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Establishment of an Environmental Control Technology laboratory with a Circulating Fluidized-Bed Combustion System

Quarterly Technical Progress Report

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ABSTRACT

This report is to present the progress made on the project entitled "Establishment of an Environmental Control Technology Laboratory (ECTL) with a Circulating Fluidized-Bed Combustion (CFBC) System" during the period January 1, 2007 through March 31, 2007. The effort in this quarter has concentrated on installing the CFBC Facility and for conducting cold fluidization operations tests in the CFBC facility. The assembly of the ash recirculation pipe duct from the cyclones back to the bed area of the combustor, including the upper and lower loop seals was completed. The electric bed pre-heater was installed to heat the fluidizing air as it enters the wind box. The induced draft fan along with its machine base and power supply was received and installed. The flue gas duct from secondary cyclone outlet to induced draft fan inlet was received and installed, as well as the induced fan flue gas discharge duct. Pressure testing from the forced draft fan to the outlet of the induced fan was completed. In related research a pilot-scale halogen addition test was conducted in the empty slipstream reactor (without (Selective Catalytic Reduction) SCR catalyst loading) and the SCR slipstream reactor with two commercial SCR catalysts. The greatest benefits of conducting slipstream tests can be flexible control and isolation of specific factors. This facility is currently used in full-scale utility and will be combined into 0.6MW CFBC in the future. This work attempts to first investigate performance of the SCR catalyst in the flue gas atmosphere when burning Powder River Basin (PRB), including the impact of PRB coal flue gas composition on the reduction of nitrogen oxides (NOx) and the oxidation of elemental mercury (Hg(0)) under SCR conditions. Secondly, the impacts of hydrogen halogens (Hydrogen fluoride (HF), Hydrogen chloride (HCl), Hydrogen Bromide (HBr) and Hydrogen Iodine (HI)) on Hg(0) oxidation and their mechanisms can be explored.

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1. EXECUTIVE SUMMARY

The effort in this quarter concentrated on the assembly of the (CFBC) facility components and the preparation of the facility for cold fluidization operation. The assembly of the ash recirculation pipe duct from both cyclones back to the bed area of the combustor, including both loop seals was completed. The electric bed pre-heater was installed so that all fluidizing air may be routed through it to effectively heat the initial bed material charge to a temperature well above the kindling temperature of the fuel. During normal operation, fluidizing air bypasses the pre-heater. The secondary combustion air blower, variable speed drive and power supply were installed. Design is underway for controlling and measuring the distribution of four levels of secondary air injection. Additionally, the induced draft fan was received and installed on its machine base. The induced draft fan was connected to a variable speed drive and power supply. Full speed operation was attained. Finally, the flue gas duct from the discharge of the secondary cyclone to the inlet of the induced draft fan and the entire discharge duct from the induced draft fan has been assembled and pressure tested. Differences in NOx reduction and Hg(0) oxidation by two commercial SCR catalysts was investigated. Ammonia (NH_3) addition seemed to inhibit Hg(0) oxidation, which indicated competitive properties between NH_3 reduction and Hg(0) oxidation on the surface of SCR catalysts. The sequence of hydrogen halogens, according to their impacts on the Hg(0) oxidation, were HBr, HI, and HCl or HF. The addition of HBr at approximately only 3 ppm could achieve 80 % Hg(0) oxidation (the baseline Hg(0) oxidation as about 30%). The addition of HI at approximately 5 ppm could achieve 40 % Hg(0) oxidation. With comparison, 40 % Hg(0) oxidation could be achieved when HCl addition needed to be up to 300 ppm. The impact of HF addition seemed to follow the same trend as that of HCl. The enhanced Hg(0) oxidation by addition of HBr and HI seemed not to be correlated to the catalytic effects by both SCR catalysts.

2. EXPERIMENTAL

2.1 Installation of the CFBC Facility

Installation of the circulating fluidized-bed combustor (CFBC) facility continued during this period. The specific tasks included the following:

a) All ash recirculation ducts were properly sized as to length, aligned and assembled with five thermal expansion joints adjusted to room temperature design dimensions.
b) Along with control ports, both loop seals were installed in ash recirculation ductwork. The lower loop seal is one support point for the hot ash recirculation ductwork.
c) The cold ash supply duct was properly sized as to length, aligned and assembled, along with one thermal expansion joint adjusted to room temperature design dimensions.
d) The induced draft fan was installed on its machine base. The power supply and variable speed drive have been connected and the fan was tested at full speed (with intake blocked) with satisfactory results.
e) The pressure gauges and manometers were received for the initial measurement of the forced draft fan discharge pressure, wind box pressure, differential pressure across the bubble plate and pressures along the riser sections and flue gas ducts, all as preparation for cold fluidization operational tests.
f) The flue duct components from secondary cyclone to induced draft fan inlet and from the induced draft fan discharge were received and assembled.
g) The flue gas tempering valve was received and will be installed near the induced draft fan inlet to maintain the temperature at the fan inlet less than 700 °F and to make optimal use of fan performance curve.
h) An in-line 36 KW electric air heater was installed in one of two combustion air ducts supplying the wind box and is used to convey heat to the initial bed charge, increasing it to well above the kindling temperature of the fuel to be utilized. During the bed pre-heating phase, the main combustion air duct is closed by an actuated valve, thus forcing all fluidizing air to pass through the heater. This valve is opened after bed pre-heating is completed to provide less restriction to primary combustion airflow.
i) Bunker weighing load cells for measuring the flow rate of up to two fuel supplies and of bed material were received, along with electronic summers and power

supplies. Data from load cells will be transmitted to the process control data logging computer.

j) Supply ducts, two thermal expansion joints, two flow proving sensors and two rotary air-lock valves were installed on supply side of combustor.

k) The primary and secondary combustion air flow sensors were ordered for use in the cold fluidization tests. Delivery is expected by May 1, 2007.

l) All riser and flue gas ductwork thermocouples have been ordered and received.

m) The advanced design of coolant system was completed. The coolant system reservoir level control has been received. Most piping supplies and still well tank have been received. The gas/liquid phase separator tank was ordered. Delivery is expected by June 15, 2007.

n) The cooling water treatment system was designed and the raw water supply for treated water system has been constructed. The reverse osmosis unit was ordered Delivery is expected by May 1, 2007.

