JV TASK 107 – PILOT-SCALE EMISSION CONTROL TECHNOLOGY TESTING FOR CONSTELLATION ENERGY

Final Report

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ABSTRACT

An Indonesian, Colombian, and Russian coal were tested in the Energy & Environmental Research Center's combustion test facility for their performance and an evaluation of mercury release and capture with selected additives in both electrostatic precipitator and baghouse configurations. Sorbents included the carbon-based materials NORIT DARCO Hg, Sorbent Technologies B-PAC and B-PAC LC, STI Rejects provided by Constellation Energy, and Envergex e-Sorb, along with ChemMod's high-temperature additive. Each coal was evaluated over several days and compared. Ash-fouling tests were conducted, and mercury levels were monitored using continuous mercury monitors (CMMs). The Ontario Hydro mercury sampling method was also utilized.

The Indonesian coal had the lowest ash content, lowest sulfur content, and lowest energy content of the three coals tested. The Colombian coal had the highest mercury content and did contain a significant level of selenium which can interfere with the ability of a CMM to monitor mercury in the gas stream. All sorbents displayed very favorable results. In most cases, mercury removal greater than 86% could be obtained. The Indonesian coal displayed the best mercury removal with sorbent addition. A maximum removal of 97% was measured with this coal using Envergex's carbon-based sorbent at a rate of 4 lb/Macf across an electrostatic precipitator. The high ash and selenium content of the Colombian coal caused it to be a problematic fuel, and ash plugging of the test furnace was a real concern. Problems with the baghouse module led to limited testing. Results indicated that native capture across the baghouse for each coal type was significant enough not to warrant sorbent addition necessary.

The fouling potential was the lowest for the Indonesian coal. Low sulfur content contributes to the poor potential for fouling, as witnessed by the lack of deposits during testing. The Russian and Colombian coals had a much higher potential for fouling primarily because of their high ash contents, but the potential was highest for the Colombian coal. Of the three coals tested, the Colombian would be the least desirable.

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NOMENCLATURE

ACI	activated carbon injection
APCD	air pollutant control device
CAMR	Clean Air Mercury Rule
CEM	continuous emission monitor
CMM	continuous mercury monitor
CTF	combustion test facility
CVAAS	cold-vapor atomic absorption spectroscopy
DOE	U.S. Department of Energy
EERC	Energy & Environmental Research Center
EPA	Environmental Protection Agency
ESP	electrostatic precipitator
FEGT	furnace exit gas temperature
FF	fabric filter
ICR	information collection request
OH	Ontario Hydro
PAC	powdered activated carbon
pc	pulverized coal
PRB	Powder River Basin
SCMO	solid calcium magnesium oxide
SCR	selective catalytic reduction
SEA	sorbent enhancement additive
SEMPC	scanning electron microscope point count analysis
SNCR	selective noncatalytic reduction
XRF	x-ray fluorescence

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EXECUTIVE SUMMARY

Pilot-scale tests were performed to compare three foreign coals on the Energy & Environmental Research Center's (EERC's) combustion test facility for their potential for fouling and the ability to capture mercury in an electrostatic precipitator (ESP) and baghouse configuration. Sorbents used during mercury testing included NORIT DARCO Hg, Envergex e-Sorb, Sorbent Technologies B-PAC and B-PAC LC, STI Rejects provided by Constellation Energy, and ChemMod's higher-temperature additives Mer-Sorb and S-Sorb. Four different formulations of e-Sorb were used depending on the characteristics of the fuel being burned. These formulations were recommended by the vendor.

Mercury concentrations were measured using continuous mercury monitors (CMMs) at the inlet and outlet of the control device. Ontario Hydro (OH) method measurements were used to verify the CMM. On a pound per trillion Btu (lb/TBtu) basis, the mercury content of the Indonesian, Russian, and Colombian coals were 3.35, 2.6, and 3.69, respectively. Limited testing was conducted with the baghouse configuration because of equipment problems. Based on the testing that was performed, the native capture using fabric filters for all of the coals was above 85%; therefore, sorbent addition was not conducted. Fouling probes were inserted in the furnace during the baseline testing of each coal, and the deposits were analyzed by x-ray fluorescence and scanning electron microscopy. The resulting data were then evaluated using FACT thermodynamic data for fouling potential.

The Indonesian coal has an ash content below 2% and a very low sulfur content. The baghouse configuration was not tested with this coal, so all tests were run with an ESP. STI Rejects performed the poorest, attaining only 67% reduction at a feed rate of 10 lb/Macf. DARCO Hg and the B-PAC products performed similarly, with a reduction range of 85% to 88% reduction at a feed rate of 5 lb/Macf. The Envergex product performed far better. At a feed rate of 4 lb/Macf, a reduction of 97% was measured. The ChemMod product showed similar results to the DARCO and B-PAC products in attaining 67% reduction with an S-Sorb rate of 6% and a Mer-Sorb rate of 0.75%. This coal did not product a deposit on the deposit probes but rather a light dusting. Analysis using FACT showed that the potential is present for significant fouling but the lack of sulfur in the coal will prevent severe deposit formation. To compare the effects of selective noncatalytic reduction (SNCR), a few tests were conducted while injecting 10 ppm NH_3 into the flue gas. Results were mixed but seemed to show a 1%–2% increase in mercury removal effectiveness.

Colombian coal was the most problematic of the coals tested. With a sulfur content of 1% and an ash content of almost 15%, there was significant concern for the system piping to plug. Evidence of this was seen after days where operation continued beyond 12 hours. The best performance with an ESP configuration was again seen with the Envergex product which yielded a 93% removal at an injection rate of 6 lb/Macf. Like with the Indonesian coal, DARCO and B-PAC gave similar results, with removals in the 55% to 65% range. Native capture with the

baghouse configuration was 84%. A test was run with B-PAC in this configuration, and the removal was increased to 94% at a rate of 3 lb/Macf. Using the ChemMod products at the same rate as used with the Indonesian coal yielded a removal of 93% with an ESP configuration. As expected, evaluation using the FACT code indicated a very high expectation of fouling to occur.

Testing with the Russian coal also indicated that the Envergex sorbent was the most effective, with a mercury removal of 92% at a rate of 3 lb/Macf. Like the other tests, DARCO and B-PAC performed similarly with a removal in the 70% to 80% range at a rate of 5 lb/Macf. The use of the baghouse module showed a native capture of 92%, so further testing was not conducted. The ChemMod products produced a mercury removal of 82% with an S-Sorb rate of 3% and a Mer-Sorb rate of 0.75%. FACT analysis indicated that Russian coal had high potential for fouling but less than the Colombian coal because of lower ash and sulfur contents.

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INTRODUCTION

The Energy & Environmental Research Center (EERC) conducted a project with Constellation Energy to examine methods to cost-effectively remove mercury from combustion gases at coal-fired power plants operating with a range of coal from around the world. The emphasis was on mercury control using electrostatic precipitators (ESPs), fabric filters (FFs), and selective catalytic reduction (SCR) air pollution control devices and a range of injection techniques with varying levels of carbon carryover.

Recently, challenges have been identified related to the ability to achieve high levels of control of greater than 80% mercury removal for high-rank bituminous coals. Effective sorbents have been identified and tested for lower-rank lignite and subbituminous coals. These approaches have included the use of oxidizing agents or sorbent enhancement additives (SEAs) alone or in combination with activated carbon injection (ACI). For high-rank coals, recent data have indicated challenges in achieving high levels of control at low costs (i.e., lower injection rates of sorbents) (1, 2).

The EERC performed a series of pilot-scale investigations using the EERC's pilot furnace known as the combustion test facility (CTF). The CTF is a 550,000-Btu/hr pulverized coal (pc)-fired unit designed to generate fly ash and flue gas representative of that produced in a full-scale utility boiler. This system can be equipped with several air pollution control devices including an ESP and an FF. Various combinations of air pollution control devices, can be configured to evaluate mercury control technologies. The combustion system can be configured for existing Constellation Energy plant configurations as well as examined for future combinations of devices for multipollutant control. Sorbent injection as well as chemical additives specifically aimed at bituminous coals will be tested in the pilot-scale system in order to identify the best combination to test at the full scale.

BACKGROUND

Mercury is an immediate concern for the U.S. electric power industry because of the U.S. Environmental Protection Agency's (EPA's) December 2000 decision that regulation of mercury from coal-fired electric utility steam-generating units is appropriate and necessary under Section 112 of the Clean Air Act (1). EPA determined that mercury emissions from power plants pose significant hazards to public health and must be reduced. The 1997 EPA Mercury Study Report to Congress (2) and the 1998 Utility Hazardous Air Pollutant Report to Congress (3) both identified coal-fired boilers as the largest single category of atmospheric mercury emissions in the United States, accounting for about one-third of total anthropogenic emissions. On December 15, 2003, EPA published the proposed Utility Mercury Reductions Rule in order to solicit comments on multiple approaches for mercury emission control (4). EPA recently announced the Clean Air Mercury Rule for coal-fired power plants. The cap-and-trade provision of the rule would reduce mercury emissions from 48 to 38 tons/year by 2010 and to 15 tons/year in 2018, accounting for a reduction of nearly 69%.

Mercury Control Challenge for Bituminous Coals

Mercury emissions from utilities burning U.S. coals were determined under EPA's information collection request (ICR), which mandated Hg and chlorine analyses on coal shipped to units larger than 25 MWe during 1999 and emission testing on 84 units selected to represent different categories of air pollution control equipment and coal rank. As shown in Table 1, bituminous coals from the western United States, on average, contain significantly higher concentrations of Hg, chlorine, and sulfur than subbituminous coals from the western United States. Based on the ICR data, Powder River Basin (PRB) coals produce as much as 6 lb Hg/10^{12} Btu compared to 8 lb Hg/10^{12} Btu for North Dakota lignites, 6.5 lb Hg/10^{12} Btu for Illinois Basin bituminous coals, 9.5 lb Hg/10^{12} Btu for Appalachian bituminous coals, and 12.5 lb Hg/10^{12} Btu for Gulf Coast lignites (3).

Coal composition has a major impact on the quantity and chemical form of Hg in the flue gas and, as a result, the effectiveness of air pollutant control devices (APCDs) to remove Hg from flue gas. Coals containing greater than about 200 ppm chlorine produce flue gases that are dominated by the more easily removable mercuric compounds (Hg^{2+}), most likely mercuric chloride ($HgCl_2$). Appalachian and Illinois Basin bituminous coals generally have >200 ppm chlorine. Conversely, low-chlorine (<50 ppm) subbituminous and lignite coal combustion flue gases contain predominantly Hg^0, which is substantially more difficult to remove than Hg^{2+} (4). Additionally, the abundance of calcium in subbituminous coal fly ashes may reduce the oxidizing effect of the already-low chlorine content by reactively scavenging chlorine species (Cl, HCl, and Cl_2) from the combustion flue gas.

Initial testing of mercury control technologies indicated that the major challenge for mercury control was with western subbituminous coal and lignite coal because the form of mercury in the flue gas is dominated by the more difficult-to-control elemental form (5, 6). As a result of these initial findings, significant research, development, and testing efforts were focused on the development of mercury oxidation and enhanced sorbent technologies specifically aimed

Table 1. Average Coal Compositions and Heating Values from a Select Group of ICR Data, on a dry basis

Parameter	Eastern Appalachian	Western Subbituminous
Hg, ppm	0.126	0.068
Cl, ppm	1064	124
S, wt%	1.67	0.48
Ash, wt%	11.65	7.92
Ca, ppm	2700	14,000
HHV,[a] Btu/lb	12,900	9300
Moisture, wt%	2.5	19.4

[a] Higher heating value.

at lower-rank coals. Recent testing at power plants firing lower-rank coals has shown that mercury oxidation and enhanced sorbent technologies have successfully attained removal efficiencies above 85% to 90% during short-term testing (1 month) using 1 to 3 lb/Macf carbon (7). Bituminous coals, on the other hand, have shown 50% to 80% with 5 to 7 lb/Macf of carbon (1, 2).

Mercury Control Options

Options for controlling Hg_{total} emissions are being investigated that have the potential to attain >90% removal of Hg_{total} from flue gas. An overview of methods being considered is shown in Figure 1. Investigation of mercury control technology options for coal-fired power plants must consider the coal type fired (may need to consider potential for changes in fuel type), firing conditions, existing APCDs, and future air pollution systems. The options for mercury control include coal cleaning, chemical addition for oxidation, sorbent injection upstream of control devices, oxidation catalysts, SCR catalysts, and sorbent beds.

Many potential Hg sorbents have been evaluated (8). These evaluations have demonstrated that the chemical speciation of Hg controls its capture mechanism and ultimate environmental fate. ACI is the most tested technology available for Hg_{total} control. Activated carbons have the potential to effectively adsorb Hg^0 and Hg^{2+}, depending on the carbon characteristics and flue gas composition (8). Most activated carbon research has been performed in fixed-bed reactors that simulate relatively long-residence-time (gas–solid contact times of minutes or hours) Hg_{total} capture by a FF filter cake (9–11). However, it is important to investigate short-residence-time (seconds) in-flight capture of Hg^0 because most of the coal-burning boilers in the United States employ cold-side ESPs for controlling particulate matter emissions.

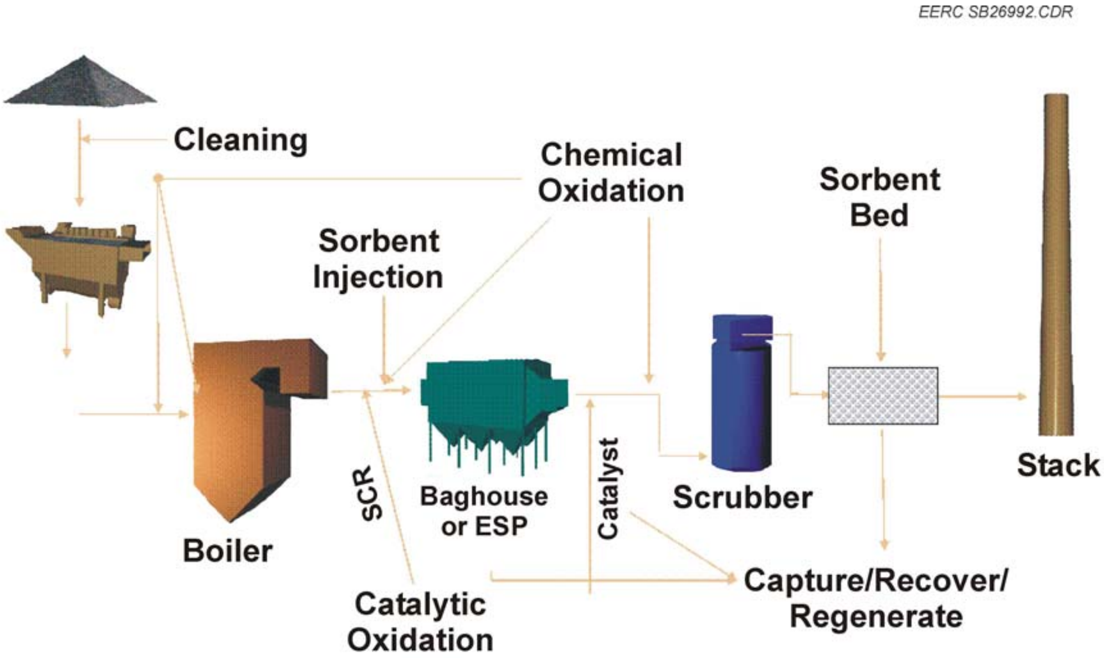

Figure 1. Options for mercury control for all coal types.

The projected annual cost for activated carbon adsorption of Hg in a duct injection system is significant. Carbon-to-mercury weight ratios of 3000–18,000 (lb carbon injected/lb Hg in flue gas) have been estimated to achieve 90% Hg_{total} removal from a coal combustion flue gas containing 10 µg/Nm^3 of Hg_{total} (12). More efficient carbon-based sorbents are required to enable lower carbon-to-mercury weight ratios to be used, thus reducing the costs. As a result of the high costs, measures were developed for low-rank coals to enhance the carbon by additive or injection of sorbent enhancement agents to improve the reactivity.

Hg^0 oxidation technologies being investigated for lignite and subbituminous coals include catalysis, chemical additives, and cofiring fuels. The catalysts that have been tested include metal-impregnated, oxide-impregnated, noble metal, and SCR catalysts for NO_x reduction. The chemical additives tested are generally halogen-containing salts. The cofired fuels tested contained oxidizing agents (13).

Mercury speciation sampling was conducted upstream and downstream of SCR catalysts at power plants firing bituminous and subbituminous coals (14). Test results indicated evidence of Hg^0 oxidation across SCR catalysts when bituminous coals were fired. However, when subbituminous coal was fired, the results indicated limited Hg^0 oxidation, and more testing needs to be conducted on low-rank coals. The capability of SCR systems to promote Hg^0 oxidation is coal-specific and probably related to the chlorine, sulfur, and calcium contents of the coal as well as the temperature and specific operation of the SCR catalyst including space velocity.

ESP-Only Testing

Figure 2 shows results obtained from the Phase II mercury control field tests conducted on several plants with various types of mercury control technologies. These technologies included ACI, enhanced carbon injection, and SEA combined with carbon. The best methods include SEA2 combined with activated carbon and enhanced carbons for lower-rank coals. Results for higher-rank coals indicate relatively high injection rates in order to attain higher removal rates that are 2 to 4 times higher than that attained for lower-rank coals. Figure 3 shows that over 5 lb/Macf of carbon is required to achieve 60% to 80% control for an eastern bituminous coal fired in a pc-fired unit equipped only with an ESP. Figure 4 shows additional data indicating that high levels of carbon are required for mercury removal.

ESP–FF Testing

EERC pilot-scale and full-scale ESP and ESP–FF (TOXECON) Hg removal efficiencies for bituminous coal are compared to Fort Union lignite and subbituminous coal in Figure 4 while activated carbons are injected. As indicated in Figure 4, coal type (i.e., composition) was an important parameter that affected the Hg_{total} removal efficiency of a control device. During the pilot-scale lignite and utility-scale eastern bituminous coal tests, Hg_{total} removal efficiencies increased with increasing ACI rates. Conversely, Hg_{total} removal efficiencies were never greater than 70%, regardless of the ACI rate into the PRB subbituminous coal combustion flue gas. This limitation is probably caused by the low amount of acidic flue gas constituents, such as HCl, that promote Hg-activated carbon reactivity.

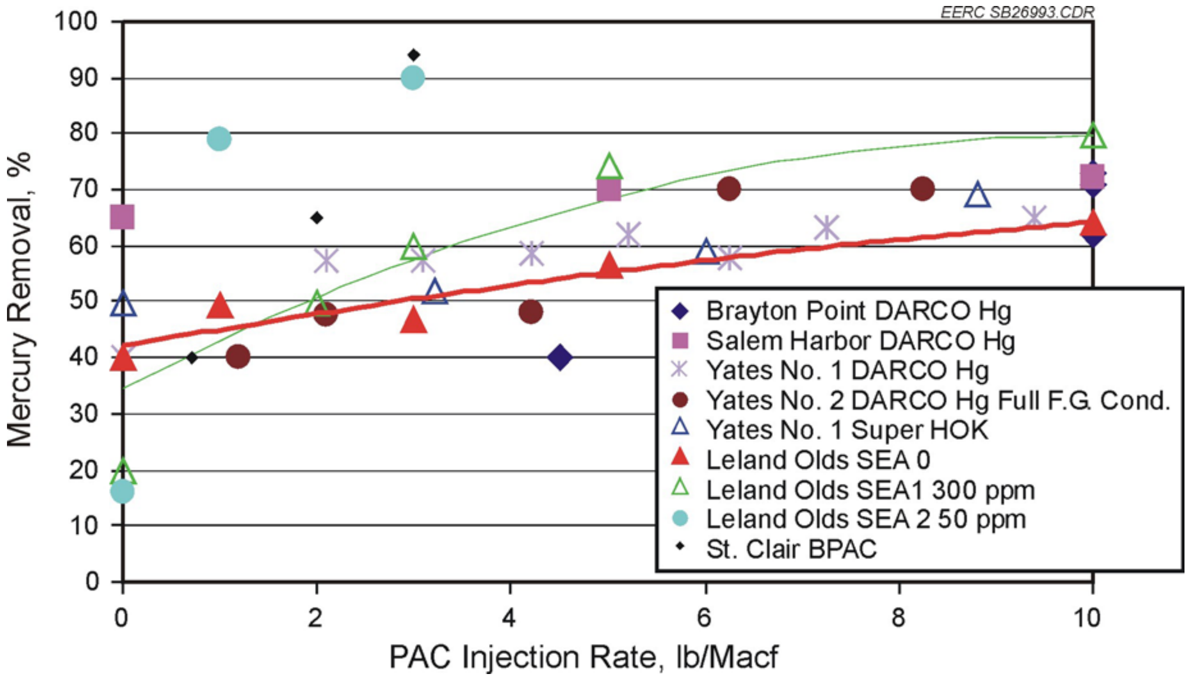

Figure 2. Hg_{total} removal percentages across the ESP during full-scale testing supported by the U.S. Department of Energy (DOE) (Leland Olds – lignite-fired, St. Clair – subbituminous-fired, Brayton Point – bituminous-fired, Yates – bituminous-fired, and Salem Harbor – bituminous-fired).

