STORM TECHNOLOGIES, INC.

Specialists in Combustion and Power

Service Report 24-33-01
EKPC – J.S. Cooper
Unit 2 Combustion Testing
Onsite: July 9 – July 12, 2024
Submitted: September 6, 2024

Storm Technologies
P.O. Box 429 411 N Depot St. Albemarle, NC 28002
Phone (704) 983-2040 Fax (704) 982-9657

STORM TECHNOLOGIES, INC
411 North Depot Street, PO Box 429 Albemarle, NC 28001
Phone: (704) 983-2040 • Fax: (704) 982-9657

September 6, 2024

Kevin Pinson
Eastern Kentucky Power Cooperative, Inc.
J.S. Cooper Station
670 Cooper Power Plant Rd.
Somerset, KY 42501
(606) 425-6583
Email: Kevin.Pinson@EKPC.coop

Subject: Service Report 24-33-01 Unit 1 Combustion Testing

Mr. Pinson,

Storm Technologies was recently onsite to evaluate the combustion and overall performance on Unit 2 at EKPC's J.S. Cooper Station. This included testing of the pulverizers and their fineness and the furnace through HVT, economizer outlet, and air heater outlet testing.

Similarly to Storm's testing of Unit 1, the fuel stream from the burners appears to be impacting the rear wall of the furnace. However, this was not as easy to confirm as inserting the HVT probe into the rear of the furnace resulted in the tip of the probe melting off and no reliable data being collected other than knowing it is excessively hot (>2,600^{O}F) and had areas of extreme CO (>6,000ppm) and the CO did not carry over to the economizer outlet significantly.

Leakage across the air heater was measured at an average of 7.27% across two tests. The recommended leakage for regenerative air heaters is 7-9%, so this heater appears to be in good condition with seals. The gas side efficiency was a little low at 59.5% and the X-Ratio was measured at 0.69. Overall, the PTC 4 based efficiency worksheet estimates Unit 2 boiler efficiency at 86.38%.

The Unit 2 mills all met Storm's recommended fineness passing 200-mesh, but almost all of them seemed to have excessive fuel remaining on a 50-mesh. Only Mill A fell outside recommendations for dirty air deviation, while Mills A, D, and F fell outside recommendations for fuel balance.

There was some concern with how PA was introduced to the mills, as at the top end for some of them the volume damper would continuously open while the measured airflow would go down. This may have something to do with the geometry of the duct, and it is recommended that a CFD model of the duct be completed with some possible adjustments (e.g.: turning vanes, baffles, etc.).

The following report further details Storm's testing during this visit as well as what Storm recommends moving forward to further improve the performance and reliability of Unit 2 at J.S. Cooper Station. It was a sincere pleasure working with you and the rest of the team at Cooper, again, and we look forward to continuing that relationship in the future.

Respectfully Submitted,

Scott Andrew Russell
Project Manager
Storm Technologies, Inc.

Executive Summary

Storm Technologies was recently contracted to perform a combustion evaluation of Unit 2 at EKPC's J.S. Cooper Station. Unit 2 is a B&W wall fired boiler with six four-pipe pulverizers. The burners were upgraded to B&W DRB-XCL Low NO_X burners, though there was no OFA included in the upgrade. The unit uses Eastern Kentucky Bituminous Fuel. The pulverizers are EL-76 model mills with a 3-phase 60Hz motor rated for 350 HP at 61.5 Amps and 4,000 volts and a service factor of 1.15.

Mill testing was accomplished first on all six pulverizers. Dirty air distribution was within Storm's recommended ±5% deviation for all mills except Mill A. The recommended deviation of ±10% for fuel flow was measured on half of the mills with Mills A, D, and F falling outside of this standard. Fineness was greater than Storm's recommended 75% passing a 200-mesh sieve on all the mills, but only Mill E met the standard of 0.1% remaining on a 50-mesh sieve with the other mills as high as 0.8%.

The average fuel pipe velocity measured was 4,341 fpm, though this value deviated from 4,542 fpm to 5,421 fpm. The primary air (PA), in general, did not seem to behave normally. The mills were tested at between 38 and 40 klbs/hr of fuel flow. This is the top end of where they would ever run but was based on communication from the Operations Team that the PA was insufficient at the upper end, shown by the mill loading up and unloading fuel in waves and the amps spiking. Storm found this to be true and tried quite a few methods of working the mill to the higher load points in ways to maintain the PA setpoint. It doesn't appear to be based on the accuracy of indication, installed curves, or damper feedback. It seems to be the geometry of the ducting, as for many of the mills opening the PA damper results in lower PA when allowed to settle past 35 klbs/hr. This was especially prevalent in the middle mills, which supports the theory that duct geometry is the cause. For Mill C, the issue with insufficient PA was so great that the mill could not be reasonably stabilized for testing beyond 33 klbs/hr of fuel flow.

Furnace HVT testing was attempted very near the nose arch on the back wall of the furnace through the only port not obstructed. The temperatures through the port shot up suddenly to above 2,600°F and melted the radiation shield and thermocouple of the probe. The O_2 measured during this averaged 2.82% and there was an average of 3,241 ppm of CO with spikes above 6,000 ppm.

The economizer outlet didn't mimic the furnace's poor combustion conditions with an average O_2 of 3.9% and an average CO of 13 ppm across two tests. This may suggest that, similarly to what was found on Unit 1, the fuel streams from the burners are impacting the rear of the furnace. Either way, the burners were adjusted slightly between the two tests resulting in an improved average CO of 8 ppm from 18 ppm at the economizer outlet.

The air heater (APH) outlet was tested twice, as well, and showed an average O_2 of 5.17% and 8.5 ppm CO. Using the data across the air heater, an average leakage of 7.27% was calculated along with a gas side efficiency of 59.5% and an X-Ratio of 0.69. Including the ultimate analysis and calculations/values found in the ASME PTC 4, an overall boiler efficiency of 86.38% was calculated.

It's strongly recommended that a CFD analysis of the PA duct be completed to evaluate the flow of air within the geometry of the duct. Furthermore, as a long-term solution to the high CO in the rear of the furnace and to help with NO_X production, a Fan Boosted Overfire Air system is recommended for installation on the unit.

The following report contains detailed analysis of the test results obtained during this visit along with short-term and long-term goals for achieving combustion optimization on Unit 2 at J.S. Cooper.

Pulverizer Performance Testing

Storm Technologies accomplishes pulverizer performance testing through a combination of ‘dirty air’ testing, isokinetic fuel sampling, and fuel fineness testing. Dirty air testing is the measurement of fuel laden mass airflow through each individual fuel conduit. This test assists in confirming desirable balance of air between fuel lines. Furthermore, this test allows for the velocity of the fuel-air mixture to be measured within the test plane, which is valuable data for unit performance and is used to perform isokinetic sampling of the fuel.

The Storm Team samples fuel lines isokinetically, as explained in Figure 1. To accomplish this, Storm measures the velocity pressure through each of the fuel lines to calculate the fuel sampling rate. Using an aspirating assembly (also shown in Figure 1) fabricated by Storm, the average velocity measured within the fuel line is matched during the sampling process and thus the sampling is isokinetic.

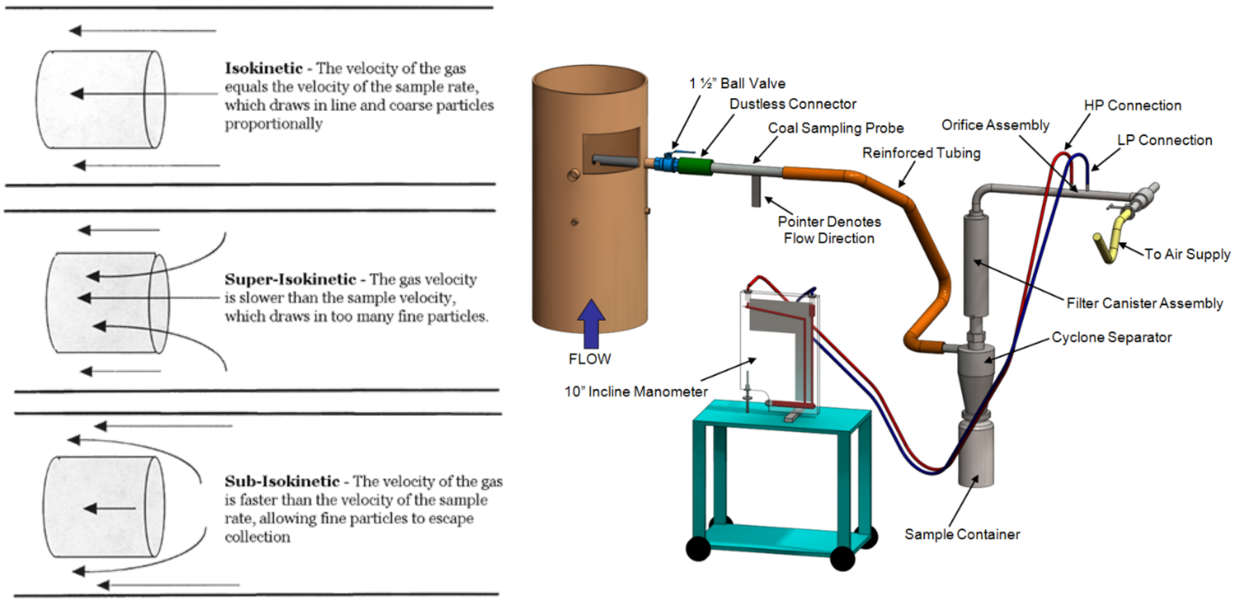


Figure 1: Conditions and Equipment for Isokinetic Fuel Sampling

Storm Technologies recommends a strict standard of ±5% deviation from the mean for dirty air results from the individual fuel lines of each mill. The recommended deviation of fuel flow from the mean is ±10%. These standards may seem stringent, but adherence results in an efficient and optimized distribution of fuel and PA to the individual burners which is a huge step forward in balanced combustion, and overall unit performance.

After sampling the fuel from the mills, Storm personnel evaluate its fineness through the sieve method described in ASTM D197-87. Achieving consistent and optimized fineness is paramount in supporting efficient combustion with carbon completely consumed within the combustion zone of the furnace, reducing environments eliminated, and instances of slagging and fouling reduced. As means to this end; Storm recommends a fineness of 75% passing 200-mesh and 99.9% passing 50-mesh, this fineness equates to an average particle size of around 55 µm.

The six Unit 2 Mills at J.S. Cooper Station were tested in the above manner. The measured dirty air balance was within Storm's standards except for Mill A, as can be seen in Figure 2. Mill A had a low pipe (Pipe 1) at -13.03% and a high pipe (Pipe 3) at 8.61% deviation from the mean.

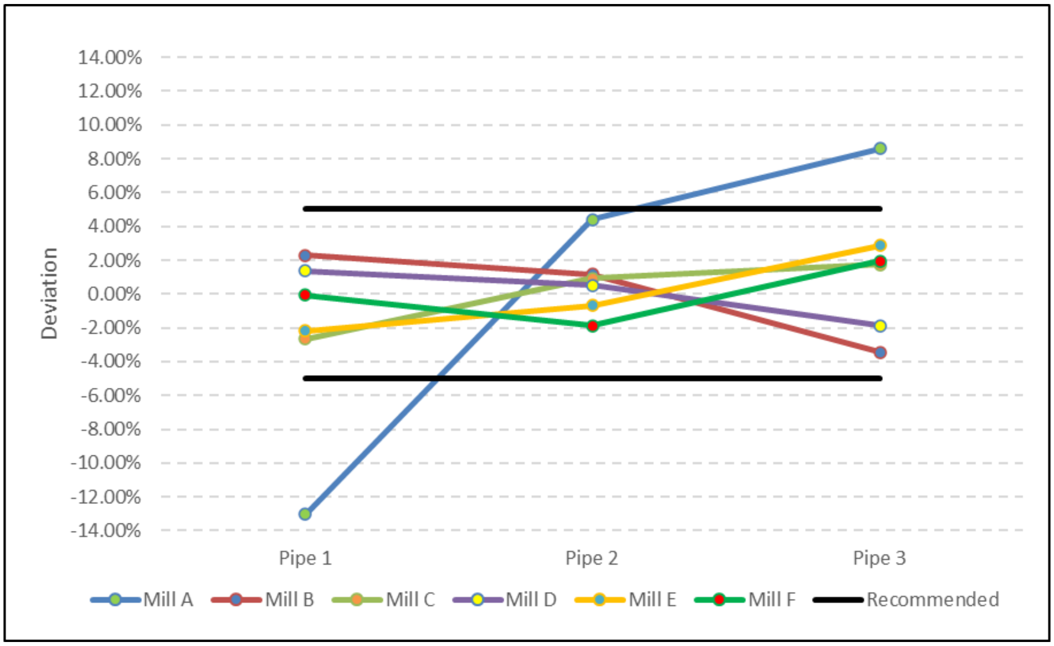


Figure 2: Unit 2 Dirty Air Balance

The fuel balance was within standards for three of the mills while Mills A and F fell extremely outside them with Mill A Pipe 2 at 42.99% and Pipe 3 at -46.7% while on Mill F there was Pipe 1 at 23.7% and Pipe 2 at -28.25%. A graphical representation of the fuel flow balance is shown in the figure below.

