PILOT TESTING OF WRI'S NOVEL MERCURY CONTROL TECHNOLOGY BY PRE-COMBUSTION THERMAL TREATMENT OF COAL

FINAL TECHNICAL REPORT

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DISCLAIMER

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ABSTRACT

The challenges to the coal-fired power industry continue to focus on the emission control technologies, such as mercury, and plant efficiency improvements. An alternate approach to post-combustion control of mercury, while improving plant efficiency deals with Western Research Institute's (WRI)'s patented pre-combustion mercury removal and coal upgrading technology. WRI was awarded under the DOE's Phase III Mercury program, to evaluate the effectiveness of WRI's novel thermal pretreatment process to achieve >50% mercury removal, and at costs of <$30,000/lb of Hg removed.

WRI has teamed with Etaa Energy, Energy and Environmental Research Center (EERC), Foster Wheeler North America Corp. (FWNA), and Washington Division of URS (WD-URS), and with project co-sponsors including Electric Power Research Institute (EPRI), Southern Company, Basin Electric Power Cooperative (BEPC), Montana-Dakota Utilities (MDU), North Dakota Industrial Commission (NDIC), Detroit Edison (DTE), and SaskPower to undertake this evaluation.

The technical objectives of the project were structured in two phases: Phase I - coal selection and characterization, and bench-and PDU-scale WRI process testing and; and Phase II - pilot-scale pc combustion testing, design of an integrated boiler commercial configuration, its impacts on the boiler performance and the economics of the technology related to market applications. This report covers the results of the Phase I testing.

The conclusion of the Phase I testing was that the WRI process is a technically viable technology for (1) removing essentially all of the moisture from low rank coals, thereby raising the heating value of the coal by about 30% for subbituminous coals and up to 40% for lignite coals, and (2) for removing volatile trace mercury species (up to 89%) from the coal prior to combustion. The results established that the process meets the goals of DOE of removing <50% of the mercury from the coals by pre-combustion methods. As such, further testing, demonstration and economic analysis as described in the Phase II effort is warranted and should be pursued.

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Background

Coal-based power generation will continue to play a major role for decades. However, the coal use faces challenges through continuously evolving regulatory requirements with regard to gaseous pollutant emissions that impact the air quality. The challenges are being addressed through research and development efforts that focus on the emission control technologies and plant efficiency improvements. One of the key pollutants of concern is mercury. Many post-combustion mercury control technologies are under development with funding under DOE Phase I, II and III awards. Some of these technologies face challenges such as finding a suitable sorbent, the impact of mercury-laden sorbents on ash sales and/or disposal, reduced availability and performance of the back-end equipment and interference from flue gas species on the Hg capture performance of sorbents. An alternate approach contained in this research program deals with pre-combustion mercury removal. Western Research Institute's (WRI)'s patented (Patent No. 5,403,365) pre-combustion mercury removal technology deals specifically with reducing emissions and improving power plant efficiency

Objectives

Under the Phase III Mercury program, WRI conducted bench- and pilot-scale coal treatment and combustion testing in order to evaluate the effectiveness of WRI's novel thermal pretreatment process to achieve >50% mercury removal, and at costs of <$30,000/lb of Hg removed.

Team Members

The project is conducted by WRI, Etaa Energy, Energy and Environmental Research Center (EERC), Foster Wheeler North America Corp. (FWNA), and Washington Division of URS (WD-URS). Project co-sponsors include Electric Power Research Institute (EPRI), Southern Company, Basin Electric Power Cooperative (BEPC), Montana-Dakota Utilities (MDU), North Dakota Industrial Commission (NDIC), Detroit Edison (DTE), and SaskPower.

Technical Results

The technical objectives of the project were structured in two phases: Phase I - coal selection and characterization, and bench-and PDU-scale WRI process testing and; and Phase II - pilot-scale pc combustion testing, design of an integrated boiler commercial configuration, its impacts on the boiler performance and the economics of the technology related to market applications.

The project to date (through the first project period) has produced the following technical accomplishments and results

- All eight coals planned for the project have been characterized for the chemical constituents and physical properties. The range in mercury is from 0.006 to 0.266 ppmw(d) in the acquired coals.

- Bench-scale testing of all eight coals including drying and mercury release steps were conducted. A major finding of the project is that mercury removals of nearly 50 to 87%

are possible with the WRI process. Residence time may have a significant impact on the mercury release for certain coals.

- A unique facility to test mercury sorbents at 550-600°F has been successfully commissioned. Five sorbent from various vendors/suppliers were evaluated. In addition to activated carbon, carbon-based and non-carbon-based sorbents were tested. A major finding of the testing is that certain non-carbon high temperature sorbents can capture mercury at high loadings in the temperature range needed by the WRI process.

- The pilot-scale process development unit (PDU) has been commissioned and confirmation runs with the project coals have been completed. Preliminary data indicate that the results of the bench-scale testing were confirmed with the PDU. Water recovered was of sufficient quality that only limited treatment is needed in order to use the water in the power plant.

The overall conclusion of the Phase I testing was that the WRI process is a technically viable technology for (1) removing essentially all of the moisture from low rank coals, thereby raising the heating value of the coal by about 30% for subbituminous coals and up to 40% for lignite coals, and (2) for removing volatile trace mercury species (up to 89%) from the coal prior to combustion. The results established that the process meets the goals of DOE of removing <50% of the mercury from the coals by pre-combustion methods. As such, further testing, demonstration and economic analysis as described in the Phase II effort is warranted and should be pursued.

1.0 BACKGROUND AND OBJECTIVES

Coal-based power generation will continue to play a major role for decades. However, the coal use faces challenges through continuously evolving regulatory requirements with regard to gaseous pollutant emissions that impact the air quality. The challenges are being addressed through research and development efforts that focus on the emission control technologies and plant efficiency improvements. One of the key pollutants of concern is mercury. Many post-combustion mercury control technologies are under development with funding under DOE Phase I, II and III awards. Some of these technologies face challenges such as finding a suitable sorbent, the impact of mercury-laden sorbents on ash sales and/or disposal, reduced availability and performance of the back-end equipment and interference from flue gas species on the Hg capture performance of sorbents. An alternate approach contained in this research program dealt with pre-combustion mercury removal. Western Research Institute's (WRI)'s patented (Patent No. 5,403,365) pre-combustion mercury removal technology deals specifically with reducing emissions and improving power plant efficiency

Under this Phase III DOE-awarded program, WRI conducted bench- and pilot-scale coal treatment and combustion testing to evaluate the effectiveness of WRI's novel thermal pretreatment process to achieve >50% mercury removal, and at costs of <$30,000/lb of Hg removed. The technical objectives of the project were structured in two phases: Phase I - coal selection and characterization, and bench-and PDU-scale WRI process testing; and Phase II - pilot-scale pc combustion testing, design of an integrated boiler commercial configuration, its impacts on the boiler performance and the economics of the technology related to market applications.