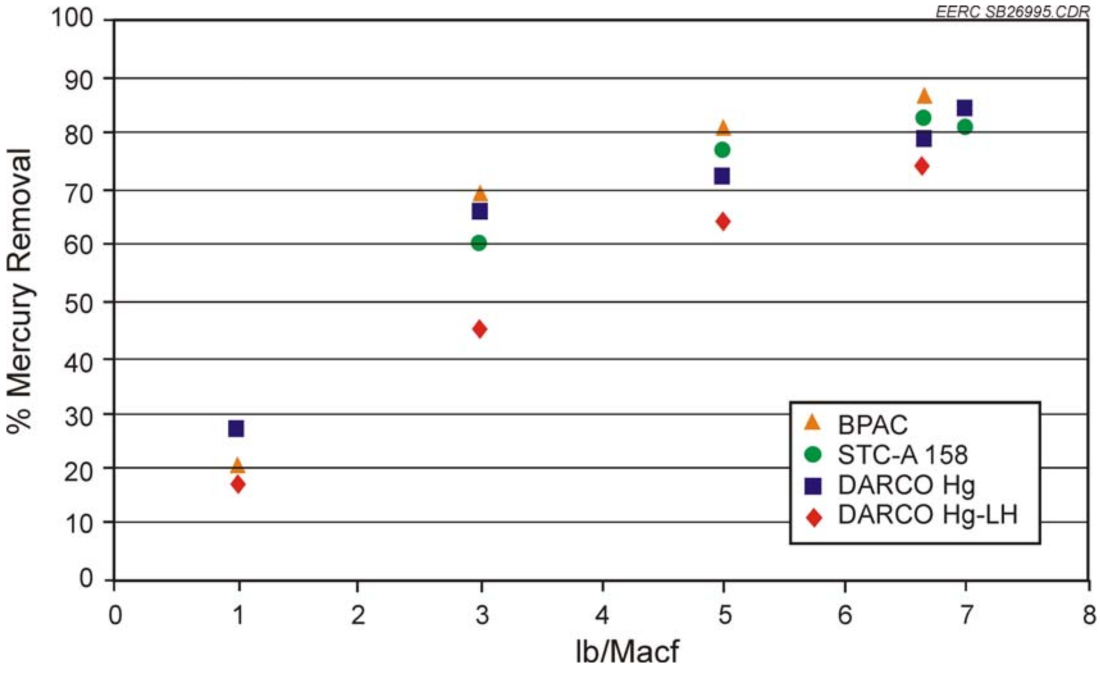

Figure 3. Results of testing at Duke Power's Allen Station (pc with ESP only) (1).

Coal	PM Unit	Hg Removal	lb/Macf	Plant	Utility	Data
Bitum. Low-S	CS ESP	85%	5.0	Allen	Duke	Apogee/ST
Bitum. High-S	CS ESP	70%	4.0	Lausche	OhioH	SorbTech
Bitum. High SO_3	CS ESP	NA**	4.0	Merrimack	PSNH	SorbTech
Bitum. Low-S	HS ESP	80%*	6.4	Cliffside	Duke	SorbTech
Bitum. Low-S	HS ESP	50%	5.0	Buck	Duke	SorbTech
Subbitum. Blend	CS ESP	90%	3.0	St. Clair	Detroit Ed.	SorbTech
Subbituminous	CS ESP	90+%	3.0	St. Clair	Detroit Ed.	SorbTech
Subbituminous	CS ESP	90%	3.2	Stanton 1	GRE	EERC/URS
Lignite	SD/FF	95%	1.5	Stanton 10	GRE	EERC/URS
Lignite	CS ESP***	70%***	1.5	Stanton 10	GRE	EERC/URS

* When under low-load conditions at this plant.
** Public Service of New Hampshire has not yet publicly released these data.
*** Actually the in-flight-Hg removal across the spray dryer.

Figure 4. Summary of mercury control data for bituminous, subbituminous, and lignitic coals (2).

EXPERIMENTAL

Pilot-scale tests were performed on the EERC’s combustion test facility to compare the properties of three foreign coals: Indonesian, Colombian, and Russian. During testing, Hg control technologies were injected into the flue gas to determine their effectiveness at reducing the Hg generated from the combustion of these coals. A description of the experimental methods and apparatuses used in the evaluation of these coals is discussed below.

Description of the Combustion Test Facility

An isometric drawing of the EERC’s CTF is shown in Figure 5. The furnace capacity is approximately 100 lb/hr (750,000 Btu/hr) of a moderately high-Btu-content fuel. The combustion chamber is 30 inches in diameter, 8 feet high, and refractory-lined and has been used for combustion testing of fuels of all rank. The furnace can be configured in many different arrangements, and the graphic shows a second probe bank used for low-temperature ash-fouling evaluations. This section was replaced by a series of water-cooled, refractory-lined heat exchangers for the tests reported here.

The furnace diameter may be reduced to 26 inches to elevate the temperature entering the convective pass. Furnace exit gas temperatures (FEGTs) as high as 2550°F have been achieved during combustion testing in this mode. Two Type S thermocouples, located at the top of the combustion chamber, are used to monitor the FEGT. They are situated 180° apart at the midpoint of the transition from vertical to horizontal flow. Excess air levels are controlled manually by adjusting valves on the primary and secondary airstreams. The typical distribution is 15%

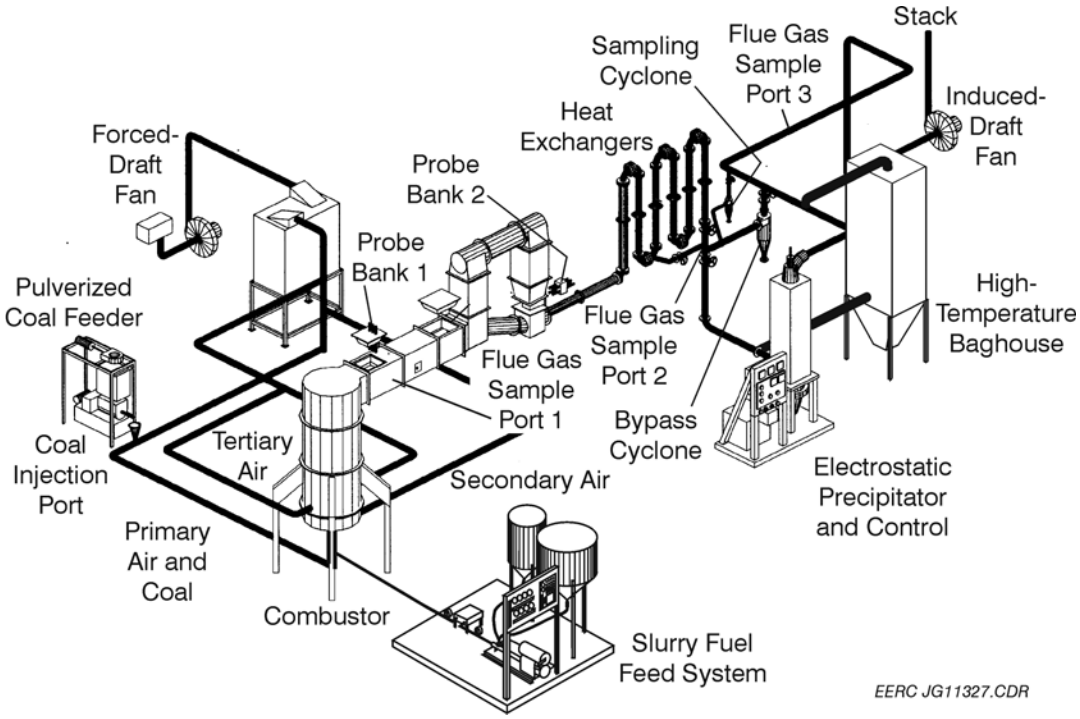

Figure 5. CTF and auxiliary systems.

primary and 85% secondary to achieve the specified excess air level, which is typically 25% or higher for combustion of biomass.

When solid fuels are fired, the fuel is normally pulverized remotely in a hammer mill pulverizer, targeted to a size of 70% less than 200 mesh. It is then charged to a microprocessor-controlled weight loss feeder from a transport hopper. Combustion air is preheated by an electric air heater. The pulverized fuel is screw-fed by the gravimetric feeder into the throat of a venturi section in the primary air line to the burner. Heated secondary air is introduced through an adjustable swirl burner, which uses only primary and secondary air. Flue gas passes out of the furnace into a 25-cm (10-inch)-square duct that is also refractory-lined. Located in the duct is a vertical probe bank designed to simulate superheater surfaces in a commercial boiler. After leaving the probe duct, the flue gas passes through a series of water-cooled, refractory-lined heat exchangers and a series of air-cooled heat exchangers before being discharged through either an ESP or a baghouse. A baghouse was used for the tests performed here.

Gas Analyses

The CTF utilizes two banks of Rosemount NGA gas analyzers to monitor O_2, CO, CO_2, and NO_x. Sulfur dioxide (SO_2) is monitored by analyzers manufactured by Ametek. The analyzers are typically located at the furnace exit and the particulate control device exit. The gas analyses are reported on a dry basis. Baldwin Environmental manufactures the flue gas conditioners used to remove water vapor from each gas sample. The flue gas constituents are constantly monitored and recorded by the CTF's data acquisition system.

Continuous Mercury Monitoring

Throughout testing, mercury continuous emission monitors (CEMs), also referred to as continuous mercury monitors (CMMs), were used to measure the Hg levels and to periodically determine the vapor-phase speciation.

The Tekran Model 2537A atomic fluorescence-based Hg vapor analyzer was used in conjunction with a PS Analytical S235C400 wet-chemistry conversion unit to continuously monitor Hg^0 and total Hg concentrations at the inlet of the particulate control device and at the outlet. All of the testing, except the last test day in February, was done on the PS Analytical. The PS Analytical uses two separate liquid flow paths, one to continuously reduce Hg^{2+} to Hg^0, resulting in a total gas-phases Hg sample and the other to continuously scrub out Hg^{2+}, resulting in an Hg^0 sample. The PS Analytical also uses a Peltier thermoelectric cooler module to cool and dry the sample gases prior to analysis.

The Tekran instrument traps the Hg vapor from the conditioned sample onto a cartridge containing an ultrapure gold sorbent. The amalgamated Hg is then thermally desorbed and detected using atomic fluorescent spectrometry. A dual-cartridge design allows alternate sampling and desorption, resulting in continuous measurement of the sample stream. The Tekran Model allows two methods of calibration: manual injection or an automatic permeation source. The permeation source was used to calibrate the instrument daily. Manual injection calibration on both cartridges was performed for verification. The Tekran instrument can either measure total Hg or Hg^0, with one analysis point being obtained approximately every 2.5 minutes.

Ontario Hydro (OH) Method Flue Gas Mercury Measurements

OH method samples were withdrawn from the flue gas stream isokinetically through a probe/filter system, maintained at 120°C or the flue gas temperature, whichever was greater, followed by a series of impinger solutions in an ice bath. Particle-bound mercury (Hg_p) was collected on a quartz filter in the front half of the sampling train. Hg^{2+} was collected in impingers containing a chilled aqueous potassium chloride solution. Hg^0 was collected in subsequent impingers (one impinger containing a chilled aqueous acidic solution of hydrogen peroxide and three impingers containing chilled aqueous acidic solutions of potassium permanganate). Samples were recovered and sent to the lab for analysis. The OH samples were typically prepared and analyzed the same day of collection or the following day. Hg was determined by cold-vapor atomic absorption spectroscopy (CVAAS) using a CETAC M6000A automated Hg analyzer. Calculations for reporting results in units of $\mu g/dNm^3$ are shown in Appendix A. The main purpose of the OH sample will be to validate the CEM measurements and provide capture efficiency and full Hg speciation information.

Analyses of Combustion Residues

The coal deposits were analyzed using x-ray fluorescence (XRF) to determine the chemical composition of the deposit. The ash samples will also be analyzed for CHN (carbon, hydrogen, and nitrogen) to characterize the combustion and determine if there were any effects from the injection sorbent and powdered activated carbon (PAC) injection.

Coal Analyses

Coal samples were analyzed for mercury, chlorine, and selenium content, and a select number of samples also underwent proximate and ultimate analyses and Btu. The coal Hg content provided the basis for determining native Hg capture at each site along with the percent mercury removal achieved during parametric sorbent testing. Variability in coal composition was noted and provided a representative picture of the coal fired during each test period as well as the entire project.

Powdered Activated Carbon/Sorbents

Currently, PAC injection has shown the most promise as a near-term Hg control technology. PAC is typically injected downstream of a plant's air heater and upstream of a particulate control device, either an ESP or FF. The powdered activated carbons and sorbents used in the testing are as follows: BPAC LC, BPAC, STI Rejects, Envergex 1, Envergex 2, Envergex 3, Envergex 4, DARCO Hg, and Chem-Mod's Mer-Sorb and S-Sorb. A description of the PACs tested can be found in Table 2.

RESULTS AND DISCUSSION

The results from testing of the three chosen coals (Indonesian, Colombian, and Russian) are presented below. Twelve days of testing were completed on the EERC's CTF. During testing, several sorbents were evaluated for their effectiveness at removing Hg from the flue gas generated by each coal. Each day of testing consisted of baseline testing in the morning, until the

Table 2. PACs Tested

Sorbent Name	Manufacturer	Average Particle Size, µm	Description	Price at Time of Testing ($/lb)[a]
DARCO Hg	NORIT Americas	19	Lignite-derived activated carbon; baseline carbon	$0.60 $0.60
Envergex		Proprietary	Proprietary	$1.00–$1.50
BPAC	Sorbent Technologies	20	Brominated lignite-derived activated carbon	$0.65–$0.75
BPAC-LC	Sorbent Technologies	20	Brominated lignite-derived activated carbon; lower-cost version of BAC	< $0.75

[a] Price does not include freight.

unit reached a steady state, followed by parametric style testing of the different sorbents. The sorbents testing were BPAC with and without NH_3, STI Rejects with and without NH_3, Envergex 1, Envergex 2, Envergex 3, Envergex 4, DARCO, BPAC LC, and Chem-Mods (S-Sorb and M-Sorb). Table 3 summarizes the results from testing reported as an average for each test period. Daily summary plots can be found in Appendix A.

Coal and Baseline Analysis

Mercury emissions from coal-fired power plants are a direct result of the volatilization of mercury present in the fuel; therefore, characterization of coal mercury concentration was accomplished through detailed coal sampling and analysis. The results for the overall average coal data for each coal can be found in Table 4. Hg concentrations measured in the coal were similar for all three coals and were 0.04115, 0.0441, and 0.0327 ppm for the Indonesian, Colombian, and Russian, respectively. The coal Hg concentration on a flue gas basis was calculated to enable a comparison of the mercury entering the system with the coal with those Hg concentrations measured in the flue gas by both the CMMs and the OH method. The average Hg concentrations calculated from the coal for the entire test period for the Indonesian, Colombian, and Russian were 4.85, 5.21, and 3.68 $\mu g/Nm^3$, respectively. Coal-derived Hg concentrations compared for all three coals can be seen in Figure 6. Coal inlet Hg variability was seen throughout the test program in all three coals. The greatest variability of inlet coal Hg concentrations occurred with the Indonesian coal, with coal Hg concentrations ranging from 0.032 to 0.0503 ppm (dry) (3.78 to 5.93 $\mu g/Nm^3$). Coal Hg variability for the Russian coal was very minimal ranging from 0.0322 to 0.0332 ppm (dry) (3.62 to 3.73 $\mu g/Nm^3$). Table 5 shows the coal Hg variability for all three coals.

The Indonesian coal had a low ash percentage of 1.71% compared to the Russian and Colombian coals, which were 11.97% and 14.91%, respectively on a H_2O-free basis. The Indonesian and Russian coal had lower sulfur concentrations, 0.12% and 0.20%, respectively, compared to the high value of 1.00% on a H_2O-free basis in the Colombian coal. The Russian coal had the highest energy content of the three coals at 12108 Btu/lb, followed by the Colombian coal at 11,709 Btu/lb and the Indonesian coal at 9592 Btu/lb on an as-fired basis.

The chlorine and selenium values for each coal are present in Table 4. The chlorine was approximately at the same concentration for the Indonesian, 28.7 ppm, and Russian, 34.7 ppm. The Colombian coal had significantly higher chlorine, 158 ppm. The selenium concentration was similar in the Indonesian, 0.245 ppm, and Russian, 0.635 ppm coals. The Colombian had significantly higher selenium, 4.08 ppm. It was found during Hg measurement of the Colombian coal that selenium is present, and CMM measurement had to be modified to compensate for its interference. Increasing the temperature of the heated sample line to the CMM prevented the selenium from condensing out of solution. Even with this modification, it would be possible for the CMM and OH not to match because selenium can interfere with the CMM and would not interfere with the OH.

Table 3. Summary of Test Results

Date	Test Condition	Coal Type	PAC Injection, lb/Macf	Hg % Removal Coal:Outlet	O_2, %	CO_2, %	CO, ppm	SO_2, ppm	NO_x, ppm	ESP Flow,	ESP/BH Temp, °F
12/4/2006	Baseline	Indonesian	0	37.64	4.07	15.60	15	89	261	82	327
12/4/2006	BPAC LC	Indonesian	1.38	72.33	3.79	15.61	12	106	250	75	316
12/4/2006	BPAC LC	Indonesian	1.98	74.16	3.78	15.62	12	110	246	76	320
12/4/2006	BPAC LC	Indonesian	3	76.52	3.65	15.70	12	107	241	76	324
12/4/2006	BPAC LC	Indonesian	5.02	83.08	3.92	15.48	12	95	242	40	341
12/4/2006	BPAC LC	Indonesian	10	89.02	3.87	15.48	12	97	243	39	341
12/4/2006	BPAC LC	Indonesian	5	85.16	3.89	15.42	11	97	238	39	342
12/4/2006	BPAC LC + 10 ppm NH_3	Indonesian	5	87.02	3.80	15.48	12	100	240	39	340
12/4/2006	BPAC LC	Indonesian	5	81.60	3.84	15.42	11	103	238	39	336
12/5/2006	Baseline	Indonesian	0	52.87	4.21	13.79	37	112	254	90	327
12/5/2006	STI Rejects	Indonesian	2	57.06	4.01	15.28	16	87	247	92	331
12/5/2006	STI Rejects	Indonesian	5	59.95	4.12	15.21	14	86	244	92	334
12/5/2006	STI Rejects	Indonesian	10	66.98	4.04	15.28	13	85	243	92	350
12/5/2006	STI Rejects + 10 ppm NH_3	Indonesian	10	68.48	3.93	15.37	12	84	239	92	335
12/5/2006	Baseline	Indonesian	0	49.52	3.68	15.72	13	85	247	89	350
12/5/2006	Envergex 1	Indonesian	0.8	81.85	3.83	15.51	13	85	245	92	338
12/5/2006	Envergex 1	Indonesian	1.2	87.65	3.95	15.36	12	85	250	92	339
12/5/2006	Envergex 1	Indonesian	2	92.40	3.93	15.37	13	85	245	92	338
12/5/2006	Envergex 1 (NH_3)	Indonesian	2	94.10	3.94	15.34	14	86	242	92	338
12/5/2006	Envergex 1	Indonesian	4	96.82	3.89	15.36	14	89	236	92	339
12/6/2006	Baseline	Colombian	0	25.82	3.85	15.28	25	541	397	92	338
12/6/2006	BPAC LC	Colombian	1.45	50.71	4.45	14.66	16	513	375	91	336
12/6/2006	BPAC LC	Colombian	3	51.48	4.54	14.55	24	505	418	91	355
12/6/2006	BPAC LC	Colombian	5	71.73	4.14	14.85	27	513	401	90	339
12/6/2006	DARCO	Colombian	1	43.99	4.91	13.72	16	503	319	93	329
12/6/2006	DARCO	Colombian	3	50.71	4.35	14.68	16	516	344	92	331
12/6/2006	DARCO	Colombian	5	59.77	4.39	14.64	17	512	349	92	335
12/6/2006	Envergex 1	Colombian	1.5	58.47	4.41	14.64	17	507	364	93	341
12/7/2006	Baseline	Colombian	0	32.35	4.07	14.87	22	509	449	91	365
12/7/2006	Envergex 2	Colombian	0.76	41.86	3.99	14.77	22	514	445	91	337
12/7/2006	Envergex 2	Colombian	1.53	47.76	3.92	14.82	22	516	445	90	336
12/7/2006	Envergex 2	Colombian	2.65	61.07	3.91	14.84	22	517	451	90	363
12/7/2006	Envergex 2	Colombian	4.14	71.95	3.85	14.89	22	518	447	88	355
12/7/2006	Envergex 3	Colombian	1.53	57.07	3.99	14.81	21	514	464	82	340
12/7/2006	Baseline	Colombian	0	25.43	3.83	15.08	21	524	474	80	331
12/7/2006	BPAC Blend	Colombian	3	51.58	3.96	14.80	22	510	470	91	342
12/7/2006	BPAC Blend	Colombian	5	56.10	3.94	14.82	22	508	477	91	342

Continued . . .

