snedic
President



Market-Ready Solutions

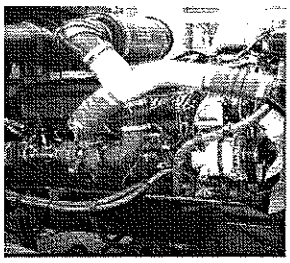
UTD-Sponsored Products Enter the Marketplace

The over-riding goal of Utilization Technology Development is to support the introduction of new end-use technologies into the marketplace to enhance the ability of natural gas consumers to save money, reduce emissions, improve efficiencies, and optimize the use of natural gas as a premium fuel.

Through a combination of research, development, testing, and marketing activities, every year a number of UTD-supported projects evolve into commercially available products.

UTD is proud to present highlights of some recent milestones and market-ready solutions:

Products Commercially Available or Being Readied for Commercialization



> Cummins Westport (CWI) High-Horsepower NGV Engine

Cummins Westport Inc.

CWI, with UTD support, developed a new 12-liter 400-HP NGV engine (ISX12 G) for the large truck and bus market segment such as regional haulers, refuse transfer trucks, and other larger vehicles. The engine satisfies the stringent California emission requirements. Now in full production, through the end of 2013, CWI had manufactured more than 2,000 ISX12 G engines. *(Project Summary, p. 113.)*

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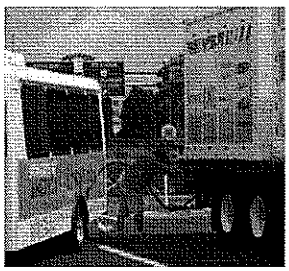
604-718-2024
sptucha@cummins.com
www.cumminswestport.com



> Ultimate CNG FuelMule

Ultimate CNG, LLC

The FuelMule is a mobile fueling solution that is capable of dispensing eight diesel gallon equivalent (dge) per minute at a pressure of 3,600 pounds per square inch. The FuelMule is fitted with onboard storage capacity of 700 dge that can fuel 35 to 50 medium- to heavy-duty vehicles. Separate electronic metering allows for the filling of two vehicles simultaneously. *(Project Summary, p. 123.)*

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703-209-4086
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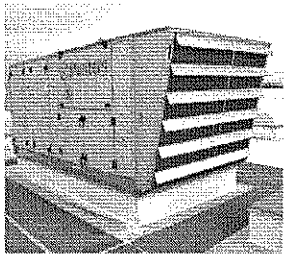
www.ultimatecng.com



> Dedicated Outside Air System (DOAS)

Munters Corporation

A condensing heating version of this Munters DOAS is in final development. A field evaluation was conducted during the winter of 2013 at a "big box" retail store. UTD research was instrumental in establishing baseline store-heating energy use, developing the DOAS condensing heating module,and defining combustion condensate disposal practices from rooftops. *(Project Summary, p. 41.)*

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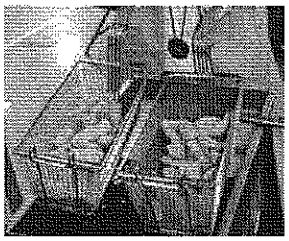

> Low-Oil-Volume Fryers

Frymaster, a Manitowoc Foodservice company

A new commercial foodservice low-oil-volume fryer has undergone development and pre-commercial testing with successful results. The fryer, marketed by Frymaster as Protector® fryers, increases energy efficiency while also extending cooking-oil quality and life to provide significant customer savings.

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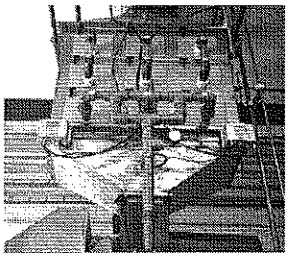

> Cannon Boiler Works' Ultramizer®

Cannon Boiler Works, Inc.

An advanced heat-and-water recovery system, including Transport Membrane Condenser technology, was installed and commissioned at Baxter Healthcare in Thousand Oaks, CA, meeting performance expectations and increasing the boiler efficiency from 80% to 93% – saving the customer 15% on fuel bills, reducing greenhouse emissions by 15%, and saving over 250,000 gallons of water.

Contact: Chris Giron
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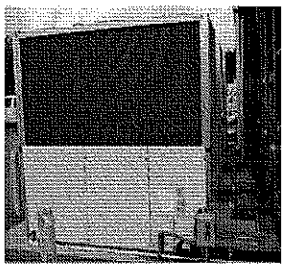
724-335-8541 x414
sales@cannonboilerworks.com
www.cannonboilerworks.com



> NextAire™ Gas Heat Pump

IntelliChoice Energy

Researchers conducted a series of tests of the Next-Aire 8-ton and 15-ton gas heat pump (GHP) in commercial applications. This advanced unit uses variable refrigerant flow and multi- zone capabilities (up to 33 zones for the 15-ton unit) to efficiently heat and cool commercial building space with substantially less electricity requirements (up to 80% reduction). *(Project Summaries, p. 53, 63, and 73.)*

Contact: Tom Young
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tyoung@iceghp.com
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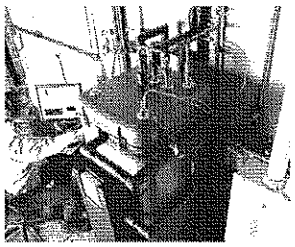


> Equinox Solar-Assisted Heating System

Solar Usage Now, LLC

The Equinox system is a combination thermal storage tank and instantaneous water heater capable of providing 100% of domestic hot-water and space-heating needs. This unit was tested in multiple residential and commercial sites and is available from Solar Usage Now as the S.U.N. Equinox Heating System.®

Contact: Tom Rieker
Solar Usage Now, LLC
614-759-7242
service@netwalk.com
www.solarusagenow.com

> Cummins 8.9L Ultra-Low-Emissions Engine

Cummins Westport Inc. (CWI)

This is the first engine certified to the highly stringent California 2010 standards for heavy-duty vehicle engines – achieving emission levels below the 0.2 g NO_x/hp-hr requirement while also retaining high shaft efficiency. Since its introduction in 2007, the engine has been widely used, with more than 13,000 engines now in service throughout the world in transit, refuse-collection, and regional hauling applications.

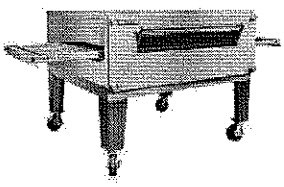
Contact: Stephen Ptucha
Cummins Westport Inc.
604-718-2024
sptucha@cummins.com
www.cumminswestport.com

> High-Efficiency Broilers

The Montague Company

New, higher-efficiency broilers were demonstrated in cooperation with The Montague Company. These units use thermostatic broiler-temperature control and an energy-saving hood. Field testing showed an average of 23% energy savings.

Contact: The Montague Company
800-345-1830
www.montaguecompany.com



> Energy Star Conveyor Oven

Lincoln, a division of Manitowoc Foodservice

Testing confirmed significant energy savings from Energy-Star-rated conveyor ovens from Lincoln. These products include an advanced energy-management system to reduce energy consumption up to 38%.

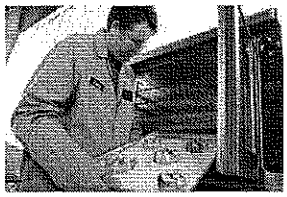
Contact: Lincoln, a division of Manitowoc Foodservice
260-459-8200
www.lincolnfp.com

> Market Forge Countertop Steamer

Market Forge Industries Inc.

This compact gas-fired countertop steamer for commercial foodservice offers enhanced cooking rates while providing users with added savings of energy and water consumption. The unit is the first gas-fired boilerless steamer with an Energy Star rating.

Contact: Market Forge Industries Inc.
617-387-4100 – 866-698-3188
custserv@mfii
www.mfii.com

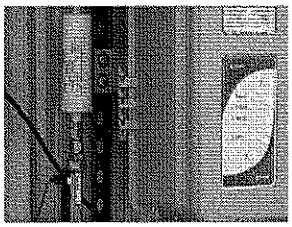


> Avantec Combi-Oven

Avantec Food Service Equipment

The combination oven uses a patented technology for improving cooking performance, quality, and efficiency. Able to operate in various cooking modes, the oven provides enhanced cooking uniformity when compared to similar-sized ovens.

Contact: Dave Goble
Avantec Food Service Equipment
800-322-4374
dave@twomarket.com
www.avantecequipment.com



> BRC FuelMaker's *Phill*

BRC FuelMaker

A field demonstration program was conducted to assess the performance, reliability, and economics of a natural-gas-fueling product that allows for the re-fueling of natural gas vehicles at homes and businesses. Data was analyzed and a user survey was conducted at the conclusion of the demonstration.

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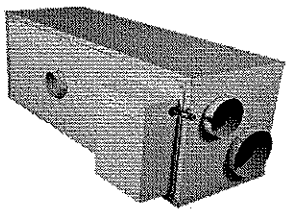
BRC FuelMaker
+39 0172.48.68.656
F.Donalisio@brc.it



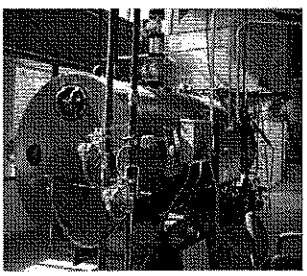
> NovelAire ComfortDry™ 400

NovelAire Technologies

This advanced supplemental dehumidifier was developed for residential and light-commercial buildings where humidity or moisture-related allergen concerns prevail. Research provided enhanced operation and reliability, along with reduced cost, weight, size, and installation requirements.

Contact: Scott Janke
NovelAire Technologies
770-664-4756
sljanke@novelaire.com
www.novelaire.com/
residential-dehumidifiers.html

Significant Milestones



> FlexCHP High-Efficiency Ultra-Clean Power and Steam Package

Researchers are developing a cost-effective supplemental burner, integrated with a gas-turbine-based combined heat-and-power system. Laboratory tests have shown total efficiency of over 85% and NO_x emissions that are below stringent California emission levels. In 2013, the FlexCHP-65 system was installed a the facilities of a California food processor for a field demonstration. *(Project Summary, p. 85.)*

Contact: Dave Cygan
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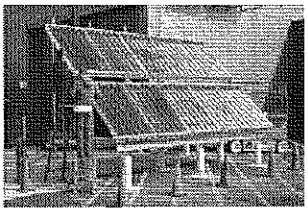
david.cygan@gastechnology.org



> Solar-Assisted Natural Gas Energy Systems

Progress continues with the installation of solar-thermal collectors using B2U Solar's higher-temperature Non-Imaging Concentrator Collector (NICC) technology. Additional testing is planned with a major food-processing company. *(Project Summaries, p. 43, 87, 93, and 95.)*

Contact: Dave Cygan
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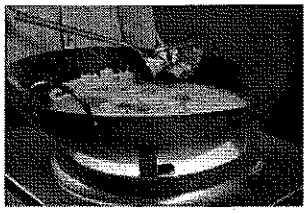

> High-Efficiency Wok

A new high-efficiency wok has undergone extensive laboratory testing and is now progressing through field testing prior to commercial launch. Tests show up to a 75% efficiency improvement over conventional woks. Royal Range and other foodservice organizations are evaluating options for commercialization.

Contact: Frank Johnson
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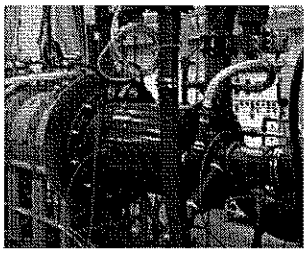

> Ultra-Low-NO_x Burner

Power Flame Inc. is developing an Ultra-Low-NO_x (ULN) burner for firetube-boiler applications to achieve NO_x emissions below 5 ppm without the use of Selective Catalytic Reduction or external Flue Gas Recirculation. A prototype unit rated at 4 million Btu/hr was designed, fabricated, and installed at Gas Technology Institute research laboratories for performance validation testing. *(Project Summary, p. 49.)*

Contact: Derek Wissmiller
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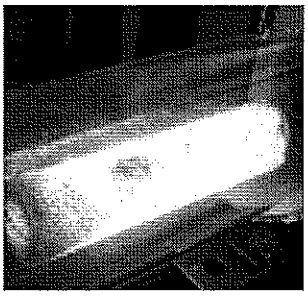

> Low-NO_x Furnace

Low-NO_x combustion systems developed in with California's South Coast Air Quality Management District (SCAQMD) and five residential furnace manufacturers achieved emissions levels of less than 14 ng/J. Innovative burner materials, including metal mesh and metal foam, were used to achieve even heat transfer and uniform flame temperatures. Commercial residetial furnace burners are currently being developed based on these designs. *(Project Summary, p. 11.)*

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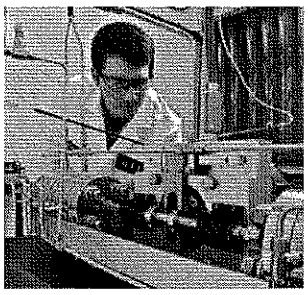

> Home Compressor

A cost-effective home-fueling appliance has the potential to significantly change the light-duty passenger NGV market. With UTD cost share, Gas Technology Institute and the University of Texas, Austin (with specialty materials from Argonne Laboratories), have embarked on a novel approach using a linear motor and only one moving piston. The prototype is scheduled to be running in the laboratory by late 2014.
(Project Summary, p. 127.)

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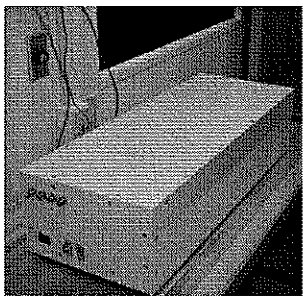

> Gas Quality Sensor

A research team is developing a commercial prototype of the Gas Quality Sensor (GQS), a sensor utilizing infrared light absorption spectroscopy to measure Btu content and gas composition. Extensive filed trials of a laboratory prototype demonstrated that the GQS is capable of monitoring natural and bio gas composition and heating value in real time with an accuracy of 0.5% or better. The cost of the commercial GQS is expected to be competitively priced to the cost of a gas chromatograph.
(Project Summary, p. 101.)

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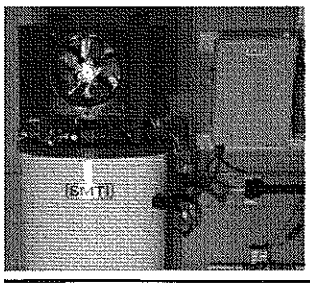

> Gas-Fired Heat Pump Water Heater

Researchers designed and demonstrated a novel Gas-Fired Heat Pump Water Heater (GHPWH) through laboratory proof-of-concept testing. The GHPWH has compatibility with SCAQMD NO_x requirements and an Energy Factor (EF) of 1.3 – over twice that of standard gas water heaters. When commercially available in 2016, it will be the only water-heating technology with a source energy-based EF of greater than 1.0. *(Project Summary, p. 17.)*

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Analytical Tools & Information Products

> ASHRAE Standard 105-2014 "Standard Methods of Determining, Expressing, and Comparing Building Energy Performance and Green Gas Emissions

A revised standard now includes a more comprehensive primary (or source) energy-based methodology for comparing building energy performance. This is a significant advancement over the prior standard that only included site energy metrics.

Contact: Neil Leslie | Gas Technology Institute | neil.leslie@gastechnology.org

> Source Energy and Emissions Analysis Tool

The Source Energy and Emissions Analysis Tool (SEEAT) allows calculation of the energy source and greenhouse-gas emissions related to point-of-use (site) energy consumption by fuel type for each energy-consuming device (e.g., appliances and vehicles). SEEAT includes a source-energy and carbon-emission calculation methodology that accounts for primary energy consumption and related emissions for the full fuel cycle for residential and commercial buildings, industrial applications, and light-duty vehicles. *(Available online at www.cmictools.com.)*

Contact: Neil Leslie | Gas Technology Institute | neil.leslie@gastechnology.org

> International Green Construction Code (IGCC)

The International Green Construction Code (IGCC) development committee shifted from site energy to source energy and greenhouse-gas (GHG) emissions as the basis of the performance requirements in IGCC. The latest publication includes a single-reference building approach that will implement the source energy and GHG emission-compliance requirements consistently and equitably.

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> Whole House Residential Energy Efficiency Wizard (REEW)

The REEW provides UTD members and their customers with a user-friendly Internet-server-based tool allowing for the analysis and easy selection of the latest technologies applicable to residential buildings energy-efficiency measures customized to a specific member service territory. *(Project Summary, p. 3.)*

Contact: Jennifer Yang | Gas Technology Institute | jennifer.yang@gastechnology.org

> Commercial Green Building Analyzer (CGBA)

The CGBA is designed to be a user-friendly tool allowing for easy selection of the latest applicable commercial "green" building energy-efficiency measures customized to a specific member service territory. Several new building envelope materials were added to the recent version. *(Project Summary, p. 39.)*

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> Venting Solutions

VENT-II, the industry standard software program for vent system design, offers application with commonly used desktop operating systems and spreadsheet tools. A venting Technical Advisors Group includes 30 subject- matter experts, manufacturers, industry groups and associations, and Gas Technology Institute.

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UTD RESEARCH PROJECT SUMMARIES 2013 - 2014

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Whole House Energy Efficiency Wizard

A user-friendly Internet-based tool was developed to allow for the analysis and easy selection of the latest applicable energy-saving technologies for residential applications. The tool is available to any authorized user with Internet access.

Project Description

Energy conservation is becoming a permanent concern of the U.S. energy market, affecting both energy providers and consumers. Utilities are being encouraged to support energy-efficiency programs and consumers are increasingly searching for ways to mitigate rising utility costs.

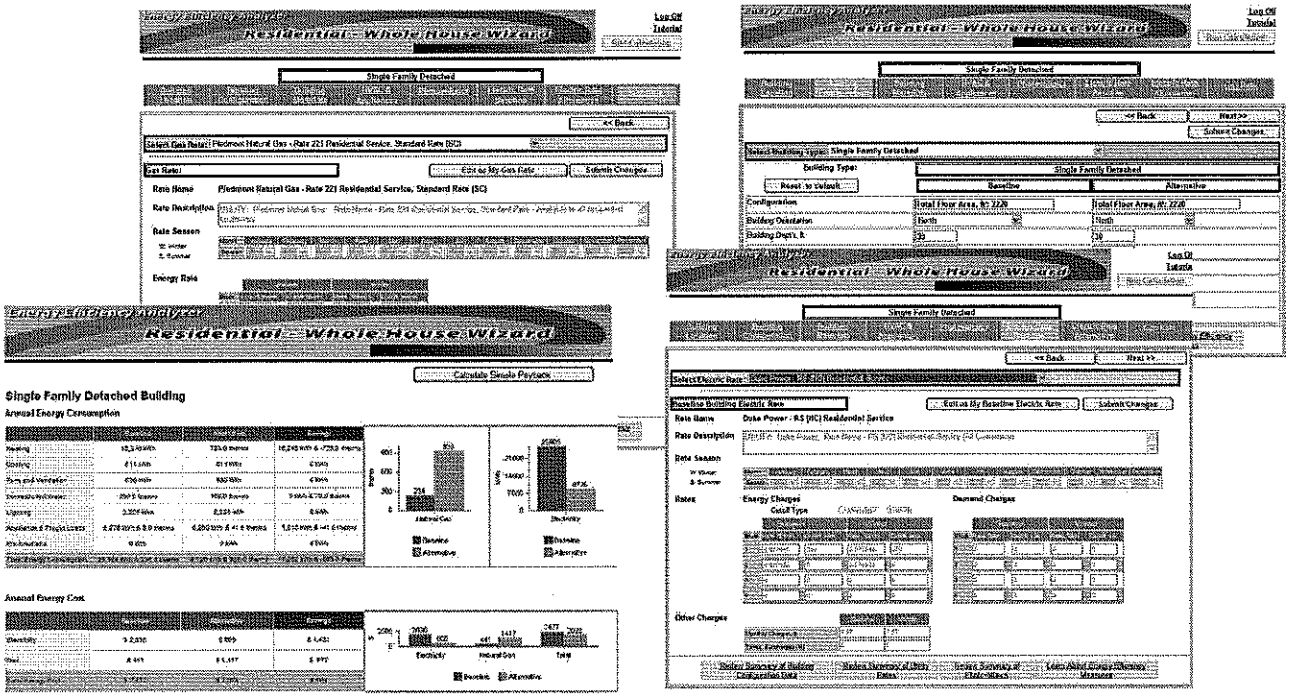
An increasing number of vendors have started to bring to the residential market a range of new energy-efficient products – from lighting, appliances, and HVAC systems (cooling, heating, ventilation, ducts) to building envelope (glazing, insulation, cool roof) and domestic hot-water technologies. Unfortunately, the economic and the energy-savings impacts of these technologies are building- and location-specific.

Recognizing that energy savings can not be easily calculated without sophisticated modeling tools (that can be costly and difficult to use), in this project UTD members supported the development of a user-friendly, Internet-based tool for analysis and easy selection of energy-saving options for residential applications. The on-line tool – called the Residential Whole House Wizard (RWHW) – is available to any authorized user with access to the Internet and can be customized to address specific service territories.

Benefits / Market Implications

The RWHW supports energy conservation by helping residential customers put realistic values on the economic and environmental benefits of implementing various home energy-efficiency/conservation measures.

Researchers note that up to 30% energy conservation can be achieved with economically acceptable paybacks in typical existing residential applications. Considering the fact that approximately one-third of the total energy consumed in the U.S. is used by the residential sector, the scale of potential energy conservation can be significant.



The Residential Whole House Wizard is designed for easy analysis of technology applications, payback periods, greenhouse gas impacts, energy use, cost savings, and other factors.

Technical Concept & Approach

The RWHW is based on Gas Technology Institute's Building Energy Analyzer (BEA) proprietary building-modeling software tool.

The project involved the following tasks:

- **BEA Computational Engine Modification**

  Researchers developed a dynamic link library (DLL) version of the BEA that can be installed on a server to be run remotely using Internet browser access. A separate DLL component was developed to support multi-user access for calculating electric demand, energy, and natural gas savings estimates for each of the energy-efficiency measures evaluated.

- **Development of Residential Prototypes**

  Residential building prototypes in the analysis tool include detached single-family homes, semi-detached duplexes, and multifamily units (e.g. townhouses, low-rise apartments, and condominiums).

- **Development of Energy Efficiency Library**

  A library of energy-efficiency measures applicable to residential buildings was developed to allow end users to evaluate electric demand, energy, and natural-gas savings, as well as the associated installation costs expected through the implementation of each of the following weather-sensitive efficiency measures:

  - Programmable thermostat
  - High-efficiency air conditioner
  - High-efficiency furnace
  - Duct-sealing measures
  - Ceiling insulation
  - Wall insulation
  - High-performance windows.

In addition, the following non-weather-sensitive energy-efficiency measures were available for evaluation:

  - High-efficiency lighting
  - High-efficiency refrigerators
  - High-efficiency clothes dryers
  - High-efficiency clothes washers
  - High-efficiency dishwashers
  - High-efficiency water-heating measures.

- **Internet Portal Access Interface Development and Implementation**

  The Internet-access portal was designed to accommodate the most commonly used web browsers (MS Explorer, Netscape, and Firefox). The end user is able to describe house profiles by selecting items from drop-down menus. The program analyzes the end user's house profile and recommends energy-saving ideas in on-screen displays as well as printed reports.

- **Customization for Service Territory**

  UTD members interested in a customized version of the RWHW can be provided a members-branded Internet portal access. The library of residential building prototypes will be customized to account for the member's local climatic conditions.

Results

A library of residential building prototypes was developed that includes detached single-family homes, semi-detached duplexes, townhomes, and low-rise apartments. The user can modify major parameters (e.g., building square footage, number of floors, fenestration, location, and orientation). A library of energy-efficiency measures applicable to residential buildings was also developed and the RWHW Internet portal access interface was completed.

The latest version (4.0), released in 2012, includes new building templates (raised floor, crawlspace, and basement), an enhanced library of wall insulation and glazing, and an option to model buildings in heating-only HVAC configuration.

Status

The Whole House Energy Efficiency Wizard is available to UTD members through the UTD website: *www.utd-co.org.*

A team is providing user support, training, and internet server upkeep.

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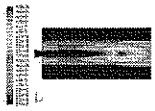
greg.maxfield@gastechnology.org

UTD Utilization Technology Development

Low-Cost Condensing Water Heater Development



In this project, research is focused on the development of a low-cost, high-efficiency, low-emissions burner – specifically, a single-port Forced Internal Recirculation (FIR) design – for application in a condensing gas water heater.

Project Description

Current product offerings for high-efficiency condensing gas water heaters are approximately 92% thermally efficient and come with a significant added cost ($1,150 over a conventional residential water heater). In commercial water heaters, the price difference becomes even greater (starting at $2,700).

In California, commercial water heaters require more expensive burners in order to meet the 14 ng NO_x/J 2012 output emission requirements of Rule 1146.2 promulgated by the California South Coast Air Quality Management District (SCAQMD). With electric water-heating technology shifting to electric heat-pump technology, to remain competitive gas water heating needs to reduce the first cost of high-efficiency condensing water heaters.

The objective of this project is to develop and test a low-cost, high-efficiency, low-NO_x burner for application in a condensing gas water heater.

Benefits / Market Implications

Current high-efficiency gas-water-heater options are price limited. Reducing first cost will increase the product's market share and provide consumers with a more attractive alternative to electric water heating.

Technical Concept & Approach

Researchers are exploring a single-port Forced Internal Recirculation (FIR) concept to produce a burner that will meet or exceed 2012 SCAQMD NO_x requirements at low cost.

In this project, a research team will develop:

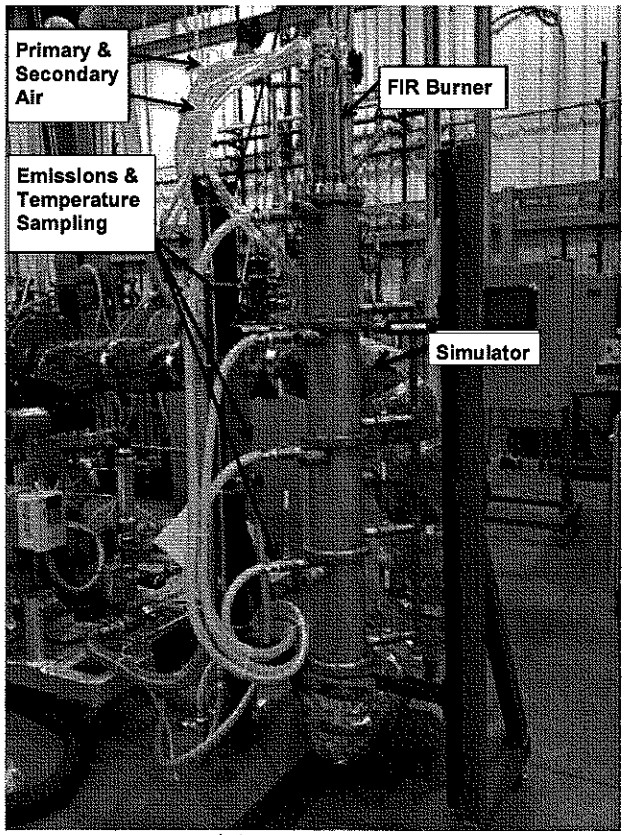
- Baseline measurements of new powered-burner designs that meet low-NO_x emissions and manufacturing cost requirements
- A simulator design for burner testing
- Two burner designs
- Designs for cost estimation and experimental testing.
- Burner prototype fabrication and testing.

Results

Researchers initially performed Computational Fluid Dynamics (CFD) modeling of a burner prototype for combustion analysis and burner stability.

A literature survey, initial screening design, and preliminary calculations resulted in a sound theoretical baseline design for analysis. A CFD model analyzed various primary/secondary air balances, burner geometry, and flame characteristics and dynamics of the FIR burner concept.

A single-nozzle design approach was developed. This central FIR burner concept was not extensively researched previously, especially at low pressures/firing rates. Under ideal primary/secondary air balances, the



Laboratory test set-up.

"SoCalGas is committed to providing our customers with safe, reliable, and energy-efficient gas-fired products – and we have specific gas-use-reduction targets that we strive to meet through the promotion of energy-efficiency programs. However, even with utility incentive funding, many high-efficiency products, such as condensing water heaters, are still expensive for the consumer. Consequently, we've been an active supporter of research to reduce the cost of condensing water heaters."

- Steve Simons
Senior Project Manager, Technology Development
Southern California Gas Company

FIR burner concept shows to have recirculation ratios and secondary temperatures consistent with low-NO_x emissions.

CFD modeling at a primary air ratio of 80% show baseline FIR burner concept performance of 18 ng NO_x/J output, which is compliant with current SCAQMD NO_x emission restrictions; however, 2012 restrictions are at 14 ng NO_x/J output. Over the expected operational range, flame stability appears to be approximately independent of βP, which implies that onboard tuning of the ratio of primary/secondary air would be feasible to maximize efficiency or minimize NO_x without inducing blowoff or flashback.

A technical review with a water-heater manufacturer concluded that the burner design has the potential to offer significant cost and performance advantages over burners currently in use.

Subsequently, researchers completed CFD modeling on a 199KBtu/hr burner. (Previously, all work had been done on a 120KBtu/hr burner; the 199KBtu/hr burner is a more popular size). Modeling showed that increasing the size of the burner from 120KBtu/hr to 199KBtu/hr resulted in a lengthening of the flame which hindered recirculation. Recirculation is critical to low-NO_x burner operation in an FIR burner. This resulted in a redesign of the nozzle (size and angle) and secondary distribution strategy.

Two burner designs were developed. A fixed design for the manufacturer to estimate costs and a design to allow for real-time modification of burner parameters while testing.

A simulator design was completed and fabrication initiated – central to the experimental portion of this project. By design, the simulator facilitates direct testing of powered burners by recreating the heat transfer and flue-gas flow conditions of an actual commercial water heater while allowing for *in-situ* measurements that are not possible otherwise. This simulator reaches steady state within minutes and provides real-time feedback on flame characteristics, heat transfer, and emissions as burner adjustments are made.

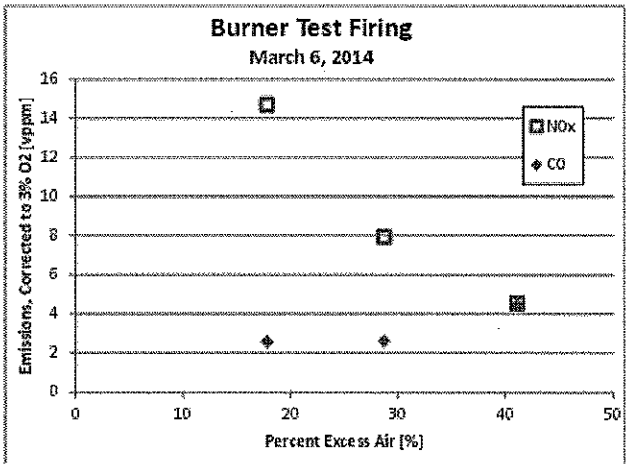
The manufacturing partner provided a commercial water heater for proof-of-concept testing.

Testing of the FIR burner prototype was conducted in 2013. Results demonstrated the capability of achieving <5 ppm NO_x and CO ppm. Researcher also found the need to balance emissions performance with blower requirements and excess air levels

Status

In March 2014, Phase 1 of this project concluded with additional testing of a highly flexible research burner. A Final Report outlining Phase 1 research to date is being written.

In July 2014, Phase 2 was initiated. In this second phase, experimental investigations continue to refine and finalize design parameters, including air-to-fuel ratio optimization, cycling time, secondary air staging, firing rate, nozzle parameters (material, geometry, positioning), and recirculation-sleeve optimization. The goal is to develop, build, and test a first-generation FIR burner in a commercial water heater. Testing demonstrated the performance of the burner at both 20 ppm NO_x (current regulations) and 8 ppm NO_x (proposed regulations) with operation at moderate to low excess air levels.



Results indicate that elements of the FIR burner approach are capable of achieving low emissions of < 5 ppm NO_x and CO.

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UTD Utilization Technology Development

Residential Hybrid Gas-Solar Water-Heating System Demonstrations

In this project, a demonstration program for a residential hybrid gas-solar water-heating system was conducted to develop performance information and facilitate the introduction of the technology in North American markets. Research shows that the system can provide energy savings of at least 40% over conventional systems.

Project Description

Over the years, productivity improvements at utilities have resulted in considerable savings for consumers. However, the ability for natural gas utilities to provide added-value service to all ranges of customers has diminished. However, decoupling and the increase in emerging technology programs present opportunities to address special customer classes with new gas-based technologies.

One new and promising technology is hybrid gas-solar water heating. Popular in countries with tropical and temperate climates, it has only recently started to make inroads in U.S. markets.

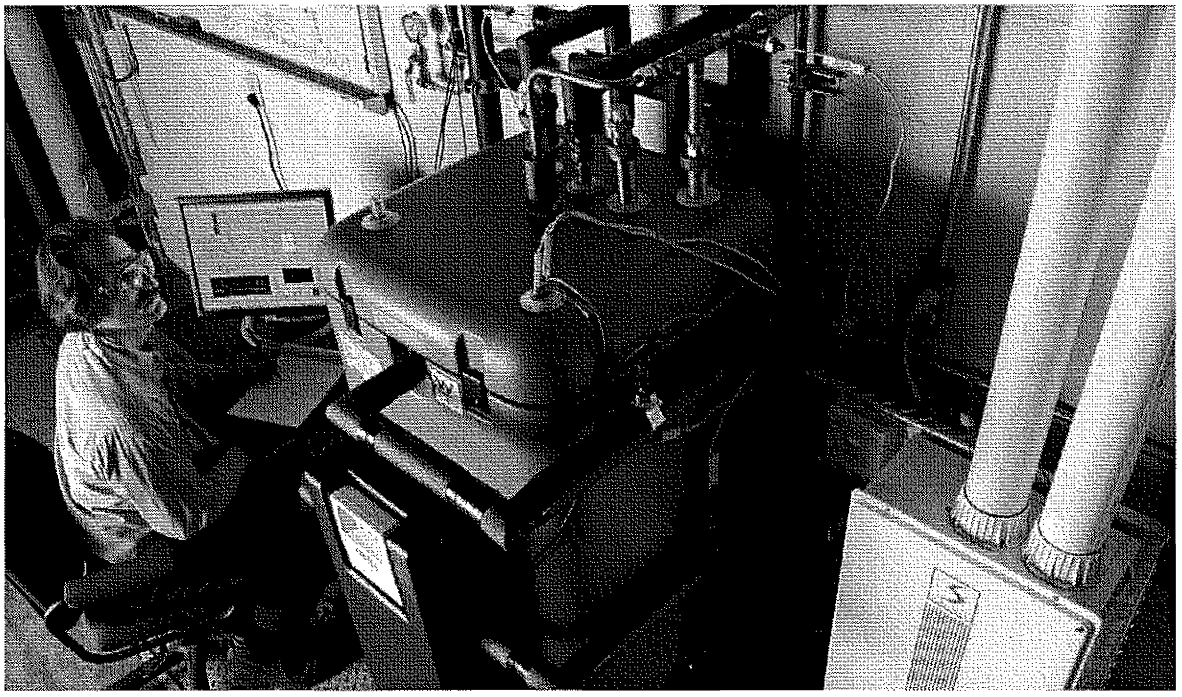
In a separate project, UTD is sponsoring research to reduce the material, manufacturing, and installation costs of a residential hybrid gas-solar hot-water system manufactured by Solar Usage Now (the Equinox system). The major components of the system under development include evacuated-tube solar collectors, polyethylene hot-water storage tanks, and condensing tankless water heaters. Through technology advances, investigators expect to provide the industry with a highly efficient hot-water-delivery system that can meet the reliability and performance needs of most residential applications.

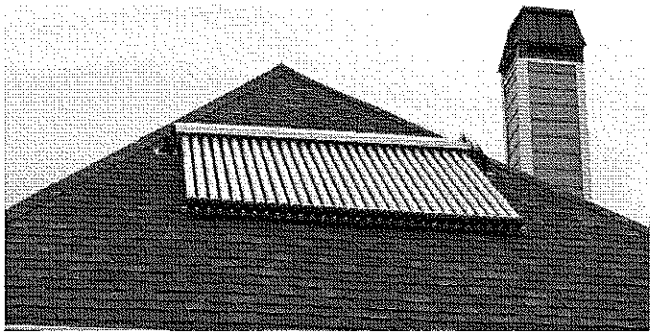
In this project, research was expanded to include demonstrations and showcase installations of the hybrid gas-solar water-heating system in various UTD-member territories. Five field sites around the U.S. in UTD-member territories were selected, solar-thermal systems were installed, fully-instrumented, and their performance was monitored for one year.

Benefits / Market Implications

A solar-assisted gas water-heating system that can provide a 40% energy savings over conventional gas water heating would equate to an average savings of 82 therms per year. At $1.10 per therm, the gas consumer could save $90 per year on the gas commodity alone.

The system uses the most efficient technologies on the market and integrates them into an energy-efficient and economical package.





Technical Concept & Approach

This project included the following tasks:

- **Host Site Agreements**

  Five host sites were selected for field demonstrations.

- **Design Engineering and Fabrication**

  Engineers designed and fabricated a residential solar-assisted gas water-heating system for each selected host site.

- **Field Unit Installation**

  Technicians provided the mechanical and electrical installation of the solar-assisted system at each selected host site.

- **Data Collection, Processing, and Analysis**

  The field performance of the solar-assisted system was validated through a comprehensive testing program at each host site.

- **Technology Transfer Activities**

  A plan was developed to make the knowledge gained, experimental results, and lessons learned available to key decision-makers.

- **Production Readiness Plan**

  A plan was developed that outlines needed activities that can lead to the manufacturing of the technologies developed in this project or to the commercialization of the project's results.

Results

The Equinox residential system was demonstrated at five field sites around the U.S. in UTD member territories in California, Florida, Louisiana, North Carolina, an Utah.

Field-site installations began in April 2011 and concluded in April 2013. Each site was commissioned with a data-acquisition system, which collected information every minute, and could be accessed remotely.

During the summer months, all sites demonstrated a solar fraction between 40% to 90% of their domestic hot-water loads, depending on the climate and the solar system. (Solar fraction is the portion of the total conventional hot-water heating load provided by solar energy, which includes both delivered energy and tank standby losses.)

The systems were able to demonstrate the targeted 40% savings in natural gas for domestic hot water as compared to the baseline system, with an average of 43.7%. In the summer months, this percentage was as high as 98%.

During the course of this study, the price of natural gas dropped significantly making the economics challenging in many areas of the U.S. Using real-time natural gas prices reported by the Energy Information Administration (EIA), most systems showed an annual savings ranging from $100 - $200. However, there are still competitive market areas that have higher prices for natural gas, high solar-radiation indices, aggressive state rebates, and streamlined permitting requirements.

Based on the findings in the field, the system design has evolved. The reconfigured system reduces the material and installation costs. Preliminary results indicate that in the Midwest and Northeast this would increase the annual gas savings from 20% to 65%, in the Southeast and Northwest from 60% to 86%, and in the Southwest from 58% to 98%.

Status

This project is completed. A Final Report was issued in July 2014.

Recommendations for further research:

- Develop a low-cost tank option
- Conduct a laboratory assessment of the reconfigured system paired with advanced hydronic air handlers designed for supply water temperatures of 120°F
- Conduct laboratory testing to understand the effect of higher tankless supply water temperatures (120°F or less) and how this would affect the tankless' ability to condense.

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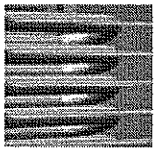
UTD Utilization Technology Development

Low-Cost, High-Efficiency Condensing Unit Heater



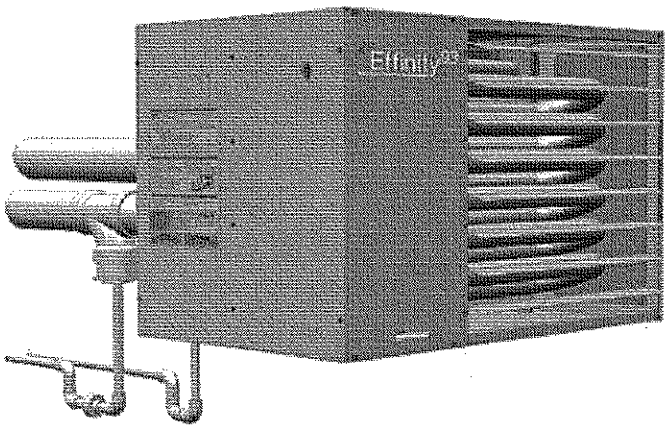
Researchers are investigating a variety of issues associated with use of high-efficiency, condensing furnace technology in gas-fired unit heaters. Through interactions with HVAC manufacturers, end users, and gas utilities, efforts are under way to stimulate lower-cost product introductions, validate equipment performance, and address economic and regulatory concerns.

Project Description

Increasing energy prices and mounting regulatory initiatives have led to the introduction of higher-efficiency electric air-conditioning technology in packaged space-conditioning equipment. On the gas-heating side, condensing furnace technology – which has already established strong market demand in the residential sector – is now being positioned to expand into the small to mid-size commercial, institutional, and industrial markets and offer net energy savings. However, several technical and economic issues need to be addressed for both condensing gas-heating rooftop units (RTUs) and unit heaters.

Currently, two of the top three unit-heater manufacturers have adopted this high-efficiency technology option into their product lines. However, confirmation of the potential energy savings in actual application and introduction of lower-cost products are needed to promote the high-efficiency unit-heater market growth.

Unlike gas-heating RTUs – that need to operate in an outdoor rooftop environment – unit heaters are typically installed indoors, suspended from the ceiling in factories, warehouses, service shops, "big box" retail stores, etc., and will not require additional equipment provisions to ensure condensate freeze protection. As a result, condensing technology for unit-heater product lines may initially offer a less challenging path than gas RTUs for inroads into these small to mid-size commercial, institutional, and industrial markets.



Modine Manufacturing Company entered the high-efficiency condensing unit-heater market in 2009 with its 93% TE product line, the Effinity 93 Model PTC.

In this project, research is focused on an investigation of various issues associated with the development and introduction of low-cost, high-efficiency condensing unit heaters. A research team is interacting with HVAC manufacturers, end users, and gas utilities to stimulate lower-cost product introductions, validate equipment performance in laboratory evaluations and field-monitoring activities, delineate payback economics in various building applications/climatic locations, define appropriate energy-efficiency program incentives, and explore emerging efficiency and emission regulations in domestic and overseas marketplaces.

Benefits / Market Implications

One manufacturer notes that typical annual net operating energy cost savings for a high-efficiency condensing unit heater ranges from $337 in Atlanta to $516 in Chicago and $710 in Minneapolis. Depending on capacity, pricing for the models ranges from $1,150 to $3,000, with simple paybacks of 5.5 years in Atlanta, 3.6 years in Chicago, to 2.6 years in Minneapolis.

This project can help to:

- Better define the real-world application economics for unit heaters
- Implement competitive, cost-reduction initiatives for high-efficiency products with unit-heater manufacturers
- Establish utility financial-incentive scenarios to support current and next-generation, lower-cost, high-efficiency condensing-unit-heater product lines.

Technical Concept & Approach

In this project, research is focused on a unit heater market-situation analysis, cost reductions, laboratory evaluations, and field-performance validations.

Research results will include a market-situation report that includes a breakdown of the projected payback economics for high-efficiency unit heaters (by building application and climatic location) along with recommendations for structuring energy-efficiency-program financial incentives. These economics will be supported by documented results from targeted validation testing in the field with major end users.

A series of cost-reduction recommendations implemented in the laboratory will be provided to participating manufacturers for next-generation, lower-cost, high-efficiency unit heaters incorporating these refinements.

Results

Initial investigations indicate that in the development and introduction of low-cost, high-efficiency condensing unit heaters:

- No code barriers exist
- Additional installation costs are incurred, including costs for proper condensate drainage
- While first cost is an issue, one manufacturer has been able to minimize costs by fitting secondary (condensing) heat exchangers into its existing non-condensing unit housings.

Researchers also held discussions with various end-use building managers responsible for HVAC equipment selection and energy use.

During the project, non-condensing unit heater (UH) runtimes in the retail sector were monitored. The key finding from the retail-store monitoring is that one can't assume heating season savings potential is the same for all the unit heaters in a given building. Very diverse runtimes were seen for UHs on a given building, but certain patterns emerged, such as:

- UHs conditioning building zones subject to infiltration loads (entry/exit points for customers/workers and shipments/deliveries) see the greater runtimes
- UHs conditioning interior zones see the smaller runtimes, with some having no runtime at all – especially in the larger square footage buildings
- National account buildings with identical UH layouts can show consistent UH runtime patterns. With predictable runtime patterns for UH layouts, it presents an opportunity for selective high-efficiency upgrades for high-runtime UHs in the future.

In collaboration with the Nicor Gas Energy Efficiency Program (EEP), Resource Solutions Group, (implementation contractor for the unit heater rebate program in Chicagoland), and other partners, monitoring of the non-condensing unit heater runtimes were expanded beyond the retail sector into manufacturing, warehousing, and automotive/truck service applications. Whereas, retail applications account for only 10% of the unit-heater market, manufacturing accounts for 30%, warehousing 20%, and automotive 20%. The data analysis from these additional applications show runtime trends similar to those previously described for the retail stores.

For testing, a condensing unit heater was retrofitted with a transport membrane humidifier (TMH) in place of its original secondary condensing fin-tubed heat exchanger. This preliminary laboratory investigation was intended to determine if the TMH and its conversion of condensate into humidified supply air could possibly preclude the need for a costly condensate drain line. In the TMH-equipped unit heater, the initial design did not produce the anticipated magnitude of humidification effect because of the altered combustion air-pressure and temperature levels exiting the primary heat exchanger. The results were encouraging enough, however, that a separate follow-on project has been brought forward for consideration that would test a second, improved design of the TMH equipped unit heater.

Status

Remaining tasks include:

- Delineate payback economics in various building applications/climatic locations and define appropriate energy efficiency program incentives, based on all the unit heater runtime/gas use results from the field
- Finalize TMH recommendations for alternative treatment of unit heater condensate and potential elimination of condensate drain line.

A Final Report will be available by year end 2014.

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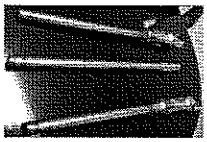
UTD Utilization Technology Development

Low-NO_x Residential Furnace Design Development

In this project, a research team evaluate several residential furnace technologies with the potential to provide significant emissions reductions. The goal is to develop products capable of meeting emission levels adopted in southern California without significantly changing existing residential furnace designs.



Project Description

In 2009, California's South Coast Air Quality Management District (SCAQMD) announced a new nitrogen oxide (NO_x) emissions requirement of 14 Ng/J (nanograms per Joule) emissions for regions of southern California. Currently, manufacturers of residential gas-fired furnaces cannot achieve this level with their existing designs.

In this project, researchers are teaming with the gas industry and residential furnace manufacturers to develop designs for residential furnaces capable of meeting the new SCAQMD NO_x emissions rate.

In a previous UTD project, researchers identified several technologies that have the potential to lower the NO_x emissions of existing residential furnaces. In this project, research focused on the evaluation of four technologies that could potentially meet the emissions requirements without significantly redesigning existing residential furnaces:

- Metal Foam Burners
- Inshot Burner with Screen Mesh Burner Extension
- Flue Internal Recirculation Inserts (FIRI)
- Modified Cyclonic Burner.

Four prototype furnaces using the four technologies will be developed.

Reports will provide details on the NO_x-lowering potential, the cost, and the feasibility of installing each technology into a production residential furnace.

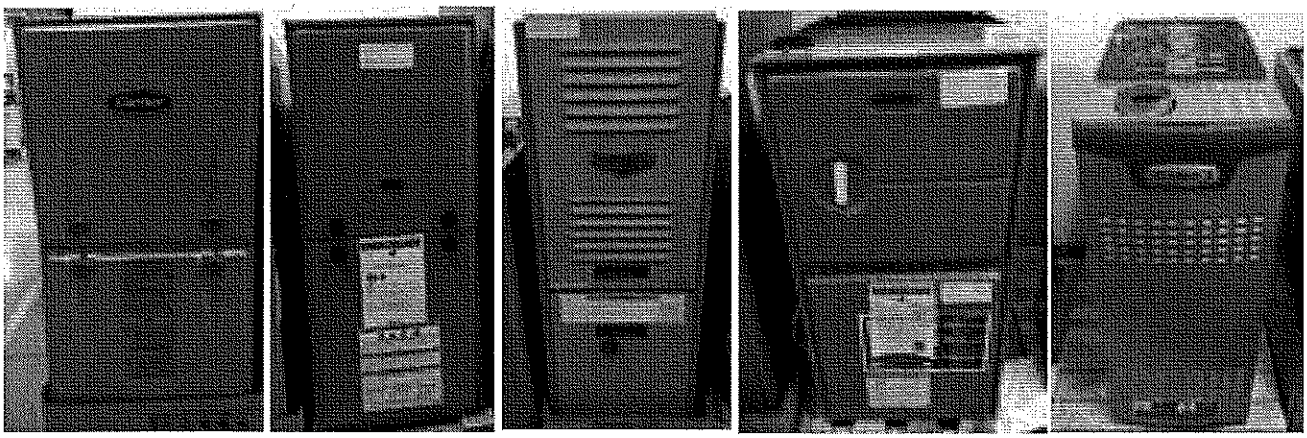
Benefits / Market Implications

Gas-fired furnaces have been shown to provide significant environments benefits over electric equipment. According to the Carbon Management Information Center, for every gas-fired furnace replaced with an electric unit, the national average increase in carbon dioxide emissions is 1,720 lbs/unit (a 23% increase over a gas-fired unit).

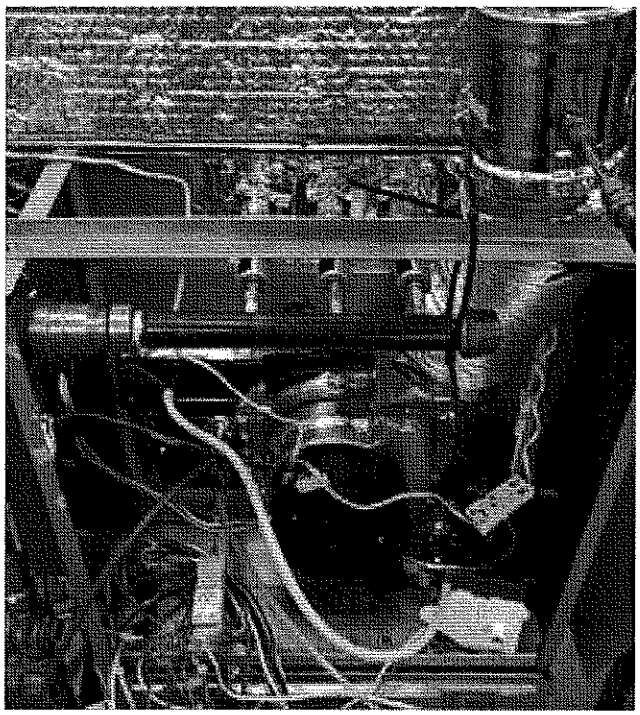
Technical Concept & Approach

In this project, four technologies were evaluated to determine their exact NO_x-lowering capabilities and the feasibility of installation in existing residential furnaces. Each technology was prototyped, bench tested, modified, installed, and tested in existing residential furnaces. Both condensing and non-condensing furnaces will be studied and tested.

Results will be presented to residential furnace manufacturers to help in determining the technologies that meet individual needs. Efforts are under way to partner with manufacturers to integrate the technologies into existing residential furnaces and test the performance.



Prototype furnaces used for performance and NO_x testing.



Burner installation in a prototype furnace.

Results

Initially, a test furnace was designed and installed at Gas Technology Institute (GTI) laboratories for the investigation of burner technologies. Prototype burners were constructed, with designs for the Metal Mesh, Metal Foam, Cyclonic, and FIRI burners developed and refined.

Two burners designs – the metal foam extension and metal mesh extension burners – were extensively tested with varying results. The emission analysis for these burners showed that some of the air-fuel mix was bypassing the flame zone, resulting in elevated CO and unburned hydrocarbons. Further evaluation of each burner determined that the percentage open area for the distribution was too large to achieve the desired flame distribution at typical induced draft pressures. To correct this, each foam burner was redesigned with a new distribution plate.

In 2012-2013, prototype residential furnaces of varying sizes from five manufacturers were tested for NO_x emissions and performance.

Because of the geometric constraints of the furnace, the round foam burner has advantages over the other designs. Several new round burners were designed and constructed. A new burner was built using a smaller distribution tube (5/8-inch diameter) which resulted in the improved flame distribution. Data showed the performance of this burner to be the best so far.

A Screen Mesh Extension Burner was designed, built, and tested. Initial testing of the burner showed that the flame tended to burn at the end of the burner. To correct this issue, the induced draft blower pressure was reduced by opening a gap between the quartz tube and burner mount to allow secondary air to flow around the burner.

Testing of the FIRI burner resulted in NO_x emissions in a range of 10 to 20 Ng/J at CO emissions in excess of 100 ppm. Another version of the FIRI burner was constructed by adding a tube to the burner face of a standard furnace inshot burner.

The method of achieving low NO_x emissions involves changing only two components on the existing manufacturer's furnaces: burners and blowers.

Burner tube and foam metal manufacturers were identified and the prototype distribution tubes delivered to GTI.

Status

The prototype development phase was completed in 2013 and the design specifications delivered to the manufacturers.

The project team is also working on a method to ignite the burners. Existing methods used with inshot burners that have wings on the burner that transfer the flame to all the burners would not work in this application. A potential solution involves an igniter used for high-end residential cooktops. The igniter has a single circuit that can create a spark and flame sense at six different igniter locations. GTI obtained one of these ignition modules and tested the unit to confirm its performance. Information about the unit is being transferred to the manufacturing partners.

Commercialization plans include meetings with manufacturers to discuss results and issues

Next steps involve assisting furnace manufacturers with installing the low NO_x burner technology into commercial units

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UTD
Utilization Technology Development

North American Field Demonstration of Combination Space- and Water-Heating Systems

For this project, researchers collected performance data on a large sample of combination space- and water-heating systems for evaluation and use in policy papers, energy-efficiency programs, and in guiding future product improvements and developments.

Project Description

While space heating currently dominates the energy budget in homes in northern-tier states, it is being supplanted by water heating and air conditioning in new homes and energy retrofits. As space heating becomes less important, the willingness to pay a cost premium associated with high-efficiency natural gas in both space and water heating is diminished. To maintain natural gas as a relevant option, a strategic move for the natural gas industry is to address both space and water heating with an efficient single piece of equipment, such as a combination space- and water-heating system.