2.0 EXPERIMENTAL METHODS AND RESULTS

The technical objectives for Phase I of the project were structured into a series of four technical tasks.

- Task 1.0 – Coal Selection and Characterization
- Task 2.0 – Bench-scale Coal Testing
- Task 3.0 – Sorbent Testing

- Task 4.0 – PDU Tests

Details of these activities that highlight experimental methods and the results are bellowed in the following.

2. 1 Task 1.0 – Coal Selection and Characterization

Eight coals – three Powder River Basin (PRB) subbituminous, three Fort Union lignites, one Gulf Coast lignite and one western bituminous coal, were selected and thoroughly characterized (Table 2.1). The eight coals represent the northern, eastern, and southern regions of the PRB, as well as two Fort Union lignites from North Dakota, one Fort Union coal from Canada, and one Gulf Coast lignite. The eighth coal represented the Colorado bituminous coal. The moisture content varied with coal rank with the lignite coals having moistures in the range of 20-37%, the subbituminous coals in the range of 22-28%, and the western bituminous coal 17.4%. A large variability was observed in the mercury content of the coals ranging from 0.006 to 0.226 ppmw(d). Chlorine, another important parameter, ranged from 28 to 94 ppmw(d), typical of western low rank coals. In addition to the variability of the mercury content of the coals, the rank of the coals and the moisture content, there is a notable smaller mean particle size of the Canadian lignite, upon crushing to 1” top size, compared to the other coals. This has a significant impact on the testing in that there is a high potential for carrying off of coal from the reactors (either the bench-scale unit or the process development unit) by the fluidizing gas, leaving limited residence time for trace metals removal.

2.2 Task 2.0 – Bench-scale Coal Testing

The existing bench-scale unit at WRI was modified to perform parametric testing of the eight coals, including time - temperature and mercury evolution relationships. As such, the testing identified the optimum temperature for drying and for mercury removal.

The eight test coals were screened using WRI’s bubbling fluidized bed reactor (BFBR), which helps to determine an optimum temperature window for maximum mercury removal. Fig. 2.1 shows typical results for the removal of mercury during thermal treatment of lignite coals, while Fig 2.2 shows the mercury removal of the Powder River subbituminous coals.

Table 2.1 Project Raw Coal Characterization Data

Coal Analysis / Parameter		Gulf Coast Lignite	Canada Lignite	ND Lignite-C	ND Lignite-A	Southern PRB	Eastern PRB	Northern PRB	Colo. Bit.
Proximate Analysis, wt.%	Moisture	20.91	34.68	36.55	36.39	28.09	28.36	22.40	17.39
	Ash	14.57	15.34	6.62	7.68	4.82	4.99	10.90	5.24
	VM	35.97	28.74	31.26	29.93	34.36	34.14	32.89	36.36
	FC	28.55	21.24	25.57	26.00	32.73	32.51	33.81	41.01
Ultimate Analysis, wt.%	Carbon	47.23	33.78	40.73	40.29	50.00	49.88	50.49	60.53
	Hydrogen	3.32	2.29	2.69	2.70	3.49	3.49	3.38	3.98
	Nitrogen	0.39	0.26	0.43	0.33	0.48	0.68	0.61	1.35
	Sulfur	1.77	0.52	0.71	0.74	0.33	0.32	0.72	0.40
	Oxygen	11.81	13.13	12.26	11.86	12.79	12.29	11.49	11.11
	Cl, ppmd	94	86	28	48	46	82	57	88
HHV	Btu/lb	8153	5501	6996	6864	8616	8590	8684	10510
Forms Sulfur, wt.%	Pyritic	0.52	0.22	0.18	0.16	0.04	0.01	0.16	0.02
	Sulfate	0.04	0.07	0.03	0.03	0.01	0.00	0.01	0.01
	Organic	1.21	0.24	0.50	0.56	0.29	0.30	0.56	0.37
Mineral Analysis, wt.% ash	SiO_2	45.28	42.99	22.65	29.20	27.93	30.22	33.13	48.54
	TiO_2	0.87	0.43	0.24	0.25	1.11	1.47	0.95	0.98
	Al_2O_3	16.00	19.28	12.32	12.18	12.47	15.69	18.95	21.58
	Fe_2O_3	12.60	4.89	9.72	8.45	6.26	4.93	4.83	4.24
	CaO	8.63	13.88	20.84	19.96	26.90	22.82	24.17	7.74
	MgO	1.95	4.75	5.24	6.34	6.32	4.32	2.61	1.47
	K_2O	0.62	1.02	0.76	0.73	0.26	0.31	0.71	0.73
	Na_2O	0.19	0.52	7.68	2.99	1.71	1.34	0.38	1.94
	P_2O_5	0.10	0.04	0.18	0.04	0.67	0.57	0.19	1.64
	SO_3	10.07	7.43	16.18	14.27	10.80	12.70	11.28	8.40
Trace Metals, ppmd	Mercury	0.266	0.179	0.184	0.149	0.075	0.126	0.053	0.006[1]
	Arsenic	6.2	5.7	10.4	5.4	6.2	4.2	3.9	0.8
	Selenium	1.0	1.1	0.8	1.0	0.9	0.9	1.0	0.7
HGI		70	60	33	47	65	60	55	56
Particle Size Distrib. cum. wt. %	> ½ inch	23.33	4.08	14.81	11.30	8.60	6.76	6.18	11.27
	½ x ¼ inch	53.33	15.69	49.81	40.53	40.54	34.53	34.18	42.94
	¼ x 6 mesh	64.44	29.14	72.16	64.48	64.47	61.19	59.95	86.52
	6 x 30 mesh	93.33	65.51	92.11	86.32	87.53	86.40	87.54	90.24
	30 x 60 mesh	96.67	85.03	95.99	92.11	93.20	92.53	94.06	95.53
	60 x 100 mesh	97.78	93.52	97.85	94.65	95.43	94.86	96.37	97.14
	< 100 mesh	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

HGI - Hardgrove Grindability Index; na – not available; 1.High variability of analysis due to low concentration.

The low concentration of mercury in the western bituminous coal makes it difficult to quantify the removal on a repeatable and consistent basis. It should be noted that the raw coal mercury concentrations listed in Table 2.1 may not always match with the concentration in the smaller subset used for the bench-scale testing.