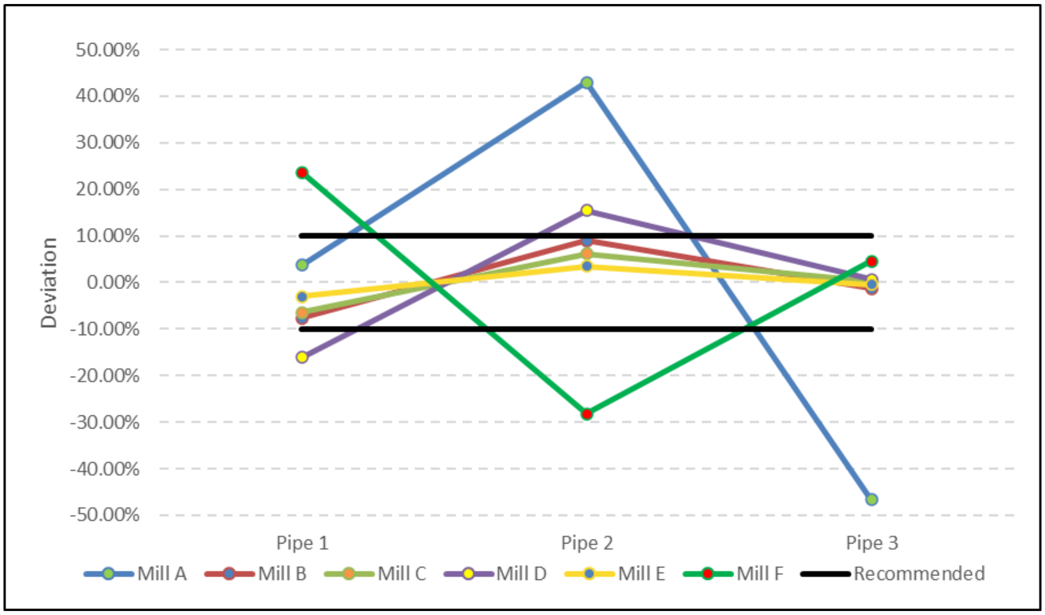
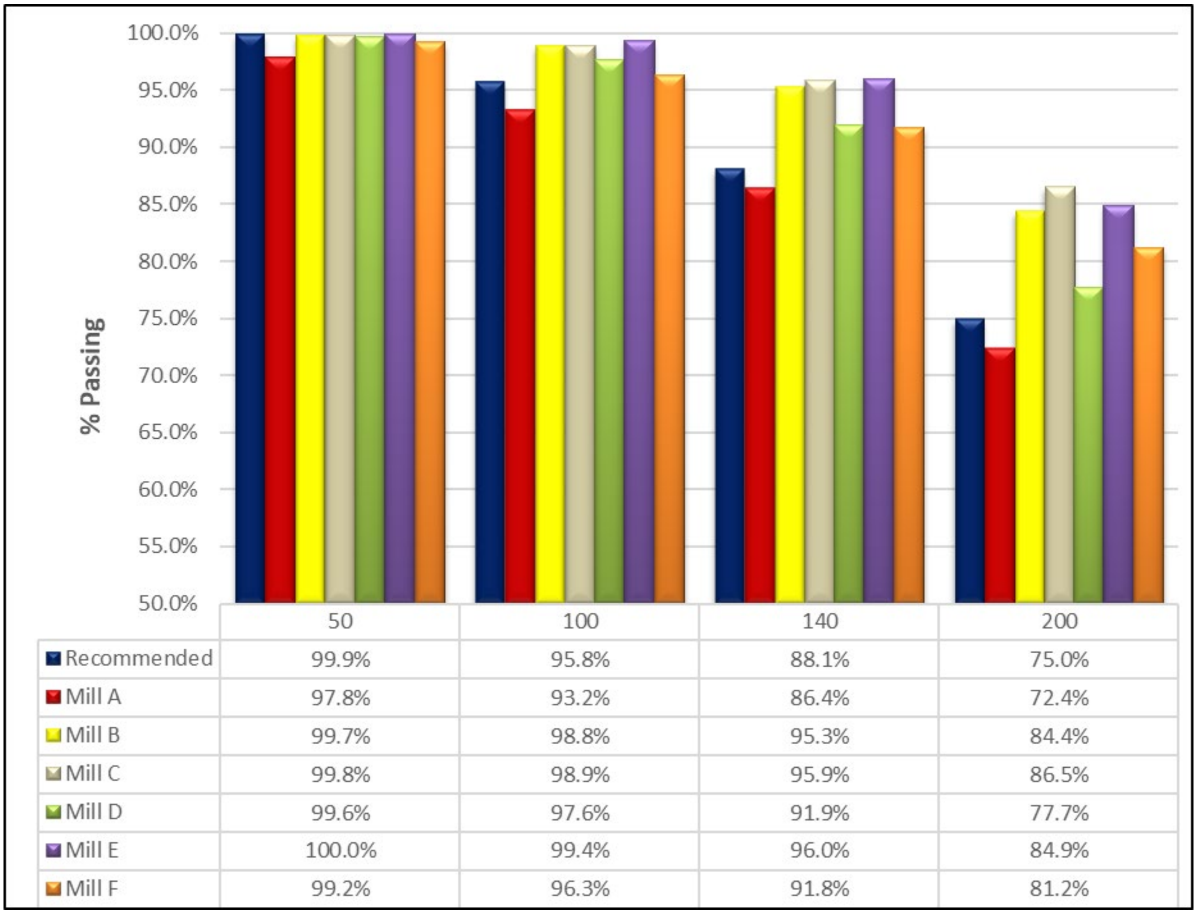


Figure 3: Unit 2 Fuel Flow Balance

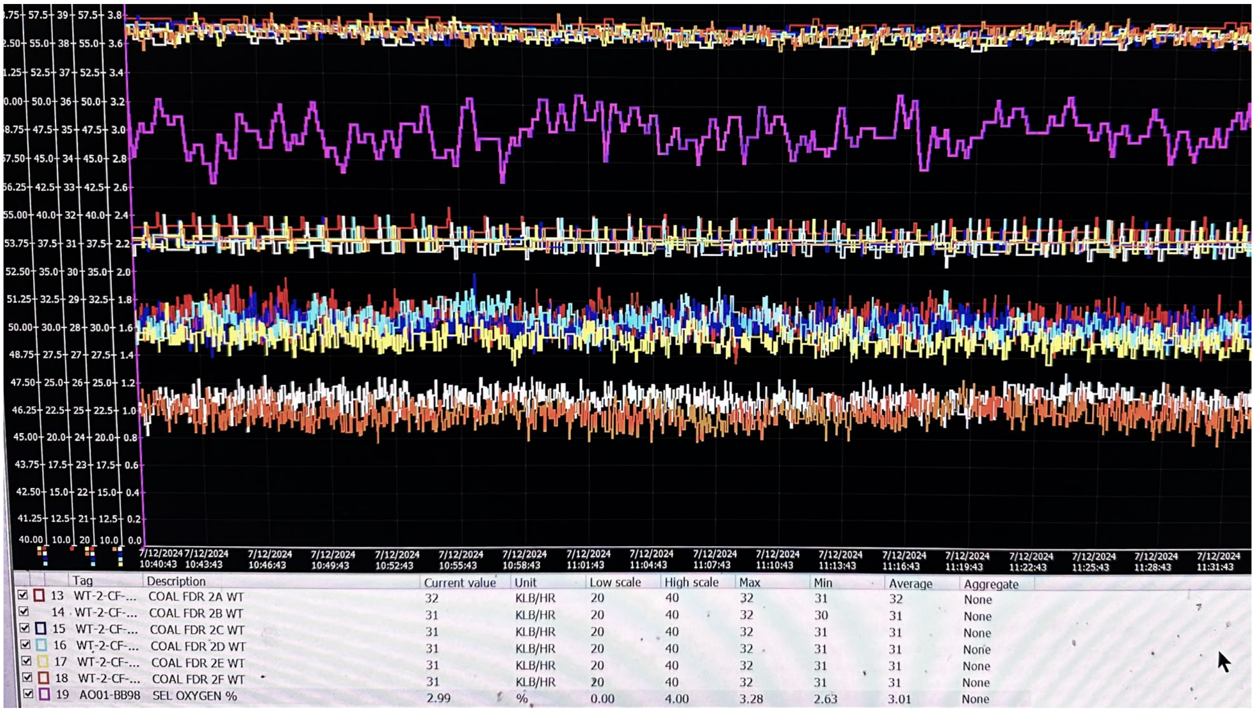
The samples of fuel obtained during testing were sieved onsite to obtain the fineness measurements displayed in Figure 4. All the mills except Mill A exceeded Storm's standards for fineness passing a 200-mesh sieve. However, only Mill E met that standard for fuel remaining on a 50-mesh sieve. The poorest in that metric was also Mill A with 2.2% remaining on a 50-mesh sieve.



	50	100	140	200
Recommended	99.9%	95.8%	88.1%	75.0%
Mill A	97.8%	93.2%	86.4%	72.4%
Mill B	99.7%	98.8%	95.3%	84.4%
Mill C	99.8%	98.9%	95.9%	86.5%
Mill D	99.6%	97.6%	91.9%	77.7%
Mill E	100.0%	99.4%	96.0%	84.9%
Mill F	99.2%	96.3%	91.8%	81.2%

Figure 4: Unit 2 Fuel Fineness

The test locations could have influenced some of the results with roping and non-laminar flow, especially given that the worst performing mills with regards to dirty, and fuel balance were the bottom two (A and F) where the test ports were right at the burner. Beyond that, some of the tests may have been influenced by the loading and sudden unloading of the mills expressed by the Operations Team as a consistent struggle in operation of them at the upper end. This appeared to be happening given other observation methods, as well. The trend below shows some performance characteristics over more than an hour of time. The pink trendline shows the furnace O_2, which was reported as swinging significantly when the mills amp up and seem to be loading and unloading. The group of lines at the top of the trend are the Bowl DPs, while the group immediately under the O_2 are Mill Amps. The bottom group is feeder speeds, with Mills B and F being biased down due to excessive mill motor amperage. The color scheme, shown in the legend, is Mill A – Red, Mill B – White, Mill C – Blue, Mill D – Cyan, Mill E – Yellow, and Mill F – Orange.



	Tag	Description	Current value	Unit	Low scale	High scale	Max	Min	Average	Aggregate
☑ ☐ 13	WT-2-CF-...	COAL FDR 2A WT	32	KLB/HR	20	40	32	31	32	None
☑ 14	WT-2-CF-...	COAL FDR 2B WT	31	KLB/HR	20	40	32	30	31	None
☑ ☐ 15	WT-2-CF-...	COAL FDR 2C WT	31	KLB/HR	20	40	32	31	31	None
☑ ☐ 16	WT-2-CF-...	COAL FDR 2D WT	31	KLB/HR	20	40	32	31	31	None
☑ ☐ 17	WT-2-CF-...	COAL FDR 2E WT	31	KLB/HR	20	40	32	31	31	None
☑ ☐ 18	WT-2-CF-...	COAL FDR 2F WT	31	KLB/HR	20	40	32	31	31	None
☑ ☐ 19	AO01-BB98	SEL OXYGEN %	2.99	%	0.00	4.00	3.28	2.63	3.01	None

Figure 5: Trend of Mill Performance Variables (Feeders, Amps, Bowl Dp) and O_2

The measured values, in aggregate, also seemed to indicate some issues with the mills loading up, or the feeders requiring calibration. It was communicated to Storm that the mill feeders are regularly calibrated but, as can be seen in the table below, only Mill F was not measured to have more fuel flow than indicated. Given moisture in the fuel, with a perfectly calibrated feeder, Storm would expect to measure around 10-15% less fuel in the lines than indicated at the feeder. As a result of this, the Air-to-Fuel Ratios were especially low with Mill A at only 1.2 measured and Mills C, D, and E at 1.46, 1.41, and 1.31 respectively. Interestingly, the mill outlet temperatures, line velocities, and rejects were still performing decently, which works against the idea that the mills are loading and unloading. However, the O_2 swings, variable throttle pressures, spiking mill amps and bowl ΔPs suggest this is happening. And the cause appears to potentially be impacted by how the primary air is being fed into the mills.

The issue with the PA supply was very closely monitored over the course of two days for the testing of Mill C, and the mill was ultimately tested at only 33 klbs/hr fuel feed rate (compared to 38-40 klbs/hr on the other mills) because that was the only place it could meet its own PA setpoint. And this was even with a five-mill configuration at 200 MW gross, meaning there should have been more than enough air available in the system. The mill appeared to begin loading up as low as 34 klbs/hr. Strangely, when the mill was raised to 36 klbs/hr, the air could not stay above 60 klbs/hr. The PA damper crept open (way too slowly) towards 100% while the airflow dropped as low as 58 klbs/hr, but the mill was adjusted back to 33 klbs/hr, the air jumped up to 65 klbs/hr. The damper response is very slow, but it moved from 70% to 50% over the course of about ten minutes without the airflow reducing at all. It's almost like once the mill is above 32 klbs feed rate, the damper can't really control the airflow.

Table 1: Indicated, Calculated, and Measured Values of Unit 2 Mill Testing

Control Indications		Mill A	Mill B	Mill C	Mill D	Mill E	Mill F
Date	mm/dd/yyyy	7/10/2024	7/9/2024	7/11/2024	7/10/2024	7/9/2024	7/10/2024
Coal Flow	klb/hr	40.0	38.5	33.0	38.5	36.0	40.0
PA Flow	lb/hr	68.1	62.0	60.7	68.1	61.7	71.3
Amps	A	50.5	51.0	51.0	54.0	53.0	48.5
PA Bias	%	0.0	0.0	0.0	0.0	0.0	0.0
PA Damper	%	85	103	49	35	56	48
Hot Air Damper	%	56	54	52	48	63	61
Hot Air Temp	°F	626	490	600	623	490	632
Cold Air Damper	%	44	46	48	52	37	39
Cold Air Temp	°F	85	83	85	90	87	83
Pulv. Outlet Temp	°F	155	155	155	156	156	155

Measured Values		Mill A	Mill B	Mill C	Mill D	Mill E	Mill F
Total Pulv. Air Flow:	lbs./hr	71,602	72,028	65,762	69,509	72,515	78,532
Total Pulverizer Fuel:	lbs./hr	59,460	44,013	45,121	49,460	55,245	35,111
Pulv. Air to Fuel Ratio:	# Air/# Coal	1.20	1.64	1.46	1.41	1.31	2.24
Avg. Pipe Velocity:	fpm	4,955	4,941	4,542	4,789	4,996	5,421
Avg. Pipe Air Flow	lbs./hr	23,867	24,009	21,921	23,170	24,172	26,177
Avg. Pipe Fuel Flow:	lbs./hr	19,820	14,671	15,040	16,487	18,415	11,704
Average Pipe Temp.:	°F	154	154	154	154	154	154

% Difference (Fuel Flow)	%	48.65%	14.32%	36.73%	28.47%	53.46%	-12.22%

Dirty Air Balance		Mill A	Mill B	Mill C	Mill D	Mill E	Mill F	Goal
Pipe 1	% Mean Dev.	-13.03%	2.28%	-2.67%	1.35%	-2.20%	-0.07%	±5.0%
Pipe 2	% Mean Dev.	4.42%	1.17%	0.93%	0.52%	-0.67%	-1.88%	
Pipe 3	% Mean Dev.	8.61%	-3.45%	1.74%	-1.87%	2.87%	1.95%	
Fuel Balance		**Mill A**	**Mill B**	**Mill C**	**Mill D**	**Mill E**	**Mill F**	**Goal**
Pipe 1	% Mean Dev.	3.71%	-7.65%	-6.42%	-16.11%	-3.02%	23.70%	±10.0%
Pipe 2	% Mean Dev.	42.99%	9.01%	6.18%	15.46%	3.49%	-28.25%	
Pipe 3	% Mean Dev.	-46.70%	-1.36%	0.23%	0.65%	-0.47%	4.55%	
Coal Fineness (Weighted Avg.)		**Mill A**	**Mill B**	**Mill C**	**Mill D**	**Mill E**	**Mill F**	**Goal**
Passing 50 Mesh	%	97.83	99.74	99.79	99.63	99.96	99.20	99.90
Remaining On 50 Mesh	%	2.17	0.26	0.21	0.37	0.04	0.80	0.10
Passing 100 Mesh	%	93.20	98.84	98.88	97.64	99.40	96.32	95.75
Passing 140 Mesh	%	86.38	95.28	95.87	91.95	96.03	91.76	88.13
Passing 200 Mesh	%	72.37	84.42	86.47	77.67	84.89	81.23	75.00

The prevailing theory from the Plant Team as to why these mills behave so strangely at the upper load points is the geometry of the common duct that feeds PA into the mills. It was communicated that there are no turning vanes or internal components to guide the air into the mills and it appears like the middle mills on the duct struggle the most to get air. This could be evaluated with CFD modeling, and if it appears to be true, possible solutions could be modeled, as well. Aside from that, it's recommended that Storm be invited onsite during an outage to assist in the inspections of the mills as well as the duct to ensure there is no unknown variable contributing to these performance abnormalities.