In a previous research program, 30 combination space- and condensing-water-heating systems were field tested throughout North America. The research data provided useful information on component reliability and failure, installation techniques impacting system performance, optimization, and efficiency.

In recent years, the variety of available combination systems and configurations has increased. Revised standards for combination systems have been issued in Canada (CSA P.9) and are under consideration in the United States (SPC-124). Current limitations are that its coverage excludes electric appliances, is limited to forced-air heating, and water heating does not reflect "Real Use." SPC-124 is currently under revision to combine the two standards and expand the standard to include radiant in-floor and hydronic heating.

In this project, high-resolution data-acquisition systems were used to measure combination system performance and efficiency in a large set of installations. Deliverables for this project include: a data-acquisition package; field-test protocols and procedures; a field survey report; a combination system field performance report; and standards updates.

Benefits / Market Implications

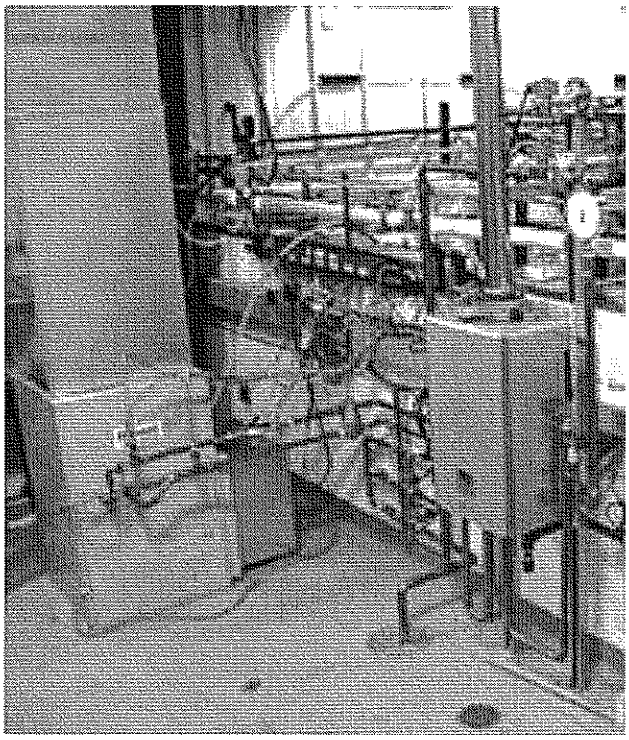
Information developed in this program will help utilities, plumbers, and HVAC professionals identify combination system configuration, integration, and installation variations and practices that limit combination system performance.

Technical Concept & Approach

This project focuses on data gathering and analysis, information development and dissemination, and support for the development of codes and standards. Specific activities include the development of common site-evaluation criteria, installation, site commissioning/ decommissioning, and data-collection protocols for a field test of combination space- and water-heating systems.

A research team will participate with weatherization and energy-efficiency programs and provide data-acquisition systems to selected programs. Data-acquisition equipment will be installed, commissioned, and used to collect data for one year. Researchers will analyze and report performance and efficiency data through monthly teleconferences.

Installers were surveyed to determine installation costs, techniques, equipment, sizing, and recommendations. Homeowners were surveyed on water use, cost, performance, and space-heating comfort.



System Efficiencies in Field Demonstrations

Site	Location	Description	Overall Efficiency
1	Ballston Spa, NY	System G - Hybrid solar thermal collector with separate tankless	75.90%
2	Warsaw, NY	System A - Integrated appliance tankless-AHU combo system	77.30%
3	Orchard Park, NY	System A - Integrated appliance tankless-AHU combo system	91.90%
4	East Syracuse, NY	System B - Integrated appliance tankless-AHU combo system	82.00%
5	Marilla, NY	System C - Combi boiler system	72.00%
6	Syracuse, NY	System B - Integrated appliance tankless-AHU combo system	86.30%
7	Ithaca, NY	System D - Separate tankless plus third party AHU combo system	92.60%
8	Ballston Spa, NY	System E - Separate tankless plus third party AHU combo system	89.89%
9	Binghamton, NY	System F - Separate tankless plus third party AHU combo system	91.70%
10	Syracuse, NY	System A - Integrated appliance tankless-AHU combo system	87.40%
11	Westchester, IL	System B - Integrated appliance tankless-AHU combo system	82.58%
12	Glen Ellyn, IL	System B - Integrated appliance tankless-AHU combo system	88.01%
13	Hoffman Estates, IL	System B - Integrated appliance tankless-AHU combo system	85.36%
14	Libertyville, IL	System B - Integrated appliance tankless-AHU combo system	85.76%
15	Oswego, IL	System B - Integrated appliance tankless-AHU combo system	82.76%

Results

Results of leveraged field tests were presented through DOE's Build America Program and at the ACEEE Annual Water Heater Workshop. Results were also shared directly with manufacturers who have used the information to guide next-generation system development.

During the project researchers participated in the combination system performance standards under development under ASHRAE 124.

Fifteen field test sites were leveraged in this project in New York and Illinois: 13 forced-air tankless water heater combination systems, one gas-solar hybrid combination system, and one combination boiler system.

Major Findings:

- Combination systems installed in all of the monitored homes for this study met the space-heating loads. Host sites were from about 1,500 square feet to more than 3,000 square feet.
- Some homeowners reported cold-water slugs between hot-water flows. This is known as the cold-water sandwich effect and is a fairly common complaint with tankless water-heater operation. The cold-water sandwich effect is not attributed to added space-heating loads.
- An average of 130 therms per year (or 11.5% of domestic hot-water and space-heating gas use) was saved with the combination system when compared to a conventional furnace at 80% AFUE and water heater at 0.59 EF.
- Cumulative combination system efficiencies were from near 77% to about 93%.
- Most currently available hydronic air-handling units (AHUs) are not designed for combination systems with a condensing heating plant; therefore, water temperatures returning from the AHU to the water heater were not low enough to induce condensing water-heater operation.
- As with other space-heating systems (including boilers and furnaces), combination system efficiencies are negatively impacted by low space-heating load scenarios that increase cycling losses.
- Field tests for this study exposed installation deficiencies due to contractor unfamiliarity with the products and the complexity of field engineering and system adjustments to achieve high efficiencies.
- The average installed cost for forced-air combination systems was determined to be about $5,750. That cost would need to come down by about 15% to 25% to make the systems marginally acceptable in terms of utility total resource cost for the applications evaluated.
- Combination systems for year-round space-conditioning include an evaporator coil in the AHU that is often unrated with the hydronic furnace for cooling efficiency (SEER/EER rating).

Status

Systems are currently being decommissioned.

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UTD Utilization Technology Development

Integrated Contact Condensing Water Heater

In this project, proof-of-concept research was conducted in an effort to develop a low-emissions gas-fired condensing water heater that recuperates heat and recycles moisture.

Project Description

In recent years, electric water heating has been shifting to electric heat-pump technology. Industry experts note that for gas water heating to remain competitive, the first cost of high-efficiency condensing water heaters needs to be reduced.

A significant area of opportunity for cost reduction is in lower-cost, more efficient condensing heat-exchanger designs. Another opportunity is in enhancements to high-efficiency, low-emission burners.

Current product offerings for high-efficiency condensing gas water heaters have thermal efficiencies over 90%; however, they come with significant added costs when compared to non-condensing water heaters. Also making an impact on the market is the fact that commercial water-heater burners are being replaced with more expensive burners in order to meet emission regulations.

Current storage-water-heater designs contain down-fired burners with submerged multi-pass condenser heat exchangers. To condense, the submerged condensers require that the water temperature around the condenser be below the flue gas dew point temperatures (no greater than 115°F-120°F). For this reason, condensing storage water heaters typically advertise an "up-to" efficiency rating, acknowledging that they may only reduce flue temperatures to that of the water in the storage tank. These systems do not always condense, operating well below advertised >90% efficiencies when the tank bottom has hot water.

Researchers are exploring potential external condensers to solve this condensing issue and have filed a U.S. patent application for an integrated contact condensing water heater.

The objective of this project is to prove the concept – through component development and testing – of a low-emissions condensing water heater for residential and commercial applications that recuperates heat and recycles moisture.

Benefits / Market Implications

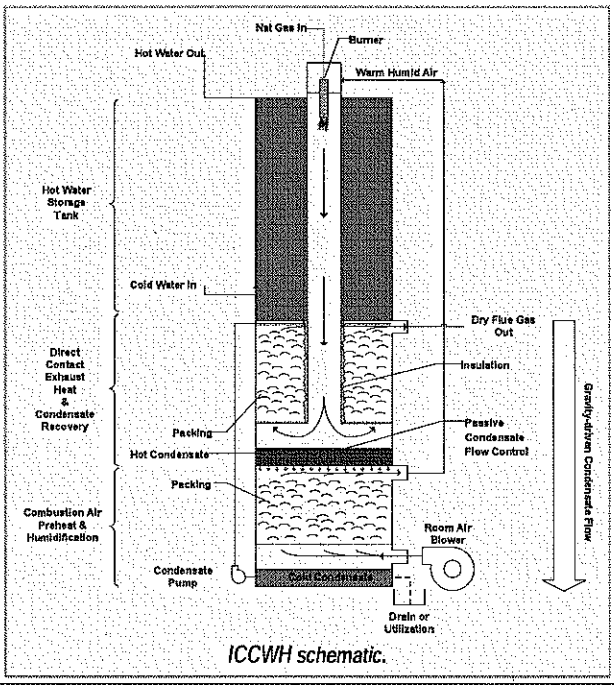
According to shipment data from the Air-Conditioning, Heating, and Refrigeration Institute, there are 100,000 gas-fired commercial water heaters shipped per year. Low- to mid-size condensing systems are priced from $5,000 to $15,000. Successful proof of concept would result in the development of a low-cost condensing water heater with increased market penetration and options for the consumer.

The Integrated Contact Condensing Water Heater (ICCWH) offers the potential to condense continuously, with a reduced storage tank size and less use of exotic metals.

Specific goals included the development of a low-emissions water heater that meets the regulations (14 ng/J NO_x) of California's South Coast Air Quality Management District.

Technical Concept & Approach

The design for the ICCWH is similar to the water vapor pump/wet-way combustion concept developed by Gaz de France and other research organizations.



ICCWH schematic.

Table 1

Application	Residential	Commercial	Industrial	Other
Domestic Hot Water	•	•	•	
Space Heating	•	•	•	
Space Cooling		•	•	
Cleaning		•	•	
Food Processing		•	•	
Sterilization		•	•	
Drying		•	•	
Dairy		•	•	
Mining			•	
Waste				•
Wastewater Treatment				•
Desalination				•

The ICCWH consists of three distinct segments: 1) the hot water storage tank, 2) the direct contact exhaust heat and condensate recovery system, and 3) the combustion air preheat and humidification sections. The overall goal of the latter two areas is to exchange the latent heat within the humid combustion products to the combustion air and keep it within the cycle. The system rejects dry, cool exhaust products and cold condensate, which during steady state is equal to the amount replenishing from hydrogen oxidation. That cold condensate that is not drained or utilized is recycled to the exhaust heat and condensate recovery system.

As a packaged system, the ICCWH will have a similar footprint to existing residential and commercial water heaters.

Specific tasks include:

- A patent and literature search to fine tune the experimental design
- Review of existing analytical and numerical models that characterize the transfer mechanisms of dehumidification, evaporation, and condensation processes for the ICCWH design
- Fabrication of the direct contact exhaust heat and condensate recovery system and the combustion air preheat and humidification sections of the ICCWH design
- Development and execution of a test plan.

Results

A review of potential markets found that the ICCWH technology has extensive possible applications (Table 1).

One set of experiments validated the ability of the ICCWH technology to condense flue gases at a lower dewpoint temperature. In lowering the dewpoint temperature, the ICCWH technology recovers both sensible and latent heat resulting in a lower flue-gas temperature and humidity. In one test, the result of recovered sensible and latent heat was a lowering of the flue gas temperature from 146°F to 77°F.

A second set of experiments was conducted to validate wet combustion, or the ability of the ICCWH technology to reuse or put the recovered sensible and latent heat back into the combustion air. Wet combustion results in higher burner efficiency, reduced emissions, and lower overall fuel consumption. While testing showed the process was able to increase combustion air temperature by 20°F and increase humidity up to saturation.

Status

ICCWH proof-of-concept testing occurred from June through July 2014. Results from these tests proved the ICCWH concept.

A Final Report is being prepared.

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Next-Generation Water-Heating Component Support

In this project, various gas-heat-pump water-heater components are being developed and evaluated in an effort to enhance the operation and lower the cost of the next generation of gas-fired heat pump water heaters.

Project Description

In efforts to maintain and enhance gas-fired water heating as a competitive and viable option, research is under way to develop next-generation gas water-heating equipment that incorporates advanced thermodynamic cycles.

In this project, a team of researchers is developing a residential/small commercial Gas Heat Pump Water Heater (GHPWH) to reduce costs and improve reliability through the refinement of a number of system components. The initial GHPWH development initiative was funded by the U.S. Department of Energy (DOE) through late 2012. This project was part of and is now a continuation of that development, led by Stone Mountain Technologies, Inc. (SMTI), with team members A.O. Smith Corporation, Georgia Technology Institute, and Gas Technology Institute.

Benefits / Market Implications

The motivation for developing a GHPWH is efficiency-driven. When delivered to the market, the GHPWH will be the only technology of its kind with a primary energy efficiency of greater than 100%. With natural gas prices projected to be at or below than $5/MMBtu for the next 10 years, the efficiency gains are not trivial with efficiency factors of 1.5 or greater, 88% to 140% greater than condensing and non-condensing water heaters, respectively.

Results from this project have the potential to reduce the cost, increase the reliability, and enhance the performance of the next generation of gas heat pump water heaters.

Technical Concept & Approach

Project efforts are addressing:

- **Corrosion Control**

  For ammonia-water absorption systems, corrosion of components and piping is unavoidable; however, it must be managed to outlast the corrosion rate of the hot-water storage tank. A literature and patent review was conducted to better support this critical feature of the GHPWH.

- **Codes and Standards**

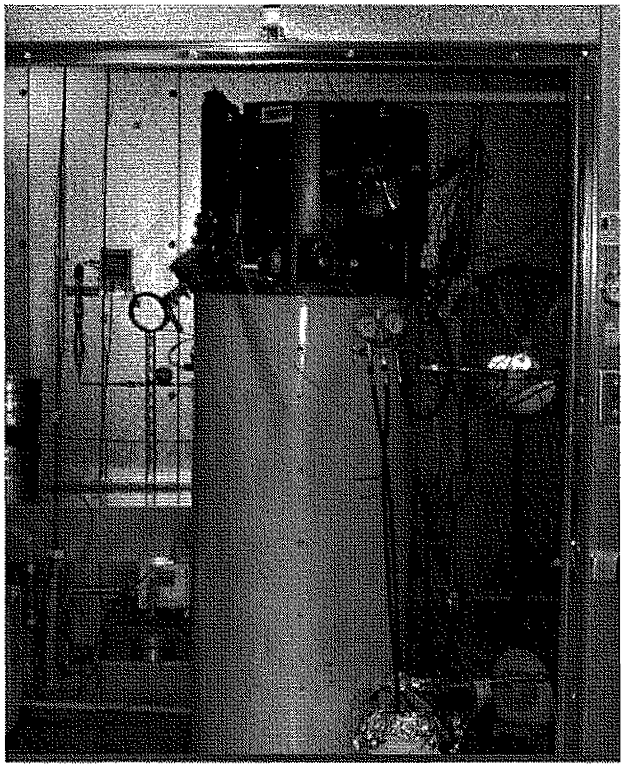
  As sized, the GHPWH will be classified as a residential storage water heater and a heat pump. With this "dual identity," many overlapping design and certification requirements must be understood.

- **Optimized GHPWH Evaporator and Thermal Expansion Valve Design**

  For the purposes of GHPWH breadboard testing, the evaporator of the cycle was water cooled to better facilitate measurement of heat transfer.

- **Aggressive Testing of Refined Beta Prototypes**

  Following the close of the DOE program, the project team will have three working beta prototypes. As an intermediate step between the completion of



First-generation beta GHPWH testing.

these laboratory-packaged units and the rollout of multiple refined GHPWHs prototypes into a friendly field test, beta units were tested and refined through a series of aggressive tests.

"We are very pleased to be supporting this initiative. In the next five to 10 years, proposed government performance standards for residential water heaters will increase, necessitating that natural-gas water-heating products meet or exceed these energy-efficiency targets. The performance target established for this product-development program ensures that these requirements will be fulfilled."

- Bill Castellan
Senior Program Manager, DSM Technology Business Development and Customer Strategy
Enbridge Inc.

Results

In 2013, the project team completed a multi-year effort to develop and demonstrate a cost-competitive gas-fired absorption heat pump water heater through laboratory research. Unlike the typical storage water heaters, the GHPWH heats water with a small natural gas burner (approximately 6.5 kBtu/hr) driving an ammonia-water absorption cycle.

Development included:

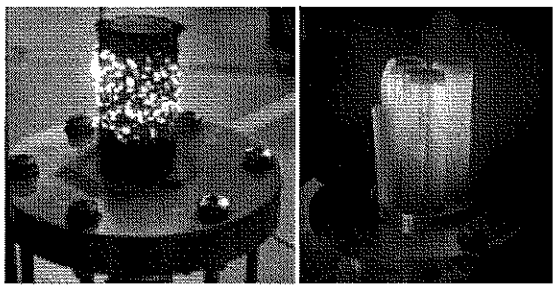
- Absorption cyclic modeling
- Experimental breadboard evaluation of standard single-effect and more advanced cycles
- Design of heat pump/storage tank integration, component development (e.g., the gas burner), and
- Evaluation of packaged prototype GHPWHs.

The project team met primary performance goals with COPs above 1.5 and with projected compliance with emissions requirements.

A report was issued in December 2013 that details the development of a combustion system and the evaluation of a packaged Beta GHPWH within an environmental chamber.

Findings

Combustion System Development – Initially, a working combustion system composed largely of off-the-shelf components was specified to operate a breadboard heat pump system. This assembly met performance targets, however it lacked robustness and did not meet CO emission targets. Subsequent component refinement was required, and a complete gas train was specified for the packaged GHPWH prototype that met performance targets.



Burner testing.

Beta Packaged System DOE Testing – Following the heat pump cycle modeling, breadboard heat pump testing, heat exchanger and tank design, and development of an effective solution pump, an Alpha packaged prototype was fabricated and evaluated. From these initial results, three single-effect Beta GHPWH packaged prototypes were designed and built for evaluation. Testing focused on non-standard conditions within an environmental chamber. Performing seven 24-hour simulated-use tests, five ambient conditions were tested with dry bulb and dewpoint temperatures simulating a range of conditions. Heat pump and system-wide coefficients of performance (COP) exceed 2.0/1.5 at the hot/humid condition and 1.5/1.2 at the cold/dry condition respectively. A clear path is defined to reaching the 1.3 Energy Factor (EF) target.

Water Heating System Application Modeling & Test Method Development – Through three interested parties: the DOE, Air Conditioning, Heating, and Refrigeration Institute (AHRI), and ASHRAE, the method of defining and rating residential water heaters are both currently under revision. As a task wholly cofunded from a California Energy Commission program focusing on opportunities for high-efficiency water heating, data generated during this GHPWH development were used to inform this revision process, through the ASHRAE Standard Projects Committee (SPC) 118.2 and also used to develop a comparative analysis of operating economics for GHPWH versus other gas water heating options.

Status

The project is currently in the field-testing phase.

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UTD Utilization Technology Development

Impact of Water Quality on High-Efficiency Water-Heating Equipment

A study was conducted to define water-quality issues impacting gas water heating, research the industry's current approach in addressing water-quality issues, and identify the potential pathways toward improving the reliability and performance of gas water-heating equipment.

Project Description

Common water contaminants (e.g., chlorides, fluorides, and sulfates) can cause corrosion of heat exchangers, piping and pipe connections, and the tank wall of water heaters – and the rate at which internal corrosion or scale buildup occurs increases with elevated water temperatures in the water heater. In addition, condensing heat exchangers, with their high surface area-to-volume ratios and rapid heat transfer, are more susceptible to liming and water-quality problems.

Prior to the initiation of this project, there had been no studies conducted to characterize the effects of water quality on high-efficiency condensing water-heating-equipment performance.

A 1987 study concluded that the efficiency of gas-fired water heaters declined about 5% with 60 pounds of scale buildup. This equates to about 20 years of normal usage with very hard water. Gas units tested in the study were bottom-fired units. (No high-efficiency units were tested). Reduced efficiency would be significantly less to non-existent in gas-fired top-fired water heaters and in water heaters located in softwater areas or in households that employ water softeners. While the efficiency of electric water heaters tested in the study remained constant, scale buildup did cause some electric heating elements to fail pre-maturely.

In 2009, limited accelerated life testing sponsored by the Water Quality Association found that noncondensing tankless water heaters operating on unsoftened water showed an average thermal efficiency drop from 80 % to 72% after an equivalent 1.6 years of service. At that point, a maintenance de-liming procedure was used to clean the heat exchanger. After the procedure, average efficiency only recovered to 77%. While the results of the study point out the benefit of water softening treatment, the study was not complete due to a very short running time (90 days of testing). In addition, condensing storage and tankless water heaters were not part of the study.

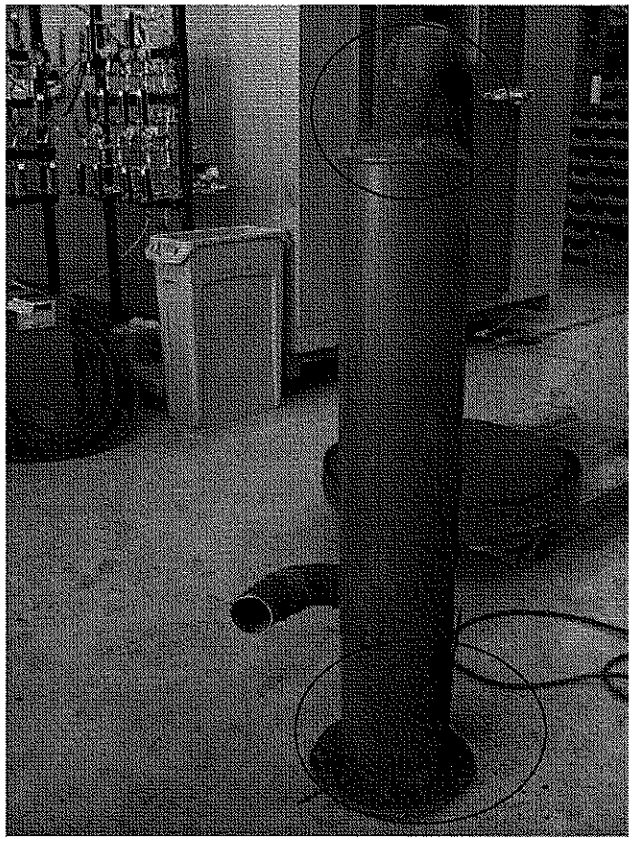
Experts note that the recent growth in market share of high-efficiency water heating and the rate of population growth in areas of hard water warrant a preliminary investigation into water-quality issues and strategies.

The objective of this study was to define water-quality issues impacting gas water heating, clarify the industry's current approach in addressing water-quality issues, and establish if a technical approach is needed to ensure the reliability and performance of high-efficiency gas water-heating equipment.

Deliverables from this project include a case study of condensing water-heater failures, an annotated literature review, survey results, and a primer on water-quality issues impacting gas water-heating equipment.

Benefits / Market Implications

A 3% change in the efficiency of an appliance can be a significant impact in demand-side management and energy-efficiency programs.



Heat exchanger shows signs of heavy usage; accelerated glass degradation (circled).

In a recent U.S. Department of Energy residential water heater rulemaking analysis, tankless water heaters with an annual maintenance cost of $50/year for de-liming showed a payback of 21-25 years.

Knowing the long-term impacts of water quality on the efficiency and performance of high-efficiency water-heating equipment can result in better energy-efficiency program designs and objectives and targeted research in improving long-term equipment performance.

Technical Concept & Approach

As part of this project, researchers conducted a case-study investigation on failed high-efficiency water heaters. A foodservice chain that was experiencing premature failure of its condensing water heaters was used for the case study.

Subject systems were investigated through a variety of methods, including: microscopic examination/fractography, scanning electron microscopy, infrared spectroscopy, chemical analysis, and physical properties testing.

The results will be compiled into a Final Report with recommendations where appropriate.

The research team also reviewed available literature and test data to clarify water-quality issues and methods of treatment. Interviews were conducted with manufacturers, end users, and industry experts on water-quality issues. Researchers will provide feedback to manufacturers and industry experts and develop a strategic research plan on water quality.

Results

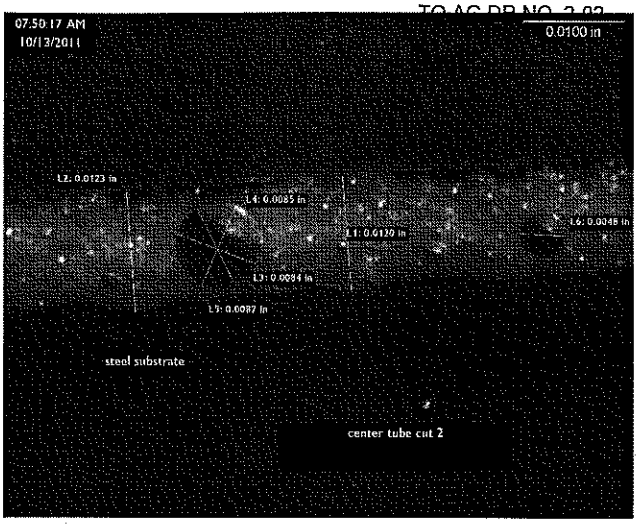
In June 2011, researchers launched a case-study investigation at a chain restaurant to determine if water quality contributed to the failure of a commercial condensing water heater before its expected service life.

Research found uneven glaze coating of the heat-exchanger coating. Large bubbles in the glaze coating of the tank and heat exchanger suggest contamination during the coating process. These bubbles could develop into failure points in the coating resulting in water-to-metal corrosion.

Recommendations are to improve the manufacturing process, review and improve quality control, and institute an inspection process.

Key Manufacturer Findings:

- Signs of heavy usage; accelerated glass degradation. (Suggests under-sizing and /or operational issues.)



Cross-section view of glaze coating with large bubbles.

- Uneven coating; missed spots. (Suggests slurry/ process issues in manufacturing.)
- Bubbles. (Suggests insufficient blast/contamination).

Prior to this investigation, the manufacturer instituted the an improved blast process for metal surface cleaning prior to coating (new equipment /doubled blasting). Two quality-control inspections (visual inspection and electrochemical detection of exposed steel) were established in its manufacturing process to ensure a proper glaze coating

According to the manufacturer, these measures should significantly improve the lifetime of commercial water-heating units even if exposed to heavy use or undersized applications.

Status

The case study investigation report on the failure of a commercial condensing water heater is complete. Results of a literature review are in the final stage of review.

Discussions with tankless installers and industry subject-matter experts are being collated for the Final Report.

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UTD Utilization Technology Development

Opportunities to Include Gas with Residential Electricity Feedback Devices and Programs

In this project, investigators evaluated a range of energy-feedback systems – from basic enhanced monthly bill inserts to fully automated disaggregated home energy management – and highlighted opportunities for the integration of natural gas with electricity feedback, sensors, and controls.

Project Description

Feedback enables individual households to better understand their energy use, thereby fostering energy savings. In addition to energy savings, feedback can help educate consumers about energy use, demand, efficiency, and greenhouse-gas emissions. A 2010 study found that household energy-feedback initiatives, on average, reduced individual household electricity consumption between 4% to 12% across a multi-continent sample. Research also shows that feedback accompanied by automation and controls increases energy and demand reductions.

In recent years, there has been significant research, interest, and innovation in enhanced energy-feedback systems. New metering and infrastructure technologies are allowing for new possibilities for enhanced feedback on both sides of the meter. However, the large majority of feedback programs are for electricity only, despite the fact that gas represents a significant portion of energy usage and cost for many of the nation's residential consumers.

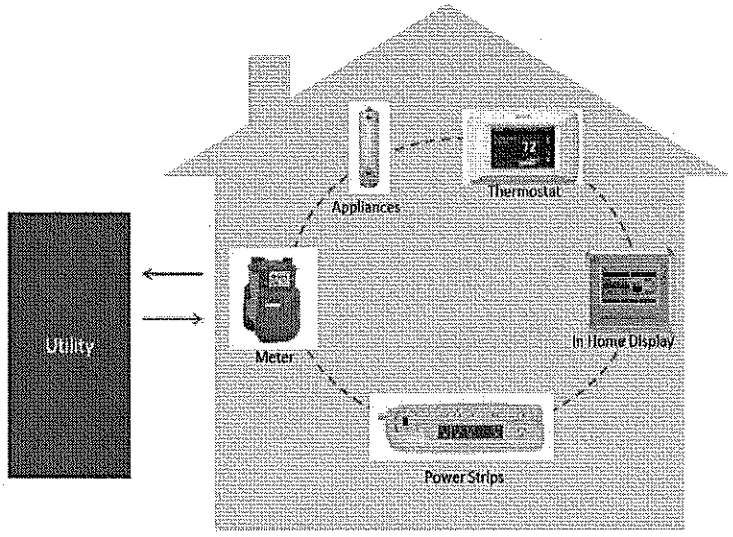
The introduction and use of feedback devices and programs is motivated by several factors, not all of which apply to gas (e.g., electricity demand management and peak avoidance). As natural gas represents a significant part of source energy consumption in many U.S. residences, it is logical to include natural gas as part of any whole-home feedback and control strategy.

The objective of this project was to evaluate residential energy-feedback systems across the technology spectrum from basic enhanced monthly bill inserts to fully automated disaggregated home energy management.

Research results will be presented in a detailed report that can serve as a guide for utilities. The guide will provide an overview of technology and program options and opportunities, program costs, expected savings, viability, ancillary benefits associated with different approaches, case studies of feedback programs in action, and "best practices" for successful program design and technology selection.

Benefits / Market Implications

Energy-use feedback and education represents a significant opportunity to enhance residential customer service, meet energy-efficiency-program goals, and initiate related energy-efficiency programs. Results of this project can assist the gas industry in helping to offer homeowners a full view of their energy consumption, especially in climates where gas represents the majority of residential energy use.



Technical Concept & Approach

Main tasks in this project included:

- An evaluation of residential energy-feedback systems across the technology spectrum from basic enhanced monthly bill inserts to fully automated disaggregated home energy feedback and management
- Identification of cost-effective options with likelihood of commercial success
- An evaluation of how to integrate natural gas with electricity feedback and controls
- Identification of principal opportunities and risks related to energy-efficiency programs and general operations of feedback and other behavior-related initiatives.

Results

As part of the information-gathering effort, researchers participated in the U.S. Department of Energy's Building America Standing Technical Committee on Home Energy Management Systems and attended Behavior, Energy, and Climate Change conferences. Researchers also performed numerous interviews with a broad selection of stakeholders, including utilities, software and hardware developers, and academic researchers.

This project effort was co-funded by the U.S. Department of Energy's Building America Partnership for Improved Residential Construction team led by the Florida Solar Energy Center.

Initially, a literature review was performed and stakeholders, product manufacturers, and academic experts were interviewed. Feedback can be categorized as direct (real time) or indirect (post facto), and existing research has demonstrated that these two types achieve different levels of savings. Direct feedback can achieve whole-home energy savings averaging about 5% to 15%, while indirect feedback generally yields savings averaging about 4% to 8%.

A primary direct feedback option is an in-home display (IHD) that can show a variety of information, such as real-time energy use, energy cost for a day or month to date, and historical energy use. Commercially available IHDs monitor electricity and even water use in some cases, but no options for monitoring gas were identified. There has been ongoing debate about how critical or not an IHD is to providing effective feedback, and given the challenges faced by an IHD for gas monitoring, it is clear that non-IHD options should be considered.

Indirect gas feedback through enhanced billing does not offer consumers information in real time, but does provide significantly more information than a typical utility bill (including neighbor comparisons, tips and recommendations, and normative ratings). Enhanced billing has grown rapidly over the past three years, with estimates that about 5% of U.S. households received these types of comparative reports in 2011.

While not considered a feedback device in itself, the development of advanced, internet-connected thermostats presents an early-market entry point for residential gas feedback.

The nascent, but growing smart gas grid infrastructure represents another feedback opportunity. Although less market-ready than enhanced billing and smart thermostats, gas advanced metering infrastructure offers two-way communication potential and the ability to access real-time meter data. This could be used to develop an alert/notification system for consumers regarding their gas use, including warning of unusually large usage, providing recommendations, or even participation in an energy savings goal-setting program.

Status

Research for this project has been completed and a Final Report is being prepared.

The timeline for the project was extended to develop a better understanding of customer perceptions of feedback value, business models for delivering feedback, valuing additional non-efficiency benefits (such as operational and measurement and verification benefits), and other issues. While the project initially targeted residential customers and home energy-management systems, the business value and potential opportunity with commercial gas customers are being evaluated as the customer is focused on improved profitability and reduced overhead. Advanced metering and diagnostics may have initial success in markets where the value of such technology can be readily equated to the bottom line.

A roundtable discussion with national account businesses (hotel/motel, large restaurant, "Big Box" retail) will evaluate advanced gas communications/feedback technology features in relationship to day-to-day business operations. In addition four to five small-to-medium-size businesses will be interviewed to assess technology needs in advanced gas communications/ feedback technology.

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UTD Utilization Technology Development

Evaluation of Whole-House Residential Retrofit Technologies

For this project, researchers are conducting laboratory tests, field studies, and energy analyses to support the option for gas technologies designed to reduce energy costs in existing residential buildings.

Project Description

Whole-house residential retrofit energy-efficiency programs are becoming more prevalent throughout the United States. In many climates – particularly, cold regions – natural gas represents the majority of the energy-savings potential.

The focus of this project is on developing needed information and supporting the natural gas industry in communicating the benefits of gas technologies – specifically, the ability of gas-based technologies to provide cost-effective energy use and carbon-emission reductions.

Activities in the program are being conducted by a research team at Gas Technology Institute (GTI). GTI leads the Partnership for Advanced Residential Retrofit (PARR), a U.S. Department of Energy (DOE) Building America (BA) team. PARR has a mid-western cold-climate-technology focus dominated by space-heating energy consumption. BA research provides opportunities to present UTD findings promoting intelligent use of gas appliances to reduce source-energy consumption in existing homes.

Benefits / Market Implications

This project is providing data and analysis to support natural gas technology assessment and installation practices in existing residential buildings. It is anticipated that project results will support the continued use of gas equipment and systems in retrofit situations as the most cost-effective potential single measure or as a part of an energy-efficiency package.

Technical Concept & Approach

In cooperation with the BA program, researchers are verifying the performance of measure packages that provide cost and energy savings, addressing code concerns, and investigating new opportunities in existing single and multifamily buildings.

Investigations are under way on several key areas of research: 1) optimizing gas furnace performance in the field, 2) testing the laboratory performance of furnaces removed from the field, 3) improving the performance of multifamily buildings that use gas for steam and hydronic heat, 4) measuring the laboratory and field performance of combination heating and water-heating systems, and 5) determining the optimum energy upgrade packages for typical mid-western single-family building types.

Research is focusing on the following areas:

- **Combustion Safety**

  The project team will perform an analysis of combustion-air requirements and indoor pressure limits for common atmospherically vented appliances to identify needs. The team will subsequently investigate likely depressurization scenarios and communicate design guidelines for combustion safety to BA and the manufacturers.

- **Combination Systems**

  The project team will evaluate installation and sizing issues that could potentially reduce the performance of combination systems and identify needed changes in installation practices and rating standards to support the best installed performance for this product category. In addition, the team will conduct a laboratory test for a typical combination system and evaluate the performance under common part-load conditions to determine the likely impact on equipment efficiency in a retrofit situation.

Archetype home in Chicago included in ongoing investigations.

- **Multifamily Hydronic Systems**

  The project team will study the performance of hydronic- and steam-heating systems in multifamily buildings and investigate techniques for improving their performance. The team identified two hot-water-heated multifamily buildings in which to implement retrofits. Retrofits are to be installed in 2014 in order to collect several months of pre- and post-retrofit usage data.

Results

As previously reported, the PARR Building America team tested three furnaces in the laboratory using the standard ASHRAE 103 AFUE (Annual Fuel Utilization Efficiency) test procedure with varying levels of oversizing and external static pressure. Results show that high-efficiency furnace AFUEs are insensitive to oversizing in the range of 70% to 120% when evaluated according to the ASHRAE standard.

Twelve vintage furnaces were collected from the field for laboratory testing. Steady-state efficiency was calculated for each furnace from the field data. Test results show that there was no degradation in performance with time and that the efficiency of the furnaces in the field could be increased an average of 6% through tune-ups. In recent research, tuning steam and hydronic systems in existing multifamily buildings was shown to reduce energy costs by up to 10%. Appropriately sizing the steam traps, headers, risers, and pumps (hydronic), provided significant savings. The results of this research are being used by field practitioners.

The project team also supported a Chicagoland housing-characterization study of hydronic systems in multifamily housing and a measure guideline for combustion safety based on the National Fuel Gas Code.

Data was also collected for research in the following areas:

- **Combined Heating and Water Heating Systems**

  Five fully-monitored condensing combined heating and water heating systems were installed in the Chicagoland area, in New York, and in southern California. Data is being collected to support the use of this technology as a low-capacity solution in zero-energy-ready buildings.

- **Combustion Safety**

  PARR developed and submitted the Combustion Safety Measure Guideline for appliances using indoor air. The guideline was published by Building America. PARR has aligned with the Minnesota Center for Energy and the Environment, the Illinois Sustainable Technology Center, and Lawrence Berkeley National Laboratory to finalize a field-test plan and begin collecting data on the potential for vent-system failures in very tight houses where exhaust fans are used.

- **Single-Family Archetypes**

  PARR conducted an analysis of cost-optimal energy packages from the Illinois Home Performance program with the Energy Star program as compared to the packages selected by the Building Energy optimization tool for 15 single-family archetypes. The results show that applying cost-saving measures according to construction type in existing buildings can be an effective mechanism for energy savings without an extensive audit. In addition, homeowners tend not to select cost-optimal measures when given a menu of options, indicating the need for better tools for this sector.

Status

The research team continues to collect data on combination system performance from the laboratory and the field. A report will be published in 2014.

A 2013 study to identify the efficacy of floor air sealing as a radon-reduction technique was inconclusive. Activities in this effort are ongoing.

The research team proposes four key avenues for research for the gas industry:

1. Continue to work with BA to identify approaches to support atmospheric gas appliances while emphasizing combustion safety in residential retrofit.
2. Continue to develop field-performance information on combined space- and water-heating systems to address control system issues and improve the modeling of these systems.
3. Investigate the opportunity for outdoor-temperature-controlled ventilation to take advantage of buoyancy effects in cold climates.
4. Continue to investigate a low-cost method of mitigating radon in order to improve the home's energy efficiency with minimal safety impact.

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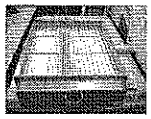
UTD Utilization Technology Development

Transport Membrane Humidifier – Low-Cost Fabrication Method Development and Evaluation

Efforts are under way to advance the introduction of a novel humidifier for home furnaces through the development of a low-cost fabrication method to significantly reduce the cost of production, assembly, and installation.



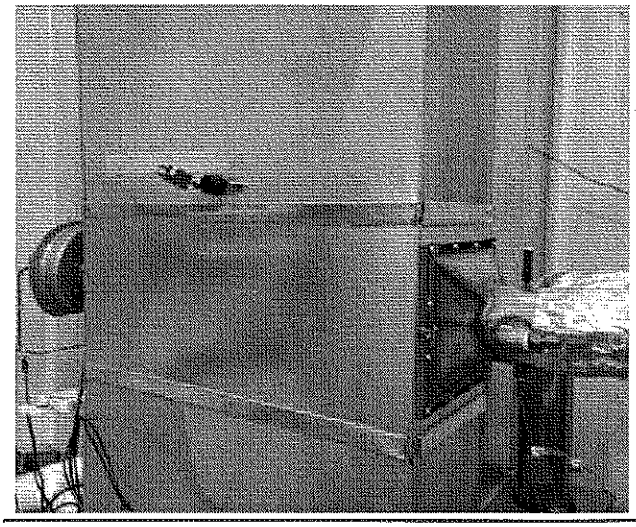
Project Description

Heated air in a home can be uncomfortably dry – especially on cold days – unless a humidifier is used. Consequently, millions of humidifiers have been installed on residential furnaces to help keep people comfortable and healthy, and also protect dry-sensitive home belongings from damage.

Currently, the most widely used residential humidification technologies are forced-air-furnace-mounted bypass-wetted media, spray mist, and steam humidifiers. However, these conventional home humidifiers have significant drawbacks, such as:

- Increased furnace fuel consumption
- City water consumption
- White dust formation in the home
- Mineral deposition requiring cleaning, and
- Microbial growth.

In previous research supported by UTD, researchers developed Transport Membrane Humidifier (TMH) technology, which can provide whole-house humidification without external water use and significantly boost a mid-efficiency home furnace efficiency by more than 15%. The technology was previously demonstrated in two single-family homes for two heating seasons.



In the initial phase of this project, assembly, installation, and TMH parts-manufacturing methods were investigated, resulting in the development of a low-cost fabrication tool for large-quantity parts fabrication. In the current phase, a pre-production TMH unit will be built by this method and laboratory tested.

Benefits / Market Implications

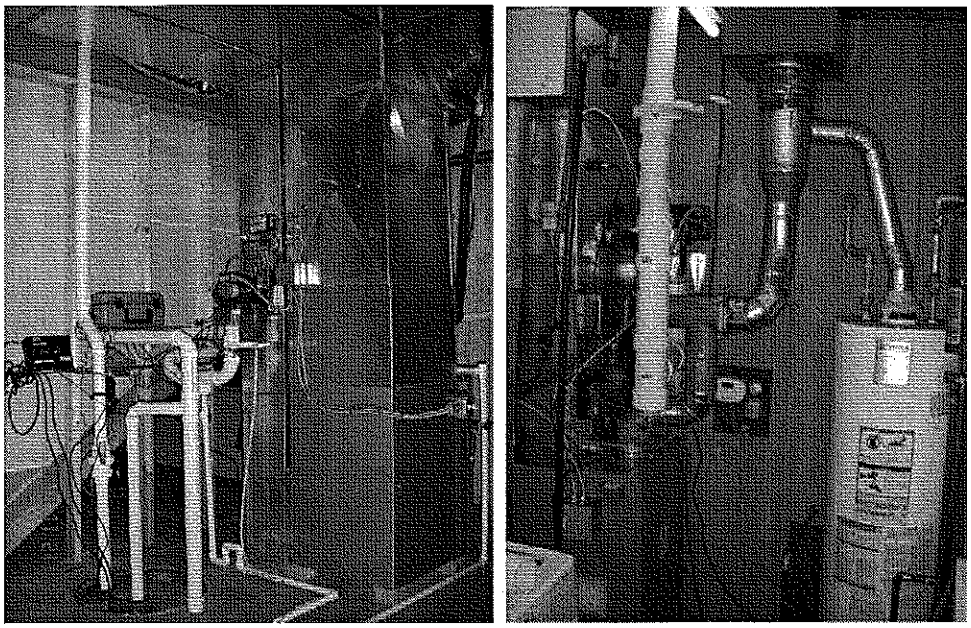
Gas furnaces typically have lower efficiencies for higher water-vapor content in the flue gas. However, the TMH can effectively use this water vapor for home humidification and at the same time improve the furnace efficiency, making the product potentially more attractive than other furnaces powered by electricity or low-hydrogen-content fuels.

Field-operating results showed that the TMH is a robust technology that can be used for home furnaces with significant advantages over conventional home humidifiers on the market, including:

- No need for additional furnace fuel consumption for water evaporation since the water is already in vapor phase coming from the flue gas
- Zero city water consumption
- No white dust in the home since only water vapor is coming from the flue gas through the TMH nanoporous membrane
- No mineral deposition requiring cleaning or changing of the wetted media, and
- No microbial growth because there is no standing water in the TMH to allow its growth.

Technical Concept & Approach

This project initially focused on the investigation and development of low-cost manufacturing techniques that can produce TMH parts in large quantity at a much lower cost so that the TMH cost can be significantly reduced to meet future commercialization cost requirements (mainly the payback period to justify the economics of the product).



Field trial TMH installations in two homes.

In 2012-2013, a low-cost fabrication method was developed and a sample amount of parts fabricated. The current phase focuses on a demonstration of the TMH unit operation using parts and the assembly method developed through this project. Using the easy installation approach that was developed, the TMH unit will be installed into a test furnace for performance tests.

Longer-term testing will be arranged to demonstrate the new TMH performance and showcase the TMH to potential commercializers.

Results

Although many fabrication methods were considered, sheet-metal stamping methods were selected to fabricate the TMH tube sheets, as well as other major parts (e.g., the inlet/outlet flue gas plenums). Since the TMH assembly requires much lower dimension tolerance than the Transport Membrane Condenser (TMC), the tube sheets – just like the other parts – can be made from sheet metal. This may significantly drop the cost and is also consistent with the material currently widely being used in the HVAC industry.

This method has the flexibility to fabricate different sizes of TMH parts by simple fabrication-tool programming adjustments.

Key features of the new fabrication tool:

- A built-in air bypass damper allows for humidity adjustment
- All TMH parts are made from sheet metal (about gauge 20) for low cost and easy fabrication-tool adjustment to fit all furnace/ductwork sizes on the market
- The current TMH module's two tube sheets and two side plates are now consolidated into one part instead of four, greatly reducing fabrication and assembly costs.
- For easy field installation, now the TMH module is sized exactly as the cross section of the air inlet ductwork. Thus, instead of inserting it into the ductwork (which needs opening holes in the ductwork, providing support for the module, and finally sealing of the openings), the new module can now be installed as one would replace a section of the ductwork and can be connected easily with the original ductwork with standard sheet-metal S-cleats.
- The two end flue-gas chambers can also be made from sheet metals easily with minimum welding requirements.

Status

The pre-production TMH unit for a condensing furnace was installed into a laboratory furnace to verify its performance. Long-term performance testing and monitoring are under way.

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UTD Utilization Technology Development

Enhancements for Combination Space- and Water-Heating Systems

The objective of this project is to conduct laboratory evaluations of potential enhancements to basic combination space- and water-heating system approaches that could improve load response, water-temperature stability, efficiency, and other operations.

Project Description

The application of gas-fired combination (combi) space- and water-heating systems has been gaining interest due to several factors, including:

- More thermally efficient building envelopes
- The decline of average home space-heating loads, and
- The emergence of new combi product lines capable of meeting domestic hot-water- (DHW) and space-heating loads with onboard integrated controls.

Gas industry research has responded with increased efforts in both laboratory and field activities to establish cost-effectiveness over competing high-efficiency equipment options, provide guidance for best practices, and validate simulation models.

Recent collaborative activity with manufacturers and research organizations identified several potential enhancements that can improve the performance and market competitiveness for combi systems.

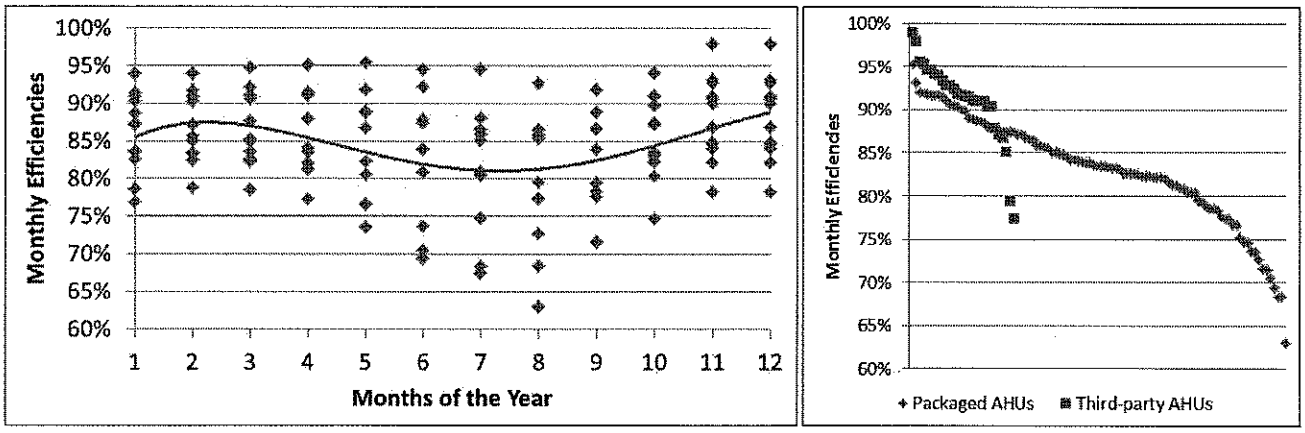
In other UTD-supported efforts, laboratory research for the DOE Building America program was conducted to test the performance attributes of various combi system configurations. Researchers also interacted with a portfolio of water-heater and air-handler manufacturers to install demonstration systems in New York, Illinois, California, and Connecticut. Nearly 20 single-family residential dwellings were retrofitted with combi systems and were or are being monitored for 12 months.

The objective of this specific project is to conduct laboratory evaluations of potential enhancements to basic combi-system approaches that could improve load response, water-temperature stability, efficiency, and other equipment operations. The attributes of systems that use air handler units with pre-engineered cooling components will also be tested.

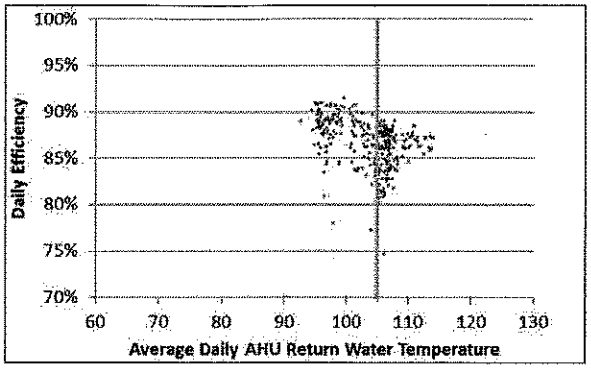
Benefits / Market Implications

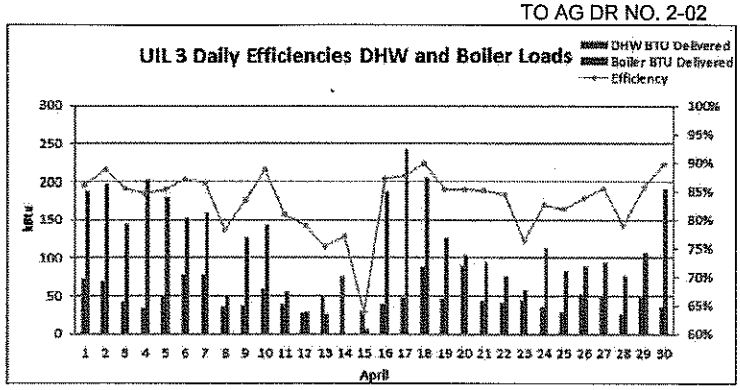
Some principal benefits of combi systems are:

- They address both major residential gas loads – single-gas hook-up and single-direct vent
- Integrated system improves program and consumer economics of upgrading to a high-efficiency water heater for domestic water uses
- Investing in one piece of high-efficiency equipment, and realizing significant energy savings for two end-use loads (and possibly three with cooling), improves technology utilization and thus payback for consumers



Researchers are analyzing a variety of data in efforts to enhance combination space- and water-heating systems.





- Multiple major manufacturers are entering the marketplace with competitively priced systems and national product support and training.

Modeling from UTD project 1.10.C indicated about 120 therms of potential gas savings annually for moderately-sized homes in cold climates. Data from 15 pilot homes in Illinois and New York demonstrated about 130 therms of gas savings on average. Savings are representative of both DHW and space-heating savings realized from the replacement of a traditional furnace and water heater with a combined high-efficiency (e.g., 94%) system. Carbon mitigation benefits are directly correlated with energy savings. Based on estimated therm savings, over 1,700 pounds of carbon dioxide emissions could be eliminated annually per combi system installation.

Technical Concept & Approach

This project focuses on the technical development and testing of three key combi-system enhancements:

1. Small, integrated storage volume
2. Combi-system air-handler improvements
3. Addition of a cooling component to allow for a triple-integrated appliance.

Specific goals are to:

- Identify the market drivers and manufacturers currently pursuing specific enhancement strategies
- Verify the potential benefits
- Generate specifications for the enhancements
- Develop, build, and test alpha prototypes in the laboratory under controlled and realistic conditions to determine if they meet specifications
- Identify technical challenges in meeting the specifications
- Develop a commercialization strategy.

Results / Status

This project laboratory testing related to integrated storage, advanced air-handler design, and integrated cooling for combis is ongoing.

The laboratory work was leveraged to secure multiple field demonstration projects with NYSERDA. In addition, the Gas Technology Institute (GTI) U.S. Department of Energy Building America team, Partnership for Advanced Residential Retrofit, and GTI's Emerging Technology Program are supplementing UTD combi system research through field demonstrations with Nicor Gas, Southern California Gas Company, and United Illuminating Company. These pilot projects are under way with well over 30 additional combi units installed for field research.

Field data confirmed laboratory findings that efficiencies are strongly correlated with the heating-loop operating temperature as well as the space-heating and DHW loads.

Laboratory research also found that integrating small well-insulated storage volumes (e.g., less than ¼ gallon) can dampen the effects of cold-water-sandwich by 60% to 70%. This can be done with oversized headers and can be more effective and less expensive than adding small electric water heaters, as is often recommended in the plumbing industry.

In collaboration with Auburn University, research is under way to further develop a combi system hydronic air-handler design that will demonstrate an advanced hybrid system with NYSERDA in 2015. That system incorporates an electric heat pump, on-demand gas water heater, and advanced hydronic air handler.

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UTD Utilization Technology Development

Unplugged Energy Star Water Heater

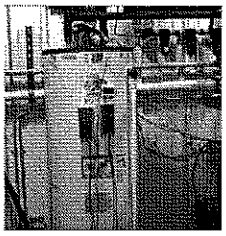
Research in this project focuses on the design and demonstration of an unplugged Energy Star water heater to provide a lower-cost option in high-efficiency water heating and an alternative to high-efficiency water heating that requires a plug.

Project Description

Currently, 88% of the gas water heaters in use are non-powered and operate during a power outage. However, no current high-efficiency gas water heaters can operate during a power outage due to their powered connection. That powered connection is at minimum a $150 cost addition to installation, and, in many municipalities, the cost is even higher. In the case of Energy Star water heaters, that cost addition can put the price of the water heater on par with that of the electric heat pump water heater.