Table 3. Summary of Test Results (continued)

Date	Test Condition	Coal Type	Chem-Mod Injection Rate S-Sorb	Chem-Mod Injection Rate Mer-Sorb	Injection Unit	Hg % Removal Coal:Outlet	O_2, %	CO_2, %	CO, ppm	SO_2, ppm	NO_x, ppm	ESP Flow,	ESP/BH Temp, °F
12/12/2006	Baseline	Indonesian				49.22	3.70	15.41	16	128	408	87	322
12/12/2006	S-Sorb	Indonesian	3	0	%	70.25	3.97	15.09	15	71	370	88	330
12/12/2006	S-Sorb	Indonesian	3	0	%	61.23	4.11	14.96	13	54	421	89	334
12/12/2006	S-Sorb	Indonesian	6	0	%	59.74	4.20	14.82	11	150	386	88	336
12/12/2006	S-Sorb/Mer-Sorb	Indonesian	6	0.5	%	57.43	4.19	14.80	11	36	387	87	338
12/12/2006	S-Sorb/Mer-Sorb	Indonesian	6	1.3	%	78.45	7.59	9.84	33	15	287	75	347
12/12/2006	S-Sorb/Mer-Sorb	Indonesian	6	0.25	%	65.42	4.56	14.43	17	28	388	91	347
12/12/2006	S-Sorb/Mer-Sorb	Indonesian	6	1.3	%	57.10	4.49	14.44	8	14	385	90	341
12/12/2006	Mer-Sorb	Indonesian	0	1.3	%	57.65	3.84	14.95	8	19	396	87	333
12/13/2006	Baseline	Russian	0	0		79.30	3.85	15.19	21	141	571	89	339
12/13/2006	S-Sorb/Mer-Sorb	Russian	6	0.5	%	83.39	4.80	14.15	21	108	519	92	342
12/13/2006	S-Sorb/Mer-Sorb	Russian	6	0.75	%	79.73	4.78	14.16	22	101	533	75	326
12/13/2006	S-Sorb/Mer-Sorb	Russian	6	0.75	%	85.10	4.72	14.18	21	112	523	87	338
12/13/2006	S-Sorb/Mer-Sorb	Russian	3	0.75	%	84.00	4.74	14.22	20	119	535	87	338
12/13/2006	S-Sorb/Mer-Sorb	Russian	6	1.3	%	80.61	4.72	14.25	22	111	526	87	339
12/15/2006	Baseline	Russian	0	0		93.05	3.98	14.99	9	171	554	136	355
12/15/2006	Baseline	Russian	0	0		56.33	4.30	14.72	8	165	566	91	349
12/15/2006	S-Sorb	Russian	3	0	%	58.11	4.73	14.22	9	149	506	90	352
12/15/2006	S-Sorb/Mer-Sorb	Russian	3	0.25	%	72.65	4.57	14.28	10	138	506	86	355
12/15/2006	S-Sorb/Mer-Sorb	Russian	6	0.25	%	83.05	4.76	14.11	9	128	505	83	349
12/15/2006	S-Sorb/Mer-Sorb	Russian	3	0.5	%	80.48	4.81	14.01	7	120	491	80	341
12/15/2006	S-Sorb/Mer-Sorb	Russian	6	0.5	%	83.34	4.72	14.01	6	115	480	80	342
12/15/2006	S-Sorb/Mer-Sorb	Russian	6	1.3	%	77.20	4.69	14.09	9	91	488	79	343
1/3/2007	Baseline	Colombian	0	0		62.33	5.37	13.97	17	475	466	86	344
1/3/2007	S-Sorb/Mer-Sorb	Colombian	3	0.5	%	90.12	5.36	13.98	20	479	472	87	351
1/3/2007	S-Sorb/Mer-Sorb	Colombian	6	0.5	%	91.77	5.21	14.08	17	479	465	86	351
1/3/2007	S-Sorb/Mer-Sorb	Colombian	6	0.75	%	92.23	5.20	14.11	20	464	457	86	352
1/3/2007	S-Sorb/Mer-Sorb	Colombian	3	0.75	%	88.46	5.31	14.03	13	469	460	86	353
2/8/2007	Baseline	Indonesian				60.81	5.24	14.16	26	118	227	94	389
2/8/2007	S-Sorb/Mer-Sorb	Indonesian	6	0.75	%	65.56	5.47	13.93	26	73	230	92	385
2/20/2007	Baseline	Colombian				53.31	4.98	14.38	6.98	429	336	88	325
2/20/2007	S-Sorb	Colombian	3.00	0	%	49.79	5.83	13.54	4.66	408	306	90	351
2/20/2007	S-Sorb/Mer-Sorb	Colombian	3.00	0.25	%	86.30	5.85	13.53	5.80	399	301	87	353
2/20/2007	S-Sorb/Mer-Sorb	Colombian	3.00	0.25	%	84.72	5.92	13.49	3.85	393	304	83	353
2/20/2007	S-Sorb/Mer-Sorb	Colombian	6.00	0.50	%	87.66	5.74	13.64	3.76	388	303	80	359
2/20/2007	S-Sorb/Mer-Sorb	Colombian	6.00	0.75	%	86.47	5.62	13.74	3.47	381	309	76	362

Continued . . .

Table 3. Summary of Test Results (continued)

Date	Test Condition	Coal Type	PAC Injection, lb/Macf	Hg % Removal Coal:Outlet	O_2, %	CO_2, %	CO, ppm	SO_2, ppm	NO_x, ppm	ESP Flow,	ESP/BH Temp, °F
12/8/2006	Baseline	Russian	0	62.92	3.95	15.03	13	150	437	65	304
12/8/2006	DARCO	Russian	1	62.44	3.81	15.10	7	161	538	89	355
12/8/2006	DARCO	Russian	3	69.07	3.75	15.15	6	161	567	74	414
12/8/2006	DARCO	Russian	5	73.29	3.67	15.18	6	162	578	72	361
12/8/2006	Envergex 1	Russian	0.75	86.84	4.04	14.87	22	166	564	87	395
12/8/2006	Envergex 1	Russian	1.53	88.37	3.98	14.89	21	165	564	87	346
12/8/2006	Envergex 1	Russian	3	92.79	4.11	14.79	21	166	592	84	363
12/8/2006	Envergex 2	Russian	1.5	80.59	4.10	14.73	23	166	592	39	353
12/8/2006	Envergex 2	Russian	3	88.22	4.25	14.64	23	165	599	67	361
12/8/2006	BPAC	Russian	3	74.97	4.26	14.61	24	166	593	47	354
12/8/2006	BPAC	Russian	5	81.99	4.36	14.53	24	165	601	40	345
12/14/2006	Baseline	Colombian	0	28.06	3.87	15.14	19	491	532	87	334
12/14/2006	Envergex 4	Colombian	1.5	55.06	3.82	14.91	18	507	532	87	330
12/14/2006	Envergex 4	Colombian	3	76.01	3.92	14.84	19	508	536	67	351
12/14/2006	Envergex 4	Colombian	6	93.48	3.94	14.90	20	512	533	87	334
12/14/2006	Envergex 4 + NH_3	Colombian	6	97.47	3.79	15.06	20	517	525	87	336
12/14/2006	Baseline	Colombian	0	84.22	3.83	15.17	21	538	546	135	338
12/14/2006	BPAC-LC	Colombian	1	91.40	4.06	14.73	47	524	519	139	328
12/14/2006	BPAC-LC	Colombian	3	93.67	4.07	14.72	48	527	516	139	330
*1/3/2007	Baseline	Colombian	0	92.69	3.82	15.14	18	499	392	128	337
1/3/2007	Baseline	Colombian	0	46.08	4.02	15.02	19	513	402	70	328
1/3/2007	STI	Colombian	5.9	45.52	4.19	14.63	17	498	393	90	345
1/3/2007	STI	Colombian	14.7	50.14	4.44	14.44	15	490	398	83	358
1/3/2007	STI	Colombian	29.4	51.24	4.43	14.45	15	490	398	83	358
1/3/2007	STI+NH_3	Colombian	29.4	67.53	4.59	14.33	13	486	393	86	336
1/3/2007	STI	Colombian	29.4	71.71	4.62	14.26	24	487	385	82	361
2/8/2007	Baseline	Indonesian	0	50.39	4.04	15.88	23.60	128	237	85	337
2/8/2007	DARCO	Indonesian	1	73.04	4.09	15.21	16.76	128	274	94	N/A
2/8/2007	DARCO	Indonesian	3	80.75	4.20	15.13	26.49	133	203	93	359
2/8/2007	Baseline	Indonesian	0	60.91	4.10	15.43	26.73	136	194	85	363
2/8/2007	BPAC	Indonesian	1	71.64	4.40	14.97	26.77	134	211	93	N/A
2/8/2007	BPAC	Indonesian	3	84.98	4.44	14.98	26.75	130.47	229	94	N/A
2/8/2007	BPAC	Indonesian	5	88.11	4.42	15.04	26.90	128	227	94	N/A

Continued . . .

Table 3. Summary of Test Results (continued)

			Chem-Mod										
Date	Test Condition	Coal Type	Injection Rate S-Sorb	Injection Rate Mer-Sorb	Injection Unit	Hg % Removal Coal:Outlet	O_2, %	CO_2, %	CO, ppm	SO_2, ppm	NO_x, ppm	ESP Flow,	ESP/BH Temp, °F
3/20/2007	Baseline	Indonesian				76.16	3.94	14.73	16.80	93	213	83	355
3/20/2007	S-Sorb	Indonesian	3	0	%	66.23	4.72	12.86	18.02	84	226	100	360
3/20/2007	S-Sorb/Mer-Sorb	Indonesian	3	0.25	%	85.50	4.82	12.79	16.94	65	226	101	354
3/20/2007	S-Sorb/Mer-Sorb	Indonesian	3	0.5	%	81.80	4.87	12.81	16.95	47	240	100	351
3/20/2007	S-Sorb/Mer-Sorb	Indonesian	6	0.5	%	87.86	4.87	12.89	15.55	36	237	100	353
3/20/2007	Mer-Sorb	Indonesian	0	0.125	%	86.41	4.92	13.13	13.93	69	232	99	360
3/20/2007	S-Sorb/Mer-Sorb	Indonesian	3	0.125	%	86.50	4.90	13.19	14.08	64	228	99	360
3/20/2007	Mer-Sorb	Indonesian	0	0.125	%	86.12	4.89	13.24	13.87	66	227	99	360
3/20/2007	Mer-Sorb	Indonesian	0	0.05	%	85.79	4.94	13.21	13.80	72	227	99	361
3/20/2007	S-Sorb/Mer-Sorb	Indonesian				85.91	5.08	13.08	13.48	72	231	99	361

Table 4. Summary of Coal Analysis Results

Sample ID, Parameters, Unit	Indonesian		Colombian		Russian	
Mercury, ppm (dry)	0.04115		0.0441		0.0327	
Chlorine, ppm (dry)	28.7		158		34.7	
Selenium, ppm (dry)	0.245		4.08		0.635	
Proximate	As-Fired	H_2O-Free	As-Fired	H_2O-Free	As-Fired	H_2O-Free
Moisture, wt%	22.1	N/A	2	N/A	3.7	N/A
Volatile Matter, wt%	36.34	46.65	33.01	33.68	35.12	36.47
Fixed Carbon, wt%	40.23	51.64	50.38	51.41	49.64	51.55
Ash, wt%	1.33	1.71	14.61	14.91	11.53	11.97
Ultimate Analysis	As-Fired	H_2O-Free	As-Fired	H_2O-Free	As-Fired	H_2O-Free
Hydrogen, wt%	6.27	8.05	4.63	4.72	5.14	5.34
Carbon, wt%	55	70.60	66.37	67.72	68.07	70.69
Nitrogen, wt%	0.97	1.25	1.65	1.68	2.54	2.64
Sulfur, wt%	0.09	0.12	0.98	1.00	0.19	0.20
Oxygen, wt%	36.34	46.65	11.76	12.00	12.52	13.00
Heating Value, Btu/lb	9592	12,313	11,709	11,948	12,108	12,573
Calculated Parameters						
$F_{d,}$ dscf/10^6 Btu	9451		9719		9712	
Sulfur, wt% (dry)	0.12		1.00		0.20	
Heating Value, Btu/lb (dry)	12,313		11,948		12,573	
Hg, µg/Nm^3 (flue gas basis)	4.85		5.21		3.68	
Hg, lb/TBtu (flue gas basis)	3.34		3.69		2.60	

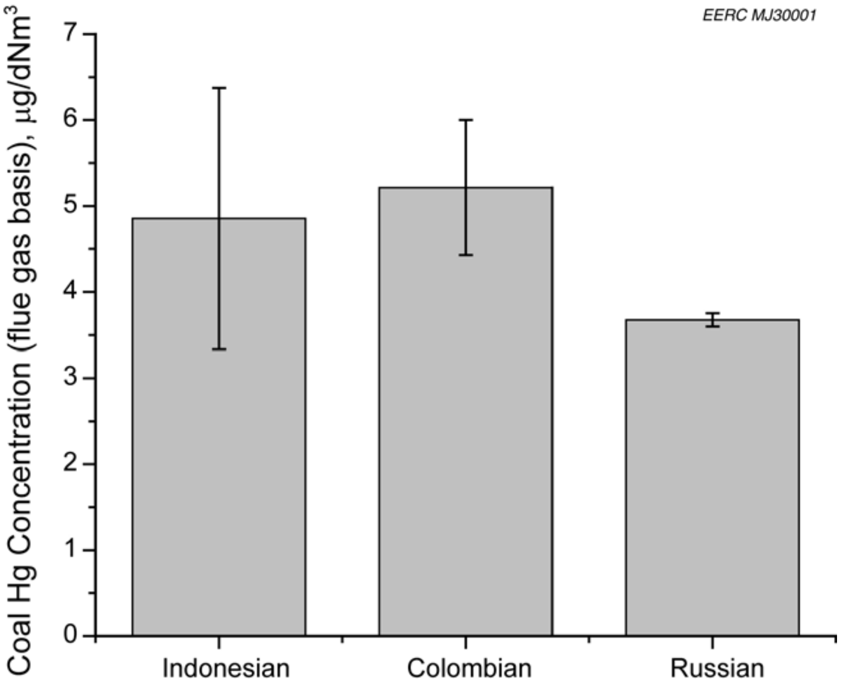

Figure 6. Calculated Hg concentrations in the flue gas based on coal data, µg/dNm^3.

Table 5. Coal Hg Variability Compared for All Three Coals

Parameter, Unit	Indonesian	Colombian	Russian
Mercury, ppm (dry)			
Average	0.04115	0.0441	0.0327
Maximum	0.0503	0.0488	0.0332
Minimum	0.032	0.0394	0.0322
Standard Deviation	0.013	0.007	0.00
Hg, µg/dNm^3 (flue gas basis)			
Average	4.855	5.215	3.675
Maximum	5.93	5.77	3.73
Minimum	3.78	4.66	3.62
Standard Deviation	1.52	0.785	0.078
Hg, lb/TBtu (flue gas basis)			
Average	3.345	3.69	2.6
Maximum	4.09	4.08	2.64
Minimum	2.6	3.3	2.56
Standard Deviation	1.05	0.552	0.057

Hg removals reported in this report were calculated based on the average CMM outlet number for a given test period referenced to the average calculated coal Hg concentration on a flue gas basis, unless noted otherwise. This method was chosen instead of using inlet Hg CMM values in order to compare overall mercury removal for all three coals. Additionally, when the Clean Air Mercury Rule (CAMR) regulations are in place for Hg control in 2010, compliance will be based on an average coal inlet Hg value on a flue gas basis in conjunction with stack Hg concentration data.

Baseline testing occurred during the first few hours at the beginning of each day or coal type switch. Hg measurements were conducted to quantify baseline Hg concentrations at the particulate control technology (ESP or FF) inlet and particulate control technology outlet prior to any Hg control technology (PAC, treated PAC, or Chem-Mod) addition. OH method measurements at the particulate control inlet indicated that the mercury speciation was approximately 50% Hg^0 for the Indonesian coal and primarily in the particulate phase for the Colombian and Russian coals. For the time periods when OH method sampling was performed, the OH method results, CMM results, and coal Hg concentration on a flue gas basis are presented and compared in Figure 7. Results show that for the Colombian and Russian test periods, the results of the OH results, CMM results, and coal Hg concentration on a flue gas basis agree within reason. For the Indonesian test period, it appears as if the OH method is reading on the low end when compared to the CMM and calculated coal Hg results.

Hg speciation was also measured by the OH method and with the CMM at times. For the Indonesian coal, the Hg appeared to be about 50% elemental and 50% oxidized. The OH method results for the Colombian coal showed that the Hg was predominantly oxidized and particulate. For the Russian coal, the results showed a high amount of particulate Hg, with only a small

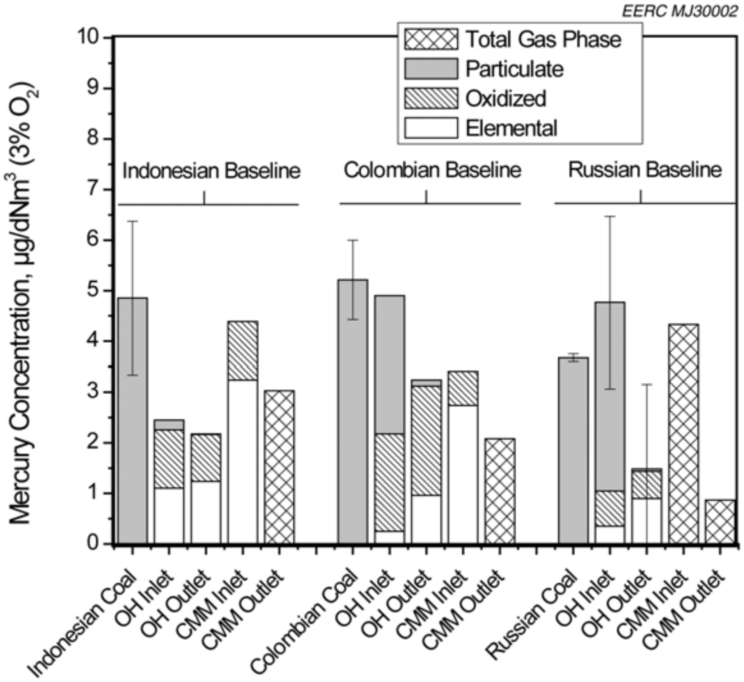

Figure 7. Results from testing during baseline conditions comparing results from different measurement techniques.

percentage being elemental. This high level of particulate Hg aided in the high native Hg capture seen. Problems with the CMM at the inlet did not allow for speciation during Russian baseline.

Mercury Control Results and Discussion

To evaluate the effect of various control technology parameters on capture and operability, parametric style testing was performed. These short-term parametric tests were conducted to determine the optimal conditions necessary to achieve a desired Hg removal. Hg removal efficiency curves were generated from the data collected during parametric testing in order to compare the different parameters tested. The parameters tested were type of sorbent and sorbent injection rate. Parametric test results for the tests when the unit was equipped with a FF showed higher Hg removal efficiencies than the tests when the unit was equipped with an ESP. Mass transfer times in units equipped with an ESP tend to be short, minimizing the time available to adsorb Hg to the sorbent, and the gas/sorbent contact time is limited by duct flow path. In contrast, a FF provides much greater gas contact because of the sorbent-laden filter cake formed on the FF bags. Testing with the FF configuration was limited because of equipment problems and time constraints.

Indonesian Coal Testing

Testing was performed over 5 days while the Indonesian (Adaro) coal was fired. During this time, several sorbents were injected upstream of the particulate control device to determine their effectiveness at removing the Hg from the flue gas. The injection of STI Rejects appears to only have a slight benefit in reducing Hg. During the injection of STI Rejects, the Hg removal efficiency started with a 53% native capture at baseline condition and reached a maximum Hg removal efficiency of 67% at 10 lb/Macf for a net reduction benefit of 14%. The best performance achieved during testing of the Indonesian coal was the injection of Envergex 1 with a maximum removal of 97% at an injection rate of 4 lb/Macf. BPAC, DARCO Hg, and BPAC LC all performed about the same. Based on previous results, it would be expected that the BPAC sorbents perform better than the DARCO Hg. Typically, halogenated carbons perform better because of their ability to oxidize the Hg, making it easier to capture with PAC.

Results for sorbent testing while Indonesian coal was fired can be seen in Figure 8. Figure 9 shows the results with the baseline Hg capture removed from the trend lines. Showing the data this way is an attempt at normalizing the data for the effects of unburned carbon in the system, which may sway baseline native captures. Total Hg removals for the technologies demonstrated are more representative of the levels demonstrated in Figure 8; this is because the Hg removal is based on the Hg chemistry in the system or percent oxidized and elemental Hg present in the flue gas. The native capture seen is typically caused by the Hg that is more easily captured and would possibly be captured easily with the lower rates of sorbent injection. The unburned carbon in the system does have an effect on how much Hg is removed, but it is hard to quantify. The important thing to notice is the trend of the Hg removal efficiency line. A typical Hg removal trend line flattens out at a specific Hg removal when the sorbent:Hg capture ratio is at its maximum. In other words, at a certain point, Hg removal reaches a maximum, and increasing sorbent injection rate has little to no effect. For example, the injection of BPAC LC yielded a maximum Hg removal of 89% at 10 lb/Macf. The trend line shows that increasing the sorbent injection rate from 5 to 10 lb/Macf showed diminishing Hg removal. If the system started at a zero native capture, it is possible that at an injection rate similar to or slightly higher than 10 lb/Macf, the Hg removal efficiency would still be close to 89%, and at 1 lb/Macf, the Hg removal would be close to, or slightly lower, than what it is with the natural capture displayed, because of the more easily captured form of Hg present in the system at baseline. Once the easier form of Hg has been captured, the remaining Hg present requires a higher sorbent to Hg ratio, and that is why we see diminishing effects with increased sorbent injection. Figure 9 is only used as a comparison method to get a better idea of how much removal above baseline is attributed to the sorbent in these specific tests.

Also tested were Chem-Mod’s technologies known as Mer-Sorb and S-Sorb. S-Sorb is a sorbent designed to reduce SO_x emissions, which can enhance Hg capture. SO_x typically competes for open sites on Hg control technologies designed to adsorb the Hg; therefore, reducing the SO_x leaves more open sites for the Hg to adsorb to. Mer-Sorb is a sorbent designed to capture Hg and is injected as a liquid into the system. Results for the Chem-Mod testing can be seen in Figure 10. The results for the Chem-Mod testing show a maximum Hg removal of 66% at an S-Sorb rate of 6% and a Mer-Sorb injection rate of 0.75% of the coal feed.

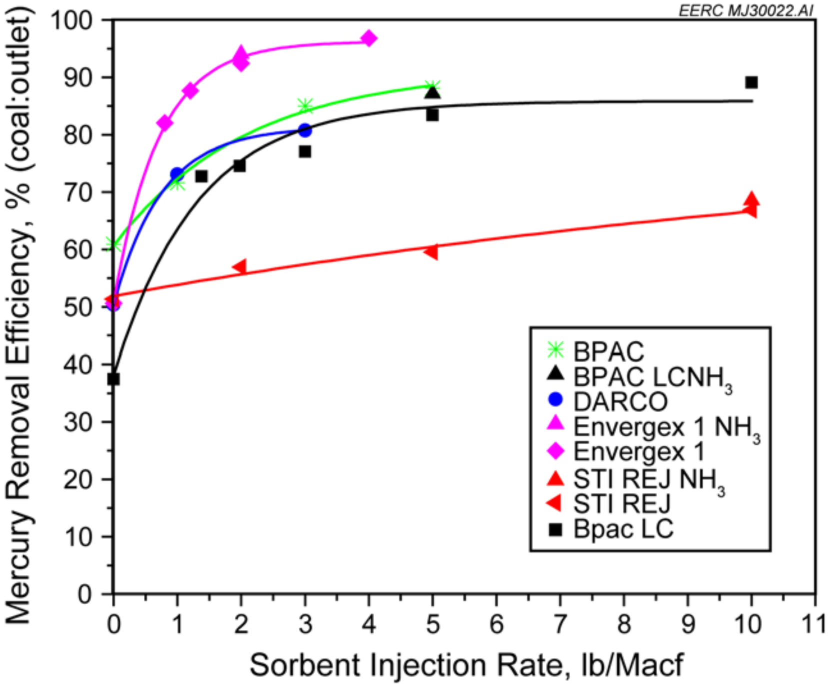

Figure 8. Hg control technology results for testing during the firing of the Indonesian coal.