Table 1 lists all construction tasks and the estimated percent complete for each.

Table 1. CFBC Construction Progress Information

Task Area	Specific Activities	Estimated Percent Completed
Ash (Hot & Cold) Supply Ducts	Assemble Ducts, Solids Bend, Thermal Exp. Joints, Loop Seals	**100**
Primary Cyclone Support	Assemble support, align to ash ducts and secondary cyclone	**100**
Secondary Cyclone Support	Assemble support, align to ash ducts	**100**
Fuel/Bed Material Supply Ducts	Assemble Ducts, Rotary Valves, Windows, Thermal Exp. Joints	**80**
ID Fan	Parameters established, Initiate RFQs, Purchase, Install	**100**
ID Fan Variable Speed Drive (VSD)	Parameters established, Initiate RFQs, Purchase, Install	**100**
Lower Loop Seal Flow Control	Determine required control properties	**10**
Upper Loop Seal Flow Control	Determine required control properties	**10**
Secondary Combustion Air Blowers	Confirm Parameters, Initiate RFQs, Purchase	**100**
Secondary Air Variable Speed Drives (VSD)	Establish Parameters, Initiate RFQs, Purchase, Install	**100**
Secondary Air Control Valves	Establish Parameters, Initiate RFQs, Purchase, Install	**85**
Ash Bunker Auger	Specify Auger Design, Order, Install	**60**
Ash Bunker Auger Drive	Confirm Parameters, Initiate RFQs, Purchase, Install	**60**
Ash Bunker Auger Power Supply	Establish Parameters, Initiate RFQs, Purchase, Install	**50**
Ash Supply Auger Tube	Determine if on site, proceed from this finding	**100**
Ash Supply Bunker Auger	Mass Flow establised, Establish other Parameters, Intiate RFQs	**40**
Flue Duct: Secondary Cyclone to ID Fan	Duct: Design, Specify, Purchase, Install	**100**
ID Fan Discharge Duct	Duct: Design, Specify, Purchase, Install	**95**

Lower Loop Seal Flow Control	Provide controlled compressed air, piping & computer control	**5**
Upper Loop Seal Flow Control	Provide controlled compressed air, piping & computer control	**5**
Pressure & Temperature Sensors	Specify Components, Purchase	**75**
Rotary Air Lock Valve Drives	Determine Locations, Specify, Initiate RFQs, Purchase	**50**
Rotary Air Lock Valve Drive Power Supplies	Parameters established, Initiate RFQs, Purchase, Install	**80**
Fuel Duct Window for Flow Proving Sensors	Complete Design, Acquire Materials,Construct	**100**
Secondary Combustion Air Blower	Establish location, Install	**95**
Secondary Combustion Air VSD	Parameters established, Initiate RFQs, Purchase, Install	**100**
Secondary Air Blower Power Supplies	Parameters established, Initiate RFQs, Purchase, Install	**100**
Supply Bunker Augers (3 ea.)	Mass Flow establised, Establish other Parameters, Intiate RFQs	**50**
Supply Transverse Auger	Mass Flow establised, Establish other Parameters, Intiate RFQs	**50**
Supply Transverse Auger Power Supply	Establish parameters, initiate RFQs	**70**
Supply Bunker Auger Drive Power Supplies	Parameters established, Initiate RFQs, Purchase, Install	**50**
Power Supplies for all Computer Interfaces	Determine Location, Specify, Initiate RFQs, Purchase	**5**
Un-used Ports	Identify & Specify Closures for all	**100**
Ash Bunker Auger Drive Control	Signal cable, conduit: Specify, Purchase, Install	**25**
Ash Bunker Auger Drive Control Interface	Install in Enclosure, connect control & data cable	**5**
Ash Bunker Auger Drive Interface Enclosure	Determine Location, Specify, Purchase, Install	**5**
Ash Supply Bunker Support	Develop Support Design, Acquire Materials,Construct	**100**
Bubble Plate Refractory Molding	Research geometry & materials; Apply to Plate; Assemble Plate	**40**
Cargo Lift System	Complete Design, Purchase Supplies, Construct	**30**
FD Fan VSD Control	Signal cable, conduit: Specify, Purchase, Install	**5**
FD Fan VSD Control Interface	Install in Enclosure, connect control & data cable	**5**
Fluidizing Air/Bed Preheater	Parameters established, Initiate RFQs, Purchase, Install	**90**
ID Fan Control	Computer Control & Display Program	**85**
ID Fan VSD Control	Signal cable, conduit: Specify, Purchase, Install	**5**
ID Fan VSD Control Interface	Install in Enclosure, connect control & data cable	**5**
ID Fan VSD Control Interface Enclosure	Determine Location, Specify, Purchase, Install	**5**
Pressure & Temperature Sensors	Modify Riser Ports/ Surrounding Floor Frame, Install	**50**
Rotary Air Lock Valve Drive Controls	Signal cable, conduit: Specify, Purchase, Install	**5**
Rotary Air Lock Valve Drive Interfaces	Install in Enclosure, connect control & data cable	**5**
Rotary Valve Drive Interface Enclosures	Determine Location, Specify, Purchase, Install	**5**
Secondary Air Blower Controls	Computer Control & Display Program	**85**
Secondary Air Blower VSD Controls	Signal cable, conduit: Specify, Purchase, Install	**5**
Secondary Air Blower VSD Control Interfaces	Install in Enclosure, connect control & data cable	**5**
Sec. Air Blower Control Interface Enclosures	Determine Location, Specify, Purchase, Install	**5**
Secondary Air Blower Discharge Ducts	Specify material(s), size, locations	**50**
Sensor Signal	Signal cable, conduit: Specify, Purchase, Install	**5**
Sensor Signal Interface	Install in Enclosure, connect control & data cable	**5**
Sensor Signal Interface Enclosure	Determine Locations, Specify, Purchase, Install	**5**
Windbox & Ash Drain	Determine Ash Drain Sliding Seal Design, Assemble Windbox	**100**
Fluidizing Air Supply	Assemble flexible duct from Blower Duct to Windbox inlet	**100**
Supply Bunker Supports	Complete Design, Purchase Supplies, Construct	**20**
Supply Bunker Augers (3 ea.)	Install Augers, Design Seals & Support Bearings, construct	**55**
Supply Transverse Auger Drive	Parameters established, Initiate RFQs, Purchase, Install	**50**
Transverse Auger Tube to Rotary Valve Adpt.	Design and Construct corrected adapter allowing connection	**40**
All Other Sensors	Parameters established, Initiate RFQs	**40**
Supply Bunker Auger Tubes Assembly	Determine if on site, proceed from this finding	**25**

