LG&E/KU – Mill Creek Station

Phase II Air Quality Control Study

Materials of Construction

February, 2011
Revision B – Client Review

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1.0 Introduction

The Mill Creek Station is located in southwestern Jefferson County, approximately 10.5 miles southwest of the city of Louisville, Kentucky, on a 509 acre site. Mill Creek Station includes four coal fired electric generating units with a gross total generating capacity of 1,608 MW. All four boilers fire high sulfur bituminous coal (i.e., high sulfur western Kentucky bituminous coal from Illinois Basin, natural gas for startup). Each Mill Creek Station unit includes one GE reheat tandem compound, double-flow turbine with a condenser and hydrogen-cooled generator. Units 1 and 2 each consist of one Combustion Engineering subcritical, balanced draft boiler and have a gross capacity of 330 MW each. Units 1 and 2 are equipped with LNBs and OFA for NO_x control, a CS-ESP for PM control, and a WFGD for SO_2 and HCl (hydrogen chloride) control. Units 3 and 4 each consist of one Babcock & Wilcox (B&W) balanced draft, Carolina type radiant boiler and have a gross capacity of 423 MW and 525 MW, respectively. Each is equipped with LNBs and SCR for NO_x control; a CS-ESP for PM control and a WFGD for SO_2 and HCl control.

The following Air Quality Control (AQC) technologies were evaluated to ensure that there is compliance with the emissions reductions that are required to meet future regulations:

- Pulse Jet Fabric Filter (PJFF) with sorbent (trona/lime) injection on Units 1-4.
- Selective Catalytic Reduction (SCR) on Units 1 and 2.
- Refurbishing or replacing wet scrubbers on Units 1, 2 and 4, including using Unit 4's scrubber for Unit 3.
- New Wet Flue Gas Desulfurization (WFGD) on Unit 4.
- Powdered activated carbon (PAC) injection on Units 1-4.

This document states the materials of construction for different AQC equipment.

2.0 Materials of Construction

This section describes details of materials of construction for each of the air quality control equipment described in Section 1.0. The equipment stated in this section includes WFGD, PJFF, SCR, sorbent injection and PAC injection.

2.1 Wet Flue Gas Desulfurization (WFGD)

A WFGD system can be divided into several zones. These zones are shown on Figure 2-1 and their relative environmental conditions are described in Table 2-1. Not shown in the figure are the process tanks (e.g., hydrocyclone underflow transfer tank, hydrocyclone overflow tank), tank agitators, hydrocyclones, process pumps (e.g., recycle pumps, slurry bleed pumps, underflow transfer pumps, chloride bleed pumps), and process piping. The agitators, pumps, and piping associated with each zone typically have the same environmental characteristic of that zone with the exception of the erosion potential.