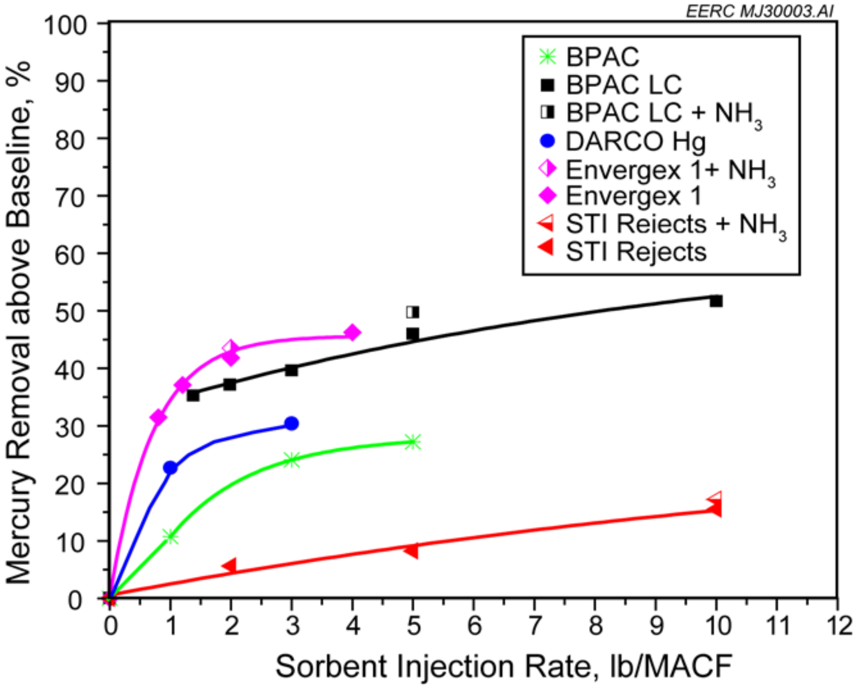

Figure 9. Hg control technology results with baseline removed from trends for testing during the firing of the Indonesian coal.

During the testing with BPAC, Envergex 1, and STI Rejects, ammonia was added to the flue gas at a rate to produce approximately 10 ppm NH_3 in the flue gas. This was done to create a comparative flue gas stream if a selective noncatalytic reduction (SNCR) would be installed at Constellation Energy's Wagner and Crane Plants. In systems equipped with SNCRs, ammonia is present, and this testing was done to gain a better understanding of how this ammonia may affect Hg reduction via sorbent injection. When the ammonia was added to the system, it appeared to increase the Hg removal only slightly (1%–2%) and can be seen in Figure 8.

Colombian Coal Testing

Testing was performed over 5 days while the Colombian coal was fired. During this time, several sorbents were injected upstream of the particulate control device to determine their effectiveness at removing the Hg from the flue gas. The results of the parametric style sorbent injection tests show that Envergex 4 sorbent performed the best with a maximum Hg removal of 93% at an injection rate of 6 lb/Macf. Envergex 1, 2, and 3 were also tested, with the results for Envergex 1 and 3 being approximately the same as Envergex 4 and Envergex 2 performing slightly lower. BPAC, BPAC LC, and DARCO Hg all performed approximately the same, which is what was seen for the Indonesian coal as well. Table 2 summarizes the results of the sorbent injection tests. STI Rejects was also tested during the Colombian coal burn, and results indicated only a small increase in the Hg removal efficiency over baseline. The maximum Hg removal achieved during the injection of STI Rejects was 51% at an injection rate of ~30 lb/Macf, only a 6% net increase over baseline. Results for sorbent testing while Colombian coal was fired can be seen in Figure 11. Figure 12 shows the results with the baseline Hg capture removed from the trend lines. Results of the STI Rejects testing can be seen in Figure 13.

During the sorbent injection testing, ammonia was again added to the stream during a steady-state injection period for the Envergex 4 and STI Rejects testing. The results again indicate a slight benefit from this addition of 10 ppm NH_3 equivalence in the flue gas. In the Envergex 4 NH_3 injection test, the Hg removal efficiency increased from 93% to 97%, an increase of 4%. A bigger increase was noticed during the NH_3 injection with the STI Rejects, with the Hg removal efficiency increasing from 51% to 67%, an increase of 16%.

While the Colombian coal was tested, the system configuration was changed to include a FF for the pollution control device instead of an ESP for the duration of one sorbent injection test. During this test, BPAC LC was injected upstream of the FF, and the Hg concentration was measured. Baseline Hg removal efficiencies were 50%–55% higher during the FF testing, with the baseline native capture being 84%. The injection of BPAC LC increased this Hg removal efficiency to a maximum of 94% at 3 lb/Macf. Hg removal efficiencies are much higher when compared to the ESP BPAC LC testing. This is expected because of the longer residence time achieved when a FF is used. Mass transfer times in units equipped with an ESP tend to be short, minimizing the time available to adsorb Hg to the sorbent, and the gas/sorbent contact time is limited by duct flow path. In contrast, a FF provides much greater gas contact because of the sorbent-laden filter cake formed on the FF bags. The high native Hg capture was not expected and is typically not seen in a full-scale fabric filter, but the unknown ash reactivity could have contributed to this large native capture.

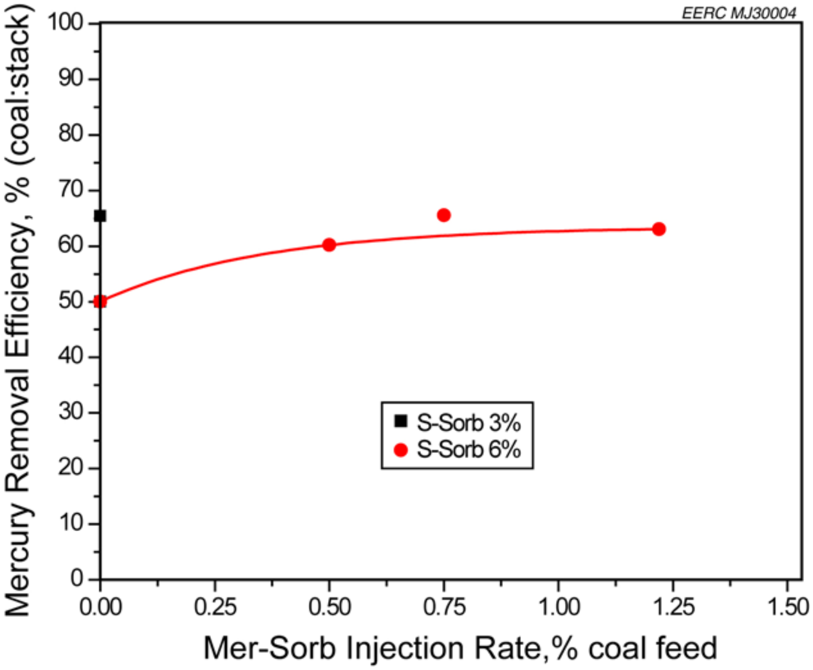

Figure 10. Chem-Mod results for testing during the firing of Indonesian coal.

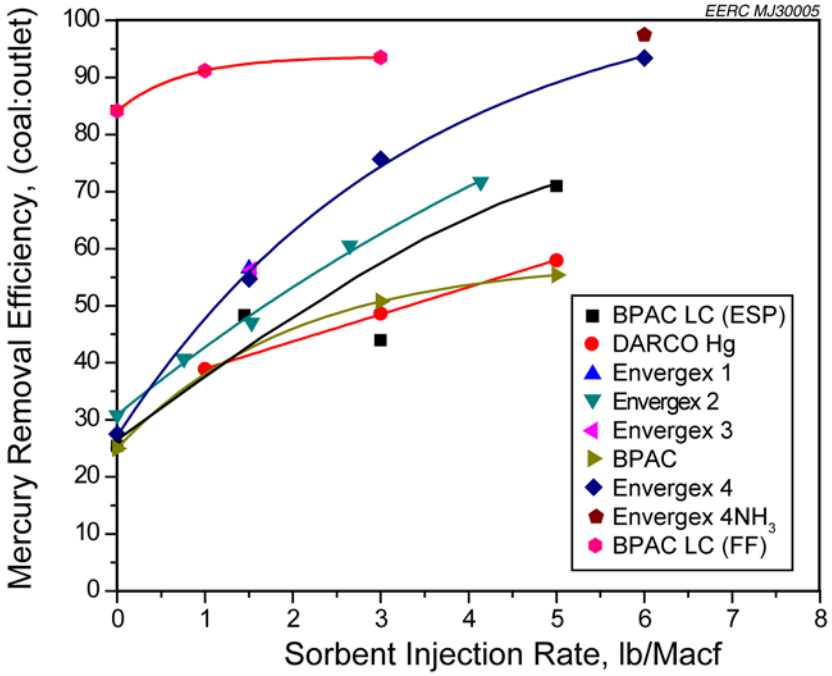

Figure 11. Hg control technology results for testing during the firing of Colombian coal.

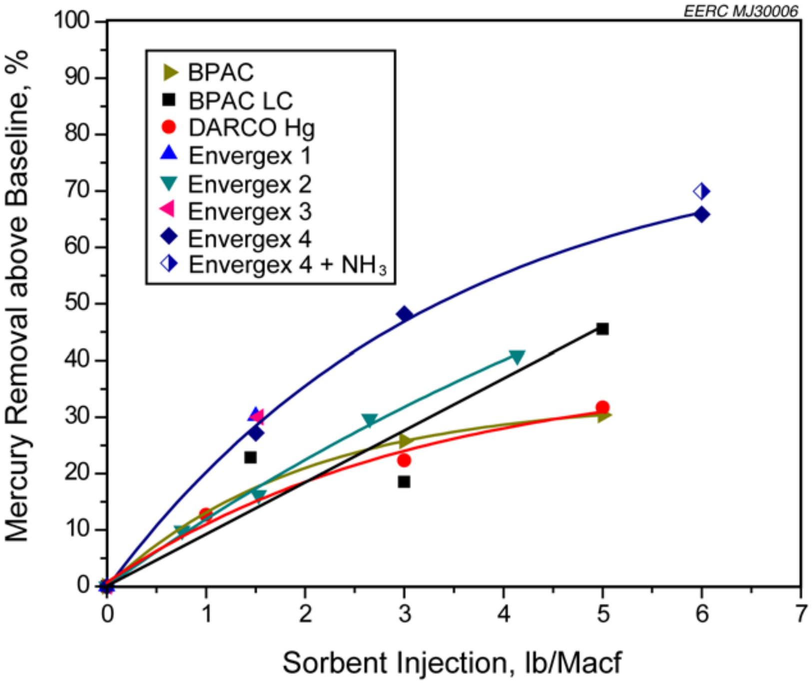

Figure 12. Hg control technology results with baseline removed from trends for testing during the firing of Colombian coal.

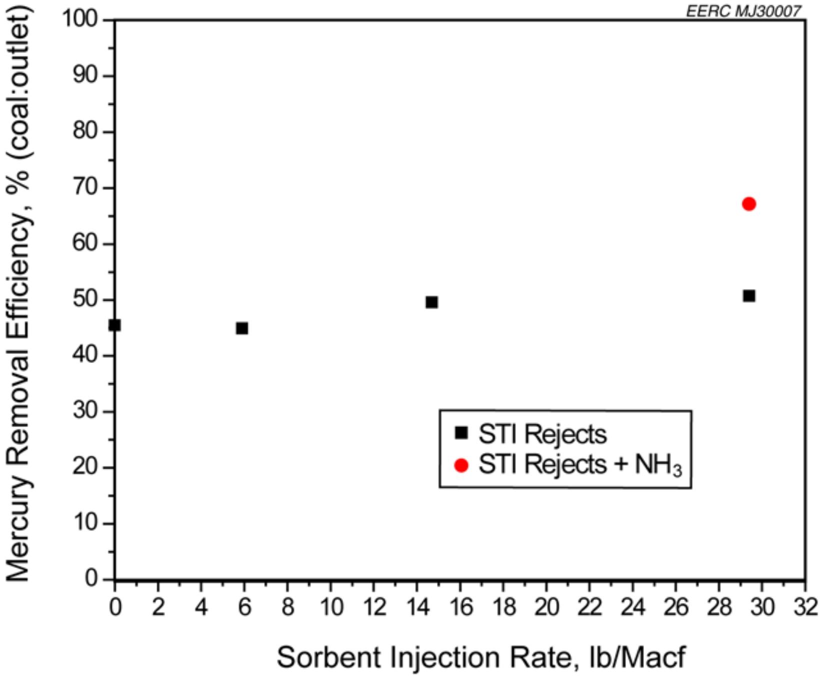

Figure 13. Results of injecting STI Rejects while Colombian coal was fired.

Also tested was Chem-Mod’s technologies. The results indicated high removals of Hg, with the maximum Hg removal of 93% at an S-Sorb injection rate of 6% and a Mer-Sorb injection rate of 0.75%. Increasing the injection rate of S-Sorb from 3% to 6% had an insignificant effect on the Hg removal efficiency. Although the Hg removal is high for the Chem-Mod tests, the baseline native capture was also high when compared to the other tests with the Colombian coal; therefore, it is hard to make a definitive statement as to the Chem-Mod technologies performing better than the other technologies tested. The results for the Chem-Mod testing can be seen in Figure 14. The Chem-Mod technology was tested a second time on March 20, 2007. The results are similar to the first test. The results from this day of testing can be seen in Figure 15. During the testing, there were deposits forming on the Mer-Sorb injection probe. The deposit would build up on the tip and then break off. This test indicates that the removal of the mercury was strictly a result of the Mer-Sorb and S-Sorb additives, not because of buildup of ash in the combustion testing unit.

Russian Coal Testing

Testing was performed over 3 days while the Colombian coal was fired. During this time, several sorbents were injected upstream of the particulate control device to determine their effectiveness at removing Hg from the flue gas. Baseline measurements indicate a large native capture of 63%, which is indicated by both the CMM and the OH method. The results from the parametric style sorbent injection testing show that the Envergex 1 technology performed the best for this coal. The maximum Hg removal efficiency achieved during the injection of Envergex 1 was 92% at an injection rate of 3 lb/Macf. Envergex 2 performed slightly lower than Envergex 1 but was the second top performer, with a maximum Hg removal of 87% at an injection rate of 3 lb/Macf. BPAC and DARCO Hg were also tested and performed relatively the same, with the BPAC results being 5%–8% higher than the DARCO Hg. Figure 16 displays the results for the sorbent injection testing. Figure 17 shows the results with the baseline Hg capture removed from the trend lines.

Baseline testing with a FF for the particulate control device occurred during the firing of Russian coal. The results indicated a very high native Hg capture of 92% vs. only 63% during ESP testing. It was expected that the FF would perform better than the ESP because of the longer reaction time achieved when using a FF, but a native capture this high is typically not seen in full-scale testing. Mass transfer times in units equipped with an ESP tend to be short, minimizing the time available to adsorb Hg to the sorbent, and the gas/sorbent contact time is limited by duct flow path. In contrast, a FF provides much greater gas contact because of the sorbent-laden filter cake formed on the FF bags. The unknown ash reactivity could have contributed to this large native capture.

Chem-Mod’s technologies were also tested with the Russian coal. The results indicated high removals of Hg with the maximum Hg removal of 82% at an S-Sorb injection rate of 3% and a Mer-Sorb injection rate of 0.75%. Increasing the injection rate of S-Sorb from 3% to 6% had an insignificant effect on the Hg removal efficiency. The results for the Chem-Mod testing can be seen in Figure 18.

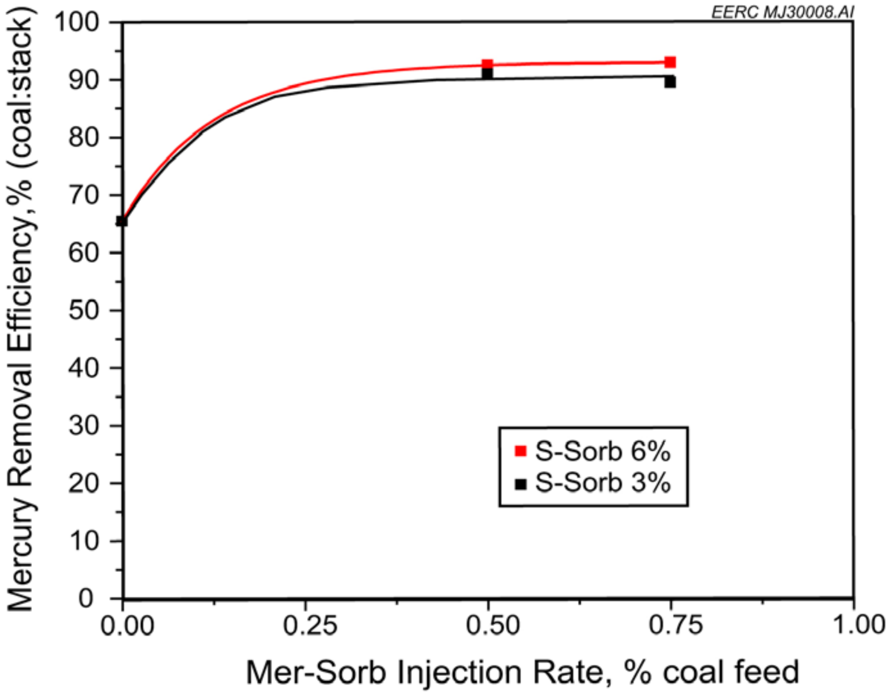

Figure 14. Chem-Mod injection results for testing during the firing of Colombian coal.

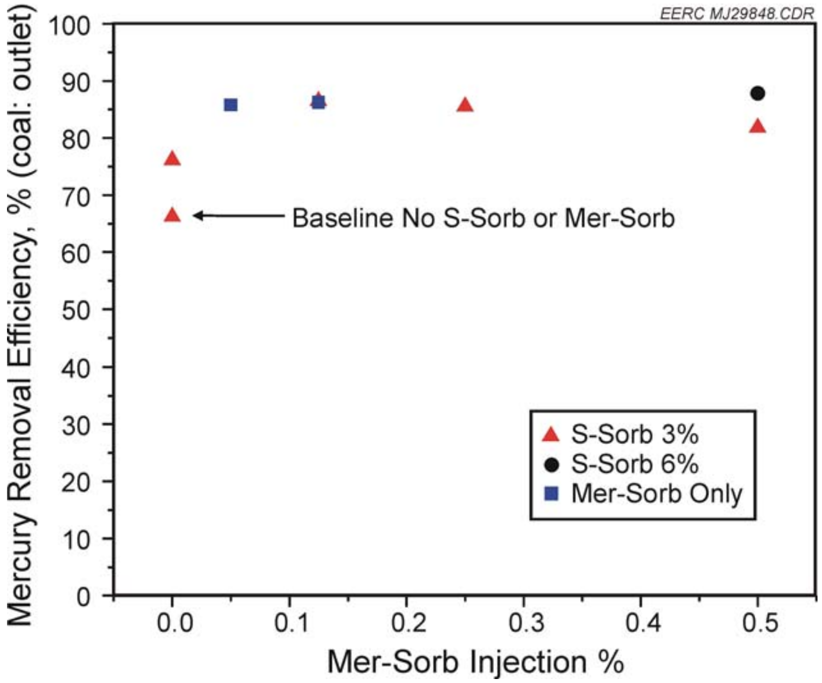

Figure 15. Chem-Mod injection results for the testing during the firing of Colombian coal on March 20.

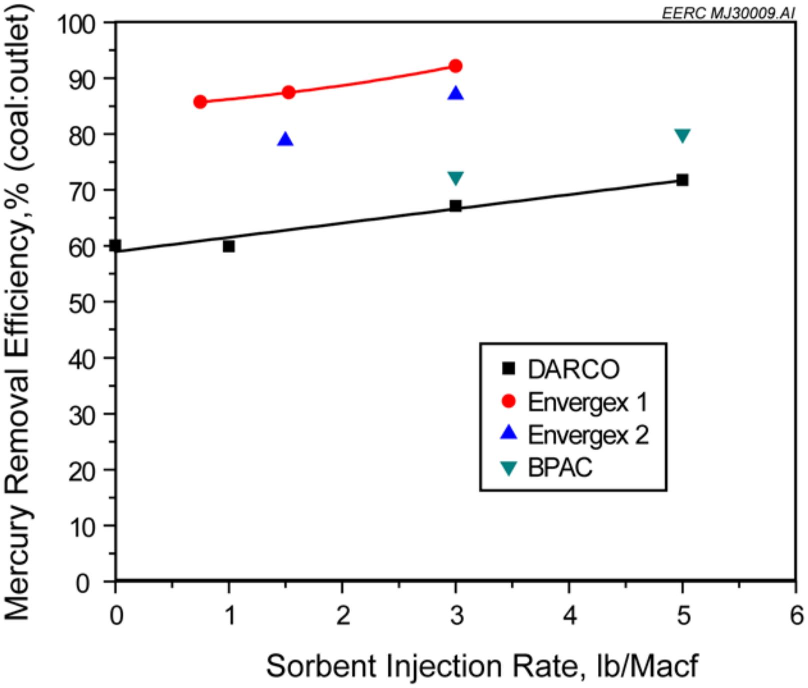

Figure 16. Hg control technology results for testing during the firing of Russian coal.