Supply Bunker Auger Drive Interfaces	Install in Enclosure, connect control & data cable	10
Supply Bunker Auger Drive Interface Encl.	Determine Location, Specify, Purchase, Install	10
Supply Flow Proving Sensors	Design Complete, Specify Components…	50
Supply Transverse Auger	Install Auger, Design Seal & Support Bearings, construct	40
Supply Transverse Auger Tube	Determine if on site, proceed from this finding	10
Supply Transverse Auger Drive Controls	Signal cable, conduit: Specify, Purchase, Install	10
Supply Transverse Auger Drive Interfaces	Install in Enclosure, connect control & data cable	10
Supply Transverse Auger Drive Interface Encl.	Determine Location, Specify, Purchase, Install	10
Visual Display of all other Process Variables	Design Complete, Specify Components…	75
Process Meas. & Control System	Correct/Modify as Required; Otherwise nearly Complete	95
Ash (Hot & Cold) Supply Ducts	All Ash Ducts on site	100
Ash Supply Bunker	Ash Supply Bunker on site	100
Fuel/Bed Material Supply Ducts	All Supply Ducts on site	100
Rotary Air Lock Valves, Motors (2 ea.)	All Rotary Valves, Motors on site	100
Supply Bunker Auger Drive Controls	All Supply Drive Controls on site	100
Supply Bunker Auger Drives (3 ea.)	All Supply Drives on site	100
Supply Bunker Load Cells	All Load Cells on site	100
Supply Bunkers	All Supply Bunkers on site	100
Heat Exchangers	Coolant control Valves: Specify, Purchase, Install	70

2.2 Experimental Study on Mercury Oxidation Halogen Additions in a Slipstream Selective Reduction Catalyst (SCR) Reactor when Burning Sub-bituminous Coal

2.2.1 Test Boiler, Slipstream Facility and SCR Catalysts. The detailed information on test boiler, the schematic of the experimental set-up and quality assurance and quality control (QA/QC) of mercury measurement can be found in previous studies (1-2). The average temperature of the SCR facility in this study varied between 620 ^{o}F and 690 ^{o}F, which was dependent on boiler loads when tests were conducted. The residence time of flue gas inside the slipstream reactor was controlled at about 1 second. When the SCR catalyst was loaded, the space velocity (the ratio of volumetric gas flow to catalyst volume) was set at 3600 hr^{-1}. Commercial honeycomb SCR catalysts were provided by two commercial vendors. The pitch sizes and cell numbers are 7.6 mm and 18x18 for Catalyst #1, and 10 mm and 15 x 16 for Catalyst #2, respectively.

2.2.2 Characterizations of Coal, Ash and Flue Gas of PRB Coal. Coal is sampled as it is transferred into the coal bunkers. Ash is a composite of all fly ash removed from the electric precipitator (ESP) hoppers from the test unit. The coal and ash analysis results are shown in Table 2. The analysis methods and QA/QC procedures could be found in reference (1). There were three phases of testing conducted in this study. During

Phase 1, tests without SCR catalysts in the slipstream reactor were conducted. The average sulfur, chlorine and mercury contents in the PRB were about 0.37 %, 72 ppm and 0.08 ppm by weight, respectively. The bromine and iodine contents in the coals were under the detection limit. During Phase 2 and Phase 3, tests with SCR Catalyst #1 and #2 in the SCR slipstream reactor were conducted, respectively. The average sulfur, chlorine and mercury contents (by weight) in the burned PRB coal were approximately 0.44 %, 127 ppm and 0.07 ppm in the second phase and 0.39 %, 88 ppm and 0.09 ppm, respectively in the third phase.

2.2.3 NOx Reduction by SCR Catalysts. The reduction performance of the two SCR catalysts were evaluated by monitoring the NOx concentration at the inlet and outlet locations of the SCR slipstream reactor. Due to the low-NOx burner installed in the test unit, NOx concentrations, introduced into the slipstream reactor, were found to be low - about 90 ppm (with 3% O_2 correction) at the SCR inlet location. Under NH_3 addition, both SCR catalysts worked properly in the SCR slipstream reactor. Lower NOx at the slipstream outlet location can be achieved by SCR Catalyst #1 than by SCR Catalyst #2. A NOx reduction of 92.5% was expected by SCR Catalyst #1 and 86.5% by SCR Catalyst #2 when the ratio of NH_3 to NOx was close to 1. The results are shown in Figure 1. The corresponding NOx concentrations at the slipstream outlet were 6 ppm and 12 ppm (3% O_2 correction), respectively.