In 2008, investigators conducted a review and conceptual analysis of low-power systems used for the ignition of natural gas in heating appliances and other combustion devices. Researchers also designed and evaluated potential thermoelectric concepts for water-heater integration based on performance, manufacturability, and serviceability.

The review and conceptual analysis found that:



- Power consumption of stand-alone ignition systems were approaching theoretically predicted minimum ignition energies, and
- A water-heater burner can require as low as 1 W of power for ignition.

Ignition circuits usually incorporate controls with sensing, alarming, reporting, and emergency shut-off features. These controls are readily available from several manufacturers with 12 VDC and 24 VAC power inputs; however, the systems are not optimized for low-power consumption. One low-power ignition/control unit demonstrated reliable ignition and safe re-ignition of the burner.

The review further found that powered control and shut-off valves had high power consumption. Some industrial control valves included direct-acting solenoids and magnetic latches that could be incorporated in water-heater control-valve designs and optimized for power consumption. Costs needed to be determined as well as implications to reliability and safety.

The project also included an investigation of alternative power sources for operational power or battery recharge. Five thermoelectric design concepts for water-heater integration were evaluated.

The objective of this new project is to build and demonstrate an unplugged Energy Star water heater with the following features:

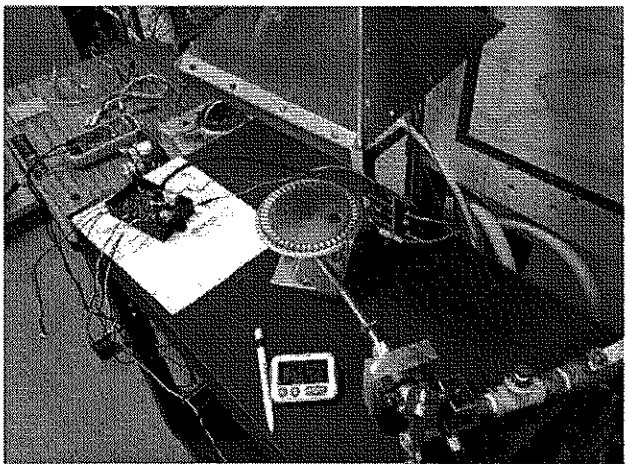
- An Energy Factor (EF) of .67
- Battery operation that powers a gas control valve
- Pilotless ignition system
- Vent damper.

Benefits / Market Implications

The goal of this project are to provide a lower-cost option in high-efficiency water heating and an alternative to high-efficiency water heating that requires a plug.

The design concept:

- Eliminates the standing pilot light (saving Btus)
- Eliminates the need for a powered connection (saving installation costs)
- Maintains Energy Star performance and high efficiency



Benchtop testing.

- Incorporates ultra-low-power components that can be used in other gas appliances.

Technical Concept & Approach

Specific tasks include: development of a control-strategy design; development of component specifications; component and system testing; and a review of results and modifications to components as needed.

Final system testing that will include a baseline test of an Energy Star water heater, a baseline test of an unplugged Energy Star water heater, and comparison reviews.

Efforts are also under way to develop performance curves of a prototype two-phase thermo-syphon water heater.

Results

In 2013, an opportunity assessment of the an "unplugged" residential gas storage water heater concluded:

- There are over 50 million residential gas storage-type water heaters in place today that are unpowered
- An "unplugged" water heater that was Energy Star compliant could will fill a product gap by providing high-efficiency water heating without an electric power connection
- The market opportunity for an "unplugged" Energy Star water heater was estimated at 169,000 units annually
- New efficiency requirements, effective 2015, stabilize the near-term opportunity for an "unplugged" Energy Star gas water-heater product
- An "unplugged" Energy Star gas water heater must be price competitive to its competition, $625 to $999 (2013)
- The "unplugged" technology target cost to the manufacturer is $130 to $200.

In benchtop testing, component functionality of a prototype "unplugged" system was proven. Preliminary measurements were made to establish a power budget. The system was subjected to five cycles where observations and measurements were taken to confirm operational functionality and to gather some basic data on the "unplugged" system. During a burner cycle, 2.8 Joules of energy were expended before the system recharge exceeded power use.

A powered Energy Star gas water heater was baselined for efficiency. The water heater was then modified and retested using the "unplugged" system. Efficiency results were comparable and consistent with estimates that the "unplugged" system should have a slight efficiency gain of 0.005 EF since it self-generates its own operational power

Status

A Final Report detailing testing and results is under final review. The technology has been licensed to a component manufacturer.

A follow-on test plan in support of the manufacturer is currently under implementation in 2014. Activities include:

- Characterization of the "unplugged" system performance to establish:
  - The power budget of the "unplugged" system during a burner cycle
  - The minimum power required to initiate a burner cycle
  - Minimum and maximum operating gas pressures under which the "unplugged" system can successfully operate
  - The minimum time required for power storage recharge.
- Evaluation of thermo–electric generators (TEGs)
  - Performance map and compare selected off-the-shelf TEGs
  - Examine conditional extremes that impact performance reliability.
- Demonstration of a reliable gas valve for use in an "unplugged" system
  - Modify an off-the-shelf hydraulic-actuated gas valve (30mV gas valve) with manually lit pilot to operate within the "unplugged system
  - Characterize the operational integrity of a hydraulic-actuated gas valve pre- and post-modification.

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UTD Utilization Technology Development

Codes and Standards for Advanced Gas Technologies

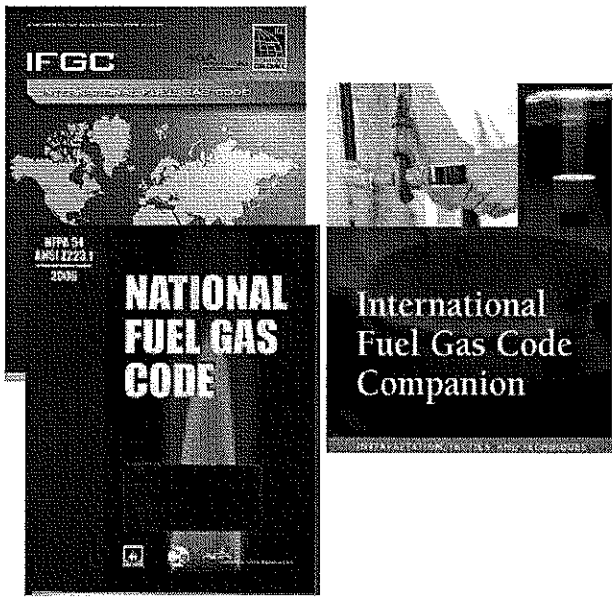
Through interactions with industry associations and code-development organizations, researchers are presenting scientific data and addressing codes and standards that can be barriers to the use of cost-effective advanced gas technologies.

Project Description

With low natural gas prices, electricity peaking challenges, and the growing concern with greenhouse-gas emissions, natural gas is becoming a more competitive option in the U.S. energy marketplace. However, the introduction of advanced natural gas technologies can be challenged by a variety of issues between the prototype stage and full market adoption.

In many cases, among the most significant and last remaining hurdles to widespread adoption are codes and standards (C&S). Advanced technologies are often developed to address problems with existing alternatives; however, new technologies are evaluated using existing criteria which may misrepresent performance, necessitate costly engineering redundancies, and delay market introduction. In many cases, advanced technologies will not be included in C&S without appropriate action. In addition, efficiency levels on existing technologies continue to increase, offering challenges for the gas industry with regard to installation, vent systems, durability, and reliability.

Another important area of focus relates to the tendency to increase the tightness of new and existing homes and the impact that has on the National Fuel Gas Code requirements for outdoor air for combustion and ventilation.



Previous UTD-supported C&S efforts include participation in the development of:

- ASHRAE 124 *Methods of Testing for Rating Combination Space-Heating and Water-Heating Appliances,* which included new data from laboratory experience.
- ASHRAE 118.2 *Method of Testing for Rating Residential Water Heaters* (resulting in de-rating of tankless gas units by building codes in California and Florida)
- NFPA 54, the National Fuel Gas Code (where sidewall vent penetration locations for high-efficiency equipment are restricted based on rules developed for lower-efficiency products)
- ASHRAE 103 furnace and boiler standards, recommending changes based on laboratory test results
- ASHRAE SPC 204 method for testing micro-combined-heat-and-power systems
- Codes related to condensing heat exchangers and condensate disposal from rooftop heaters and unit heaters.

The objective of this program is to address additional barriers to the use of cost-effective advanced gas technologies caused by gaps in standards development and testing, building code requirements and enforcement, and performance information for analytical tools used for energy code compliance.

Benefits / Market Implications

Information tools, cost-effectiveness calculations, case studies, technical data, and other products developed through this project will help the gas industry and its customers benefit by increasing the options of efficient, market-appropriate gas technologies.

By providing compelling data on market value, advanced gas technologies can be more rapidly developed and introduced to benefit gas consumers and help energy providers meet energy-efficiency-program goals.

Technical Concept & Approach

Through this project, research representatives are engaging with decision makers and providing credible technical data for input into the development of codes and standards.

By partnering with the U.S. Department of Energy (DOE), ASHRAE, Natural Resources Canada (NRCAN), the International Code Council (ICC), the American Gas Association(AGA), enforcement bodies, and other organizations, the research team will help to ensure that gas technologies are appropriately characterized and evaluated.

Specific tasks include:

- Identification of target codes and standards opportunities
- Advanced technology characterization for energy codes and standards
- Advanced technology characterization for safety codes.

Key target groups for technology-transfer initiatives include ASHRAE, AHRI (Air-Conditioning, Heating, and Refrigeration Institute), the AGA Building and Energy Codes and Standards Committee, the ICC, and other regional and national model codes.

Results / Status

In 2013, activities focused on water heating, combination systems, and gas furnaces. Other products will be addressed in 2014.

A representative from the research team joined the ASHRAE committee that is reviewing a revision to the method of test (MOT) for commercial water heaters. Substantial changes to the current MOT are expected to be made in 2014. These include:

- *Reduced Thermostat Setting* – Reducing the thermostat/temperature setting from 135°F to 125°F, to reflect temperature settings more typical of residential use.
- *Distributed Hot-Water-Draw Patterns* – The proposed MOT aims to quantify the energy efficiency of a water heater through execution of a 24-hour daily hot-water-use pattern.
- *Broadening of Scope* – The categories affected are electric tankless water heaters and storage water heaters with between two gallons and 20 gallons of storage.

"Codes and standards represent significant barriers to the adoption of new gas technologies as well as the consistent application of existing technologies across many jurisdictions. Research in this area has proven to be of significant value to the industry as we address and resolve code barriers."

- Jim Tilley
Sales Manager, Louisiana and Mississippi Region
CenterPoint Energy

The DOE released a summary report from its laboratory arm, NIST, evaluating the proposed MOT and held an all-day meeting in December, 2013, in which a project team member participated. DOE subsequently solicited comments from the industry. DOE, with NIST, will review and take into consideration all comments and plan to issue a final revised MOT in the middle of 2014.

For the ASHRAE winter meeting in 2014, researchers shared results from the testing of a modulating storage water heater with hydronic air handler for the ASHRAE Standard 124 combination heating and water heating standard development. Separate heating profiles were provided that could be tested in conjunction with water-draw profiles. The heating profiles are based on actual field test data at locations where systems are sized to meet specific outdoor design temperature conditions. These profiles, combined with data collected from other organizations and other field sites, can be used to determine typical usage profiles.

Also for the ASHRAE winter meeting in 2014, researchers participated in the update of ASHRAE Standard 103, *Method of Test for Annual Fuel Utilization of Residential Central Furnaces and Boilers*. Researchers supported revisions to the text to include mandatory language, updating references, updating references to codes, several substantive changes, and many editorial changes that make the standard consistent with the software and techniques used by manufacturers for testing high-efficiency furnaces. Legacy AFUE ratings continue to be supported in this update. The updated standard is expected to be approved by the committee at the January 2015 meeting.

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UTD Utilization Technology Development

Application of Innovative Gas Heat Pump Design to Space Conditioning

Current market conditions are providing opportunities for gas-fired heat pumps to become competitive with electric heat pumps in residential and small-commercial applications. This project focuses on the development and testing of a packaged gas heat pump prototype for space-heating applications.

Project Description

Gas-fired absorption cooling at the residential/small-commercial scale has traditionally experienced low market penetration and a lack of a domestic market. Familiar players in the 2- to 10-ton cooling size have limited offerings in North America and equipment costs estimated at $1,200-$2,000/ton on the low end.

With cooling coefficients of performance (COPs) at approximately 0.70, EnergyStar® efficiency vapor-compression electric air conditioners with COPs of 3.4 and above and with similar equipment costs are often more attractive. Similarly, gas-fired heat pumps (GHPs) in heating applications (air source) are able to offer substantial efficiency gains over typical non-condensing and condensing warm-air furnaces and hydronic boilers alike, with COPs estimated at or above 1.5 versus thermal efficiencies of 80% to 95%. Thus, a cost-competitive GHP could gain market share in the space-heating and/or cooling markets for residential and small-commercial applications.

In recent years, the gas industry has shown increased interest in these heat- and engine-driven heat pump cycles, primarily for residential and commercial applications. Key factors to this resurgence in interest are: a greater emphasis on energy efficiency with recognition that natural gas is a key driver to primary energy and carbon emissions reductions, strides made in material science and numerical simulation techniques, and the suppressed price of domestic natural gas.

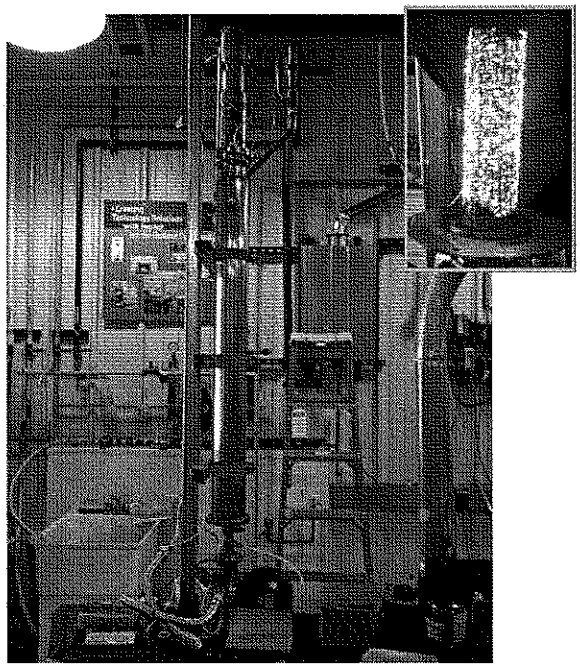
An example of this resurgence in GHP technology interest is an active program with U.S. Department of Energy (DOE) funding to Stone Mountain Technologies Inc., A.O. Smith Corporation, Georgia Institute of Technology, and Gas Technology Institute to develop a residential size GHP water heater (GHPWH), which was successfully demonstrated as the only technology of its kind with a primary energy efficiency greater than 100%. This R&D effort, now shifting into field evaluation, is being support by UTD to complement DOE funding, with cross-cutting efforts across platforms concerning investigations of diaphragm seal dynamics and corrosion protection.

Building on the proof-of-concept laboratory successes with the ammonia-water GHPWH, this same project team is extending this technology into space heating. While the system differs slightly, the engine driving the heat pump (the ammonia-water absorption refrigeration cycle) is fundamentally unchanged.

The goal of this project is to build and test a packaged heat pump prototype with a nominal capacity of 80,000 Btu/hr at 47°F ambient temperature at a manufacturing cost that supports a simple three- to five-year payback. The prototype will be tested over a range of ambient temperatures to verify efficiency and volume manufacturing cost.

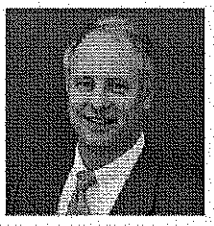
Benefits / Market Implications

The natural gas industry currently has the opportunity to move gas heat pumps into the residential and small-commercial space conditioning to compete with traditional electricity-driven vapor-compression heat pumps. One driver is depressed fuel prices, with natural gas prices projected to be at or below $5/MMBtu for the next 10 years, which makes GHP cooling more attractive. Another driver is the efficiency gains versus



Test rig used in evaluations. Inset: cylindrical burn in testing.

traditional gas-fired heating. For example, conservative estimates of GHP heating COPs are 60% to 90% greater than condensing and non-condensing warm air furnaces.



"Space conditioning represents the largest energy-consuming appliance in residential and most commercial office-building applications, and consequently has the biggest environmental impact. Natural gas heat pump technologies offer significant reductions in total energy consumption and emissions for both space-heating and cooling applications while improving building comfort. Research to develop and prove a cost-effective gas heat pump for space conditioning is a notable milestone for gas technology development."

- Steve Lisk
Manager,Engineering Codes and Standards
Piedmont Natural Gas Company, Inc.

Technical Concept & Approach

Specific tasks for this project include:

- Development of a combustion system for the GHP through laboratory testing
- Development of a corrosion protection methodology by building on prior review and limited testing.
- Preparation of an environmental chamber to simulate ambient climate conditions
- Development of a matrix to simulate GHP versus the competing electric heat pump and baseline (warm-air furnace) for four installation types at 10 U.S. and Canadian locations.

Results / Status

Beginning from initial desorber dimensions, a baseline computational fluid dynamics (CFD) model was built. The desorber is similar in design to that used in the gas-fired heat pump water heater prototype.

In the development of the GHPWH burner design, it was readily identified that CO emissions were excessive, with early experimental data showing difficulty in meeting 50 ppm CO (dry air free) target. Following this testing, CFD modeling was performed, focusing the impact of the chamber geometry on the quenching of post flame CO oxidation on the chamber walls. With this burner design, a ported cylindrical backing plate covered by a woven metal fiber mesh increasing the chamber radius was found to have a more pronounced impact on CO emission reduction than the chamber height, by virtue of its retaining beneficial recirculation patterns. This trend was verified by later testing of smaller-diameter burners, which had the same effect by increasing the radial gap between the flame and the interior chamber wall.

A baseline model was developed with the same model assumptions as previously used (e.g. turbulence model selection, combustion model methodology, etc.). From this initial run, the CO emission problem was shown to be intensified.

With the goal of eliminating the need for stainless steel componentry throughout the absorption heat pump and identifying and verifying the performance of a compatible and cost-effective corrosion inhibitor, researchers reviewed corrosion mechanisms in detail, drafting and sharing materials which explain the relation between solution pH and its control with strong bases, presence of non-soluble gases (namely hydrogen), cathodic/anodic protection, temperature, presence of oxidized iron particles, and formation of stress corrosion cracking.

A literature review was conducted on the in-tube boiling of ammonia to identify the best flow map and experimental correlations for the evaporator design.

Results indicate that CO emissions are significantly lower than predicted by prior CFD for the cylindrical burner, although not ideal.

Two styles of burners were evaluated: 1) those with metal woven meshes and 2) those with metallic foams as flame holders. Both performed well. High-fire flue gas temperatures were in the desired range of 300°-350°F. CO and NO_x emissions were good for both burners and acceptable for this first-generation design.

In January 2014, researchers performed a brief evaluation of a Polidoro-designed burner operating with open-air firing at 55,000 Btu/hr and 28,000 Btu/hr.

A numerical model of the evaporator was developed by setting sub-heat exchangers along the ammonia flow direction and assuming the properties of ammonia remain constant in each sub-heat exchanger. Air flow was simulated as external flow over tubes and internal flow through ducts, and the air-side heat transfer coefficient was estimated as the average of the above two situations. The model was verified and delivered in January 2014. The comparison between the model outputs and the data shows that the model can reasonably predict the ammonia vapor quality, the temperature at the evaporator exit, and the air temperature.

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UTD Utilization Technology Development

Gas Technologies in Energy-Efficient (Foamed) Houses

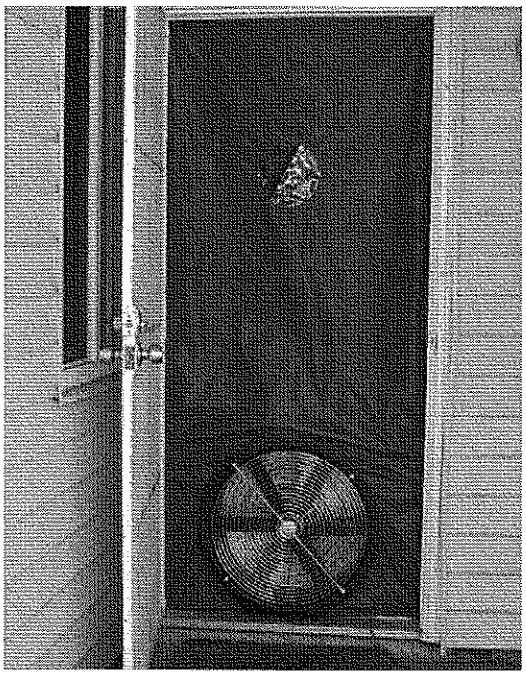
Research into venting issues is being conducted to support the gas and building industries in addressing options in new construction and whole-house retrofit applications where construction processes include the use of air sealing to reduce the infiltration-based heating and cooling load.

Project Description

Atmospherically vented gas appliances have demonstrated more than 60 years of safe operation. However, recent developments in "super-tight" construction practices have cast some doubt on the continued safety of draft-hood-equipped appliances where combustion air is not as readily available and house pressure levels are unknown.

Through this project, needed information will be developed based on field tests to determine if advanced infiltration-control techniques or spray foam insulation significantly reduce the ability of atmospheric appliances to vent safely.

According to the Spray Polyurethane Foam (SPF) Alliance, SPF serves as both a thermal insulator and continuous air barrier which seals the building envelope for increased energy efficiency and total thermal comfort. The linkage between spray foam and house tightness is clear, as is the implication that mechanical ventilation systems are required when SPF systems are applied to provide acceptable indoor air quality.



Researchers are evaluating the effect of air-tightening practices on blower-door air-infiltration rates to determine if adequate air is available for appliances.

The issue is whether or not common techniques for house tightening and insulation have an impact on the air for combustion and dilution of flue gases for atmospherically ventilated appliances.

According to a U.S. Department of Energy study, air infiltration accounts for 30% of a home's heating and cooling energy use and allows unwanted moisture to enter the home in humid climates. ASHRAE 62.2 ventilation requirements encourage the tightening of houses for energy efficiency by assuring acceptable indoor air quality through mechanical ventilation. The standard can be applied with either exhaust-only ventilation, which impacts house pressure, or heat-recovery ventilation, which is more expensive but avoids depressurization.

The objective of this project is to support gas options in new construction and whole-house retrofit where construction processes include the use of air sealing to reduce the infiltration-based heating and cooling load. Field studies and analysis options will be pursued.

Benefits / Market Implications

The benefits from this project are derived through the increased use of atmospheric gas appliances as the most cost-effective solution in many areas of the country, especially for water heating.

Providing support for this product provides benefits for all members of the value chain: the homeowner through life-cycle cost reduction; the manufacturing community through reduced warranty experience of a time-tested product; the builder through supporting commonly understood construction and installation practices; and the gas industry through the avoidance of customer fuel-switching to electric resistance water heaters.

This project will also provide data and analysis to support the builder's decision to include natural gas appliances in existing residential buildings.

Technical Concept & Approach

The focus of this project is on an evaluation of the effect of air-tightening practices on blower-door air-infiltration rates and the indoor air pressure near the gas appliances in order to determine if adequate combustion and dilution air is available to the appliance. The project includes a field survey, using data from existing buildings as much as possible and supplemented with field measurements where necessary.

The team will perform a literature search on the topic to determine the code treatment; recommendations by government agencies, the engineering community and installing contractors; and the availability of existing data from the research community.

The project team, sponsoring utilities, and insulation contractors will identify homes where spray foam insulation is being used or where other advanced house-tightening measures are practiced.

Air-infiltration measurements and analysis will be performed. Researchers will investigate the interactive effects of other operating appliances on house depressurization (e.g., air handler with integrated ventilation, ducts in the attic, enthalpy heat exchangers, clothes dryer, kitchen ventilation, and fireplaces).

Upon completion of the project, the research team will provide recommendations for the use of gas appliances in high-efficiency houses under expected operating scenarios:

- Draft-hood-equipped appliances for space and water heating
- Fan-assisted appliances for space and water heating
- Direct-vent appliances for space and water heating
- Ranges and range hoods.

The project team will identify the cost of these solutions and the payback, including the cost of the foam-insulation or house-infiltration reduction measure. Simplified inspection procedures will be developed to identify possible combustion safety issues.

Results / Status

A scoping study was conducted to address pressurization data requested by the American Gas Association (AGA). The research team subsequently developed an interim depressurization Work Paper with AGA.

A simple model was developed to demonstrate the effect of occupant activity on a single-family residence in terms of depressurization due to typical sources, such as exhaust-only ventilation, range hood, and dryer operation. An analysis of depressurization using VENT-II was also conducted. Case studies and other information were presented in a report to sponsors.

"It is important for the natural gas industry to recognize new energy-efficiency measures and to assist in the adaptation of natural-gas-fueled systems to new building environments. This new initiative will benefit the public by identifying how atmospheric natural-gas-fueled systems can best be integrated with highly insulated buildings. The comfort, economy, and low emissions of natural gas – coupled with the insulating benefits of foamed houses – will provide homeowners with substantial benefits."

- Fred Neu
Sales Representative
Atmos Energy

Preliminary results show that standard gas appliances perform well in traditional houses that have moderate air-infiltration levels at minimum. When exhaust fans are operating, depressurization levels for tight houses and for moderate-to-tight houses can increase and can interfere with appliance vent performance. Following the National Fuel Gas Code recommendations on combustion air openings resolves the issue. Further work is planned to evaluate the other recommendations in the National Fuel Gas Code.

Research is addressing the following questions:

- For atmospheric combustion technologies (draft-hood-equipped appliances and Category I fan-assisted appliances), are B-vents a robust solution in negative-pressure environments? Under what conditions will there be excessive spillage and backdrafting?
- For positive-pressure vent systems, non-atmospheric technologies (direct-vent and powered-vent systems Category III and Category IV), are these systems fully robust in a negative-pressure environment when standard exhaust fans are operating?
- What is the basis for builder recommendations for direct-vent-only appliances in foamed houses?
- What is the impact of weather on depressurization levels? Do they vary with the season or wind?
- What is the impact of various ventilation techniques on the performance of the gas appliances?

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COMMERCIAL APPLICATIONS

UTD
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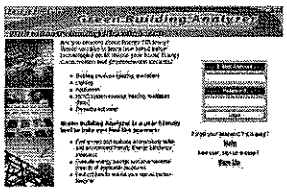
Commercial Green Building Analyzer



The Commercial Green Building Analyzer is designed to provide utilities and their customers with a user-friendly method for the selection of commercial "green" building energy-efficiency measures to conserve energy and reduce a building's carbon footprint. This new analytical tool shares some components of the DOE2.1e computational model engine DLL module previously developed for the analysis of residential applications.

Project Description

Energy conservation and efforts to reduce carbon emissions are becoming permanent features in the energy market, affecting both providers and consumers alike. Utilities are being encouraged to support energy-efficiency programs and consumers are increasingly searching for ways to mitigate rising utility costs.

In response, an increasing number of vendors are bringing to the market new energy-efficient products aimed at the commercial buildings market. Products range from lighting and HVAC systems (cooling, heating), to building envelopes (glazing, insulation, cool roofs), and domestic hot-water-saving technologies.

Unfortunately, the economic, energy savings, and environmental impacts of these technologies can not be easily calculated. Currently, detailed technology evaluations require the use of sophisticated modeling tools that can be costly, difficult to use, and/or require extensive training.

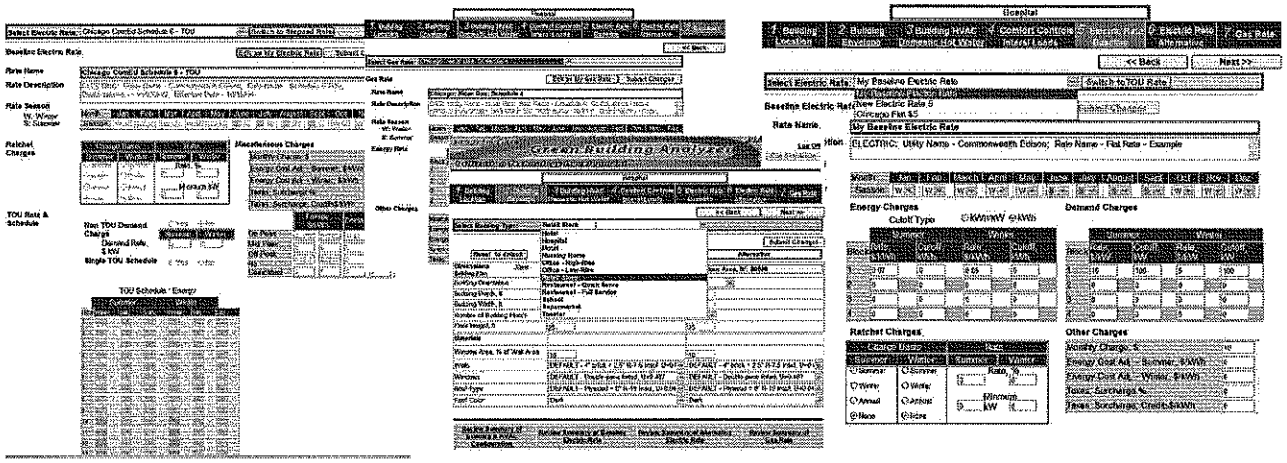
This project was aimed at developing an Internet-based tool (called the Commercial Green Building Analyzer) that allows for fast economic and environmental analysis and easy selection of the latest energy-efficiency measures applicable to specific commercial building structures. Information can be customized to a specific service territory and provide evaluations of impacts such measures have on a building's carbon footprint.

In a complementary UTD project, Gas Technology Institute (GTI) developed the Building Energy Analyzer (BEA) software tool, which provides sophisticated energy and life-cycle economic analysis for various types of buildings.

Benefits / Market Implications

The Commercial Green Building Analyzer will help utilities and consumers conserve energy and reduce carbon footprints by providing the ability to put realistic value on the economic and environmental benefits of implementing various energy-efficiency/conservation measures.

Research has shown that up to 25% energy conservation can be achieved with economically acceptable paybacks in a typical existing commercial building application. Considering that approximately one-third of the total energy consumed in the United States is used by the commercial buildings sector, the scale of potential energy conservation can be significant.



The Commercial Green Building Analyzer provides easy-to-use drop-down menus and other features for quick and reliable calculations of energy use, benefits, and other factors.

Technical Concept & Approach

Specific project tasks focused on:

- **BEA Computational Engine Modification**

  The current version of BEA was designed for the Windows operating system environment and can only run on a personal computer by a single end user at a time. This task involved the enhancement of a dynamic link library (DLL) of the BEA (developed for the residential applications) to address commercial applications and to run remotely using Internet browser access. A separate DLL component was developed to support multi-user access for calculating electricity demand, energy, and natural-gas savings estimates for each of the energy-efficiency measures evaluated.

- **Prototype Development**

  Twelve generic commercial application modules were developed:

  - *Hotel*
  - *Hospital*
  - *Motel*
  - *Nursing Home*
  - *Office Building*
  - *Retail Store*
  - *Restaurants*
  - *School*
  - *Supermarket*
  - *Theater*

  Each prototype's characteristics was modified to create sub-models that are representative of buildings in a specific service territory.

- **Development of Energy Efficiency Library**

  A library of energy-efficiency measures applicable to commercial buildings was developed, including:

  - *Ceiling/roof insulation*
  - *Wall type/insulation*
  - *High-efficiency furnace or boiler*
  - *High-efficiency air conditioner or chiller*
  - *Gas absorption chiller*
  - *Hybrid cooling systems (gas/electric)*
  - *High-efficiency domestic hot-water systems*
  - *High-efficiency lighting*
  - *Programable comfort controls*
  - *Light-colored/cool roof*
  - *Low solar heat gain coefficient windows*

- **Internet Portal Access Interface Development and Implementation**

  An Internet access portal was designed to accommodate most commonly used web browsers. The user is able to describe a building profile by answering simple questions and/or selecting items from drop-down menus. The program analyzes the end user's building profile and recommends energy-saving options in on-screen display as well as printed reports.

- **Customization for Service Territories**

  Sponsoring companies interested in a customized version of the Commercial Green Building Analyzer will be provided with branded Internet portal access. The library of commercial building prototypes will be customized to account for the user's local climatic conditions. The end users will also have access to specific energy rates associated with the local utilities.

Results

The generic Beta version of the analyzer is complete and a users' guide developed.

For this project, researchers enhanced a dynamic link DLL of the version developed for the residential applications under UTD Project 1.7.D., "Whole House Energy Efficiency Wizard."

A library of selected commercial building prototypes was developed and designed so that the user can modify major parameters (e.g., building location, orientation, square footage, number of floors, fenestration, and building materials). A library of energy-efficient measures applicable to commercial buildings was also developed.

Since its introduction in 2010, various program enhancements were implemented, including the incorporation of electric ratchet schedules and the latest eGRID 2012 v. 1.0. databases to calculate CO_2, NO_x, and SO_x emissions in the version 1.5.

Several new building-envelope materials (walls and windows) were added to version 1.5.

Status

Future actions will focus on customizing the model for sponsors' service territories.

The project team is investigating web portal/tool access, support, training, server upkeep and other key issues generated from user feedback.

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UTD Utilization Technology Development

High-Efficiency Gas-Heating Rooftop Package

For this project, researchers investigated issues associated with the use of condensing-furnace technology and conducted laboratory and field testing in an effort to develop a rooftop packaged gas heating/electric cooling product for the commercial sector.

Project Description

Through an alliance comprised of UTD, Gas Technology Institute (GTI), and the Consortium for Energy Efficiency (CEE), research was conducted in efforts to introduce a condensing gas PAC (packaged air conditioner) for rooftop applications in the commercial marketplace.

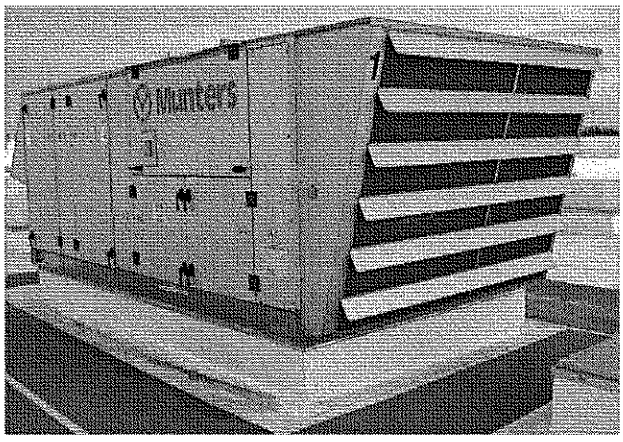
In earlier efforts, the CEE conducted activities to characterize this equipment market segment, define the market viability for a high-efficiency product, and identify the key economic and technical issues associated with using condensing furnace technology in a rooftop package. GTI continued and expanded these efforts with HVAC manufacturers, utility representatives, and industry experts, and helped to assess industry interest and define regulatory drivers that can enhance the market economics.

In this project, researchers investigated various issues to determine cost-effective solutions that can lead to a commercial product.

This project involved partnering with a manufacturer to validate performance in laboratory evaluations and field tests with a major national account in advance of commercialization.

Benefits / Market Implications

Increasing energy prices and new regulatory initiatives have led to the introduction of higher-efficiency air-conditioning technology in gas PACs.



Currently, gas PACs from the major manufacturers typically have non-condensing efficiencies of 80%. However, efficiency levels can be raised into the 90+% range with condensing technology.

If technical and economic issues can be successfully addressed, condensing-furnace technology – which has established a strong market demand in the residential sector – can be positioned to enter the small-commercial rooftop market sector and offer net energy savings.

Understanding the economic tradeoffs is essential to the creation of financial incentives by utility energy efficiency programs (EEPs) to improve the economics. Regulated EEP criteria usually require that the net present value (NPV) of energy savings equal or exceed (up to three times) the NPV of the EEP costs that support the product deployment. State commissions are increasingly decoupling rate structures, often to accommodate EEP formation, and provide for recovery of its costs and lost-delivery service revenue by the utility, as part of regulatory interests in promoting energy conservation and limit energy-demand growth.

Technical Concept & Approach

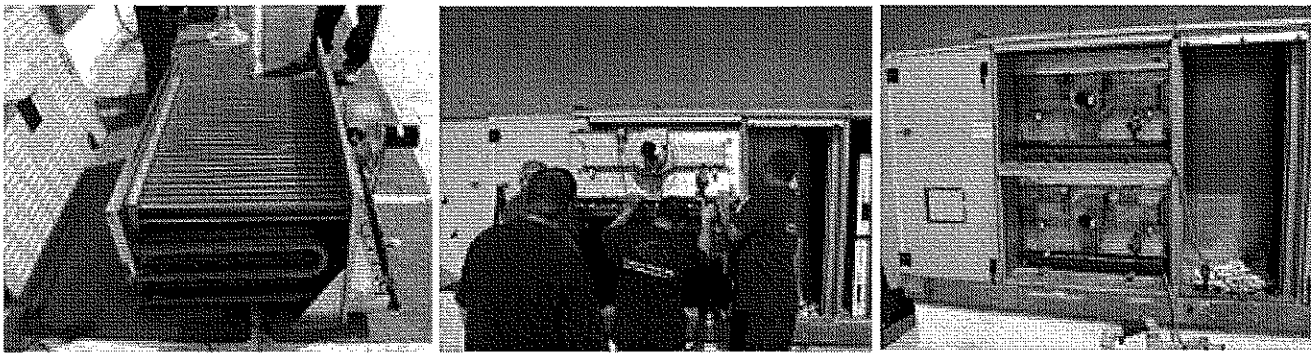
Research addressed a variety of issues, including:

- Acceptable first-cost premiums
- Overall net-energy-savings potential
- Condensing heat-exchanger corrosion
- Freeze protection, and
- Condensate (acidic) disposal from condensing rooftop equipment.

Specific activities included the development of specifications, fabrication of a prototype condensing furnace, and laboratory tests.

Field activities were executed in a two-step process:

1. Conventional-Efficiency Gas PAC Monitoring
2. Early-Market-Entry High-Efficiency Gas PAC Field Test



Condensing heating module (left) being Installed (center) and with both modules in place in the DOAS (right).

Results

Initially, various activities were conducted to reconcile conflicting building models and their differences in heating loads to validate those results with end users through gas-usage billing/monitoring data, and to arrive at a consensus set of high-efficiency economics. The research team also contacted HVAC manufacturers to understand current gas PAC product lines and potential interest in high-efficiency product development and application.

Monitoring at 11 Chicagoland buildings (ranging in size from 2,500 to 200,000 square feet) was conducted to establish baseline heating runtimes and gas use for conventional efficiency RTUs to provide a basis for higher-efficiency RTU savings calculations.

"This project's field test of the high-efficiency DOAS was essential for determining the cost-effectiveness of its potential future use with one of Munters' key 'big box' retail clients, as well as being key to defining the best practices for installation of the combustion condensate drain line and neutralization system."

- Larry Klekar
Director of National Accounts
Munters Corporation

Research found that dedicated outside air systems (DOAS) seen in "big box" retail stores exhibit the highest heating/gas loads and present the early-market-entry point for high-efficiency, condensing heating applications. Consequently, investigators directed efforts at organizing a development and deployment team for a high-efficiency, condensing heating DOAS application to a "big box" retail store.

Condensing heating modules were evaluated as installed in a truncated rooftop unit (RTU) prior to field installation at the plants of the heating module and RTU manufacturers.

A field evaluation was conducted over the 2012-2013 heating season of two non-condensing DOAS retrofitted with condensing heating modules at a 24/7 "big box" retail store in the Chicago area. Each of the two 5,000 cfm DOAS has a four-stage heating capacity system to condition 100% outside air to provide continuous ventilation air to the 200,000-square-foot retail building on a 24-hour-a-day, seven-day-a-week basis. Testing demonstrated that a condensing DOAS provides gas savings of 11% or 2,400 therms with 1,285 kWh of added fan electricity over a year for an annual net energy savings of $1,444 with gas and electricity prices of $0.65/therm ($6.16/GJ) and $0.09/kWh, respectively.

Based on an installed cost premium of $6,085 for the condensing DOAS and its condensate system, plus a projected annual combustion condensate neutralizer maintenance cost of $65 for calcium carbonate replenishment, a simple payback of 4.4 years is estimated.

Experience in the field clearly shows that pooling and freezing of the combustion condensate can be readily avoided by collecting the combustion condensate from the secondary heat exchanger and piping it downward (vertically) through the base of the RTU and into the conditioned space, where a condensate trap is then placed in the drain line.

Status

This project has been completed and a Final Report will be available by the end of 2014.

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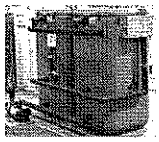
UTD Utilization Technology Development

Commercial Hybrid Gas-Solar Water-Heating System Demonstrations



In this project, researchers conducted demonstrations of a solar-assisted natural gas water-heating system for use in commercial, industrial, and agricultural applications. The system has the capability of providing energy savings of up to 40% and a 10%-20% installation savings over alternative systems.

Project Description

Industry experts note that a significant increase in market penetration for solar-assisted water heating is possible and can provide considerable benefits for use in the food-processing industry and in commercial buildings. However, use of the technology has been limited due to standard practices coupled with skepticism about the magnitude of the energy savings potential in real applications.

In continuing efforts to introduce cost-saving equipment for the commercial sector, this project focused on the demonstration of a solar-assisted natural gas water-heating system. In a parallel project, UTD is sponsoring development activities for a hybrid gas-solar hot-water system for the residential market to reduce the material, manufacturing, and installation costs. This technology is also suitable for commercial hot-water applications up to 190°F.

The research team is partnering with Solar Usage Now – manufacturers of a hybrid solar-assisted water-heating system – to provide a pathway for expanded use of the technology. Also involved in the project are Apricus Solar Co. Ltd. (a manufacturer of solar thermal collectors); Knecht's Plumbing & Heating (a California contractor); Courtside Cellars Winemaking (a host site); the Santa Barbara County Vintners' Association; and UTD member companies.

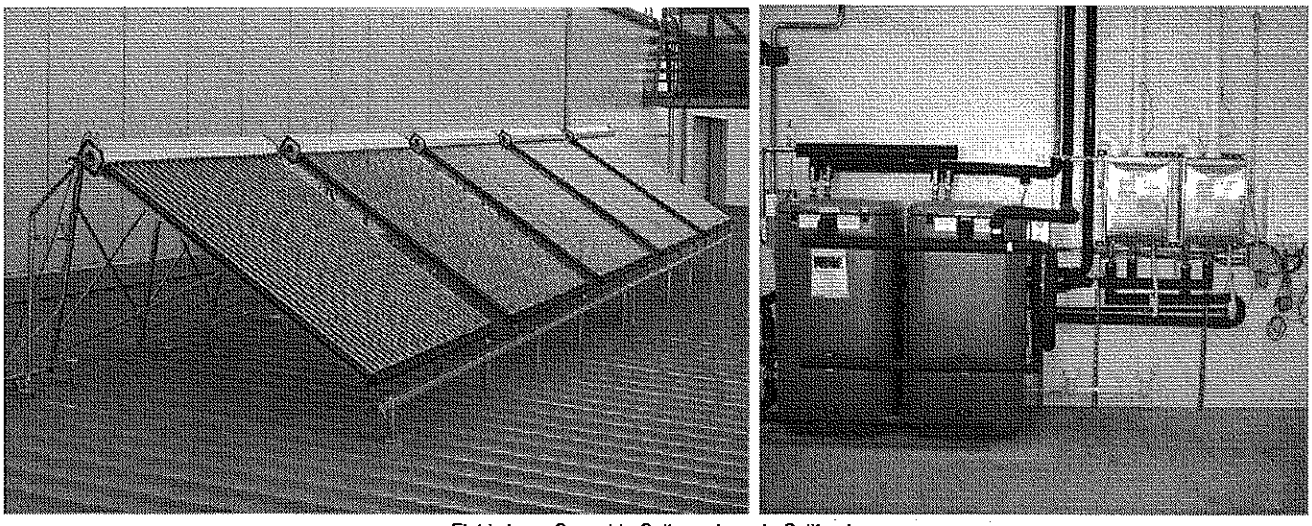
Benefits / Market Implications

Results developed in this project will serve to make advanced water-heating implementation more attractive, mitigate greenhouse gas emissions, improve the competitiveness of the industry, and improve the reliability at end-user sites.

Initial research indicates that in commercial, industrial, and agricultural applications, a hybrid solar-gas water-heating system can provide energy savings of up to 40% and a 10%-20% savings on installation costs.

Energy savings are derived from:

- Efficient thermal distribution systems, including solar-assisted systems that allow overcoming short- and long-term interruptions in power supply
- Lower-energy-consuming water-heating technology development
- Reduced energy consumption per unit of production
- Reduced risk through the demonstration of the technology in the target market.



Field site at Courtside Cellars winery in California.

Technical Concept & Approach

The solar-assisted gas hot-water system (the Equinox Heating System from Solar Usage Now, LLC) is a combination of an atmospheric storage tank, a highly efficient natural-gas-fired tankless water heater, and a very efficient solar thermal collector. The modular design of the hot-water storage tank makes them ideal to be linked together to replace boilers used in large commercial applications such as breweries, soft-drink production, hotels, schools, and hospitals.

There are several attractive applications for solar-assisted systems in the food-processing industry, including wineries, breweries, and juice and soft-drink manufacturers. Hot water is an especially important ingredient in the wine-making process. At larger wineries, boilers are generally used in the hot-water-generation system; whereas, at small- to medium-size wineries, conventional storage-tank water heaters are employed.

"The SUN Equinox was developed to efficiently utilize the benefits of gas condensing technology and free solar energy for the production of hygienic hot water in residential and commercial environment. By testing the Equinox heating system in controlled settings, we were able to make adjustments and improvements to the overall system. We are grateful and honored to be part of the project team."

- Thom Blake
President/CEO
Solar Usage Now, LLC

The opportunity for substantial energy-cost savings in smaller wineries comes at a higher purchase cost and longer payback. By reducing the purchase cost and increasing the potential savings, quicker paybacks can be realized.

Results

Hybrid gas-solar water-heating systems and data-acquisition equipment were installed at a North Carolina healthcare facility and a California winery.

Enhancements made to the system include:

- A lid redesign and increased insulation to reduce standby loss
- Check valves to eliminate thermosiphon
- A single-unit collector that reduces installation costs
- Improved temperature stability through the use of hot/cold inlet check valves on the mixing valve
- Redesigned float refill valve.

Data was successfully received from both field sites via a cell modem and a summary of the 12 months of data was prepared. The data-acquisition systems allowed for the access of information in real time and logs operating data continuously every minute for 24 hours a day.

In contrast to the system installed at the North Carolina location, the system at the Courtside Cellars site is not a stand-alone system providing the hot water to the site. There are two systems operating in a parallel mode servicing the site to ensure uninterrupted hot water availability for production and to allow for more flexibility in operation and maintenance. The system is providing approximately one quarter of the hot-water load demand. This split in hot-water-demand supply is controlled by a differential pressure control valve installed in the system that was designed to supply cold supply water to the boiler system upon the hot-water demand reaching the 31 gallons per minute flow rate maximum of the installed system.

In early 2014, work plans were prepared for removal of the field-data-acquisition equipment and turning the systems over to the host site owners.

Status

The project team continues to acquire system-performance data from the two field sites.

Overall, the Equinox heating system performed extremely well. At peak conditions, the fuel efficiency was over 95% and demonstrated the ability to generate more than 1,700 gallons of hot water daily. Compared to the standard baseline efficiency gas boiler, the system saved approximately 1190 therms of natural gas during the year of monitoring. This energy savings corresponds to a potential reduction of 17,500 pounds of greenhouse-gas emissions per year.

The estimated payback period for the system was 7.3 years, coupled with the present incentives provided by state and federal governments. Payback periods are dependent upon the solar fraction and the available incentives. Solar-assisted systems can provide a financially viable alternative over traditional water-heating systems as documented in the 15-year lifecycle cost.

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UTD Utilization Technology Development

Commercial Foodservice Audit and Survey

Investigators are conducting an audit and survey of commercial foodservice equipment that is currently in use and available in Canada and the United States in an effort to determine the population and energy usage of typical foodservice appliances.

Project Description

The potential to impact energy savings is significant in the commercial foodservice (CFS) industry because the population is largely comprised of older or inefficient equipment. However, the exact nature of old or inefficient equipment in use and the corresponding potential for energy savings are not known. This project addresses this issue through a survey of the existing equipment to determine the population and energy usage and an audit of the equipment that is commercially available for replacement throughout North America.

There is some existing research that has attempted to resolve key questions; however, data is often out of date, incomplete, and/or exclusive to a certain region.

Information developed in this project will provide the population and performance characteristics of appliances currently installed and operational in foodservice establishments as well as commercially available replacement options.

The results from this project will provide a roadmap for future CFS projects.

Benefits / Market Implications

Information developed through this project can be used by the gas industry to prioritize the CFS equipment opportunities in order to promote energy efficiency in gas-fired appliances.

In addition, by identifying gaps and opportunities for the development of better performing and more efficient appliances, research can be directed toward areas that can have the most significant benefits for gas consumers.

Technical Concept & Approach

This project focuses on the identification of opportunities within the CFS industry to develop and demonstrate enhanced gas-fired appliances.

Specific tasks include:

- **An Audit of Currently Available Equipment**

  Researchers compiled information on currently

available gas-fired appliances in the major appliance categories. Information collected includes: sales, cost, efficiency, and other key characteristics, as appropriate.

- **A Survey of Installed Equipment**

  Researchers are gathering information and data to estimate the current population of installed gas-fired appliances in the major appliance categories. Analysis will be conducted to determine the number of installed units, average age, efficiency, and cooking performance for each category.

- **Identification of Gaps and Opportunities**

  Based on the results from the audit and survey, researchers will identify where the gaps and opportunities for technological advancement exist in the CFS industry.

  Investigators will develop a research roadmap for potential projects that have the best opportunity to improve appliance performance and efficiency and have significant impact for the gas industry.

Results

In 2013, the audit portion of the project was completed.

Appliance summaries were completed for broilers, ovens, ranges, steamers, fryers, and griddles. Summaries include information on the cooking process, appliance features, capacities, input rates, efficiencies, lifetimes, market saturation/ownership, cost, Energy Star options (if applicable), and current trends. Data was collected on Energy Star market saturation in recent years for each of these main appliance groups. Information was collected on the number of foodservice establishments by type in the U.S. and Canada.

A literature review indicated that a large amount of the more current research has relied upon data presented in a 1993 report by the Arthur D. Little management consulting firm. Reports in this project applied some assumed growth rate to the Arthur D. Little data to estimate the current population.

A review of energy use and economic health in the CFS sector was drafted and research was completed on the role of standards in driving CFS equipment design and sale.

The research team has been interacting with organizations with expertise in this field to identify information resources and key individuals.

A Whole Kitchen Assessment Plan was developed to supplement the survey and to help identify gaps and potential for further gas savings.

Status

The survey portion of project is ongoing.

Whole kitchen assessments are being organized in conjunction with other projects. A potential demonstration site for fryer testing was identified. A comparison test of three different models from different manufacturers and will be conducted.

The audit portion of the project is available to utilities and other interested foodservice-related entities.

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UTD Utilization Technology Development

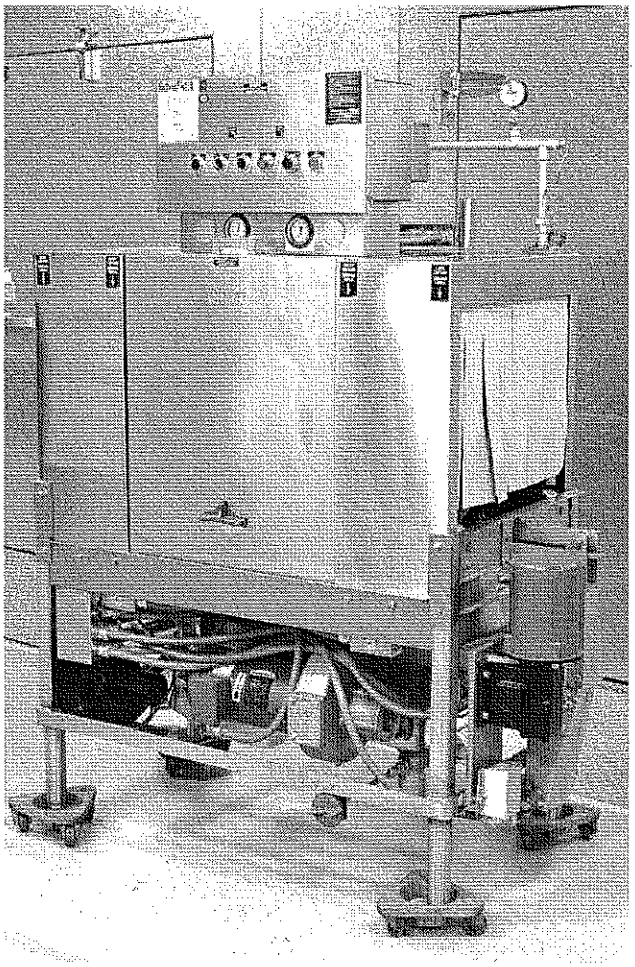
Gas-Fired Conveyor Warewasher

A research team and representatives from a major manufacturer of foodservice warewashing systems are investigating the technical challenges facing the introduction of gas-fired conveyor/flight type warewashers. This project involves the modification of the design of a previously available gas-fired model to improve system reliability.

Project Description

Commercial foodservice warewashers are available in three designs – the flight type, the rack conveyor, and the stationary-door type. (Flight type and conveyor warewashers are used for high-volume applications.) Most are all-electric units.

Electric warewashers are easier to design and manufacture than gas-fired units because of the limited space available within the confines of a system. Gas units require a water-heating system that incorporates a burner, tank, gas train, and vent. Consequently, there are relatively few gas-fired warewashers on the market.



In the mid-1990s, Stero Warewasher Systems introduced a gas-fired infrared heating system that was readily accepted by industry operators and design consultants because of its high-temperature application and significantly reduced energy consumption. Sales of the Stero gas system peaked in 2000. However, the product experienced several technical challenges – including ignition issues, burner clogging, pressure-switch failures, and unpredictable performance in high altitudes – and sales dropped significantly.

Stero expressed interest in addressing performance issues and introducing a reliable gas model to include in their product line. In this project, researchers have teamed with Stero to identify product issues and develop and promote a new gas-fired system.