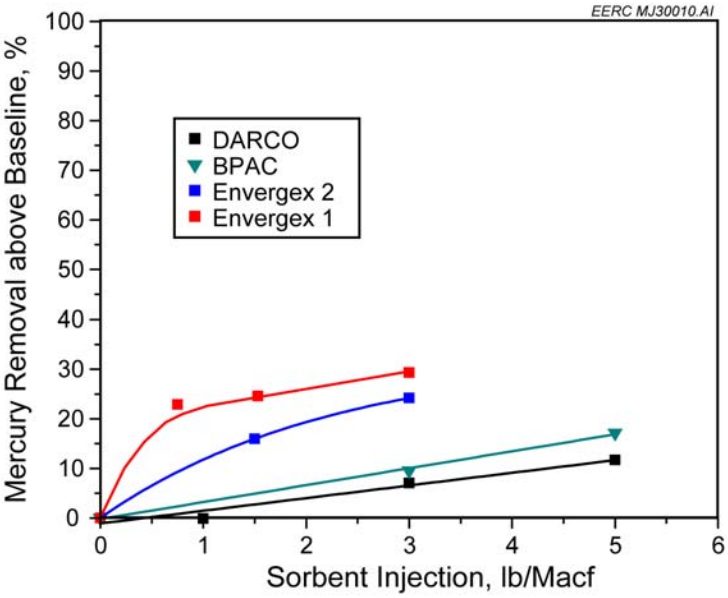

Figure 17. Hg control technology results with baseline removed from trends for testing during the firing of Russian coal.

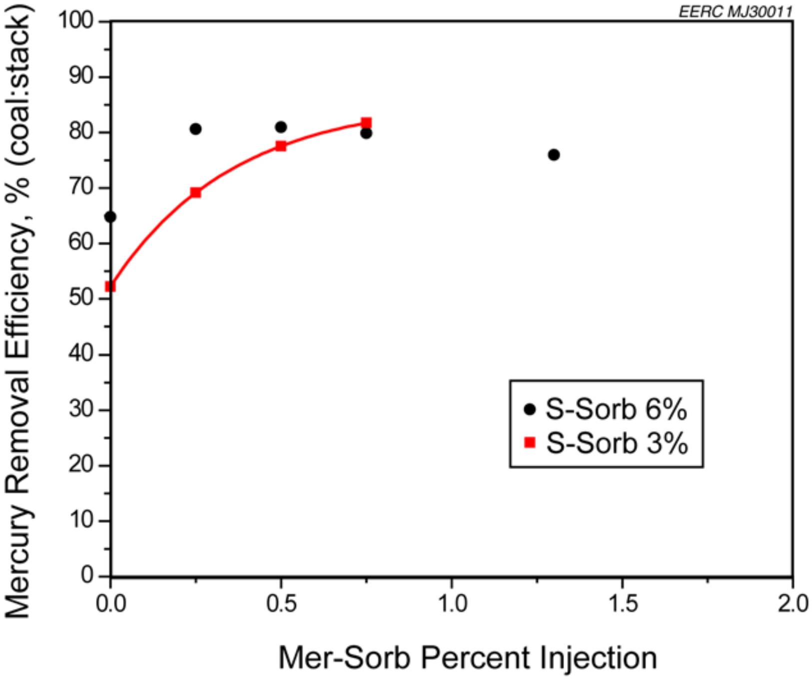

Figure 18. Chem-Mod injection results for testing during the firing of Russian coal.

Hg Control Summary

In terms of Hg control, the sorbent technologies performed best on the Indonesian coal flue gases, followed by the Russian and then Colombian coals. The top two Hg control technologies for each coal are compared in Figure 19. Results show that for each coal, the Envergex sorbent performed the best, with BPAC the only other technology making it on the graph for the Indonesian coal. The Chem-Mod technology performed the best for the Colombian coal and the worst for the Indonesian coal. Figures 20–22 compare the results from the Chem-Mod technology testing. For all of the different sorbents tested, besides the Chem-Mod technology, the Indonesian coal performed the best. Figure 23 compares the results for all of the different sorbents tested.

During baseline testing, the ash was collected and analyzed for the percent carbon it contained. This analysis was performed to determine the amount of unburned carbon in the system, which may impact or enhance native Hg removal. Experience has shown that the unburned carbon in the system, caused by incomplete combustion, does capture Hg, but is not as effective as injecting a commercially available PAC on a lb per lb basis. Figure 24 compares the percent carbon in the system with the native Hg removal measured during the baseline periods for each coal. As shown in Figure 24, no definitive conclusion can be made on the impact of the unburned carbon. For the Indonesian coal, the percent carbon in the ash during baseline was less than 0.50%, and a native Hg capture of greater than 35% was measured. During the Colombian

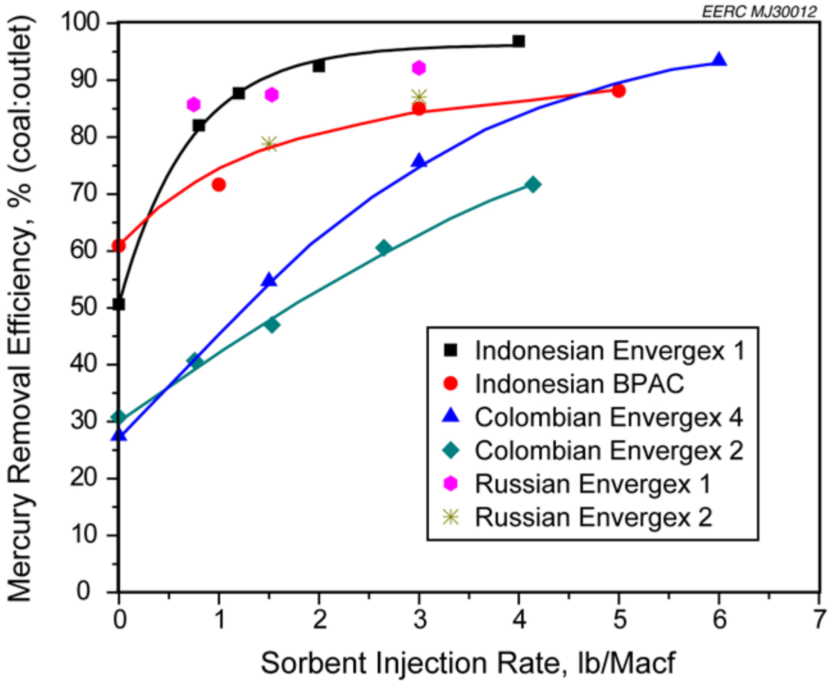

Figure 19. Comparison of the two top-performing Hg control technologies tested for all three coals.

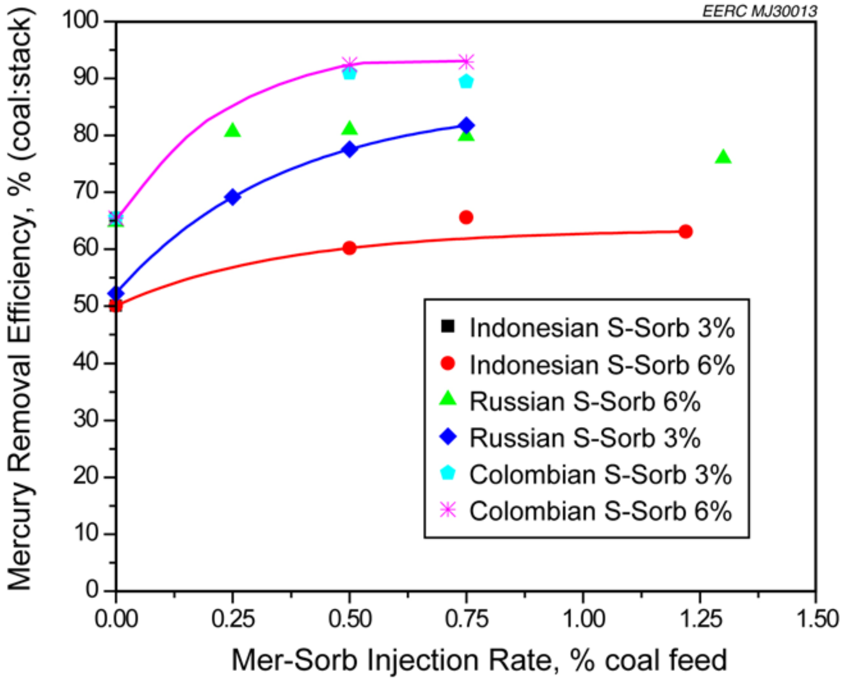

Figure 20. Comparison of the Chem-Mod technology tests for all three coals.

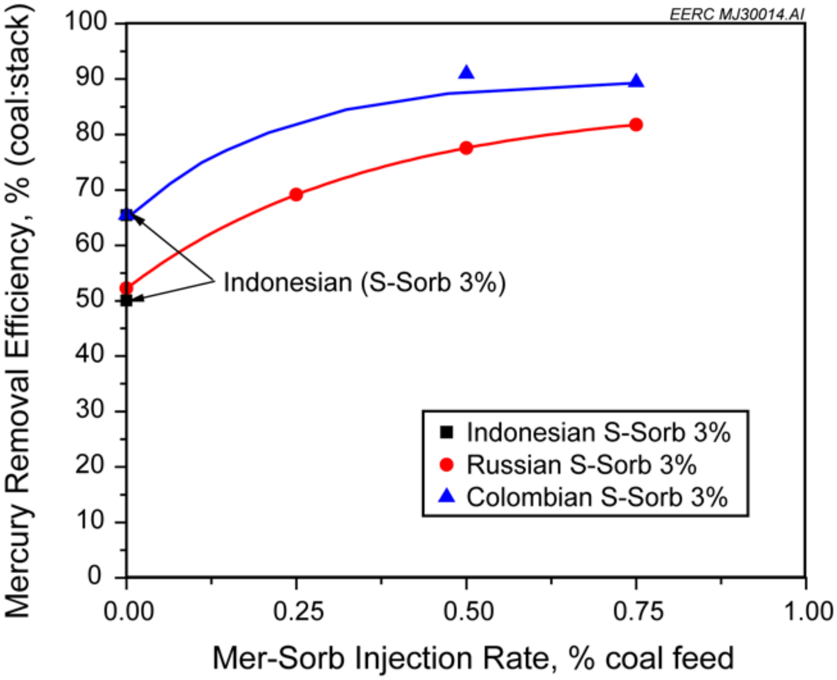

Figure 21. Comparison of the Chem-Mod technology tests for all three coals at an S-Sorb rate of 3%.

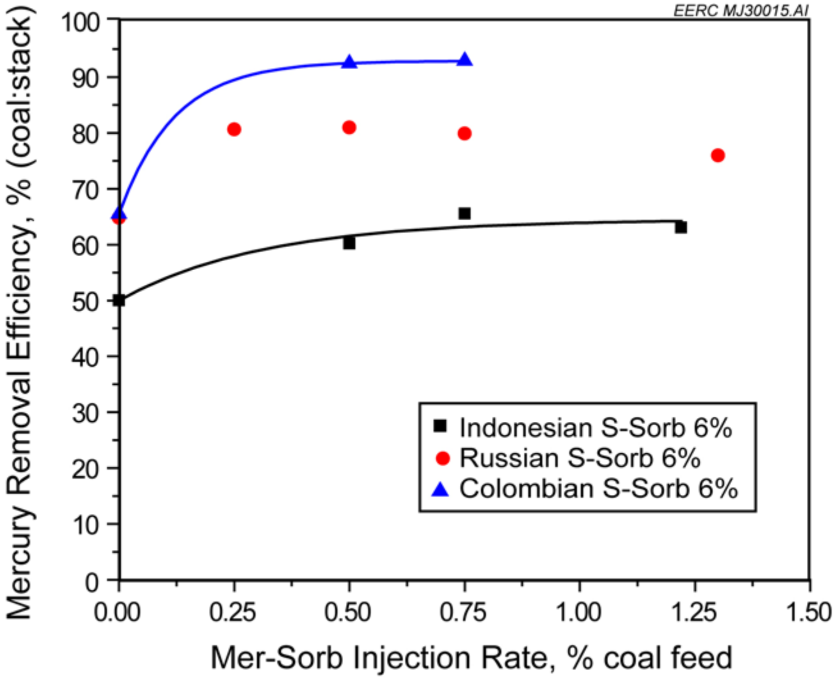

Figure 22. Comparison of the Chem-Mod technology tests for all three coals at an S-Sorb rate of 6%.

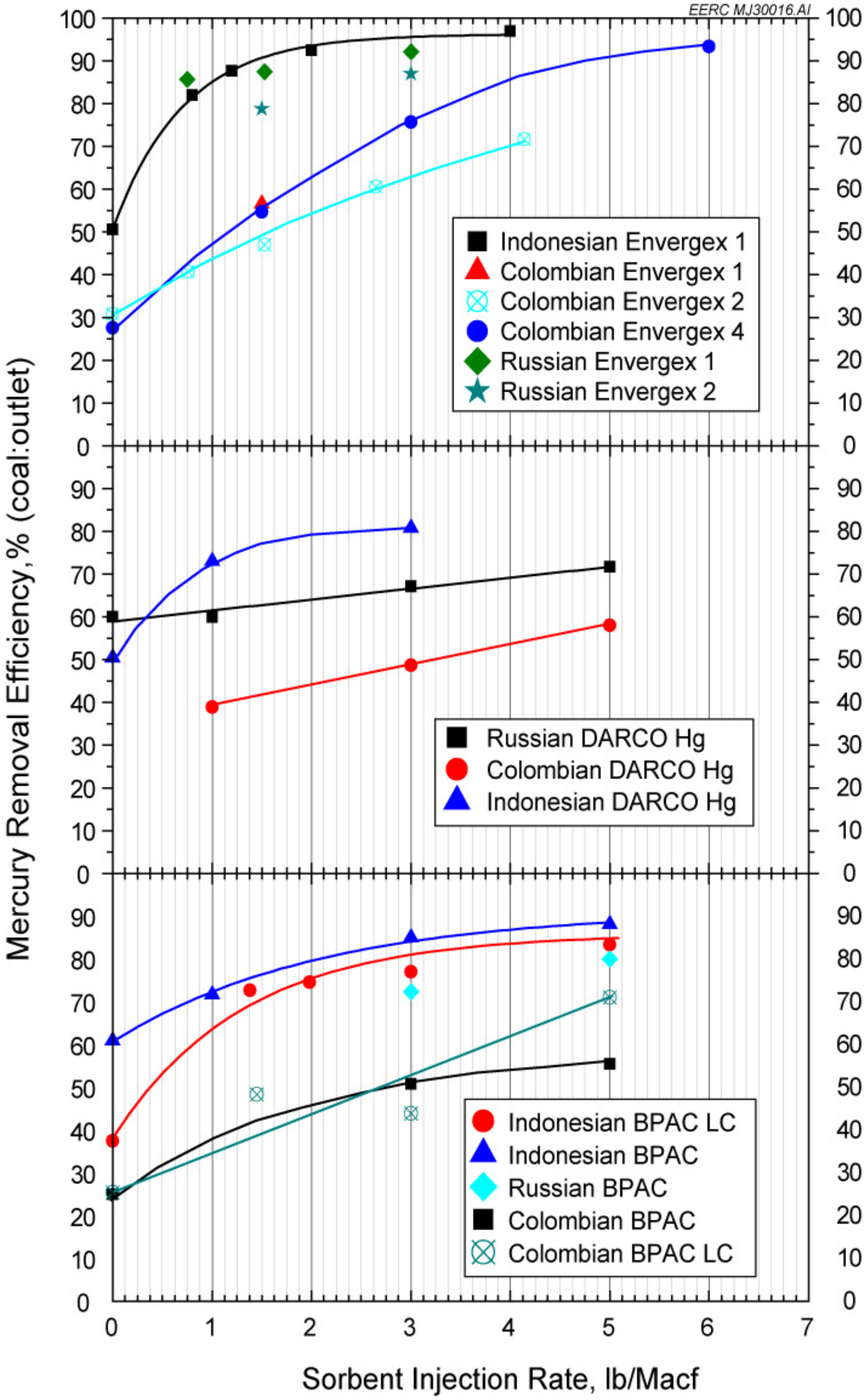

Figure 23. Comparison of Hg control technologies for all coals tested.

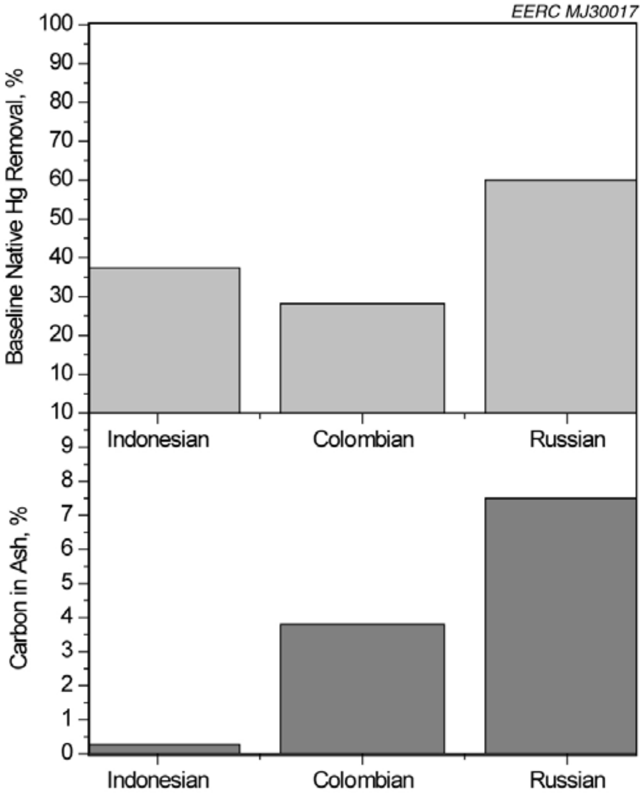

Figure 24. The effects of unburned carbon in the system as determined by the carbon in the ash.

baseline testing, the percent carbon in the ash was ~4.0% with a slightly lower native capture measured of 28%. The Russian coal had the highest percent carbon in the ash during baseline, measuring 7.50%, which did lead to the highest native Hg capture of 60%. The native capture is not only affected by the unburned carbon in the system, but it is also attributed to many other factors such as forms of Hg present (oxidized, elemental, particulate) and other elements that may enhance capture such as halogens and selenium that are present in the coal.

Flue Gas and Coal Combustion By-Product Analyses

Deposit Analysis

During the primary baseline testing for each fuel, probe ash deposits were collected to determine the fouling potential. Table 6 shows the test condition for formation of the deposit and the composition of the deposit for each fuel. The Indonesian coal had insignificant deposits on the probe bank. The limited amount of deposit only allowed for a morphology analysis; thus the deposit information has higher error than the XRF analysis for the Colombian and Russian coals. The analyses are valid for comparison purposes.

Table 6. Deposit Testing Conditions and Compositions for Each Fuel

	Indonesian		Colombian		Russian	
FEGT, °F	2211		2219		2189	
Probe Metal Temp., °F	1000		1000		1000	
Length of Run, hr	5.45		5.75		5.25	
Fuel Feed Rate, lb/hr	65.59		52.22		49.94	
Ash Input Rate, lb/hr	0.87		7.63		5.76	
Deposit Weight, g	0.89		344.6		201	
Deposition Rate, g/hr	0.16		62.00		38.29	
	As-Fired	SO_3-Free	As-Fired	SO_3-Free	As-Fired	SO_3-Free
SiO_2	37.5	40.3	62.2	62.2	54.7	54.8
Al_2O_3	16.12	17.3	19.8	19.8	22.9	22.9
Fe_2O_3	21.01	22.57	9.52	9.52	6.85	6.85
TiO_2	0.93	1.00	1.05	1.06	0.95	0.95
P_2O_5	0.03	0.03	0.16	0.16	0.80	0.80
CaO	13.21	14.19	2.5	2.5	7.9	7.9
MgO	2.50	2.69	1.98	1.98	2.67	2.68
Na_2O	0.00	0.00	0.70	0.70	1.21	1.21
K_2O	1.74	1.87	2.05	2.05	1.91	1.91
SO_3	6.91	N/A	0.04	N/A	0.08	N/A
Total	99.95	99.95	100	99.97	99.97	100

The Colombian and Russian coal deposition rates were 62 and 38.29 g/hr, respectively. The FEGTs were within 30°F. The Indonesian fuel did not have a significant ash deposition because of the low ash content, 1.71% on a H_2O-free basis, in the fuel. The Colombian and Russian coal had significantly higher ash content, 14.91% and 11.97%, respectively, on a H_2O-free basis.

The ash composition of the deposits is shown in Table 6. The Colombian and Russian coals had similar deposit compositions. Their deposits were primarily composed of silicate, with the Colombian coal at 62.2% and the Russian coal at 54.8%, and aluminum, with the Colombian coal at 19.8% and the Russian coal at 22.9%. The Colombian and Russian coals also had significant portions of iron, calcium, magnesium, potassium, and sodium and little or no sulfur, indicating clays are present in the coal. The Russian coal had slightly lower iron, 6.85%, compared to 9.52% for the Colombian. The Colombian coal had lower phosphorus at 0.16%, calcium at 2.5%, and sodium at 0.70% compared to the Russian coal at 0.80%, 7.9%, and 1.21%, respectively.

The Indonesian coal had a different ash composition than the Russian and Colombian coals. The Indonesian had a significant weight percent of silicate at 40.3%, aluminum at 17.3%, iron at 22.57%, sulfur at 6.91%, and calcium at 13.21%. The Indonesian coal had a significantly higher percentage of iron and sulfur than the other coals, indicating pyrite was in the coal.

The Colombian and Russian coals had the most significant fouling, with the Colombian having a higher deposition rate, 62 g/hr, than the Russian, which was 38.29 g/hr. The Indonesian coal had an insignificant or small amount of fouling on the probe banks. The Colombian and Russian coals likely had lower crystalline melting temperatures than the Indonesian coal, resulting in greater fouling of the system.

Ash Analysis

Table 7 shows the carbon percentages for some of the ash samples taken during testing. The corresponding O_2 and CO averages are also present. The low carbon content of the Indonesian ash, 0.28%, indicates almost complete combustion for the fuel. The injection of sorbents did affect the percentage of carbon in the ash, varying it 2.62%–5.70%.