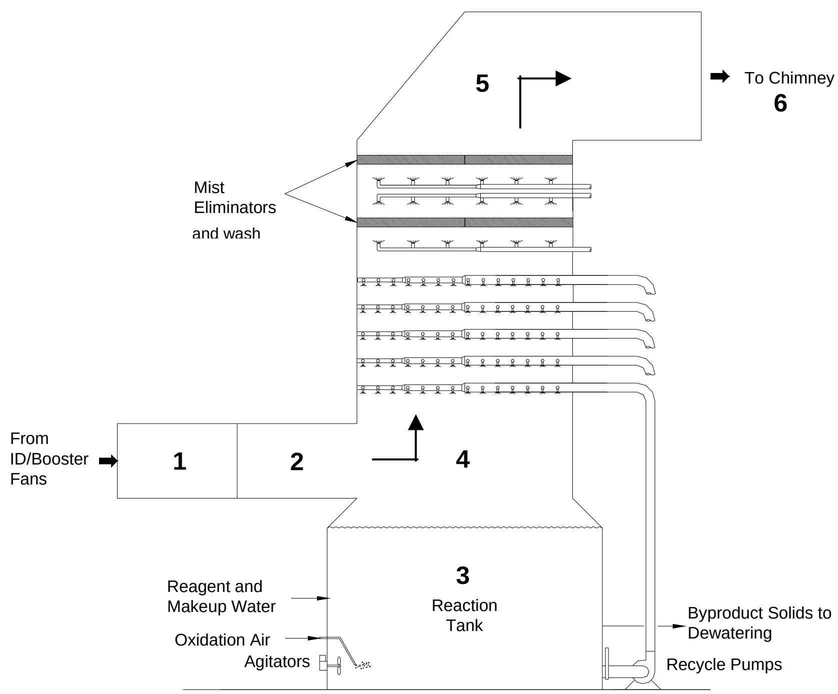

Figure 2-1
WFGD Operating Environment Zones

Table 2-1
WFGD Zones and Environmental Conditions

Zone	Location	Environmental Conditions			
		Scaling	**Corrosive**	**Abrasive**	**Temperature**
1	Gas inlet duct	No	No	No	Dry, 250 to 370° F Excursions to 800° F
2	Inlet duct and quench zone (wet-dry zone)	High	Severe	Moderate	Wet, 125 to 135° F Excursions to 800° F
3	Reaction tank	Moderate	Moderate to high	Moderate	125 to 135° F
4	Spray zone	Moderate	Moderate to high	High	Wet, 125 to 135° F Excursions to 800° F
5	Mist Eliminator /outlet ductwork	Low to moderate	High	Low	Wet, 125 to 135° F Excursions to 800° F
6	Chimney	Low	High	Low	Wet, 125 to 135° F Excursions to 800° F
	Process tanks	Low	Moderate	Moderate	75 to 135° F
	Tank agitators	Low	Moderate	Moderate	100 to 135° F
	Slurry pumps	Low	Moderate	Moderate to high	100 to 135° F
	Process piping	Low	Moderate	Low to high	100 to 135° F

The following subsections discuss the materials of construction for each operating zone of the WFGD system, based on a maximum chloride level of 12,000 mg/L. A maximum of 12,000 ppm chloride concentration in the recycle slurry is currently assumed as the base design point for this project and would result in the recommended materials for this project.

2.1.1 Zone 1--Flue Gas Inlet Ductwork

The flue gas inlet ductwork is the area of ductwork that remains dry and does not see much exposure to moisture from the absorber or reduced temperature. This dry interface typically ends at a point 10 to 15 feet upstream of the actual absorber inlet or where water or slurry is injected into the flue gas. The hot, dry environment of this section of duct work allows use of standard carbon steel plate which is adequate for this service.

2.1.2 Zone 2--Inlet Breeching and Quench Zone (Wet-Dry Zone)

This zone extends from end of the inlet ductwork to the absorber module. This zone presents the most severe operating conditions in the WFGD system. It is subject to both high and low fluctuating temperatures and has a strong potential for formation of slurry deposits on the wet/dry interface.

The materials that have demonstrated extended life for most WFGD applications in this zone are corrosion-resistant (and expensive) nickel alloys such as Alloy C-276 and higher. Solid alloy plate is considered to be suitable for this service, especially in the wet/dry interface area. A more design specific approach can be considered when a Stebbins (ceramic tile manufactured by Stebbins Engineering and Manufacturing Company) lined concrete absorber vessel is chosen as the base design utilizing Pennguard block (Pennguard block is a light-weight, closed-cell, borosilicate glass foam lining produced by Hadek Protective System) to line the concrete inlet ductwork in this zone. A minimum of 3/16" thick solid C-276 alloy plate is recommended as the material of construction for this wet-dry interface duct.

2.1.3 Zone 3--Reaction Tank

This zone presents less severe operating conditions than the other zones in the WFGD module. The materials here are not as severely exposed to varying temperatures, and erosion is relatively limited in the tank itself.

Duplex stainless steels such as Alloy 2205 and Alloy 255 can be used for maximum chlorides levels up to 12,000 mg/L.

Lined carbon steel (either rubber-lined or resin-lined), epoxy and vinyl ester linings, resin lining (flakeglass reinforced polyester or epoxy lining), duplex stainless steels lining and 6 percent molybdenum stainless steel (e.g., Alloy 6XN) and nickel alloys would be suitable lining materials for this service.

2.1.4 Zone 4--Spray Zone

The operating conditions in Zone 4 are similar to those in Zone 3 with the additional factor for consideration of abrasion from falling slurry or slurry spray impingement. Resin-lined carbon steel, duplex stainless steel, 6 percent molybdenum stainless steel, and nickel alloy-clad carbon steel are feasible metallic alternatives for this area.

The main spray headers in this area can be fabricated of FRP pipe with an erosion resistant exterior coating, or of a duplex stainless steel. The slurry spray nozzles are fabricated of extremely erosion/corrosion resistant silicon carbide in all major WFGD vendors' designs.

2.1.5 Zone 5--Mist Eliminator and Outlet Ductwork

Zone 5 is not exposed to slurry spray impingement. Generally, the same materials used in Zones 3 and 4 are used in the absorber walls at the mist eliminator (ME) location and absorber outlet.

ME blades and supports can be typically fabricated out of polypropylene, polysulfone, 300 series stainless steel or FRP.