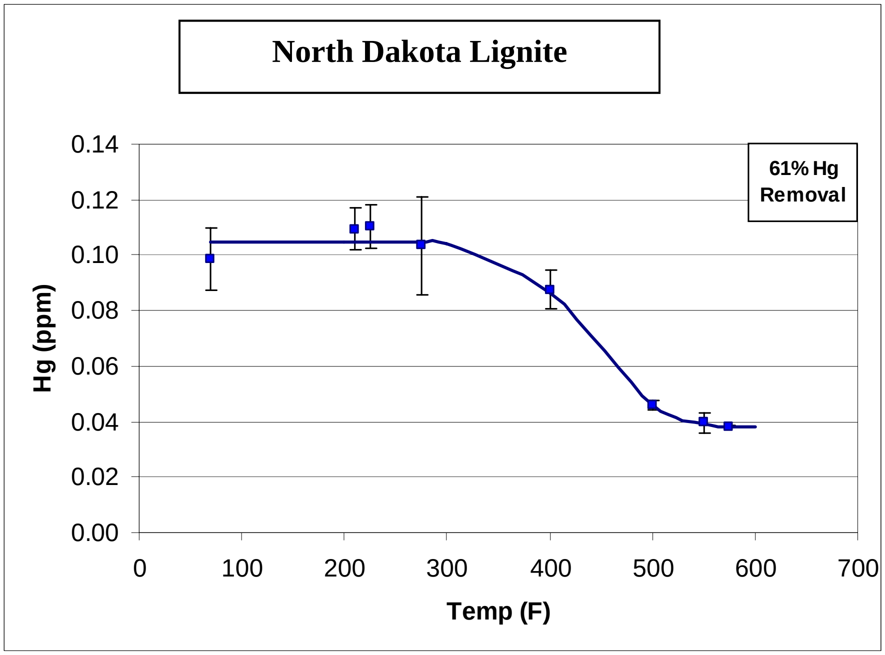

Fig. 2.1. Mercury Removal versus Temperature Plot for ND Lignite.

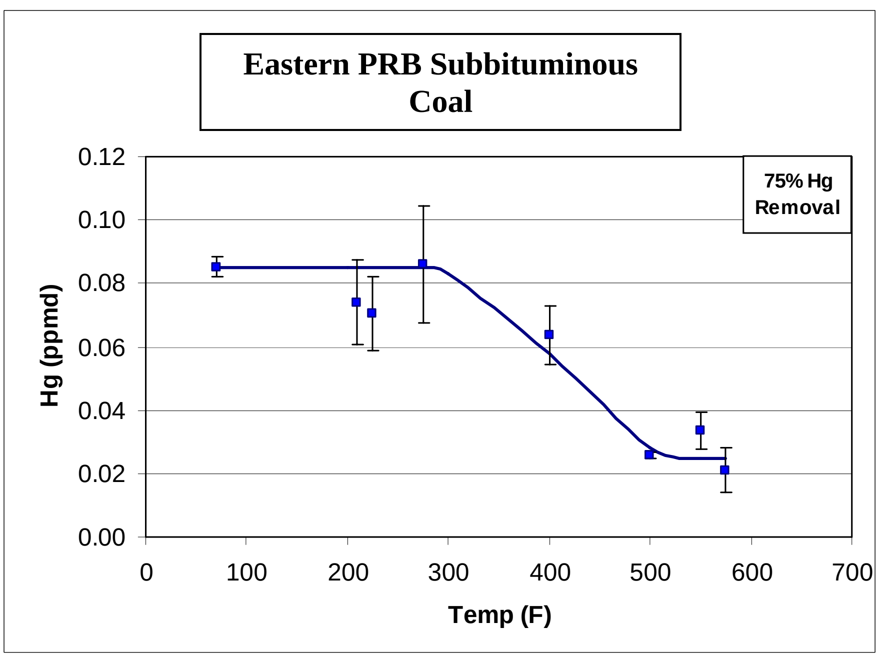

Fig. 2.2 Mercury Removal versus Temperature Plot for a PRB Subbituminous Coal.

The effect of residence time between 8 and 16 minutes for a PRB subbituminous coal and a North Dakota lignite is presented in Fig. 2.3 and 2.4 respectively. It shows increased mercury reduction with residence time.

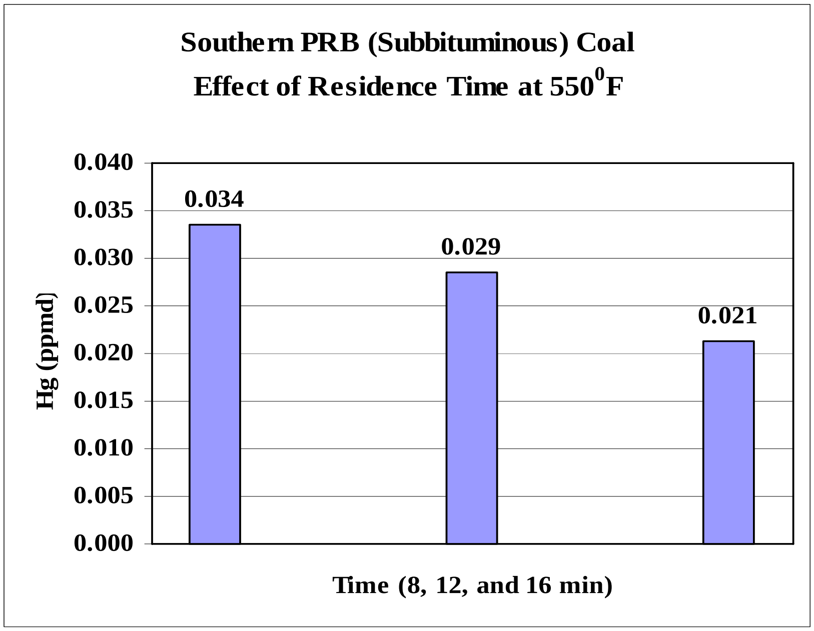

Fig. 2.3. Residence Time Impact on Hg Removal for a PRB Subbituminous Coal

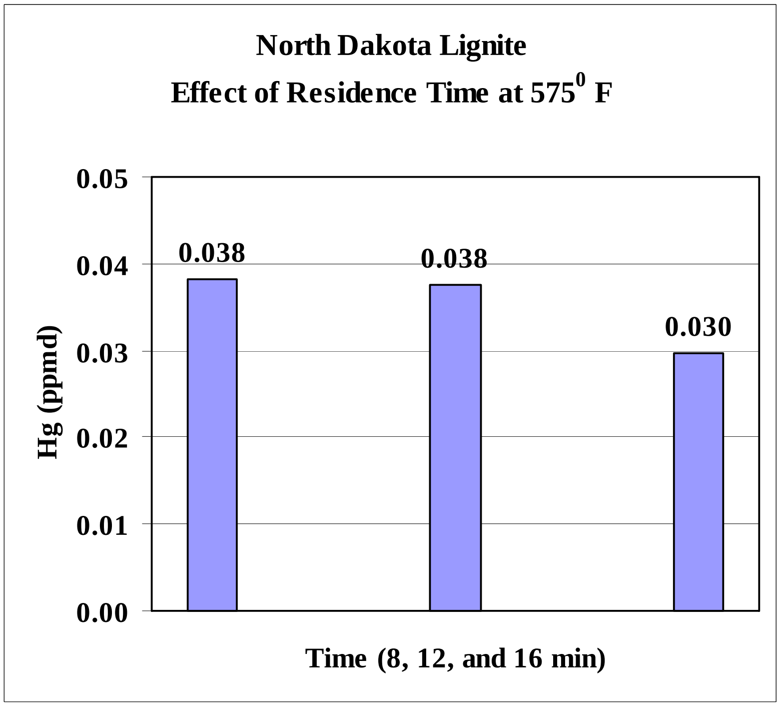

Fig. 2.4.. Residence Time Impact on Hg Removal for a ND Lignite.