Figure 1. NOx Reduction by SCR Catalyst#1 and #2

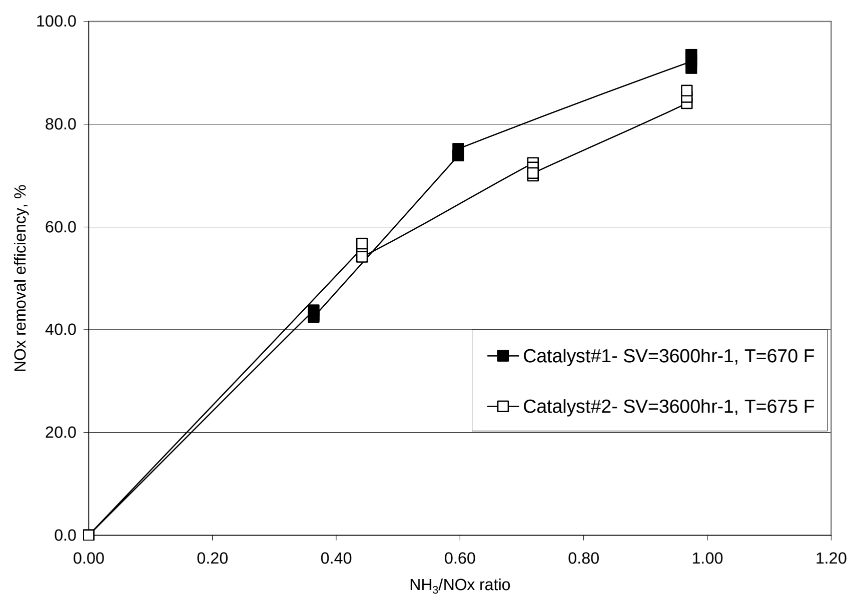


Table 2. Characterization of Coal, Ash and Flue Gas with PRB Coal

Coal Analysis, dry basis													
Testing phase	ADL %	Moisture %	Ash %	Vol. Mat %	Sulfur %	Btu BTU/lb	Carbon %	Hydrogen %	Nitrogen %	Oxygen %	Cl ppmw	Hg ppmw	F ppmw
1st phase: empty Bed	20.08	11.33	7.13	46.38	0.47	11990	70.27	5.00	2.17	14.97	87	0.08	28
2nd phase, Catalyst#1	22.06	9.70	6.86	43.27	0.44	12022	69.32	5.01	0.74	17.55	127	0.07	44
3rd phase, Catalyst#2	19.59	11.66	7.13	47.00	0.39	11921	69.31	5.11	1.25	16.81	88	0.09	51

Note: 1. ADL means Air dry loss
2. Except ADL and Mositure, all other items are in dry basis
3. ppmw means parts per million by weight

Ash analyses					
Testing phase	Sulfur %	Chloride ppmw	Mercury ppmw	Fluoride ppmw	LOI %
1st phase: Empty Bed	0.65	192.88	0.11	70.00	0.46
2nd phase, Catalyst#1	0.54	156.17	0.19	111.67	0.65
3rdphase, Catalyst#2	0.59	131.38	0.17	126.13	0.65

Note: 1. LOI means Loss of Ignition
2. All otems in table are in dry basis

Total Flue Gas Concentration dry, 3% O_2 (Without Halogens addition)							
Testing phase	HCl ppmv	Cl_2 ppmv	SO_2 ppmv	SO_3 ppmv	HF ppmv	HBr ppmv	HI ppmv
1st phase: Empty Bed	22.6	1.13	133.6	1.34	1.61	UD	UA
2nd phase, Catalyst#1	9.7	0.48	189.1	1.89	3.01	UD	UA
3rd phase, Catalyst#2	6.1	0.31	174.8	1.75	3.89	UD	UA

Note: 1. SO_2 is measured by instrument
2. SO_3 is predicted as to be 1% of SO_2 in the flue gas
3. HCl, Cl2, HF, HBr are directly measured based on EPA Method 26A (Ion Chromatograph)
4. UA means Unavaiable
5. UD means Under Detect Limitation
6.ppmv means parts per million by volume

2.2.4 Additive Injections. NH_3, HCl and HBr gases were injected in the slipstream reactor through the use of the mass flow controller (MFC). Liquid solution. Static mixers in the slipstream reactor ensured good mixing of additives and the flue gas. All additives were injected through several ports below the mercury sampling port at the SCR inlet, thus leaving this sampling port unaffected by the additives. In this study, the concentrations of the individual additives or spike gases in the flue gas were controlled at ranges of 0 - 300 ppm for HCl, 0 - 9 ppm for HBr, 0 - 20 ppm for HF and 0-15 ppm for HI.