ME wash headers can be fabricated of FRP or a metallic alloy pipe. The outlet duct to the chimney can be fabricated of resin-lined carbon steel, 6 percent molybdenum stainless steel, FRP, or nickel alloy-clad carbon steel.

Pennguard block-lined (borosilicate foamed glass block) carbon steel is an alternative in this area as well. Internal bracing in wet ductwork can be fabricated of carbon steel wrapped with nickel alloy sheets or of nickel alloy-clad carbon steel sheets formed into pipe.

2.1.6 Zone 6--Chimney

Refer to the Chimney Analysis for materials of construction recommendations.

2.1.7 Process Tanks

Hydrocyclone underflow transfer tank and hydrocyclone overflow tank are exposed to corrosive conditions because of the presence of elevated levels of chlorides. Resin-lined carbon steel, FRP and Stebbins tile is the most commonly applied material for these tanks.

2.1.8 Agitators

Agitators may be either of the side-entry or top-entry type. Either type may be used in the absorber module's reagent tank. For top-entry agitators, when chlorides are kept below 12,000 mg/L, a duplex stainless steel may be used for both shaft and impellers.

The side-entry agitator's typical material of construction for both impeller blades and shafts is duplex stainless steel or 6 percent molybdenum. Rubber linings are not suitable because of the dynamic forces imposed by the high rotational rates.

2.1.9 Slurry Pumps

Horizontal centrifugal slurry pumps are offered with bolt-in casing liners of either rubber or hard, high-chromium cast iron or, less frequently, with hard metal casings without a lining. Horizontal pump impellers may be either a very hard, high-chromium cast iron or rubber-covered cast iron.

2.1.10 Process Piping

The two materials that have been historically applied to WFGD process piping are rubber-lined carbon steel and abrasion-resistant FRP.

Stainless steel process piping has been applied in a few existing WFGD systems, specifically as internal spray headers in most cases. HDPE pipe has also been applied in specific WFGD applications.

Table 2-2 provides an overview of the resistance to the various operating environments offered by each of the common materials of construction along with their relative advantages and disadvantages. Extra caution must be exercised when using rubber lined piping.

Table 2-2
Characteristics of Available Materials of Construction

Material	Resistance: Corrosion	Resistance: Erosion	Resistance: Temp.	Advantages	Disadvantages	Typical Applications	Other Considerations
Rubber-lined carbon steel	Excellent, not affected by Cl	Very good	Limited to <150° F	• Corrosion/ erosion resistance. • Good erosion protection	• Flammable. • Delamination. • 15+ yr life. • Requires periodic repair	Zones 3 and 4. Slurry piping and pumps. Storage tank and agitator coatings.	Delamination can plug downstream equipment.
Resin-lined carbon steel	Excellent, not affected by Cl	Fair to good	Limited to <150° F	• Corrosion resistance. • Low cost.	• 10-15 yr life. • Susceptible to thermal damage. • Requires periodic repair	Zones 3, 4, and 5. Storage tank coatings.	Life very sensitive to installation QA.
Pennguard block lined carbon steel	Excellent, not affected by Cl	Very poor	Limited to <450° F	• Corrosion resistance. • Ease of installation.	• Susceptible to physical damage.	Zone 5 ductwork and Zone 6.	Provides thermal insulation.
317 LMN stainless steel	Fair, 8,000 to 10,000 mg/L Cl	Good	Within FGD design range	• Moderate cost. • 30+ yr life.	• Limited corrosion resistance.	Zones 3, 4, and 5 (not ductwork). Storage tanks.	
22% Cr duplex stainless steel (Alloy 2205)	Good, 12,000 to 15,000 mg/L Cl	Good	Within FGD design range	• Improved corrosion resistance. • 30+ yr life.	• Higher initial capital cost.	Zones 3, 4, and 5 (not ductwork). Storage tanks.	
25% Cr duplex stainless steel (Alloy 255)	Good, 20,000 mg/L Cl	Good	Within FGD design range	• Improved corrosion resistance. • 30+ yr life.	• Higher initial capital cost.	Zones 3, 4, and 5 (not ductwork). Storage tanks.	