2.3 Task 3.0 – Sorbent Testing:

A bench-scale apparatus shown in recent presentations (e.g., Bland et al. 2007, 2008) was used to evaluate the performance and the potential of high temperature (around 550°F) mercury sorbents. Both carbon and non-carbon-based high temperature sorbents were evaluated. A Norit activated carbon was tested as the baseline, one carbon-based sorbent and four non-carbon based sorbents were acquired and tested. The testing was designed to assess the maximum loading and breakthrough loadings (<90% capture) in a fixed bed mode.

An example of the typical testing curves is shown in Fig. 2.5. Upon passing the mercury contained gas mixture through the sorbent bed, the mercury detected in the back-side of the sorbent bed is essentially zero. With time the sorbent begins to become unable to capture all of the mercury passing through the bed and the mercury concentration on the back-side of the sorbent begins to increase. When the mercury capture becomes less than 90% it is considered at the break-through and the loading at that point was determined.

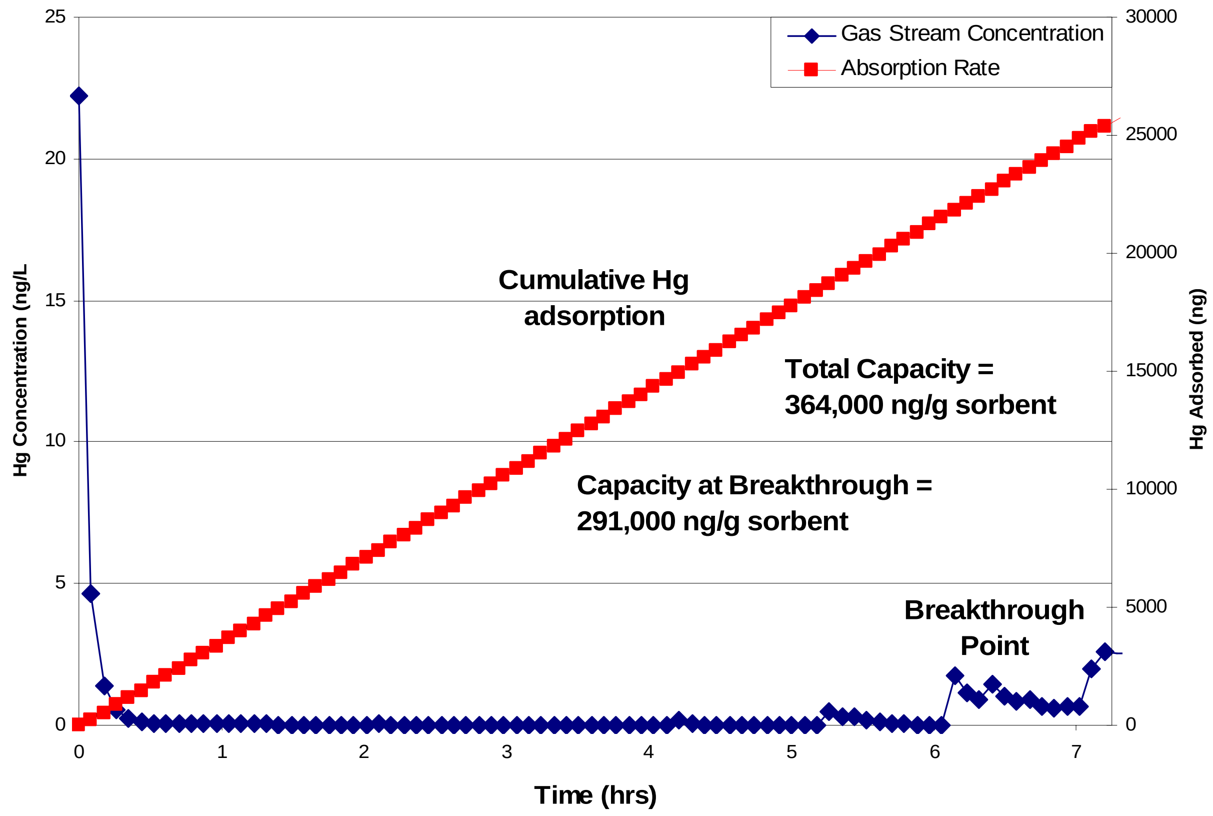

Fig. 2.5. Typical Sorbent Testing Curve of HT Non-carbon Sorbent

As the testing continued the mercury capture again became essentially zero, at which point the total mercury loading is calculated. These two parameters are used to size the sorbent beds needed for the PDU, as well as for the larger plant capacities.

The sorbents were tested at different operating temperatures and under different gas compositions. The range of gas conditions ranged from 0 to 3.6% oxygen in addition to the SO_2. The results of this testing are summarized in Fig. 2.6 through 2.8. Fig. 2.6 shows the impact of temperature on the breakthrough temperatures that were expected for the WRI process. As can be seen from Table 2.2, there is a significant impact on sorbent loading at peak temperatures and gas composition of the sweep gas.