Benefits / Market Implications

A redesigned, more reliable gas-fired conveyor warewasher will provide the foodservice industry with an efficient alternative to all-electric warewashing equipment.

A restaurant changing to a gas-fired conveyor warewasher from an electric model would produce an estimated 1,100 therms annually in gas use and reduce the carbon footprint of the restaurant from 49,610 pounds of CO_2 per year with electric use to 16,088 pounds of CO_2 per year with natural gas.

Technical Concept & Approach

The research plan involves determining the causes for problems with models in the field, developing design changes to resolve the issues, and then proving the reliability of the changes with laboratory tests and accelerated life tests.

Researchers and local service representatives will visit installation sites of the current design and study issues encountered during the life of the units. The extent of design changes will vary based on what is discovered during the examination of current appliances and problems encountered.

Igniters in previous models became undependable and the machines would not consistently heat to the temperatures required to produce clean and sanitary dishes. Despite three different ignition systems, the igniter issue continued. Inconsistent operation due to variations in the caloric value of gas was also a concern. All of these issues – along with any others discovered – are being be addressed with design changes.

Results

In 2011, Stero's gas-fired warewasher was installed in the laboratory for testing. Technicians tested the initial combustion performance of the system. Initial indications are that the system is efficient; however, very tight combustion could lead to combustion issues under varying environmental conditions.

In 2012, one installation site that was not functional was restored to a functional condition and the parts were removed and studied to determine the extent of the problems. The main problems were with blower and burner clogging, leading to a high pressure drop, and, as a result, unsafe combustion. This site was instrumented with data loggers to monitor the ignition sequence, if any misfires occur, and the runtime of all of the burners.

The research team identified a new blower option. The team also had an alternate metal mesh power burner created to test and compare to the current cloth radiant burner system being used.

Testing was initiated on a heat exchanger and burner assembly for some alternate igniter and control products. Stero subsequently manufactured an alternate heat exchanger with a larger crossover tube to reduce pressure drop across the heat exchanger and potentially improve the burner combustion reliability. Testing on the alternate heat exchanger was completed in 2013.

In 2013, researchers united with an igniter and control manufacturer to test new ignition systems.

Several burner and blower options were also tested in efforts to improve reliability. The standard burner and blower was tested to confirm combustion and pressure drop levels. A new single-layer burner designed to reduce pressure drop was tested. In addition, a metal mesh burner was fabricated and performance tested. Both the metal mesh and single-layer burner should reduce burner clogging issues, one of the biggest concerns with the old system.

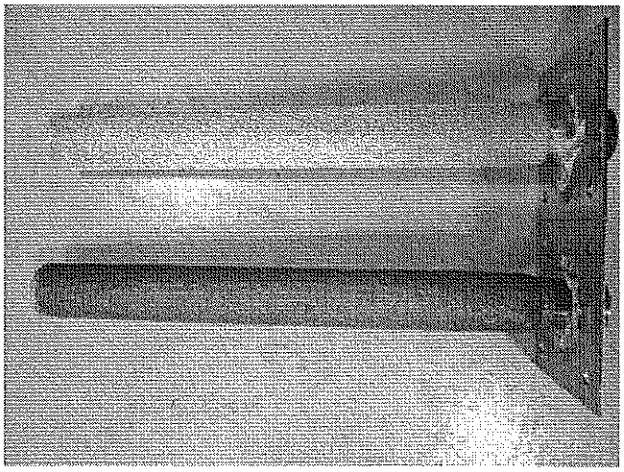
Researchers suspect that one of the biggest problems with the warewasher was a lack of proper oxygen for combustion. The system was shipped at low (1%-3% O_2) levels and blower and burner clogging led to eventual oxygen levels that could not support stable ignition and combustion. The project team is recommending a switch in the burner from the fiber burner to a metal mesh burner, which demonstrated a much lower pressure drop in testing. Research also suggests that corrosion issues are reducing flow in the wet-room environments of restaurants. The research team is recommending a switch to a new blower frequently used in marine environments. Researchers conducted extensive testing of the new blower and burner across a variety of excess air levels to determine the optimal excess air for both ignition and stable combustion and found the units should be shipped in the 6%-7% O_2-level range, which will still allow a wide margin of excess air if any clogging does occur to still maintain stable ignition and combustion.

Status

A new spark-ignition control module is being installed on a prototype to be tested for its reliability. Once the spark-ignition testing is completed, a product re-design will be conducted.

Researchers report that Stero is eager to begin implementing the changes in new warewashers. Once the igniter control has been finalized, Stero would like to conduct a small field demonstration of one conveyor warewasher incorporating all of the changes to determine any issues that may be encountered in the field.

Researchers are also in the process of mapping all the burners performance at various oxygen levels with a variable speed blower to determine successful ignition and combustion levels.



Laboratory testing of metal mesh burners.

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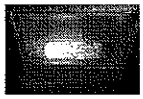
UTD Utilization Technology Development

Initial Evaluation of Ultra-Low-NO_x Burner Technologies

Investigators are conducting an evaluation of burner technologies and system designs that could achieve ultra-low-NO_x emissions of 5 ppm or less for use in residential and commercial applications.



Project Description

Residential furnace manufacturers are being challenged by California's South Coast Air Quality Management District (SCAQMD) acceptable levels for NO_x emissions of 14 Ng/J for residential furnaces in regions of southern California. In addition, information from SCAQMD and the gas industry suggests a strong interest in achieving NO_x emissions in the ultra-low region or 4 Ng/J or less, and that ultra-low NO_x emissions requirements will be applicable for all gas-fired appliances. Currently, appliances cannot reach levels below 20 Ng/J.

In response, UTD, SCAQMD, and the furnace industry have initiated efforts to develop technologies to achieve the new emissions level.

Research has shown that to achieve NO_x emissions of less than 5 ppm for both powered and non-powered burners in the firing range of 30,000 to 200,000 Btu/hr would require significant changes in the design of the appliance and/or combustion system. Either the method of aeration of the burner or the design of the burner will need to be altered.

In this project, investigators are using available data to determine potential methodologies to pursue in order to reach ultra-low-NO_x (ULN) emissions.

Current research on water heaters and furnaces shows potential for ULN burner designs that could be used in other appliances.

The objective of this project is to perform an initial evaluation of burner technologies and system designs that could achieve ULN emissions of 5 ppm or less for burners in the residential and commercial area with firing rates in the range of 30,000 to 200,000 Btu/hr.

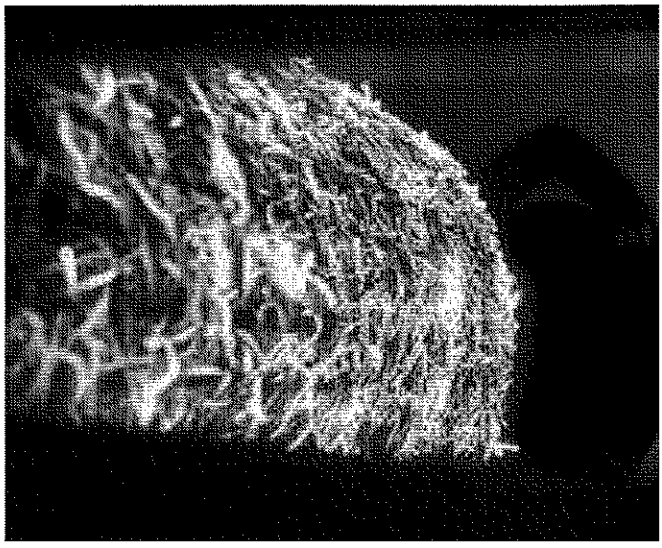
Benefits / Market Implications

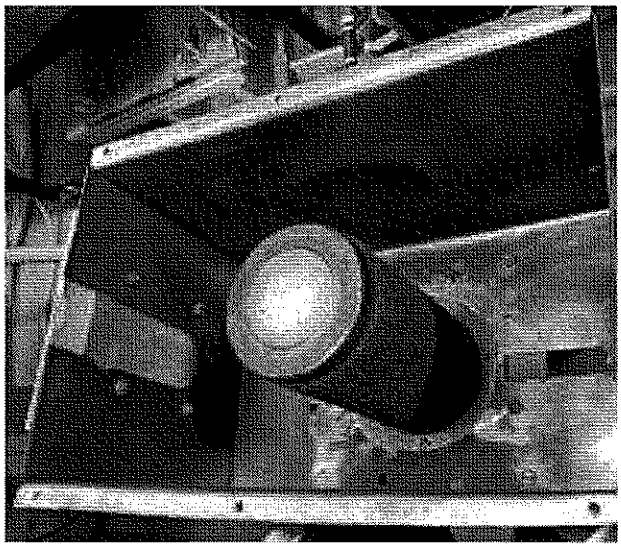
Results from this project will assist in developing designs for residential and commercial gas-fired equipment that are capable of meeting the new NO_x emissions requirements and provide consumers with enhanced options for homes and business.

Technical Concept & Approach

Research in this project focuses on gathering data and information on the potential NO_x emissions characteristics of different burner designs and control methods.

Different technologies will be evaluated for the potential use in different types of residential/commercial appliances, including water heaters, furnaces, and com-





Left: Mesh burner in burner box. Right: Prototype furnace burner.

Results

Investigators initially reviewed existing data for NO_x emissions for burners in the desired firing rate range and tested new burner designs, finding that few burners had emissions of less than 10 Ng/J, and none of those burners were optimized for NO_x emissions.

Different burner designs for both this project and existing furnace and water-heater low-NO_x projects were studied. Emissions were recorded for each burner and the different designs and evaluated for potential use in other appliances.

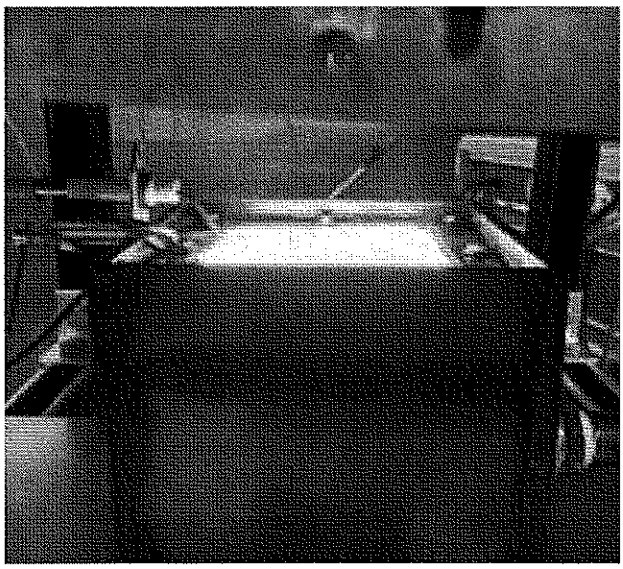
The most promising burners tested were metal foam and metal mesh burners. A prototype for the metal mesh extension burner was tested in a bench-scale test stand with a typical inshot burner venturi attached to the inlet of the burner.

Researchers also investigated the Modified Cyclonic Burner technology, a burner designed for an industrial boiler application. The burner uses a rapid-mixing concept to premix air and fuel to minimize the formation of areas of higher flame temperatures and oxygen availability in the flame, both of which promote the formation of NO_x. Research determined that in order for this version of the burner to provide NO_x emissions similar to the industrial version (less than 10 ppm corrected to 3% O2), the application needs to involve cooling to the housing of the burner. This is required because combustion occurs inside the burner housing and thus the outer shell of the burner needs to be cooled.

The results for naturally aspirated tube burners showed that NO_x emissions could be improved, but not to levels below 20 ppm without significantly increasing the NO_x values.

In 2012, activities focused on testing existing and new burner designs in the desired firing rate range. The operational characteristic of each burner was varied to determine the optimal NO_x emissions that could be achieved but still maintain safe combustion.

In 2013, construction was initiated on a new heat exchanger for a forced-air residential furnace to accommodate the ULN using a cylindrical metal burner that is mounted to the burner box, but operates without a power blower. Initial testing achieved NO_x emissions of about 6 ppm with CO less than 100 ppm. The new design moves the burner inside the air chamber because too much heat was lost to the combustion box mounted on the outside and overheating the furnace.



A water-heater burner prototype .being bench tested to determine optimal emissions.

Design of the water-heater burner was also initiated. The design incorporates a power burner with a foam metal burner head. A test burner was designed and constructed to determine the burner surface size and firing rate.

Status

Testing was completed in 2014. A Final Report has been submitted to UTD members for their review and input.

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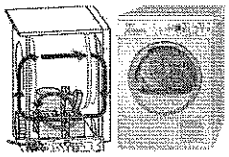
UTD Utilization Technology Development

Residential & Commercial Gas-Fired Clothes Dryer Opportunity Assessment & Technology Development



Research was conducted to identify the potential for improvements for residential and commercial gas-fired clothes dryers. Laboratory evaluations of promising technologies are under way, to be followed by the integration of enhancements into a pre-prototype gas-fired dryer.

Project Description

The census figures for 2010 note that of the approximately 117 million households in the U.S., 62% have an electric dryer, 19% have a gas dryer, and the remaining 19% do not have an in-home dryer.

Clearly, clothes dryers represent a significant market opportunity. Although gas-fired dryers have not had many technological advances in recent years, experts see considerable potential to enhance gas dryers through improvements to dryness sensors, controls, exhaust-heat recovery, and other areas.

The commercial dryer market, although not as large as the residential market, is also significant. Commercial laundry is processed by a number of facilities, including coin laundries (35,000 facilities), multi-housing laundries (300,000-600,000), on-premise laundries for institutions such as hospitals, lodging, and universities (60,000), industrial laundries (1,800), and dry cleaners (30,000).

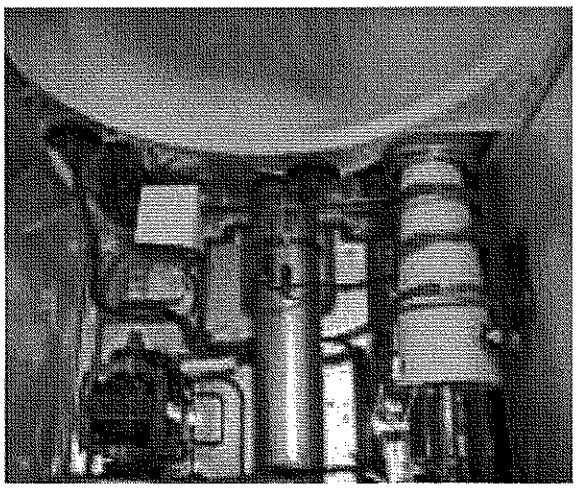
In California and some other states, gas dryers have a larger share in the commercial market. (In California, gas dryers represent 70% of commercial dryers.)

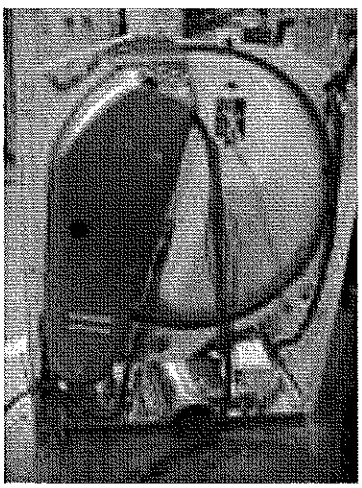
The opportunity for energy savings is substantial in the commercial segment due to longer operating periods, higher energy costs, and efficiency-improving technologies that would provide rapid paybacks.

The residential U.S. clothes-dryer market is highly mature and relatively saturated. Although there was significant growth throughout the second half of the 20th century, it has stabilized somewhat in the past decade.

In the mid-1990s, research was conducted to develop a detailed market assessment for major residential gas appliances to identify key issues and the driving forces for change within each sub-sector of the appliance industry (including clothes dryers). This earlier assessment focused primarily on industry concerns to ensure that future R&D projects were closely linked to industry needs. While progress has been made within some of the areas identified by this assessment, challenges and opportunities still remain – including needed improvement in waste-heat recovery, and moisture sensors.

Enhanced water extraction at the end of the wash cycle is often viewed as the most promising means for improving the efficiency of the dryer. However, in recent years technologies have begun to emerge that demonstrate the potential for efficiency improvements within the dryer appliance itself. Improvements in design and function offer the potential for a residential gas dryer to qualify as an energy-efficiency upgrade, which would enable utilities to achieve a reduction in energy consumption while still preserving and even possibly growing the overall gas share in the dryer market.





The objective of this project was to identify potential improvements for residential and commercial gas-fired clothes dryers.

Benefits / Market Implications

In 2005, U.S. clothes-dryer shipments totaled 8.1 million units and were valued at nearly $2.5 billion – a value greater than the shipments of either water heaters or room air-conditioners. With about 81% of U.S. households having a clothes dryer and a significant commercial laundry sector, the potential business value of improvements to design and function is significant. Improvements would provide consumers with a more efficient product and help to stabilize and increase the competitiveness of gas dryers.

Technical Concept & Approach

Investigators updated previous market assessments conducted in the 1990s to determine key issues in the dryer market (e.g., why customers choose electric over gas) and potential technology improvement areas to gas-fired dryers.

After a review of the assessment, the project team began testing possible techniques and technologies to improve gas-fired dryer performance. Potential areas of improvement include system efficiency, waste-heat recovery, moisture sensors, and additional areas identified by the market assessment.

Results

In 2012, the research team completed a market assessment of gas-fired dryers along with an assessment of potential technologies to improve these products. The assessment addresses both residential and commercial clothes dryers and reports on market size and trends, regional variations, manufacture market shares, financial incentives for high-efficiency options, and efficiency standards and initiatives. Technologies investigated include tumble dryers, stacked dryers, combination washer/dryers, heat-pump units, microwave products, condensing/ventless dryers, and modulating units.

Research found ample opportunity to increase the efficiency, reduce the drying time, and expand the operational savings in the residential and commercial markets.

The best opportunity for a high-efficiency residential gas model appears to be incorporating a modulating burner system into a dryer. Modulating systems have been on the market for a long time and are widely used in a variety of commercially available appliances. A major manufacturer developed a modulating gas dryer in 2005 which showed a 15%-25% reduction in energy use and reduced drying time, along with lower operating temperatures, which is better for temperature-sensitive clothes.

In 2013, a joint development agreement was made with a major appliance manufacturer. The project team is focusing on laboratory testing potential modulating levels for a dryer, along with basic burner and primary aeration changes to improve efficiency.

Initial baseline testing was completed to determine the performance and airflows at various air entry points throughout the ducting.

A dryer was installed at Gas Technology Institute laboratories. The unit includes extensive instrumentation (e.g., gas meter, electric meter, 60 thermocouples, flue gas taps, and pressure transducer). Modulating levels from 11kBtu/hr to 40kBtu/hr were tested for their effect on the burner combustion and CEF of the dryer. It was found the current burner could handle firing rates across that whole range with stable combustion. The higher firing rates provide the opportunity for quicker drying in the early drying stages (a potential advantage versus electric dryers which can't dry at higher watt draws). The lower firing rates can then be used in the late stages of drying to save energy.

Benchtop testing was conducted on the dryer burner to determine optimal levels of primary air and dilution air. Various dilution air and primary air levels were also tested in the dryer and run through a CEF test. Reducing secondary air and increasing primary air had a large improvement in combustion and a large drop in CO, but did not have as much effect on the efficiency as was anticipated.

The addition of waste-heat recovery to a dryer is another higher-efficiency option for the future.

Status

Researchers continue to investigate high-efficiency options in the laboratory with a manufacturing partner.

Technicians are testing modulating levels by adjusting the manifold pressure manually; however, a modulating valve needs to be incorporated and tested with dryer controls to optimize performance.

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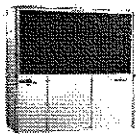
UTD Utilization Technology Development

NextAire Gas Heat Pump & Chiller Link Case Study



A case study was developed on the 18-month performance of NextAire gas heat pump and Chiller Link equipment at Energen Corporation's headquarters in Birmingham, AL. At the site, 13 15-ton gas-engine-driven heat pumps were installed to replace absorption chiller and boiler equipment for space heating and cooling.

Project Description

A significant goal of the natural gas industry is to develop and apply gas heat pumps in the broad market for HVAC equipment in commercial buildings. As part of this initiative, this project focused on the NextAire™ Multi-Zone Gas-Engine-Driven Heat Pump (GHP), which offers a heating COP (Coefficient of Performance) of 1.2-1.4 and a cooling COP of 0.95-1.3.

Engine-driven heat pumps are used throughout Europe and Asia and are starting to gain popularity in North America. The NextAire engine-driven heat pump (distributed by IntelliChoice Energy) was tested extensively in hot/dry climates with good performance. The product offers 10:1 capacity modulation using a variable refrigerant-flow management system and a scroll compressor powered by an Aisin natural gas engine. In this project, researchers collected data on the performance of the NextAire system in a hot/humid climate in a large multi-zone office building (the Energen Corporation headquarters building in Birmingham, AL).

Researchers developed a case study on the combined performance of the installed NextAire and Chiller Link system. As one of the largest GHP installations, 13 15-ton GHPs replaced an electric chiller, a decommissioned absorption chiller, and their associated cooling towers. Chiller Link heat exchangers allow the GHPs to be retrofit to an existing four-pipe hydronic HVAC system.

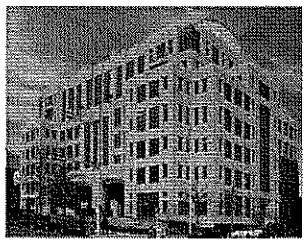
Benefits / Market Implications

The NextAire gas heat pump offers a viable natural gas option to electric heat pumps and conventional HVAC equipment.

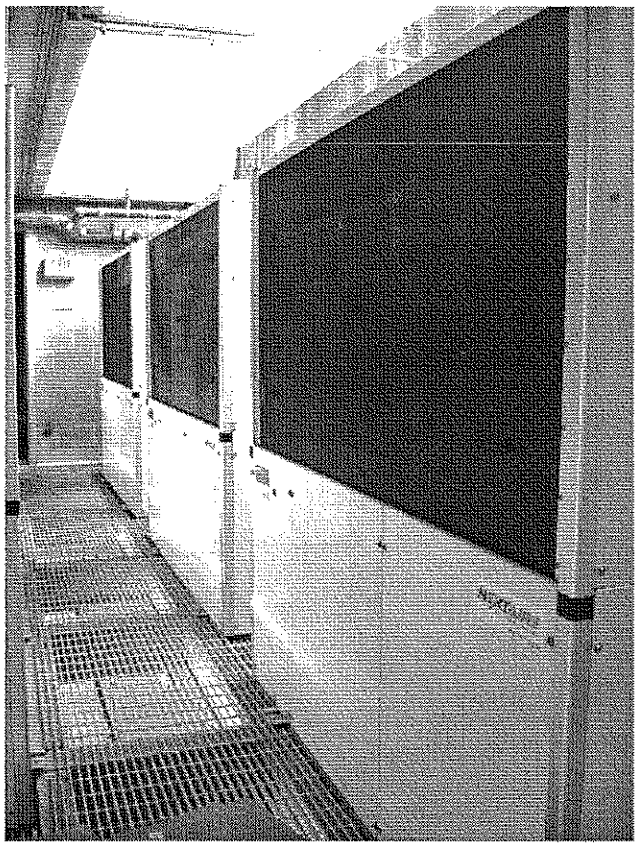
The operating and maintenance costs for the NextAire unit are projected to be 30% less than comparable electric heat pump equipment. Electric power consumption is expected to be up to 80% less than conventional equipment. This packaged unit does not require a separate cooling tower and reduction in water consumption per 15-ton unit is estimated up to 17,000 gallons per year in dry climates.

NextAire gas heat pumps are equipped with an electronic speed controller that regulates the revolution rate of the engine by taking both indoor and outdoor temperatures into account. This results in minor energy loss and a constant indoor temperature when compared to traditional electric heat pumps.

Technical Concept & Approach



This project involved the installation and instrumentation of a new 13-unit NextAire system retrofit to the existing hydronic system at Energen headquar-



The NextAire gas heat pump installation in Alabama.

ONE-OF-A-KIND BENEFITS	Natural Gas Heat Pump (VRF)	Electric Heat Pump	Electric Heat Pump (VRF)	Natural Gas Forced Air Furnace	Electric A/C Condenser	Chiller-Boiler System
Recovers waste heat	■	—	—	—	—	—
Potential to reduce a building's electric requirements	■	—	—	■	—	—
Environmentally friendly (Saves water & optimizes the use of source energy)	■	—	—	■	—	—
Quieter than 59 decibels	■	—	■	—	—	—
Up to 33 zones with individual climate control	■	—	■	—	—	■
Ducted air handlers	■	■	■	■	■	■
Ductless air handlers	■	■	■	—	—	—
Located remotely from building (up to 400 feet)	■	—	■	—	—	■

NextAire gas heat pumps can offer a range of benefits.

"The NextAire gas-fired heat pump matched with their Chiller Link technology offers an efficient approach for natural-gas heating and cooling for a traditional four-pipe system. In an ever-changing cooling market, this innovative technology gives the gas industry an improved ability to compete with mainstream variable-refrigerant-flow technologies as well as the traditional electric chiller cooling approach. The Energen installation will provide the factual support needed by the gas industry to successfully promote this cutting-edge technology."

- Steve Roberson
Manager of Technical Services
Alagasco

ters and measure the performance and energy consumption of the new equipment.

Instrumentation measured energy consumption for each heat pump and heat exchanger pair as well as the total chilled water delivered to the building through the Chiller Link heat exchangers.

Data was analyzed to determine the performance of the equipment under cycling conditions, with varying outdoor temperature, and the ability of the equipment to meet the demands of the building. Data collection was conducted for one full year, with monthly data analysis.

Chiller Link heat exchangers were used to retrofit the GHPs to an existing four-pipe hydronic HVAC system.

Results

The installation of the NextAire system and instrumentation at Energen headquarters was completed in early 2012. System operation and data collection began in April 2012 and was monitored through October 2013.

The heat pump system is used to meet the year-round cooling load at the Energen headquarters.

The research team collected performance data (cooling delivered, gas and electricity consumption, etc.) and calculated monthly and cumulative COPs.

Data indicated that the GHP system performed per specifications. Based on data collected from October 2012 to May 2013, the system had an average cooling efficiency of 1.01 COP (gas only).

Since installation, the GHP units performed well with no reliability issues. Peak electric demand was reduced by 29% compared to the average of 2011 and 2010 (normalized to cooling degree days).

Status

This project was completed in 2013.

The GHP system continues to meet total space cooling demand at the Energen headquarters.

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UTD Utilization Technology Development

Commercial Foodservice Equipment Demonstration

This project focuses on the identification and demonstration of gas-fired commercial foodservice equipment. Demonstration locations are being developed for specific products to quantify costs and cooking performance.

Project Description

In this project, researchers and gas-industry representatives have teamed to identify gas-fired commercial foodservice (CFS) equipment and demonstration locations to quantify the benefits of equipment in terms of cost and cooking performance.

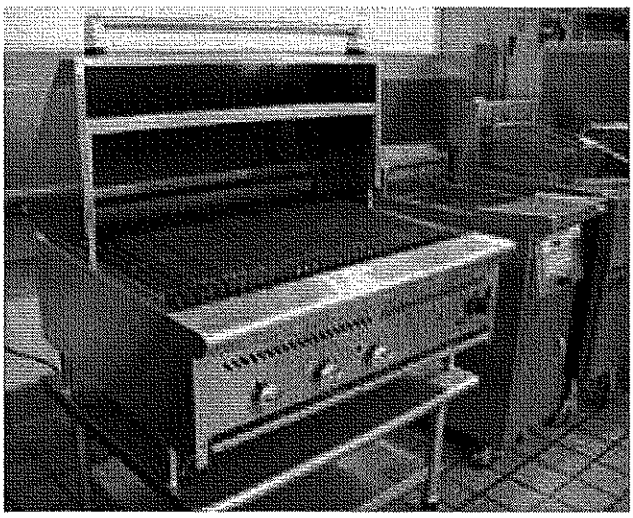
This project addresses the issue with CFS operators who are often reluctant to replace existing equipment with newer models because of concerns with costs and the uncertainty that the new equipment will be able to prepare the food as expected. This reluctance has increased the difficulty of introducing new gas-fired equipment into the market.

Chain restaurants –which represent about 50% of the CFS industry – are recognizing the long-term cost benefits of newer equipment; however, this important information is not generally available to the rest of the industry.

For this project, technicians will test selected equipment in the laboratory and/or at commercial demonstration sites and document performance.

The potential list of appliances is expected to include some of the industry's most recent market introductions, including a steam kettle, range, wok, conveyor oven, convection oven, boilerless steamer, low-oil-volume fryer, and griddle. Any other appliance of particular interest could be targeted for laboratory performance testing or field demonstrations.

A Final Report will detail the performance of each appliance chosen for field demonstrations or laboratory testing.



Charbroiler

Benefits / Market Implications

Verifying the performance of a CFS technology in the laboratory or the field will demonstrate the advantages of specific technologies and provide valuable marketing information.

This project would provide utilities with the ability to quickly evaluate appliances, whether a gas-fired technology or an electric competitor, and understand the true performance of the appliance.

Technical Concept & Approach

Initial plans are to demonstrate CFS appliances of interest in the territories of Oklahoma Natural Gas (ONG) and Peoples Gas (in Chicago).

The research team and the utilities will determine preferred appliances to demonstrate and identify test sites. The appliance performance and feedback from the test sites will be incorporated into a report detailing the benefits and performance of the systems.

Additional demonstrations can be conducted at additional utilities' territories if new funding is provided. The program is designed to be able to quickly respond to a demonstration need if a utility becomes interested. The time and cost will vary based on the appliance and scope of the tests.

Potential partners include:

- Test Kitchens
- Culinary Schools
- Universities

"Restaurant operators must continue to look for ways to minimize operating expenses through efficient energy-management practices. Nationwide, natural gas costs have gone down while other expenses continue to rise. Installing high-efficiency natural gas equipment will not only increase energy savings, but will also help chefs produce food that's more evenly prepared and better tasting. Cooking with high-efficiency natural gas equipment can provide the competitive edge over the competition because costs are lower, which, ultimately means the customer pays less."

- Brian Sudol
Manager, Key Accounts & Market Development
Oklahoma Natural Gas

- Sports Arenas
- Restaurants
- Cafeterias
- Hospitals
- Manufacturers.

Results

Initially, arrangements were made for a specific range top as a test appliance at the banquet kitchen in Catoosa, OK. However, issues with the range prevented its use. Subsequently, two sites were identified in ONG's territory for conducting a demonstration of a convection oven and a lidded charbroiler.

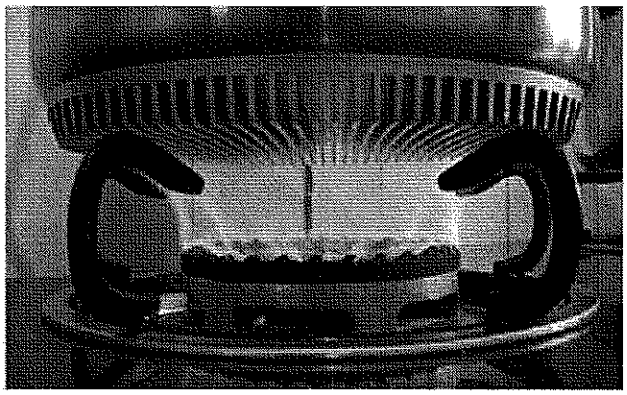
Testing will also include the use of Turbo Pots, a brand of pots and pans that include a finned heat exchanger either milled or attached to the bottom. Turbo Pots have been shown to significantly increase the cooking efficiency of a range top.

The research team identified a fryer as a demonstration appliance for Peoples Gas. Once the first unit is ready, it will be tested in the laboratory and then installed in a demonstration site for monitoring.

Status

The research team is working with participating utilities and manufacturers in identifying, evaluating, and preparing demonstration sites.

Testing is expected to commence in 2014.



Turbo Pot.

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UTD Utilization Technology Development

Oil-Saving Fryer

This project focuses on the testing a new patented method for significantly reducing the oil usage of a standard commercial foodservice deep-fat fryer.

Project Description

Experts within the foodservice industry have expressed the need for deep-fat fryers with reduced operational costs, including oil usage. According to data gathered on a previous UTD project, the cost of oil in a fryer can range between $2,500 to $5,000 per year, depending on the volume of food cooked.

In response to this need, manufacturers have developed fryers that lower oil costs by reducing the volume of oil in the fryer. Field testing for the Frymaster fryer showed significant oil savings using the lower oil-volume method; however, some issues where observed with the fryers regarding the volume of food cooked. Because of the reduction in thermal mass with lower oil-volume fryers, the same volume of food that can be prepared is smaller for a given amount of time.

Gas Technology Institute (GTI), through UTD, developed a method that has the potential to reduce oil usage in a typical commercial foodservice deep-fat fryer by 25%. Instead of lowering the total volume of the oil used in a fryer, as is done with low-oil-volume fryers, the method extends oil life by calculating the required volume for extraction of old oil and replacement with new oil at defined intervals. The dilution of old oil with new oil extends the useful life of the oil. GTI has applied for a patent for this method.

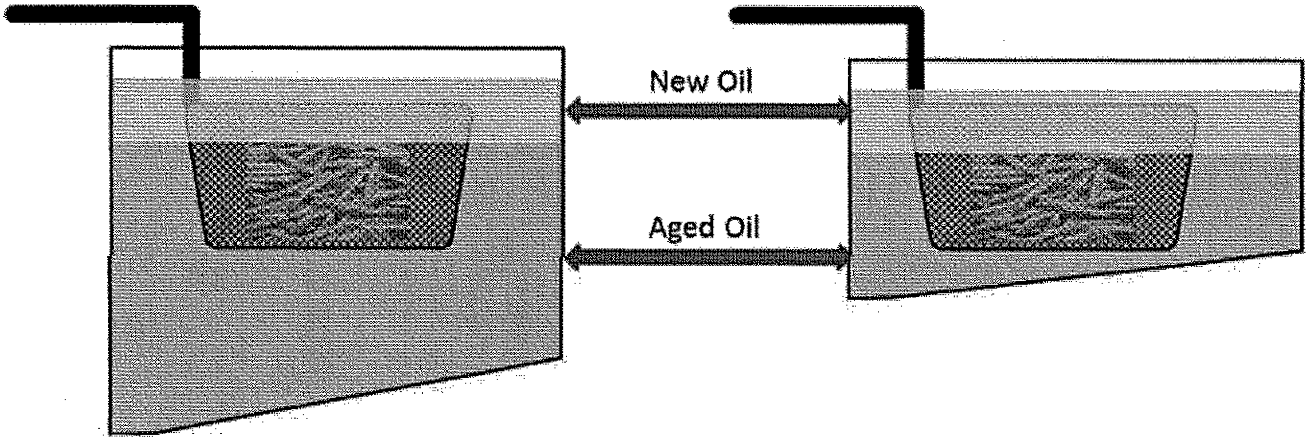
In this project, the new method will be demonstrated to determine the actual savings compared with calculations. Based on established fryer cooking test methods, GTI will test the oil life of a typical fryer under normal usage and compare usage when using the new oil-extraction method. The results will be used to approach potential manufacturing partners for licensing the technology and developing a new fryer.

The final deliverable for this project will be a defined operational method that reduces the oil usage in a standard deep-fat fryer and the savings potential of the method based on fryer size and usage rate.

Benefits / Market Implications

The ultimate objective of this effort is to develop a commercial deep-fat fryer that meets reduces oil usage and will maintaining the cooking characteristics expected by end users.

Calculations predict that the GTI method has the potential to reduce oil usage in a typical commercial foodservice deep-fat fryer by 25%. Based on typical oil usage and costs, this method could save an estimated $1,000 per year per fryer.



Researchers are testing a method to extend oil life in a deep-fat fryer by calculating the volume for extraction of old oil and replacement with new oil.

Technical Concept & Approach

Activities in the project focus on testing the GTI method for reducing the oil usage in a typical deep-fat fryer.

GTI will acquire, install, and instrument a typical commercial foodservice deep-fat fryer in the laboratory. The unit will be of typical vat volume and efficiency.

Researchers will test the fryer to determine the oil usage rate for both baseline usage and using the new method. The fryer will be tested using a specified volume of food in repeated batches until the oil is determined to have reached its useful life. This will be determined by using the ebro oil analyzer.

The project team will follow ASTM standard F1361 for open deep-fat fryers when applicable to oil life.

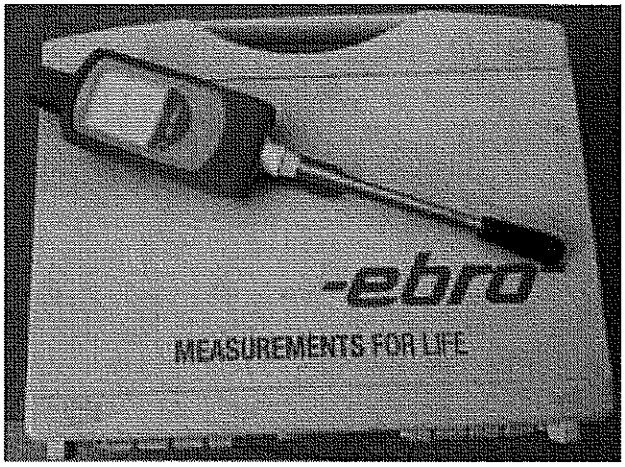
Results

In 2013, a fryer was purchased, laboratory prepared, and instrumented for testing under a restaurant hood in the laboratory.

A data-acquisition system was also prepared for laboratory testing and a test plan was organized.

Chicken nuggets will be tested because chicken tends to degrade the oil faster and this food product will make it easier to determine the effectiveness of oil-saving methods.

A patent associated with this project was awarded in January 2014.



Ebro oil analyzer probe.

Status

Currently, a high-volume fryer is being laboratory tested, requiring resources needed by the oil-saving fryer. Once testing with the high-volume fryer is completed, the oil-saving fryer will be tested.

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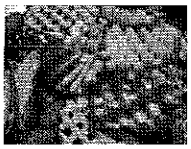
UTD Utilization Technology Development

High-Volume Gas Fryer

In this project, researchers are assisting a major commercial foodservice equipment manufacturer in the development of a high-volume deep fat gas fryer that can provide the same performance and food quality as electric models with a significant reduction in energy use.



Project Description

The majority of commercial foodservice appliances have an equal if not greater sales of gas-fired units compared with similar electrical models. However, one of the few exceptions is the high-volume deep fat fryer.

Currently, more than 90% of the high-volume fryers in use are electric, mainly because a combustion system has not been developed that can meet the energy density that the electric models can achieve. The higher energy input is needed for the frying of potato products such as waffle cut fries (as made at Chik-Fil-A) and fresh cut fries (as made at In-N-Out). The waffle fries have larger surface area compared to other fries and thus a larger heat-transfer surface for cooking. Fresh cut fries have a much higher moisture content and require higher heat transfer to convert the water to steam during the cooking process. Under-powered fryer designs have resulted in unsatisfactory cooking qualities of the final product.

In this project, researchers are assisting a major fryer manufacturer in developing a new combustion system that can deliver the required heat input for their high-volume fryer design. The objectives are to develop a new gas-fired combustion system, integrate it into the manufacturer's high-volume fryer, and conduct an efficiency and cook tests.

The manufacturer's current electric high-volume fryer is touted as being able to cook up to 21 pounds of food per load with only 100 pounds of frying oil. The gas model is listed as being able to cook up to 18 pounds of food per hour but with 130 pounds of oil required.

Benefits / Market Implications

Gas-fired models of the high-volume fryer will provide significant savings in energy use for end users over their electric counterparts.

Providing a gas-fired model that can compete on a performance basis with electric models should give gas high-volume fryers an advantage over electric units and increase the sales of gas-fired units.

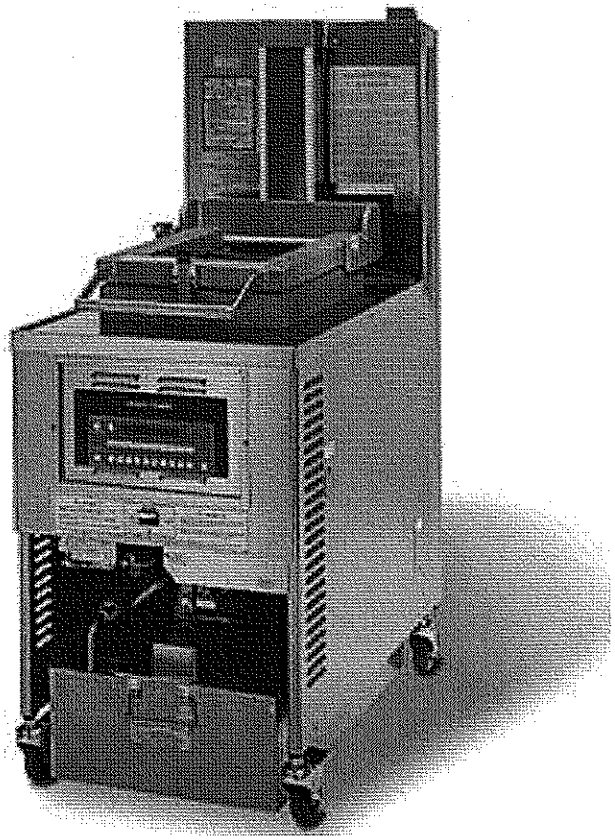
Technical Concept & Approach

Researchers and the manufacturer are focused on the development a new combustion system that can deliver the required heat input for the manufacturer's high-volume fryer design. The biggest challenge will be maximizing the heat-transfer efficiency of the heat exchanger while also not burning oil.

A baseline simulation model was created based on a standard manufacturer fryer design and compared to performance data from the fryer.

Heat-exchanger designs were modeled for combustion, heat transfer, and efficiency performance.

The performance of a new prototype fryer will be tested for efficiency and cooking quality.



Results

In 2013, the research team and the manufacturer investigated a fryer-control scheme to modulate the burner design to meet the current load. Preliminary ASTM cooking tests were conducted with a new fryer control.

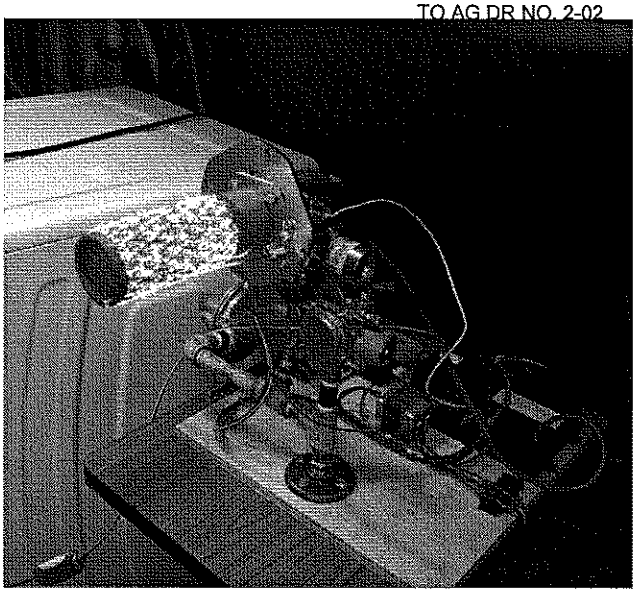
A variety of four different burners were tested along with an additional side-path heat exchanger to further boost the efficiency.

Highlights

- Modulating baseline tests were completed at high, medium, low firing rates from 20k to 75k Btu/hr. The system performed well at all firing rates.
- Two burner options were tested from different manufacturers, with both burners performing well.
- A new baffle was designed, manufactured, and tested, resulting in an increase in the efficiency over the original design.
- Varying excess air levels were tested to map the system performance to optimize combustion and efficiency.

A preferred heat exchanger design was chosen from the original four designs based on the best heat transfer performance and lowest pressure drop. Additional modifications were chosen to attempt to improve the heat exchangers' performance.

In 2014, a prototype incorporating all design changes was built and sent to the project team for testing.



A prototype fryer is undergoing testing in the laboratory. Modifications resulted in significant performance improvements.

Status

The prototype design was completed, tested, and shipped to the manufacturer, who is planning on manufacturing dozens of the model for reliability testing in its facility before finalizing the design and moving forward with production.

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UTD Utilization Technology Development

Commercial Building Reference Models

Initiatives are under way to help ensure that DOE reference and ASHRAE standard baseline computer-simulation models properly represent gas-heating loads in commercial buildings.

Project Description

The objective of this project is to ensure that U.S. Department of Energy (DOE) reference and ASHRAE standard baseline computer-simulation models properly represent gas-heating loads in commercial buildings. Activities involve development of comparative datasets from commercial building gas-usage billing data and collaboration with DOE and ASHRAE (and their respective supporting modelers) that will apply these datasets in computer-simulation validation activities.

The influence of these reference building models is growing. The DOE's EnergyPlus building energy use software is the current state-of-the-art whole-building energy-simulation program and utilizes these reference commercial and institutional building models to establish the basis for building energy-savings projections from higher-efficiency equipment. Such analysis dictates research and development policy decision making from federal government agencies to HVAC and professional societies including:

- DOE R&D program development (as already seen in high-performance home programs such as DOE's Building America) and
- ASHRAE standards development, including 90.1 and others (that lead to code-driven market transformation to higher efficiency).

However, these building models from DOE and ASHRAE often provide conflicting results and sometimes under-represent gas use. This has been confirmed by past field-monitoring efforts of commercial gas-fired equipment in the Chicagoland area. The lower heating loads and lower gas usage represented in these models in turn reduces their energy-savings projections for higher-efficiency, advanced heating equipment. That hinders the establishment of consensus market economics and discourages the development of energy-efficiency upgrades for gas equipment.

Other UTD project activities bringing high-efficiency heating equipment (e.g., condensing gas PACs and unit heaters) into the commercial sector have documented the under-sizing of heating loads in DOE reference building models and ASHRAE Standard 90.1 baseline building models compared to the results from recent monitoring of heating-equipment operations in actual buildings.

For this project, researchers will develop a set of annual space-heating Energy Use Intensities (EUIs) (therms/ft^2) for a variety of commercial building types and climatic locations based on gas billing data and building characteristics. This database will be compared to existing DOE and ASHRAE reference models in a Final Report. Investigators will share these results with DOE and ASHRAE and collaborate to improve the representation of gas-heating loads.

Chicago Small Office Building	Gas Heating Load (therms/ft^2)
DOE/NRELModeled 11/08 5,500 ft^2 Compliant 90.1-2004	0.165
DOE/NRELModeled 5/09 5,500 ft^2 Compliant 90.1-2004	0.226
ASHRAE/PNNL Modeled 10/09 5,500 ft^2 Compliant 90.1-2004	0.066
DOE/NRELModeled 10/09 5,500 ft^2 Compliant 90.1-2004	0.156
DOE/NRELModeled 9/10 5,500 ft^2 Compliant 90.1-2004	0.121
GTI Monitored 10/10-6/11 12,500 ft^2 Completed 2007	0.292

Data documented runtimes and gas usage of conventional, non-condensing packaged gas units for a small commercial office. When the monitored EUI is compared to the DOE and ASHRAE reference building model, both the degree of conflict in model results and the potential for under-representation of gas use are evident.

Benefits / Market Implications

Experts note that equitable treatment of information on gas use and equipment requires timely generation of more robust "real-world" datasets to validate the modeling process and direct interaction with modelers to ensure more realistic representation of gas usage. Otherwise, development of higher-efficiency, gas-heating equipment will continue to be undervalued in future research programs and building energy-efficiency standards and codes. Such datasets can also be utilized by participating utilities in their own emerging technology and energy-efficiency programs as a basis for establishing end-user savings for the application of higher-efficiency products.

Technical Concept & Approach

In this project, efforts are being made to:

1. Collaborate with DOE and ASHRAE on bringing forward more representative heating-load building models by sharing currently limited field-monitoring results, and
2. Expand the "real-world" database through such new project activities as a gas-billing database using 12 consecutive months of gas-usage data for hundreds of buildings from multiple utilities.

The database will address a variety of variables, including billing history and building characteristics (including square footage, number of stories, and vintage). Researchers will determine annual space heating EUI. When the calculated EUI is compared to DOE and ASHRAE reference building model EUI, both the degree of conflict in model results and the potential for under-representation of gas use will become evident.

The wide variation in these simulated results are generally due to differences in DOE and ASHRAE modeling assumptions – such as infiltration loads, ventilation loads, occupancy and HVAC operating schedules, etc. – even when applied to the same building envelope. By providing a large dataset based on real-world gas usage, the research team will provide ASHRAE and DOE with the needed data to help improve the accuracy of the models.

DOE referenced commercial building models provide EnergyPlus input files for 16 building types, three vintages (new construction, >1980, <1980), and 16 climatic locations. ASHRAE baseline commercial building models serve as the basis for ongoing Standard 90.1 revisions and provide EnergyPlus input files for an initial comparable subset series of seven new construction building types supported by ASHRAE advanced building-design guides.

Specific tasks focus on:

- **EnergyPlus Reference Building Model Prioritization and Pilot Data Collection** – This task is to generate a prioritized list of the 16 reference building models (e.g., small office buildings) to establish those with the greatest disparity between modeled heating loads and actual loads.
- **Expanded Data Collection** – Investigators will gather 12 consecutive months of therm-usage data for the prioritized list of commercial building types from participating utilities.
- **Develop EUIs for Comparison to Reference Building Models** – Once billing data has been collected, researchers will develop EUIs and make comparisons to the reference building models.

Results

In 2013, the project team secured participation from three utilities willing to provide commercial customer therm-usage data. Researchers also identified a resource for third-party building characteristic data to be merged with gas billing data in order to create the EUIs for each of the building types. The project team interfaced with data analysts at the respective utilities to complete data requests and specify the target customers and needed information.

Pilot data collection was completed for actual gas heating use from the field for select retail stores, quick-service restaurants, and small office building to provide guidance on development of a prioritized list of heating-load disparities among the 16 DOE/ASHRAE reference building computer models.

Status

In 2014, researchers will meet with DOE, ASHRAE, and their national laboratory partners to address findings and their implications on reference building computer-model heating loads. Researchers are completing the EUI development from the real-world utility dataset and making comparisons with the DOE and ASHRAE reference building models.

The Final Report is being prepared.

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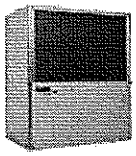
UTD Utilization Technology Development

Cold-Climate Performance Evaluation of NextAire™ Gas-Engine-Driven Heat Pump



A research team is evaluating the cold-climate performance of the NextAire™ 15-ton Multi-Zone Gas-Engine-Driven Heat Pump (GHP). The technology is currently targeted as a gas-cooling option in hot climates; however its high heating efficiency and low emissions present a potential for wider markets.

Project Description

A significant goal of the natural gas industry is to develop and apply gas heat pumps (GHPs) in the broad market for commercial buildings. The GHP design is similar to electric air-source heat pumps, but uses an advanced natural gas combustion engine in place of an electric motor. Variable-speed engine controls allow the GHP to closely follow load and maintain efficiency. GHPs combine high efficiency heating (1.2-1.4 COP) and cooling (0.95-1.2 COP), offering the potential to reduce operating and lifecycle costs compared to conventional HVAC equipment.

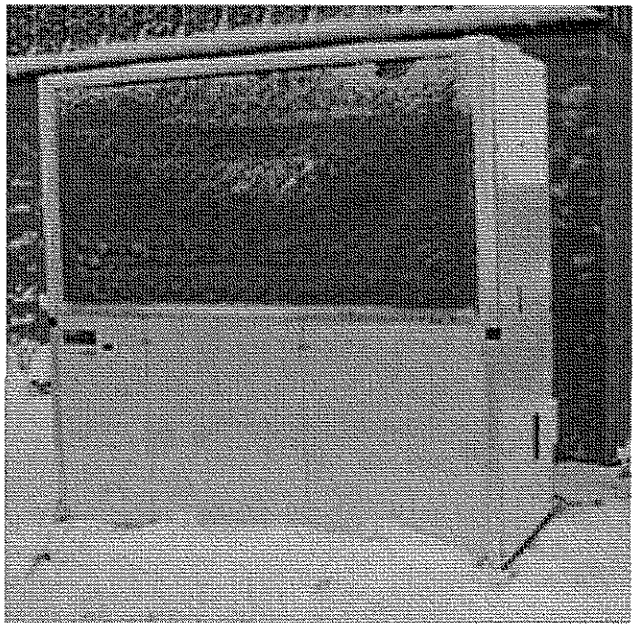
Although GHPs have a significant share of the Japanese and European markets, they have only recently been introduced to the U.S. market. IntelliChoice Energy's (ICE) NextAire™ Multi-Zone gas engine heat pump was introduced in 2009. The NextAire GHP consists of high-efficiency scroll compressors paired with an Aisin engine with a demonstrated long life (30,000 hours). The units have a maintenance interval of 6,000 to 10,000 hours. The multi-zone GHP is equipped with an electronic speed controller that regulates the revolution rate of the engine by taking both indoor and outdoor temperatures into account. This results in minimal energy loss and a constant indoor temperature when compared to traditional electric heat pumps.

The NextAire Multi-Zone GHP is available in 8-ton and 15-ton units to provide zoned heating and cooling for up to 17 zones and 33 zones, respectively. Units can be coupled together for larger installations of 100, 200, and 300+ tons. The multi-zone GHP is powered by a single phase, 208-230V, 20 amp circuit. GHPs can be used in new construction or as retrofits for commercial or residential buildings.

The NextAire 11-ton rooftop packaged gas heat pump, commercialized in 2010, is designed for rooftop installation in "big box" commercial buildings and has the same high-efficiency performance (18 SEER) as the multi-zone GHP. The rooftop GHP received the 2010 National Society of Professional Engineers New Product Award and was also selected by *R&D* magazine in 2011 as one of the top 100 technologically significant products introduced into the marketplace.

Initial GHP field demonstrations focused on hot climates where reducing electric energy, peak electric demand, and water use produced significant savings in operating costs. In earlier field demonstrations funded by UTD, NextAire GHP systems were monitored in a multi-zone environment in Orlando, FL, and in a hydronic application in Birmingham, AL. These case studies validated both the energy savings and the reliability of the NextAire GHP in warm climates.

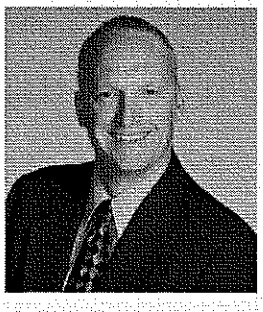
The latest version of the NextAire Multi-Zone GHP, the Model E, was introduced to the U.S. market in 2013. Unlike earlier designs, the Model E GHP can be adapted for any U.S. climate, including colder climates. Preliminary analyses indicate that GHPs in colder climates with high heating loads can generate additional savings in source energy and operating costs due to high-efficiency heating performance. The NextAire 15-ton GHP offers heating efficiencies up to 140% at rated conditions, as compared to high-efficiency furnaces rated at 90% to 97%. Heat recovered from the engine cooling jacket and engine exhaust can supplement the GHP output during heating mode, increasing overall system efficiency – similar to a combined heat and power system. In contrast, electric heat pumps require inefficient resistance heating due to



operational limitations and reduced capacity at low outdoor temperatures. Colder climates have the potential to take advantage of the high-efficiency heating performance and generate more than enough energy savings to offset the initial cost premium. The cost premium is further reduced by providing heating and cooling with the same unit. Increasing the target market for GHPs to include cold climates could potentially lead to higher production volumes and reduced first costs.