3. RESULTS AND DISCUSSION

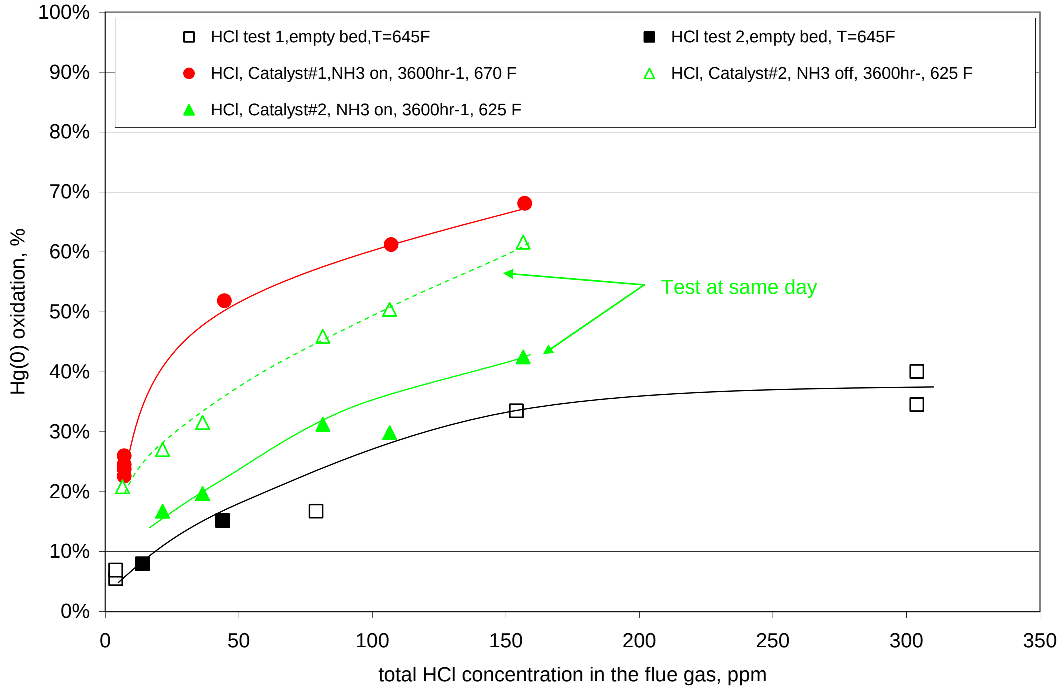
Hg(0) oxidation in the SCR may occur through two processes (2-6), 1) homogenous oxidation, which occurs in the gas phase, and 2) heterogeneous oxidation, which occurs on the interface of solids (SCR catalyst or fly ash). In order to determine the contribution of SCR catalyst on Hg(0) oxidation, two types of tests were conducted in this study. Tests with no SCR catalyst present in the slipstream reactor were conducted to investigate the possible mercury oxidation mechanism by mercury homogenous oxidation and also mercury heterogeneous oxidation by interaction with "in-flight" fly ash. Tests conducted SCR catalyst present in the slipstream reactor were conducted to investigate any additional Hg(0) oxidation that may occur. The difference in the mercury oxidation rates between two types of tests should present the contribution from the catalytic effect of the SCR catalyst. Results were presented as an incremental percentage variation between the Hg(0) concentration at the SCR reactor inlet, ($Hg(0)_{in}$), and the Hg(0) concentration at the SCR reactor outlet, ($Hg(0)_{out}$), as indicated in Equation(1).

$$\% \; Hg(0) \text{ oxidation} = 100 * \{[Hg(0)]_{in} - Hg(0)]_{out}] / [Hg(0)]_{in}\} \qquad \text{Equation(1)}$$

3.1 Addition of Hydrogen Chloride (HCl). In the coal-derived flue gases, chlorine is mainly exists as HCl. It is the most important species affecting mercury oxidation since the major oxidized mercury species in coal-fired flue gas is $Hg(Cl)_2$. The effects of the HCl spike gas on the Hg(0) oxidation during tests in the empty slipstream reactor and those in the SCR slipstream reactor is shown in Figure 2. Whether the SCR catalysts were present or not, HCl showed a positive impact to increase Hg(2+) in the flue gas when burning PRB coal in this study. Tests in the empty slipstream reactor indicated that the percentage of Hg(0) oxidation increased to 7.9 %, 15.2 %, 16.7 %, 33.5 % and 37.5 % with additional inputs or spikes of HCl at concentrations of 10, 40, 75, 150 and 300 ppm, respectively. A results of investigation, the total chlorine concentration in the flue gas was approximately 16.9, 44, 79, 154 and 304 ppm, respectively. With the increase of HCl addition concentration above 150 ppm, the Hg(0) oxidation curve became flat.

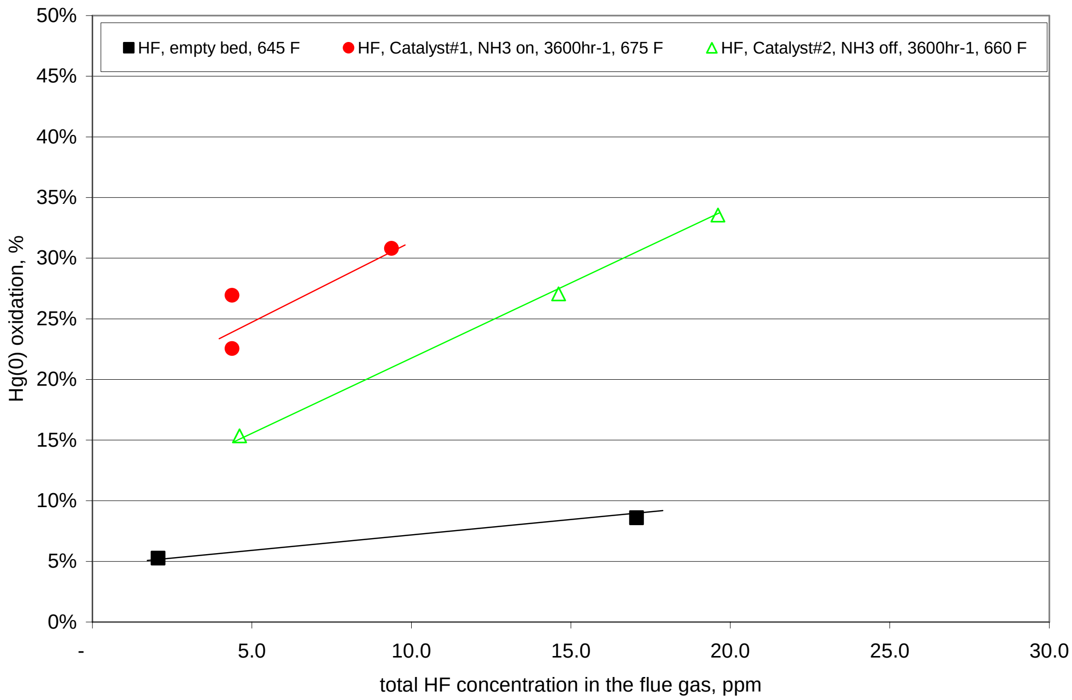
During tests with SCR Catalyst #1 with an NH_3 addition ratio of about 1(NH_3/NO~1), Hg(0) oxidation was increased by approximately 30 % when compare to those employing an tests in the empty reactor at similar HCl addition concentrations. With the HCl additions at 100 ppm and 150 ppm, the Hg(0) oxidation increased to about 62 % and 68 %, respectively. During tests with SCR Catalyst #2 at a similar NH_3 addition ratio (NH_3/NO~1), the oxidation of Hg(0) was approximately 30 % and 45 %, respectively at HCl additions at 100 ppm and 150 ppm. The degree of Hg(0) oxidation was only about 10 % at similar HCl addition concentrations to an empty reactor. It was apparently lower than those tests with SCR Catalyst#1. Thus, both SCR catalysts were shown to have catalytic effects on Hg(0) oxidation, but to a different extent. For SCR Catalyst #2, stopping injection of NH_3 apparently could improve Hg(0) oxidation by approximately 15%. That implies NH_3 that had negative impact on the Hg(0) oxidation process, at least for SCR Catalyst #2. This study confirms that NOx reduction by NH_3 and Hg(0) oxidation by chlorine species occurs competitively on the surface of the SCR catalysts. The catalytic nature of the SCR catalyst on the Hg(0) oxidation process is clearly presented. However, their catalytic effects are varied and are dependent on properties of SCR catalysts (catalyst pore structures and/or formulas). Catalyst pore structures and/or formulas could impact the performance of the SCR catalyst on the Hg(0) oxidation through the mass transfer rate and kinetics of the chemical reaction.