Table 2-2 (Continued)
Characteristics of Available Materials of Construction

Material	Resistance			Advantages	Disadvantages	Typical Applications	Other Considerations
	Corrosion	Erosion	Temp.				
6% Mo stainless steel (Alloy 6XN)	Very good, 40,000 mg/L Cl	Good	Within FGD design range	• Improved corrosion resistance. • 30+ yr life.	• Higher initial capital cost.	Zones 1, 3, 4, and 5. Storage tanks.	
Nickel alloy plate (C-276)	Excellent, 50,000 mg/L Cl	Good	Within FGD design range	• Improved corrosion resistance. • 30+ yr life.	• Highest initial capital cost.	Zones 2, 3, 4, 5, and 6.	Best choice for locations with both high temp and very high Cl.
Nickel wallpaper on carbon steel	Excellent, 50,000 mg/L Cl	Good	Within FGD design range	• Improved corrosion resistance. • 30+ yr life.	• Much higher initial capital cost. • Difficult to detect leaks.	Zones 3, 4, 5, and 6.	Welding QA procedures critical to success. Not suitable for submerged service.
Nickel alloy-clad carbon steel	Excellent, 50,000 mg/L Cl	Good	Within FGD design range	• Improved corrosion resistance. • 30+ yr life.	• Much higher initial capital cost.	Zones 3, 4, 5, and 6. Storage tanks.	Welding QA procedures critical to success.
Fiberglass reinforced plastic (FRP)	Excellent, not affected by Cl	Fair	Limited to <200° F	• Improved corrosion resistance. • 30+ yr life.	• Less experience (vessels). • Higher initial capital cost.	Zones 3, 4, 5, and 6. Slurry piping and storage tanks.	
Stebbins tile	Excellent, not affected by Cl	Excellent	Limited to <250° F	• Improved corrosion resistance. • 30+ yr life.	• Less experience. • Higher initial capital cost.	Zones 3, 4, and 5 (not ductwork). Storage tanks.	Thicker walls created, must protect underlying support surface from liquid contact

2.2 Pulse Jet Fabric Filter (PJFF)

The casing of the PJFF shall be made up of carbon steel. PJFF uses fabric bags as filters to collect particulate.

2.2.1 PJFF Bag Cages

PJFF bag cage material is very important to overall performance and durability of the filter bags. The cages feature evenly spaced rings and wires, with a rounded bottom pan to help ensure proper filter bag fit.

Low carbon steel (bright basic wire), Galvanized low carbon steel, Type 304 stainless steel, Type 316 stainless steel can be used for the construction of fabric filter cages. The cages can also be enamel coated.

2.2.2 PJFF Bag Casings

PJFF bag casings are typically made up of carbon steel. Table 2-3 shows a summary of the materials of construction for different parts of PJFF.

Table 2-3
PJFF Material of Construction

Component	**Material**
Casing plate, stiffeners, and baffles	ASTM A36
Ductwork plates and shapes	ASTM A36
Hoppers	ASTM A36
Structural steel	ASTM A36
Miscellaneous steel	ASTM A36
Steel pipe for interior stiffeners	ASTM A53 Schedule 80 minimum
High strength shop and field bolts, including nuts and washers	ASTM A325
Hot-dip galvanizing	ASTM A123, A153, and A385
Mechanical galvanizing (load indicating washers only)	ASTM B695
Instrument valve manifold bodies and trim	316 stainless steel

2.2.3 PJFF Bags

Table 2-4 specifies the most popular styles of fabric for PJFF bags and the conditions they are most suited to handle.

Table 2-4
PJFF Bags Material

Fabrics	Polypropylene	Acrylic	Polyester	PPS	Aramid	P84	Fiberglass	Teflon
Maximum Continuous Operating Temperature, ºF	170	265	275	375	400	356-500	500	500
Abrasion	Excellent	Good	Excellent	Good	Excellent	Fair	Fair	Good
Energy Absorption	Good	Good	Excellent	Good	Good	Good	Fair	Good
Filtration Properties	Good	Good	Excellent	Excellent	Excellent	Excellent	Fair	Fair
Moist Heat	Excellent	Excellent	Poor	Good	Good	Good	Excellent	Excellent
Alkalines	Excellent	Fair	Fair	Excellent	Good	Fair	Fair	Excellent
Mineral Acids	Excellent	Good	Fair	Excellent	Fair	Good	Poor	Excellent
Oxygen (15%+)	Excellent	Excellent	Excellent	Poor	Excellent	Excellent	Excellent	Excellent

2.2.4 PJFF Air Dryers

Table 2-5 shows the materials of construction for for air dryers.

Table 2-5
PJFF Air Dryer Materials

Component	Material
Mineral fiber thermal insulating cement	ASTM C195
Heat reactivated dryer heating elements, alloy cladding	UNS N08810
Heat reactivated dryer insulation for external reactivation heater and purge piping	ASTM C533
Insulation jacketing	ASTM B209 Alclad 3004, or acceptable equal
Inlet and outlet flanges	ASTM A105 or A181

2.2.5 PJFF Air Compressors

Table 2-6 shows the materials of construction for air compressors.