The objective of this project is to evaluate the cold-climate performance of the NextAire 15-ton Multi-Zone Model E GHP under controlled laboratory conditions.

"Southwest Gas has always supported natural gas air-conditioning technology. We are extremely encouraged that over 300 NextAire gas heat pump (GHP) units have been installed in our service territory. The GHP technology has proven to be successful, with more than 2.2 million cumulative run hours. Using natural gas for cooling saves energy, reduces costs, and lowers greenhouse gas emissions. It's a win-win for all!"



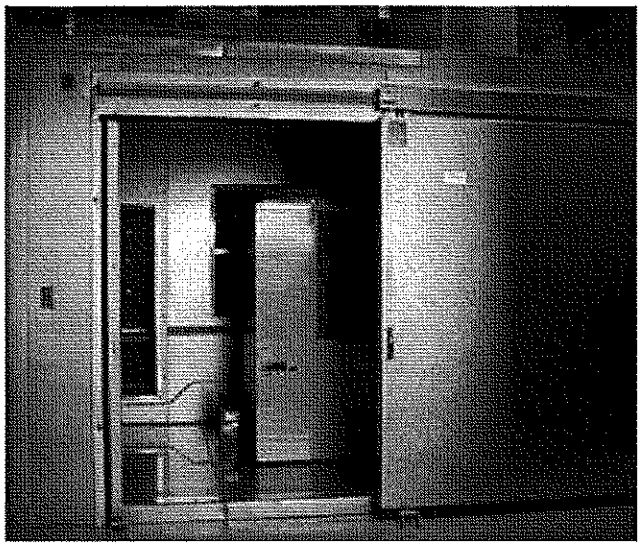
- Anthony Hills, PE
Director
Southwest Gas Corporation

Benefits / Market Implications

- High heating efficiency provides potential savings in operating costs, source energy use, and emissions
- Electric power use is reduced by up to 80% compared to conventional equipment, with significant reductions in peak electric demand
- Operating and maintenance costs are projected to be up to 30% lower than conventional HVAC equipment
- Water consumption is reduced by up to 17,000 gallons/year per 15-ton unit.

Technical Concept & Approach

The scope of this project (Phase 1) is to conduct a laboratory evaluation of the NextAire™ 15-ton Multi-Zone Model E GHP to evaluate the performance and heat capacity under cold-climate conditions in a large environmental chamber. The GHP unit and air handlers were instrumented to measure performance, capacity, and gas and electric consumption under various conditions. The data will be analyzed to determine the COP of the equipment as well as the capacity and part-load performance with varying outdoor temperature.



A GHP was tested in a large environmental chamber designed to accommodate commercial equipment.

Following Phase 1 laboratory testing in this project, a cold-climate field demonstration of the Model E GHP will be conducted in Boise, ID, at an Intermountain Gas Company facility in a follow-on project. The demonstration unit will be installed in 2014 and will be monitored for a full calendar year.

Results

The outdoor unit was installed in an environmental chamber and the simulated "outdoor" temperature was maintained within +5°F. Gas consumption was measured by a temperature-compensated gas meter with a precision of 40 pulses/cf. Natural gas heating value supplied to the facility averaged 1,003 Btu/cf during testing.

The 15-ton GHP unit was evaluated at rating conditions (47°F for heating, 95°F for cooling) and colder temperatures as low as 5°F. The GHP performance was measured at different capacities ranging from three tons (20% part-load) to 20 tons (133% part-load). A heating COP of 1.4 was measured at the rated conditions (47°F). At lower temperatures (5°F), heating capacity decreased by less than 5%.

Status

Testing is expected to be completed in 2014.

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UTD Utilization Technology Development

Commercial Foodservice Whole Kitchen Assessments & Demonstrations

Research is under way to identify gas-fired commercial foodservice equipment and potential demonstration locations to quantify the benefits of selected appliances in terms of cost and cooking performance.

Project Description

Traditionally, commercial foodservice (CFS) operators have been reluctant to replace existing equipment with newer models for several reasons, including costs and concerns over the ability of new equipment to prepare food as expected. This has made the introduction of more efficient new gas-fired equipment a challenge for manufacturers.

Chain restaurants, which represent about 50% of the CFS industry, have a better understanding of the long-term benefits of newer equipment, but that information is not generally available. In this project, research is under way to identify gas-fired CFS equipment and potential demonstration locations and quantify the benefits of equipment in terms of cost and cooking performance.

Selected equipment will be tested in the laboratory and/or at restaurant demonstration sites.

Researchers will conduct whole kitchen assessments to quantify the existing population of CFS equipment to help locate sites for conducting demonstrations.

The potential list of appliances to be investigated includes, but is not limited to: a steam kettle, range, wok, conveyor oven, convection oven, boilerless steamer, low-oil-volume fryer, and griddle. Any appliance of specific interest to a sponsor could also be targeted for laboratory performance testing or field demonstrations.

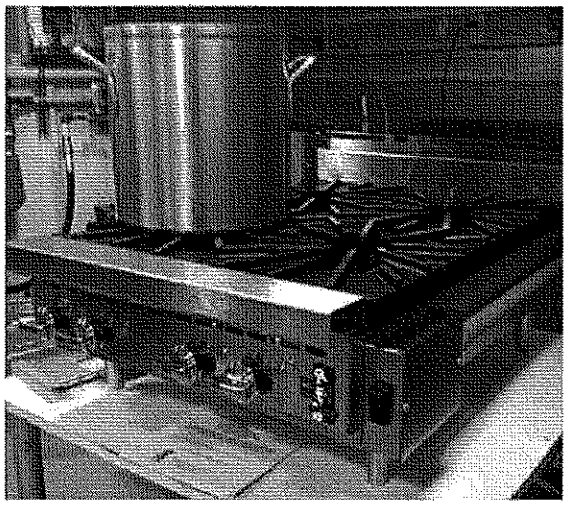
In addition to the equipment assessments, the project also involves the development of tools and/or calculators that combine the available information, tools, and calculators that can be used by the gas and restaurant industries to determine the economic and environmental benefits of using new, more advanced gas-fired foodservice equipment.

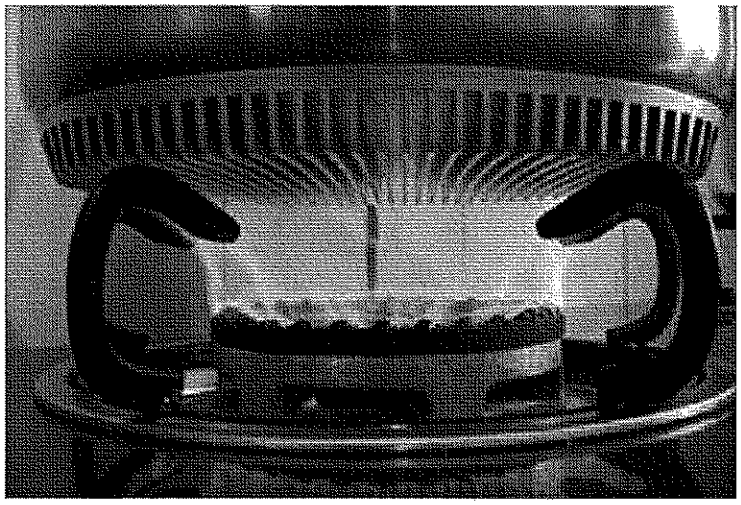
Benefits / Market Implications

Verifying the performance of a commercial foodservice technology in the laboratory or the field allows utilities to understand the advantages of specific technologies and how to promote them.

Results from this project will provide utilities with the ability to quickly evaluate appliances, whether a gas-fired technology or an electric competitor, and determine the true performance of the appliance.

Of the over $660 billion in sales of CFS appliances in 2011, the majority sold for each appliance category are units with efficiencies not rated in the top 20%. The main reason is that equipment choices are based mostly on application and first cost. However, increased awareness of the long-term savings of more efficient equipment and incentives from the gas industry have improved the sales and development of higher efficiency equipment over the past decade. Despite the limited number of Energy Star®-listed units, most ap-





A pilotless countertop range a brand of pots and pans that include a finned heat exchanger are among the first appliances to be demonstrated in this project.

appliance categories have more efficient options available. The issue has been making the end user aware of the lifetime benefits of buying more efficient appliances.

Technical Concept & Approach

To maximize the benefit to the gas industry and consumers, this project does not focus on a single model of commercial foodservice equipment. Instead, the project approach is on identifying several newer and more efficient designs of commercial foodservice appliances for each demonstration location.

Based on the cooking needs of each individual demonstration site, the project team will identify specific appliances from different manufacturers.

This program is divided into two types of tasks: One focuses on a single-utility-sponsored demonstration and the other focuses on conducting whole kitchen assessments at as many locations as possible. The project team will identify an assessment site for evaluating the installed CFS units. Researcher will complete an audit of the existing equipment in each location, complete a cost/benefit analysis of replacement with more efficient options, and identify makes and models for potential demonstrations.

Usage time and energy consumption for both the existing and replacement units will be monitored, and energy and cost savings calculated. Consumer surveys comparing the cooking performance and the usage of the new units will also be completed and compiled into the Final Report.

Results / Status

The project team developed a Whole Kitchen Assessment form to assist in overall evaluations.

An assessment site agreement is also being developed.

Whole kitchen evaluations were conducted at two sites in Oklahoma. Once the information is reviewed and the potential savings calculated for using more energy-efficient appliances, demonstrations of two applilances will be conducted.

Testing will also include the use of a brand of pots and pans that include a finned heat exchanger (either milled or attached to the bottom) that have been shown to significantly increase the cooking efficiency of a range top.

The project team compiled a list of existing calculators and information. Based on an initial evaluation, it was determined that none of the calculators included a source energy calculation; therefore, an existing calculator is being modified to use with commercial foodservice applications.

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UTD Utilization Technology Development

Commercial Foodservice Tools and Calculators

In this project, a research team is analyzing tools and/or calculators used by the commercial foodservice industry in an effort to combine information available from various sources into a single web-based tool that can be used to determine the economic and environmental benefits of using new, more advanced equipment.

Project Description

Results from the UTD Commercial Foodservice (CFS) Audit and Survey (project 1.11.A) show the growing importance of addressing "green"-related issues – such as sustainability – in the CFS industry.

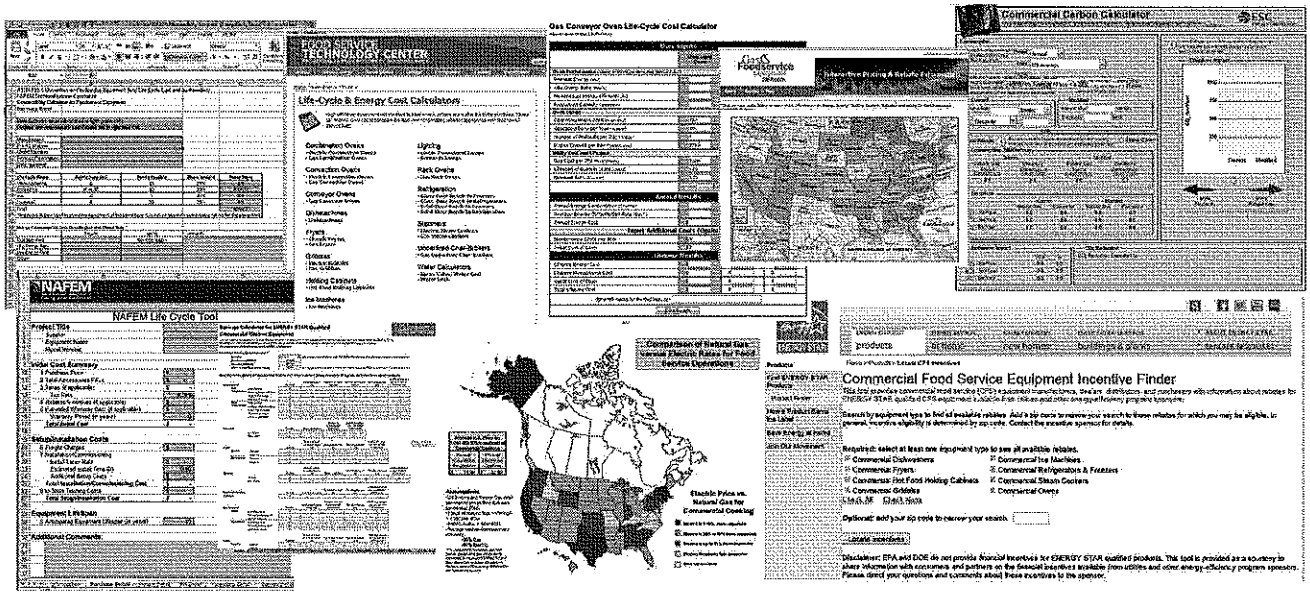
For the foodservice industry, sustainability includes elements such as environmental compliance, recyclable materials, material usage, packing, energy usage, water usage, and disposal. The North American Food Equipment Manufacturers (NAFEM) association developed a spreadsheet that calculates many of these values; however, the calculator does not fully address the source-energy consumption and air emissions for the appliances.

To fully realize the environmental benefits of more efficient appliances, this information would be needed and can be provided using the Source Energy and Emissions Analysis Tool developed by the Carbon Management Information Center (CMIC) at Gas Technology Institute. NAFEM and CMIC have agreed to develop a method for using both resources for CFS applications. Also, GFEN (Gas Foodservice Equipment Network) has agreed to participate in the project, adding its calculators, equipment databases, and other resources.

The focus of this project is on the creation of tools and/or calculators that combine the information available from various sources that can be used by the gas and restaurant industries to determine the economic and environmental benefits of using new, more advanced CFS equipment. The tools and calculators will show the potential energy and cost benefits of replacing or buying more energy-efficient equipment, typically Energy-Star rated. The project team will develop a webpage and mobile applications for easy usage in commercial kitchens.

Benefits / Market Implications

CFS owners and operators have traditionally been hesitant to replace functioning equipment or buying new, more efficient equipment because of first costs. The objective of this project is to identify and simplify access to different calculators and tools for the CFS industry for information and data that can demonstrate the energy and cost savings of replacing out-dated or broken equipment with energy-efficient models. Tools and calculators can also show how rebates and long-term cost savings will reduce the burden of increased purchasing costs of new equipment.



Researchers analyzed a variety of source information from various industry organizations.

Technical Concept & Approach

Researchers are interacting with various organizations on evaluating existing calculators and determining what elements are useful to the CFS industry.

Available databases for the stock efficiency of CFS appliances, information for available rebates in North America, and Energy Star ratings, are being compiled.

The research team will also:

- Identify informational needs
- Show the value of existing tools/calculators, and
- Identify gaps of weaknesses in existing tools/ calculators

Information will be compiled into a webpage. The web interface will include a list, explanation, and links to other calculators that could be of use to the industry. The project team will also explore developing mobile-based applications for some of the information or tools.

Results

The project team compiled a list of existing calculators and a brief overview of each. Based on the initial evaluation, it was determined that none of the calculators included a source-energy calculation; therefore, the existing CMIC calculator is being modified for use with the CFS.

The following information sources were investigated:

- NAFEM: Sustainability Calculator
- NAFEM: Equipment Life Cycle/Total Cost of Ownership
- Fisher Nickel Foodservice Equipment Total Life Cost Tool
- CMIC Source Energy and Emissions Analysis Tool
- Food Service Technology Center (FSTC): The Energy Efficient Kitchen Tool
- FSTC: Life-Cycle $ Energy Cost Calculators
- GFEN: Comparison of Natural Gas versus Electric Rates for Foodservice Operations
- GFEN: Utility Pricing and Rebate Information
- Energy Star: Guide for Restaurants
- Energy Star: Commercial Kitchen Package Resource
- Energy Star: Savings Fact Sheet
- Energy Star: CFS Program Administrator Guide for Utilities Energy Star
- Energy Star: Commercial Food Service Equipment Incentive Finder
- National Restaurant Association: Conservation Guide
- Consortium for Energy Efficiency: High Efficiency Incentive Guide
- U.S. Department of Energy : Database of State Incentives and Renewables & Efficiency
- Energy Solutions Center: Commercial Carbon Calculator.

Status

A web interface was designed and the webpage will be made available in 2014.

Also, activities were initiated to develop mobile applications based on information from this project.

The project team continues to analyze information sources.

Remaining activities include:

- The design a web interface to use a select group of calculators
- The identification of which calculators could be made into applications for smart devices
- A webinar to review the calculators and tools.

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UTD Utilization Technology Development

Commercial Foodservice Ventilation

Research in this program is focused on the evaluation of currently available ventilation systems for commercial kitchens and foodservice facilities.

Project Description

Previous energy and water-usage studies in commercial foodservice facilities have shown that significant energy losses occur because of recoverable heat lost in the ventilation. However, systems or methods for preventing these types of energy losses have not been tested and proven in actual foodservice operations.

The objective of this program is to identify and quantify ventilation equipment that could reduce the energy usage within commercial foodservice facilities.

Activities are focused on an analysis of heat-recovery systems for casual dining restaurants.

Benefits / Market Implications

Significant energy loss in commercial foodservice facilities are due to the heat generated and ejected from the building via the ventilation system.

Despite available methods for recovering this heat, the effectiveness of these systems has not been thoroughly evaluated and thus the actual energy savings has not been measured.

Data and reports from this project are expected to accelerate the installation of these systems in foodservice facilities and drive the development and market acceptance of new, more efficient equipment.

Technical Concept & Approach

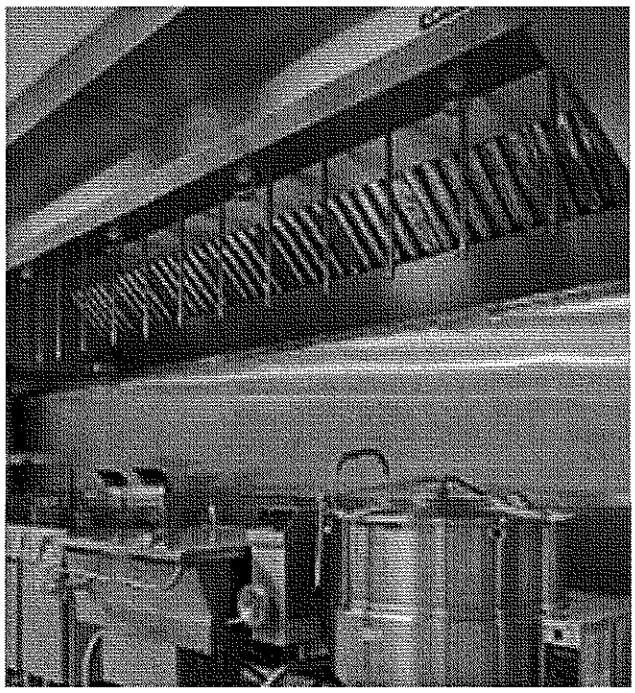
For this project, researchers will analyze and validate the energy/water savings of different heat-recovery and water-management systems in casual dining restaurants, including point-of-use water-heating systems.

Results

Initial activities in this project focused on gathering information about different heat-recovery systems, including systems from Blissfield Manufacturing Company and Halton Group. Data sources include a report completed by Fisher-Nickel, Inc., and a field study completed by CLEAResult Company.

Blissfield Manufacturing offers a unique vent hood insert that doubles as a grease filter and heat-reclamation device. This product, called the Dragon Fire Thermo Recovery Filter™, combines a grease filter and trap with a three-pass heat exchanger to use heat created from the kitchen grill to heat water or make-up air. Distributors claim the Dragon Fire system will convert up to 60% of the energy normally lost in the exhaust hood from the cook line into heat for water or make-up air. When used for water heating, the heated water (which has an output temperature of up to 180°F) can be used at the cook line and/or pumped to the water heater for storage or additional heating.

Halton Group specializes in indoor climate solutions, focusing on developing unique systems that provide energy-saving solutions for capturing heat and emissions associated with the cooking process in professional kitchens. These systems allow for a more comfortable and productive thermal environment with reduced operational costs. The company claims its Halton Capture Jet® technology is the only system that can reduce a commercial kitchen's energy bill by 30% or more with no compromise of the air quality of the foodservice environment.



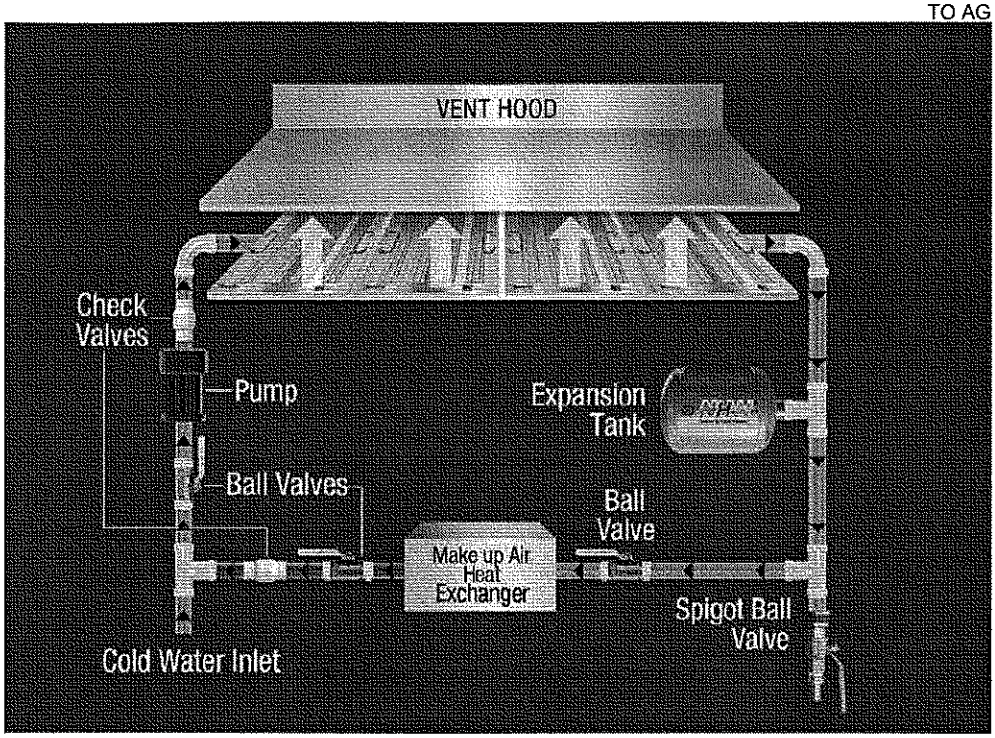


Diagram of the Dragon Fire™ heat-recovery system.

Status

The project team continues to gather and analyze data on existing systems.

A site was identified with an installation of a heat-recovery system in the ventilation system. The project team is acquiring information about the system and its performance for input into the project results.

Fisher-Nickel will provide a summary and evaluation of existing ventilation systems.

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UTD Utilization Technology Development

Increasing Commercial RTU Thermal Efficiency Above 90%

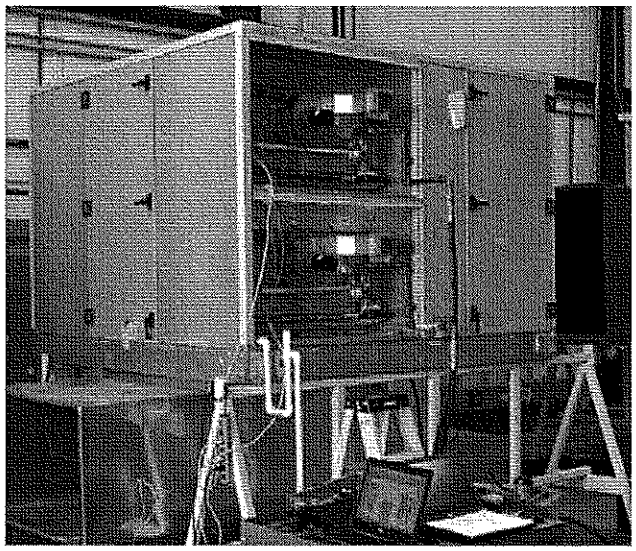
Efforts are under way to implement and validate design changes to a HVAC rooftop unit (RTU) to meet or exceed efficiency goals in the laboratory and quantify potential energy savings across climate zones and building types.

Project Description

Packaged gas heating and electric air-conditioning rooftop units (RTUs) are self-contained HVAC systems used in nearly half of all air-conditioned commercial floor space. While RTUs can be major energy consumers, significant energy savings can be achieved in various commercial building types, particularly in cold climates, by deploying emerging high-efficiency RTU product lines.

Currently, the introduction of high-efficiency heating RTUs has been slowed by certain economical and technical challenges. To accelerate the market impact, sufficient net annual energy savings potential must be demonstrated to pay back the cost premium of the condensing RTU.

Research has found that gas operating cost savings during the heating season may be reduced by increased electricity consumption for the blower to move supply air through the additional pressure drop of the secondary condensing heat exchanger year round. Unlike a residential furnace application, the RTU supply air fan will often run continuously during the HVAC operating schedule to meet air-distribution requirements in commercial and institutional buildings. Thus, higher efficiency must come at a reasonable pressure drop penalty.



Testing of first-generation condensing heating modules in RTU testbed.

Condensing combustion technology has been applied for years in many HVAC product lines indoors – from gas-fired home furnaces to water/steam boilers in the residential through industrial sectors. However, outdoor packaged gas heating and electric air-conditioning RTUs have lagged behind due to concerns about combustion condensate management in freezing environments. Only recently have smaller manufacturers started applying condensing combustion technology in limited RTU product lines and demonstrated adequate freeze protection, code-acceptable sanitary sewer disposal, and neutralization of the acidic content of the condensate.

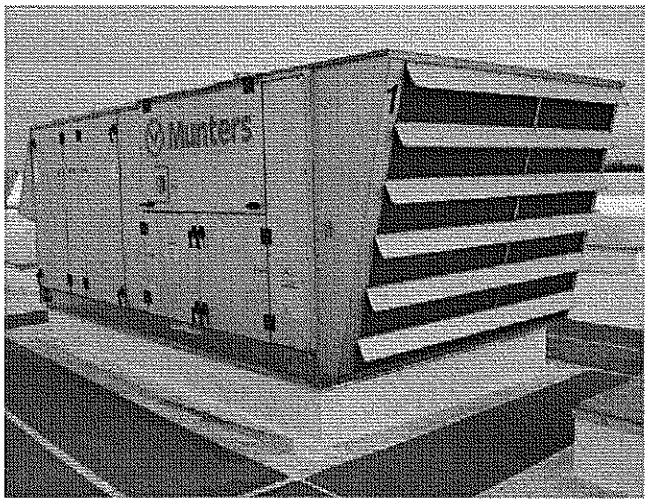
In a previous UTD project, laboratory testing of a first-generation condensing heating module design were performed and field tests were conducted. After successive iterations with minor modifications, a significant outstanding challenge remained in meeting or exceeding the 93% thermal efficiency target. The goal of this new project is to achieve even higher thermal efficiencies.

In parallel with laboratory development and validation, researchers will conduct a market and technical assessment of current and emerging RTU equipment for commercial or industrial markets to determine potential energy savings compared to current baseline operation.

Benefits / Market Implications

The increase in thermal efficiency from first generation (<90%) to second generation (>93%) can enhance savings for utility customers. However, the cost effectiveness of condensing RTUs is predicated on sufficient heating-season runtime to generate the annual net energy savings to pay back the combined premiums on first cost, installation cost, and any ongoing maintenance cost (neutralization system calcium carbonate replenishment) in an acceptable timeframe. This circumstance naturally favors more northern utilities in colder climates in the U.S. and Canada.

The introduction of condensing technology in RTU product lines offers a timely opportunity for energy-efficiency programs to begin expanding popular rebate



Standard 80% thermal efficiency RTU for baseline monitoring.

programs for condensing technology (in residential furnaces through condensing industrial boilers) to the commercial and institutional low-rise building HVAC equipment sector.

Technical Concept & Approach

During laboratory testing of RTU heating modules, researchers found areas for improvement through design modification:

- **Improving the flue gas manifold for even distribution of condensing efficiency**

  Central mounting of flue gas inducer results in an uneven distribution of flue-gas flow throughout the tube bank, leading to condensing conditions preferentially along the perimeter tubes, where flue-gas flow rate is the reduced.

- **Alternative to "stacked" arrangement of modules**

  The preferred arrangement for compatibility with existing installation methods is stacking one heating module on top of another. While suitable for field retrofits, this contributes to the aforementioned efficiency limit. The heated airflow passing over the heat modules is in a downdraft arrangement, in which the heated air passing over the first module (primary and secondary sections) is preheated before reaching the second module. With inter-module air temperatures exceeding 130°F at standard conditions, the lower module is unable to effectively reach condensing efficiency.

- **Emissions and Excess Aeration**

  With design modifications, the condensing RTU heating modules may be able to reduce excess air levels, improving efficiency further without exceeding emissions limitations.

Specific tasks for this project include:

- Design of a modified primary/secondary heat-exchanger layout
- Fabrication of modified heating modules for evaluation within an RTU testbed in the laboratory
- Laboratory testing to evaluate a modified-heating-module-equipped RTU with representative outdoor and indoor air streams to demonstrate 93% or better thermal efficiency
- Development of a field-test plan for future evaluation of a second-generation condensing RTU in the field
- Benchmark EnergyPlus modeling of standard-heating-efficiency RTUs to establish baseline energy use for selected building types and climate zones
- Comparitive EnergyPlus modeling using baseline building types and climate zones of first- and second-generation condensing-heating-efficiency RTUs.

Results / Status

Following discussions with manufacturers, the project team opted to shift away from "second-tier" manufacturers and focus on the major OEMs. Efforts are under way to establish engineering contacts to serve at major manufacturers as technical advisors throughout the experimental phase of this effort. Researchers specified and procured a Carrier WeatherMaker® RTU to serve as platform for laboratory testing.

As cost-sharing to Canada's Centre for Energy Advancement through Technological Innovation, the research team completed building modeling of non-condensing vs. condensing efficiency RTUs in several U.S. and Canadian cities. Analysis was extended to include the impact of demand-control ventilation and energy-recovery ventilation.

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UTD Utilization Technology Development

SPC204 MCHP Test Method Standard Support

Efforts are under way to develop a draft standard test method for determining the net electrical-generating performance and heat-recovery performance of small combined heat and power devices (50kW or less).

Project Description

While small (micro) combined heat and power (MCHP) systems are becoming well established in Europe and Asia, the technology has been under-utilized in the United States and Canada.

Among the barriers in the North American market is the lack of a standard test method to determine the net electrical-generating performance and heat-recovery performance of MCHP systems.

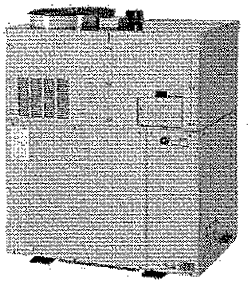
Since 2010, ASHRAE Standard Project Committee 204 (SPC 204) has been active but unsuccessful in developing a test method for rating MCHP devices.

Previously, Gas Technology Institute (GTI) played a major role along with Underwriters Laboratories in developing a distributed generation and CHP laboratory testing protocol for systems in sizes ranging from 30kW to 1 MW. The protocol was adopted and used by the by Association of State Energy Research and Technology Transfer Institutions.

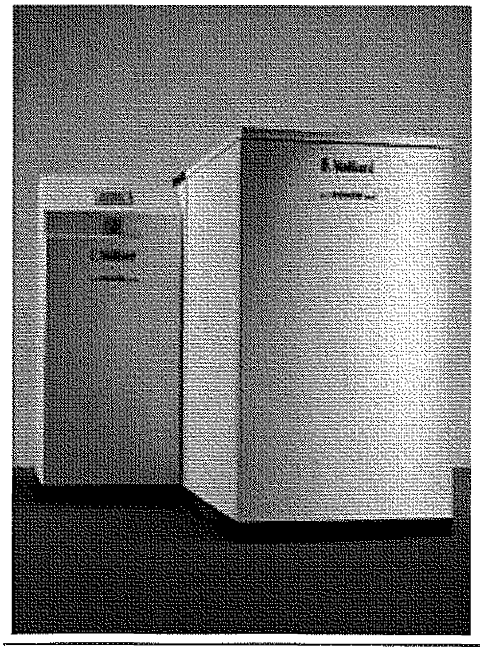
In this project, a research team will develop and provide to the SPC 204 Committee a draft MCHP test method in the ASTM format for consideration. The project is being conducted in collaboration with Canada's Natural Gas Technology Centre (NGTC) to ensure that the draft provides a harmonized approach to standards development for the North American MCHP market.

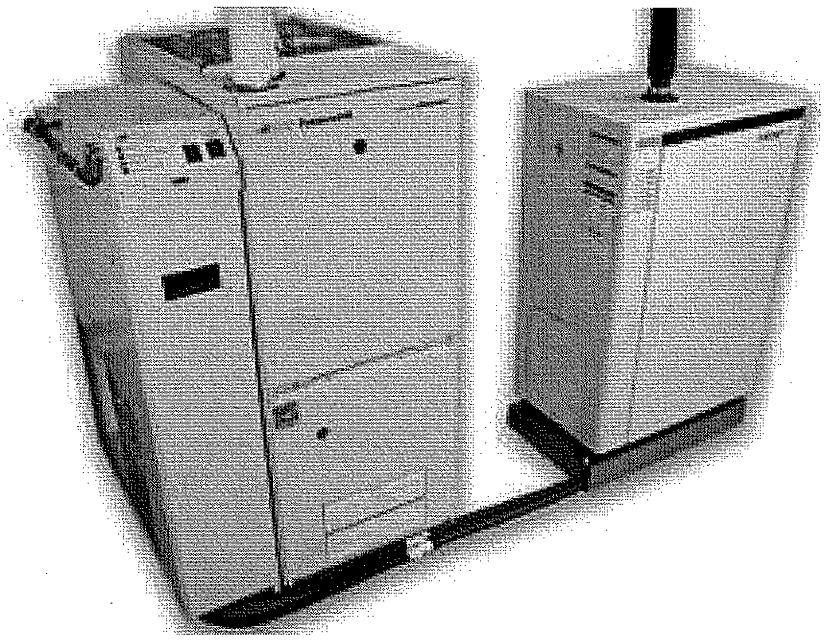
Benefits / Market Implications

Of the approximately 35 manufacturers of MCHP worldwide, experts report that less than half are evaluating entry into the North American market. A standardized method of testing and rating would provide a path towards consistent and clear treatment throughout North American markets.



A standard test method would provide a level playing field for MCHP manufacturers in establishing product efficiency for a large market. Such ratings provide a valuable metric for end users to compare products or for utilities to evaluate a class of products for inclusion in efficiency and rebate programs.





Technical Concept & Approach

This project is a fast-track initiative to develop a test method for small combined heat and power systems.

The project will draw from existing material that has been developed in previous efforts.

The project involves:

- A review GTI protocols and procedures for testing MCHP systems
- Rewriting protocols and procedures for testing MCHP systems in ASME standards format to best extent possible
- Collaboration with NGTC on a review of tests, protocols, and procedures

Presentations will be made to the SPC 204 committee on progress.

Results

The SPC 204 Committee convened at the ASHRAE winter meeting on January 20, 2014, in New York City. At the meeting, researchers presented an overview of the test parameters that would be used in developing a draft test method to establish an overall Efficiency MCHP. The committee provided guidance on establishing boundary conditions for testing, and testing at high-temperature and low-temperature conditions.

The committee subsequently made two substantive changes to its scope and purpose. First, limits to size and heat-to-power ratio were proposed to more accurately define "micro" combined heat and power systems. Because the ratio of heat output to electrical output varies by the type of prime mover, a limit on solely the electrical power could result in a very large system with a poor electrical efficiency. Such a system would be significantly larger than those for which the test procedures were designed. (The additional clarification did not exclude any currently available MCHP products.) Second, fuel sources were limited to natural gas, propane, or diesel fuel. The change purposely excludes both biomass and biogas because of the difficulty in quantifying the heat content of those fuels. In addition, to improve clarity, phrasing that identified specific types of prime movers was eliminated, as were references to "stand-alone" and "packaged" systems. These changes were voted on and submitted to ASHRAE in March 2014.

Status

A subcommittee of representatives from GTI, the National Institute of Standards and Technology, Natural Resources Canada, and NGTC continue work on developing a draft method of test for the full committee to review in the fall of 2014.

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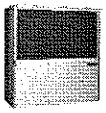
UTD Utilization Technology Development

Field Demonstration of the Model E NextAire Gas-Engine-Driven Heat Pump



This project focuses on the introduction of an enhanced gas heat pump design incorporated into a line of equipment from NextAire™. Researchers are monitoring the performance of a new 15-ton model installation in Georgia.

Project Description

In 2013, IntelliChoice Energy introduced a revised gas heat pump (GHP) design, Model E, incorporating engineering changes for improved part-load performance and an increased rated capacity for more favorable economics. This project is focused on the development of a case study for the new NextAire™ Model E design being installed in a municipal building in Dublin, GA.

Previous field studies of the NextAire GHP demonstrated energy and cost savings and confirmed its robust and reliable performance. These studies also show some variation in performance depending on climate, installation, and operation of the system.

The Model E is the latest design of the NextAire Multi-Zone GHP and incorporates several design changes. The Model E uses two compressors instead of four. The unit also has a higher ventilation rate and has a slightly smaller footprint. Unlike the previous model (which required significant changes for hot, moderate or cold climates), the Model E will be used for all U.S. locations and only requires a retrofit kit for installations in colder climates. The use of a single platform for all U.S. climates is expected to reduce equipment costs as production volumes increase.

In a parallel UTD project, a laboratory evaluation of the Model E cold-climate performance is under way.

Benefits / Market Implications

GHPs combine high-efficiency heating (1.2-1.5 COP) and cooling (0.95-1.2 COP), offering reduced operating and life-cycle costs as compared to conventional HVAC equipment. GHPs also significantly reduce peak electric demand and water use compared to electric chillers.

GHPs offer a viable option to compete with electric heat pumps and air conditioning. The increased rated capacity of the Model E improves economics.

Based on previous field studies, operating and maintenance costs are projected to be 30% less than electric heat pump equipment. Electric power use is expected to be up to 80% less than conventional equipment. In addition, this packaged unit does not require a separate cooling tower and reduction in water consumption is estimated up to 17,000 gallons per 15-ton unit per year.

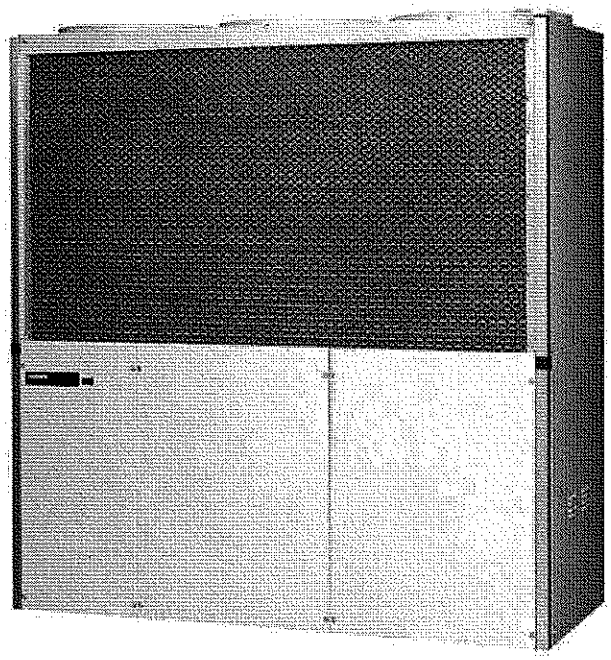
Technical Concept & Approach

For this project, a research team will monitor the performance the new Model E 15-ton NextAire Multi-Zone GHP and create a case study to present the Model E performance and economics.

A detailed analysis will be conducted of one year of performance data collected at the Dublin installation. Annual performance and cost benefits will be presented in a brief case study format.

One 15-ton heat pump and 11 air handlers will serve 11 zones at the City Hall municipal building in Dublin, GA.

Researchers will measure system performance, including energy use and energy delivered to the conditioned



Dublin, GA, City Hall site for the Model E demonstration.

space. All 11 air handlers will be monitored for temperature and humidity levels in the return and delivered air stream and the electric usage of each air handler. Power consumption and natural gas usage will also be measured at the heat pump.

Results / Status

A field test plan was developed in 2013 that included instrumentation selection, measurement protocols, data collection procedures, and a site visit.

Related components as well as the data-acquisition equipment were incorporated in the first quarter of 2014. The Model E NextAire Gas-Engine-Driven Heat Pump and air-handling units were installed and commissioned during the first and second quarters of 2014.

Due to a product design change, a specified temperature/humidity sensor could no longer be used in air-handler cassettes to measure delivered air temperature, and a new sensor had to be identified and evaluated. A adequate replacement was found and installed. The data-acquisition system was installed during the second and third quarters of 2014. Field test commissioning is scheduled the fall of 2014.

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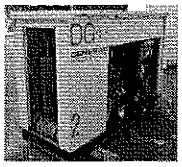
DISTRIBUTED GENERATION

UTD Utilization Technology Development

Generac DG50 Product Concept



In this project, researchers analyzed the technical requirements, market needs, and potential risks for the re-introduction of a Generac Power Systems' natural-gas-powered distributed-generation system. The system – the DG50 – was first brought to market about 10 years ago; however, production was halted due to unfavorable market conditions at the time.

Project Description

With increased domestic production of natural gas, average annual wellhead prices are predicted to remain below $5 per thousand cubic feet through 2023. At these gas prices – and with electricity prices predicted to remain steady or rise – significant opportunities exist for energy and operating-cost savings from distributed generation (DG).

Attaining cost feasibility has been a challenge for small DG systems (e.g., < 100 kW). However, while competing technologies are priced well above $1,200/kW for equipment alone, the DG50 from Generac Power Systems had an approximate installed cost of $600/kW when first introduced.

For this project, researchers analyzed the technical requirements, market needs, and potential risks for the re-introduction of Generac Power Systems' DG50, a natural-gas-powered distributed-generation system.

The "bang-for-the-buck" factor on the DG50 was the key to its attractiveness when it was first introduced. The costs of generating electricity with that unit were about 9.5 cents/kWh on a machine with a 30,000-hour life. For a total installed cost of about $30,000, a customer received both a standby power system and an effective energy-management tool.

The DG50 was also the first Generac product to feature Generac's MPS (modular power systems) capabilities, whereby up to 15 generators could be operated in parallel without the need for any additional external switchgear or controls.

The Generac Power System's DG50 was based upon a 5.7L spark-ignited engine that was modified for extended-life operation. The engine was configured for natural gas operation and the system was optimized to achieve 30% efficiency.

Benefits / Market Implications

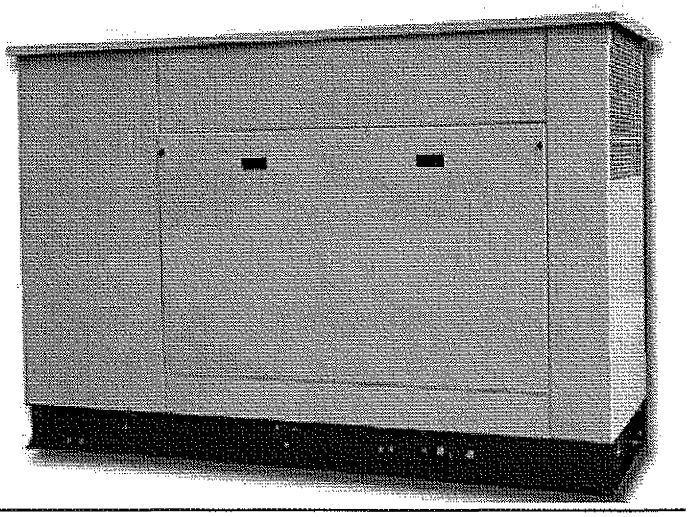
Initial research found various potential advantages of a re-introduced DG50, including low capital cost, high efficiency in real applications, quiet operation, and suitability for both emergency standby and peak-shaving operation.

A number of the historical constraints associated with utilizing reciprocating technology at small power levels (noise, emissions, maintenance cycle, switchgear cost, etc.) could be removed through strategic system design. The net result would be a re-introduced distributed-generation product with standby-like installed costs and an operating cost of $0.10/kWh (assuming a gas cost of $.80/therm).

Technical Concept & Approach

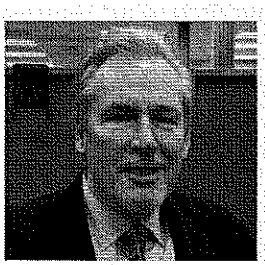
In evaluating distributed-generation applications, various criteria were considered, including: capital cost, system efficiency, reliability, serviceability, maintenance cycles, product life, exhaust emissions, noise emissions, systems integration, and modes of operation supported.

Exploratory research was conducted to prove the product concept in the distributed-generation market. A market research analysis was conducted to determine if the market opportunity was attractive enough to justify the investment and commercialization of a revised product.



"Reliability of fuel supply tends to be of great concern for authorities having jurisdiction. On-site fuel (most often diesel) is typically required for life-safety applications, and many mission-critical applications, such as 911 call centers, specify it because it is perceived to be more reliable. Nonetheless, maintenance issues and delivery concerns of diesel fuel in an emergency, combined with the reliability and cost-effectiveness of natural gas, must be considered in a standby power system. As data regarding the reliability of the gas delivery infrastructure becomes more readily available to the consulting engineering community and permitting authorities, we are confident that the bias toward on-site diesel-fueled solutions will become less of a factor over time."

- Bob Heller, Director, New Business Development
Generac Power Systems, Inc.



Results

To understand the market potential for DG equipment, average electrical demand was estimated based on data from the Energy Information Administration Commercial Buildings Energy Consumption Survey (CBECS). To estimate the average power required for different commercial building types, cumulative distributions of average power consumption were plotted for each type of building available. These distributions were analyzed to determine the average power requirements to satisfy 50%, 75%, and 90% of the U.S. market for that commercial building type.

Research suggested that with current low gas prices and with electricity prices predicted to remain steady or rise, potential opportunities exist for DG systems to provide savings in operating costs. Based on discussions with utilities and spark-spread calculations, the DG50 system has potential to be economically attractive for some market segments with favorable paybacks of less than three years in Alaska, California, Connecticut, New York, and New Jersey.

Researchers identified product criteria required for a successful DG solution, including target installed costs, O&M costs, operation modes, durability, and environmental impact.

Interviews with potential stakeholders were conducted to further define the market requirements for a successful DG solution. Feedback was less than enthusiastic from end users representing national accounts in key market segments (big-box home improvement, fast food, grocery, large retail, etc.) who were reluctant to manage a substantial distributed-generation operation (e.g., ~3,000 hrs/yr); however, the investigation provided insight into the end use energy market needs. Gas utility contacts indicated that payback periods below three years would be required to interest the commercial and industrial end-users in their territories, suggesting that a potential market opportunity may exist in the states with the largest spark spreads.

Other factors that contribute to the viability of DG offerings are often region specific. For California, very stringent emission requirements apply to electric generation used for more than backup power. In a Canadian region, backup generation requires firing to full load in less than 15 seconds for hospitals, so to serve as backup power, a DG solution must meet this specification as well. In other territories, high standby charges for grid parallel operation and hourly metering requirements suggest that a high degree of automation of the equipment will be required to manage costs and extract the best possible payback times.

One of the primary barriers was concern about system complexity. Several end-use contacts responded that they do not generally have personnel on-site who are qualified to manage a DG system, and most believe a DG system will require active management.

Status

Research found a strong regional market for the DG50, but marginal support from key market sectors. As such, Generac has migrated development efforts toward a larger (e.g., 250kW), lower-runtime system than the DG50 to support extended-outage and possibly demand-response (DR) markets.

This natural-gas-fueled DR unit could operate during outages for a longer time than typical emergency generators. It could also be dispatched by the electric utilities during periods of high electric demand to relieve local grid stress and potentially prevent brownouts. However, there are regulatory barriers related to diesel versus gas reliability that need to be documented and disseminated in support of those development efforts.

Follow-on activities related to this project include the development of guidelines to help the gas industry understand current market barriers to natural gas standby generators and a dissemination plan to help the gas industry and backup-generator users make well-informed decisions. Researchers will collect and document historical data on gas outages, particularly during major weather events, and address reliability concerns with diesel standby generation.

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UTD Utilization Technology Development

Evaluation of the VOCGEN Combined Heat and Power Solution

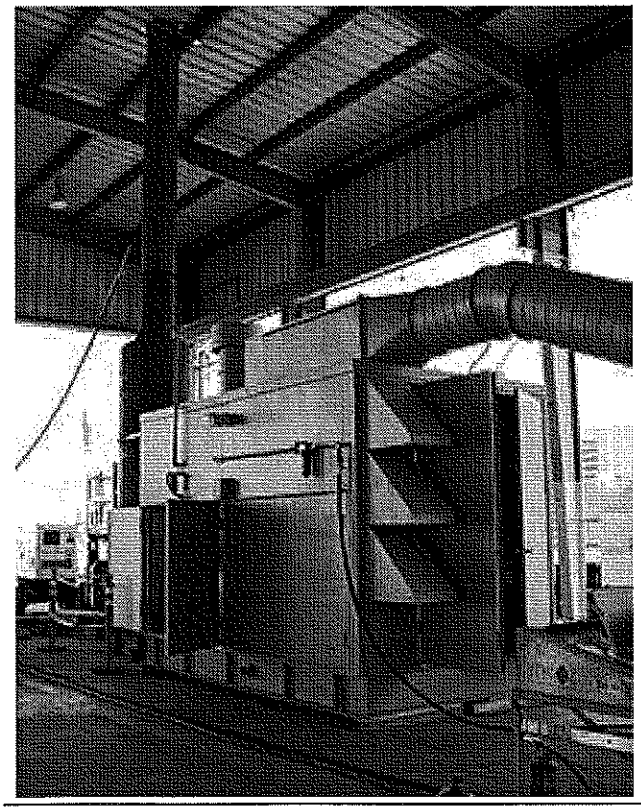
This project includes research to validate a technical/economic feasibility screening tool and develop a case study to assist UTD members in the evaluation of potential applications of VOCGEN technology as a combined heat and power solution for the destruction of process streams containing VOCs.

Project Description

There are numerous existing industrial facilities that control emissions of volatile organic compounds (VOCs) through the use of thermal oxidizers (TOs). However, while TOs are a proven technology for achieving high destruction efficiencies, TOs – and even the Regenerative Thermal Oxidizers – typically reject a substantial amount of low-quality waste heat to the stack.

This project focuses on supporting development of a technology that could achieve the required VOC efficiencies while reducing the energy losses associated with TOs.

A research team is partnering with Environment & Power Systems International (EPSI), a company that developed a small industrial gas turbine combined with an innovative combustion chamber designed to burn regulated volatile organic air emissions as a secondary fuel. Several years ago, the first-generation combustor/ gas turbine technology was successfully installed and tested at a plant in California. Lessons learned have been incorporated into a next-generation packaged system called VOCGEN.



The objective of the current phase of the project is to validate a screening tool developed and used by EPSI and develop a case study that will assist in the evaluation of potential applications of VOCGEN technology as a combined heat and power solution for the destruction of process streams containing VOCs.

Benefits / Market Implications

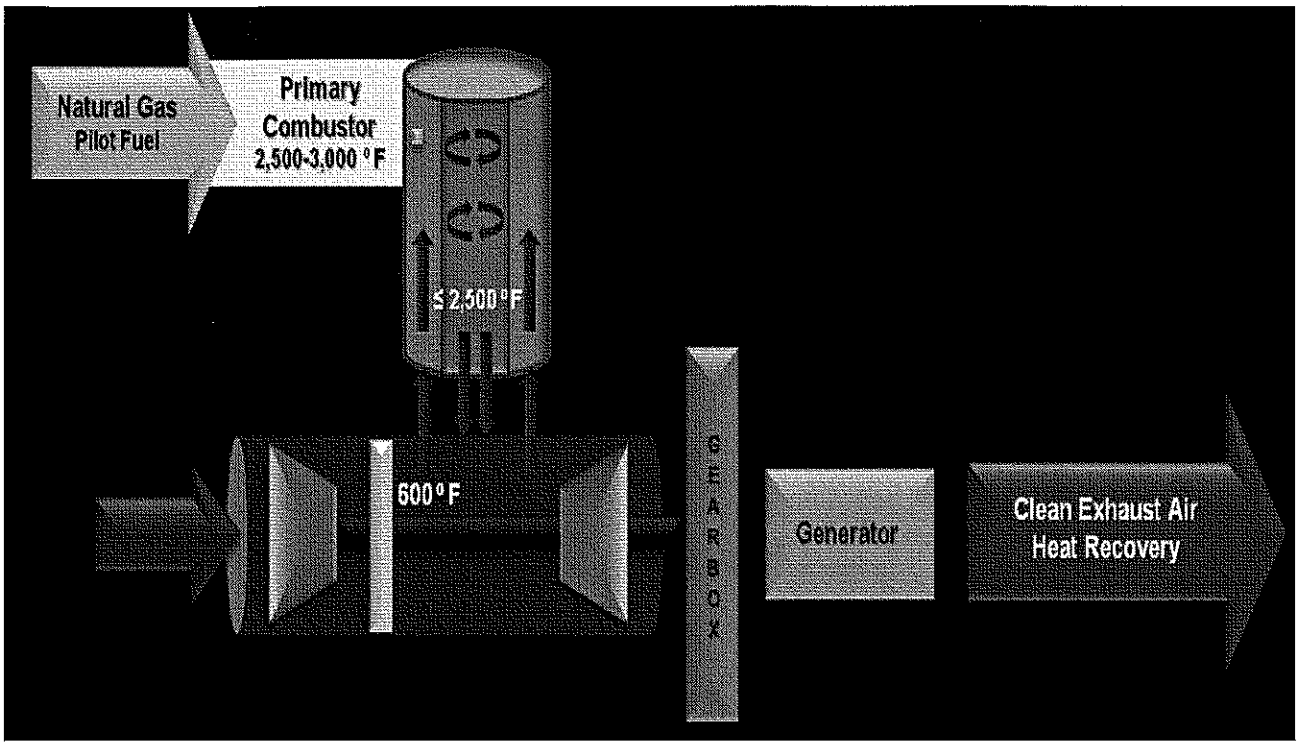
By replacing existing TOs with VOCGEN, customers who are interested in generating their own power and using high-quality waste heat for combined heat and power can find an attractive solution in terms of payback period or financing options.