Furnace and Economizer Outlet Testing

When given the opportunity, Storm Technologies performs High Velocity Thermocouple (HVT) testing to assess combustion efficiency directly. This test is accomplished by inserting a water-cooled gas sampling probe and traversing directly across the furnace above the combustion zone around the nose arch elevation of the boiler. An aspirator on the probe pulls gas from the furnace at a high velocity across the tip of a thermocouple which is protected by a stainless-steel radiation shield. This provides for a true furnace exit gas temperature measurement. After temperature across the plane has been accurately measured, the aspirating assembly is cut off and a small pump pulls gas samples from the furnace into a portable gas analyzer that is designed to quantify values of carbon monoxide (CO), nitrogen oxides (NO_X), and oxygen (O_2) in the sample on a dry gas basis. For Cooper Station Unit 2, this testing was attempted through a single observation port at the upper furnace. Similarly to the results in 2018, there were elevated temperatures (2,600+°F) and high CO (avg. 3,241 ppm), which supports the idea that the combustion within the burner belt should be improved. Variations to the spinner/spreaders could be evaluated, but the best solution would be a Fan Boosted Overfire Air system, discussed more in the *Recommendations* portion of this report.

The data from the HVT Test, however, is not included and probably not completely valid as the temperatures about ten feet into the furnace were so high that the melted the tip and thermocouple of the HVT probe, as shown in the picture below. The probe was black when removed, though. Which suggests the elevated CO values measured were accurate, maybe even low, despite the difficulty of the pump to pull a sample through the melted tip.

Figure 6: Melted HVT Probe Tip

Economizer outlet testing was also performed through six recently installed multipoint probes across the ducting exiting the boiler. The general balance of constituents was very good, and the extreme spikes of CO at the rear of the furnace were not reflected with the highest point measured at 26 ppm. The table below shows the results of the baseline testing at the economizer outlet.

Table 2: Baseline Economizer Outlet Results

Economizer Outlet Averages	Temp	O_2	CO	NO_X	NO_X
	°F	%	ppm	ppm	lb/mmbtu
	704	3.9	18	355	0.5123

The burner settings initially found onsite are displayed in the table below. It was noted that the windbox pressure was around 3.7" w.c. during this initial test. It is possible that this could be increased to further improve the balance of secondary air between the burners, improving combustion in the burner belt.

Table 3: Unit 2 'As Found' Burner Settings

	Front Wall			
Row 5	**D1**	**D2**	**C2**	**D3**
Inner Register	3	3	2	2
Outer Register	1	1	0	0
Shroud Opening	11	10 3/4	10 3/4	11 1/4
Row 4	**C1**	**B1**	**B2**	**C3**
Inner Register	3	3	2	2
Outer Register	1	1	0	0
Shroud Opening	11	11	11	11
Row 3	**E1**	**E2**	**E3**	**B3**
Inner Register	3	3	2	2
Outer Register	1	1	0	0
Shroud Opening	10	7 3/4	8	9 3/4
Row 2	**F1**	**F2**	**A2**	**F3**
Inner Register	3	4	3	3
Outer Register	1	1	0	0
Shroud Opening	9 1/2	8 3/4	8 3/4	9
Row 1	**A1**			**A3**
Inner Register	3			3
Outer Register	1			0
Shroud Opening	8 1/4			8 3/4
Note: Register indicated is number of holes showing				
Note: Shroud opening is distance measured inside "collar to collar"				

For repeatability of leakage testing, a second economizer outlet test was performed. Along with this, adjustments were made to some of the burner shrouds to increase windbox pressure and encourage a little more air into the upper furnace. While the economizer outlet was not excessively high in CO, a reduction in these numbers would reflect an improvement to the area observed in the furnace. The results of testing following these changes are shown in the table below, and average CO was reduced to 8 ppm from 18 ppm.

Table 4: Final Economizer Outlet Results

Economizer Outlet Averages	Temp	O_2	CO	NO_X	NO_X
	°F	%	ppm	ppm	lb/mmbtu
	680	3.9	8	315	0.4540

The table below shows the final burner settings left by Storm. While there was an improvement to the CO and NO_X measured at the economizer, it's still recommended that the spinner/spreaders be investigated, and a Fan Boosted Overfire Air system would introduce significant improvements to the issues noted in HVT attempts and would further improve the NO_X emissions for the unit.

Table 5: Unit 2 'As Left' Burner Settings

	Front Wall			
Row 5	**D1**	**D2**	**C2**	**D3**
Inner Register	3	3	2	2
Outer Register	1	1	0	0
Shroud Opening	11	10 3/4	10 3/4	11 1/4
Row 4	**C1**	**B1**	**B2**	**C3**
Inner Register	3	3	2	2
Outer Register	1	1	0	0
Shroud Opening	11 1/2	11 1/2	11 1/2	11 1/2
Row 3	**E1**	**E2**	**E3**	**B3**
Inner Register	3	3	2	2
Outer Register	1	1	0	0
Shroud Opening	10	7 3/4	8	9 3/4
Row 2	**F1**	**F2**	**A2**	**F3**
Inner Register	3	4	3	3
Outer Register	1	1	0	0
Shroud Opening	8 1/2	7 3/4	7 3/4	8
Row 1	**A1**			**A3**
Inner Register	3			3
Outer Register	1			0
Shroud Opening	7 1/4			7 3/4

Note: Register indicated is number of holes showing

Note: Shroud opening is distance measured inside "collar to collar"

Air Heater Testing and Efficiency Calculations

Testing was also performed at the air heater outlet through five ports along a single duct. The air heater used on Unit 2 is a Ljungstrom bi-sector regenerative air heater with variable sector plates. Using a 'boiler exit' probe, the ports were traversed to establish static pressure, temperature, oxygen (O_2), carbon monoxide (CO), and nitrogen oxides (NO_X) exiting the air heater. The table below shows the averages across both tests completed in this manner.

Table 6: Air Heater Testing Averages

Test 1 APH Out Averages					
Static Press. (" w.c.)	Temp (°F)	O_2 (%)	CO (ppm)	NO_X (ppm)	NO_X (lb/mmbtu)
-28.66	318	5.07	9	43	0.0661
Test 2 APH Out Averages					
Static Press. (" w.c.)	Temp (°F)	O_2 (%)	CO (ppm)	NO_X (ppm)	NO_X (lb/mmbtu)
-28.63	319	5.27	8	43	0.0673

The reason for testing across the air heater (economizer outlet and APH outlet) is that the results allow for calculation of leakage across air heater, as well as calculations for the gas side effectiveness and X-Ratio. The leakage is calculated with the O_2 rise between the two testing locations versus the known O_2 levels of ambient air. The table below shows the O_2 rise in these two locations and the leakage calculated for each test.

Table 7: Unit 2 Measured Oxygen Rise and Leakage

Oxygen Rise (%)	**Test 1**	**Test 2**	**Average**
Economizer Outlet	3.90	3.90	3.90
Air Heater Outlet	5.07	5.27	5.17
Total Leakage	6.7	7.9	7.3

Along with the leakage, knowing the temperature of the gas entering and exiting the heater along with the air entering and exiting allows for calculations of how efficiently the system is performing. The two values that result from these calculations are the Gas Side Effectiveness and the X-Ratio, both of which give insight into the performance of the air heater. For both numbers, the exit gas temperature is corrected to what it would be if there were no leakage. The X-Ratio is a simple comparison of the difference in temperature between the air sides and the gas sides with no leakage. The Gas Side Effectiveness does not consider the air out temperature. For Unit 2, the X-Ratio was calculated at 0.69 and the Gas Side Effectiveness was calculated at 59.5%, these along with the leakage are shown in the figure below. The worksheet used for calculating these values is included in the appendix.

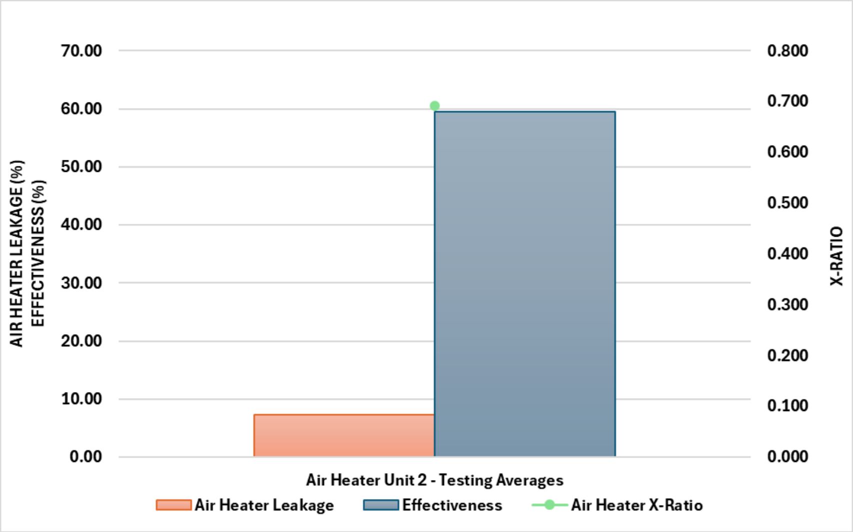


Figure 7: Unit 2 Air Heater Leakage and Gas Side Effectiveness

Another useful value that can be calculated with the testing completed on Unit 2 is the Boiler Efficiency. Along with the oxygen rise and measured CO, an ultimate analysis and ash sample of the fuel is needed. This method of calculating boiler efficiency can be found in the ASME PTC 4, and the worksheet used for Unit 2 is shown in the *Appendix* of this report. Essentially, using data collected at the boiler and air heater exits along with known values and constituents in the fuel, a series of heat loss components are calculated and a heat credit from the temperature of the air entering the test boundary. This results in an overall efficiency value. What was completed during this visit was an abbreviated version of the PTC 4 and, while it is not as exact as performing an entire complete evaluation of the boiler in accordance with ASME PTC 4, it serves as good a relative marker for the condition of the boiler system and is not difficult or expensive to continue checking over the course of multiple years and visits. The ultimate analysis used for Unit 2 was from November 2023. Furthermore, the only BTU value found on the analysis provided to Storm was a 'dry' value, and this calculation calls for an 'as received' value. The BTU was adjusted by around 1,500 based on similar coals Storm has worked with in the past, but this calculation could be much more accurate in the future if the Cooper Team provides an ultimate fuel analysis for exactly the fuel tested with every variable included that can be found in the attached worksheet for the efficiency calculation. As it stands, the estimated Boiler Efficiency for Unit 2 was 86.38%. This value should be checked and tracked over repeat visits in the coming years. It should be noted that the drawback of the ASME PTC 4 is its lack of consideration for air in-leakage between the furnace and economizer outlet and combustion conditions in the furnace that could impact the boiler in many different ways.

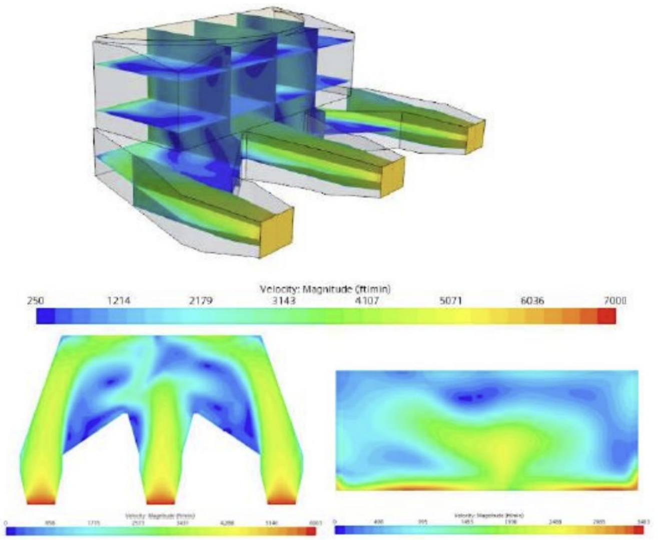
Recommendations

Storm Technologies has earned its reputation for combustion optimization through the implementation of and adherence to the '*13 Essentials for Combustion Optimization'* which are depicted at the bottom of the report. Following the testing completed on Unit 2 at Cooper Station, it's obvious that there are challenges to combustion occurring especially towards the back wall of the furnace. Plant personnel also expressed some concern in the amount of NO_X produced by the unit and ways to mitigate this production. The most pressing issue identified was in the behavior of the mills at the upper load points. What follows are some short-term and long-term recommendations that would improve the performance and lifespan of the unit in accordance with the Cooper Team's goals.

As discussed in the report, the mills appeared to be loading up with fuel and then quickly unloading in ways that caused the boiler to swing noticeably when the mills were at feed rates beyond around 35-36 klbs/hr of fuel. Storm's experience with EL-76 mills is that they can easily operate at the design capacity of 40 klbs/hr of fuel without experiencing these swings. From Storm's initial observations, the swings seemed to be caused by the PA being insufficient at these load ranges. The PA curves were more than adequate as the mills were trying to maintain a 1.9-2.0 air-to-fuel ratio, they just couldn't provide enough air to make that ratio. The PA dampers would creep open slowly, but the actual airflow would start to decrease. It could be caused by the increase in back pressure due to the slow response of the primary air and inability to transport the fuel out of the mill effectively.

The PA duct is a common duct that bends ninety degrees, is fed from one side, and reduced in internal area as it approaches the sixth mill. The middle mills on this duct seemed to be the most prone to loading/unloading. This gives credence to the idea that the airflow profile within the geometry of the common duct is the cause of the insufficient flows. Plant personnel noted that in past duct inspections, there was less obvious wear on the ducting of the middle mills exiting the common duct, as well.

It's very plausible that either the geometry of or the pressure within the duct is causing this, but it could be confirmed by CFD modeling of the duct. CFD modelling allows the Storm Team to model and analyze velocities, pressures, temperatures, airflow profiles and develop a complete picture of the results of potential physical changes made to access their impact. Storm has completed CFD analysis projects for other companies including analysis of Primary Air (PA) duct work, venturis, OFA duct work, coal pulverizers, classifiers, and wind boxes. Not only could the profile of air be evaluated for its impact on the issue, but potential turning vanes and other engineered solutions could be modeled for viability. This is obviously a challenge to the performance of the pulverizers that should be addressed as soon as possible, and the best way to do that affordably and within a short amount of time would be the CFD modeling. Along with that, it's recommended that Storm be brought onsite for performance inspections of the mills' internal conditions and the ducting in and around the PA inlets. Coupled with this, inspections of the windboxes and burner conditions would also be of great value to the Cooper Team. Below is an example of CFD analysis on similar systems that was used for similar results.



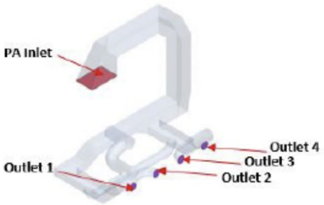


Table 3: PA Outlet Mass Flow and Velocity % Deviation.