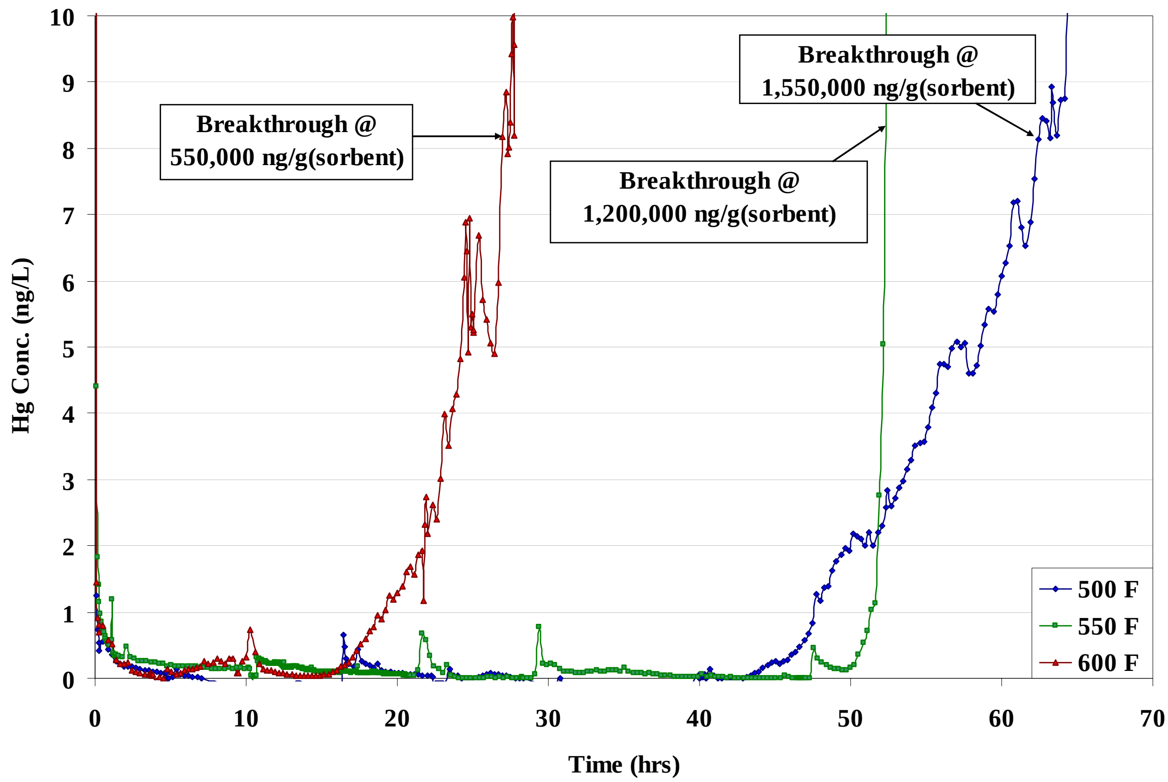

Fig. 2.6. HT Sorbent Breakthrough Loading at Different Temperatures (Oxidizing Conditions)

Fig. 2.7 illustrates the impact of reducing conditions on the breakthrough performance of the sorbent in Fig. 2.6 above.

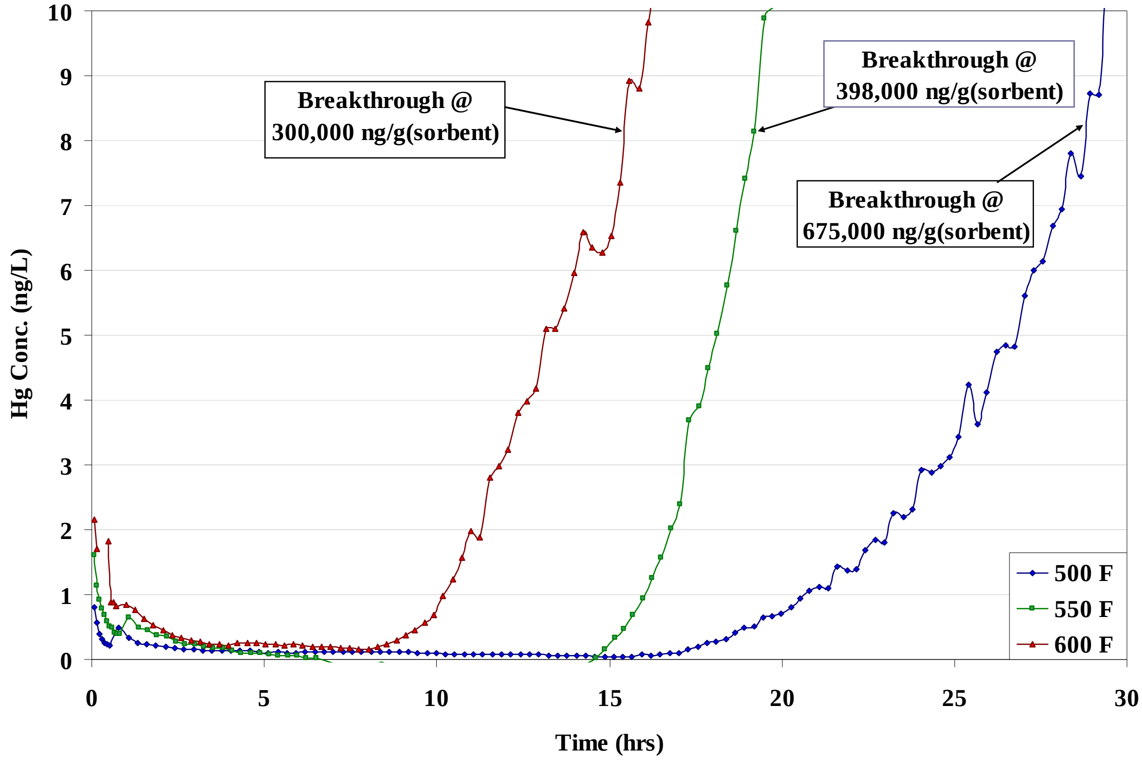

Fig. 2.7. HT Sorbent Breakthrough Loading at Different Temperatures (Reducing Conditions)

The impact of oxidizing conditions versus reducing conditions is shown in Fig. 2.8.

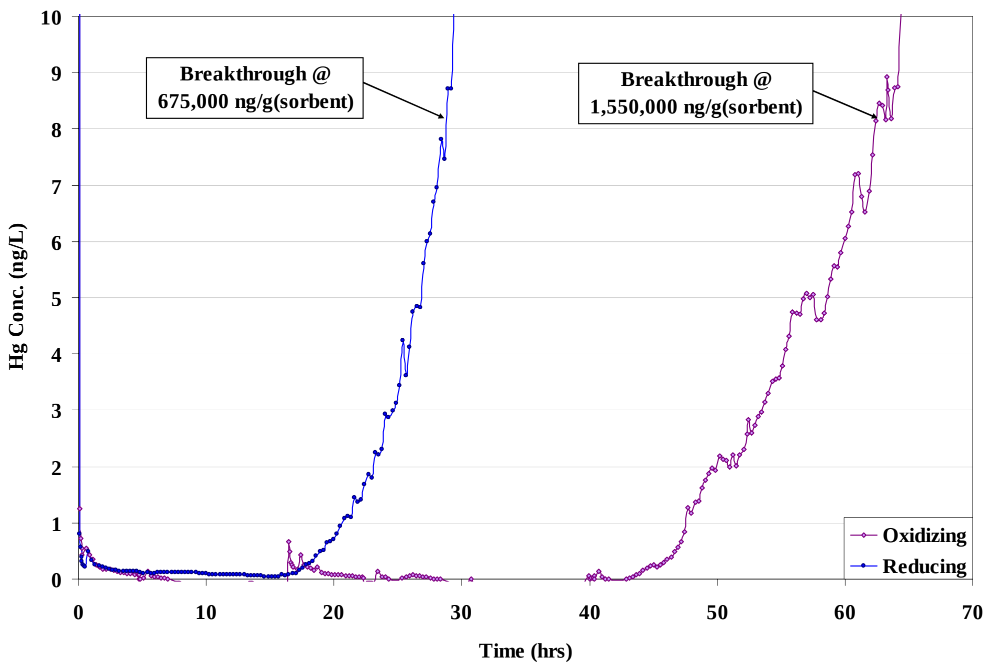

Fig. 2.8. HT Sorbent Performance under Oxidizing and Reducing Conditions (Temperature =500°F)

The addition of SO_2 into the sweep gas had a major impact on the breakthrough loading of one of the sorbents, which became ineffective under these conditions. As presented in Table 2.2 and in Fig. 2.9, there is a major de-activation of the sorbents. This particular sorbent was not suitable for gas streams containing SO_2 species.