Technical Concept & Approach

Researchers are independently evaluating the screening methodology used by the VOCGEN developer and commercial agents. The screening approach quantifies the technical and economic feasibility by comparing requirements and costs for using current TO technologies versus the VOCGEN technology. The approach includes evaluating specific plants within UTD member service areas to assess key assumptions included with the tool. This tool can be made available for gas marketers and account managers to screen for applicable customers.

The project team also plans to conduct an independent monitoring program as a plant implements VOCGEN technology. Technicians will provide instrumentation required to measure key performance parameters associated with the VOCGEN system. Measurements will include natural gas usage, power consumption, power delivered, and heat delivered in terms of temperatures and flow.

The systems will be monitored for one year, after which the data will be reduced, analyzed, and performance metrics will be summarized in a Final Report.



With VOCGEN, VOC-laden air emissions enter the compressor section of the gas turbine engine, where it is compressed to 132 psi, raising the air temperature to 600°F. The air then enters the VOC combustion chamber (secondary combustor) where it is mixed with 3,000°F air from the primary combustor of the turbine engine. The resultant combined air (≈1,850°F) then travels in a cyclonic fashion inside the secondary combustor. Cyclonic action allows for the VOC-laden air to stay in the chamber for approximately 0.44 seconds to assure complete mixing, resulting in 97% to 99.99% destruction of the most VOC species used by industry. The high-energy expanding air is then routed through the turbine section of the engine, rotating the turbine shaft. The shaft is connected to a generator producing 500 to 560kW electrical power and 6.5 MMBtu/hr high-quality heat.

In addition to providing as-installed performance, the case studies will help validate the manufacturer's screening process.

Results / Status

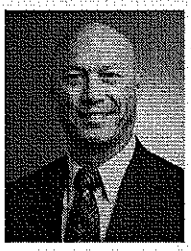
To date, the research team, EPSI, and UTD respresentatives have investigated potential VOCGEN applications within the service territories of several utilities.

Researchers are reviewing examples of outputs from a VOCGEN screening tool.

EPSI indicates that the intention is to combine a project questionnaire with its "Level 1 feasibility" criteria to create an application online that prospective customers could use to quickly assess the value of a VOCGEN project versus alternative technology options.

Potential applications of the VOCGEN technology are generally facilities that currently use TOs for VOC destruction that might be interested in producing some of their electricity and have thermal loads that can use waste heat from the gas turbine exhaust.

"Oklahoma Natural Gas Company's interest in the VOCGEN technology was fueled by the opportunity to help our customers improve their operating efficiencies, which would strengthen their bottom line. An improved bottom line may mean that the customer stays in business longer, which is not only good for us, but also for our community."



- Jack Conner
Manager, Key Accounts and Development
Oklahoma Natural Gas

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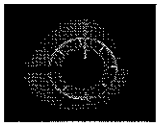
INDUSTRIAL APPLICATIONS

UTD Utilization Technology Development

FlexCHP High-Efficiency Ultra-Clean Power and Steam Package



A research team is developing a cost-effective, small- to medium-size gas-turbine-based CHP system that can significantly increase energy efficiency while meeting stringent air-emissions regulations. A supplemental burner, employing state-of-the-art design concepts, is being optimized for selected power generators.

Project Description

Combined heat and power (CHP) systems can save energy for industrial, institutional, and commercial users of natural gas. However, exhaust losses from gas-turbine CHP systems can be relatively high. Some of the energy loss can be recouped by firing supplemental burners (e.g., duct burners), which consume the extra oxygen and reduce the exhaust loss. But even with state-of-the-art low-NO_x duct burners, CHP systems fired by natural gas cannot meet the California Air Resources Board (CARB) emissions requirement of 0.07 lb NO_x per MWh total output.

In response, researchers are developing a unique supplemental burner shown capable of meeting the CARB regulations for nitrogen oxide (NO_x) and carbon monoxide (CO).

This project follows on the success of an earlier program, in which Gas Technology Institute (GTI) developed a new supplemental burner with advanced features that can fire natural gas with turbine exhaust gas (TEG) and meet the most stringent output-based NO_x regulations. The key to the new design is staged combustion with engineered internal recirculation that exposes NO_x and NO_x precursors to a well-mixed reducing environment, resulting in lower emissions per unit of total energy output. Tests showed NO_x reduction in the range of 35% to 70%, and demonstrated that the system has impressive performance for both air quality and energy efficiency.

Benefits / Market Implications

While supplemental firing can boost heat output and thermal efficiency from gas-turbine-based CHP systems in a cost-effective manner, CARB NO_x targets can currently be met only with the addition of selective catalytic reduction (SCR) flue-gas treatment, which increases capital costs up to 25%. This is a significant barrier to the adoption of CHP systems, especially for small- to medium-capacity facilities (15 MW or less). The supplemental burner with advanced features can remove this barrier by eliminating the need for SCR. Similarly, CO levels have been measured well below the 0.10 lb/MWh limit.

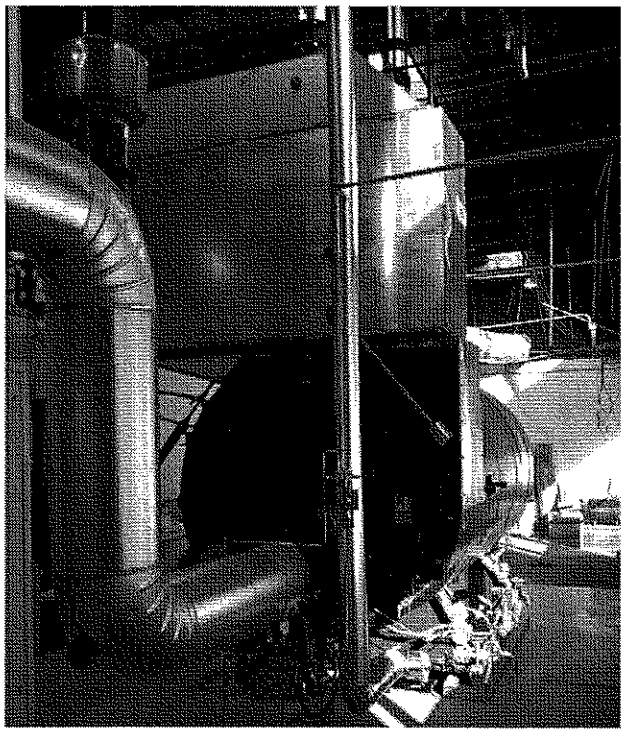
It is estimated that the supplemental burner adds no more capital cost than a conventional duct burner, and that cost will be recouped in less than 1.5 years through increased energy efficiency.

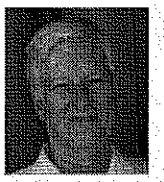
Technical Concept & Approach

Project goals are to develop advanced supplemental firing for two selected cases representing a large portion of the California market. These cases will both include a gas turbine properly matched to a steam boiler and/or chiller. The supplemental burner will be optimized for the selected power generators, and a specific package will be demonstrated at an industrial, commercial, or institutional host site in California.

The project involves the following specific tasks:

- CHP system computer simulation models will be used to construct a design basis for a gas-turbine engine-generator, a supplemental burner, and a heat-recovery boiler and/or chiller.





"When the FlexCHP is in operation, we achieve a 25% reduction in combined electric and gas utility costs in comparison to purchasing an equivalent amount of electricity from the utility and generating an equivalent amount of steam with our conventional gas-fired boilers."

- Mark Sterner
CEO
Inland Empire Foods Inc.

- Engineers will design, fabricate, and laboratory test a supplemental ULN burner using both simulated TEG and actual TEG generated by a microturbine.
- The research team will develop and field test an integrated CHP system design package that includes an turbine-generator.

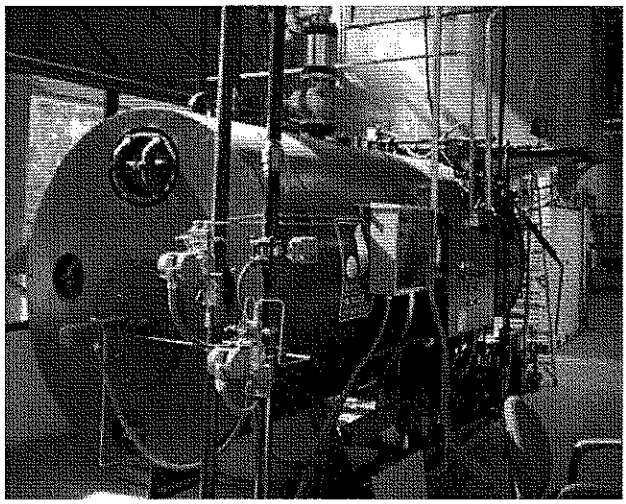
Results

Laboratory testing demonstrated that the FlexCHP system is capable of meeting CARB 2007 NO_x emissions requirements for distributed generation systems over a turndown ratio of 2:1. The NO_x emissions at the exit of the supplemental burner were the same or lower than the NO_x emissions in the simulated turbine exhaust gas, representing an overall reduction in NO_x for the system.

In 2013, the FlexCHP-65 system was installed a the facilities of a California food processor for a field demonstration. Initial results demonstrated the ability of the FlexCHP system to achieve an overall efficiency of 82.4%, as based on measurements of the fuel inputs, electricity, steam, and hot water outputs. Based on the flue gas conditions (233°F; 6.6% O_2) and an estimation of jacket losses, the efficiency is calculated to be 84.2%. Results also show that the FlexCHP system provides significant emissions reductions across the full range of firing rates. The system is capable of far exceeding stringent criteria, with NO_x emissions as low as 50% less than the limit of 0.07 lb/MWh. CO and total hydrocarbon emissions are also significantly lower than the CARB 2007 criteria, with levels below 1 ppm.

Air-quality source test measurements taken by an independent third-party agency validated the performance of the FlexCHP in achieving target emissions levels. Continued monitoring throughout the demonstration period showed the FlexCHP system's ability to maintain desired performance levels over extended operation.

As the system was brought online, some technical issues were uncovered and addressed. Modifications to the economizer allow for flue gases to be bypassed around the economizer to achieve desired water and



flue temperatures. Additional instrumentation was installed for monitoring facility gas pressure, turbine exhaust pressure, and combustion-chamber pressure. Further modifications were also made to the system controls logic to transition the technology from prototype to commercial unit.

Status

The system operated continuously for several months with satisfactory turndown and cycle times to meet facility steam and electricity demands. Outside of some minor technical issues – which provided excellent insight as the project team transitions the technology to commercial product – the system performed reliably and the host site has indicated being satisfied with the system performance.

Data gathering and performance monitoring of the system continues.

Several new opportunities for continued development and demonstration of the FlexCHP technology have arisen from strong end-user interest. The project team was approached by multiple turbine distributors and boiler manufacturers, all of whom have customers requesting efficient steam production coupled to their turbine generator units. These opportunities range from 65 to 2000 kWe in size and span across the continental U.S. In response to this strong interest, the project team is accelerating efforts with the commercialization team and pursuing additional funding to facilitate scale-up development and demonstration activities.

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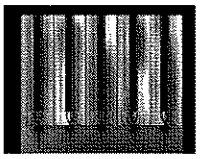
UTD Utilization Technology Development

Solar-Assisted Natural Gas Energy Systems

Researchers see significant potential for efficiency improvements in several applications by combining solar-related technologies with natural-gas-fired equipment. In this project, engineers investigated promising commercial and industrial markets in preparation for the development and demonstration of a prototype solar-assisted natural-gas-based system.



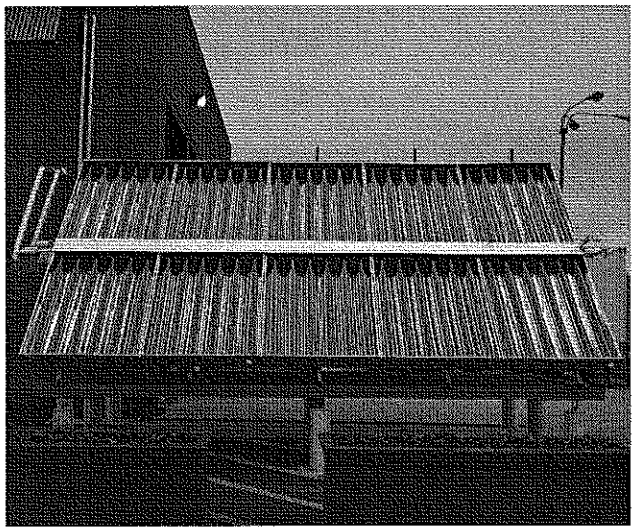
Project Description

Experts have expressed confidence that by combining natural-gas-fired boilers, heaters, and absorption chillers with the latest developments in medium- to high-temperature solar collectors, cost-effective technologies can be developed for industrial, commercial, and residential customers in high-solar-exposure areas.

In this project, research was conducted to identify potential markets for the application of hybrid systems that use high-efficiency solar energy to complement natural-gas-based systems. Researchers and b2u Solar completed laboratory performance testing, an assessment of field sites, and field installation planning of an advanced medium-temperature non-tracking, Non-Imaging Concentrator Collector (NICC) solar thermal technology for applications for food processing and other industrial facilities in California.

Benefits / Market Implications

The integrated NICC solar thermal installation is suitable for driving key industrial process-heat applications – displacing natural gas and electricity use – and is expected to be replicable in a wide range of facilities across California and elsewhere. It should improve energy efficiency, reduce greenhouse gas emissions, reduce reliance on fossil fuels, and benefit ratepayers. With approximately 50,000 industrial plants, California's industrial sector consumes almost 50 billion kilowatt hours of electricity and over six billion therms of natural gas each year. This energy represents 19% of the state's total end-use electricity and 47% of the state's end-use natural gas consumption.



Mid-temperature solar array installed at Gas Technology Institute.

Researchers point to the need for solar-based systems that can be retrofitted to existing gas-fired applications and take advantage of the latest high-efficiency, low-cost technologies (e.g., heat exchangers, heat-transfer fluids, controls, and system diagnostics). These solar-assisted systems (added to natural-gas-fired equipment) would take advantage of a common infrastructure wherever possible. Studies estimate that a solar-gas hot-water system can reduce annual energy costs by as much as 40%.

Solar energy can assist in efficient waste-heat recovery by adding necessary energy input to make waste streams useful for further use (e.g., steam generation, thermo-chemical recuperation, heating, and cooling).

Other benefits of these systems include an increase in solar usage during peak daytime periods when most commercial/industrial equipment is active, and a decrease in greenhouse-gas emissions proportional to the decrease in natural-gas usage.

Technical Concept & Approach

The b2u Solar NICC technology addresses the temperature spectrum between about 212°F (100°C) and 392°F (200°C) that has been largely neglected by market incumbents. This range includes a wide variety of heat-driven industrial process applications, including double-effect absorption chilling, boiler feedwater and commercial water heating, and industrial drying.

The technology pairs an evacuated tube solar collector with an external non-imaging reflector in a non-

tracking system. The combination enables NICC to capture sunlight from an acceptance angle of +/-60° and achieve temperatures in excess of 392°F (200°C) at 50% efficiency, defined as the percentage of solar energy hitting the collector aperture that is converted to useful heat energy, even under heavily cloudy/hazy conditions. This capability separates the technology from market incumbents which cannot attain these temperatures without tracking or direct sunlight.

Results

The team designed, constructed, and conducted testing of an NICC module on a laboratory-scale thermal loop over a 12-month period, demonstrating excellent temperature and thermal performance and reliability.

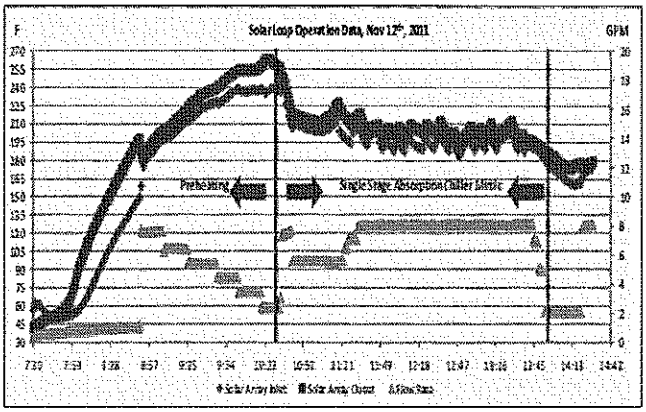
Researchers also assessed procedures for assembling a small batch of panels and system installation and integration with a boiler; assessed two food-processing facilities for integration of the NICC technology; and developed an NICC installation manual. The planned field tests have not yet been carried out because of changing business conditions at the original and alternate sites.

Planned field testing involved installation and testing of an integrated, 100kW$_{th}$ NICC package at an industrial host site in California. Specific activities planned included securing the necessary permits, installing the NICC package at the host facility and integrating it with the host's process-heating needs, system shakedown, instrumentation calibration, and collecting operations data. Issues related to the solar system were planned to be identified and resolved, test results analyzed, and system reliability assessed.

The majority of efforts focused on assessing a brewing facility in California. This involved identifying suitable process-heating applications for the NICC technology at the site, developing design packages and costs for 100kW$_{th}$ and 500kW$_{th}$ systems, and negotiating a three-way field-test agreement. When the brewery withdrew from the project, similar activities were conducted with an alternate site owned by a major foods manufacturer; however, this effort failed to come to fruition.

As part of the project, thermally driven chillers that can be used in solar thermal cooling applications were investigated. Research found that the solar heat manifested can drive a double-effect absorption chiller, benefiting both cooling and heating demands year round, augmented by diverse energy sources that include natural gas, steam, and hot water. The integrated system could reduce operational costs where electrical pricing is high by using an environmentally safe, non-chlorine-mixture-based refrigerant, with reduced greenhouse-gas emissions.

Results of tests demonstrated that the NICC technology performs as expected and is well suited to integration into process heating and that the technology is ready for demonstration at an industrial facility in an integrated process-heating application.



Status

This project was terminated in 2014. A Final Report was issued in June 2014.

With the project now closed as a result of b2u's inability to move forward with a demonstration, the project team is shifting its focus towards other industrial solar efforts in partnership with b2u's sister organization, Winston Cone Optics.

The following summarizes key conclusions drawn based on results of the laboratory and field testing of NICC technology:

- The non-tracking collector is able to reach temperatures over 150°C (302°F) with 50% efficiency during the laboratory tests
- Optical and thermal design lead to higher energy density and less heat loss than other non-tracking collectors
- The ability to use diffuse light leads to less variable performance than concentrating collectors
- Angled pyranometer is better able to capture and measure the solar radiation, striking the array without the use of any correction factors
- The collector requires three days of clear weather to fully melt snow from covered collectors.

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UTD Utilization Technology Development

Low-Temperature Heat and Water Recovery

The objective of this project was to develop and evaluate an advanced, cost-effective wastewater re-use technology and obtain the necessary engineering data for a full-scale unit design and demonstration at a food-processing plant.

Project Description

A number of industries – particularly food processors – are currently being challenged by available energy, water-resource costs, and emerging environmental issues.

In this project, researchers investigated the feasibility of using a new wastewater recovery and re-use technology to enhance the operational efficiency of various food-processing applications. Activities involved obtaining data on size, throughput, and energy balances for a follow-on technology demonstration.

Research suggests that the low-potential waste heat (<500°F) widely available from most of the food-processing plants can be effectively used for wastewater re-use. The focus of this project was on the application of an advanced method for the indirect regenerative evaporation process (by using available waste heat) combined with the advanced condensation in a multi-channeled block of wet and dry passages.

The technology integrates waste heat and wastewater recovery in an optimal combination of evaporation, condensation, and heat-transfer processes. Recovered clean water is collected for re-use in plant processes/ services meeting water-quality standards. Water collection and drawdown may put the condensation zones under positive pressure to accelerate system production, reduce system size, and improve the operating efficiency.

With engineering enhancements, the technology is expected to cost-effectively recover at least 50% of the industrial wastewater for re-use with a potential to boost it up to 100%.

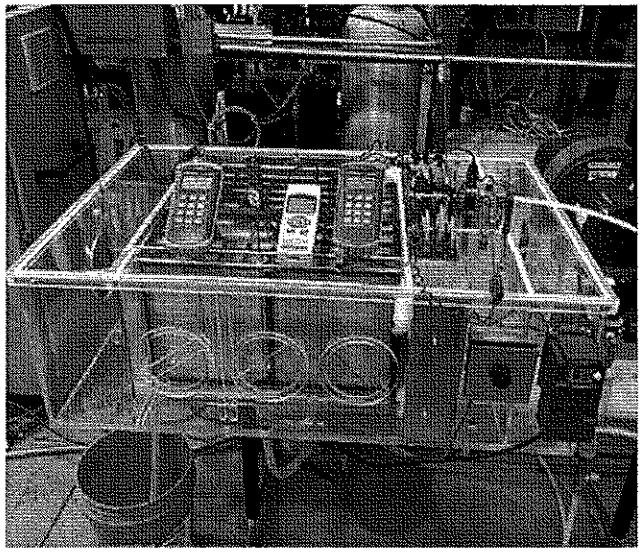
Initial applications of the technology will be driven by available waste heat. However, in most industrial facilities there is much more wastewater available than waste heat required to treat that wastewater for re-use. In these cases, the technology under development assumes natural-gas preheating or other heat-source assistance (e.g., solar) to greatly increase the capacity of a system.

A Final Report will detail the design, testing, and analysis results for the wastewater-recovery process. Researchers will also outline a path through future activities to develop, demonstrate, and commercialize the technology for multiple industrial and commercial applications.

Benefits / Market Implications

Many industrial facilities have available low-level waste-heat streams (e.g., exhaust gases and hot liquids) as well as wastewater streams from which clean water can be reclaimed for re-use. The new technology will allow for a significant increase in wastewater recycling and reduction in energy consumption associated with conventional methods. Successful development and demonstration of the technology for food-processing applications will provide significant energy and water savings for the industry. These savings are also tied to an energy-efficiency increase and reduction in pumping power for process water supply. The ability to integrate waste-heat recovery with wastewater re-use also leads to product cost-reduction opportunities for commercial food-processing producers.

The full potential market for the approach to low-level heat recovery has not yet been determined. However, a study of the California food-processing industry showed that technology implementation in that sector alone offers a potential annual savings of $40 million



Overview of the laboratory-scale unit.

provided by a savings of 440 million gallons of water, 30 million therms of natural gas, and 185 million kWh of electricity. Much larger savings are anticipated when considering nationwide implementation across multiple industry sectors.

Adoption of the technology will also help to generate higher plant efficiencies by retaining the ability to use natural gas rather than more costly electrically heated processes.

In addition, reduced energy demand for the wastewater reclamation leads to reductions in carbon dioxide and nitrogen oxide emissions.

Technical Concept & Approach

Initial activities included a review of "Best Practices" involving an investigation of various technology applications, followed by technical feasibility and economy testing.

Testing – in the framework of an ongoing project funded by the California Energy Commission (CEC) – was conducted to determine performance characteristics and efficiencies over operating temperature, pressure, and flow-rate ranges.

After testing and evaluation, the project team will develop plans to bring the technology to the industrial market, including the analysis of the wastewater compositions' diversity.

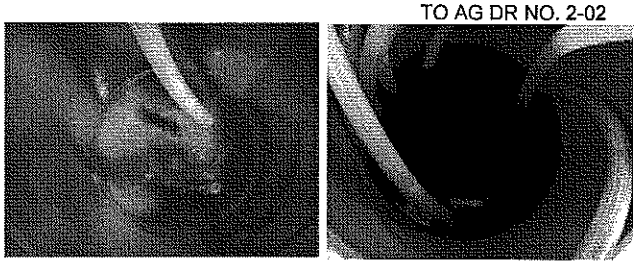
Because of the costs of energy and water, any technology utilizing low-level waste heat to reclaim wastewater must be simple and cost-effective to install and operate. The technology must also be robust, require little maintenance, and flexible enough to be used over a wide range of flow rates, temperatures, and capacities with many types of wastewaters in various types of industries. Until now, no available technology has fully met these requirements.

Results

This project began with an evaluation of a wide spectrum of commercially available distillation techniques and development markets.

Best Practices on wastewater recovery/re-use were identified and reviewed. Technical and economic feasibility studies were completed, with the pros and cons of the existing technologies identified and analyzed.

In 2012, a laboratory test unit was designed, fabricated, and assembled, and data collection initiated. Shakedown of the laboratory-scale test unit resulted in test-unit modifications (e.g., increasing the wetting area for the incoming air flow as well as incoming flows pre-heating options).



Left: Recovered clean water for re-use; right: waste discharge.

In 2013, the test unit was extensively evaluated at different operating conditions. Temperature and humidity measurements were performed, along with visual recording of the condensate production.

The waste-heat input was simulated by a residential water-heating unit (~140°F). Introduction of waste heat (or simulated natural gas assistance) significantly increased the condensate output.

Observing outlets of the condensing channels during the distillation unit operation showed some channels plugging with the condensate. Increasing air-flow rate through the channels allowed the unit to operate more efficiently, with less channels being plugged with condensing water. The highest system efficiency (distillation rate) was achieved when hot water (at temperature ~140°F) is used for moist air re-humidification.

The highest distillation rate in the experiments achieved was 55% of evaporated water. The distillation rate can be significantly increased (up to 100%) by appropriate design of the evaluated concept and optimizing the process variables.

Performance data were collected at different operating regimes, wastewater recovery rate was established, and information was processed and analyzed.

Status

Laboratory testing is completed. Data is being processed and analyzed.

A Final Report detailing project results is being prepared.

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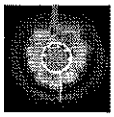
UTD Utilization Technology Development

5 ppm NO_x Burner

For this project, researchers teamed with a major manufacturer of industrial burners to develop a 5 ppm NO_x natural-gas-fired burner to meet current requirements in California as well as expected future requirements in other areas.

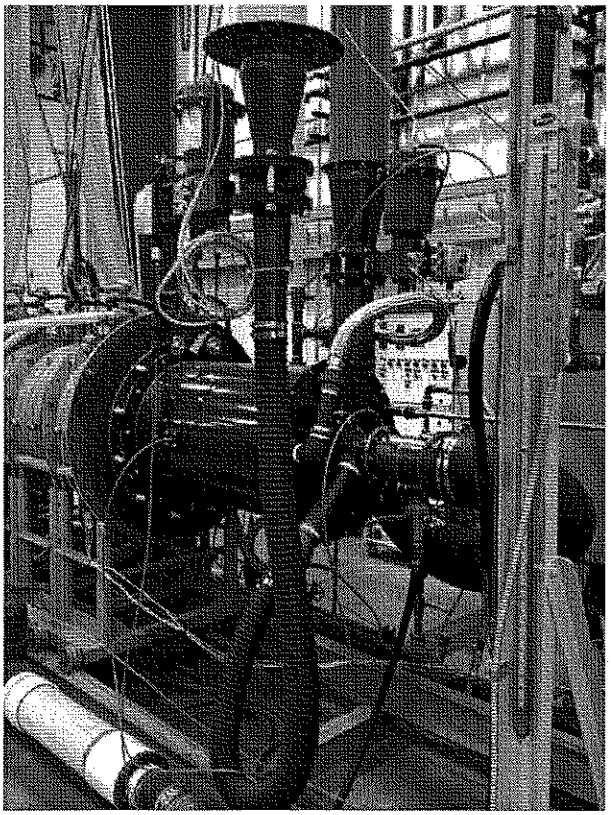


Project Description

California has imposed increased restrictions on emissions from gas-fired industrial burners (kilns, furnaces, boilers, etc.), requiring less than 5 parts per million (ppm) nitrogen oxide (NO_x) emissions. However, while current state-of-the-art industrial burners are able to achieve NO_x emissions of less than 9 ppm, burners with emissions below 5 ppm are not available.

To date, the only option to meet the California emissions level is to install selective catalyst reduction (SCR) equipment. However, SCR systems are expensive, require additional permitting, incur additional maintenance costs, consume additional floor space, and require expendable costs (e.g., for urea and aqueous ammonia).

This project focuses on the development of a cost-effective sub-5-ppm burner to provide an option to SCR systems.



Prototype burner mounted to boiler simulator.

In a previous project, researchers developed and licensed a <9 ppm-NO_x Forced Internal Recirculation (FIR) burner. While the burner demonstrated the ability to attain <5 ppm NO_x, there were issues with the system's stability and controls. Since then, there have been further developments in the area of combustion stability and controls. The original FIR research performed on combustion stability was focused on a single-stage FIR burner with a 4 MMBtu/hr input. Extensive testing was performed with the cooperation of The Georgia Institute of Technology with advanced acoustic equipment that helped identify problem frequencies. The research revealed a modeling method for determining the problem frequencies based on the physical dimensions of the system.

In this project, researchers incorporated the new techniques into the burner design. Research shows that ultra-low NO_x burners can achieve low NO_x values through lowering the thermal component of NO_x generation. The practical methods for accomplishing this are through flue-gas recirculation, combustion staging, or a combination of the two.

The key to any of these methods is to lower the peak flame temperature to lower the thermal NO_x generated. However, when these flame temperatures get too low, self-ignition becomes an issue and carbon monoxide and hydrocarbons are produced. The envelope between keeping NO_x low and maintaining complete combustion becomes smaller as the requirements for NO_x become lower. Because of this, more precise controls will be needed to keep the flame operating within this envelope.

Benefits / Market Implications

Currently, requirements for industrial burners to produce NO_x <5 ppm result in customers purchasing expensive SCR equipment or moving their operations to other areas. The state of California plans to expand the <5 ppm requirement to smaller burners in the future, which will affect more end users. Experts project that the >400 non-attainment areas within the U.S. are also likely to reduce emission limits.

Through the development of new technology, industrial and commercial end users can continue to use gas-

fired equipment, more cost-effectively meet emissions requirements, and help to maintain the viability of many industrial operations in California and elsewhere

Technical Concept & Approach

Power Flame Incorporated (one of the leading manufacturers of burners for commercial/industrial boilers) joined the research team as a project partner/ commercialization partner. Research focused on the areas of burner design, incorporation of advanced control systems, and combustion-stability control.

Individual tasks included:

- Computational Fluid Dynamics (CFD) Modeling
- Design Development
- Laboratory Evaluation.

Results

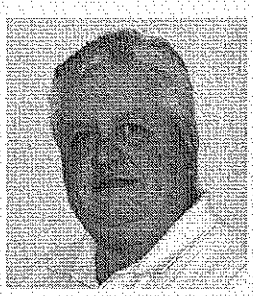
The research team initially examined the combustion chamber sizes for Hurst boilers (a large number of which incorporate Power Flame burners) to determine which would be common for the initial burner prototype testing.

Investigators also conducted an extensive data search, evaluating current technological trends and the status of low-emission-burner technology. Particular attention was devoted to development of assemblies to improve environmental indexes of design, comparative calculations of standard burner designs and modernized ones, validation of computed data to measured values for selection of appropriate models of procedures (transport and combustion constituents), and deriving suitable numerical coefficients in CFD equations.

Testing was completed with new high-stability nozzles that evaluated light-off conditions and the excess oxygen operating envelope. Both of these parameters showed improvement over the existing nozzles. Further testing of commercially available nozzles yielded excellent results in regard to ignition, flame stability, and emissions. A range of firing rates and equivalence ratios, as well as variations in fuel/air delivery methods, were studied. Flame shape, stability, turndown, and emissions were characterized across a wide range of operating conditions.

In 2013, Power Flame Incorporated fabricated the air-staged burner. Testing of the 4 MMBtu/hr prototype burner investigated performance across a broader range of operational conditions. At full fire (4,000 MBtu/hr), the burner was capable of achieving <5 ppm NO_x for excess O_2 operation of 6% and <9 ppm NO_x for excess O_2 operation of 4.5%. Operation below NO_x target levels of 12 and 20 ppm were achieved as well, demonstrating the ability of this burner technology to be applied across a wide segment of the U.S. boiler market. Commercially available burner technologies are operating at excess O_2 levels up to 8.8% to achieve <9 ppm NO_x. By dropping excess O_2 levels from 8.8 to 4.5%, the prototype burner technology offers an increase in boiler efficiency of more than 2%.

"As regulatory standards for criteria air pollutants continue to tighten in key non-attainment areas, it's imperative for us to offer advanced product lines that satisfy these requirements. Power Flame sees the FIR burner concept as a viable, cost-competitive approach for achieving compliance in several major U.S. markets."



- Bob Rizza
VP Sales & Marketing
Power Flame Incorporated

The burner exhibits low emissions throughout its operating range, with an achieved turndown of 4:1. The project team is working with Power Flame to further refine performance targets regarding turndown and blower power requirements.

A proposal submitted to the California Energy Commission (CEC) to demonstrate the burner technology at a host site in California was accepted and the proj-ect is expected to begin before the end of 2014. Completion of this upcoming demonstration project will allow for close collaboration with Power Flame in packaging the burner for commercial deployment. Further, this will provide an opportunity for independent performance monitoring and verification of the system.

Status

The project team is continuing laboratory testing and development activities to incorporate design feedback from the commercialization partner. This will ensure that the final burner product will have the greatest market appeal as the team transitions towards commercialization.

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UTD Utilization Technology Development

Solar Cooling

A research team is exploring the feasibility of coupling a solar thermal collection system to a solar-driven double-effect absorption chiller to augment natural gas with clean and cost-effective solar energy.

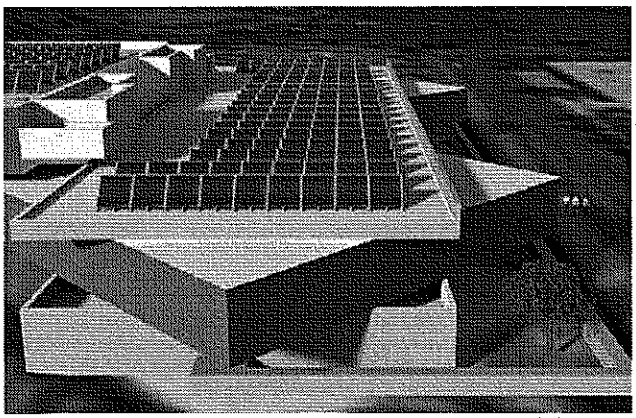
Project Description

For decades, the promise of competitive gas cooling technologies has gone unfilled in North America due to complex and costly technology, a lack of matched collector/chiller products, and fluctuating gas prices.

However, recent developments are creating an opportunity for hybrid natural gas/solar cooling to meet current and future customer needs. Contributing to the opportunity for gas cooling to make market in-roads are:

- Lower gas prices with stable long-term prospects
- Electric peaking issues in an aging electric infrastructure
- "Smart-grid" communications
- Energy-efficiency programs as revenue generators
- Increased importance in greenhouse-gas emission reductions
- The growing dominance of space cooling in building energy budgets.

The coincidental peak demand for cooling during solar thermal generation is compelling; however, competitive solar technologies either suffer from the inability to reach the required operational temperatures (flat, non-evacuated panels) to drive absorption cooling machines, or are prohibitive in high-per-unit areas and costs (solar troughs). Panels and troughs are often applied in the industrial process heat market, but have water shortages and lower efficiencies from dry cooling or lower temperatures than used by modern steam generation. The cost of these panels and troughs in commercial markets, however, are two to four times the typical solar design.



Architectural concepts for the Palm Springs Art Museum demonstrations.

Researchers have developed the building blocks for highly cost-effective solar cooling applications. However, data from field implementation is required to confirm and enhance the performance in the areas of optical abilities, absorbing material, system balance, operation procedures under real-weather patterns, system reliability, and user interface for control/programming.

Several technical components applied in this project have been implemented successfully in other countries. A significant barrier in the North American market is the lack of public awareness and experience with solar thermal cooling implemented in thermally-driven absorption chillers. This project provides a demonstration opportunity to facilitate performance comparison, collect field data, and gain user feedback that will be critical for preparing for a commercial launch.

The goal is to implement technology to displace peak electricity demand (along with peak time-of-day rates) for cooling.

Superior to other distributed solar power generation, the technologies under investigation are designed to provide maximum value to ratepayers, avoid blackouts, improve the Levelized Cost of Energy (LCOE), and reduce carbon emissions and pollution.

For this project, a research team is exploring the feasibility using of a solar thermal collection system coupled to a solar-driven double-effect absorption chiller to augment natural gas with clean and cost-effective solar energy.

Benefits / Market Implications

The cooling market remains principally untapped for the natural gas industry. However, experts note that natural gas/solar-assisted augmented cooling technology can help penetrate the market.

The fastest growing new construction markets are cooling dominated (e.g., the Southwest), have stressed electric grids, and, in many cases, have progressive state greenhouse-gas policies. With low gas prices, gas cooling is an increasingly viable alternative to electric technologies.

Offsetting gas use with solar thermal technology also frees the commodity for other uses. As California has made considerable investment in advanced gas-fired electricity generation, the reduction of natural gas use through the use of solar thermal energy helps ensure adequate supply and price stability.

Technical Concept & Approach

The approach is to investigate a solar-augmented natural gas absorption chiller and secure a commitment from a host site for a field demonstration.

The technology being investigated in this project fills a gap not addressed by currently available solar systems by providing sufficient heat for an absorption-chiller-based commercial cooling system.

Activities focus on the evaluation of a hybrid system. Researchers will investigate and compare various installation approaches for the solar array. The research team will subsequently generate a preliminary design for a solar thermal collection system coupled to a double-effect absorption chiller for commercial host sites.

A standardized design approach will allow the hybrid system to be offered as an integrated package.

Results

Various mid-temperature solar collectors were investigated, with models of three preliminary cooling systems of varying complexity developed for evaluation.

Installation opportunities were identified at the Palm Springs Art Museum, located in Palm Springs, CA.

The research team proposed to install a solar-assisted hybrid system sized to replace an outdated 50-ton reciprocating chiller and central plant system at the museum's Architectural and Design Center (Edward Harris Pavilion). An array of 64 non-imaging concentrator solar collectors would be mounted on the roof. The solar-assisted hybrid system will have natural gas back-up.

For the Main Museum Facility, the research team proposed to install a solar-assisted hybrid system sized to replace an outdated 135-ton reciprocating chiller and two 1.1-million Btu boilers. An array of 188 non-imaging concentrator solar collectors would be mounted on the roof.

The research team also submitted a concept paper in response to a solicitation from the U.S. Department of Defense's Environmental Security Technology Certification Program (ESTCP). The intent was to demonstrate a hybrid natural gas solar-assisted cooling system at a military base. Dialogue was initiated with the Naval Air Station Fort Worth Joint Reserve Base for a potential demonstration at the base.

In 2014, the concept paper proposing a high-efficiency Solar Cooling and Heating (SC&H) system at the Palm Springs Art Museum was submitted to the California Energy Commission for funding consideration. The project will demonstrate a new, high-efficiency, concentrating solar collector developed by University of California, Merced, with an inline natural-gas-fired supplementary heater to simultaneously drive a high-efficiency double-effect absorption chiller and generate hot water. The system will be integrated with the building's existing chilled and hot water loops to meet its cooling and heating demands, while significantly reducing electricity consumption and associated emissions. The collector incorporates a number of advanced features to simultaneously increase output temperatures to >230°C/446°F and overall efficiency, while reducing the system costs.

The primary market for SC&H technology is commercial buildings, including offices, schools, hospitals, government buildings, restaurants, and other facilities. Additionally, the technology has applications in certain industrial facilities with combined cooling and heating needs.

Status

The research team continues to search for potential host sites and funding opportunities. Efforts are under way to secure funding sources for the Palm Springs Art Museum demonstrations.

In 2014, the research team received notice that the concept paper for a demonstration project at the Naval Air Station Fort Worth Joint Reserve Base was not to move towards a full proposal and the concept paper to the California Energy Commission placed as a finalist. However, the available funds were allocated to higher-ranking proposals.

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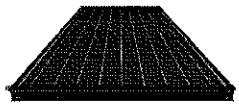
UTD Utilization Technology Development

Evaluation of a Low-Cost Solar-Thermal System



An evaluation of the performance of a low-cost solar-thermal system is under way in an effort to develop technology to improve the market penetration of solar-thermal systems that can be linked to natural-gas-fired space- and water-heating systems.

Project Description

While solar-thermal systems in the Americas represent a small percentage of the worldwide market, the technology has made significant inroads in the Asian-Pacific region (67% of the market) and in Europe (24%). The lack of market impact in the U.S. has been largely due to high equipment and installation costs, inconsistent/unpredicted incentives from government agencies, and paybacks ranging from three to 10 years.

Solar water heating is a mature technology; however, its diffusion is still severely limited by high initial component and installation costs in the US. Increasingly, governments have introduced regulations mandating that a certain percentage of hot-water demand in all new or renovated buildings be met by solar energy. These regulations create market niches for solar-thermal technology. However without reduced costs, permanent rebates, or permanent mandates, solar will continue to be a high-cost, long-payback option.

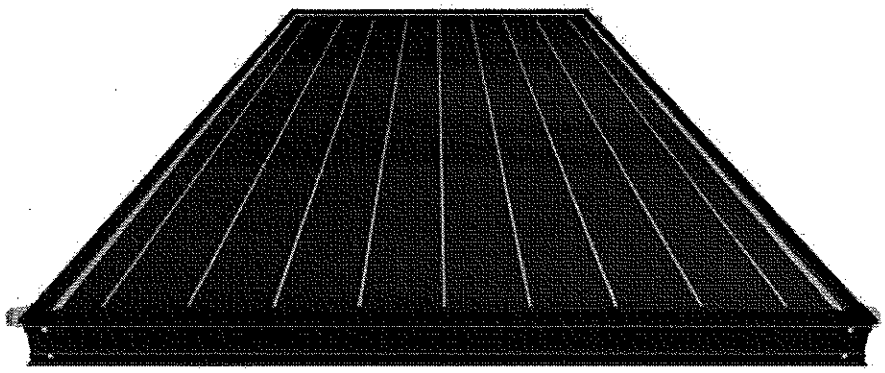
Under a current UTD-sponsored program, a highly efficient solar-thermal water- and space-heating system (the Equinox system from Solar Usage Now) was tested over a one-year period. The Equinox system is a combination of an atmospheric storage tank, a highly efficient natural-gas-fired tankless water heater, air handler, and a very efficient solar-thermal collector (using evacuated-tube and heat-pipe technology). This system uses the most efficient technologies on the market in an integrated, energy-efficient package. The modular design of the hot-water storage tank allows it to be easily used in boiler replacements (<212°F) in applications such as cleaners, food processing, hotels, schools, and hospitals.

The goal of this project is to evaluate the performance of a similar low-cost solar-thermal system with performance comparable to commercially available systems. This lower-cost "plug-n-play" offering could improve the market penetration of solar thermal systems by providing a payback period of less than three years.

Deliverables from this project will include system design specifications, the creation of an operational laboratory test loop, and data analysis.

Benefits / Market Implications

The development of a low-cost solar/natural gas hot-water system will allow utilities to offer a unique solution that provides a safe, clean, renewable energy source; enhances solar-thermal technology market penetration; and contributes to revenue streams while assisting with natural gas load-retention objectives.



Technical Concept & Approach

In this project, a research team partnered with Apricus Inc. – a major manufacturer of solar thermal equipment – to develop and evaluate a low-cost solar thermal system similar to the Equinox system.

This initial system under evaluation in this project consisted of an atmospheric storage tank, a natural-gas-fired tankless water heater, air handler, and a solar thermal collector. The collector is a drain-back flat-panel design. The major advantages with this system are 1) the potential for a substantially reduced payback due to the low-cost collectors and 2) reduced installation cost due to the plug-n-play design.

Specific tasks include:

- System Design
- System Fabrication and Installation
- System Evaluation
- Data Analysis and Reduction.

Results

Apricus finished the first round of certification testing; however, product performance did not meet R&D goals. The company made some minor changes and the collectors were re-tested.

System shakedown of the low-cost solar thermal prototype tank identified several issues that prevented proper operation. Consequently, Apricus abandoned the prototype.

Status

Apricus' current focus is to finalize the manufacture of its new low-cost flat-plate solar thermal-collector.

The project team and Apricus have had a number of conversations about the state of the Apricus low-cost system. The evacuated-tube collector has come down in price over the past few years due to the scale of production and economies of scale. The evacuated-tube collector series costs the contractor about \$17.65/gross ft^2 and the flat-plate collector series costs the contractor \$18.375/gross ft^2.

In 2014, the flat-plate collector completed certification, and the project team received the panels for laboratory testing.

Based on the findings from UTD projects 1.8.H and 1.9.E, researchers will be modifying the test loop to a solar preheat system. In the current configuration, the temperature in the tank is maintained via a tankless recharge loop. In the reconfigured Equinox, the storage tank is dedicated to solar-thermal storage only and preheats water to the tankless heater.

There are four reasons that dedicating the atmospheric storage tank for storage of solar-thermal energy only leads to higher efficiencies:

1. All storage-tank standby losses will be from solar energy alone. At a very minimum, the system efficiency would equal that of the tankless water-heater field efficiency.
2. The storage tank could store more solar energy. The 80-gallon tank has a thermal storage capacity of 80,000 Btu (assuming 180°F maximum capacity and 60°F incoming water temperatures). Under the current configuration, maintaining a minimum tank temperature of 130°F leaves only 33,500 Btu for solar-thermal energy storage. If a minimum tank temperature is not maintained, the full heat storage capacity could be utilized for solar thermal storage.
3. The system could collect additional solar energy. A 30°F temperature differential between the atmospheric storage tank and the solar collector is required before the system can initiate solar collection. The storage tank is required to maintain a minimum temperature of 130°F, so generally the collectors must be at least 160°F before solar-energy storage can initiate. With a lower tank temperature, the solar collection can initiate at much lower temperatures.
4. On days when there is no hot water load, the facility would use no natural gas. If the storage tanks were not required to maintain a set temperature, then the tankless water heaters would boost the temperature only when there was a load.

This laboratory setup will still compare the performance between the evacuated-tube and flat-plate collectors on a solar system delivering domestic hot water and space heating. A bulk of the reconfiguration work was performed during this reporting period.

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UTD Utilization Technology Development

Waste-Heat Recovery from Corrosive Industrial Exhaust Gases

The objective of this project is to demonstrate a practical, robust, and affordable recuperator technology to recover useful waste heat from corrosive industrial exhaust gases. A new approach offers the opportunity to improve energy efficiency for many industrial processes.

Project Description

The focus of this project is on the Gas Guard Regenerative (GGR) heat-recovery system designed to enable aluminum re-melt furnaces and other industrial processes to recover waste heat from corrosive furnace gases for increased efficiency, fuel cost savings, and reduced air pollution.

Conventional recuperators have substantially decreased longevity when used to recover heat from corrosive exhaust gases, and consequently are not commonly utilized for waste-heat recovery from aluminum smelting and other industrial furnaces with corrosive exhaust gases, thereby resulting in high fuel usage and costs as well as increased emissions of greenhouse gases and other process generated air pollutants.

Foe this project, researchers completed pilot-scale tests of the GGR heat-recovery system technology and are preparing a field-demonstration stage leading to commercial designs and technology deployment on aluminum smelting and other furnaces throughout the U.S.

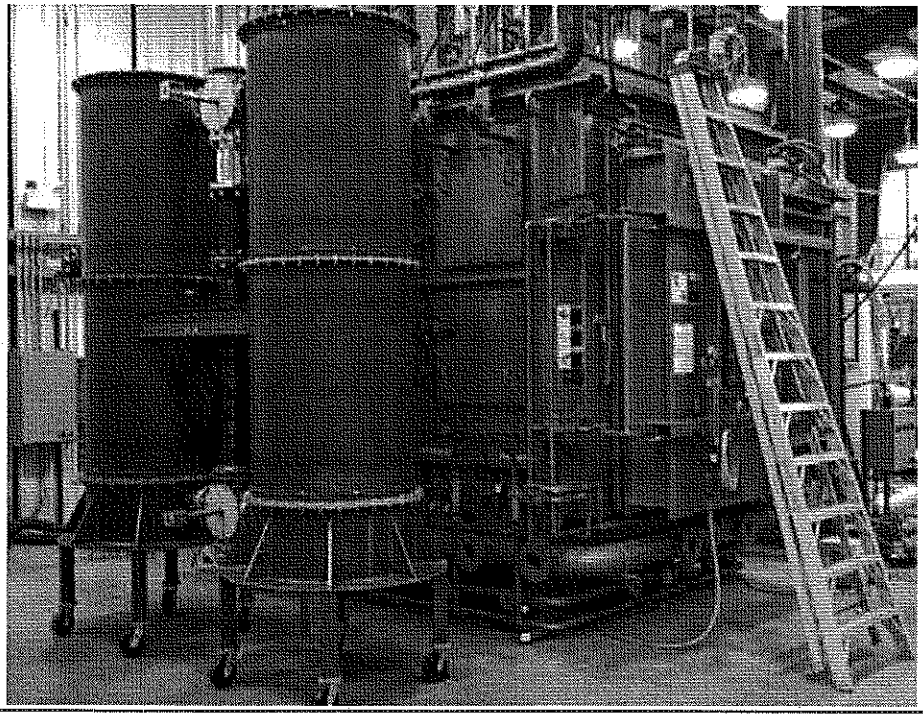
This project is also supported by the California Energy Commission.

Benefits / Market Implications

The ability to recover waste heat improves furnace efficiency. Since no practical technology exists to recover heat from corrosive exhaust gas streams, this new approach offers a significant opportunity to improve energy efficiency for many industrial processes. The goal is to provide 15% to 30% energy savings to sites using the technology.

GGR technology can be installed on furnaces in the aluminum industry and other markets that currently have no potential for waste-heat recovery due to the corrosiveness of the flue gas. The technology has the potential to recover 43% of the exhaust gas heat, increasing the overall thermal efficiency to 40%. This could save 2.37 trillion Btu of natural gas annually in the U.S., with significant reductions of CO_2, CO, and NO_x emissions.

Application of the GGR technology on a small aluminum remelt furnace with a capacity of 80 tons of aluminum per day is expected to provide efficiency gains from 25% to 40% and savings of 1.5 MMBtu per ton of aluminum.



Technical Concept & Approach

GGR technology takes a practical, innovative approach to heat recovery.

In the process, hot exhaust gas passes through a guard bed of sacrificial sodium minerals that scour chlorine and fluorine from the gas. Hot, clean gas then passes through a heat exchanger that preheats air for heat transfer to the burners.

The only furnace alternation needed is to operate burners on preheated air instead of ambient air. The guard-bed materials are readily available, low-cost minerals that can be easily replaced when necessary.

Results

Initially, the research team developed numerical models of heat regeneration and toxic fluorine compound removal in the GGR, which were used to develop design specifications. After a number of sorbents were considered for this application, sodium carbonate was found to be the most effective, with the capacity to reduce chorine and fluorine from flue gases having concentrations up to 5,000 ppm.

Parametric modeling of the GGR was conducted to achieve optimal performance characteristics. A GGR demonstration unit was subsequently designed, fabricated, and tested.

Pilot-scale tests consisted of two key technical steps: 1) Component design and bench-scale laboratory testing; and 2) System fabrication and pilot-scale prototype testing with simulated corrosive gases. Laboratory tests were conducted under conditions simulating a typical aluminum melting furnace.

Modeling and bench-scale testing were employed to develop the necessary information to design a suitable gas/solid guard bed contactor to maximize contaminant removal efficiency and minimize sorbent utilization. Once the gas/solid contactor design and laboratory testing were completed a pilot-scale GGR heat-recovery system was designed that integrated regenerative heat recovery into a single prototype unit. The GGR heat-recovery system was installed in the laboratory and hot tests were carried out using a test furnace as the source of hot gases.

At the conclusion of testing, the nominal results included a reduction in exhaust gas average temperature from an average of 1,006°F to an average of 176°F during the first half of the cycle, while the combustion air was heated from an average of 124°F to an average of 810°F during the second half of the cycle. The change in temperature of the exhaust gas is equal to an extraction of 63% of the energy (sensible and latent heat) contained in the exhaust gas at 1,006°F.

A Final Report on laboratory, demonstration, and technology transfer activities was prepared in 2013.

Key Findings and Conclusions:

- Conventional recuperators, unlike GGR technology, rapidly deteriorate when used to recover heat from corrosive furnace exhaust gases and typically provide 450°F - 750°F combustion air when flue gases range from 1300°F - 1600°F.
- An aluminum melting furnace with 1,800°F flue-gas temperature equipped with a GGR System –
  - Preheats combustion air to 800°F, increases furnace thermal efficiency from 35% to 45% resulting in a 23% fuel reduction
  - Preheats combustion air to 1,000°F, increases furnace thermal efficiency from 35% to 49% result ing in a 28% fuel reduction
  - Reduces the concentration of HCl in the hot exhaust gases by 96%
  - Reduces greenhouse gas emissions by 23% -28%.

Given the relatively small footprint of the GGR heat-recovery system and the utilization of commercially available components, the projected installed cost is expected to be moderate. The target for a simple payback is considered to be 18 to 24 months. Readily available inert and sorbent media used in the packed beds were selected with operating costs in mind. The frequency of media replacements will be identified in a proposed follow-on field demonstration of a beta prototype GGR heat-recovery system.

UTD members were notified regarding a field-test opportunity for a GGR field demonstration. A variety of potential sites were subsequently investigated and discussions were held with prospective participants.

Status

Development funding support will be necessary to finalize the commercial design, engineering, fabrication of the GGR heat-recovery system, and carrying out the field demonstration prior to licensing.

The research team is pursuing GGR field-demonstration opportunities with several companies.

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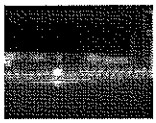
UTD
Utilization Technology Development

Ribbon Burner Improvements



The overall objective of this project is to develop and demonstrate a new class of advanced low-NO_X ribbon burners as cost-effective replacements to the traditional ribbon burners that are used for a wide variety of industrial processes.

Project Description

The ribbon burner is a tube or block that regulates where the flame is centered and the amount of gas and air used to create the flame. State-of-the-art ribbon burners have emission production of 25-30 vppm of NO_x and < 15 vppm of CO both at 3% O_2.

In 2012, exploratory R&D was conducted to validate potential ways for NO_x reduction while maintaining stable operation of the conventional pipe ribbon burner that is widely employed in industrial bakeries. After extensive baseline testing, researchers established the best ribbon burner performance at the firing range of 1,000-1,500 Btu/hr. Follow-on experiments with controlled air staging clearly indicated the dynamics of the emission formation and combustion stability, bringing the project team in the position to demonstrate an alpha version of an advanced low-NO_x (ALN) ribbon burner.