Figure 2. Effect of HCl Addition on Mercury Oxidation



3.2 Addition of Hydrogen Fluoride (HF). Fluorine is another common halogen element formed in PRB coal. The fluorine content of PRB coal varies from 20 ppm to 50 ppm and is comparable to that of chlorine (100 ppm on a average), as indicated in Table 1. The effects of spike HF gases on Hg(0) oxidation during tests in the empty slipstream reactor and SCR slipstream reactor are shown in Figure 3. In both cases, HF additions showed a positive impact to increase the Hg(2+) present in the flue gas when burning PRB coal, however, the capability of HF addition on the Hg(0) oxidation seemed limited. Results were very similar to the Hg(0) oxidation by HCl addition. In the empty slipstream reactor, the percentage of the Hg(0) oxidation was only 8.5% with HF addition concentration up to 15 ppm (the total fluorine concentration in the flue gas was approximately 17.5 ppm). In the SCR slipstream reactor with Catalyst #1 under the circumstance of NH_3 addition, the Hg(0) oxidations were about 25 % and 30 % with the addition of HF at about 3 ppm to 8 ppm (the total fluorine concentrations in the flue gas at about 5 ppm and 10 ppm), respectively. In the SCR slipstream reactor with Catalyst #2, however without NH_3 addition, the Hg(0) oxidations were approximately 15 %, 26 % and 34 % with HF addition at 3 ppm, 13 ppm and 18 ppm (the total Fluorine concentrations in the flue gas at about 5 ppm,15 ppm and 20 ppm), respectively. Thus, both SCR catalysts in this study promoted Hg(0) oxidation in comparison to the case of the empty slipstream reactor. Considering the negative effect of NH_3 addition on the Hg(0) oxidation, SCR Catalyst #1 should show a higher oxidation activity than Catalyst #2 during the addition of HF.

Figure 3. Effect of HF Addition on Mercury Oxidation



3.3 Addition of Hydrogen Bromide (HBr). The effects of HBr additions on the Hg(0) oxidation in the empty slipstream reactor and in the slipstream reactor filled with SCR catalyst are shown in Figure 4. Whether the SCR catalysts were available or not, HBr showed a very strong impact in increasing Hg(2+) in the PRB coal-derived flue gas. Tests in the empty slipstream reactor indicated, the percentage of Hg(0) oxidation increased to 83 % and 85.9 % with additional concentrations of HBr at only 3 ppm and 6 ppm, respectively. The increase of HBr addition concentration from 3 ppm to 6 ppm had no apparent effect on the Hg(0) oxidation curve which already was flat at 3 ppm level. This may indicate that no apparent additional Hg(0) oxidation could be achieved by continuous addition of the HBr. During tests with SCR Catalyst #1 at a preferred NH_3 addition ratio of 1 (NH_3/NO~1), the percentages of Hg(0) oxidation were approximately 68.2 % and 78.9 % at HBr addition concentrations of 6 ppm and 9 ppm, respectively. When NH_3 was not added, the percentages of Hg(0) oxidation were approximately 57.3 % and 64.4 % at HBr addition concentrations of 3 ppm and 6 ppm, respectively. During tests with SCR Catalyst #2 at a similar NH_3 addition ratio of 1 (NH_3/NO~1), the percentages of Hg(0) oxidation were approximately 74.7 % and 83.2 % at HBr addition concentrations of 3 ppm and 9 ppm, respectively. When NH_3 was not added, the percentages of Hg(0) oxidation were approximately 81 % and 84.2 % at HBr addition concentrations of 3 ppm and 6 ppm, respectively.

There was good match between results from tests in the empty slipstream reactor and SCR slipstream reactor with Catalyst #2, which indicated that the SCR catalyst apparently did not promote of Hg(0) oxidation and was also independent of impacts from NH_3 addition. Tests with SCR Catalyst#1 showed a slightly lower Hg(0) oxidation efficiencies by HBr addition when compared to cases in the empty slipstream reactor and SCR slipstream reactor with Catalyst #2. This may be the result of lower Hg(0) oxidation efficiencies at the baseline level (zero addition of HBr). In this study, The Hg(0) oxidation efficiencies were approximately 6.1% and 19% at the baseline level during tests with SCR Catalyst#1 and increased to 37.2% and 29.8% in the empty slipstream reactor and SCR slipstream reactor, respectively. This finding may indicate the promising possibility function of HBr addition on Hg(0) oxidation. The oxidation of Hg(0) was found to be less dependent on the availability of SCR catalysts, which was different from those by additions of HCl or HF.