Table 2.2. Summary of Breakthrough Loadings of One HT Sorbent with SO_2 in the Gas Stream.

SO_2 Concentration (ppmvw)	Hg Loading on the Sorbent at Breakthrough (ng/g sorbent)
40	5,600
20	11,600
10	60,500
5	134,000
0	1,200,000

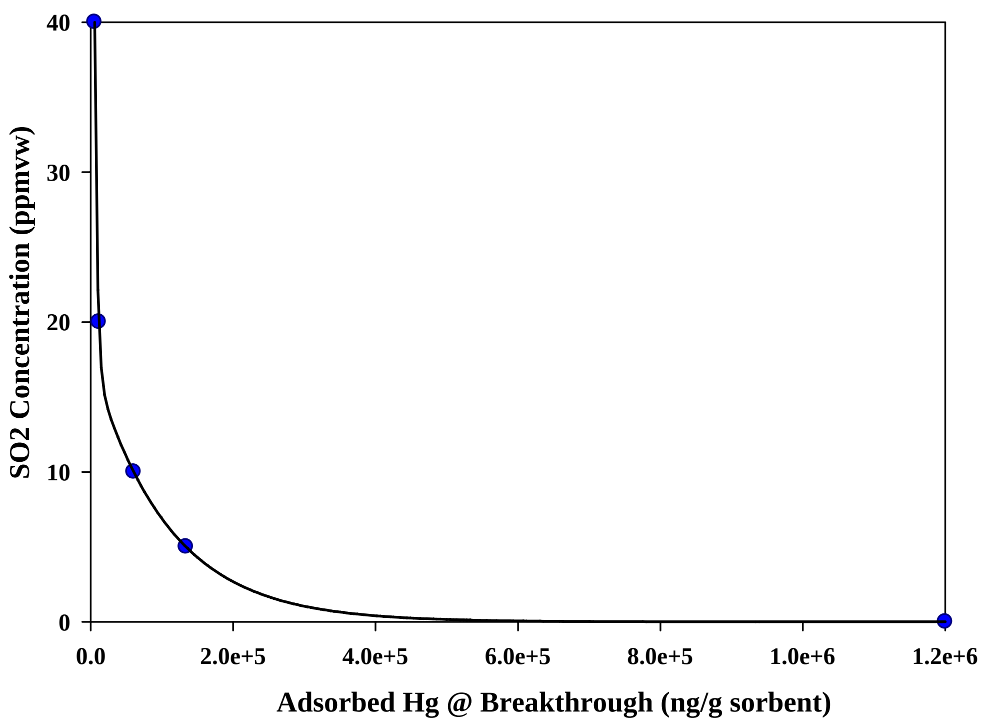

Fig. 2.9. Impact of SO_2 Content in the Sweep Gas and the Breakthrough Loadings of One HT Sorbent.

Of the five sorbents tested, the carbon-based sorbents were not effective. The non-carbon sorbents were able to perform well, except one sorbent that wilted under the presence of SO_2 mentioned above (Fig. 2.9). The remaining sorbents appear to meet the Hg capture goals. Additional testing is needed to estimate the impact of dust and regeneration capability or cost-effective once-through performance.

In summary, the preliminary data at 550ºF indicate that mercury sorption for the non-carbon-based sorbents is promising and it appears that sorbents are available that can meet the high temperature needs of the WRI process. These sorbents are either commercially available or near the threshold of commercialization. Importantly, the sorbents, as claimed by the vendors, are cost competitive. They perform at the desired temperature window without impacting the need for cooling the gas stream, thereby resulting in process energy efficiency gains.

2.4 Task 4.0 – PDU Tests

The objective of this Task was to assess and scale-up the results from the bench-scale tests to the PDU-scale unit. The existing PDU at WRI, designed to operate at a feed rate of 100 lb/hr, was upgraded to evaluate alternative mercury removal configurations. The pilot unit contains each of the components of a commercial installation, with the exception of an electrical heater which was used for process heat instead of the use of waste and process heat from the power plant. The pilot unit is instrumented for temperature and pressure across the drying and mercury removal steps. A schematic 3D view of the pilot unit is shown in Fig. 2.10.

A series of commissioning and bench-scale test confirmation runs with vibratory fluid bed mercury removal reactor were conducted using coals that were tested earlier in the bench-scale apparatus. The pilot-scale facility was operated at a fixed residence time and at selected temperatures from the bench-scale tests. Each test run included mass balances around the system.

The composition of the treated coals derived from the pilot testing of the paired raw coals that was presented earlier in Table 2.1 is presented in Table 2.3. The data illustrates a significant improvement in the heating value of the treated coals and a significant reduction in the mercury content (as well as arsenic and selenium in some cases).