Iteration	Iteration 1		Iteration 2	
% Deviation	Mass Flow	Velocity	Mass Flow	Velocity
PA Outlet 1	-8%	-2%	-7%	-2%
PA Outlet 2	12%	8%	12%	8%
PA Outlet 3	5%	1%	5%	0%
PA Outlet 4	-10%	-7%	-9%	-7%

Figure 8: Example of Air System CFD Analysis

For ideal combustion at the burner fronts, the burner nozzles, registers, rope breakers and inputs must be optimized. Figure 8 depicts an overview of the combustion process and flame propagation of a typical DRB type burner. Meaningful adjustment of the inner and outer spin vanes along with the spinner/spreader on the DRB-XCL burners can impact the combustion performance of each individual burner given there is adequate air for combustion supplied. With many burners like these, it is likely that they have become so bound with ash or rust on the linkages that they need to be cleaned internally and broken free before they will be operable. Even following this cleaning process, the burners may only be easily adjusted for a short period of time and is essential that additional tuning of the burners be accomplished immediately following any work completed on the burners to free up the registers. Furthermore, it is not recommended that the spin vanes be set based solely on economizer outlet testing as the test plane is so far removed from the combustion zone that it is difficult to identify exact burner columns that would benefit from the changes. Storm normally prefers to fine tune DRB-XCL registers and dampers iteratively in conjunction with HVT testing which occurs with a water-cooled probe directly above the combustion zone inside the furnace. Access to ports for HVT testing is an obstacle on Unit 2 at Cooper, but this could be overcome with a mixture of probe lengths if the temperatures in the rear furnace are corrected enough not to melt the probe tips. It's likely that tuning in this way will result in an improvement to the combustion challenges noted but will probably not solve them completely. It's recommended that the condition of the spinner/spreaders be evaluated and potential adjustments to their design be considered to assist in improving combustion conditions in the back of the furnace.

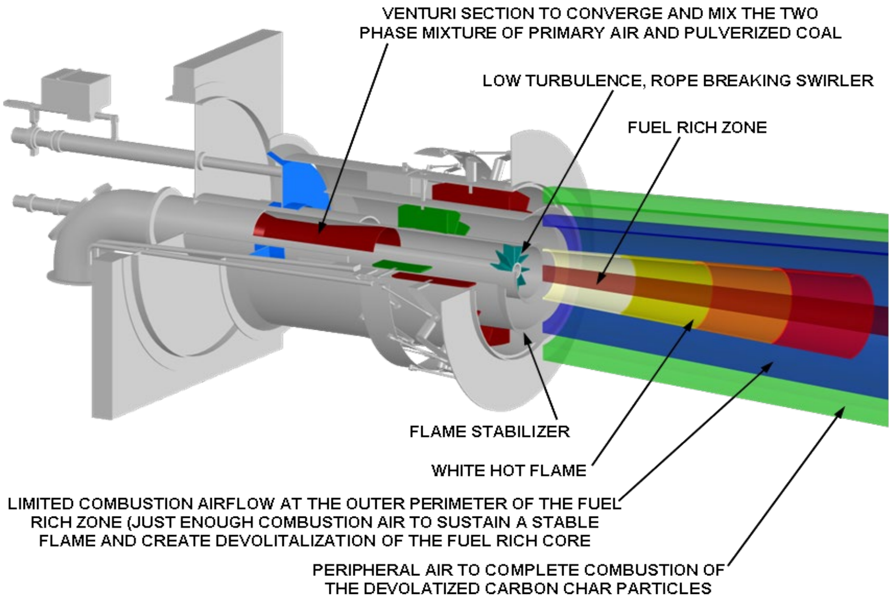


Figure 9: Optimized Burner Performance Characteristics

Furthermore, combustion tuning and/or improving the spinner/spreaders (possibly adjusting the O_2 curve) could also reduce the NO_X. Most similar units with a goal of low NO_X production rarely operate with more than 3% excess O_2. Storm has found that a comprehensive approach to optimizing the inputs (air and fuel) for combustion will aid in reducing both NO_X and LOI in the boiler, as indicated in the picture below.

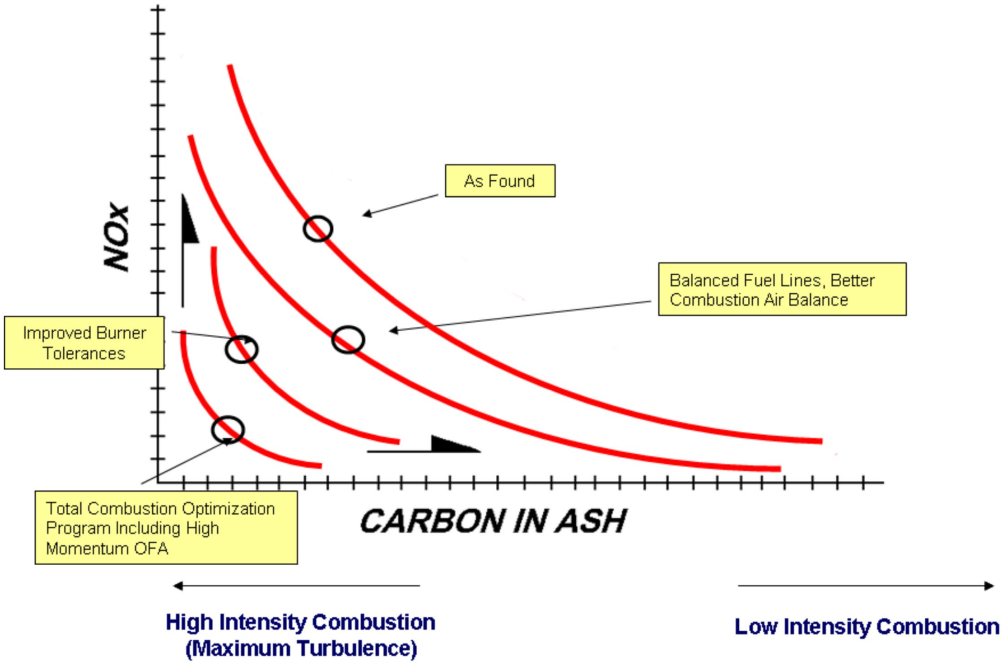


Figure 10: The Effect of Combustion Optimization on NO_X and LOI

As a long-term solution, an overfire air system is strongly recommended for both units at Cooper Station. This system would reduce in-furnace NO_X emissions by staging combustion within the furnace. This method strips a portion, ~15% - 20%, of the total air to the boiler and supplies it to the OFA system which injects the air above the burner belt zone. This is the most effective solution to reducing the in-furnace NO_X production and the load carried by the SCR to reduce NO_X. By reducing the inlet NO_X to the SCR, ammonia usage will decrease. It is encouraged that Cooper explores the possibility of this air system with Storm moving forward. Historically, Storm's Fan Boosted Overfire Air (FBOFA) has been able to achieve an in-furnace NO_X reduction of over 40% and articles regarding these systems can be found in the report appendix. The figure below shows a Storm designed FBOFA like the one Storm is recommending for Cooper's Unit 1.

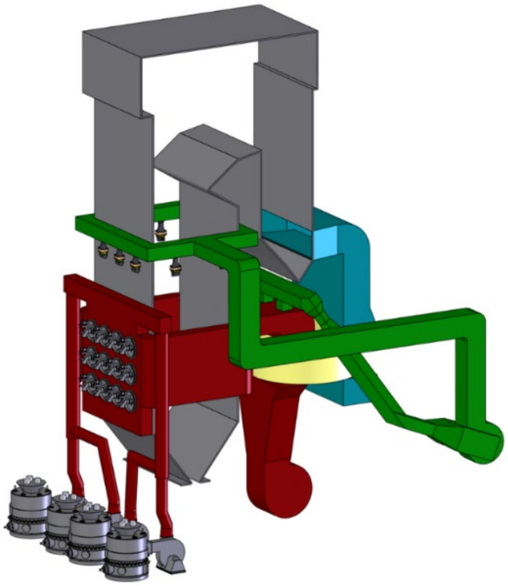


Figure 11: Storm Designed Fan Boosted OFA System

The proposed FBOFA system would do more to aid combustion within the furnace than simply reducing the in-furnace NO_X. A finely tuned and controlled overfire air system can reduce FEGT's, improve heat rate, and reduce water wall wastage and/or forced outages. Given the depth of benefits and reduction of ammonia consumption, the FBOFA system could easily pay for itself within a relatively short period.

An effective overfire air system burns the remaining carbon char in the upper furnace, reducing the formation of NO_X but not negatively impacting the temperatures of combustion in the burner belt or lower furnace. The reason Storm recommends a fan boosted system over a more typical OFA system lies in the controllability of the airflow and the effectiveness of the fan boosted stream of air penetrating the entirety of the furnace. In a Storm designed FBOFA, flow control across the system precisely measures and balances the total overfire air. This prevents the OFA from inadvertently robbing the SA system in the manner that has been observed in many other units with after-market OFA systems, which protects against water wall wastage and burner damage at low loads. The velocity of the air at all unit load points is another primary benefit of the system being fan boosted. Balanced introduction of OFA across the entirety of the upper furnace plane is pivotal to maintaining balanced temperatures and O_2 in the upper furnace. As shown in Figure 11, insufficient OFA velocity can lead to secondary combustion, high FEGT's and LOI's, and even damage to the pendants through extreme imbalances in metal temperatures. While some of the issues of OFA penetration can be corrected through meaningful nozzle design, a fan boosted system is the best and most effective method to control and balance the introduction of air into the upper furnace.

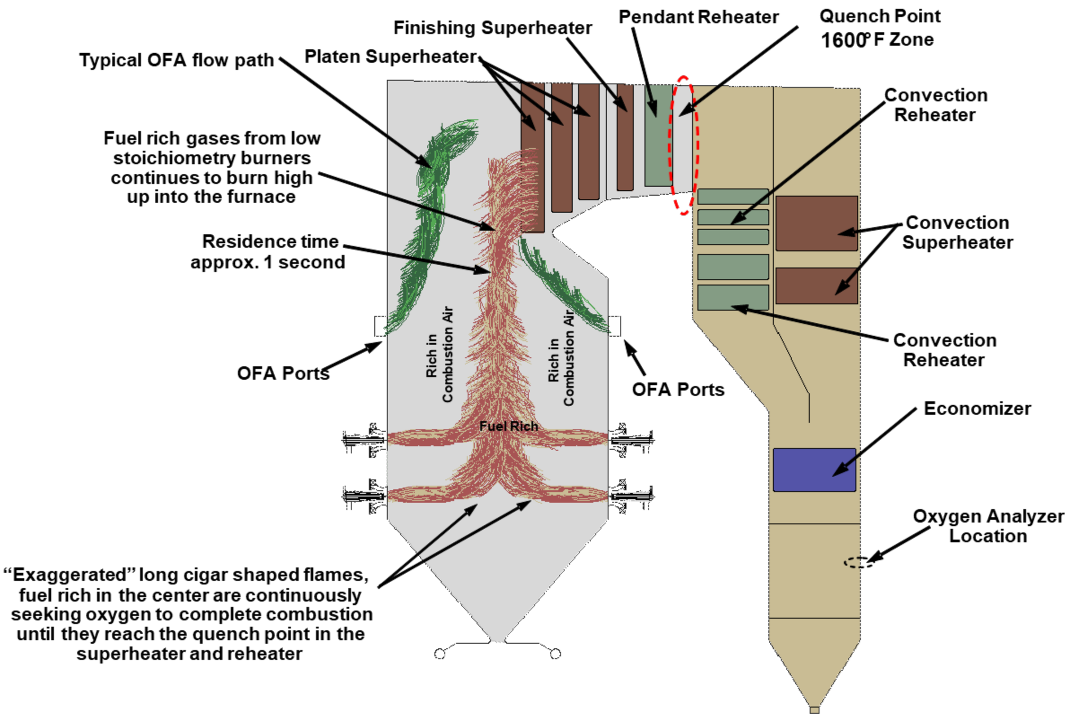
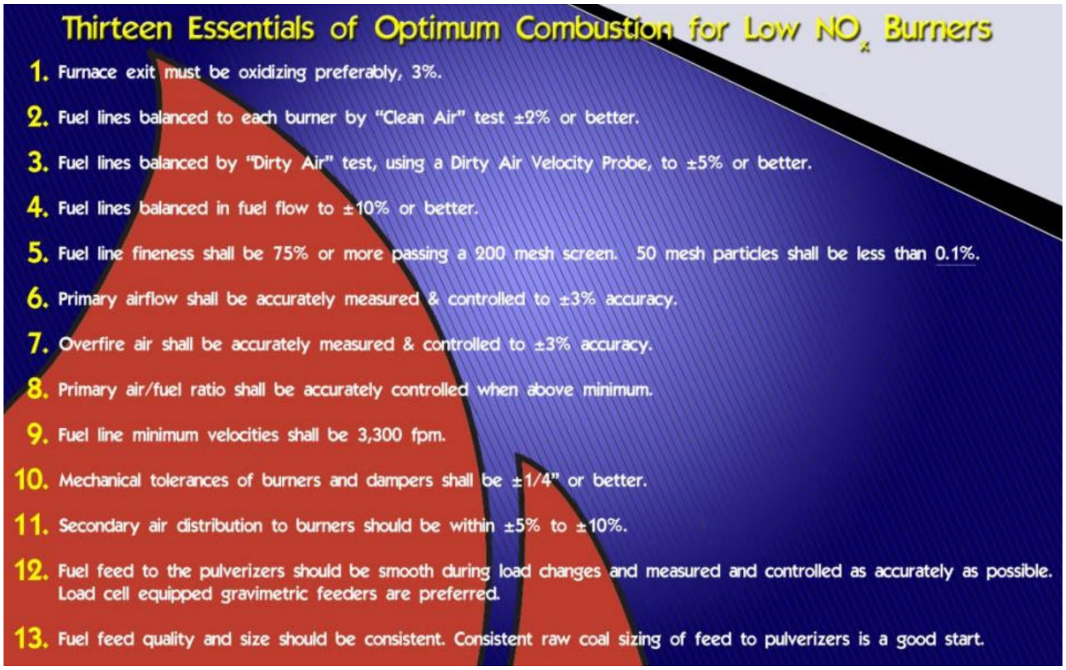


Figure 12: Combustion Challenges of Typical OFA Fed by SA and not Fan Boosted

Lastly, Storm highly recommends continuing to calibrate all airflow devices on at least an annual basis. Accurately controlled and indicated airflow is one of the most critical aspects of maintaining optimized combustion in the boiler. In addition to regularly scheduled calibration, Storm highly recommends completing calibration of all airflow devices after any outage or after any signification operational changes. Furthermore, it is recommended that transmitter sensing lines are checked for leaks and blown back frequently to ensure accurate airflow indication between calibrations.