Considering the broad application of ribbon burners for industrial processes, the ALN ribbon burner concept has the potential to support the gas industry in meeting continually more stringent emission requirements without sacrificing efficiency or process control.

The overall objective of this effort is to develop and demonstrate a new class of ALN ribbon burners as cost-effective replacements to the traditional ribbon burners that are widely employed for food processing, surface treating, drying, material thermoforming, and other applications. The ultimate goal is to reduce the ribbon burner NO_x production by 50% (currently 30 vppm at 3% O_2).

Benefits / Market Implications

According to the American Bakers Association, there are more than 700 baking facilities and baking suppliers nationwide. A typical mid-size bakery might have three production lines and would consume about 7 million cubic feet of natural gas per month, resulting in approximately 0.6 Tcf of annual natural gas consumption by the U.S. baking industry with annual CO_2 production of over three million tons. Reaching the target of 50% reduction in NO_x production (< 15 vppm at 3% O_2) could lead to significant reductions of pollutant emissions from the ribbon burner installations.

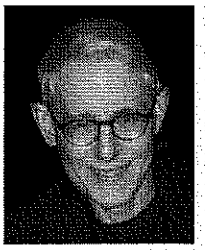
Technical Concept & Approach

This project includes the following tasks:

- Qualified Host Site Selection
- Specification, Design, and Engineering
- Fabrication and Acceptance Testing
- Installation and Shakedown
- Data Collection and Analysis
- Administration and Reporting.

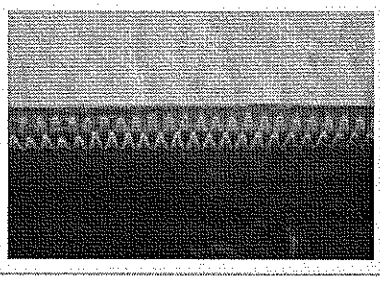
Final reporting will summarize all project findings along with the recommendations for the commercial burner design and commercialization details.

In test-rig experiments, more than 50% NO_x reduction at a stoichiometric ratio of 0.95 in primary air was achieved.



"All of us at Flynn burner are excited to be working on this project to develop a low-NO_x burner, which, when completed, promises to advance combustion technology significantly."

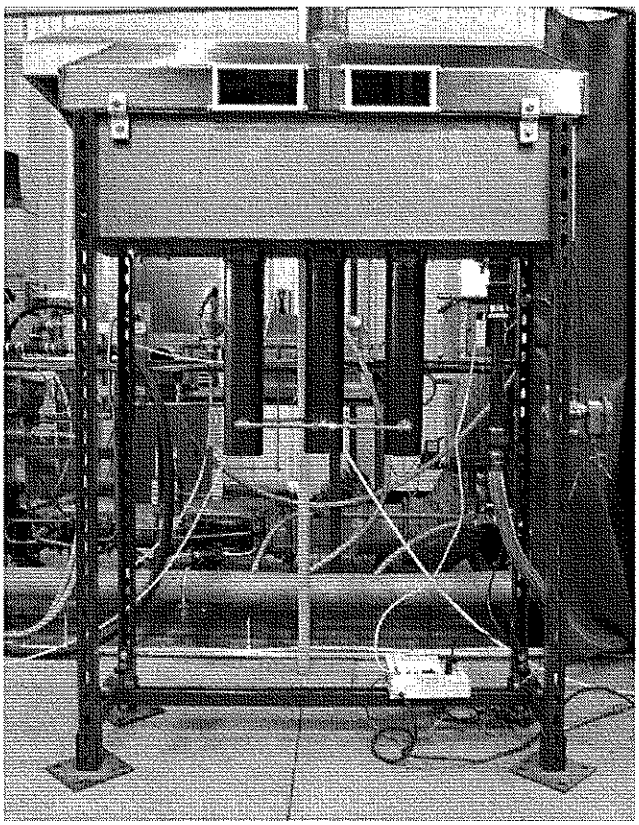
- Joe DiGiacomo
Vice President
Flynn Burner Corporation



Results

The project team built a laboratory-scale test rig around a commercially available pipe ribbon burner and has conducted experiments demonstrating that the dilution of the oxidizer with CO_2 may result in significant reduction in NO_x formation. Experiments were conducted in a wide stoichiometric ratio range.

A test burner setup was designed and assembled at Gas Technology Institute (GTI) facilities in Des Plaines, IL. The test burner was positioned inside an enclosure to eliminate the ambient air infiltration into the combustion zone. Data (air and gas flow rates, O_2, NO_x, and CO emissions) were collected.



Overview of the laboratory test facility.

The baseline tests of a traditional pipe ribbon burner provided a better understanding of the potential for lowering the overall NO_x formation by controlling the oxidation rate at the diffusion part of the ribbon burner combustion process. The test burner arrangement was made to restrict ambient air to the diffusion part of the combustion process. The quick test results demonstrated the potential for the identified approach and achieved less than 15 vppm NO_x.

A paper titled *NO_x Reduction in Partially Premixed Flame by Replacing Combustion Air with the Oven Exhaust* by members of the research team was submitted for presentation at the ASME International Mechanical Engineering Congress in November 2014.

In March 2014, the project team met with bakery representatives to discuss potential sites.

Status

The project team continues to search and evaluate a qualified baking industry host site for follow-on testing.

Results analysis is in progress, to be followed by the preparation of a Final Report detailing findings.

The project will continue through 2014-2015 and include a pilot-scale evaluation of the low-NO_x ribbon burner at a selected host site.

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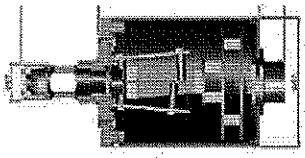
UTD Utilization Technology Development

Gas Quality Sensor (GQS) for Natural-Gas- and Renewable-Gas-Fueled Engines



The objective of this project is to develop and demonstrate a practical, reliable, and lower-cost Gas Quality Sensor (GQS) that can detect changes in the heating value, Wobbe Index, and Methane Number of natural gas and biogas/natural gas blends used in reciprocating internal combustion engines, gas turbines, and industrial burners.

Project Description

Variable natural gas composition can be problematic for operators of engines used in stationary power, gas gathering, pipeline compressor stations, and natural gas/air blending stations at landfills and wastewater treatment plants consuming renewable gas. Accurate knowledge of natural gas properties is also important at many locations on the natural gas pipeline and distribution system for a variety of reasons.

Today, many locations are experiencing wider variations in higher hydrocarbon concentrations due to new shale gas wells. To assure safe engine operation and emission compliance, it is advantageous to have real-time (less than one second) natural gas composition feedback to the engine controller.

With previous funding support from Gas Technology Institute's (GTI) Sustaining Membership Program and the U.S. Department of Energy, GTI and its technology partner, North Carolina State University (NCSU), developed and validated a Gas Quality Sensor (GQS) that utilizes the near infrared light-absorption properties of hydrocarbon gases to measure the Btu content and composition of a natural gas mixture at response times less than one second.

Commercial prototypes are expected to be ready for evaluation by engine manufacturers and end users in 2014. The commercialization partner for the project is CMR Group.

This project focuses on the development and demonstration of a detailed design for a commercial prototype that will satisfy product performance specifications and cost targets.

The goal is for the GQS to be able to detect changes in the heating value, Wobbe Index, and Methane Number of natural gas and biogas/natural gas blends and can provide data with sufficient accuracy and a signal with a response time so that it could be used by control systems of reciprocating internal combustion (IC) engines, gas turbines, or industrial burners.

Benefits / Market Implications

A real-time GQS can improve the reliability and performance of power generation and industrial process equipment operating on fuel that exhibits sudden and significant variation in Wobbe Index or Methane Number.

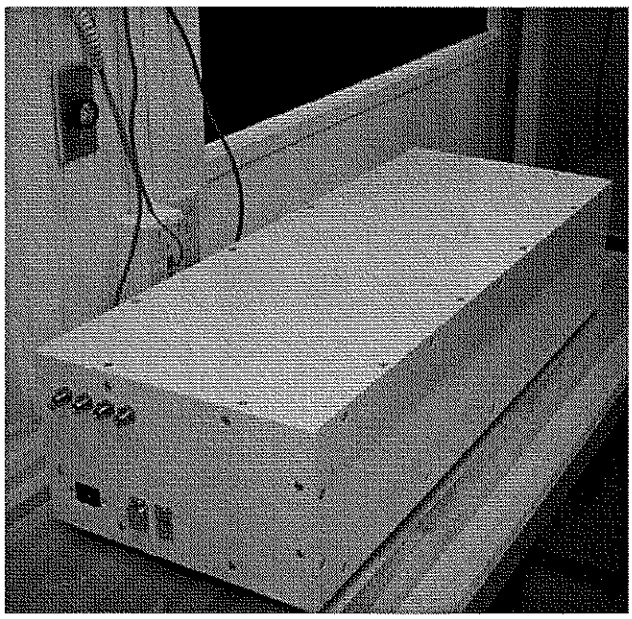
Currently available technologies such as gas chromatographs and calorimeters are not capable of providing needed information quickly enough, have a relatively high first cost, and require regular calibration. The GQS being developed in this project is targeted to be significantly lower in price than other sampling methods and will only require initial calibration.

Technical Concept & Approach

This project includes the following tasks:

- **Preliminary and Detailed Designs for a Commercial Prototype of the Gas Quality Sensor (GQS)**

  A technology transfer package will be developed that includes software code, descriptions of the



sensor's software and hardware, and the principle of operation. The developed GQS will be tested for biogas compositions of CH_4, CO_2, and opportunity fuels.

The research team will confirm that the detailed design approach that will satisfy the product performance specifications and cost target.

- **Commercial Prototype Laboratory Testing**

  Researchers will test the GQS commercial prototype in the laboratory according to an approved test plan. Technicians will test the performance, debug, and improve up to four prototypes as well as calibrate up to 20 prototypes.

- **Field Testing GQS Commercial Prototype**

  The research team will prepare a "white paper" that includes recommendations for improving the software and hardware based on the field test results.

- **Marketing Support.**

  Investigators will assist the manufacturer in identifying and evaluating additional target markets for the GQS beyond reciprocating engines.

Results

GTI and CMR agreed that a new mini-Fourier Transfer Infra-Red (FTIR) spectrometer planned on being introduced commercially to the U.S. market in 2014 appears to have the best chance of satisfying the price target for the commercial GQS. However, because the previous development of the GQS was based on conventional spectrometer technology and not FTIR, it was necessary to evaluate the new FTIR and confirm that it will satisfy technical performance requirements.

In 2013, the project team conducted preliminary testing to assess the suitability of a currently used spectrometer and the new mini-FTIR spectrometer for measuring concentrations of methane, carbon dioxide, and nitrogen at atmospheric conditions.

CMR provided evidence of a successful experience of testing an early prototype of this emerging FITR in the heavy-fuel-oil quality sensor that CMR recently introduced to the market.

"CMR and GTI are now embarking on a ground-breaking project. We are all very happy with developments so far and have customers waiting."

- James Thwaites
Group Marketing Manager
CMR Group

Using preliminary data and an analysis of principal components, researchers were able to predict the composition and heating value of fuel/air mixtures. No drift was observed in the absorbance of CO_2. This is an improvement on the spectrometer which was used in years past. Predictions on composition and heating value can be made with fairly high accuracy for a mixture containing methane, carbon dioxide, and nitrogen. Additional constituents of natural gas and landfill gas (e.g., such as propane) will be added to the mixture to further test the current multivariate methods.

Project team representatives also attended the High Horse Power Engine Summit in Chicago in September 2013. It is reported that based upon discussions with engine OEMs and information provided by speakers, market potential for the GQS looks excellent. CMR marketing continues to evaluate the possibility of future integration of the GQS into an engine/equipment "fuel train" (with regulators, valves, etc.).

Status

The project team is conducting necessary modifications of the existing laboratory GQS system to allow integration of the mini-FTIR with the existing GQS hardware and software.

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UTD Utilization Technology Development

Submerged Combustion Melting Commercialization Support

This project will provide information that is directly applicable to the commercialization of the Submerged Combustion Melting (SCM) technology. The objective is to resolve important engineering issues to accelerate the commercial introduction of the technology.

Project Description

Natural gas is the fuel of choice for glass melting. However, current melters are costly and can create a capital-intensive industry that finds it difficult to innovate or expand.

In recent years, R&D resulted in the introduction of a more flexible gas-fired glass-melter technology with an 80% lower capital cost. The technology – called Submerged Combustion Melting (SCM) – was proven in the laboratory and has operated in partnership with many glass companies.

This project addresses the need to facilitate the industrialization of the SCM technology by resolving several engineering issues.

Early efforts focused on producing a number of melts, particular mineral wool and basalt glasses, in a laboratory-scale unit. This led to a successful project that included modeling, the design of a continuous one-ton/hr pilot-scale SCM unit, and melting of a wide range of commercial glasses.

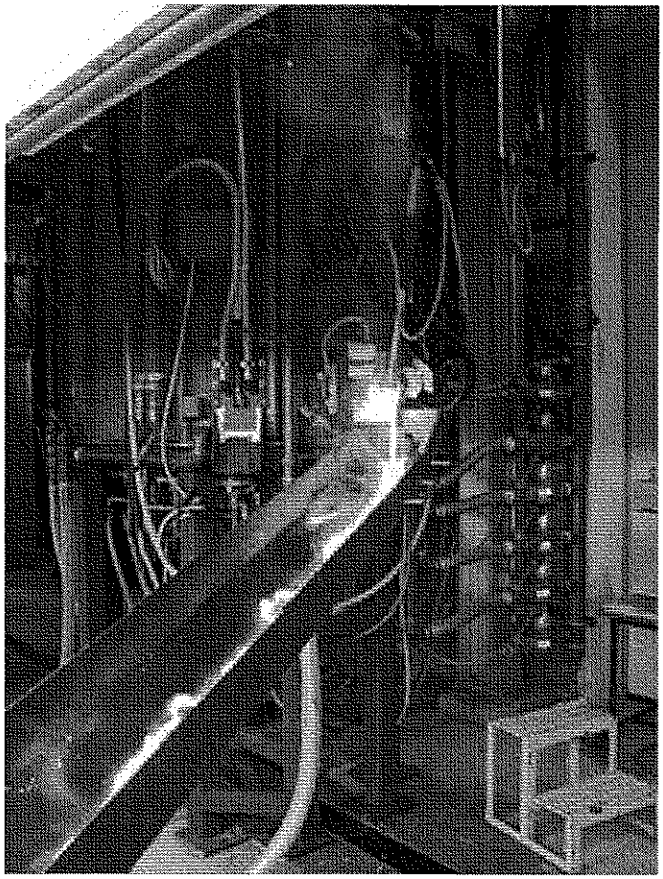
Design, fabrication, and testing of the pilot-scale unit greatly advanced the technology. Based on knowledge gained, three development-scale units were subsequently built. These units operated with varying amounts of time, producing distinctly different glass products.

Operation of the commercial demonstration SCM units with capacities of one- to five-ton/hr identified several design improvements needed to advance the technology to be able to operate on a continuous basis in an industrial setting.

Another previous project was conducted to devise a cost-effective and reliable rapid-refining process. Various approaches were considered and several were explored in cold-flow modeling tests with simulated viscous liquids, mathematical modeling, and testing with molten glass in batch tests with the pilot-scale unit. Further investigation led to development of a process called Thermal-Convective Rapid Refining (TCRR). The TCRR process uses precisely located heating below a channel of refining glass to drive the bubbly glass toward the surface where bubbles will break. Tests showed that fiberglass production can be obtained with residence times as short as 20 minutes.

The next step in testing is to modify the pilot-scale unit to conduct continuous TCRR tests. Industrial practice demands continuous production, and the switch from batch refining to continuous refining tests will provide the operating data needed to design and integrate TCRR with commercial-scale units.

This project will provide information that is directly applicable to the commercialization of the SCM technology. Results from this project will strongly increase the potential for commercial SCM deployments.



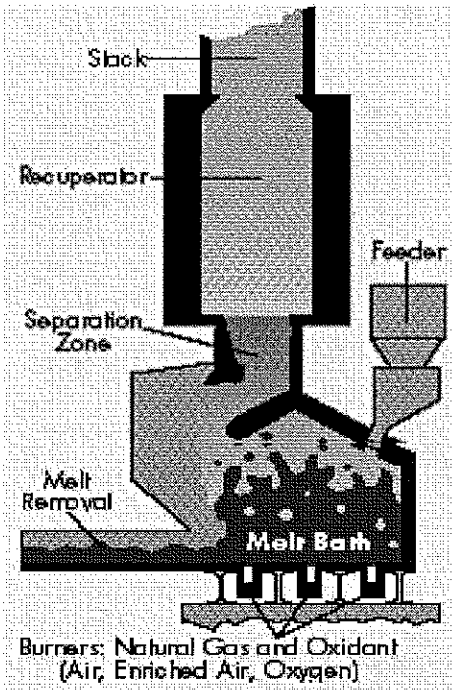
Pilot-scale melter in the laboratory.

Benefits / Market Implications

SCM is a promising technology for melting glass, mineral wool, and other inorganic materials and as a platform for processes to vitrify wastes, generate synthetic gas, burn coal and biomass, and other applications.

The two primary benefits of the technology are an 80%-90% reduction in melter capital cost and greater melter operating flexibility (fast start-up, allowance for intermittent operation, wide operating temperature range, etc.). Other benefits include a 5%-20% reduction in energy consumption and a 50% reduction in CO and NO_x emissions compared with the best commercial melters.

Negotiations are under way to sell several melters; however, these sales are contingent on resolving the long-term operability issues of refractory life and rapid refining. Additional sales would be expected after the technology becomes fully industrialized and demonstration melters have shown the benefits and reliability of the process.



Technical Concept & Approach

This project is addressing several specific engineering issues in order to move forward with full commercial deployment of the SCM technology:

- Improving the melt-discharge tap design
- Using advanced refractories for improved abrasion resistance
- Demonstrating the TCRR technique in continuous operating mode

The pilot-scale SCM unit is being modified with a new discharge system and an integrated thermal-convective refining channel. Several melt trials will be conducted to provide critical information on the performance of advanced refractories, the discharge section, and the thermal-convective refining process.

Several advanced refractories with high-temperature abrasion resistance will be installed in critical flow positions (e.g., the mouth of the discharge section). The wear of these refractories will be assessed after each trial. The performance of the new discharge section will be determined during each trial. The thermal-convective refining process will be assessed through collected product glass samples generated at different operating conditions during each trial. The collected information will be used to improve the design of the next industrial SCM demonstration units.

Results / Status

SCM project activities include DOE-supported development of the TCRR process for refining product glass, design of a research SCM unit for a major container glass manufacturer, and extension of the SCM approach to serve as the basis of a hybrid molten-bed coal/natural gas gasification process. This UTD project is providing support in several critical ways.

The design of the TCRR equipment to be added to the pilot SCM in the laboratory is complete. Fabrication will begin in the third quarter of 2014, and testing will be carried out in the fourth quarter of 2014. the project is expected to be completed by the end of 2014.

This project is not supporting the design of the research SCM unit for the container glass manufacturer; however, project engineers are monitoring activities as future SCM development will benefit from successful design and operation of this research unit.

Researchers are studying new discharge-tap designs. The platinum tap used for research is being replaced with an integral tap that provides continuous, integrated flow of molten glass from the melter to the refiner. This discharge approach is much less expensive than a platinum discharge tap and is expected to be compatible with refining-unit requirements and to be scalable to larger capacity melters.

This project is supporting the DOE-funded hybrid molten-bed (HMB) gasification process. The HMB process uses natural gas along with coal, hence the word hybrid in the title. Activities involve the evaluation of different refractories. Testing for the HMB project is scheduled to be completed in the third quarter of 2014.

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UTD Utilization Technology Development

Gas-Fired Baking Oven Performance Improvement

This project focuses on evaluating the energy distribution and consumption of a gas-fired industrial bakery oven in an effort to develop solutions for performance enhancement.

Project Description

Industrial gas customers are often constrained by available energy and water resources. Industrial bakeries can also face additional challenges posed in meeting environmental-compliance requirements.

In response, this project focuses on the ultimate goal of improving a gas-fired industrial bakery oven to help expand industrial-baking operations and provide environmentally enhanced performance.

The initial objective is to technically and economically evaluate the energy distribution and consumption of a gas-fired industrial bakery oven and develop the appropriate cost-effective solutions for its performance enhancement and production improvement.

Benefits / Market Implications

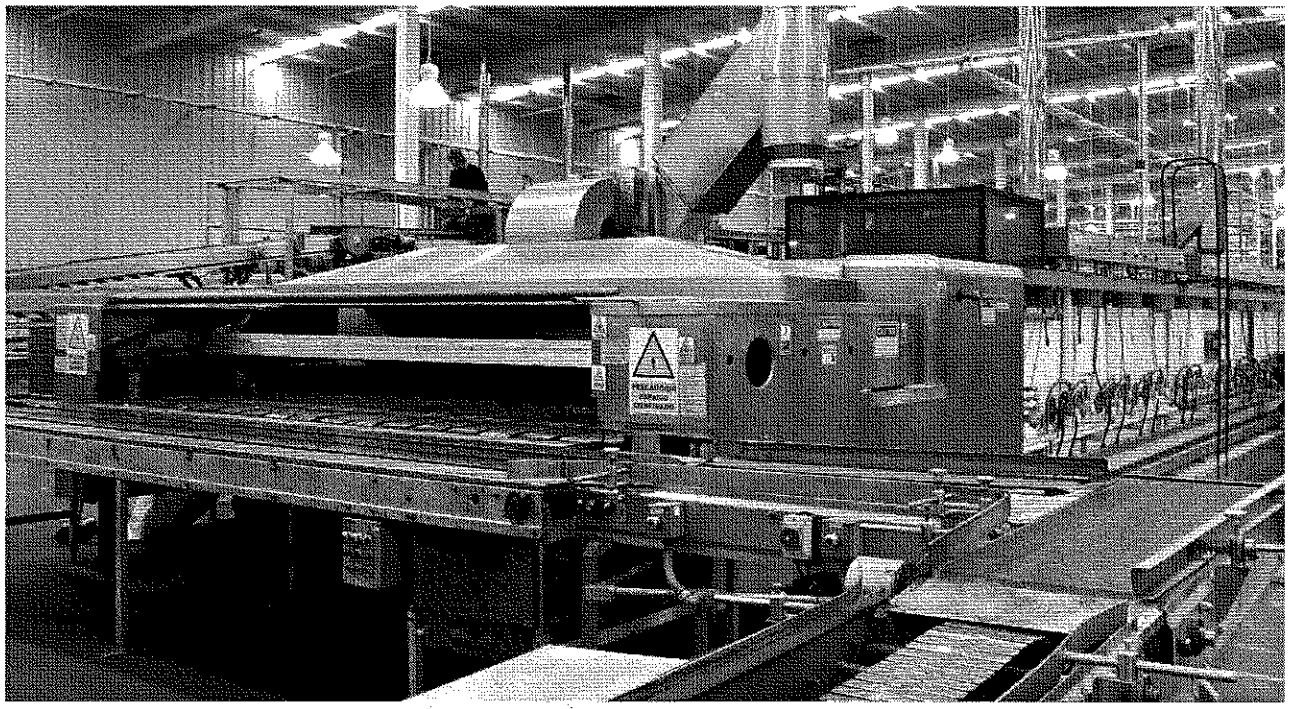
Main benefits of an enhanced gas-fired bakery are reductions in energy use and emissions.

Currently, a typical mid-size bakery can have three production lines and consume about 7,000,000 cf of natural gas per month. Nationally, industrial baking accounts for approximately 0.6 Tcf of natural gas consumption and CO_2 production of more than three million tons per year.

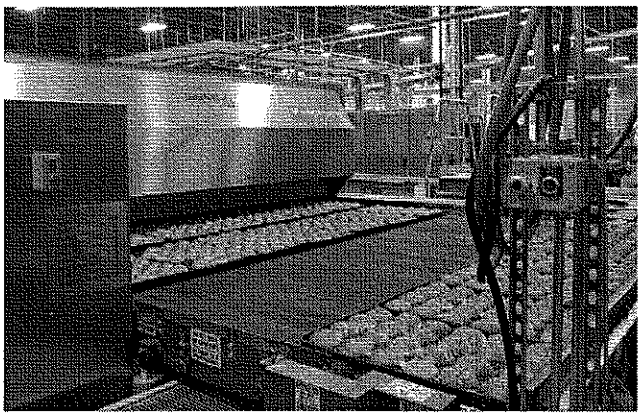
Technical Concept & Approach

To improve the gas-fired baking oven performance, several key measures were considered, including:

- Improvement of combustion-system performance via "smart" heat management
- Combustion-air flow optimization
- Preventive maintenance, and
- Cost-effective waste-heat recovery.

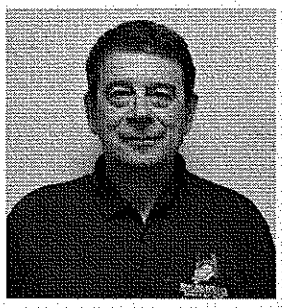


Typical layout of direct-fired industrial bread-baking oven.



The indirect-fired baking oven selected for the preliminary evaluation.

"The baking industry is always looking for approaches and technologies to save energy and mitigate environmental impact in a diversity of baking operations. We strongly believe that successful development efforts that have been undertaken by academic scientists and applied researchers could provide a big value to specific bakeries as well as be beneficial – both economically and environmentally – for the baking industry nationwide."



- Boris Golenson
Chief Engineer
Highland Baking Co.

Based on preliminary evaluations, three major directions are being considered and estimated to improve industrial gas-fired baking oven performance:

- Combustion system improvement via the implementation of advanced burners and the enhancement of the radiative component of the flame
- Minimizing or eliminating the coloraider tubes through internal heat-flux optimization, implementation of advanced heat-transfer techniques, and lateral heat balance
- Heat, water, and VOC recovery from the oven exhaust gas supplementing the fuel and hot water (and/or steam) services at the site.

The project includes the following tasks:

- **Feasibility Analysis**

  The project team will identify a qualified industrial bakery along with gas-fired oven specifications. Jointly with industrial partners and selected bakery staff, the team will review energy distribution/ consumption of the installed system.

- **Technical Solution Development.**

  The project team will develop/recommend the appropriate solutions for performance enhancement/ improvement. A cost/benefit analysis of the oven enhancements will conclude this task.

- **Oven Performance Simulation**

  The project team will simulate the performance of the selected gas-fired equipment to tentatively prove the enhancements/improvements.

- **Commercialization Plan and Demonstration Strategy**

  The findings will be consolidated, analyzed and presented along with a follow-on proposal.

Results

A preliminary list of advanced technologies and solutions for the industrial and commercial gas-fired baking ovens performance improvement was drafted. Two types of gas-fired ovens are being considered – direct-fired and indirect-fired.

In March 2014, the project team met with senior representatives from a major baking company in the framework of 2014 BakingTech in Chicago and discussed the availability of the two commercial baking sites for evaluation. However, one of the sites has been scheduled for shutdown, while other site does not allow any product loss during the baseline testing. It was decided to expand the host-site search across the industrial partner's client database beyond the direct-fired ovens. A preliminary evaluation of the combustion system at the indirect-fired oven was performed. Energy assessment across the entire bakery pending.

Status

The project team is developing energy- and fuel-consumption specifications for the selected industrial bakery (oven, hot water, proofer, etc.). After review, the specifications will be revised with suggested performance-improvement solutions for final evaluation.

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TRANSPORTATION

UTD Utilization Technology Development

Improved Efficiency for Stoichiometric Combustion with Cooled Exhaust Gas Recirculation

Research is being conducted to evaluate strategies and technologies to improve the fuel efficiency of Cummins Westport's ISL G engine and expand the capability of the engine for heavy-duty vehicles.

Project Description

Cummins Westport Inc., (CWI) – a joint venture of Cummins Inc. and Westport Innovations Inc. – develops and commercializes advanced, low-emission, alternate-fuel engines. In 2007, the company began commercial production of the ISL G engine, which is certified to EPA/CARB on-highway emission standards of 0.20 g/bhp-hr and 0.01g/bhp-hr PM.

The success of the ISL G engine in truck and bus applications sparked more interest in heavy-duty natural gas engines for over-the-road truck applications as customers recognized the fuel savings resulting from the fuel cost advantage of natural gas as compared to diesel fuel.

Through this project, researchers are evaluating strategies and/or technologies to improve the fuel efficiency of the ISL G engine, which uses stoichiometric, spark ignition, cooled exhaust gas recirculation combustion technology, and a three-way catalyst.

Following successful completion of this project, CWI anticipates initiating a product development program to implement the recommended design change(s) on the ISL G engine and/or other engines in CWI's spark-ignited natural gas product line.

Benefits / Market Implications

Improvements to the CWI ISL G engine will further enable heavy-duty vehicles to use economical natural gas within the most stringent regulations.

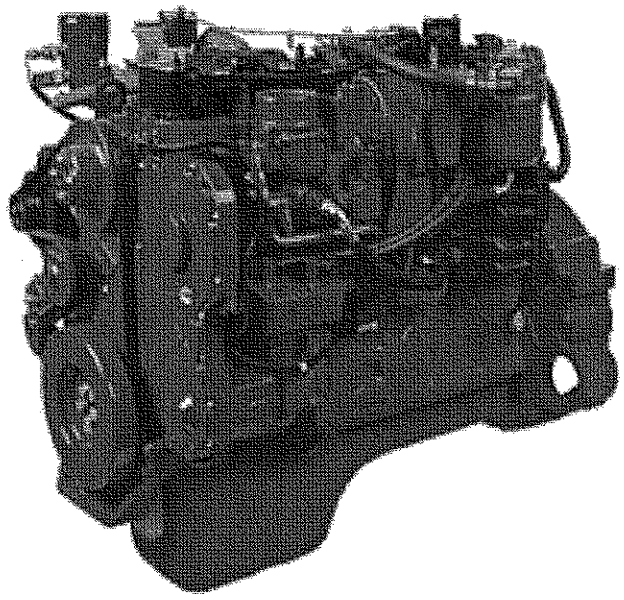
Engine benefits include:

- No exhaust-system-related maintenance costs
- Improved fuel efficiency with stoichiometric exhaust-gas-recirculation combustion
- Improved clutch-engagement torque
- Reductions in other maintenance costs.

Technical Concept & Approach

Research in this project focuses on modeling and analysis to evaluate the impact on knock margin with various designs and control strategies. This project includes cycle analysis predictions to evaluate design options for the engine, which will provide a first-order assessment of the factors impacting the efficiency. Combustion modeling will follow to develop a model to predict combustion rates and knock behaviors. The model will be calibrated with existing data from the ISL G engine. Once validated, the model will be exercised to predict combustion rates and knock capability based upon conclusions from the cycle simulation study. Both models will be used to converge on a recommended combustion chamber design that can improve engine efficiency.

Through previous research, CWI developed advanced combustion-modeling capabilities for spark-ignited engines utilizing stoichiometric, cooled EGR, spark-ignition (SESI) technology. CWI will tailor this existing engine model to conduct knock modeling specific to the ISL G engine. A research team will then evaluate the modeling results, determine the preferred strategy, and identify the required engine modifications to achieve increased knock margin.



The Cummins Westport ISL G engine.

Results

Initial activities performed by CWI at its Technical Center in Indiana included calibration of the SESI engine combustion model to match actual measured data obtained from an ISL G engine operating in a test cell.

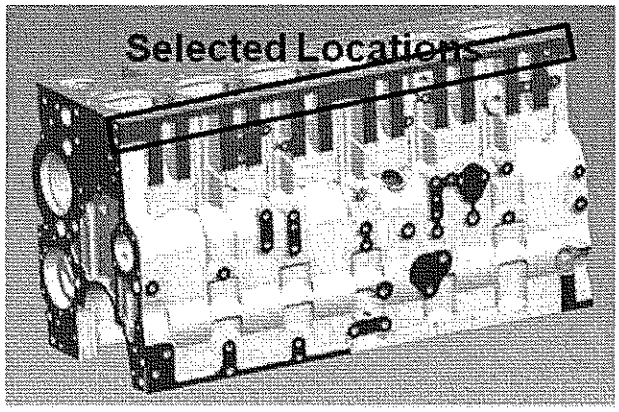
Analysis of ISL G test data indicate that controlling the knock behavior of the engine, especially at high load, could be another area for potential gain in fuel economy. More precise control of knock could allow engine operation closer to the knock threshold and therefore result in improved efficiency.

In 2013, cycle simulation techniques were used to assess the feasibility of increasing the compression ratio (CR) of the engine to improve efficiency. The model was first calibrated using current engine-design test-cell data, and good agreement was achieved. The analysis results indicated that a higher CR is feasible at same knock margin and can result in 2%-3% efficiency gain. Piston designs were completed and models readied for Computational Fluid Dynamics to predict the combustion rates with such design.

A design was completed to facilitate one knock sensor for each cylinder and an engine block was machined to allow installation and testing of this configuration. Test results will be obtained and analyzed to quantify the potential gain in efficiency with this system compared to the current system which uses only two sensors for knock control.

In addition, advances in cylinder pressure measurement technology were reviewed and a cylinder pressure sensor supplier selected for further development. This technology allows addition of these sensors in the cylinder head and continuous monitoring of combustion behavior during engine operation. Parts were procured and a design is being pursued to install the sensor in the development engine for evaluation.

In 2014, prototype pistons with 13:1 CR were installed in the engine and the combustion and performance characteristics were measured. The piston design produced good combustion with acceptable heat release duration. The measured combustion rates and duration compared well with the current production piston as well as the data for the 14:1 CR design. However, when the fuel consumption was compared to the baseline design, the 13:1 piston was inferior. It is not clear why this is, but it could be a result of the knock behavior of this higher CR design, requiring a significant spark timing retard to achieve the same knock margin as the baseline, which deteriorated the potential efficiency gain. Another contributor to the decline in efficiency is the apparent retard of the peak combustion rate as a result of the slower combustion in the beginning.



Cylinder block locations for knock sensors.

Most of the engine operating map shows a decline of fuel efficiency of about 5% at high loads and higher at part load. The reason for this is not clear and is subject to further investigation.

Analysis was completed to assess the potential efficiency gain by using a Variable Geometry Turbocharger (VGT). Several turbo frame sizes were investigated and one was selected that provided the best efficiency gain for the engine operation. Both high and low load points were predicted at rated and peak torque engine speed conditions. The results of the analysis indicate that considerable efficiency gain can be attained, which is primarily expected to be due to reduction of the gas pumping loop work. Up to 5% is predicted at high engine speed, where the pumping loop work is highest. A prototype turbocharger was ordered for engine test validation work.

Status

Ongoing activities include an analysis of camshaft optimization and validation testing of the benefits of the VGT. Cycle simulation is being used to evaluate camshaft redesign and turbocharger optimization. This research is focused on improving the pumping loop of the engine cycle.

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UTD Utilization Technology Development

Expanded Cylinder Cycle Testing Capabilities

This project involves the design, fabrication, and modification of existing laboratory facilities in order to build a test loop capable of satisfying compressed natural gas (CNG) cycle testing requirements to certify Type 4 composite cylinders per ANSI NGV 2-2007 standard.

Project Description

The natural gas vehicle (NGV) industry has long recognized that fuel storage weight, capacity, and cost are barriers that continue to hinder market growth.

To address the issue, researchers investigated Type 4 vessels, which are completely made of composite materials. Type 4 vessels are the lightest in weight of all vehicle cylinder options, but also typically the most expensive.

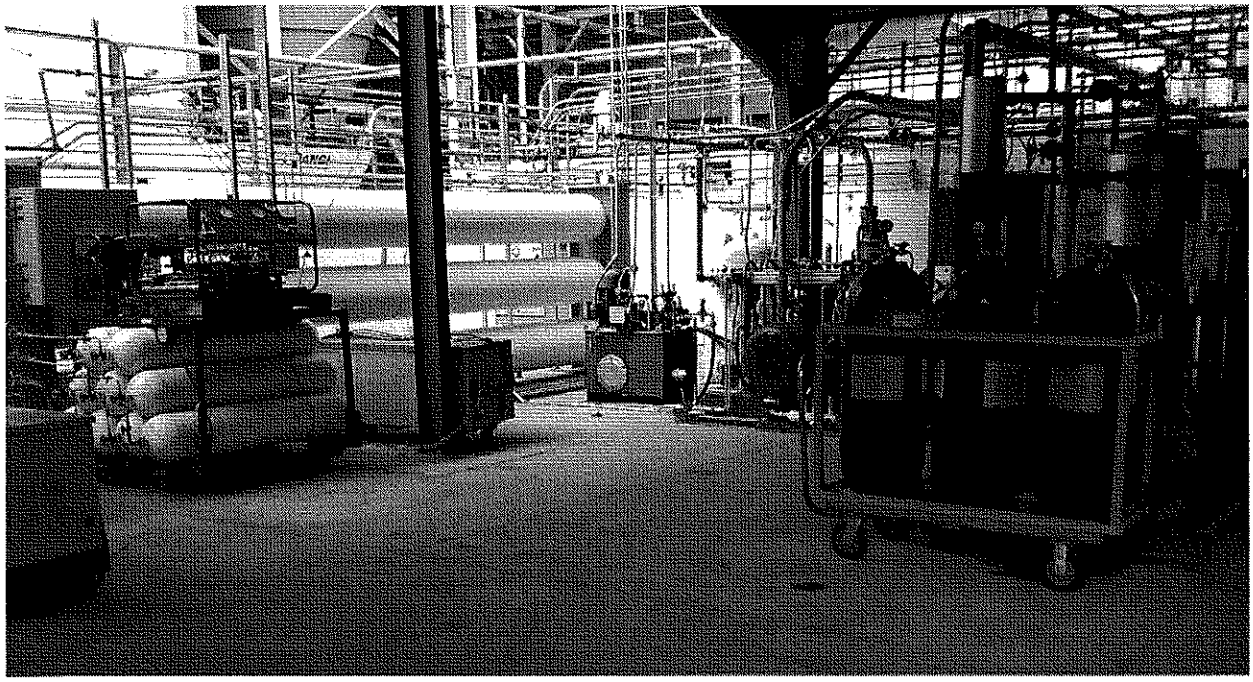
A new series of Type 4 cylinders made of advanced composite materials resulting from prior work supported by UTD are set for commercial production in 2013. These new materials and an enhanced manufacturing process are expected to reduce weight by 10%-20% and increase capacity by 10%-20% while adding no significant costs to the consumer.

Phase 1 of this project began in 2008 with support for a Type 4 cylinder development effort.

In Phase 2 (now under way), efforts will be conducted to support cylinder manufacturers in bringing a series of several sizes of a new Type 4 cylinder to market. The composite vessel utilizes a proprietary matrix resin technology to increase cylinder strength and to decrease overall weight. Testing of the resin shows improved fiber strength, before and after impact tests, as well as improved resistance to fatigue.

Due to long lead times and lack of capable laboratory facilities to perform all of the 16 tests prescribed by ANSI NGV2-2007, cylinder manufacturers have identified specifically the natural gas cycle test of the certification process as a significant barrier to timely commercialization.

This project involves the design, fabrication, and modification of laboratory facilities in order to build a test loop capable of satisfying compressed natural gas (CNG) cycle testing requirements to certify Type 4 composite cylinders per the ANSI NGV 2-2007 standard. This type of testing is required to ensure that vessel materials are capable of withstanding fatigue stresses experienced by the cylinder throughout its operational life.



Benefits / Market Implications

Currently, many cylinder manufacturers use the services of a Canadian testing firm for the natural gas cycle test described above. This has proven problematic in recent years as this one laboratory has seen the demand for these services increase and as movement of product across the border has slowed the overall progress of the cylinder manufacturers to the point that this test has become the critical path in the time schedule for the certification process.

Testing capability built through this project will provide increased availability and accessibility of qualified laboratory facilities in the United States to support the industry in fostering the innovation required to sustain future growth for the NGV industry.

Technical Concept & Approach

The objective of this project is to support cylinder-manufacturer efforts with one of its critical product certification and commercialization needs.

The project involves the design and development of a laboratory infrastructure with the capabilities to provide the industry with vital testing services. A gas cycling loop will be designed to test a variety of cylinder sizes. The time required to pressurize and bleed down the cylinder will be no longer than an hour. The test loop will operate in conjunction an existing refueling station. The test will be conducted to accumulate 1,000 test cycles. Data collection will also occur simultaneously during the test.

Specific tasks include:

- **Design of a Test Loop and Development of a Test Procedure**

  Engineering activities include, but are not limited to, the production of equipment layouts, the sizing of buffer storage volumes, and the development of system controls and safety measures. The apparatus will be designed to accommodate a variety of different-sized cylinders ranging from pony tanks (4 GGE) to side-saddle mounted tanks used in heavy-duty applications (30 GGE). The testing apparatus will subject the test specimen to its service pressure and proceed to bleed the vessel down to 10% of the defined test pressure. A test procedure will be created for, disclosed to, and approved by the cylinder manufacturer prior to the start of testing. This procedure will be controlled by a CPU and completely automated. Data collection will take place simultaneously throughout the test and status updates will be provided to the test operator.

- **Procure Materials and Fabricate/Modify Existing Facility**

  Modification of an existing infrastructure is required to accommodate the operation of a test apparatus while maintaining the delivery of fuel to customers.

- **Validate Test Loop and Complete First 1,000 Cycle Test**

  The validation of the apparatus will be performed with a Type 4 cylinder. The test procedure of the first 1,000 cycle test will be closely monitored to ensure operation and functionality of the system. A test report will be produced at the conclusion of the test.

Results

Design activities were initiated in 2014.

Input from several cylinder manufacturers and potential users of the test facility was incorporated into the design.

Status

Additional cylinder-manufacturer input is being sought to ensure that the final design of the test facility will have broad capabilities and the flexibility to serve user needs.

The schedule for activities to procure and install the test facilities is being developed to ensure that it will meet the cylinder manufacturers' needs.

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UTD Utilization Technology Development

Development and Commercialization of Ultra-Low-Emission Heavy-Duty Natural-Gas Engine

Teaming with a major manufacturer of heavy-duty vehicle engines, investigators provided consultation and funding-development services in efforts to introduce a new natural-gas-fueled engine for various truck applications.

Project Description

While technologies for natural gas vehicles (NGVs) have advanced significantly in recent years, a lack of natural-gas-engine offerings for medium- and heavy-duty platforms is hindering NGV expansion in several fleet applications.

Until recently, the largest displacement natural-gas engines available were the Cummins Westport Inc. (CWI) dedicated natural-gas 8.9-liter ISL-G engine and Westport Innovations' ISX-G 15-liter engine (using high-pressure, direct-injection diesel/natural gas technology). Although the 8.9-liter engine – with a top rating of 320 HP – is a popular and efficient option for local refuse collection, street sweepers, school buses, and transit markets, there is a need for an engine in the 400 HP range. The existing 15-liter ISX-G engine (up to 450 HP) fits well with Class 8 tractor-trailer rigs; however, there is a market for vocational applications, which include high-gross-vehicle-weight refuse collection applications, dump trucks, and concrete mixers, as well as specific target regional haul applications including, but not limited to, port drayage, less-than-truckload (LTL) commercial carriers, and utility truck applications.

Cummins has developed a new12-liter diesel engine to replace their current "M" series (10.8-liter) to serve this same market with diesel fuel. In this UTD project, researchers teamed with CWI to investigate the opportunities for developing a natural-gas version of the 12-liter engine.

Benefits / Market Implications

The U.S. commercial NGV market has been based predominantly on the following factors:

- Economics – low fuel prices and corresponding life-cycle cost advantages for fleets
- Emissions – lower levels of nitrogen oxides, noise, and greenhouse gases
- Energy Security – abundant domestic supplies of natural gas, reducing petroleum imports.

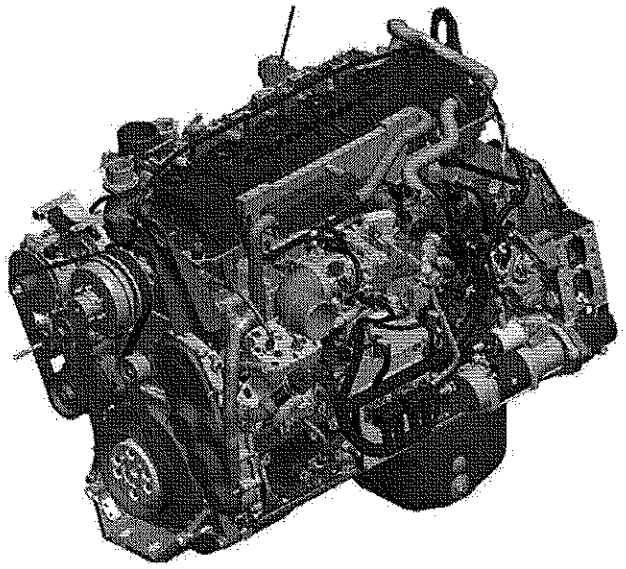
With this project, these factors will be maintained or enhanced to assist in NGV market expansion.

Fuel-cost savings enable significant lifecycle cost (LCC) advantages for NGVs vs. diesel-fueled vehicles in high-mileage applications with high fuel use. The majority of the target market applications require large displacement engines; therefore, a new 12-liter natural-gas engine is expected to provide significant LCC benefits to end users.

A factory-built offering which does not require burdensome after-treatment components provides an economical non-diesel solution and offers a significant market advantage.

Additionally, natural gas consumed as a transportation fuel provides environmental benefits vs. diesel fuel. Engine exhaust emissions of greenhouse gases from NGVs are approximately 20% lower when compared to conventional diesel fuel.

The product is also expected to provide fuel-efficiency improvements compared to other natural-gas engines in the market.



Isometric view of 12-liter natural gas engine.

Technical Concept & Approach

In recent years, CWI developed and commercialized high-performance, ultra-low-emission, natural-gas engines using stoichiometric combustion, cooled exhaust-gas recirculation, and simple, passive, three-way catalyst after-treatment technology.

The technology demonstrated diesel-like low-speed torque capability and transient response with CWI's 8.9-liter ISL-G engine. The technology is compatible with fuel stored on board the vehicle as compressed natural gas or liquefied natural gas, and has demonstrated compliance to U.S. Environmental Protection Agency (EPA) and California Air Resource Board (CARB) emission levels.

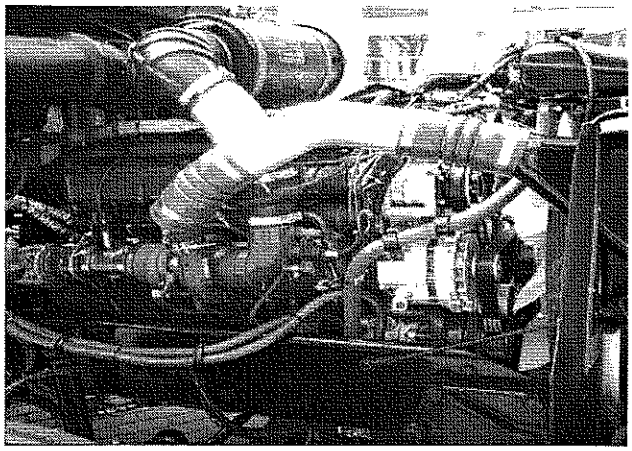
The principal objective of this project was to collaborate with CWI as the company attempts to secure government sponsorship needed to accelerate engine-development and demonstration activities. To that end, the research team and CWI developed responses to competitive grant solicitations for R&D from government agencies and other organizations. The project team also negotiated contract agreements and coordinated communications and reporting with sponsors on behalf of the CWI team.

Results

The project team and CWI prepared two proposals for phased development of the engine to the California Energy Commission's (CEC) Advanced Heavy-Duty Natural Gas Engine Research and Development Grant solicitation, resulting in awards totaling $2,777,634 in funding. The U.S. Department of Energy supported development of the engine. CWI spent more than $18 million of match funding.

A proposal was also prepared in response to the New York State Energy Research and Development Authority (NYSERDA) Program Opportunity Notices for Advanced Transportation Technologies and was selected for an award in 2009 for Phase 2 – Development and Demonstration. However, parties could not reach agreement on repayment terms and technology ownership rights.

In the Phase 1 project, the project team designed, demonstrated, and conducted preliminary development of an alpha-stage, 12-liter, heavy-duty dedicated natural gas engine, with emissions at or below EPA/CARB 2010 emission standards. The alpha engine built in the Cummins Jamestown Engine Plant demonstrated 400 HP, 1,350 lb-ft peak performance and has overcome several design challenges.



Pre-alpha ISX12 G engine installed in Kenworth T800 tractor.

In Phase 2, the ISX12 G engine was built and installed in more than a dozen heavy-duty trucks that went into demonstrations in 2011 and 2012. In 2013, a field-test fleet of more than 20 vehicles accumulated more than two million miles.

Field results aided the design team in making several improvements prior to the commercial launch of the product in August 2013.

CWI secured both EPA and CARB engine emission certifications on the engine.

Status

This project officially ended in 2013. A Final Report to the CEC was issued in March 2014. The report includes information on the completion of the engine build-out, validation testing, emissions certification, demonstration tests, and manufacturing readiness tasks leading to commercial launch of the 12-liter engine for the heavy-duty Class 8 truck market.

The new engine is now in full production at CWI. Through the end of 2013, CWI had manufactured more than 2,000 ISX12 G engines.

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UTD Utilization Technology Development

Evaluation of Natural-Gas-Based Electric Vehicle Charging Station Technology

An investigation was conducted to identify and review natural-gas technologies with the potential to serve the electric-vehicle-charging infrastructure. The goal is to develop an increased understanding of the best applications and economics with the use of a natural-gas-based off-grid charging system.

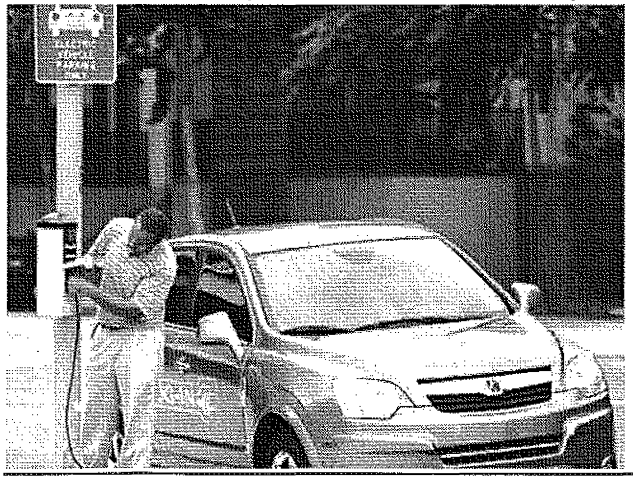
Project Description

Currently, there are more than 250 million registered vehicles in the U.S., consuming over $500 billion per year in fuel. Momentum, incentives, public policy, and public interest are favoring a shift to alternative fuels in the coming years.

In recent years, electric vehicles (EVs), comprised of both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), have become an emerging and growing market. It is estimated that there are currently less than 400,000 EVs of any type in the U.S.; however, by 2020 EVs could account for more than 60% of new light-duty-vehicle sales that require a highly distributed fueling infrastructure.

Experts note that the EV market needs a widespread high-voltage charging infrastructure to make EVs mainstream and to eliminate driver anxiety about limited range. If EVs become more commonplace, operators will desire charging options in convenient locations with reasonable charge times. Although primary electrical distribution systems are expected to be able to grow and meet the needs, distribution line transformers as well as secondary- and service-level systems will see significant impacts. The current electric delivery system in the U.S. is not capable of supporting a large volume of EVs charging during peak hours.

Distributed generation of power with natural gas offers the electric industry a potentially cost-effective and more environmentally friendly means of serving the new peak load represented by a developing EV charging infrastructure.



Current charging systems for EVs follow one of three "levels" of charging:

- Level 1 – Standard household 120 VAC, 15-20 amp requirement to provide a slow rate of charge (up to 12 hours for less than a 100 mile range)
- Level 2 – Based on 240 VAC, 40-80 amp requirement, increasing the charge rate and reducing charge times to 2-5 hours
- Level 3 – Also known as "rapid-charging," requiring 480 VAC or 400 VDC, 100-400 amps to charge a vehicle to 50% capacity or more in less than 10 minutes.

It is anticipated that a mix of the levels of charging will be needed as the EV population grows. The most desirable charging level, if available at an attractive price for the power, is a Level 3 charge made available at locations convenient to the vehicle's travels. Today's common concept of charging an EV at home will most likely be limited to the slow rate of charge from a Level 1 system because of the necessary upgrades to a residence for a dedicated higher voltage circuit. Instead, rapid-charge Level 3 systems will most likely be installed in commercial facilities such as shopping centers, rail depot parking lots, public-access stations, and along heavily traveled routes.

Preliminary analysis indicates that the systems for primary electric distribution to large geographical areas will initially see very little impact; however, the impacts to the secondary systems (transformers and services at the local level) are expected to be significant.

Although not the primary target market for EVs, select fleet applications using light- and medium-duty EVs may show attractive economics from centralized fueling from a natural-gas-fueled charging station system. This may show attractive economics from centralized fueling from a natural-gas-fueled charging station system. This may be made possible by combining the vehicle charging system with power generation for a portion of the fleet's building baseload electric needs.

Benefits / Market Implications

EVs are attracting a significant amount of attention and funding from the government and industry. If the EV market grows at a rate that challenges electric utilities in serving the charging infrastructure needs, then cost-effective and environmentally attractive alternatives to the conventional electric grid will be highly valued.

By investigating natural-gas-based technology options early in the growth period of the EV industry, the natural gas industry will be better positioned to consider their options in addressing customer needs.

Technical Concept & Approach

The goal of Phase 1 was to determine if there is a "winning proposition" for the natural gas industry in the development and promotion of a natural-gas-based technology solution for charging electric vehicles from a distributed generation infrastructure.

Specific tasks included:

- **Identification of Targeted Applications**
- **Investigation of Technology Options**
- **Cost/Benefit Analysis and Recommendations**

The conclusion of Phase 1 will provide a basis for considering further investigation or possible investment opportunities into a promising technological approach. Research quantifying and qualifying market potential will be incorporated into this phase of research.

Results

The research team completed an investigation of natural gas technologies plausible for the generation of electricity to charge EVs in a commercial and/or public infrastructure configuration.

Researchers found that several natural gas technologies appear to show promise of being competitive with respect to the cost per kWh produced, especially in light of depressed natural gas costs throughout the U.S. Significantly different treatment of electric rate structures for isolated electric loads of this type made the analysis difficult and it appears that the cost/benefit results will be locally and regionally specific because of this.

Fuel cell technologies were also investigated, but found to be impractical for this type of electric load.

The business case for investing in a charging infrastructure of this type plus the economics from the user's perspective were evaluated. Logistics surrounding the use of natural-gas-fueled generation equipment for EV charging were taken into consideration. A recommendation of applications of off-grid power production (i.e., private fleets, public rapid-charge stations, public Level 2 charging, commercial building level 1 or 2 charging, etc.) were proposed.