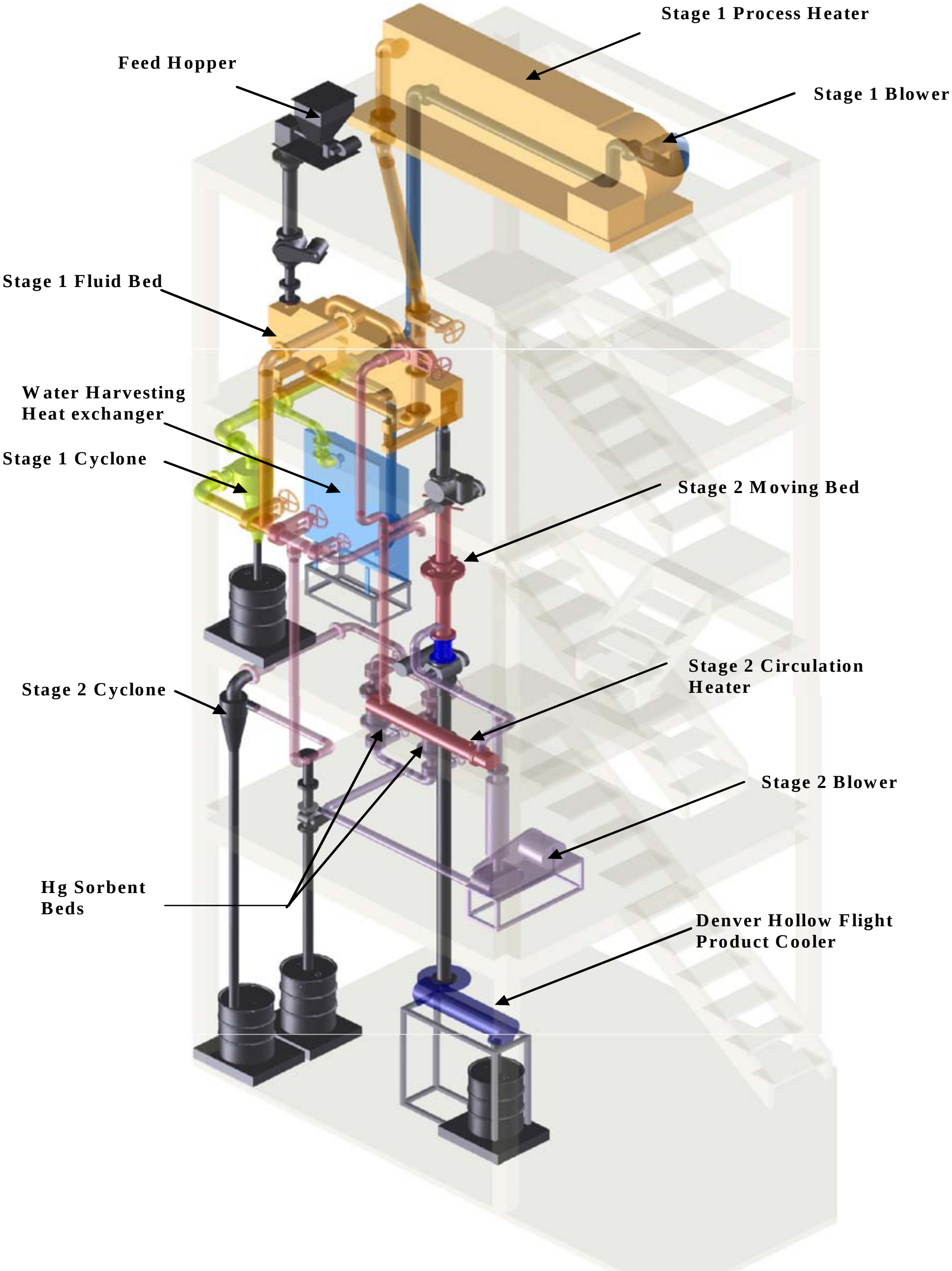

Fig. 2.10 Three Dimensional Schematic of the WRI PDU.

Table 2.3. Treated Coal Characterization Data

Coal Analysis / Parameter		Gulf Coast Lignite	Canada Lignite	ND Lignite-C	ND Lignite-A	Southern PRB	Eastern PRB	Northern PRB	Colo. Bit.
Proximate Analysis, wt.%	Moisture	3.13	0.0	2.67	0.0	0.02	0.0	0.0	0.0
	Ash	11.66	16.61	10.20	10.41	6.72	7.05	12.24	7.20
	VM	44.79	41.98	43.20	45.40	44.37	43.93	42.70	36.22
	FC	40.42	41.41	43.93	44.19	48.74	49.02	45.06	56.58
Ultimate Analysis, wt.%	Carbon	63.83	61.10	63.45	67.12	69.94	73.00	69.61	74.77
	Hydrogen	4.33	3.50	4.10	4.34	4.43	4.57	4.41	4.55
	Nitrogen	0.69	0.99	0.52	0.67	0.65	1.02	0.84	1.58
	Sulfur	1.65	0.60	1.10	1.13	0.44	0.43	0.92	0.53
	Oxygen	14.71	17.19	17.97	16.33	17.65	14.27	11.99	11.37
	Cl, ppm	74	76	24	49	31	106	76	3.31
HHV	Btu/lb	11336	10033	10877	11256	12007	12266	11695	12758
Forms Sulfur, wt.%	Pyritic	0.34	0.06	0.38	0.32	0.05	0.05	0.19	0.04
	Sulfate	0.03	0.13	0.03	0.03	0.03	0.02	0.05	0.01
	Organic	1.33	0.60	0.69	0.78	0.36	0.36	0.67	0.48
Mineral Analysis, wt.% ash	SiO_2	31.81	38.25	22.89	21.68	20.48	28.69	33.37	48.81
	TiO_2	1.06	0.53	0.31	0.24	0.29	1.46	0.91	0.62
	Al_2O_3	16.06	19.23	11.80	11.90	11.30	13.86	16.71	19.51
	Fe_2O_3	13.8	5.50	8.74	8.88	11.09	5.20	4.59	5.08
	CaO	13.8	17.87	21.97	23.82	21.83	24.82	21.31	8.45
	MgO	2.80	6.68	5.58	7.52	5.36	4.85	3.51	1.47
	K_2O	0.25	0.78	0.76	0.45	0.73	0.19	0.32	0.89
	Na_2O	0.23	0.48	6.99	3.26	6.84	1.49	0.50	1.71
	P_2O_5	0.04	0.39	0.29	0.40	0.19	12.92	0.64	1.83
	SO_3	14.91	6.48	14.96	16.46	17.01	1.00	12.40	6.76
Trace Metals, ppmd	Mercury	0.099	0.019	0.083	0.084	0.022	0.025	0.034	0.004
	Arsenic	8.3	4.4	6.5	4.6	6.3	1.4	1.6	1.1
	Selenium	0.9	1.0	1.0	0.9	1.0	1.2	0.8	0.7
HGI		49	60	48	52	50	45	49	47
Particle Size Distrib. cum. wt. %	> ½ inch	0.00	0.00	0.35	0.35	0.37	0.00	0.0	2.06
	½ x ¼ inch	7.43	0.93	4.18	4.18	4.79	6.09	5.32	30.53
	¼ x 6 mesh	40.37	12.52	30.06	30.06	30.32	39.49	28.56	72.72
	6 x 30 mesh	96.90	88.20	96.37	96.37	94.38	97.77	92.30	97.93
	30 x 60 mesh	99.23	98.95	99.35	99.35	99.37	99.63	99.39	99.43
	60 x 100 mesh	99.66	99.49	99.73	99.73	99.71	99.82	99.78	99.63
	< 100 mesh	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

HGI - Hardgrove Grindability Index;

The moisture-laden gas stream from the fluid bed dryer was cooled and the moisture was collected by a dedicated heat exchanger/condenser. The quality of the condensate was analyzed for potential in-plant use such as the boiler make-up water. Table 2.4 presents the inorganic analyses for the condensate water. The quality of the condensate from the WRI treatment process is quite clean and with limited additional treatment can be made to meet the specifications for its reuse in the plant.