Thirteen Essentials of Optimum Combustion for Low NO_x Burners

1. Furnace exit must be oxidizing preferably, 3%.
2. Fuel lines balanced to each burner by "Clean Air" test ±2% or better.
3. Fuel lines balanced by "Dirty Air" test, using a Dirty Air Velocity Probe, to ±5% or better.
4. Fuel lines balanced in fuel flow to ±10% or better.
5. Fuel line fineness shall be 75% or more passing a 200 mesh screen. 50 mesh particles shall be less than 0.1%.
6. Primary airflow shall be accurately measured & controlled to ±3% accuracy.
7. Overfire air shall be accurately measured & controlled to ±3% accuracy.
8. Primary air/fuel ratio shall be accurately controlled when above minimum.
9. Fuel line minimum velocities shall be 3,300 fpm.
10. Mechanical tolerances of burners and dampers shall be ±1/4" or better.
11. Secondary air distribution to burners should be within ±5% to ±10%.
12. Fuel feed to the pulverizers should be smooth during load changes and measured and controlled as accurately as possible. Load cell equipped gravimetric feeders are preferred.
13. Fuel feed quality and size should be consistent. Consistent raw coal sizing of feed to pulverizers is a good start.

Figure 13: Storm's Essentials for Optimum Combustion

Closing

It was great working with the team at J.S. Cooper and we look forward to continuing that relationship in the future as we help you meet your performance goals. If you have any questions regarding the information found in this report or about any of the services provided while onsite, please do not hesitate to contact us.

Respectfully submitted,

Scott Andrew Russell
Project Manager
Storm Technologies, Inc.

Appendix A: Air Heater Leakage Worksheet

EKPC - J.S. Cooper Station	Unit	2	Date	07/11/24
Air Heater Leakage/Efficiency	Test	1	APH	A

O_2 Method

$$\%Leakage = \frac{(\%O_2 Entering - \%O_2 Leaving)}{(\%O_2 Leaving - 20.9\%)} x\ 90$$

Data Inputs

% O_2 Entering	3.90		From Test
% O_2 Leaving	5.07		From Test
T Gas In	704.0	°F	From Test
T Gas Out	318.0	°F	From Test
T Air In	92.00	°F	Control Indications
T Air Out	621.00	°F	Control Indications
Air Heater Leakage =	6.65	%	

Corrected Gas Temperature (No Leakage Basis)

O_2 Method

$$Air\ Heater\ Corrected\ Exit\ Gas\ Temperature = \frac{(Air\ Heater\ Leakage\ \ x\ Cp_{Air}\ \ x\ (T_{GasOut} - T_{AirIn}))}{100\ \ x\ \ Cp_{Gas}} + T_{GasOut}$$

Cp_{Air} = Specific Heat of Air (BTU / lb ∘ F)

T_{GasOut} = Temperature of Gas Leaving Air Heater (∘F)

T_{AirIn} = Temperature of Air Entering Air Heater (∘F)

Cp_{Gas} = Specific Heat of Gas (BTU / lb ∘ F)

Equation Data

Air Heater Leakage	6.65	%
Cp Air	0.24	BTU/lb/°F
T Gas Out	318.0	°F
T Air In	92.0	°F
Cp Gas	0.2392	

Air Heater Corrected Exit Gas Temperature = 333.1 °F

X-Ratio Calculation

O_2 Method

$$Air\ Heater\ X-Ratio = \frac{T_{GasIn} - T_{GasOut}(No\ Leakage\ Basis)}{T_{AirOut} - T_{AirIn}}$$

Where:

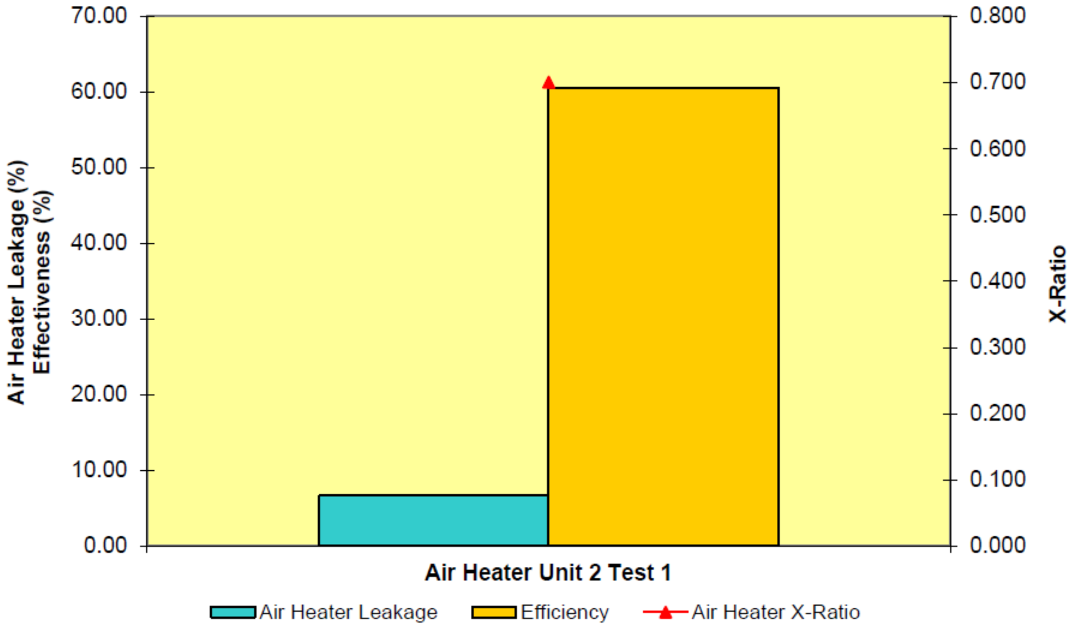
T_{GasIn} = Temperature of the Gas Entering Air Heater (°F)

$T_{GasOut(No\ Leakage\ Basis)}$ = Air Heater Gas Outlet Temperature Corrected for No Leakage (°F)

T_{AirOut} = Temperature of Air Leaving Air Heater (°F)

T_{AirIn} = Temperature of Air Entering Air Heater (°F)

	Equation Data	
T Gas In	704.0	°F
T Gas Out (No Leakage Basis)	333.1	°F
T Air Out	621.00	°F
T Air In	92.0	°F
Air Heater X-Ratio =	0.701	
η_G ≡ gas side effectiveness =	60.61	%



EKPC - J.S. Cooper Station

Unit	2	Date	07/12/24
Test	2	APH	A

Air Heater Leakage/Efficiency

O_2 Method

$$\%Leakage = \frac{(\%O_2 Entering - \%O_2 Leaving)}{(\%O_2 Leaving - 20.9\%)} x\ 90$$

Data Inputs

% O_2 Entering	3.90		From Test
% O_2 Leaving	5.27		From Test
T Gas In	680.0	°F	From Test
T Gas Out	319.0	°F	From Test
T Air In	92.00	°F	Control Indications
T Air Out	595.00	°F	Control Indications
Air Heater Leakage =	7.89	%	

Corrected Gas Temperature (No Leakage Basis)

O_2 Method

$$Air\ Heater\ Corrected\ Exit\ Gas\ Temperature = \frac{(Air\ Heater\ Leakage\ \ x\ Cp_{Air}\ x\ (T_{GasOut} - T_{AirIn}))}{100\ \ x\ \ Cp_{Gas}} + T_{GasOut}$$

$Cp_{Air} = Specific\ Heat\ of\ \ Air\ (BTU/lb \circ F)$

$T_{GasOut} = Temperature\ of\ \ Gas\ Leaving\ Air\ Heater\ (\circ F)$

$T_{AirIn} = Temperature\ of\ \ Air\ Entering\ Air\ Heater\ (\circ F)$

$Cp_{Gas} = Specific\ Heat\ of\ \ Gas\ (BTU/lb \circ F)$

Equation Data

Air Heater Leakage	7.89	%
Cp Air	0.24	BTU/lb/°F
T Gas Out	319.0	°F
T Air In	92.0	°F
Cp Gas	0.2392	

Air Heater Corrected Exit Gas Temperature =	337.0	°F

X-Ratio Calculation

O_2 Method

$$Air\ Heater\ X-Ratio = \frac{T_{GasIn} - T_{GasOut}(No\ Leakage\ Basis)}{T_{AirOut} - T_{AirIn}}$$

Where:

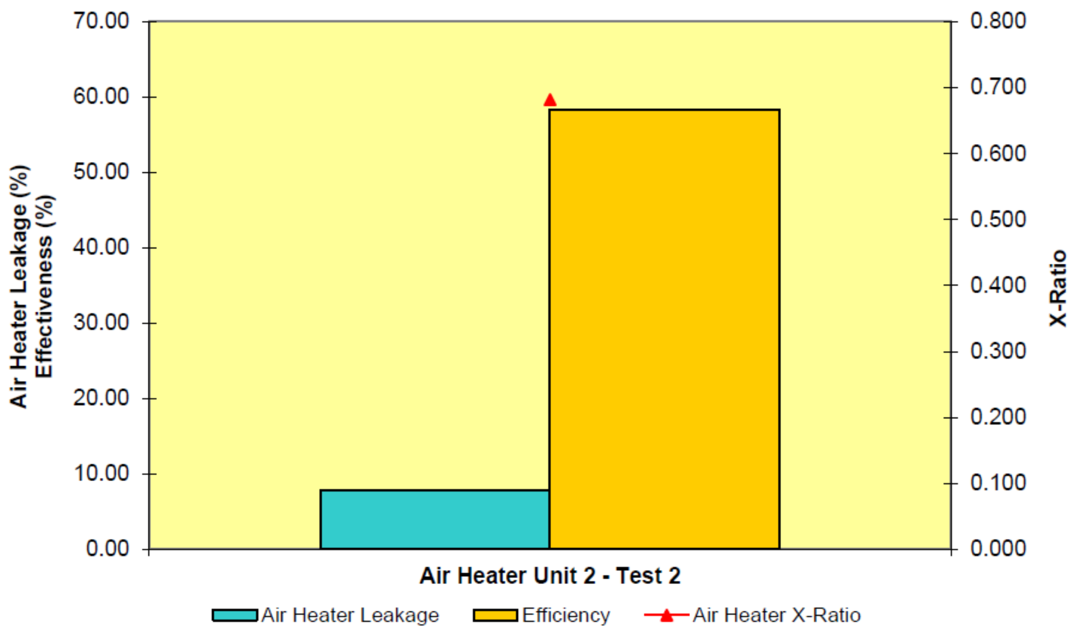
$T_{GasIn} = Temperature\ of\ the\ Gas\ Entering\ Air\ Heater\ (\circ F)$

$T_{GasOut(No\ Leakage\ Basis)} = Air\ Heater\ Gas\ Outlet\ Temperature\ Corrected\ \ for\ No\ Leakage\ (\circ F)$

$T_{AirOut} = Temperature\ of\ \ Air\ Leaving\ Air\ Heater\ (\circ F)$

$T_{AirIn} = Temperature\ of\ \ Air\ Entering\ Air\ Heater\ (\circ F)$

	Equation Data	
T Gas In	680.0	°F
T Gas Out (No Leakage Basis)	337.0	°F
T Air Out	595.00	°F
T Air In	92.0	°F
Air Heater X-Ratio =	0.682	
η_G ≡ gas side effectiveness =	58.34	%



EKPC - J.S. Cooper Station		Unit	2	Date	7/11-7/12
Air Heater Leakage/Efficiency		Test	Average	APH	A

O_2 Method

$$\%Leakage = \frac{(\%O_2 Entering - \%O_2 Leaving)}{(\%O_2 Leaving - 20.9\%)} \; x \; 90$$

Data Inputs

% O_2 Entering	3.90		From Test
% O_2 Leaving	5.17		From Test
T Gas In	692.0	°F	From Test
T Gas Out	318.5	°F	From Test
T Air In	92.00	°F	Control Indications
T Air Out	608.00	°F	Control Indications
Air Heater Leakage =	7.27	%	

Corrected Gas Temperature (No Leakage Basis)

O_2 Method

$$Air\ Heater\ Corrected\ Exit\ Gas\ Temperature = \frac{(Air\ Heater\ Leakage\ \ x\ Cp_{Air}\ \ x\ (T_{GasOut} - T_{AirIn}))}{100\ \ x\ \ Cp_{Gas}} + T_{GasOut}$$

$Cp_{Air} = Specific\,Heat\ of\ \ Air\ (BTU / lb \circ F)$

$T_{GasOut} = Temperature\ of\ \ Gas\ Leaving\ Air\ Heater\ (\circ F)$

$T_{AirIn} = Temperature\ of\ \ Air\ Entering\ Air\ Heater\ (\circ F)$

$Cp_{Gas} = Specific\,Heat\ of\ \ Gas\ (BTU / lb \circ F)$

Equation Data

Air Heater Leakage	7.27	%
Cp Air	0.24	BTU/lb/°F
T Gas Out	318.5	°F
T Air In	92.0	°F
Cp Gas	0.2392	

Air Heater Corrected Exit Gas Temperature =	335.0	$\circ F$

X-Ratio Calculation

O_2 Method

$$Air\ Heater\ X-Ratio = \frac{T_{GasIn} - T_{GasOut}(No\ Leakage\ Basis)}{T_{AirOut} - T_{AirIn}}$$

$Where:$

$T_{GasIn} = Temperature\ of\ the\ Gas\ Entering\ Air\ Heater\ (\circ F)$

$T_{GasOut(No\ Leakage\ Basis)} = Air\ Heater\ Gas\ Outlet\ Temperature\ Corrected\ \ for\ No\ Leakage\ (\circ F)$