Researchers found that Level 3 charging is a feature that is not emphasized in current product offerings. Conversely, current EV engineering and design are based on residential charging with Level 1 and Level 2 capabilities. However, slow charging rates remain a consumer concern when choosing electric as an alternative-fueled vehicle.

The research team also investigated:

- The current EV infrastructure
- Opportunities for natural gas
- Technology options
- Charging economics.

A cost and benefit analysis was developed for the infrastructure provider's position as well as the user. Results were depicted showing simple payback periods over retail pricing of electricity.

A simplified cost and benefit analysis was completed to illustrate the feasibility of EV-charging systems installed at a location without 480 VAC service.

Status

Phase 1 of this project was completed in early 2014. A Final Report detailing project findings was submitted in early 2014.

Although Phase 1 of this study positively identified market opportunity and produced encouraging paybacks utilizing on-site generation to offset overall electrical power consumption, significant industry issues remain to be resolved in order to justify continued investigation of this type of installation. A full understanding of the EV market growth and economics are required to warrant full-scale testing and demonstration of the proposed system.

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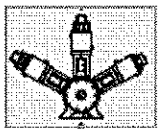
UTD Utilization Technology Development

Side-By-Side Station Evaluation of Compressor/ Booster Two-Bank Storage System

Researchers are evaluating the performance of a promising new approach to natural gas vehicle fueling systems in a side-by-side comparison to a conventional compressor/ storage arrangement at a public-access fueling station.



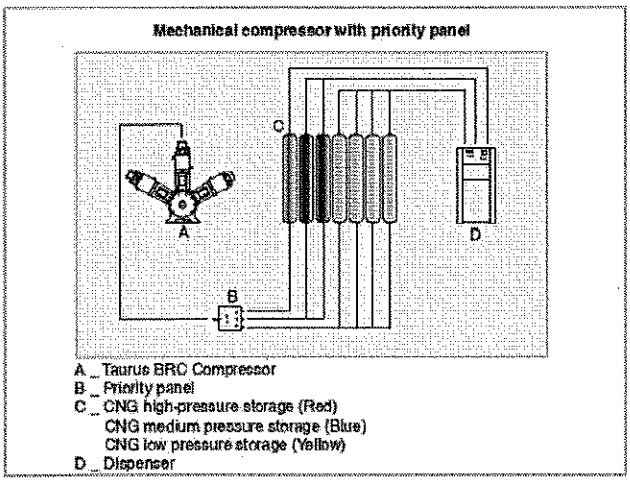
Project Description

By far the most prevalent method for fast-filling natural gas vehicles (NGVs) is to rely on pressure equalization between a large-capacity station storage vessel or vessels (relative to the vehicle's storage volume) and the vehicle being fueled. Dispensing equipment and controls then cascade the pressure equalization to occur between typically one of three storage banks based on flow rates or reduced-pressure differential. A three- or four-stage reciprocating compressor (depending on inlet natural gas pressure available) replenishes compressed natural gas (CNG) into the storage banks (see diagram below). The compressor will start and stop based on the pressure in the storage banks throughout the day.

There are several inefficiencies inherent to such an approach:

1. Approximately 65% of the gas compressed into the station storage banks is "stranded" and unusable to be dispensed into the vehicle
2. The compressor is always working against a discharge pressure equal to or greater than a predetermined "on" set point of approximately 3,000 psig, and
3. A very high station storage pressure level must strive to be achieved to accomplish a complete temperature-compensated full fill into vehicles.

This approach has become the standard strategy for most CNG station designs because the simplicity of the controls and gas management allow for use of "off-the-shelf" components and anticipated high reliability. When cost trade-off considerations are made between the typical strategy and options such as more banks of storage (four or more), using the same compressor to direct-fill the vehicle, rerouting of gas flow between the banks of storage, and other schemes, they are usually discarded because of a higher initial cost and unknown reliability.



Sophisticated dispensing control algorithms in use today can compensate for the heat of compression that warms the gas as it is charged into the vehicle's storage system. This thermodynamic effect can create 200 psig or more of pressure rise until the heat is dissipated by convection through the cylinder wall. Therefore, the pressure differential available between the station storage under hot ambient conditions is narrowed to a point that achieving a 100% temperature-compensated full fill becomes impossible under certain conditions if only pressure differential is used to "drive" gas into the vehicle. In addition, the ability for NGVs to consistently achieve complete temperature-compensated full fills in many warm-climate regions is hindered by the pressure rating limitations of commonly available storage vessels and the need to manage heat-of-compression thermodynamics which occur as cylinders are filled.

In this project, possible improvements to these issues are being addressed through an evaluation of a combination hydraulic booster-assisted compressor arrangement using a smaller-volume, two-bank buffer system and associated controls. The objective is to evaluate the performance of such a system in a side-by-side comparison to a recently installed conventional compressor/storage arrangement at a public-access CNG fueling station.

Benefits / Market Implications

Changes in fueling-station equipment and controls which can reduce the overall cost of operations, improve full-fill performance, and increase throughput without increasing capital cost would help expand the CNG fueling infrastructure in the U.S.

The anticipated savings to be demonstrated, documented, and quantified through this project will come from comparing the side-by-side operation of two CNG fueling stations of equal throughput capacity (approximately 125 gge per hour) under real-world operating conditions serving a public fueling station.

This evaluation will quantify: 1) the reduced station storage-vessel capacity needed, 2) reduced energy consumption on a per-gge-delivered basis, 3) reduced gas-management equipment and installation costs, and 4) improved fill times and full-fill performance.

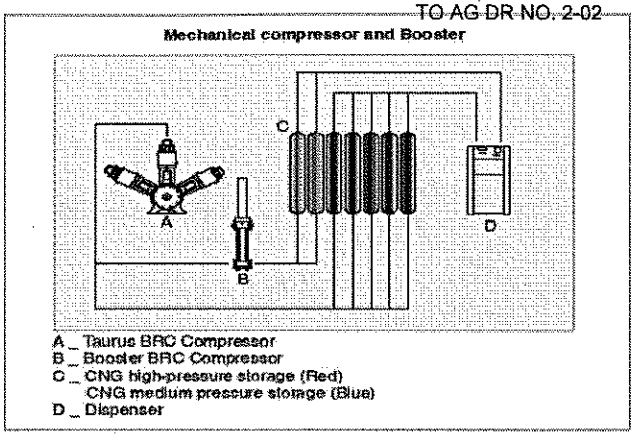
Technical Concept & Approach

Investigators identified an alternative approach to fueling NGVs with equipment manufactured by BRC Gas Equipment of Italy. The system makes use of a three-stage W-shape mechanical compressor that achieves an output of 2,300-3,000 psig and runs at a slower speed than the traditional U.S. compressors (1,200 rpm vs. 1,800 rpm).

The unit can make use of low inlet pressure (5-75 psig) by incorporating a double effect on the first stage when needed, or can take advantage of up to 1,000 psig inlet pressure with a single-acting first stage. This mechanical compressor is augmented by the use of a "booster," driven by a hydraulic pump unit, which achieves 4,500 psig. The booster is used for: 1) filling a high-pressure storage bank or 2) compressing the CNG from a medium-pressure storage bank (maintained filled by the mechanical compressor) to either high bank or to the vehicle. This approach provides energy savings and longer life cycle for the reciprocating compressor.

The overall station performance and ability to achieve full fills is improved because the booster is used to "drive" gas into the vehicle, hence eliminating the reliance on simply pressure differential to be created between a large volume of storage and the vehicle's storage system. This approach also improves fill times since low flow conditions that occur as differential pressures narrow are eliminated as the booster allows for a steady flow rate throughout the fill process. The 100% full fill regardless of ambient temperature is also achieved as a result of the booster drawing supply gas from the medium bank and compressing to the full temperature-compensated fill pressure determined by the dispenser controls.

For this project, a BRC system will be fully instrumented for data collection that can compare its performance to an identical-throughput-capacity conventional three-stage reciprocating-compressor system that uses a three-bank storage cascade. Data will be collected on the operation of both systems for up to a 12-month period. In addition, installation and equipment costs for the two systems will be evaluated along with the operating costs to provide a full-cycle cost-of-ownership comparison between the two approaches.



Results

The research team received the BRC compressor fueling station package from Italy in January of 2012. The unit was subsequently installed and commissioning occurred in the fall of 2012.

A test plan was developed to define the instrumentation and data-acquisition points required to properly capture performance and efficiency measures of the BRC CNG fueling station design against a conventional three-bank cascade-type fueling station. Mechanical tubing, valves, and safety features were installed to facilitate a wide variety of storage combinations and dispensing scenarios to be used in conjunction with the system. A data-acquisition hardware panel was installed in close proximity to the BRC compressor for testing purposes, which slightly delayed the data collection schedule.

Status

Over the past year, the unit was used as standby compression at a public-access CNG station in order to gain familiarity with its functions. In that time, a test stand was created and instrumentation was installed to collect performance data on the unit. Additional new data-collection hardware was installed to upgrade the laboratory's infrastructure.

Data collection is expected to be completed by the end of 2014 and results reported during the first quarter of 2015.

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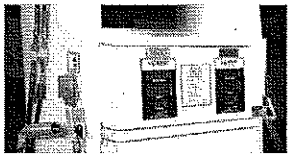
UTD
Utilization
Technology
Development

Design and Development of Time-Fill CNG Metering System and Controls

Time-fill operations for natural gas vehicles can provide significant savings; however, there is currently no cost-effective gas-measurement technique for time-fill facilities. In this project, efforts focus on the development of an affordable metering system designed for use in unattended time-fill compressed natural gas (CNG) feet vehicle applications.

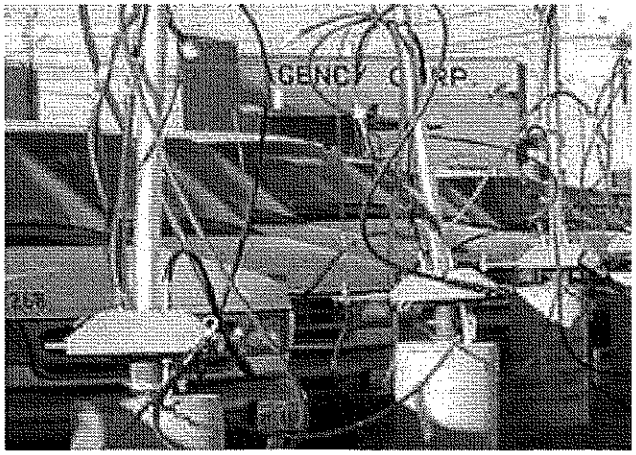


Project Description

The accurate and precise measurement of high-pressure compressed natural gas (CNG) is a necessary, yet expensive, requirement of any commercial sale of CNG. Federal, state, and sometimes local regulations dictate the accuracy tolerance of metering devices and strategies used to sell natural gas as a vehicle fuel.

Taxation and energy quantification rely on either Coriollis or sonic-nozzle technologies incorporated within the equipment used to dispense CNG into a vehicle at both a private or retail fueling station performing "fast-fill" operations. This technology is well understood and has been adopted by many dispenser manufacturers; however "time-fill" operations used by centrally-fueled fleet vehicles while unattended has relied on single-point metering of the inlet supply to the compression system directly fueling multiple vehicles at the same time. This approach does not provide a means for a station owner to determine how much fuel has gone into each vehicle, or to allow for the sale of fuel to others that may be conveniently able to share the facilities.

To address this issue, in this project a research team – in cooperation with ANGI Energy Systems, Inc. – is investigating a concept involving the use of a single metering device coupled with a control- and gas-management system capable of tracking and totalizing the fuel delivered to specific vehicles at the time-fill array.



The objective of this project is to design a cost-effective metering system for use in unattended CNG feet-vehicle applications. The goals of Phase 1 of the program are to develop the necessary control logic, test and select proper components, and verify the technical feasibility of the concept through prototype development and laboratory testing. Currently, the only means of obtaining this important data is through fast-fill metering technology.

Benefits / Market Implications

Expansion of the CNG fueling infrastructure in the United States has been hindered by high costs for fueling-station equipment and installation. Shared facilities with the ability to serve multiple users can improve the return on a station operators' investment in fueling facilities for its own fleet's use.

Fast-fill dispensers for CNG have been developed and commercialized for a wide range of vehicles and fueling conditions. However, the metering device used within these fast-fill dispensers is a significant component of the overall cost of a single- or double-hose dispenser. If multiple vehicles could be fueled through the shared use of a time-fill (6 to 10 hours) facility without the need for an expensive metering device on each supply fill hose, the convenience of unattended fueling could be accomplished cost effectively. Avoiding the need for fast-filling (3- to 5-minute) capabilities at a fueling station can save more than $100,000 from reduction and/or elimination of high-pressure CNG storage vessels and being able to exclude the cost of a fast-fill dispenser.

Time-fill station operators could provide fueling to other users parking at their facilities if a cost-effective means of achieving measurement of individual vehicle fuel dispensed could be achieved.

It is anticipated that a 20-hose metering system could sell for approximately $65,000 installed. The addition of more fill positions comes at a small incremental additional cost, yet each one will yield additional revenue. This investment is easily justified when a fast-fill

dispenser ($25,000 to $40,000) and high-pressure storage vessels (up to or in excess of $100,000) with gas-management control valves and auxiliaries can be replaced with a time-fill array at less cost.

The ability to add individual vehicle fuel use tracking and accounting for a centralized fleet operation's own private use can have an attractive payback as well. In addition, vehicle fuel use, mileage, hours of operation, and other data are critical for many fleet operators in order to optimize operations, minimize costs, and track fleet performance.

Technical Concept & Approach

The basic approach of this project to was to make use of a single commercially available high-pressure metering device (identical to those used in fast-fill dispensers) to meter flow-out to a time-fill array of fill hoses. By equipping each fill hose independently with a control isolation valve that can be actuated remotely from a control panel – and by developing control logic to track and totalize the flow directed to each hose exclusively in a sequential set of time periods – an accurate accounting of the amount of fuel delivered to each fill position can be made.

Challenges to achieving weights-and-measures-certified accuracies may require bulk custody transfer to take place at the outlet of the metering device, but a breakdown by vehicle can be provided for any required accounting purposes. Integration with fuel-management card-access systems will need to be investigated as well.

The performance requirements and specifications for each system component will be determined. Commercially available components are anticipated to be able to be used to achieve the performance desired for the final product. Select components will be tested to evaluate performance under the operating conditions required of the new application to metered time-fill prior to the development of a laboratory-scale prototype.

Results

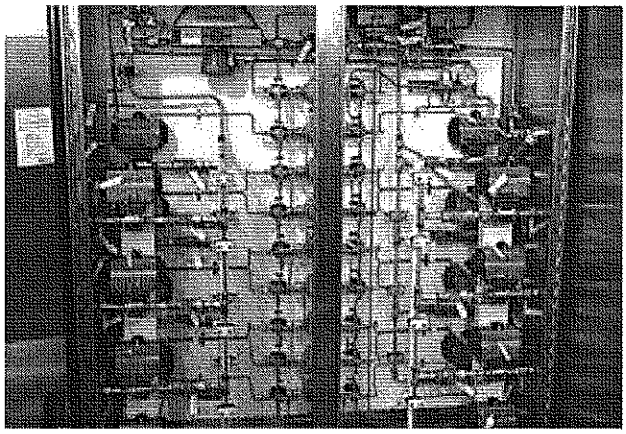
A system was designed and built making use of independent time-fill lines from a central valve distribution panel served by a single metering device. Although this design accomplishes the functional goals of the project, it has reinforced the fact that cost reduction for the key components needs to occur in order to have a cost-effective commercial product.

Investigation into commercially available components suitable for the proposed new approach resulted in the identification of valves capable of performing under the flow rates and pressures required. The valves were designed for CNG-dispenser applications and actuated by explosion-proof solenoids. These valves, in lieu of the gas-powered valves shown below, will reduce the cost of the overall system. Although valve testing showed poor sealing capabilities at small pressure differentials (less than 5 psig), the project team determined a method for overcoming this limitation.

The team developed a fueling protocol and approach to accomplish timed metered fuel dispensing. This protocol is unique in that it will allow a variety of vehicle sizes to be fueled from a single time fill station while capturing and accounting for the independent quantity accepted by each vehicle during the refueling period. A modeling tool was also developed and modified to evaluate the performance of the control logic. Through the modeling tool, the project team was able to identify shortcomings of the proposed fueling algorithm and adjusted the fueling strategy to mitigate any adverse effects to project objectives.

Status

While the project team still believes that the fueling methodology and associated algorithm presented above present a viable solution, activities on the methodology were delayed while researchers investigated another possible solution being proposed by others in the industry. In particular, a proposal using wireless pressure and temperature sensors in conjunction with radio frequency identification installed on vehicles using the time-fill station was considered.



The project team will continue to seek an opportunity in 2014 to cost-share further development and demonstration.

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UTD Utilization Technology Development

Truck-Trailer Integrated CNG Storage Design

In this project, investigators studied the feasibility of designing compressed natural gas (CNG) storage into the trailer structure of a typical tractor-trailer truck rig to provide more storage volume, increased driving range, and potential cost savings.

Project Description

The expansion of the natural gas vehicle (NGV) market into large U.S. DOT Class 8 tractor trailers represents a key opportunity for the natural gas industry and its customers over the next decade. Industry growth scenarios forecast a potential of more than 1 Tcf of natural gas demand with freight trucks, mainly driven by the substantial cost differential between natural gas and diesel fuel. Current prices indicate that a less than two-year payback is possible for these trucks that can log 80,000 to 120,000 miles per year.

Class 8 truck manufacturers such as Freightliner Trucks, Peterbilt, and Kenworth are bringing new tractor products to the market based on the latest NGV technologies for engines 12 liters and larger. In addition, a retrofit market is materializing for dual fuel (diesel/natural gas) engine technologies as they become available and demonstrate their ability to meet emissions certification. Tractor products are now available that have 80 to 155 diesel gallon equivalent (dge) of onboard compressed natural gas (CNG) storage. These can meet many regional delivery needs, but can benefit from extended range, particularly for the long-haul freight market segment.

In this project, researchers investigated the feasibility of designing CNG storage into the trailer structure of a typical tractor-trailer truck rig used in regional and long-haul applications.

Deliverables for this project include trailer-integrated CNG storage design concept(s) and economic feasibility results, presented in a report that includes recommendations for the next phase of the project.

Benefits / Market Implications

Benefits of the integrated-trailer storage design include a marked increase in storage-volume potential, increased driving range for long-haul truckers (over 1,000 mile range), ability to slow fill trailers as they are parked or being unloaded, reduced onboard tractor storage, and potential overall cost and weight savings if structural frame space and material could be substituted with integrated CNG storage.

Technical Concept & Approach

The objective of this project was to design concepts that can tightly integrate CNG storage into a Class 8 long-haul trailer.

The design intent explores two options: 1) an add-on to a current trailer and 2) a new design that incorporates CNG storage as structural members to reduce the weight of the traditional trailer frame. This latter concept includes an assessment of the benefits of a lightweight composite material for the trailer frame, building off composite truck bodies.

Specific tasks included:

- **Literature and Industry Review**

  Data was gathered on trailer counts and most common methods of utilization in less-than-truckload (LTL), regional distribution, and long-haul trucking applications. Researchers also examined how these designs are affected by industry standard practices of installing and designing fuel storage.

- **Design Concept Generation**

  This task includes the development of two designs: 1) a near-term design that could be implemented in a 1-2 year period and 2) a longer-term structurally integrated storage design where the CNG storage methods are providing structural load-carrying capability to offset the weight of a traditional trailer frame.

- **Cost Estimates and Feasibility Analysis**

  Researchers will develop a bill of materials and cost estimate. Feasibility may be impacted by current regulations, codes, and standards, which will be investigated.

Results

The literature and industry review was completed in 2014. Data was gathered on trailer counts, production forecasts, leading manufacturers, regulations, and other areas.

Key Findings:

- Approximately 250,000 trailers are produced per year in the U.S., with dry van, platform, and refrigerated being most common. The largest three manufacturers accounted for 54% of 2012 production.
- The user base of trailers in the U.S. is highly fragmented, and the wide variety of trucking and trailer operations discourages the use of trailers with dedicated features such as integrated CNG storage.
- Current U.S. regulations significantly restrict the attractiveness of the concept, especially when integrated into a trailer.
- Every person contacted emphasized the undesirability of adding weight to the trailer. A significant amount of trailers "weight out" during operations, with estimates varying from 30% of overall trucking to as high as 56% of private truck fleet operations. The incremental lost annual revenue by carrying additional weight of reserve fuel can quickly offset the incremental income of the trailer.
- Operators and users of trailers reported that there would be operational disadvantages to using specific trailers with on-board CNG storage, thus reducing operational flexibility and efficiencies.
- Trailers incur a significant amount of abuse, are in some cases serviced every 90 days, and have a long service life (approximately 12 years). Therefore reparability, robust design, and long-term durability are important considerations for users, and damage to natural gas containers in typical trailer service is likely to often occur.
- Operators and users of trailers tend to be slow to introduce new technologies, for a number of reasons. The private fleet operators identified in this study may constitute some of the largest concentrated users of trailers, and may be a good entrée point to introduce new technology.

Status

Design concepts are being generated, and their feasibility is being assessed. Cost estimates and feasibility assessments will be made for the leading design concepts.

This industry review portion of the project was completed in 2014. A Final Report is being prepared.

The report provides the following recommendations and conclusions:

- Interested parties may want to begin highlighting to federal officials that current U.S. regulations limit the amount (energy content) of natural gas that can be carried as reserve fuel in comparison to diesel fuel without becoming subject to restrictions.
- Interested parties may want to encourage the elimination of the federal requirement for natural gas to be stored in two (rather than one) containers when used as reserve fuel to substantially reduce this effective weight penalty vs. diesel.
- CNG tank manufacturers may want to offer a tank that is optimized to weigh 220 pounds when filled at 3,600 psi, and thus optimized for use as a reserve fuel tank on a trailer under current U.S. regulations. While widespread adoption of this practice may not occur due to the added weight, certain business operations such as line-haul truckload transfer of light dry goods may benefit.
- Natural gas (both CNG and LNG) as a fuel for transportation refrigeration units represent a unique application for natural gas in both combination tractor-trailers as well as on straight trucks. Some initial demonstration work was accomplished and the diesel engine suppliers to major U.S. OEMs appear to have already introduced some natural gas engines in their other product lines. Additional focus is merited on this application.
- Operational considerations for trailers indicate that the most attractive location to structurally integrate high-pressure or adsorbed natural gas vessels may be in the nose wall of the trailer, although significant operational concerns remain even in this scenario.

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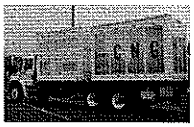
UTD
Utilization Technology Development

Ultimate CNG FuelMule Mobile Fueling Vehicle

A research team is evaluating the operation of a fully functional mobile CNG-fueling vehicle to determine performance, customer satisfaction, and economic feasibility. The concept is to provide a mobile fuel-delivery system as an alternative to a traditional fixed infrastructure.



Project Description

While many fleets and companies are interested in the prospect of natural gas vehicles, a significant number are unwilling or unable to invest in the required fueling infrastructure.

The concept for the FuelMule mobile fueling vehicle is to provide an alternative to a permanent fueling station by delivering and dispensing compressed natural gas (CNG) to fleets of vehicles.

There are many conventionally fueled vehicle fleets that currently rely on the delivery and dispensing of liquid fuels (gasoline and diesel) via tanker trucks. The FuelMule provides fleet operators the same flexibility.

The FuelMule can be a stepping stone towards the broader use of natural gas vehicles (NGVs). Amassing sufficient CNG demand to justify an investment in a fueling station is often hindered by the lack of a means of trial testing on a small number of vehicles. The FuelMule can allow a customer base to expand to the point that it would become easier to justify the construction of permanent stations given that there would be a greater existing demand supported by FuelMules.

For this project, researchers teamed with the FuelMule manufacturer (Ultimate CNG, LLC), Automotive Natural Gas Inc. (ANGI), and a truck equipment company to design and build the first prototype FuelMule.

The FuelMule's storage system contains approximately 650 diesel gallon equivalent (dge) and makes use of an onboard high-flow-rate compressor powered by the truck's natural gas engine to assist in filling fleet vehicles. Gas flow management designed into the FuelMule utilizes the onboard compressor to move gas throughout the storage array as well as to load the FuelMule when it returns to a source of supply. This novel approach allows the FuelMule to almost completely utilize the onboard storage volume by leaving very little stranded gas in the storage system. The system can provide full fills, as opposed to tube trailers that can never fully fill a vehicle and strand a significant portion of the gas onboard the storage trailer.

The FuelMule also requires no electric power source to run the compressor or controls, making it a totally self-contained fueling solution. The system can dispense 1,300-2,000 dge daily by returning to a central filling location between fleet visits.

FuelMule also has the flexibility of potentially being located where elevated delivery pressure from the local natural gas utility can used. Furthermore, permitting review and construction requirements are significantly reduced since the central refill site will consist of only an inlet gas dryer and connection for the FuelMule.

The refill site in some situations may contain trailer-mounted storage banks slow-filled to 3,250 psig by a stationary compressor. These storage banks will allow the FuelMule to more quickly refill the onboard storage using pressure equalization assisted by the onboard compressor to minimize turnaround time if needed.

The overall goal of this project is to determine performance, customer satisfaction, and economic feasibility.

Benefits / Market Implications

The FuelMule concept could significantly increase the number of NGVs on the road by eliminating the high cost of infrastructure and making CNG conveniently available to a fleet segment that otherwise would not have an economic fueling solution.

The FuelMule may also allow companies interested in testing the benefits of CNG-fueled vehicles to slowly transition to natural gas, thus easing the financial burden and making it more likely for companies to test and commit to NGVs. The FuelMule can act as the catalyst for expanded investments in permanent public-access fueling stations.

Technical Concept & Approach

This project includes measurement and monitoring measured activities to validate the safety, reliability, and economics of the FuelMule. Monitoring parameters include:

- The amount and quality of gas dispensed
- Vehicle fill pressures
- Fill efficiency (gas dispensed and gas loaded vs. energy consumed)
- Storage utilization
- Loading time, and
- Vehicle fill times.

Researchers are also studying the economic and utilization impact on the fleets that are fueled and the overall business case of using delivered fuel vs. station construction. The project team will also evaluate how many vehicles could potentially be fueled by a single FuelMule and a fleet of FuelMules once performance capabilities are determined.

Specific tasks include:

- Procurement and Installation of Data-Acquisition Equipment
- Data Collection Over a 12-Month Period
- Cost and Performance Analysis.

Results

Fabrication and shop testing of the FuelMule was completed in August 2012. Instrumentation was specified and incorporated onboard.

Data collection commenced with the first two deployments to fuel 12 shuttle buses for independent week-long demonstrations at the Republican and Democratic presidential national conventions in Tampa, FL, and Charlotte, NC, respectively.

"The FuelMule product has undergone several improvements in design for increased durability and reliability. The unit out-performed our expectations and we are very pleased with the growth of interest in the FuelMule and the services it can provide."

- Dennis Pick
CEO
Ultimate CNG, LLC

In addition, the data collection continued during demonstrations and deployments at:

- A refuse collection fleet in Houston, TX, to support the fueling of 36 refuse-collection trucks where 1,000 gallons per day (gpd) on average was dispensed for a continuous two-week period
- The City of Clearwater, FL, for the municipality to serve 300-700 gpd for nine weeks straight as a backup to their station until repairs were made
- A demonstration for AT&T in Atlanta where 52 vehicles received approximately 600 gallons at three different sites in one night
- Another refuse fleet was rescued in Chesapeake, VA, when the FuelMule fueled 15 refuse-collection trucks with 600 gpd for eight weeks in advance of the fleet's station receiving natural gas service

Status

The FuelMule continues to serve a variety of fleets and fueling station needs year-round.

Cost and performance analysis for the Final Report is under way.

The FuelMule product has undergone several improvements in design for increased durability and reliability. The unit has outperformed the expectations of Ultimate CNG and they are very pleased with the growth of interest in the FuelMule and the services it can provide.

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UTD Utilization Technology Development

NGV Fueling Appliance Prototype Testing and Evaluation

In this project, promising small-capacity natural-gas-vehicle home refueling appliances are being evaluated to determine their performance, safety factors, and suitability for use in the U.S. market in the near term.

Project Description

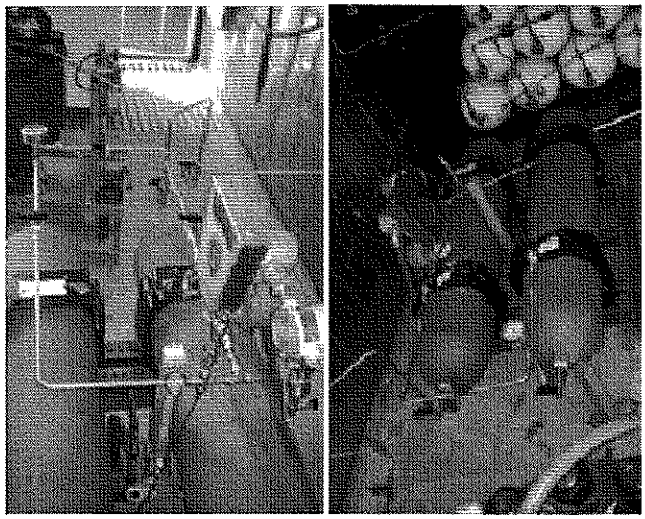
Expansion of light-duty natural gas vehicle (NGV) use could be widely advanced with the availability of a cost-effective, small-capacity fueling device suitable for residential and small-fleet use. To make a significant impact in expanded home fueling, such a device needs to provide worry-free, reliable, and safe performance backed by a stable support network for sales and service.

In another project (*NGV Home & Small Fleet Fueling Investigation*), UTD sponsored an evaluation and comparison of alternative small-capacity NGV fueling devices for residential and small fleet use. Approximately 35 products were identified as being marketed as home-fueling appliances and, of those, 23 were deemed to have sufficient data and applicability to warrant investigation.

Based on the analysis performed, it appears to be very difficult for any of the commercial production technologies to achieve a $1.00 per gallon gasoline equivalent (gge) life cycle cost of fueling (excluding the cost of natural gas, but including the installation cost and amortization of equipment and start-up costs) for a 0.5 gge per hour device. The study found that there appears to be a few non-domestic manufacturers that could bring product to the U.S. market quickly, but with little promise for cost savings to targeted levels. However, identified in this study were three technologies at or near prototype stage. Each of these is uniquely different from the conventional multi-stage reciprocating compression approach used by all of the others investigated. Further investigation is needed to determine if any of these can bring significant cost reduction potential to the small-scale refueling device marketplace. This project will help to answer this question and further advance the technologies while leveraging the investments already made and planned by these entrepreneurs.

The technologies are:

- An approach from New Gas Industries makes use of a single-stage, low-cost compressor (similar to the type in mass production for the residential HVAC market in compressing refrigerant). The single-stage compressor uses an array of several intermediate small buffer volumes with progressively higher pressure ratings. The single-stage compressor can then move gas through the system by redirecting the inlet and outlet of the single-stage compressor from one pressure plateau to the next. This concept was thermodynamically modeled under a previous UTD-funded project, resulting in guidance on power requirements and the dynamics of pressure swings in the system. New Gas Industries designed a multi-port gas valve to achieve the process flows in what appears to be a cost-effective manner, since the complexity and cost of multiple valves would most likely outweigh the savings from a low-cost compressor otherwise. A prototype was built for pressures up to 1,800 psig and is currently being expanded to 3,600 psig.
- GoNatural CNG and EcoFueler have prototype units in operation using a similar strategy, making use of a hydraulic oil pump to transfer energy to a slow-moving, double-acting, two- or three-stage piston/cylinder arrangement that compresses the natural gas on one side as hydraulic fluid moves a free-floating piston by applying force to the other side. The advantages to this technology for creating high-pressure gaseous flow are numerous. Long life durability has been demonstrated with this type of technology for other types of gases (air, nitrogen, hydrogen, etc.) because of the slow



Test chamber for assessing NGV home refueling performance.

speed and lack of mechanical linkage. Other advantages come from the more efficient relationship between power requirements and work performed compared to a reciprocating compressor using all of its stages even when the vehicle's storage pressure starts out at a much lower pressure than the compressor's capabilities. Gas quality and reduced risk of contamination are enhanced because of the separation between the process side and the working side of the piston/cylinder arrangement.

- HE System Technologies has developed a unique machine that eliminates all inter-stage tubing, cooling coils, relief valves, and numerous fittings by machining the gas passages into a monolithic block which has been bored to accept a radial arrangement of multiple cylinders per stage of compression. The compact design (material reduction) and ease of manufacturing present opportunities for cost reduction in this approach.

The objective of this new UTD project is to test and evaluate these small-capacity NGV Home Refueling Appliances (HRAs). Systems will be fully instrumented and tested in the laboratory to determine their performance and safety. Data and information will be shared with the product developers in an effort to assist in the advancement of their product to field demonstrations.

Benefits / Market Implications

The availability of a residential home-fueling and individual fleet-vehicle fueling device would provide a complement to the growing public fueling and private fleet fueling infrastructure.

The evaluations completed under this program are designed to help identify near-term opportunities to introduce a new HRA product into the North American marketplace that can improve on incumbent technologies today. The benefits to performing the testing and data collection are to determine if the critical technical issues have been resolved and if there are remaining product development needs. Furthermore, this study will ensure that meaningful and safe field demonstrations can be undertaken as a necessary next step.

Technical Concept & Approach

Investigators will perform the testing and evaluations using laboratory protocols already developed for previous projects. Units will be installed in the laboratory and connected to a variety of representative vehicle storage systems to test the performance of the units.

A primary purpose of the program is to evaluate the data collected and report on the suitability of the unit(s) for field demonstration, validate the manufacturer's claims, and make any recommendations for safety or functional improvements needed before unattended operation in a field demonstration. If deemed appropriate, units will be placed into extended-run applications to assess unit durability and reliability.

"This project has allowed us to accelerate the development and testing schedule for our NGV home refueling device. This help has been critical in placing us in a position to bring a certified product to market."

- Carl Guichard
Partner
New Gas Industries

Results

A test plan was developed and an internal hazard and operability study performed for the procedures to be followed during the laboratory preparation and HRA unit testing. A data-acquisition system and instrumentation necessary to capture the key operating parameters for the HRA tests were installed.

Initial testing was performed on the first of three compressor prototypes. The unit developed by New Gas Industries underwent preliminary testing to validate the gas flow and control schemes. Results were used to make component improvements. Additional testing and several demonstrations were conducted in cooperation with a potential commercialization partner.

The research team also supported GO Natural CNG with technical consultation and assistance in evaluating the cost of seeking component and unit certifications.

Status

The project team is preparing for the arrival of the third technology from HE System Technologies. The Final Report on the status of the three technologies supported under this project is expected to be completed early in 2015.

Phase 2 (focusing on assisting manufacturers with CSA certification and support) continues with participation in the development of CSA NGV 5.1 standards to facilitate the certification for HRAs in the U.S.

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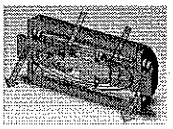
Free Piston Linear Motor Compressor

Research is under way to develop a motor compressor for home refueling appliances for natural gas vehicles. With only one moving part, the compressor has the potential to improve durability and efficiency while significantly decreasing costs of the overall system, installation costs, and maintenance.



Project Description

While low natural gas prices have driven an increased interest in natural gas vehicles (NGVs), the lack of a large infrastructure is still a significant barrier facing the widespread use of NGVs. A stepping stone towards the increased use of NGVs is the development of affordable and reliable residential fueling appliance (RFA) that allows commuters to fill up their vehicles at homes or other sites. The current state-of-the-art RFAs are considered by many to be too expensive and unreliable.

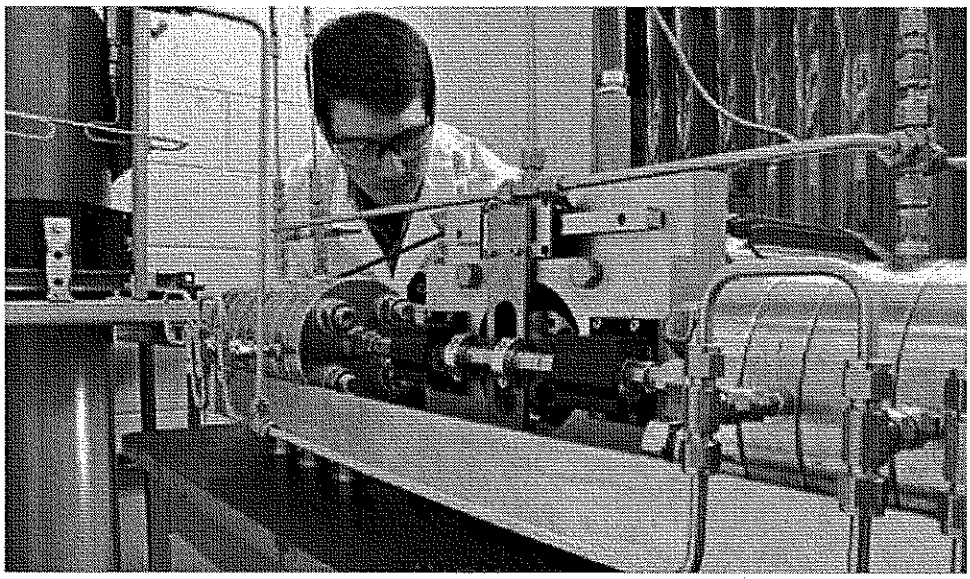
Existing natural gas RFAs are largely based on reciprocating-compressor technology, in which an electric motor drives a crankshaft tied to pistons in a multistage compressor. These units suffer from high manufacturing costs, high mechanical parasitic losses, relatively high maintenance costs, and short operational lifespans.

For this project, the University of Texas at Austin Center for Electromechanics (UT-CEM), Gas Technology Institute (GTI), and the Argonne National Laboratory (ANL) Tribology Group are partnering in a program to develop an inexpensive alternative to the technology used in current RFAs. Called a Free Piston Linear Motor Compressor (FPLMC), this compressor eliminates all but one moving part and will improve durability and compressor system efficiency while significantly decreasing costs of the overall system, installation costs, and maintenance.

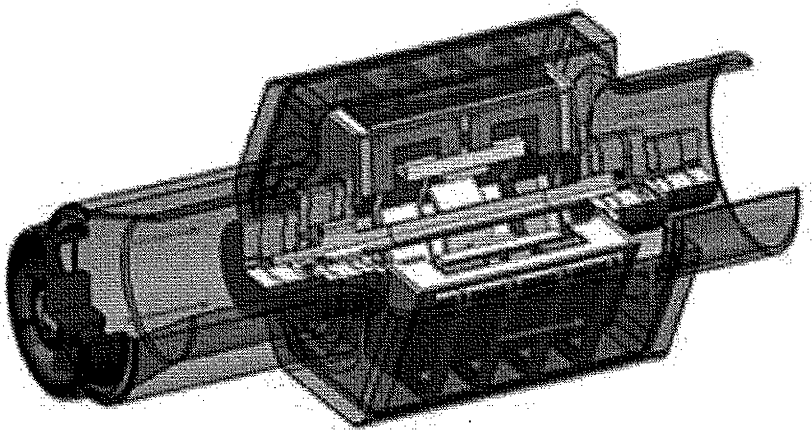
GTI, UT-CEM, and ANL will design, fabricate, and test an inexpensive alternative to the current RFA. The targets for the RFA are gas compression up to 3,600 psi at a flow rate of 2 SCFM, power consumption of less than 1.7 kW, a weight of less than 100 pounds, and a cost of less than $500. The final deliverable will be an operating compressor with a demonstrated life of at least 1,000 hours and ready for technology transfer to an OEM partner.

Benefits / Market Implications

The design of the FPLMC has the potential to significantly increase the life and reliability of small-scale compressors while simultaneously reducing the cost of manufacturing. This allows for the increased utilization of NGVs and may also result in an improved compressor design for use in other gas-compression applications.



Seal-component testing rig developed specially for the evaluation of materials and coatings.



Basic components of the compressor are shown, including the linear motor, armature and compression stages.

Technical Concept & Approach

The FPLMC concept includes a symmetric four-stage dual-acting free piston driven by a linear motor. The FPLMC uses multiple stages in which compression in a lower stage on one side feeds the inlet of the next higher stage on the opposite side. This approach uniquely combines the functions of the compressor and motor into one device with a single moving part, thus eliminating inefficiencies inherent in converting rotary motion into linear motion. The design results in fewer parts and wearing components, thus reducing parasitic friction and increasing creasing durability and reliability. The design also has the potential to ease manufacturing, reduce initial investment, lower maintenance needs, and reduce costs.

Phase 1 of the project included:

- The development of a preliminary design based on trade-off studies of the critical sub-assemblies of the linear motor compressor
- A detailed engineering analysis and design of the linear motor compressor, and
- A validation of the performance and life of critical components through benchscale tests.

In Phase 2, the team will fabricate and test compressor components, complete a fully assembled compressor, and demonstrate a field unit that is operated at an end user's facility. Two compressors will be constructed: one for life testing and one for field testing. Selected components for a third compressor will also be fabricated for spare parts during testing. A unit will be tested in a laboratory for more than 1,000 hours to prove durability and performance. The second unit will be paired with a balance of plant components to fill vehicles in a controlled time-fill setting

To bring the technology to market, the research team will identify potential third-party manufacturers.

Results

Phase 1 of the project was completed in 2013. Since then, the research team has been fabricating and testing individual system components such as the motor controller, valves, seals, and inter-stage cooling coils. These individual components have shown promising performance and durability, allowing the team to move forward with the prototype demonstration.

Status

The project team is fabricating the motor and compressor components, which are expected to be completed in September 2014. Following the fabrication, the team will independently test the motor and compressor before integrating them into the final unit.

The team is also preparing the test cell which will allow the compressor to be continuously tested in a closed loop 24 hours a day. The test cell is outfitted with pressure, temperature, and flow sensors that will record the performance and health of the system continuously. Testing of the fully integrated linear motor compressor is expected to begin in October 2014.

When the initial testing of the first unit is complete, the team plans on installing a second unit in an environmental chamber in order to test the compressor across a range of extreme environmental conditions.

Lastly, the team plans on filling actual vehicles using the FPLMC to demonstrate the real world performance.

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UTD Utilization Technology Development

CWI 6.7-Liter Medium-Duty Engine Development

This project focuses on a program with Cummins Westport Inc. and the California Energy Commission to develop and test a prototype ultra-low-emission, high-performance, 6.7-liter natural gas engine to enhance the opportunities to advance the natural gas vehicle market.

Project Description

Cummins Westport Inc. (CWI) is in the "alpha" development and prototype testing phases of its ISB6.7 G dedicated 6.7-liter natural gas engine. Researchers expect that the commercial availability of the ISB6.7 G engine will satisfy the OEM and end-user demand for natural gas vehicles throughout their product lines and operations. A wider range of engine size offerings will allow fleets to dedicate their operations to natural gas use and to fully take advantage of economies of scale throughout their operations.

A number of large truck fleets with diverse operations involving a variety of vehicle types (e.g., long haul and regional haul tractors, local pickup and delivery trucks, and yard tractors) have described to CWI their plans to transition entire operating depots and terminals from diesel fuel to natural gas when natural gas engines become available for all the vehicles operating at their fleet locations. While many truck fleets are starting to purchase Class 8 natural gas trucks due to the compelling fuel-cost-reduction opportunity, few are undertaking wholesale migrations of entire operating locations due to the continued need for diesel-powered vehicles in portions of their fleet and the proliferation of parts, training, service procedures, etc., entailed with supporting two fuel types at one location. The ISB6.7 G engine availability represents the final element of a comprehensive natural-gas-engine product line that is expected to encourage large truck fleets to commence wholesale migration of their operations to natural gas.

ISB6.7 G availability in a range of truck makes and models could accelerate natural gas adoption in other segments of the truck market. The 6.7-liter size engine is most applicable to Class 3 - 7 commercial vehicles such as school buses, package delivery box trucks, small dump trucks, etc. In certain cases such as yard tractors and rear-engine, transit-bus style Type D school buses, OEMs and end-users have elected to use larger engines, such as CWI's 8.9-liter ISL G engine in order to enable partial natural gas engine penetration. However, these vehicles are typically larger and more expensive than the vehicle models typically used in the Class 3 - 7 target markets, and as a result may not be cost effective for the majority of customers in the target markets. In the majority of cases, installing larger engines is simply not an option due to physical packaging constraints in the engine bays of the vehicles typically used in these applications.

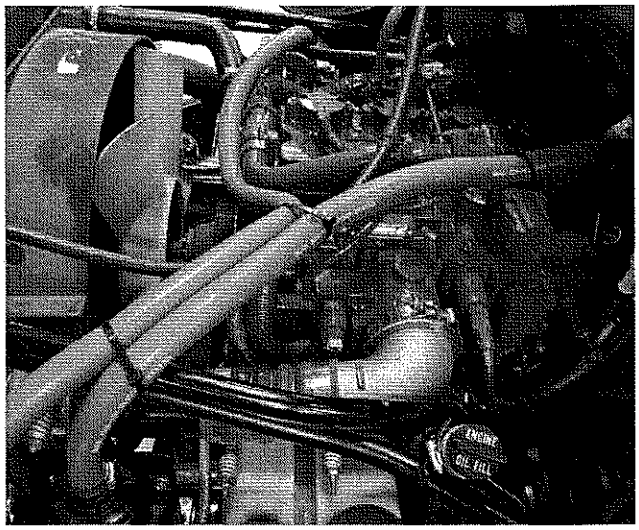
Supporting the project is the California Energy Commission (CEC). The first phase of the project is intended to lead to a subsequent product development with a targeted commercial release in 2016.

Benefits / Market Implications

Natural gas penetration into U.S. commercial vehicle markets has been based predominantly on the following three factors:

- Economics - low fuel prices and corresponding life-cycle cost advantages for fleets
- Emissions - lower NO_x, particulates, noise, and greenhouse gases
- Energy security - abundant, domestic supplies of natural gas, reducing petroleum imports.

These factors will be maintained or enhanced through this project, which will assist in expanding the NGV market. Fuel-cost savings, in conjunction with federal and state incentives to promote emission reductions



and energy security via petroleum displacement, have combined recently to enable significant life-cycle cost advantages for natural gas vehicles vs. gasoline/diesel-fueled vehicles in applications with high fuel use.

The ISB6.7 G engine will be certified with emission levels at or below EPA/CARB 2013 on-highway emission standards. In addition, the engine will also meet EPA 2017 emissions standards for greenhouse gases.

Having a factory-built offering that does not require burdensome after-treatment components and brings a favorable image of being a non-diesel solution will have a significant market advantage.

Engine exhaust emissions of greenhouse gases have shown reductions of approximately 20% when compared to conventional diesel fuel.

Technical Concept & Approach

For this project, CWI initiated alpha and beta engine development and testing stages to accelerate progress that that will lead to a product launch by 2016. Funds from CEC are being leveraged with UTD and CWI in-kind support

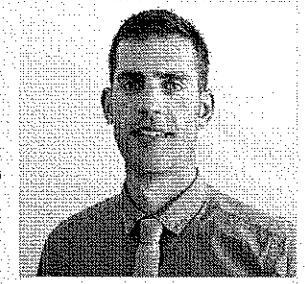
CWI plans to apply its stoichiometric, exhaust gas recirculation, three-way catalyst, spark ignition (SESI) technology to the Cummins ISB6.7 diesel engine platform. Concept development and demonstration are required to verify the feasibility of applying this technology to a 6.7-liter engine platform.

CWI's SESI technology has proven to achieve high-performance, ultra-low emissions, simplicity of vehicle packaging and maintenance, and provides significant fuel-cost savings as a dedicated natural gas engine. CWI's 8.9-liter ISL G engine with SESI technology is the leading natural gas engine in the North American commercial vehicle market, and the 2013 commercial release of CWI's 11.9-liter ISX12 G engine has performed well in field trials, accumulating over 1.5 million miles to date.

The need for a future phase to this program will be based on the level of success in the team's performance in completing the alpha engine design, build, and testing.

The overall project deliverable will be the completion of an alpha engine build and test, resulting in the design of the beta engine to be built in 2014. Ultimately, the project will result in the commercial launch by CWI of a medium-duty natural gas engine certified to the U.S. EPA/CARB 2013 emission standards.

"This most recent collaboration between Cummins Westport and UTD on the ISB6.7 G is a natural extension of the critical input provided on our previous engine development programs, most notably the 9-liter ISL G and the larger bore ISX12 G. Working with UTD on the ISB6.7 G rounds out natural-gas-engine offerings for Class 3-7 customers and advances dedicated natural-gas-engine technology further into the mainstream of on-road options."



- Stephen Ptucha
Director,
Product Management & Planning
Cummins Westport Inc.

Results

Recent accomplishments:

- Completed thermal cycle test without serious incidents.
- Successfully completed piston pin-joint robustness testing on two different piston pin designs. Results of the test verify pin bore geometry selection as well as piston pin surface treatment.
- Successfully installed pre-alpha engine into first engineering truck.
- Completed turbocharger thermal mapping. Data will be used as an input for overall verification and confirmation of the turbocharger design.
- Cylinder head cooling system concept studies were initiated.
- Successfully completed valve temperature testing. Data is being assessed by suppliers to provide a final recommendation for production valves and seat inserts. Testing will also verify the need for valve rotators.

Status

Currently CWI is on plan with the ISB6.7 G development schedule. Significant testing and analysis is being completed. In addition, major investment and effort is under way in the procurement of alpha-level hardware and in the "readiness" of the manufacturing location.

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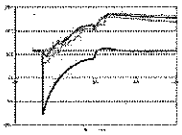
UTD Utilization Technology Development

Improvements in High-Volume Dispensing Performance

Through this project, researchers are focusing on issues with the under-filling performance of fast-fill CNG dispensers for natural gas vehicles. The goal is to demonstrate that there are methods for improving the means by which compensation for gas-density changes during the fueling process can be more accurately addressed.



Project Description

In the development of natural gas vehicles (NGVs), safely and accurately achieving a full fill in a compressed natural gas (CNG) vehicle has been a technical challenge when using a "fast-fill" dispenser.

Researchers report that dispensing systems have shown poor performance in achieving full fills into 3,600 psig-rated NGVs. Complaints of 15% to 20% under filling of vehicles is common and have been substantiated in field measurements. Historically, this shortcoming was tolerated by specifying more storage capacity than needed (in the case of transit buses and refuse trucks) or by lowering range expectations of medium- and light-duty vehicles.

In practice, in many cases the means of compensating for changes in density are addressed by slightly "over pressurizing" a cylinder (up to levels allowed by code) in an effort to have the "settled" pressure be near the proper fill level for the day's ambient conditions. While this approach has not been a significant obstacle for the safe and functional use of today's NGV dispensers, as vehicle on-board storage volumes become larger and more commonplace – and as range performance on medium- and heavy-duty vehicle becomes more critical for broader long-haul applications – achieving complete full fills is expected to become an increasingly more important issue.

The objective of this project is to assist the NGV industry in better understanding the reasons for, and potential ways for improving, under-filling performance of fast-fill CNG dispensers. Through participation in industry task forces, interpreting data, use of specific modeling tools and an environmental test chamber, and other industry efforts, the goal is to demonstrate that there are methods for improving the means by which compensation for gas-density changes during the fueling process can be more accurately addressed.

Benefits / Market Implications

Customer satisfaction with the operation of the NGV station and the consistent range traveled by the vehicles they fill can be significantly increased through the efforts of this project, the availability of modeling tools, and assistance with the integration of advanced control strategies into commercial dispenser products.

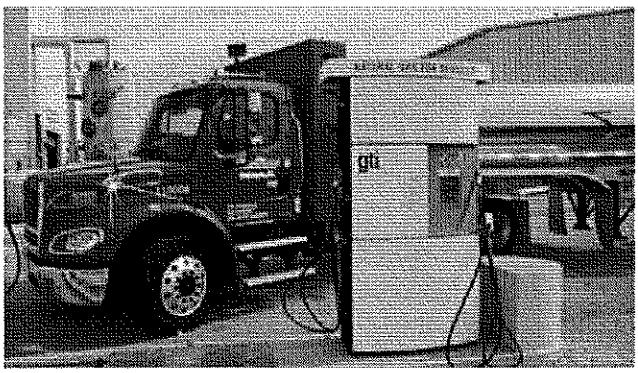
The availability of advanced tools will improve station design decisions and bring added confidence in the NGV industry's ability to deliver vehicles and fueling experiences comparable or superior to conventionally fueled vehicles.

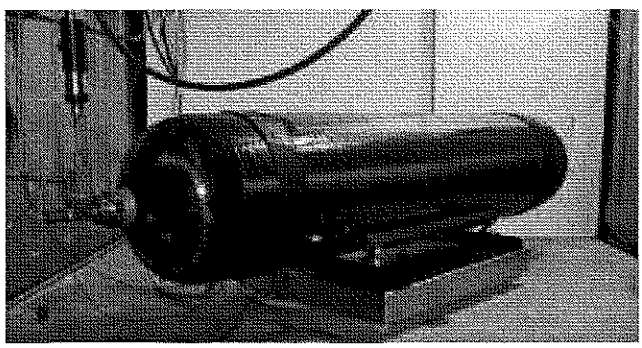
Technical Concept & Approach

This project focuses on:

- **Outreach and Participation with Industry Activities**

  Under this task, researchers will provide assistance to dispenser manufacturers, end users, station operators, and others requesting technical support and consultation.





- **Assistance with Tools and Modeling**

Roadblocks to implementing changes in the control program of a dispenser can be addressed with the use of modeling tools and data. Through this task, the research team will strive to educate those that could benefit from these tools. Researchers will be able to offer technical assistance and the use of the tools. In addition, outreach to inform dispenser manufacturers or potential new commercialization companies on the attributes of advanced algorithms to control their equipment will take place.

Results

An important first step in educating the industry was accomplished by coordinating a panel session on CNG performance issues at the NGV America annual conference in Atlanta, GA, in November 2013. A representative from the project team chaired the session and presented, along with ANGI Energy and Agility Fuel Systems, information on the challenges of achieving full fills on large-capacity vehicles being fast-filled.

Meetings were held independently with three dispenser manufacturers and offers for assistance were discussed.

Status

Options for improving dispenser performance are being investigated with three dispenser manufacturers through independent pathways. The best methods for the research team to support these manufacturers will continue to be refined.

Technical support scopes of work are anticipated to be agreed upon by the end of 2014 for testing, modeling, and consultation to produce methods for improved results early in 2015 with at least one of the partners.

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