Table 2.4. Condensate Water Quality from the Pilot-scale Tests.

Constituent D-3987 Extract	**Gulf Coast Lignite**	**Canada Lignite**	**ND Lignite -A**	**ND Lignite C**	**Southern PRB**	**Eastern PRB**	**Northern PRB**	**Colo. Bit.**
Lab pH, SU	7.0	5.0	6.1	7.0	6.5	6.6	7.1	6.8
TDS, mg/L	687	nd	nd	nd	nd	nd	nd	nd
Major Anions								
Chloride, mg/L	nd	nd	nd	nd	nd	nd	nd	nd
Alkalinity as CaCo3 - Dissolved, mg/L	44	34	nd	44	nd	nd	nd	nd
Bicarbonate Alkalinity, mg/L	nd	11	nd	nd	11	11	51	47
Carbonate Alkalinity, mg/L	nd	nd	nd	nd	nd	nd	nd	nd
Ammonia Nitrogen as N, mg/L	nd	17.0	2.3	0.91	2.6	4.2	3.1	180.0
Nitrate & Nitrite as N, mg/L	0.18	nd	nd	nd	nd	nd	nd	1
Phosphorus, mg/L	nd	nd	nd	nd	nd	nd	nd	nd
Sulfides, mg/L	nd	nd	nd	nd	nd	nd	nd	nd
Cyanide, mg/L	nd	0.048	0.061	nd	nd	0.068	0.022	0.026
Major Cations								
Calcium, dissolved, ug/L	3430	nd	4020	5750	11200	7190	nd	1.6
Iron, ug/L	nd	350	nd	4530	nd	nd	nd	13000
Lithium, ug/L	1.6	6.8	1.3	2.2	3.5	2.7	2.1	33
Magnesium, ug/L	1510	11000	1830	1530	5760	3170	3600	63000
Potassium, ug/L	454	660	310	239	486	392	nd	3200
Silicon, ug/L	755	2300	438	1700	846	552	490	6600
Sodium, ug/L	6790	2600	4050	1490	3750	4210	2100	15000
Trace metals								
Arsenic, ug/L	0.34	nd	0.74	1.6	0.7	0.82	nd	1.6
Mercury, ug/L	nd	nd	nd	nd	nd	nd	nd	nd
Selenium, ug/L	nd	nd	nd	1.1	nd	0.54	nd	7.4

nd – not detected

3.0 TECHNICAL DISCUSSION

Mercury Removal Efficiencies

The results confirm that the mercury removal seen in the bench-scale units is nearly reproducible also in the PDU pilot-scale reactor. The raw coal mercury concentrations listed in Table 2.1 matched consistently with the larger subset samples produced with the pilot-scale test runs data shown in Table 2.3.

Table 3.1 shows the mercury removal efficiencies obtained in the PDU pilot-scale reactor tests. Reductions in mercury in the coals treated in the pilot-scale runs ranged from 36% to 89%. The lower number (35.9%) for one of the PRB coals might be attributed to the shorter average coal residence time in the reactor. This coal was very friable and elutriated from the bed in substantial quantities. This may call for recycling of the elutriated coal in a commercial system and/or also providing for the taller freeboard of the bubbling fluidized bed reactor.

The data also show a reduction of arsenic of 0% to 67% and a reduction of selenium of 0% to 20%. There were also some negative removals in the data, reflecting the difficulty of getting consistent representative samples from inhomogeneous distribution of materials such as trace metals in coal.

Table 3.1. Mercury Concentrations in Raw and Treated Coals (ppmw, dry)

Fuel Type	Gulf Coast Lignite	Canada Lignite	ND Lignite - C	ND Lignite-A	Southern PRB	Eastern PRB	Northern PRB	Colo. Bit.
Raw Coal	0.266	0.179	0.184	0.149	0.075	0.126	0.053	0.006
Treated Coal	0.099	0.019	0.083	0.084	0.022	0.025	0.034	na
Hg Rem Eff.	62.78	89.39	54.89	43.62	70.67	80.16	35.85	na

na – not available due to the low concentration in the coal.

In addition, the quality of the condensate (Table 2.4) does not contain mercury or the other trace metals of concern (arsenic and selenium) and as such little additional treatment is needed in order for the water to be used in the power plant.

4.0 CONCLUSIONS

The results and conclusions of the Phase I testing program can be summarized as below:

Eight coals have been identified in collaboration with the project sponsors as outlined in the DOE award. These represent the western bituminous coal, western subbituminous (Powder River Basin) coal and North Dakota lignite, Gulf Coast lignite and Canadian lignite. The variance of the mercury concentration in the coals ranged from 0.006 ppmw(d) to 0.266 ppmw(d). Chlorine and moisture are as expected in concentration and varied with coal rank.

A bubbling-bed bench-scale unit has been upgraded to pre-screen the mercury removal characteristics of the selected coals in a fluidized bed dryer and reactor and all eight coals were tested. Mercury removals ranged from about 50% to a high of 87%, meeting the project goals. Mercury removal varied with temperature and removal is essentially complete by 550ºF. Residence time-temperature testing indicated that significant increases in mercury removal were possible with reasonable extended residence times for certain coals. The findings from the bench-scale testing also indicated that the WRI process is amenable for a wide range of low-rank coals.

A dedicated sorbent test facility that can operate at high temperatures was designed and constructed. A state-of-the-art mercury analyzer was procured to measure the vapor phase mercury species. High temperature (non-carbon and carbon-based) sorbents were tested on a lab-scale. The findings from the high temperature sorbent development and testing indicated that WRI process improvements are possible through available high-temperature sorbents that are cost-effective and potentially at the threshold of commercial demonstration.

The pilot-scale PDU, which can handle up to 100 lb/hr of raw fuel, was operated using the project coals. These tests confirm the mercury removals shown in the bench-scale tests can also be achieved in the PDU pilot-scale unit. The reductions ranged from a low of 36% to a high of 89%. Removals of arsenic and selenium were as high as 67% and 20% respectively.

The overarching conclusion of the Phase I testing was that the WRI process is a technically viable technology for (1) removing moisture from low rank coals, thereby raising the heating value of the coal by about 30% for subbituminous coals and up to 40% for lignite coals, and (2) for removing a number of volatile trace metal species, such as mercury, from the coal prior to combustion. The results established that the process meets the goals of DOE of removing <50% of the mercury from the coals by pre-combustion methods. As such, further testing, demonstration and economic analysis, as described in the Phase II effort, is warranted and should be pursued.

5.0 REFERENCES

Bland, A.E., C. Greenwell, J. Newcomer, K. Sellakumar, and B. Carney, *"Pilot Testing of WRI's Novel Mercury Control Technology by Pre-Combustion Thermal Treatment of Coal"*, U.S. DOE Mercury Control Conference, Pittsburgh, PA, December 13, 2007.

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