$T_{AirOut} = Temperature\ of\ \ Air\ Leaving\ Air\ Heater\ (\circ F)$

$T_{AirIn} = Temperature\ of\ \ Air\ Entering\ Air\ Heater\ (\circ F)$

Equation Data

T Gas In 692.0 °F

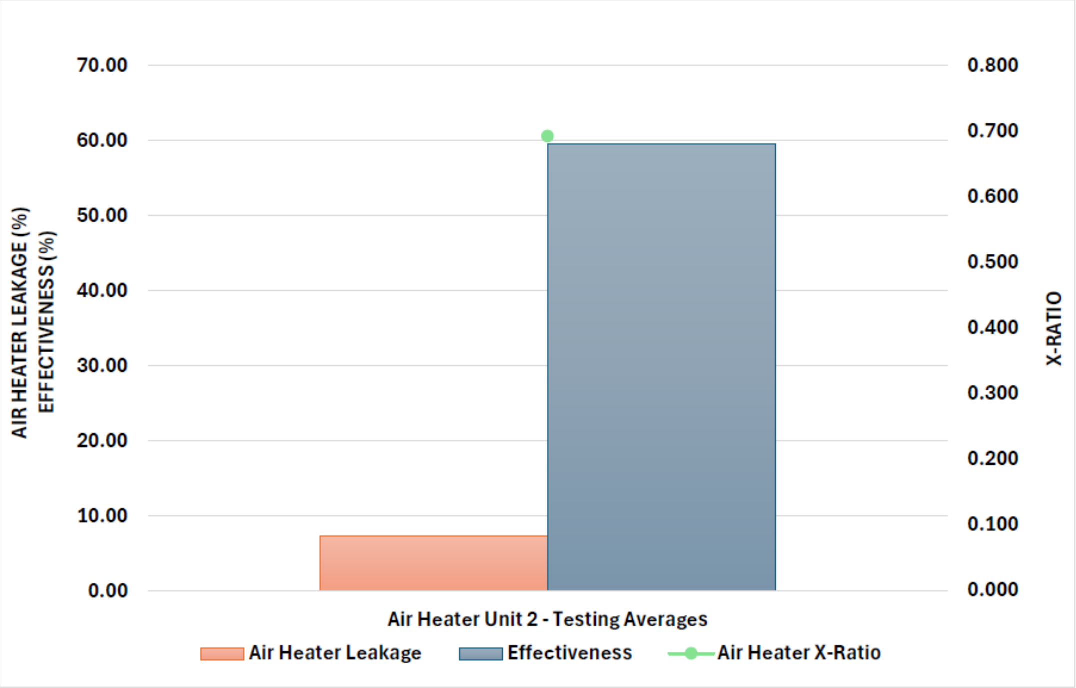
T Gas Out (No Leakage Basis) 335.0 °F

T Air Out 608.00 °F

T Air In 92.0 °F

Air Heater X-Ratio = 0.692

η_G ≡ gas side effectiveness = 59.50 %



Appendix B: Boiler Efficiency Worksheet

Description	Units	Notation	Value		
Steam Flow	lbs/hr	lbs/hr	-		
Barometric Pressure	"Hg	Bp	28.52		
Fuel Analysis			As Found	Dry Basis	
Mass percentage of Carbon in Fuel	%	MpCF	65.13	73.80	
Mass percentage of Sulfur in Fuel	%	MpSF	0.96	1.09	
Mass percentage of Nitrogen in Fuel	%	MpN2F	1.38	1.56	
Mass percentage of Hydrogen in Fuel	%	MpH2F	4.42	5.01	
Mass percentage of Oxygen in Fuel	%	MpO2F	6.59	7.47	
Mass percentage of Total Moisture in Fuel	%	MpWF	11.75	0	
Mass percentage of Ash in Fuel	%	MpAsF	7.47	11.19	
Calorific Value (HHV)	Btu/lb	HHVF	12,033		
Ash Analysis					
Mass percentage of Unburned Carbon in Flyash	%	MpUbcFa	1.004		
Mass percentage of Unburned Carbon in Bottom Ash	%	MpUbcBa	2.95		
Ash Split					
Mass percentage of Flyash	lb/lb ash	MFrFa	0.8		
Mass percentage of Bottom Ash	lb/lb ash	MFrBa	0.2		
Gas Analysis					
Carbon monoxide in dry flue gas at APH Outlet	Vol fraction	COo	0.0008	8	**CO PPM**
Oxygen in dry flue gas at APH Outlet	% by Vol	DVpO2	5.27		
Oxygen in dry flue gas at APH Inlet	% by Vol	DVpO2i	3.90		
Oxygen in dry flue gas at Economizer Outlet	% by Vol	DVpO2j	3.90		
Temperatures					
Temperature of Flue Gas Entering Air Heater	°F	Tgi	680		
Temperature of Flue Gas Exiting Air Heater	°F	Tgo	347		
Dry Bulb Ambient Air Temperature	°F	Tdb	86		
Average AH Inlet Temperature	°F	Tahi	91		
Wet Bulb Temp AH Inlet Temperature	°F	Twb	88		
Mean Specific Heat of Dry Flue Gas Exiting Air Heater	Btu/lbm*°F	MnCpFg	0.239		
Mean Specific Heat between Air Temp. Entering APH and Gas Temp. Leaving	Btu/lbm*°F	MnCpA	0.2425		

🟩	Needs to be measured onsite
🟦	From analysis
⬜	Calculated
🟪	Agreed
🟥	Supplemental

Heat Loss Components	**Units**	**Notation**	**Value**	**PTC 4**
Losses due to unburned carbon in total dry	%	QpLUbC	0.13	5.14-4.1
Losses due to heat in dry flue gas	%	QpLDFg	6.97	5.14-1
Losses due to moisture in the "as-fired" fuel	%	QpLWF	1.14	5.14-2.2
Losses due to moisture from burning	%	QpLH2F	3.83	5.14-2.1
Losses due to moisture in air	%	QpLWA	0.3787	5.14-3
Losses due to air infiltration	%	QpLALg	0.00	5.14-7
Unmeasured Losses to be assumed	%		1.50	assumed

Heat Credit Compontents				
Credits due to heat from entering air	%	QpBDA	0.32	5.15-1

Boiler Efficency	**%**	86.38

Description	Units	Notation	Value	PTC 4
Moisture in air	lbm H2O/lbm dry air	MFrWA	0.029811443	5.11-1
Partial Pressure of Water Vapor in Air	psia	PpWvA	0.640699071	5.11-2
Barometric Pressure	psia	Pa	14.00854659	5.11
Saturation Pressure of Water Vapor at wet-bulb temp	psia	PsWvTwb	0.655517768	5.11-4
Moles of dry products from combustion of fuel	moles/mass AFF	MoDP	0.054932133	5.11-12
		MqThACr	0.00727776	5.11-7
Mass fraction of theorectial air (Corrected)	lbm/lbm AFF	MFrThACr	8.757329576	5.11-8
Theoretical air (Corrected), moles/massAFF	moles/mass AFF	MoThACr	0.302362655	5.11-9
Moles of Theoretical Air required for Gasified products in fuel w/total conversion of sulfur to SO2	moles/mass AFF	MoThAPcu	0.302368421	5.9-11
Moles SO2 per lbm fuel if 100% conversion	moles/mass AFF	MoSO2	0.000300002	5.9-13
Moisture from H2O in Fuel	lbm/Btu	MqWF	9.76481E-06	5.12-2
Moisture from the Combustion of Hydrogen in Fuel	lbm/Btu	MqWH2F	3.28375E-05	5.12-3
Additional Moisture in Flue Gas (atomizing steam, sootblowing Steam)	lbm/Btu	MqWAdz	0	5.12-7
Moisture in Air entering Air Heater Outlet	lbm/Btu	MqWA	2.87851E-05	5.12-6
Moisture in Air entering Air Heater Inlet	lbm/Btu	MqWAi	2.65207E-05	5.12-6
Moisture in Air entering Air Economizer Outlet	lbm/Btu	MqWAj	2.65207E-05	5.12-6
Total Moisture in Flue Gas	lbm/Btu	MqWFgz	7.13875E-05	5.12-9
Quantity of Dry Air Exiting Air Heater	lbm/Btu	MqDA	0.000965574	5.11-29
Quantity of Dry Air Entering Air Heater	lbm/Btu	MqDAi	0.000889615	5.11-29
Quantity of Dry Air Exiting Economizer	lbm/Btu	MqDAj	0.000889615	5.11-29
Total Wet Flue Gas Weight at Air Heater Outlet	lbm/Btu	MqFg	0.001070369	5.12-10
Total Wet Flue Gas Weight at Air Heater Inlet	lbm/Btu	MqFgi	0.000992145	5.12-10
Total Wet Flue Gas Weight at Economizer Outlet	lbm/Btu	MqFgj	0.000992145	5.12-10
Rate of wet Infiltration Air	lbm/Btu	MqALg	0	5.11-31
Wet Gas From Fuel	lbm/Btu	MqFgF	7.60098E-05	5.12-1
Dry Flue Gas Weight	lbm/Btu	MqDFg	0.000998981	5.12-12
Percent Excess Air (dry basis) @ APH Outlet	%	XpA	32.67454831	5.11-11
Percent Excess Air (dry basis) @ APH Inlet	%	XpAi	22.23746408	5.11-11
Percent Excess Air (dry basis) @ Econ. Outlet	%	XpAj	22.23746408	5.11-11
Mass fraction of residue including UBC	%	MFrRs	7.575542458	
Unburned Carbon in Fuel	%	MpUbC	0.105542458	
Mass percent of Carbon burned	%	MpCb	65.02295754	5.10-9
Corrected Gas Outlet Temperature (Excluding Leakage)	°F	Tgoc	367.4792066	5.13-6
Temperature conversions to Kelvin	K	TgoK	448.1666667	5.19-27
	K	TdbK	305.9444444	5.19-27
	K	TgocK	459.5440037	5.19-27
Enthalpy				
Enthalpy of (Residue) Flyash Leaving APH	Btu/Lbm	HFaLvAph	55.30053855	5.19-26
Enthalpy of dry air at the average air temperature entering the steam generator envelope (TdbK)	Btu/Lbm	HDAEn	3.362995904	5.19-26
Enthalpy of dry air leaving the steam generator envelope corrected	Btu/Lbm	HDALgCr	82.88597774	5.19-26
Enthalpy of dry flue gas at the temperature leaving the boundary corrected for leakage (excluding leakage) (APH Outlet)	Btu/Lbm	HDFgLvCr	69.75562751	5.19-26
Enthalpy of steam at 1 psia at temperature Tgoc	Btu/Lbm	HStLvCr	1226.62667	5.19-6
Enthalpy of water vapor at TgocK	Btu/Lbm	HWLvCr	131.5437233	5.19-26
Enthalpy of water at the reference temperature Tdb	Btu/Lbm	HWRe	59	5.14.2.3
Enthalpy of infiltrating wet air	Btu/Lbm	HALgEn	5.021615271	5.19-1
Enthalpy of wet air leaving corrected	Btu/Lbm	HALvCr	84.33653534	5.19-1

Appendix C: Fan Boosted Overfire Air Case Study

ASME International
Electric Power Conference 2006
May 2 - 4, 2006, Atlanta, Georgia

PWR2006-88157

ACHIEVING SIMULATANEOUS NO$_X$ & COMBUSTION IMPROVEMENTS ON A 90MW T-FIRED UNIT BY APPLYING THE FUNDAMENTALS

Stephen K. Storm
Storm Technologies, Inc.
P.O. Box 429
Albemarle, North Carolina 28002, USA
Phone: (704) 983-2040
E-mail: skstorm1@aol.com

Co-Authors

Danny Storm, Engineering Manager
Adam C. McClellan. STI Project Engineer
R.F. “Dick” Storm, P.E., Senior Consultant

Mr. Jim Mulligan
Plant Manager
AES – Westover Station
720 Riverside Dr.
Johnson City, NY 13790

ABSTRACT

Storm Technologies in cooperation with AES Westover Station implemented a total combustion optimization system approach, including a fan boosted over-fire air system on Unit 13 to reduce the emissions of NO$_X$ while also improving and/or maintaining acceptable Carbon in Ash content levels on a daily basis.

Implementation of this total airflow & pulverizer performance utilized a fundamental and proven approach to performance optimization and the system has been installed now for over two years and continues to be successful. The results of this systems modifications was up to 60% NO$_X$ reduction and payback in months by reducing the need for NO$_X$ credits and simultaneously improving unit performance, reliability and fuels flexibility.

All of the goals of this program were accomplished and the technical success of this project is once again the results of applying a systematic and comprehensive approach addressing fundamental opportunities for improvement. The benefit of this total combustion optimization project was not only NO$_X$ reductions, but also reliability and “fuels flexibility”. Furthermore, foresight in this system was the ability to improve boiler efficiency, heat rate and reduce rates of ammonia when and/or if SCR or SNCR is installed.

Since the installation of the FBOFA System it should be noted that AES Westover has been able to consistently attain between .25-.30 lbs/mmBtu NO$_X$ and single digit carbon in ash levels with no negative effects of the system installed.

The goals of this project were as follows:

1. NO$_X$ Reduction from >.54lb/mmBtu(full load) – to $\leq$ 0.32 lb/mmBtu
2. Flyash Carbon Content less than 10%
3. Minimal slagging
4. Operations with a minimum of 2% Oxygen to maintain a “slag friendly” furnace without exceeding the NO$_X$ limits
5. Maximum Load Capability
6. Maximum Fuel Flexibility
7. Total Combustion Optimization & Performance Preservation

INTRODUCTION

AES Westover Station, Unit 13 is a tangentially fired unit manufactured by Combustion Engineering originally rated at 560,000lbs/hr steam, now operates with a gross electrical generation of 88MW. The units furnace is approximately 24’ – 10” deep by 25’ – 4” wide and it has (4) elevations of (16) burners which are fired by (4) Raymond No. 533 deep bowl pulverizers.

PERFORMANCE OVERVIEW

Unit performance, operability, load response, reliability, and capacity issues are all very much interrelated. Therefore, the approach taken by Storm Technologies Inc. (STI) was to reduce NO_X while maintaining normal excess Oxygen and without affecting unit capability, performance or reliability. To minimize secondary combustion and the potential consequent superheater and reheater tube metals overheating, steps were taken to optimize the furnace inputs. Furthermore, to minimize water wall wastage in the lower furnace, air diverters were installed and the fuel fineness, distribution and airflows were tuned to minimize wastage in the sub-stoichiometric firing zones.

As with many of the performance optimization programs provided by STORM, the approach to combustion optimization was to incorporate the *essentials of optimum combustion* as a pre-requisite to the installation of a STORM® designed Boosted Over-Fire Air System.

The essentials completed were as follows:

- Furnace exit must be oxidizing, preferably≥2%.
- Fuel lines balanced to each burner by “clean-air” test ±2% or better via square edge orifices.
- Fuel lines balanced by “Dirty Air” test, using a Dirty Air Velocity Probe, within ±5% or better.
- Fuel lines balanced by fuel flows within ±10% or better.
- Fuel line fineness 75-80% passing a 200 mesh screen and <0.1% on a 50 mesh screen.
- Primary air/fuel ratio shall be correct and accurately maintained when above minimum.
- Boosted Over-fire air shall be installed & controllable.
- Fuel line minimum velocities shall be 3,300fpm.
- Mechanical tolerances of burners and dampers within ±¼” or better.
- Secondary air distribution to burners within ±5% to ±10%.
    - ➢ Staging of air was completed with fuel/auxiliary air diverters.
- Fuel feed to the pulverizers smooth during load changes and measured & controlled as accurately as possible. Load cell equipped gravimetric feeders are preferred.
- Fuel feed quality and size should be consistent. Consistent raw coal sizing to the pulverizers is a good start.

COAL PULVERIZERS

For optimum combustion, it is the experience of the authors that fuel line fineness must be at least 75% passing 200 mesh and a maximum of 0.1% on 50 mesh. To achieve these results the following mill performance modifications were performed. For review, modifications included extended outlet skirts, extended exhauster blades, and corrected tolerances. Spring tensions were first checked and set to the proper tension ±200 Lbs. journal to journal. Classifier blade settings were checked and properly set to achieve the desired fineness. Fuel line orifice sizing was calculated and changes recommended to further improve “line-to-line” balance by the clean air method.

The following figure No. 1 details the critical tolerances applied to the Raymond 533 Mills.

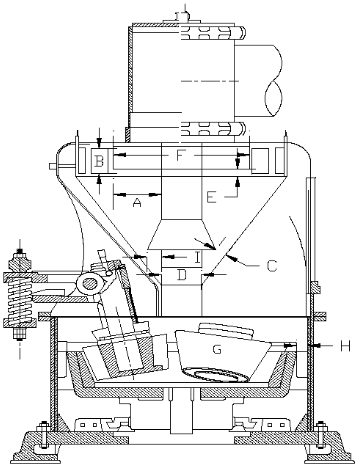


Figure 1: Pulverizer Critical Tolerances

BOOSTED OVER-FIRE AIRFLOW SYSTEM OVERVIEW

In an effort to reduce NO_X while also improving combustion, as STORM designed fan boosted Over-Fire Air (FBOFA) System was installed on Westover 13. As a basic system description, the over-fire air is drawn from the existing 600°F combustion air supply at the air heater exits and is ducted bypassing the burners to the booster fan and to the over-fire air-ports. Two venturis and dampers are provided to precisely measure, balance and control the total over-fire airflow. Manual dampers are provided to control the flow at the individual OFA ports.