3.4 Addition of Hydrogen Iodide (HI). The effects of additions of HI on Hg(0) oxidation during tests in the empty slipstream reactor and slipstream reactor filled with SCR catalyst are shown in Figure 5. In both cases, HF additions showed a stronger impact in increasing the Hg(2+) in the flue gas when burning PRB coal. In the empty slipstream reactor, the addition of HI at 5 ppm could achieve approximately 40% Hg(0) oxidation. With the same addition concentration of HI at 5 ppm in the slipstream reactor with Catalyst#1, a similar Hg(0) oxidation efficiency of 40 % could be achieved. When the HI addition concentration was increased to 10 ppm, nearly the same Hg(0) oxidation efficiencies (approximately 70 %) could be achieved for both SCR catalysts. These results may indicate that Hg(0) oxidation by HI addition was independent of the presence of a SCR catalyst. A larger increase in HI addition concentration to 15 ppm did not increase the Hg(0) oxidation efficiency for SCR Catalyst#2. Therefore, the Hg(0) oxidation efficiency is likely limited by its reaction kinetics. Hg(0) oxidation was independent of the presence of SCR catalysts when HI was added to the flue gas. This was also observed when HBr was added, but was not observed when HCl and HF were added. It is believed that Hg(0) oxidation by HI and HBr may occur through a similar mechanism .

Figure 4. Effect of HBr Addition on Mercury Oxidation

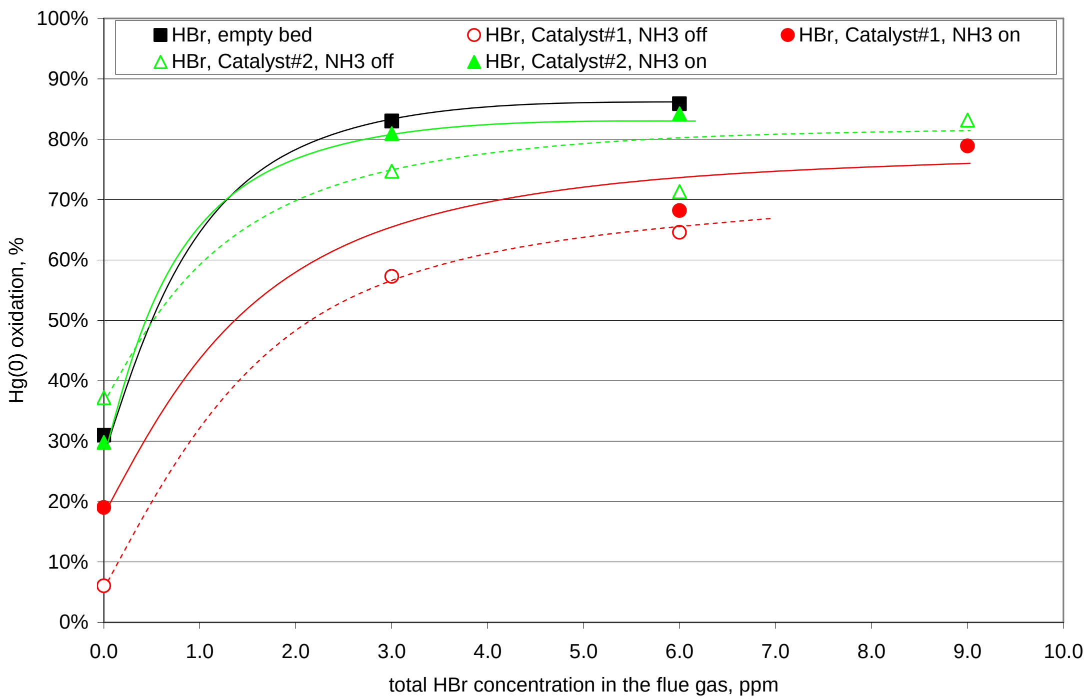
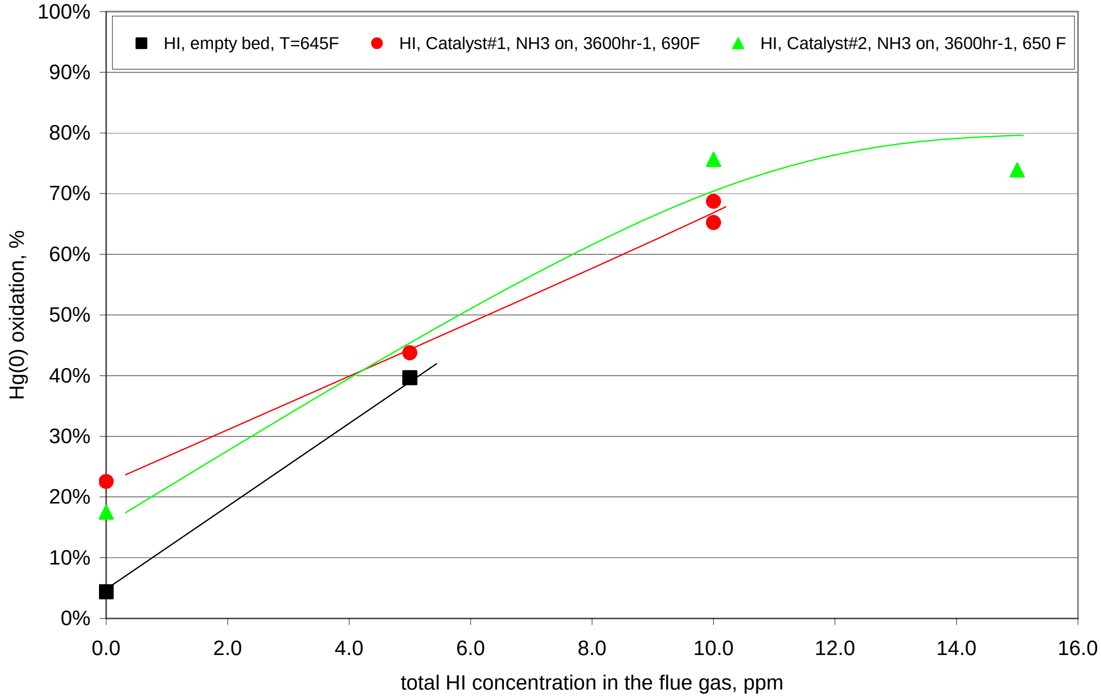