The baseline for the Colombian coal had a higher level of carbon in the ash than the samples of ash taken after sorbent injection. However, the average CO levels indicated periods of higher incomplete combustion resulting in unburned carbon in the ash. The periods were likely caused by system upsets, primarily with the coal feeder, and problems due to swelling. There were similar results for the Russian coal, which had a higher baseline carbon percentage than it did during the injections of the sorbents. Again, this is likely because of the incomplete combustion caused by the system upsets indicated by the high CO levels. Indications are that the system's performance improved over the length of the day, reducing the overall excess carbon being produced. The effects were more pronounced during testing with the Russian coal.

Table 8 shows the scanning electron microscope point count analysis (SEMPC). As indicated by the morphology results, the Indonesian deposit was primarily made up of silicate material. There was also sulfur, iron, and carbon present in the deposit. There appears to be a small discrepancy in the sulfur percentage between the morphology and the SEMPC. The difference was the process used in the analyses; the morphology is an area scan, whereas the SEMPC is a homogeneous mixture of the cross section of the material. Thus the difference was likely due to the difference in the components on the surface of the deposit compared to components on the inside. It is likely that the sulfur formed an outer coating, thereby giving the higher concentration shown in the morphology and a lower concentration on the inside as shown by the SEMPC. The silicate materials present in the deposit were quartz, albite, anorthite, altered kaolinite, illite, montmorillonite, pyroxene, dicalcium silicate, and mixed silicate material. The presences of these materials indicate clay material was present in the coal.

The SEMPC analysis indicates that the Colombian coal was primarily made of silicate. The silicate had high levels of the clay material illite (15.1%), montmorillonite clay (5.6%), quartz (28.6%), and mixed silicon-rich (43.6%). The presences of these clays can cause significant fouling, which was seen during the testing. The Russian coal deposit was primarily made of silicate materials. The crystal structures present were quartz (8.8%), anorthite (11.5%), illite (25.4%), montmorillonite (4.4%), and mixed silicon-rich (32.6%). These materials reflect the mineral content of the coal. The clays can cause significant fouling, as seen during the testing.

FACT ANALYSIS

The viscosity of the coals calculated from the composition of liquid phase predicted by FACT is shown in Figure 25. 250 poise is the point at which the material begins to flow as a liquid. During the testing, only the Indonesian coal achieved that low a viscosity. This usually leads to significant fouling of the CTF; however, because of the low ash content of the Indonesian coal,

Table 7. Percent Carbon Found in the Ash

Date	Time	Ash	Coal	Injection	Highest Injection Rate	Average O_2,%	Average CO, ppm	Carbon, %
12/4/2006	14:16	ESP ash	Indonesian	Baseline	N/A	3.44	5.64	0.28
12/4/2006	22:23	ESP ash	Indonesian	BPAC LC	5 lb/Macf	3.88	5.25	2.62
12/5/2006	13:19	ESP ash	Indonesian	STI Rejects	10 lb/Macf	3.83	4.35	5.695
12/5/2006	19:54	ESP ash	Indonesian	Envergex 1	4 lb/Macf	3.36	4.76	1.095
12/6/2006	11:49	ESP ash	Colombian	Baseline	N/A	3.46	16.87	3.59
12/6/2006	16:00	ESP ash	Colombian	BPAC LC	5 lb/Macf	3.66	14.63	3.565
12/6/2006	19:30	ESP ash	Colombian	DARCO	5 lb/Macf	3.75	7.26	3.055
12/6/2006	20:35	ESP ash	Colombian	Envergex 1	1.5 lb/Macf	3.7	6.7	3.01
12/7/2006	12:57	ESP ash	Colombian	Baseline	N/A	3.52	7.8	4
12/7/2006	19:35	ESP ash	Colombian	BPAC Blend	5 lb/Macf	3.47	5.85	3.43
12/8/2006	10:10	ESP ash	Russian	Baseline	N/A	3.76	13.01	7.495
12/8/2006	12:20	ESP ash	Russian	DARCO	5 lb/Macf	3.7	7.88	4.485
12/8/2006	15:20	ESP ash	Russian	Envergex 1	3 lb/Macf	3.78	8.85	3.373
12/8/2006	18:20	ESP ash	Russian	BPAC	5 lb/Macf	4.21	6.63	2.87
12/12/2006	20:28	ESP ash	Indonesian	Mersorb and S-Sorb	6% S-Sorb 1.3% Mersorb	3.63	3.95	0.51
12/13/2006	12:00	ESP ash	Russian	Mersorb and S-Sorb	6% S-Sorb 1.3% Mersorb	4.38	10.95	3.405
1/3/2007	20:39	ESP ash	Colombian	Mersorb and S-Sorb	6% S-Sorb 0.75% Mersorb	3.43	9.14	3.56

Table 8. SEMPC Analysis

	Indonesian Coal AF-CTS-801 16:30 12/04/06	Colombian Coal AF-CTS-804 13:53 12/06/06	Russian Coal AF-CTS-807 13:15 18/08/06
Oxide-Rich			
Iron Oxide	3.1	1.2	2.4
Spinel	0.0	0.0	0.4
Mixed Oxide-Rich	1.7	0.0	0.4
Total for Group	4.8	1.2	3.2
Sulfur-Rich			
Mixed Sulfur-Rich	2.0	0.0	0.0
Carbon-Rich			
Calcite	1.0	0.0	0.0
Altered Calcite	0.0	0.0	0.4
Mixed Carbon-Rich	3.4	0.4	1.2
Total for Group	4.4	0.4	1.6
Metal-Rich			
Iron	0.0	0.8	0.0
Mixed Metal-Rich	1.4	1.2	2.4
Total for Group	1.4	1.6	2.4
Silicon-Rich			
Quartz	12.3	28.6	8.8
Albite	0.3	0.8	0.0
Anorthite	1.4	0.1	11.5
Kaolinite	0.0	1.6	0.0
Altered Kaolinite	1.7	0.8	5.2
Illite	4.8	15.1	25.4
Montmorillonite	1.4	5.6	4.4
Pyroxene	1.0	0.0	0.0
Wollastonite	0.0	0.0	0.8
Calcium Silicate	0.0	0.0	0.0
Dicalcium Silicate	0.3	0.0	0.0
Gehlenite	0.0	0.0	0.4
Mixed Silicon-Rich	42.7	43.6	32.6
Total for Group	66.6	96.4	89.1
Halite	0.0	0.0	0.0
AlSiCa$_1$	0.0	0.4	0.8
AliSiCa$_2$	0.0	0.0	0.4
Total for Group	0.0	0.4	1.2
Other	20.8	0.0	2.0
Points Counted	293	252	252

little fouling was present. This characteristic could potentially be a problem when scaling up using the Indonesian coal because of buildup over time. The Russian and Colombian coal had similar viscosities until approximately 2350°F, where the Russian coal's viscosity decreases slightly faster than the Colombian coal. The Russian and Colombian coals had higher viscosities than the Indonesian coal; however, they fouled significantly more than the Indonesian coal because of the high coal ash content.

Figure 26 shows the percent sulfur in the solid phase. It is important to note that at the temperature of the testing (2000°–2200°F), all of the sulfur was in the gas phase. As the temperature and the flue gas cools, the sulfur forms solid sulfates binding together with other materials such as silicon and aluminum causing low-temperature fouling. The sulfur starts to form solid sulfates for the Indonesian coal at approximately 1600°F. The binding effect of the sulfates is significant; however, when the Indonesian coal is combusted, little ash is bound by the sulfates.

The Colombian coal starts to form solid sulfates at approximately 1450°F. The one reason that the Colombian coal had slightly more fouling than the Russian is because when the sulfur became a solid, it bonded to other material present in the flue gas. Although the sulfur content was not high in the coal, it was present and, at lower temperatures, can cause significant fouling. The Russian coal starts to form solid sulfur at approximately 1350°F. As in the case for the Colombian coal, the formation of the solid sulfates causes fouling.

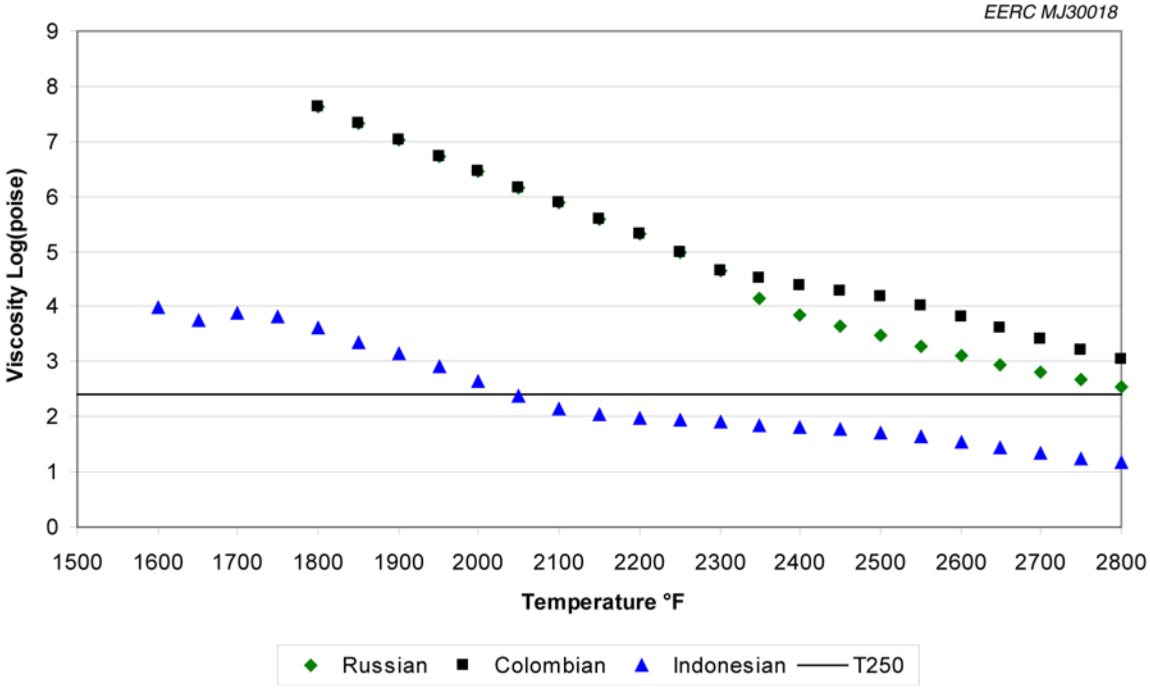

Figure 25. The viscosity of the coals calculated by FACT.

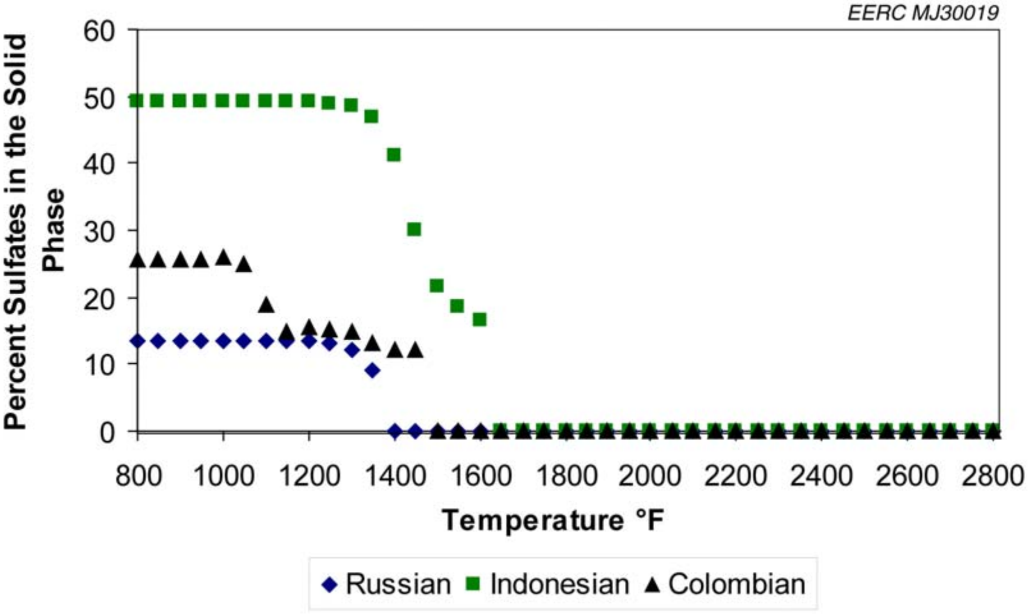

Figure 26. Percentage of sulfates in the solid phase.

The Indonesian coal had a higher percentage of sulfates in the solid phase; however, the amount of ash produced when the Indonesian coal was combusted was lower than the other two coals; thus there were less overall sulfates pound for pound. The Colombian and Russian coals had similar ash input rates; however, the percentage of sulfates in the solids was higher for the Colombian, and the Colombian had slightly more fouling than the Russian.

Figure 27 shows Slag C (liquid silicate slag solution) for each of the coals fired. For the Indonesian coal, Slag C starts to appear at approximately 1600°F and steadily increases until approximately 2000°F. From 2000° to 2200°F, Slag C increases from 3% to approximately 25%. This increase could cause significant fouling because of the increase in liquid.

For the Colombian coal, Slag C starts to appear at approximately 1800°F and steadily increases. Slag C increases approximately from 6% to 11% from 2000° to 2200°F. For the Russian coal, Slag C starts to appear at approximately 1800°F and steadily increases. Slag C increases approximately from 8% to 14% from 2000° to 2200°F. These slight increases in Slag C will contribute to fouling; however, it was not as significant as with the Indonesian coal.

Figure 28 shows the SCMO (solid calcium magnesium oxide) solution for each coal fired. The Indonesian coal begins to form below 1600°F and contains up to 25% of the solids at lower temperatures. The Colombian coal begins to form below approximately 1475°F and contains up to 15% of the solids at lower temperatures. The Russian coal begins to form below approximately 1375°F and contains up to 7% of the solids at lower temperatures.

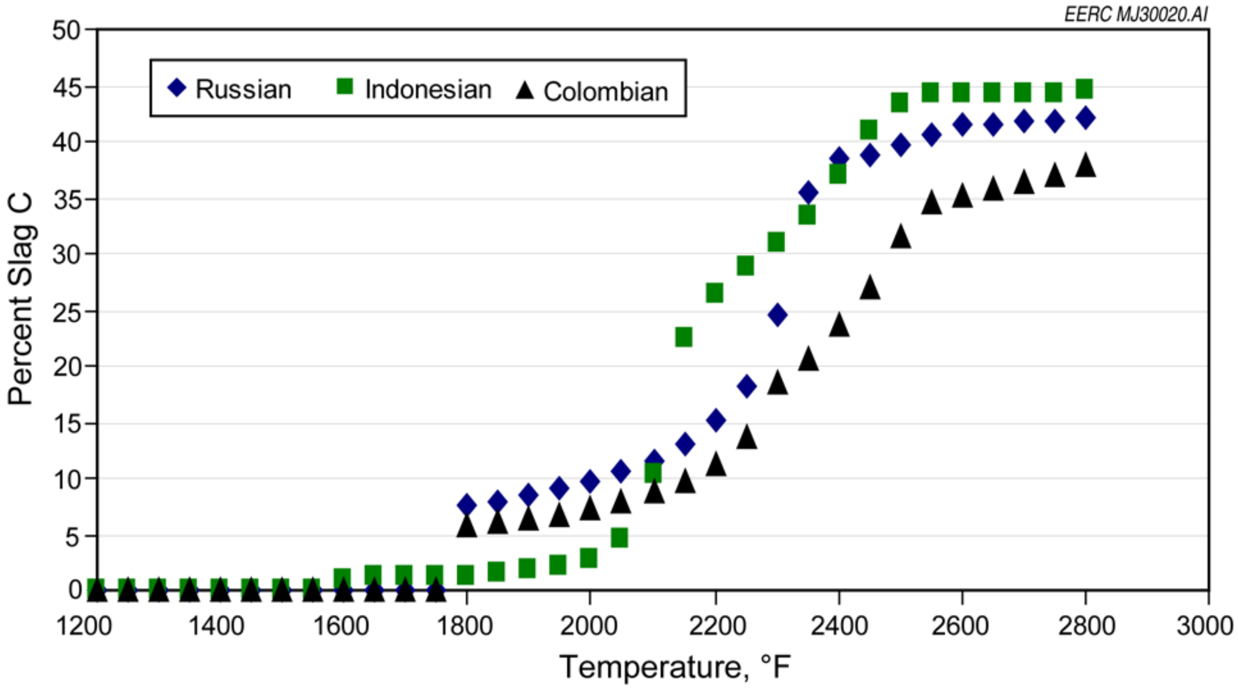

Figure 27. Percent of Slag C.

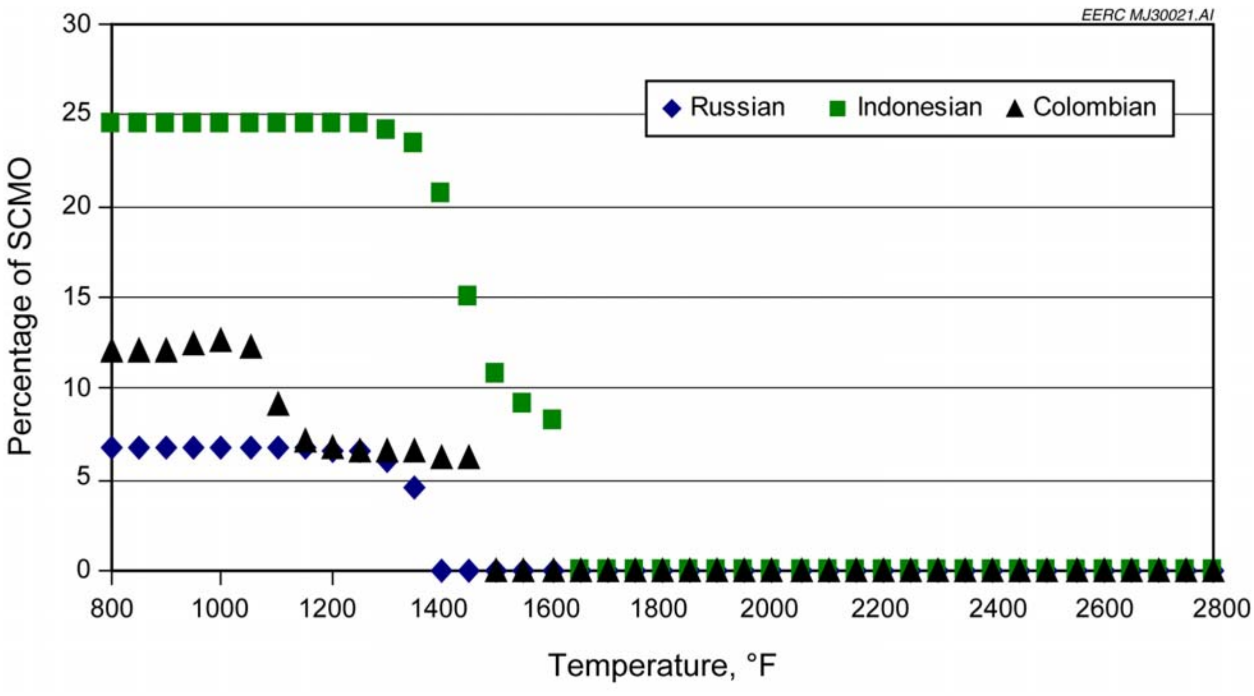

Figure 28. Percentage of SCMO.

CONCLUSIONS

The Indonesian coal is a low-sulfur, low-ash coal which displayed good Hg removal with sorbent addition. The composition and Btu of this coal allowed for smooth operation of the pilot-scale system. A maximum Hg removal of 97% was achieved across the ESP with the addition of Envergex 1 sorbent with an injection rate of 4 lb/Macf. Difficulties encountered with the FF module prevented testing with Indonesian coal and this type of particulate control device. The FACT analysis indicated that the Indonesian coal could be problematic because, when fired, the viscosity is lower than the 250 poise. The problem could present itself over time; however, the low ash and sulfur content make this an unlikely event.

The high ash content of the Colombian coal caused it to be a problematic fuel. It displayed the highest sulfur content of the three coals tested. The presence of selenium in the coal does interfere with mercury measurement and needs to be considered when the logistics of Hg measurement at full scale are examined. Ash buildup of the pilot-scale system was an issue, and plugging became a problem at the end of long testing. The FACT analysis indicated that the Colombian coal was problematic because when said sulfates form, they bond to other material, causing the significant fouling of the system. Using the ESP configuration, the maximum Hg reduction of 93% was attained using Envergex 4 at 6 lb/Macf and also Chem-Mod with an injection rate of 6% S-Sorb combined with 0.75% Mer-Sorb. Limited FF testing was performed, indicating that the native capture was reaching 85%.

The Russian coal contained lower sulfur content than the Colombian coal and fairly high ash content. Testing with the FF module yielded native capture of 90%. Sorbent testing with the FF was not conducted. With the ESP module, the maximum Hg reduction of 92% was achieved using Envergex 1 at an injection rate of 3 lb/Macf. The FACT analysis indicated that Russian coal had potential for fouling because of the sulfur present in the coal. The Russian coal did have less fouling than the Colombian because it had lower sulfur.

The addition of ammonia was examined with an injection rate of 10 ppm in the flue gas. Some effect was measured, and it appeared to enhance mercury removal but only by 1% to 2%. This effect was not found to be detrimental to mercury removal in any of the tests. The effect was not dependent on coal type.