The fan-boosted over-fire air system operates at the same design total airflow as original. The difference with the fan-boosted over-fire air system is that combustion is staged and controlled using more of the total furnace volume and height. The purpose of the Boosted Over-Fire Air is to provide proper staging of air and fuel to the furnace. This staging allows for NO_X reduction in the burner belt zone as well as the OFA system allowing oxygen to provide carbon char burn-out prior to exiting the furnace.

The concept of the eight OFA nozzles (two on each water wall) is to utilize the upper furnace for carbon char burnout. This upper furnace zone is where the flame temperatures are cooled to below the threshold thermal NO_X formation temperature of about 2,800ºF. This is shown on figure 2 (below).

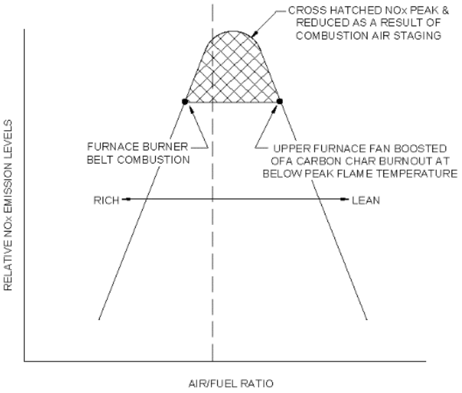


Figure 2

The previous NO_X formation graph shows the peak NO_X production at a slightly oxidizing environment. The principal purpose of the FBOFA system, is to stage combustion, so that most combustion is completed in the burner belt, at a low furnace stoichiometry. The heat energy is released in the burner belt and radiant heat transferred to the water walls, the upper furnace products of combustion will be reduced in temperature to below 2,800ºF. It is at this point that the high momentum over-fire air is injected to complete combustion of the carbon char. This final stage of the combustion process is to be completed below 2,800ºF in the lower furnace and therefore below the threshold temperature for thermal NO_X production.

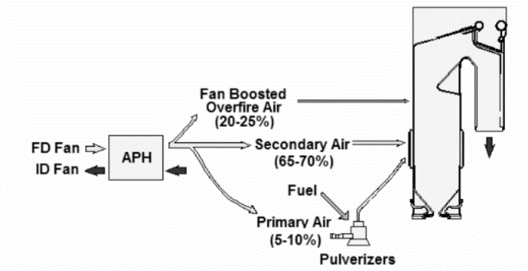


Figure 3

It is for this fundamental reason that the project is considered a “comprehensive combustion optimization,” including significant pulverizer and burner improvements.

The Over-fire air system uses a booster fan to increase the supply pressure of the OFA to approximately 10-15” w.c. using 600°F+ air so proper penetration velocities can be obtained through each of the eight water wall openings (shown in Figure 4). This penetration velocity is critical to maintain acceptable flyash LOI and exit gas carbon monoxide (CO) levels.

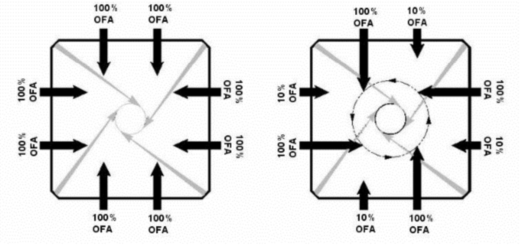


Figure 4: Overview of OFA System Distribution & Manipulation Capabilities

The key factor in combustion is to have sufficient oxygen to complete the combustion of the carbon in the ash, before carbon char is quenched below the ignition temperature in the boiler convection pass. Because most coal boilers were designed for 20% excess air, which is roughly a stoichiometry of 1.2, or about 20% additional air than the amount required to burn all of the hydrogen to water, and carbon to CO_2.

The key is having sufficient excess air in the furnace, consistent with the level of air/fuel balancing in the burner belt. Poorer balance requires more excess air to make up for the fuel rich zones in the furnace. Because of this, the 13 essentials previously noted are truly essential and put more of a demand on improving the "inputs" for combustion. In order to reduce NO_X to the goal of less than .32#/mmBtu's, a **F**an **B**oosted **O**ver-**F**ire **A**ir (FBOFA) system was installed. A general overview of the STI FBOFA system is as follows:

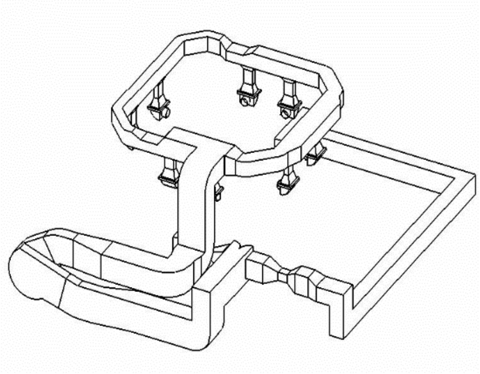


Figure 5: Westover 13's Installed Fan Boosted Over-fire Air System Fan & Ductwork Arrangement

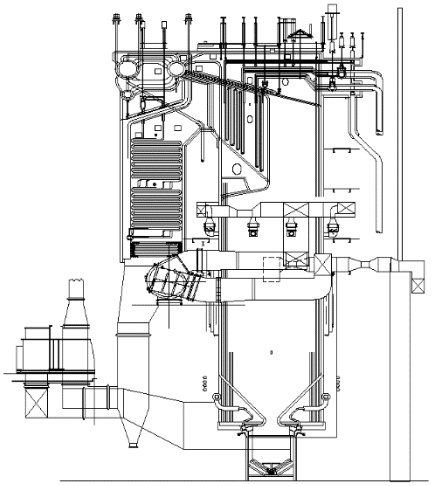


Figure 6: Westover 13 Side Elevation drawing show the Fan Boosted Over-fire Air System Fan "as installed."

PROJECT RESULTS

A summary of the major project results thus far are as follows. First of all table 1 below shows previous full load data showing the correlation between Excess air, LOI, and NO_X.

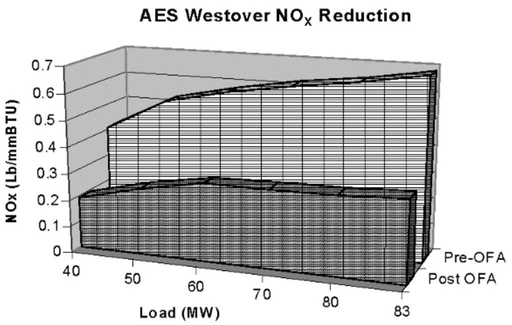
Year	Average LOI	NOx (Lb/mmBTU)
1989	3%	.61-.92
2002	>20%	.27-.54
Present	5-7%	.19-.33

Table 1: LOI vs. NO_X

The following data shown below are average data points collected following installation of the OFA and tuning period. However, currently, the boiler has been demonstrated much lower NO_X levels from operators tuning the system across the entire load range (0.18 - 0.20 Lb/MMBTU at 36 MW and 0.28 - 0.32 Lb/MMBTU at 88 MW's).

Net Load	Gross Load	OFA		Pre-OFA (2002 Ozone Season)		% Reduction	
MW	MW	lb/hr	lb/mmBtu	lb/hr	lb/mmBtu	lb/hr	b/mmBtu
40	43.0	124.8	0.304	159.7	0.409	21.8%	25.6%
50	53.5	155.5	0.309	226.8	0.441	31.4%	30.0%
60	64.0	186.2	0.313	293.8	0.474	36.6%	33.9%
70	74.5	216.9	0.318	360.9	0.506	39.9%	37.3%
80	85.0	247.6	0.322	428.0	0.539	42.1%	40.2%
83	88.0	256.4	0.323	447.1	0.548	42.7%	41.0%

Table 2: NO_X Project Performance Overview



STAGING OF FUEL AND AIR

The fuel and air were staged within the furnace both vertically and horizontally to utilize the entire furnace area. Staging vertically was performed by progressively setting the burner tilts downward, as shown below in Figure 6 showing a typical burner tilt arrangement.

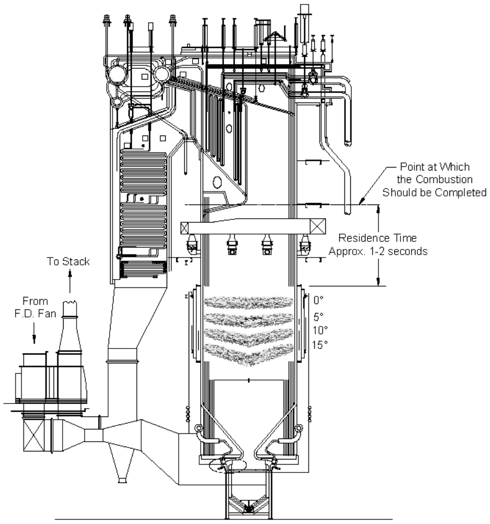


Figure 6

In order to achieve horizontal staging within the furnace, STORM Air Diverters were installed on the auxiliary air buckets. It is essential to maintain an oxidizing environment on the waterwalls to prevent waterwall wastage from occurring. By diverting a percentage of the secondary air toward the furnace walls both farther staging of the fuel and air and wastage prevention was achieved. The figure below shows the separation of the fuel and air required for staging for NO_X reduction.

CLOSING

All of the goals of this program were accomplished and the technical success of this project is once again the results of this joint efforts program in applying a systematic and comprehensive approach towards NO_X Reduction. Storm Technologies, Inc. would like to recognize the entire AES Westover team for excellence and commitment to this project.

REFERENCES

[1]"***NO_X Reduction without Low NO_X Burners***," Stephen K.Storm, Storm Technologies, Inc. & Maureen Moss, Savannah Electric Co., ASME Electric Power 2005.

[2]"***Testing Improves Results***," Stephen K.Storm, Daniel S. Storm, Sammy Tuzenew, Adam McClellan; Storm Technologies, U.S. Review of how testing can be utilized to optimize old PC fired boilers; World Coal Magazine, September 2004

[3] "***Conducting a Comprehensive Diagnostic Test on a Pulverized Coal Fueled Boiler***; Richard F. Storm, Stephen K. Storm, Sammy Tuzenew; World Coal Magazine, September 2003.

[4] "***Three Years of Operating Experience at a NOX limit of .33lbs/mmBtu with a Flyash Carbon Content of less than 5%***," G. Burney, P.E., E. Carden, R.F. Storm; 3rd Annual Unburned Carbon on Utility Flyash, 1997.

[5] "***Performance Optimization of a Boiler Equipped with Low NO_X burners***," G. Burney, P.E., M. Gallagher, M. Landseidel, R.F. Storm, P.E.; Power-Gen Paper; 1995

[6] "***Optimizing Combustion of a Boiler Equipped with Low NO_X Burners***," - R.F. Storm; McGraw-Hills Power Magazine; October 1993

[7] "***Pulverized Coal Boiler Optimization Through Fuel/Air Control***," B.E. Pulskamp, P.E., P.H. McGowen, R.F. Storm, PE; 30th Annual Kentucky Coal Utilization Conference, University of Kentucky; 1991

[8] "***A Practical Approach to Performance Optimization of Coal and Oil Fired Power Systems through Combustion Optimization***," R.F. Storm; Power Generation Committee – The Electric Council of New England; Portsmouth; New Hampshire, 1990.

[9] "***Coal Fired Boiler Performance Improvement Through Combustion Optimization***," R.F. Storm, T.J. Reilly; ASME Paper 87-JPGC-PWR-6; 1987

ASME International
Electric Power Conference 2005
April 5-7, 2005, Chicago, Illinois

PWR2005-50151

A COMPREHENSIVE APPROACH TO NO_X REDUCTION WITHOUT LOW NO_X BURNERS

Stephen K. Storm
Storm Technologies, Inc.
P.O. Box 429
Albemarle, North Carolina 28002, USA
Phone: (704) 983-2040
E-mail: skstorm1@aol.com

Maureen M. Moss
Savannah Electric
Plant McIntosh
P.O. Box 529
Rincon, Georgia 31326
E-mail: mmmoss@southernco.com

ABSTRACT

The traditional approach to reduce NO_X has been to retrofit and install commercially available "plug-in" Low NO_X burners. Typically, these use a combination of internal staging and are often used in conjunction with over-fire air to create off-stochiometric or staged combustion. That is, the complete combustion of the fuel occurs in several stages.

Often, well designed Low NO_X burners are installed without a comprehensive systems approach. The typical challenges associated with staged combustion are related to the fact that burner performance must be nearly perfect to complete combustion within the available residence time of the furnace. Specifically, attention to airflow measurement and control by use of reliable & repeatable venturis and with pulverizer performance optimization. To maintain or improve this unit's excellent reliability, a focus on optimizing the inputs and completing the combustion prior to the furnace exit was implemented.

The goals of this project were as follows:

1. NO_X Reduction from .78lb/mmBtu(full load) – 1.0#/mmBtu(low load) to less than 0.36 lb/mmBtu
2. Flyash Carbon Content less than 10%
3. Combustion Optimization
4. Minimal slagging
5. Maintain the same as baseline FEGT or reduce FEGT
6. Maximum Load Capability
7. Maximum Fuel Flexibility
8. Complete the project at the lowest cost per kW possible (with the best results)

All of the goals were accomplished. The technical success of this project is the results of applying a systematic and comprehensive approach beginning with raw coal feed to the pulverizers. The benefits of this total combustion optimization project is that later when additional NO_X reductions are required, they can be added as a complimentary change to the present system. For example, if this unit is later equipped with SNCR or SCR, reduced rates of ammonia will be required, there will be reduced "popcorn ash" production, and less SCR catalyst wear and overall unit improved performance and reliability.

INTRODUCTION

In January of 2003, intial Georgia SIP (State Implementation Plan) dictated that all coal fired plants above the 32nd parallel in Ga. Obtain 0.15 lbs/mmBtu NO_X by May 2005 during the ozone season (May-September). As an attempt to begin lowering the NO_X, Plant McIntosh researched the various strategies available. The results of this research was that typically units with no or standard over-fire air systems were not capable of achieving the desired NO_X levels without compromising unit deregulations, reliability and performance issues. Therefore, the goal of this program was to prove that NO_X reduction could be achieved without creating major performance & reliability issues. The plants NO_X reduction goal was to reduce the NO_X level to 0.35#/mmBtu **without** the installation of low NO_X burners by reducing NO_X with boosted & controlled over-fire airflow.

To remain competitive, the plant has undergone major fuel source changes and has implemented complimentary mechanical & operational changes. The primary changes are discussed within this paper. These changes utilize the 13 essentials of optimization as a punch list.

UNIT DESCRIPTION

McIntosh Unit No. 1 is located in Rincon, Georgia 26 miles NW of Savannah and is on the Savannah River. The unit consists of a 1968 vintage B&W front wall fired outdoor Carolina type radiant boiler with a balanced draft furnace 28' deep by 36' wide and 108' high from the roof to lower wall headers. This boiler design utilizes a 10'-0" deep division wall on the front side of the units separating the 4 wide x 4 high burner arrangement into two double columns of burners.