Figure 5. Effect of HI Addition on Mercury Oxidation



4. CONCLUSIONS

During this quarter, the following progress was made:

a) The installation of CFBC Facility has continued. Assembly of all hot ash recirculation ducts and cold ash supply ducts, including both loop seals and all expansion joints were completed. All flue ducts were also installed. The induced draft fan has been installed and operated successfully at full speed. The entire Combustor from forced draft fan through to the discharge port of the induced draft fan was pressurized to 5 psi and found to be leak free. The bed pre-heater, with associated air way control components was assembled. More sensors were also received and most cooling system components were received. Sensors for measuring fuel/bed material supply side operation are on hand, with design, specification and construction of fuel storage and transport components in process.

b) SCR Catalyst #1 showed higher efficiencies of both NOx reduction and Hg(0) oxidation than those of SCR Catalyst #2. The addition of NH_3apparent inhibit the Hg(0) oxidation, which indicated the existence of competitive between NH_3 reduction and Hg(0) oxidation on the surface of SCR catalysts. The sequence of hydrogen halogens, according to their impacts on the Hg(0) oxidation, were HBr, HI, and HCl or HF. The addition of HBr at approximately only 3 ppm could achieve 80 % Hg(0) oxidation. The addition of HI at approximately 5 ppm could achieve 40 % Hg(0) oxidation. In comparison to the empty reactor, 40 % Hg(0) oxidation could be achieved for HCl addition up to 300 ppm. The impact of HF addition seemed to follow the same trend as that of HCl. The enhanced Hg(0) oxidation by addition of HBr and HI did not appear to correlate to the catalytic effects by both SCR catalysts.

5. FUTURE WORK AND UPDATED SCHEDULE

5.1 Future Work

During the next quarter, work will focus on the following activities:

a) Design, order components and install pneumatic control elements and signal lines for loop seal operation.

b) Specify and install cold ash transport auger, drive, power supply and control.

c) Complete design and fabrication of secondary combustion air distribution system. There are four levels at which secondary air may be introduced to the rarified combustion zone of the Combustor. A “halo” will be constructed at each of these levels to facilitate uniform distribution to each of three supply nozzles at any one level. Flow sensors and electrically actuated valves will provide a closed loop control and measurement of secondary air flow.

d) Modify some ports to provide proper sensor installation or where building support structure interferes.

e) Specify, order and install additional sensors at designated locations.

f) Design, specify, purchase and install sensor and control signal interface hub enclosures within combustor tower facility. Install digital data lines from these hubs to the process control computer.

g) Install control elements for pneumatic operation of primary combustion/fluidizing air diverter valve operation.
h) Design, specify and install four fuel/bed material supply augers and one cold ash auger, their shaft seals, gearmotors and varible speed drives drives.
i) Install flue gas tempering valve near the induced draft fan inlet to maintain fan inlet temperature at not greater than 700 °F and to make optimal use of fan performance curve.
j) Complete the installation of all fuel/bed material supply bunkers, along with load cells and associated electronic components.
k) Install primary and secondary combustion air flow sensors. Delivery of the sensors is expected by May 1, 2007.
l) Perform cold fluidization testing to confirm proper operation of sub-systems beginning with the fluidization air supply through the induced fan. For this test, pressure and flow sensors will be in operation. Ash obtained from another commercial CFBC facility will be used in this test.
m) Explore mechanisms on Hg(0) oxidation by halogen addition in slipstream tests.
n) Explore the possibility of mutual control of sulfur oxide (SOx), nitrogen oxides (NOx) and mercury in CFBC.

5.2 Project Schedule

Based on the current status of the project, the project schedule for the remainder work is shown in Table 3.

Table 3. Project schedule

Task	Schedule
Install both loop seal operators and control lines.	May 1, 2007
Install ash transport auger, seals and bearings, gear motor, variable speed drive, power supply, control interface.	May 15, 2007

Install three gravimetric supply bunkers and associated supply duct components.	May 30, 2007
Install secondary combustion air distribution duct work; flow sensors and control interface.	May 30, 2007
Complete ordering and installation of coolant system components.	June 30, 2007
Complete specification, ordering of components and installation of water treatment system for heat exchanger coolant loop.	June 15, 2007
Complete specification and installation of sensors and control operators.	July 31, 2007
Complete process control and data acquisition computer program development.	August 31 2007
Complete the installation of the CFBC Facility.	August 31, 2007
Based on the experimental data obtained from the. laboratory-scale CFBC Facility, determine the optimal conditions for co-firing waste materials with high sulfur coals in the CFBC Facility.	September 30, 2007
Complete the study to determine the effect of air staging, fuel feeding position, and limestone feeding on the gaseous emissions in the CFBC Facility.	September 30, 2007
Complete the investigation of mercury emissions from co-firing of waste materials with high sulfur coal in the CFBC Facility.	September 30, 2007
Submit Final Report.	October 31, 2007

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ACRONYMS AND ABBREVIATIONS

CFBC	Circulating Fluidized-Bed Combustion
DOE	U.S. Department of Energy
ECTL	Environmental Control Technology Laboratory
ISCET	Institute for Combustion Science and Environmental Technology
SCR	Selective Catalytic Reduction
Hg(0)	Gaseous Elemental Mercury
Hg(2+)	Gaseous Oxidized Mercury
HCl	Hydrogen Chloride
HF	Hydrogen Fluoride
HBr	Hydrogen Bromide
HI	Hydrogen Iodide
SOx	Sulfur Oxides

NOx	Nitrogen Oxides
MFC	Mass Flow Controller
ADL	Air Dry Loss