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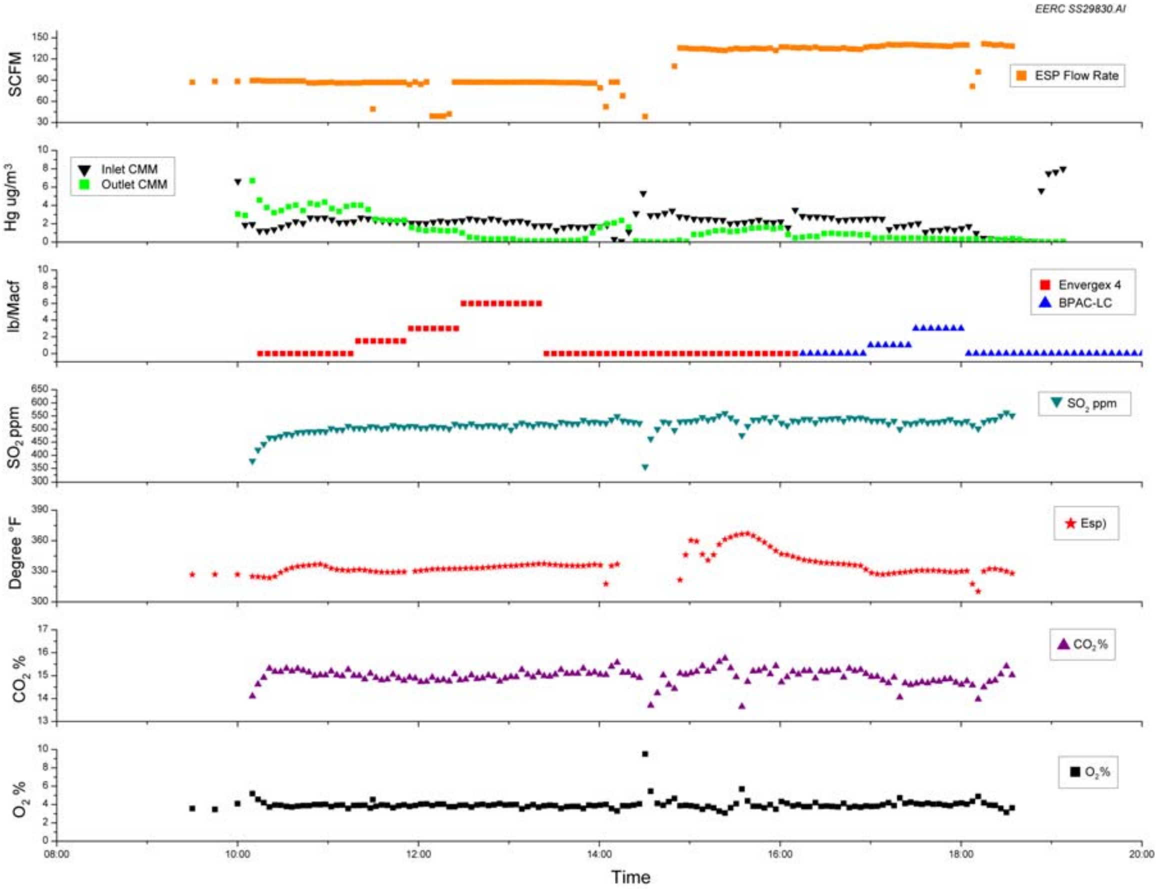
APPENDIX A

DAILY SUMMARIES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SO₂ ppm
Degree °F
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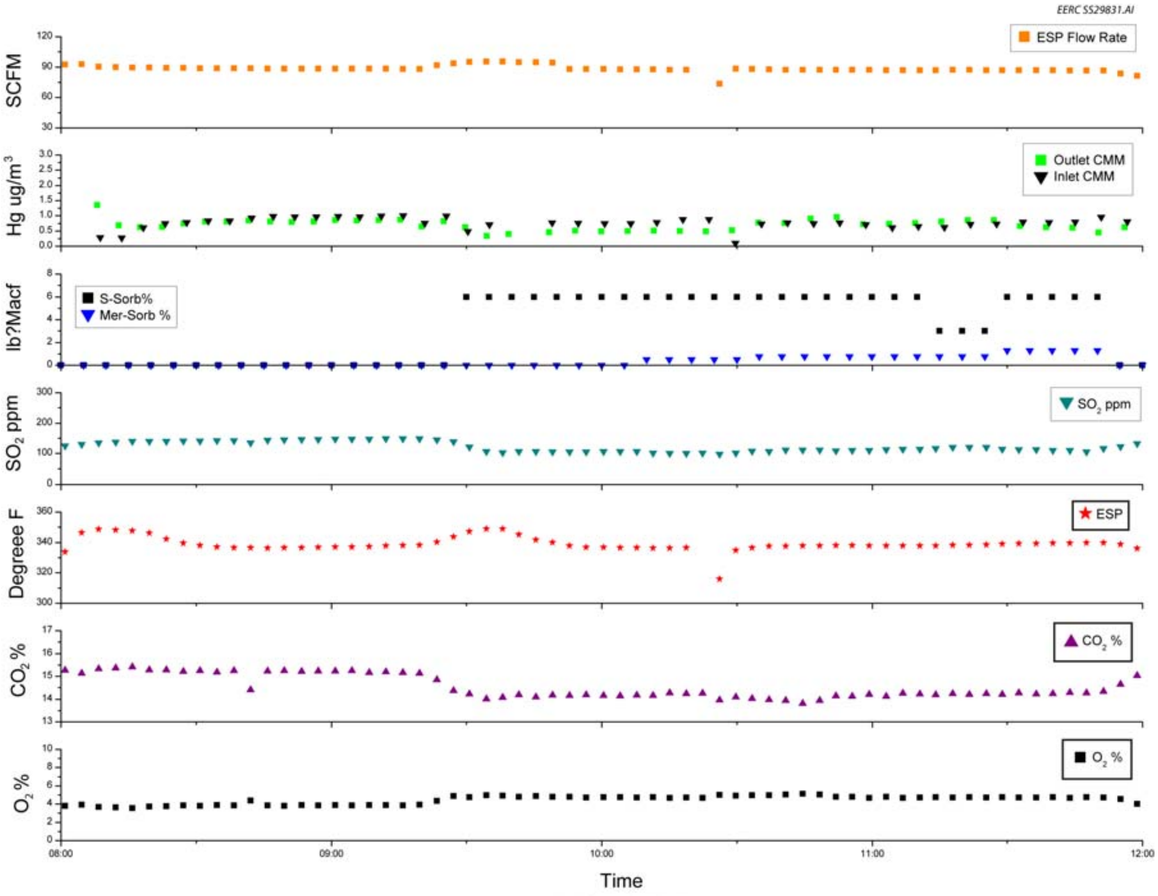
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Inlet CMM
lb?Macf
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6
4
2
0
S-Sorb%
Mer-Sorb %
SO$_2$ ppm
300
200
100
0
SO$_2$ ppm
Degreee F
360
340
320
300
ESP
CO$_2$ %
17
16
15
14
13
CO$_2$ %
O$_2$ %
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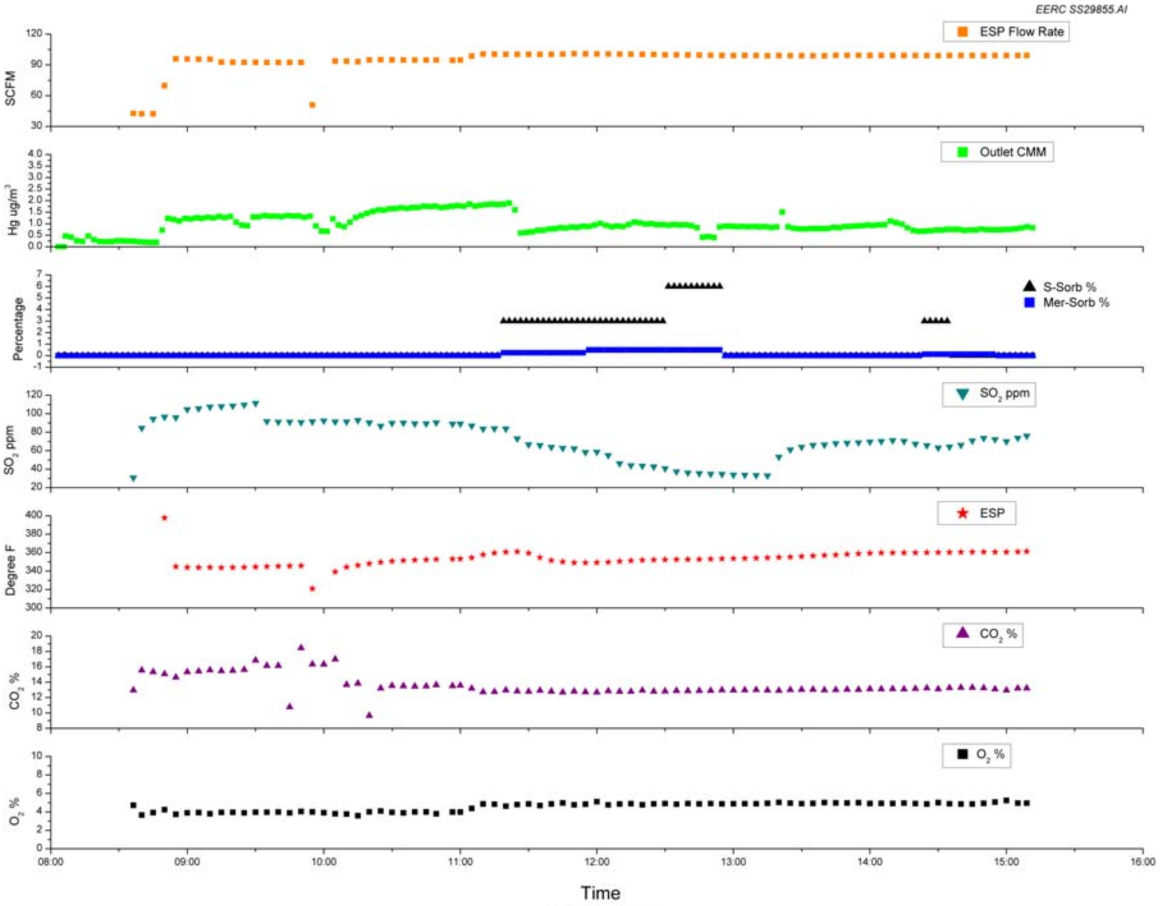
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3.0
3.5
4.0
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Mer-Sorb %
Percentage
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0
1
2
3
4
5
6
7
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20
40
60
80
100
120
ESP
Degree F
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340
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400
CO$_2$ %
8
10
12
14
16
18
20
O$_2$ %
0
2
4
6
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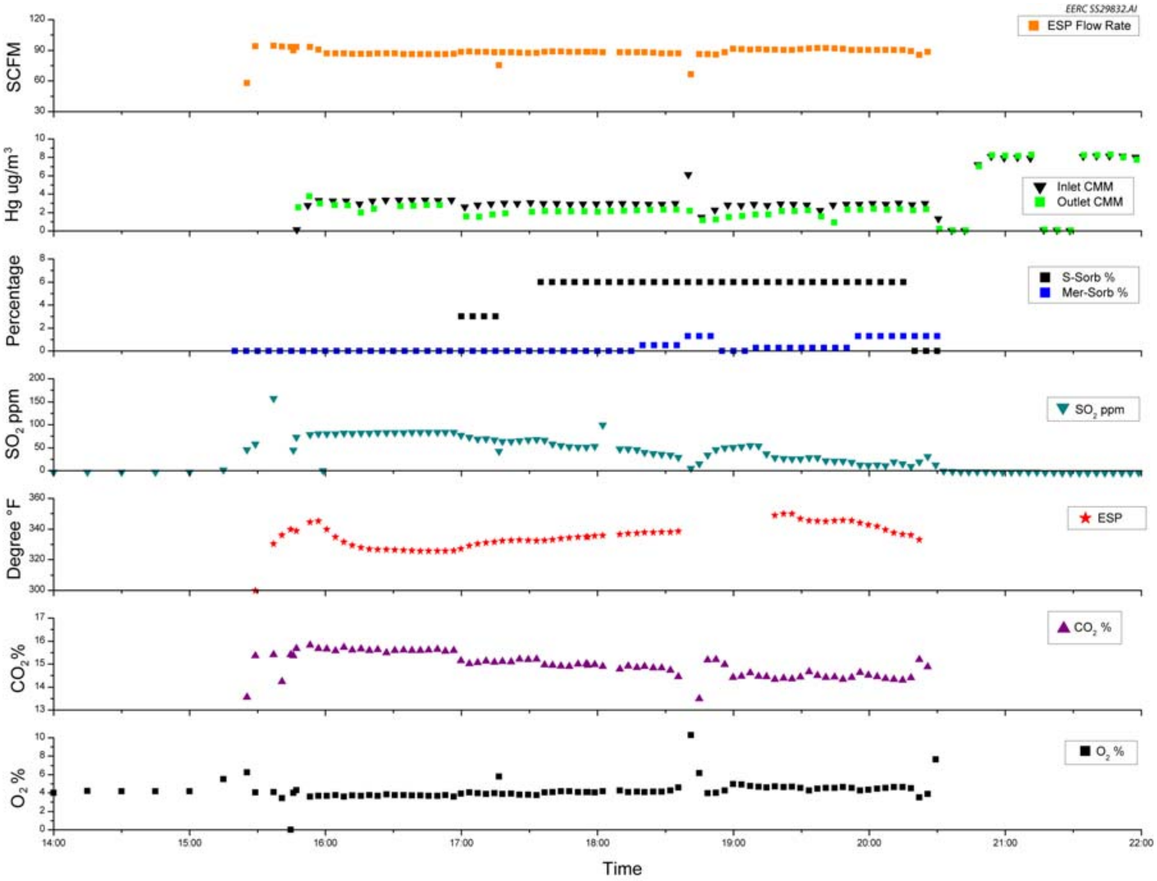
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Percentage
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6
4
2
0
S-Sorb %
Mer-Sorb %
SO$_2$ ppm
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50
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Degree °F
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O$_2$ %
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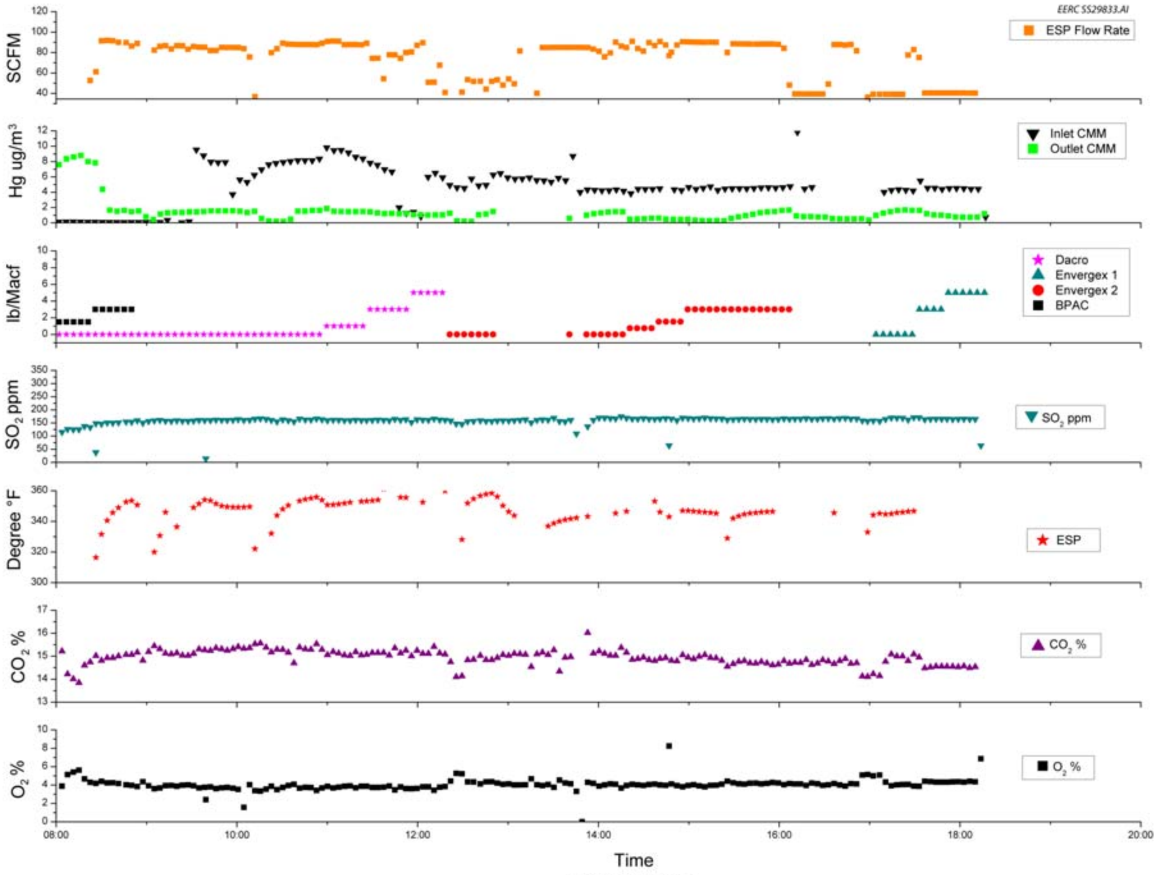
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BPAC
SO$_2$ ppm
SO$_2$ ppm
Degree °F
ESP
CO$_2$ %
CO$_2$ %
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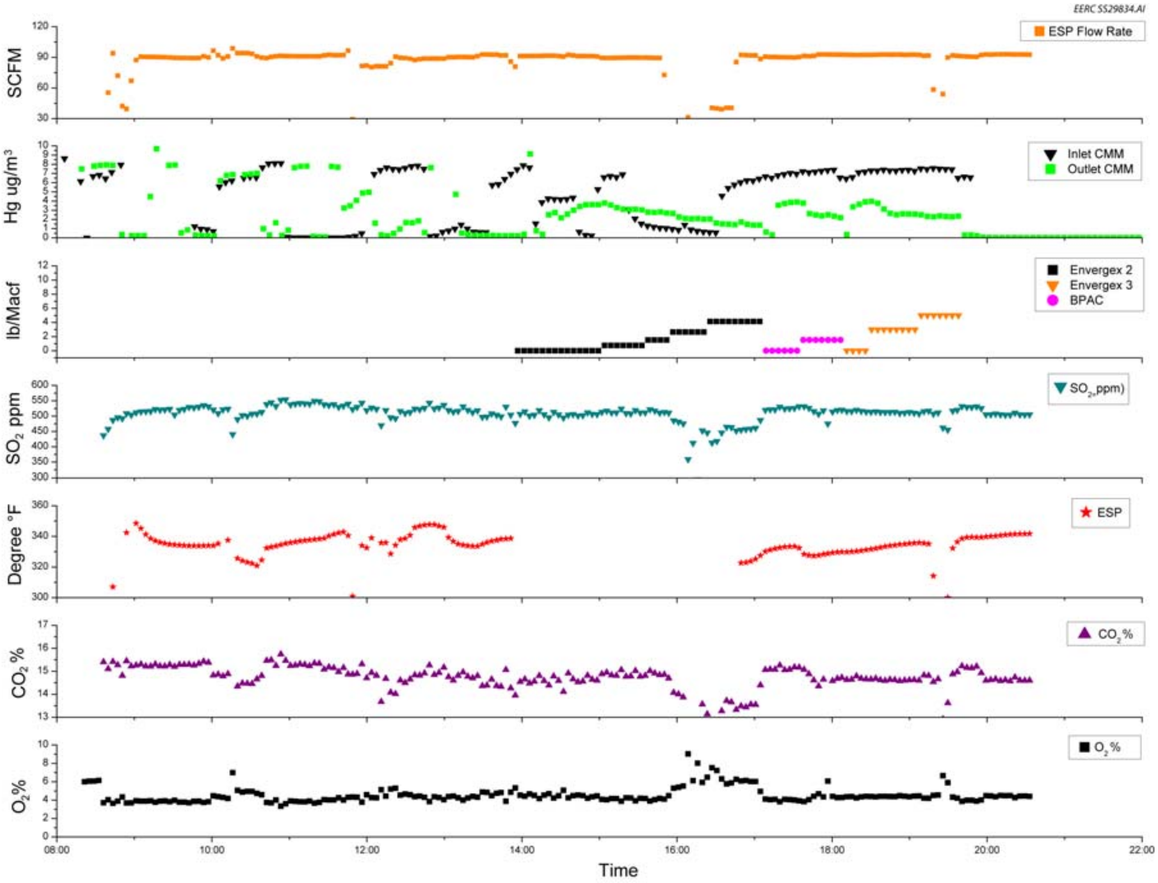
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7
6
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Inlet CMM
Outlet CMM
lb/Macf
12
10
8
6
4
2
0
Envergex 2
Envergex 3
BPAC
SO₂ ppm
600
550
500
450
400
350
300
SO₂, ppm)
Degree °F
360
340
320
300
ESP
CO₂ %
17
16
15
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CO₂ %
O₂%
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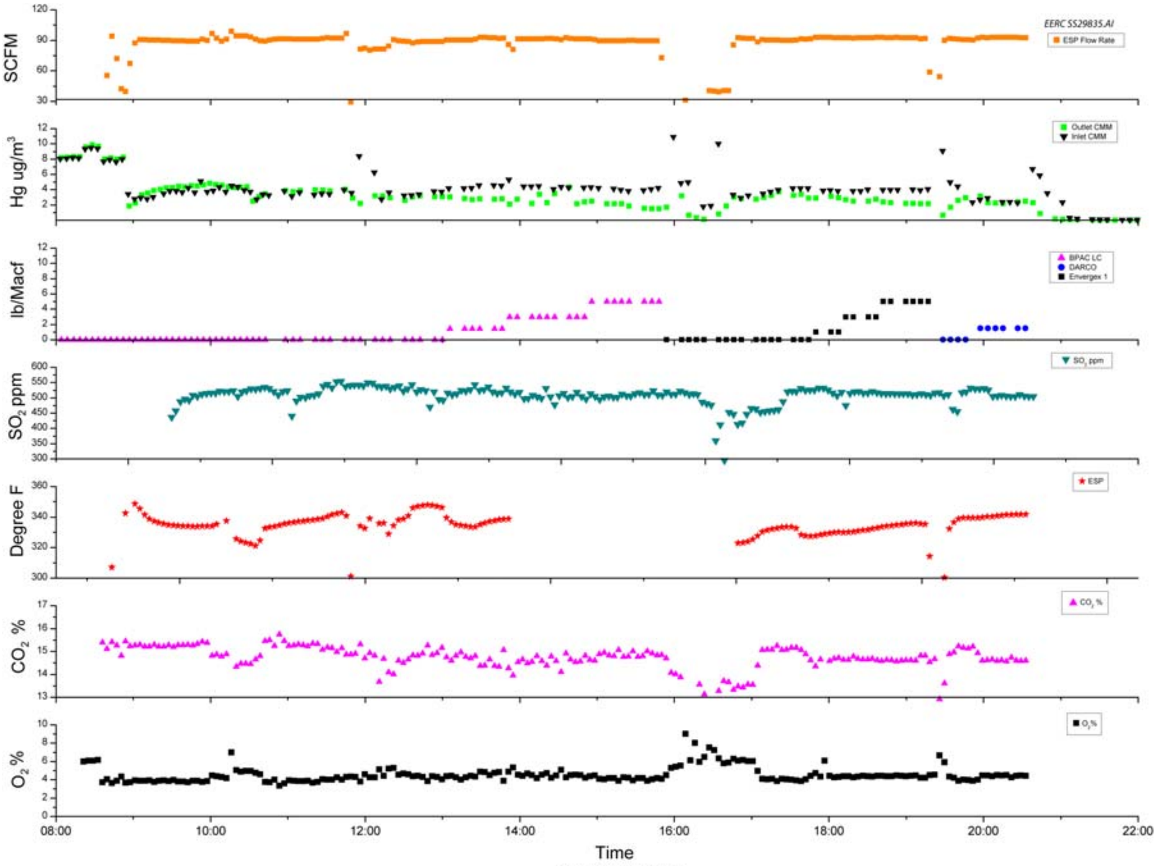
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lb/Macf
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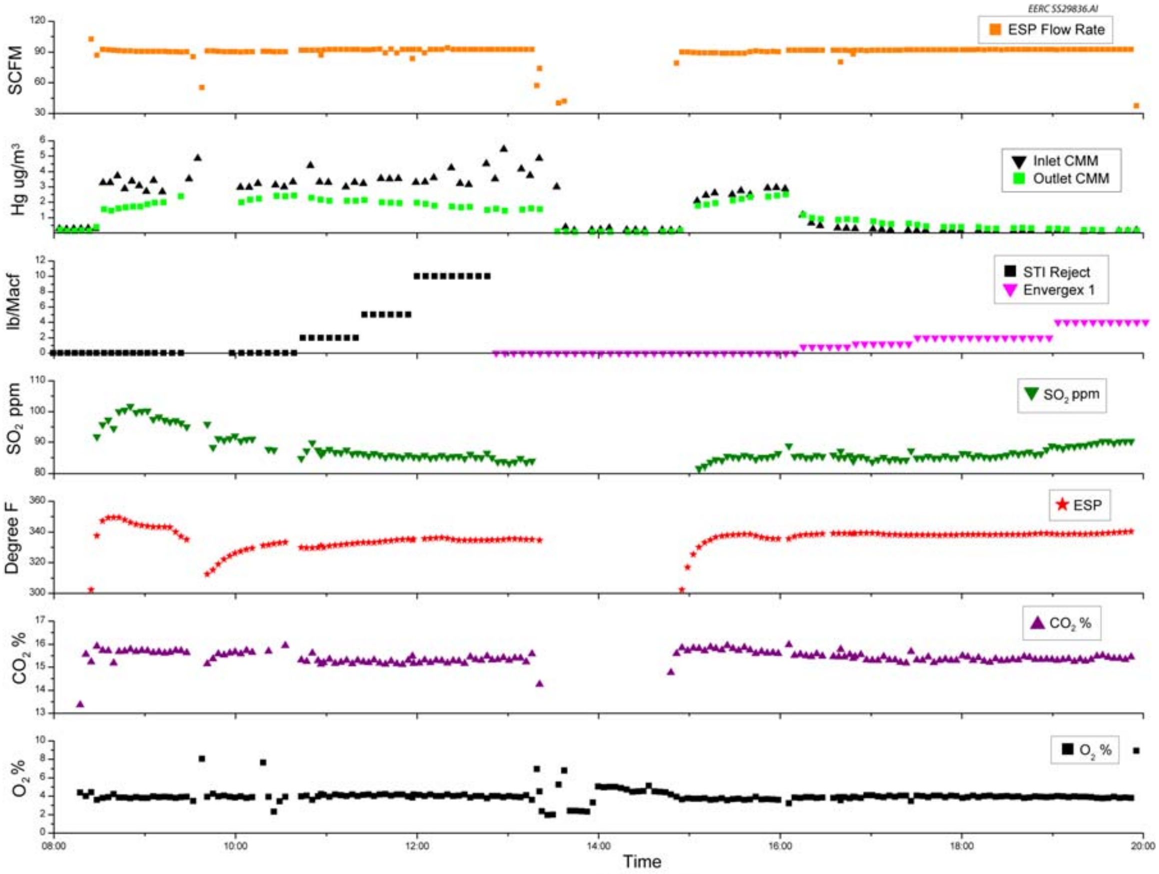
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6
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SO₂ ppm
Degree F
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ESP
CO₂ %
17
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15
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CO₂ %
O₂ %
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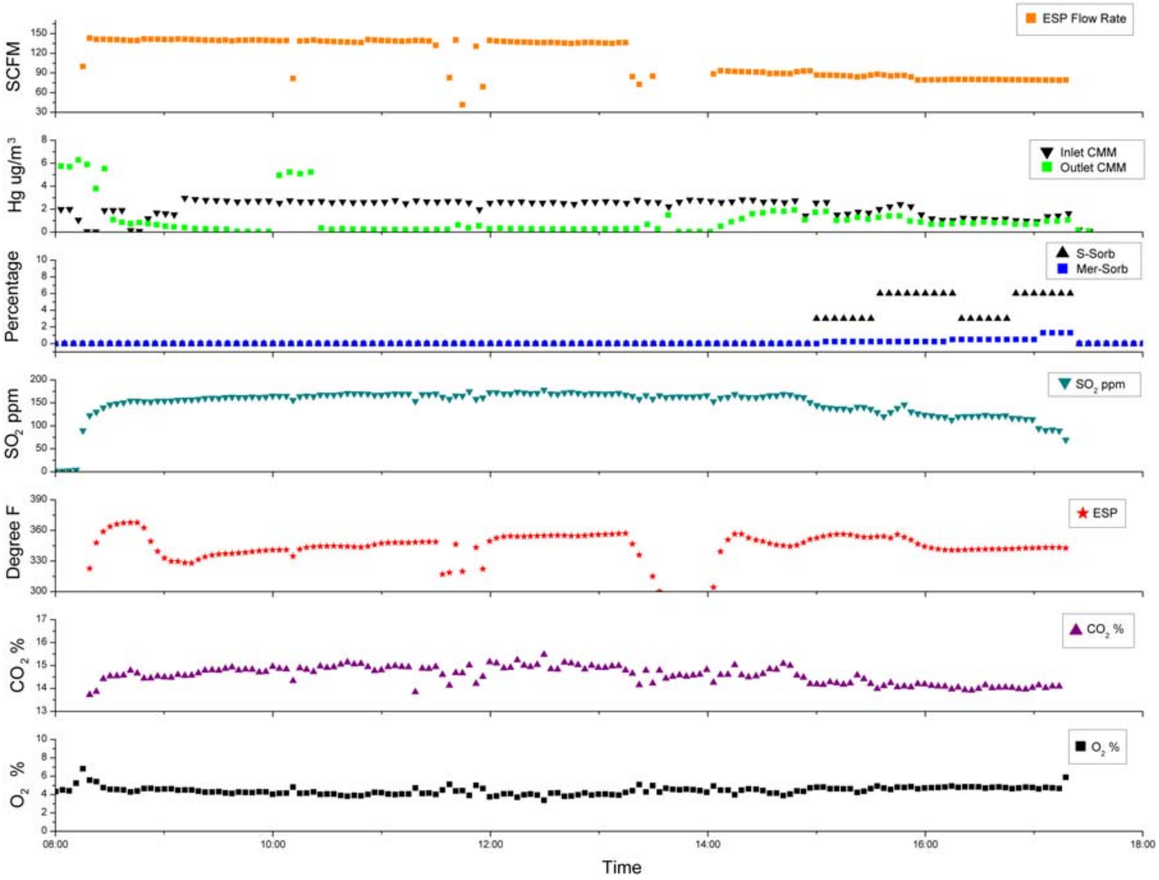