Table 2-6
PJFF Air Compressor Materials

Component	Material
Intercooler and aftercooler	
Tubes	Copper, ASTM B111
Tubesheets	Brass, ASTM B36
Oil cooler	
Tubes	Copper, ASTM B111
Tubesheets	Brass, ASTM B36
Shell and heads	ASME SA285 Grade C
Nozzles	ASME SA106 Grade B
Flanges	ASME SA105

2.3 Selective Catalytic Reduction (SCR)

Selective Catalytic Reduction (SCR) systems are the most widely used post-combustion NO_x control technology for achieving significant reductions in NO_x emissions. In SCR systems, vaporized ammonia (NH_3) injected into the flue gas stream acts as a reducing agent, achieving NO_x emission reductions when passed over an appropriate amount of catalyst.

2.3.1 SCR Reactor

The SCR reactor is the housing for the catalyst. The reactor is basically a widened section of ductwork modified by the addition of gas flow distribution devices, catalyst, catalyst support structures, access doors, and soot blowers.

Typically, carbon steel shall be used to build SCR reactor. Material which comes in contact with vaporized ammonia which is used as a reagent shall be 304 stainless steel. At temperatures above 825 ^{0}F alloy steel shall be used.

2.3.2 SCR Catalyst

The conventional SCR catalysts are either homogeneous ceramic or metal substrate coated. The catalyst composition is vanadium-based, with titanium included to disperse the vanadium catalyst and tungsten added to minimize adverse SO_2 and SO_3 oxidation reactions.

2.3.3 SCR Ammonia System

The ammonia reagent for the SCR systems will be supplied by anhydrous ammonia.

Table 2-7 shows summary of the materials used for different sections in SCR.

Table 2-7
SCR Material of Construction

Component	**Material**
SCR Reactor	Carbon Steel or Alloy Steel
SCR Catalyst	Vanadium, Titanium, Tungsten
Material in contact with vaporized ammonia	304 stainless steel
Piping in contact with vaporized ammonia	304 stainless steel

2.4 PAC and Sorbent Injection

2.4.1 Storage Silo (PAC and Hydrated Lime/ Trona)

Table 2-8 shows the materials of construction for storage silos.

Table 2-8
Sorbent Injection Storage Silo Materials

Component	**Material**
Silos or Bins, Support Steel, and Accessories	
Plates	ASTM A36/A36M*
Shapes	ASTM A36/A36M* or A992/A992M*
Plates	ASTM A572/A572M Grade 50*
Shapes	ASTM A572/A572M Grade 50* or A529/A529M Grade 50* or A992/A992M*
Temporary Erection Bolts	ASTM A307 bolts with compatible washers and nuts
Structural Bolts	ASTM A325 Type 1 bolts with compatible F436 hardened washers, A563 heavy hex nuts and F959 direct tension indicators
Surfaces which by service will be subject to corrosive attack by stored or processed material shall be protected by a suitable permanent lining or be constructed of material suitably resistant to attack.	

2.4.2 Storage Silo accessories (PAC and Hydrated Lime/ Trona)

Table 2-9 shows the materials of construction for storage silos accessories.

Table 2-9
Sorbent Injection Storage Silo Accessories Materials

Component	Material
Silo housing	ASTM A36 steel
Vent filter bag cages	Options include galvanized, epoxy coated, and stainless steel
Vent filter housing	Mild steel
Vent filter tubesheet	Mild steel
Vent filter pulse air venturi	Aluminum
Vent filter bag material	Polyester, Nomex, Gore Tex 14 or 16 oz

2.4.3 Pneumatic Conveying System (PAC and Hydrated Lime/ Trona)

Table 2-10 shows the materials of construction for pneumatic conveying system.

Table 2-10
Sorbent Injection Pneumatic Conveying System Materials

Component	Material
Pneumatic transporting piping	ASTM A106 Grade B, carbon steel, schedule 40 for large bore, schedule 80 for small bore
In-duct injection lances and supports	304L stainless steel (UNS S30403)
Elbows (in the piping)	Ceramic-lined abrasion and wear resistant material

3.0 Summary

For the WFGD system, a maximum of 12,000 ppm chloride concentration in the recycle slurry is currently assumed as the base design point for this project and would result in the recommended materials for this project:

1. Zone 1: Carbon Steel
2. Zone 2: Solid C-276 Alloy
3. Zone 3: Alloy 2205 and Alloy 255
4. Zone 4: Alloy 2205
5. Zone 5: FRP

Higher chloride concentration in the recycle slurry could be considered if the treatment cost savings for the reduced wastewater flow rate can justify the increased material costs for the WFGD system necessitated by higher corrosion resistance required or if water usage restrictions are imposed on the site. A detailed study may be required to address this issue in further details.