This front wall fired boiler is equipped with (4) MPS 67 coal pulverizers and has conventional circular register burners which were originally designed to maximize heat input with a small furnace volume with high turbulence and very high flame temperatures. The result of the burner and boiler design was the production of high levels of NO$_X$ above 1.0#/mmBtu. It should also be known that prior to this project, the NO$_X$ levels ranged from .78 (full load) – 1.0#/mmBtu (low load) while operating with a low full load excess O$_2$ set point of <2%. The unit as designed was for a MCR of 1,200,000lbs/hr. steam flow at 1990psi SH outlet pressure and with SH & RH temperatures of 1005°F supplied to a Westinghouse turbine rated at 175 MW output.

PERFORMANCE OVERVIEW

The overall unit performance, operability, load response, reliability, and capacity issues are all inter-related. The approach taken by Savannah Electric was to reduce NO$_X$ without affecting unit capability, performance or reliability. To minimize secondary combustion and the potential consequent superheater and reheater tube metals overheating, steps were taken to optimize the furnace inputs. To minimize water wall wastage in the lower furnace, fuel fineness, distribution and airflows were tuned to minimize wastage in the sub-stoichiometric firing zones.

This systems approach was implemented with an overall goal of maintaining competitive power production costs. Pulverizer optimization was implemented to provide acceptable fuel fineness and distribution with the most difficult fuels (but least expensive), which were of low HGI and required high fuel fineness for acceptable flyash LOI. The approach to combustion optimization was to incorporate the *13 essentials of optimum combustion* as a pre-requisite to the installation of a STORM® designed Boosted Over-Fire Air System.

The 13 essentials are as follows:

1. Furnace exit must be oxidizing, preferably 2-3%.
2. Fuel lines balanced to each burner by "clean-air" test ±2% or better.
3. Fuel lines balanced by "Dirty Air" test, using a Dirty Air Velocity Probe, within ±5% or better.
4. Fuel lines balanced by fuel flows within ±10% or better.
5. Fuel line fineness 75-80% passing a 200 mesh screen and <0.1% on a 50 mesh screen.
6. Primary airflow shall be accurately measured and controlled within ±3% accuracy.
7. Primary air/fuel ratio shall be correct and accurately maintained when above minimum.
8. Boosted Over-fire air shall be installed & controllable
9. Fuel line minimum velocities shall be 3,300fpm
10. Mechanical tolerances of burners and dampers within ±¼" or better.
11. Secondary air distribution to burners within ±5% to ±10%.
12. Fuel feed to the pulverizers smooth during load changes and measured & controlled as accurately as possible. Load cell equipped gravimetric feeders are preferred.
13. Fuel feed quality and size should be consistent. Consistent raw coal sizing to the pulverizers is a good start.

FIRING SYSTEM CHANGES

BURNERS (figure 1)

1. New Fuel line orifices were installed and ±2% balance was achieved
2. New Burner shrouds were installed for windbox equalization & increased pressure
3. New High strength/temperature refractory throats with ±1/4" tolerances
4. New high grade coal nozzle & igniter extensions were installed
5. Flame holders were attached to the nozzle extensions
6. New spinner/spreaders replaced the existing 75° impellers

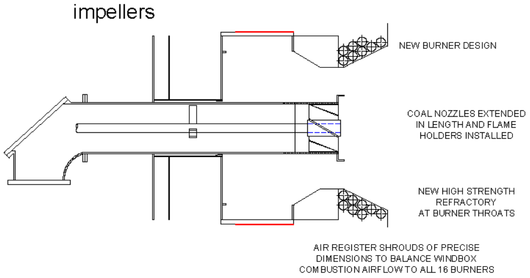


Figure 1: General burner overview

COAL PULVERIZERS (figure 2)

7. Coal pulverizer modifications

    a. Classifier and rotating throat modifications were made to allow operation with optimum air-fuel ratios and elimination of coal rejects.

    b. New primary airflow measuring venturis were installed for optimizing airflow measurement accuracy.

    c. New Gravimetric load cell coal feeder upgrades were installed for optimizing fuel flow measurement accuracy.

The following figure No. 2 details the MPS 67 Modifications

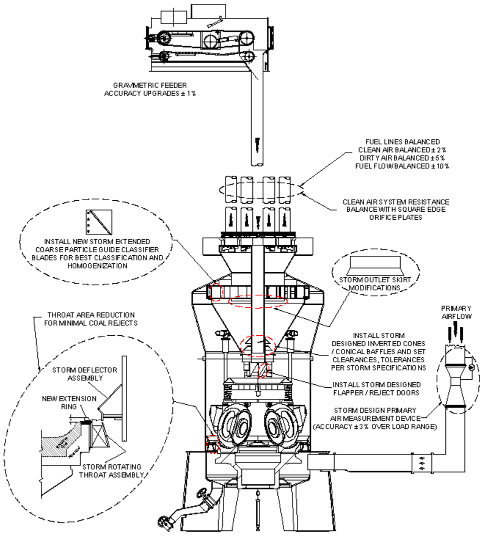


Figure 2: Pulverizer Optimization System Overview

BOOSTED OVER-FIRE AIRFLOW SYSTEM OVERVIEW

The key factor in combustion is to have sufficient oxygen to complete the combustion of the carbon in the ash, before carbon char is quenched below the ignition temperature in the boiler convection pass. Because most coal boilers were designed for 20% excess air, which is roughly a stoichiometry of 1.2, or about 20% additional air than the amount required to burn all of the hydrogen to water, and carbon to CO_2.

The key is having sufficient excess air in the furnace, consistent with the level of air/fuel balancing in the burner belt. Poorer balance requires more excess air to make up for the fuel rich zones in the furnace. Because of this, the 13 essentials previously noted are truly essential and put more of a demand on improving the "inputs" for combustion. In order to reduce NO_X to the goal of less than .36#/mmBtu's, a **F**an **B**oosted **O**ver-**F**ire **A**ir (FBOFA) system was installed. This was implemented in two phases. Phase I consisted of the upper ductwork and over-fire air ports as a traditional over-fire air system. Phase II was added one year later and incorporated the booster fan and control and measurement devices. A general overview of the FBOFA system is as follows:

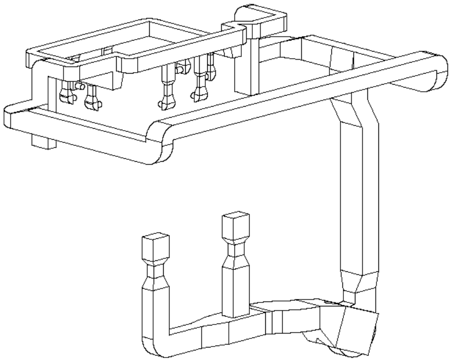


Figure 3: McIntosh Plants Boosted Over-fire Air System Overview

In it simplest form, this system takes pre-heated combustion air from the wind-box or secondary air ducts and boosts the air to strategically located nozzles. The nozzles are located above the burner zone. The airflow is metered and controlled for optimizing combustion and NO_X tuning. The following figure (no.4) shows how the dampers and venturis for each of the nozzles can be manipulated.

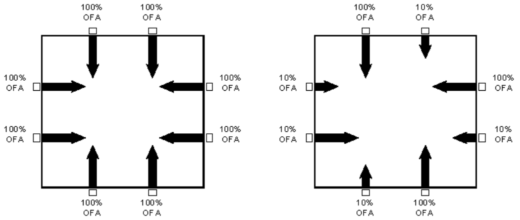


Figure 4: Overview of OFA System Distribution & Manipulation Capabilities

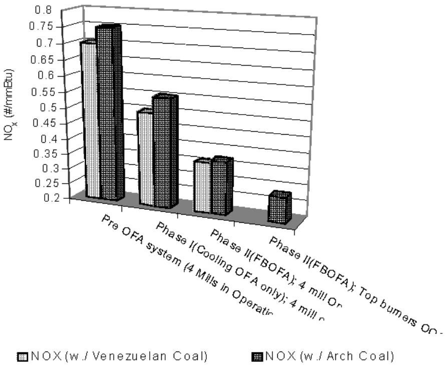
PROJECT RESULTS

A summary of the major project results thus far are as follows:

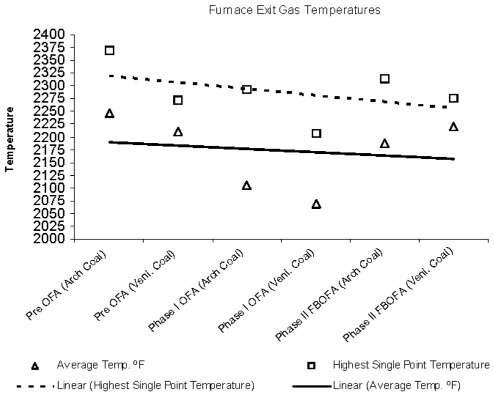
	Pre-NO_X Project (Full Load)	Post Phase II of NO_X Project (Full Load)
Coal Fineness	50 - 60% passing 200 Mesh (w/ <42 HGI)	75-80% passing 200 Mesh (w/ <42 HGI coals); Except "C" mill (at about 60% passing 200Mesh) - this mill has not been re-built with new components
Clean Airflow Balance	Distribution imbalances 5 - 10%	< 2%
Fuel Flow Balance	Distribution imbalances ±20%	Within or very near acceptable parameters of ±10%
Air-Fuel Ratios	Airflow & Fuel Flow measurement accuracy was inconsistent and A/F ratios were all >2.0lbs of air per lb of fuel across the mills load range	1.8lbs of air per lb.of fuel (after minum airflow is satisfied); All but "C" mill which is not yet modified.
Flyash LOI (%)	16% - 22% (w/ Eastern Bituminous Coals)	< 10% w/ Eastern Bituminous Coals & less than 15% LOI w/ low ash Venezuelan Coals
Furnace Exit Gas Temperatures	Very near 2,400°F peak temperatures with Averages at about 2,250°F	2,300°F peak temperature (w/ averages<2200°F)
NO_X	.78 - 1.0#/mmBtu	<.36#/mmBtu(4 mill operations); .28#/mmBtu(3 mill operations)

Table 1: NO_X Project Performance Overview

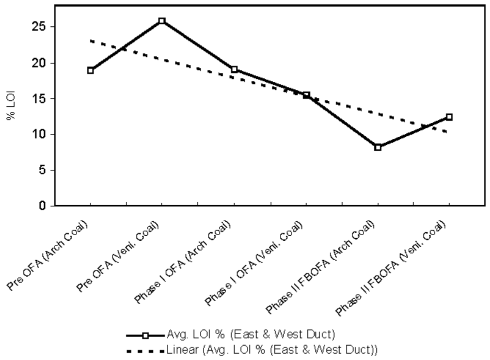
As stated within the table, the accomplishments & goals of the program was to reduce NO_X by greater than 50% without the installation of low NO_X burners while improving LOI with low Hard Grove Index(HGI) coals and without increasing the furnace exit gas temperatures. This was accomplished at a greatly reduced cost compared to other low NO_X options. A graphical overview of these major results can be seen in the three following graphs.



Graph 1: Phases of NO_X reduction



Graph 2: Furnace Exit HVT Data
(Al data collected at full load)



Graph 3: LOI Trend

SYSTEM OVERVIEW

In addition to the previous modifications, the plant has taken the initiative to implement numerous other modifcations to insure optimization from a systems approach. For example, some other recent system components installed at the site are as follows:

- FD fan cross over damper for secondary airflow distribution improvements if the APH differential affects air distribution into the Air heaters.
- CO monitors at the Economizer Outlet
- Furnace viewing Cameras
- Online FEGT Monitors

Combustion Optimization and performance preservation is an ongoing & continuous program. The plant is investigating phase III which will posibly consist of fuel blending with PRB and/or installation of SNCR to lower the levels to at least 0.15#/mmBtu.

Due to the plant having such a synergistic team of capable technical personnel, Savannah Electric was able to install the existing Low NO_X modifications at a very low cost per kW This low cost, but high performance system was the most effective for reliability and environmental friendliness.

For review, a total system overview drawing is as follows:

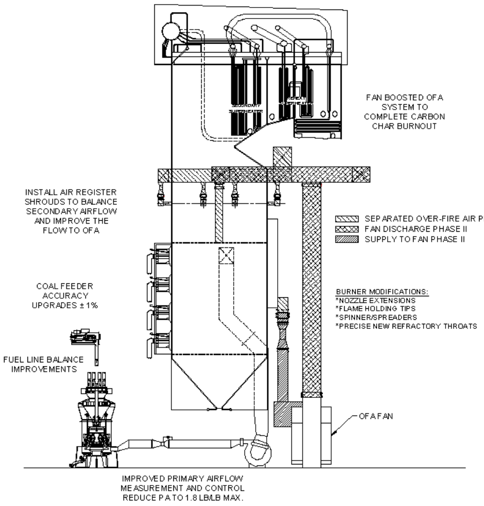


Figure 5: Total System Overview Drawing

ACKNOWLEDGMENTS

The experience of the authors is such that some of the major challenges in the power industry seem to be controllable by human performance and the ability of plant management, engineering, operations & maintenance personnel to understand the fundamentals & essentials of optimizing combustion & overall plant performance.

Storm Technologies recognizes that Savannah Electric was wholly committed to this project. The operational results and cost effectiveness of the system reflect this commitment.

REFERENCES

[1]"***Testing Improves Results***," Stephen K.Storm, Daniel S. Storm, Sammy Tuzenew, Adam McClellan; Storm Technologies, U.S. Review of how testing can be utilized to optimize old PC fired boilers; World Coal Magazine, September 2004

[2] "***Conducting a Comprehensive Diagnostic Test on a Pulverized Coal Fueled Boiler***; Richard F. Storm, Stephen K. Storm, Sammy Tuzenew; World Coal Magazine, September 2003.

[3] "***Three Years of Operating Experience at a NOX limit of .33lbs/mmBtu with a Flyash Carbon Content of less than 5%***," G. Burney, P.E., E. Carden, R.F. Storm; 3rd Annual Unburned Carbon on Utility Flyash, 1997.

[4] "***Performance Optimization of a Boiler Equipped with Low NO_X burners***," G. Burney, P.E., M. Gallagher, M. Landseidel, R.F. Storm, P.E.; Power-Gen Paper; 1995

[5] "***Optimizing Combustion of a Boiler Equipped with Low NO_X Burners***," - R.F. Storm; McGraw-Hills Power Magazine; October 1993

[6] "***Pulverized Coal Boiler Optimization Through Fuel/Air Control***," B.E. Pulskamp, P.E., P.H. McGowen, R.F. Storm, PE; 30th Annual Kentucky Coal Utilization Conference, University of Kentucky; 1991

[7] "***A Practical Approach to Performance Optimization of Coal and Oil Fired Power Systems through Combustion Optimization***," R.F. Storm; Power Generation Committee – The Electric Council of New England; Portsmouth; New Hampshire, 1990.

[8] "***Coal Fired Boiler Performance Improvement Through Combustion Optimization***," R.F. Storm, T.J. Reilly; ASME Paper 87-JPGC-PWR-6; 1987