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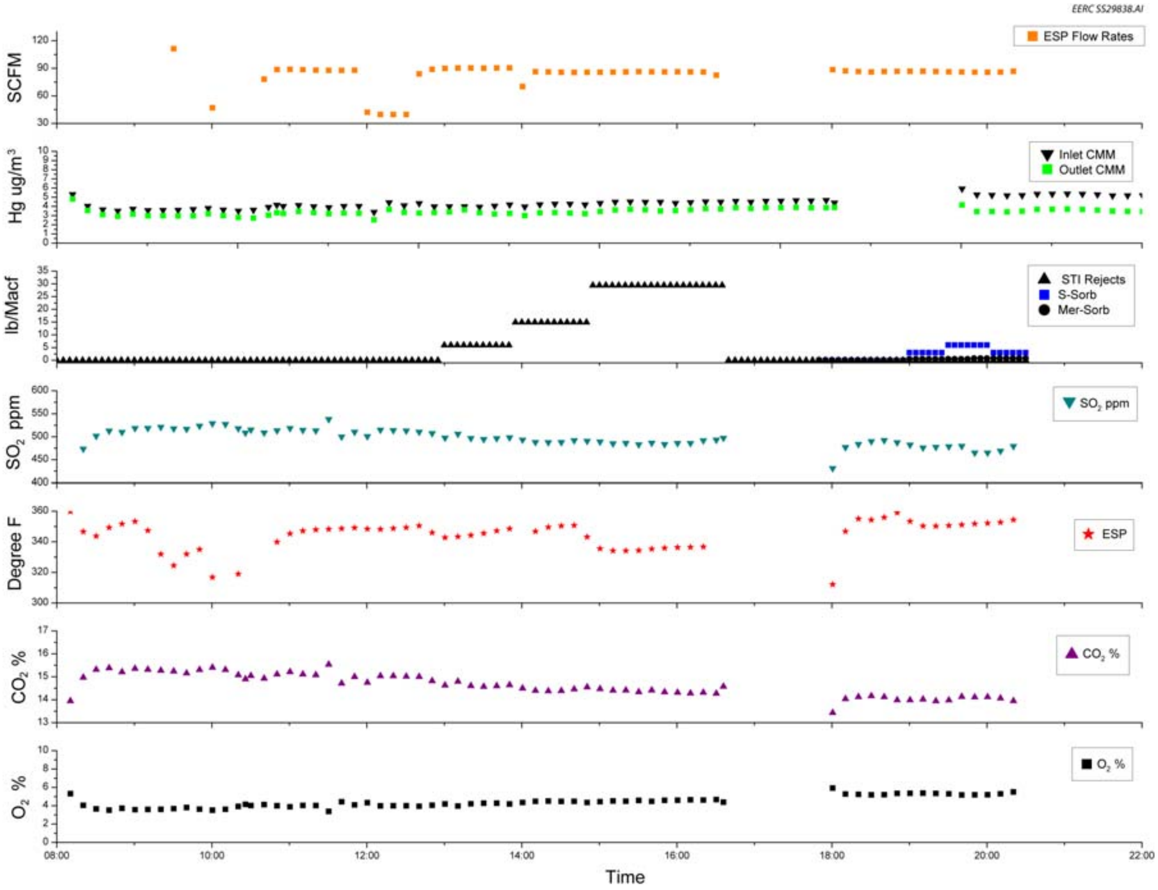
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Outlet CMM
lb/Macf
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15
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S-Sorb
Mer-Sorb
SO$_2$ ppm
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550
500
450
400
SO$_2$ ppm
Degree F
360
340
320
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ESP
CO$_2$ %
17
16
15
14
13
CO$_2$ %
O$_2$ %
10
8
6
4
2
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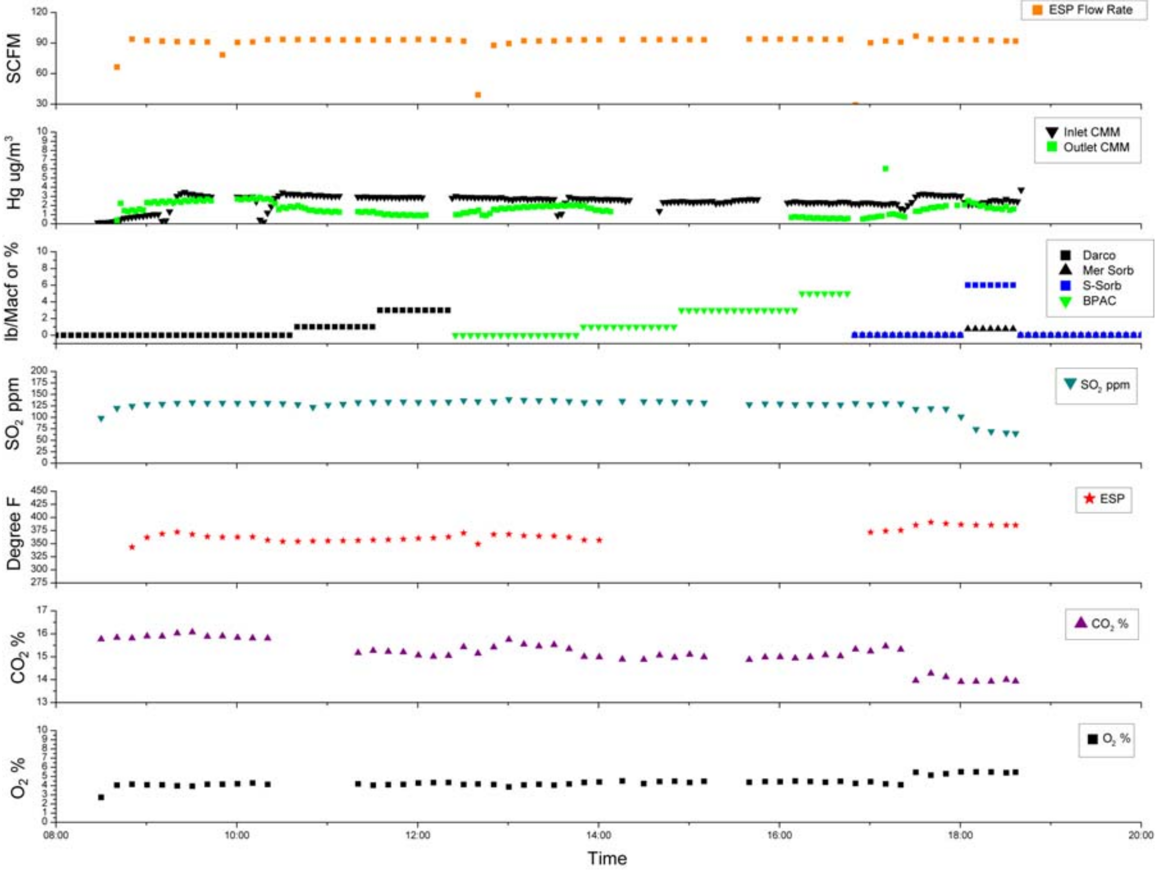

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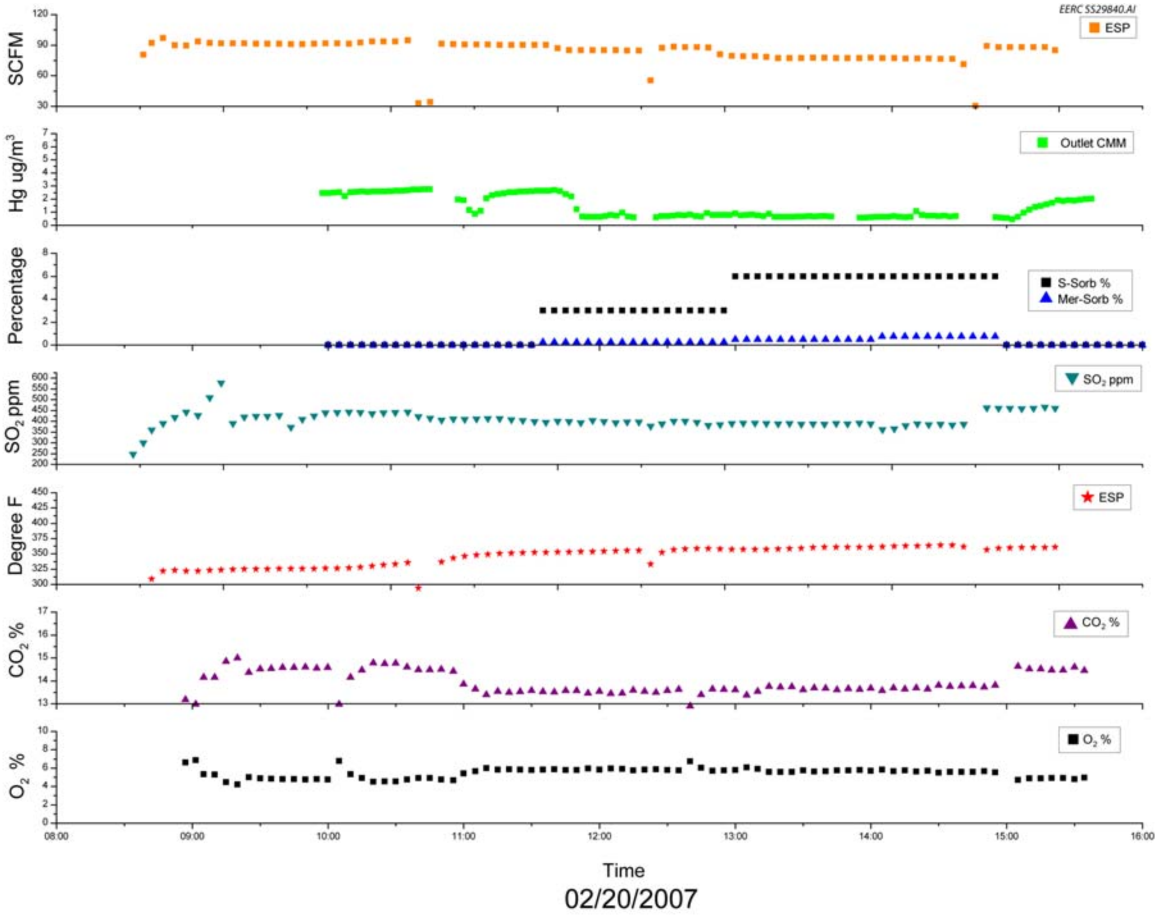
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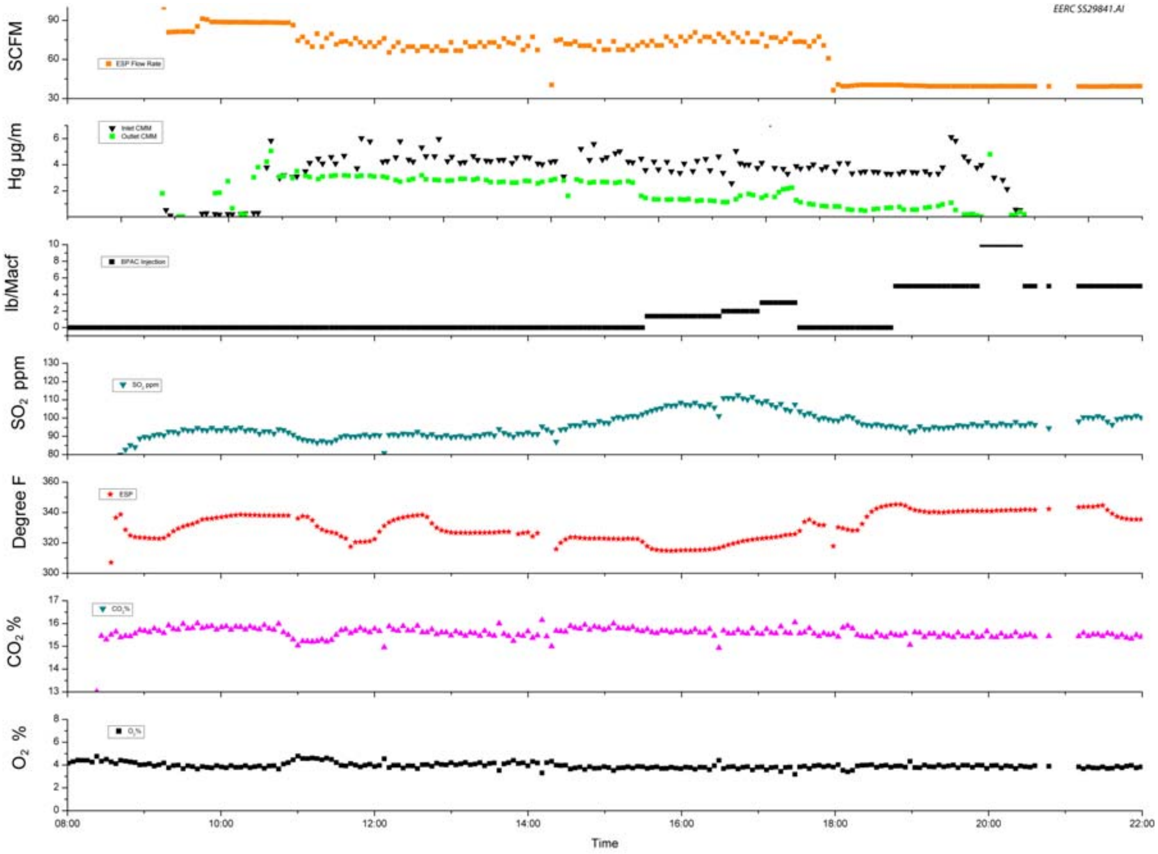
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6
4
2
0
BPAC Injection
SO$_2$ ppm
130
120
110
100
90
80
SO$_2$ ppm
Degree F
360
340
320
300
ESP
CO$_2$ %
17
16
15
14
13
CO$_2$%
O$_2$ %
8
6
4
2
0
O$_2$%
08:00
10:00
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14:00
16:00
18:00
20:00
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Time

12/04/2006