POWER SYSTEMS DEVELOPMENT FACILITY SUMMARY REPORT

GASIFICATION TEST CAMPAIGN TC22

MARCH 24, 2007 - APRIL 17, 2007

DOE Cooperative Agreement Number
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DISCLAIMER

ABSTRACT

In support of technology development to utilize coal for efficient, affordable, and environmentally clean power generation, the Power Systems Development Facility (PSDF) located in Wilsonville, Alabama, routinely demonstrates gasification technologies using various types of coals. The PSDF is an engineering scale demonstration of key features of advanced coal-fired power systems, including a KBR Transport Gasifier, a hot gas particulate control device, advanced syngas cleanup systems, and high pressure solids handling systems.

This report summarizes the results of the first demonstration of the PSDF gasification process operating with high moisture lignite from Mississippi, which was completed from March 24 to April 17, 2007, in test campaign TC22. The major objective for this test was to evaluate the process operational stability and performance using this coal. The gasification process was operated for a total of 543 hours in TC22, increasing the total gasification operation at the PSDF to over 10,000 hours.

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1.0 SUMMARY

Test campaign TC22 was the first demonstration of the Power Systems Development Facility (PSDF) gasification process operating with high moisture lignite from Mississippi. The major objective for this test was to evaluate the process operational stability and performance using this coal. TC22 was completed from March 24 to April 17, 2007, for a total of 543 hours, increasing the total gasification operation at the PSDF to over 10,000 hours.

The PSDF gasification process, shown in Figure 1, features a KBR (formerly Kellogg Brown & Root) Transport Gasifier, a pressurized, advanced circulating fluidized bed reactor consisting of a mixing zone, riser, solids separation unit, seal leg, standpipe, and J-leg. Coal is fed through a lock hopper system and pneumatically conveyed into the gasifier. The particulate laden syngas exiting the gasifier is cooled in a primary syngas cooler and then filtered by a downstream high temperature, high pressure filter vessel, the particulate control device (PCD). Gasification ash is removed from the gasifier and PCD using continuous ash depressurization systems.

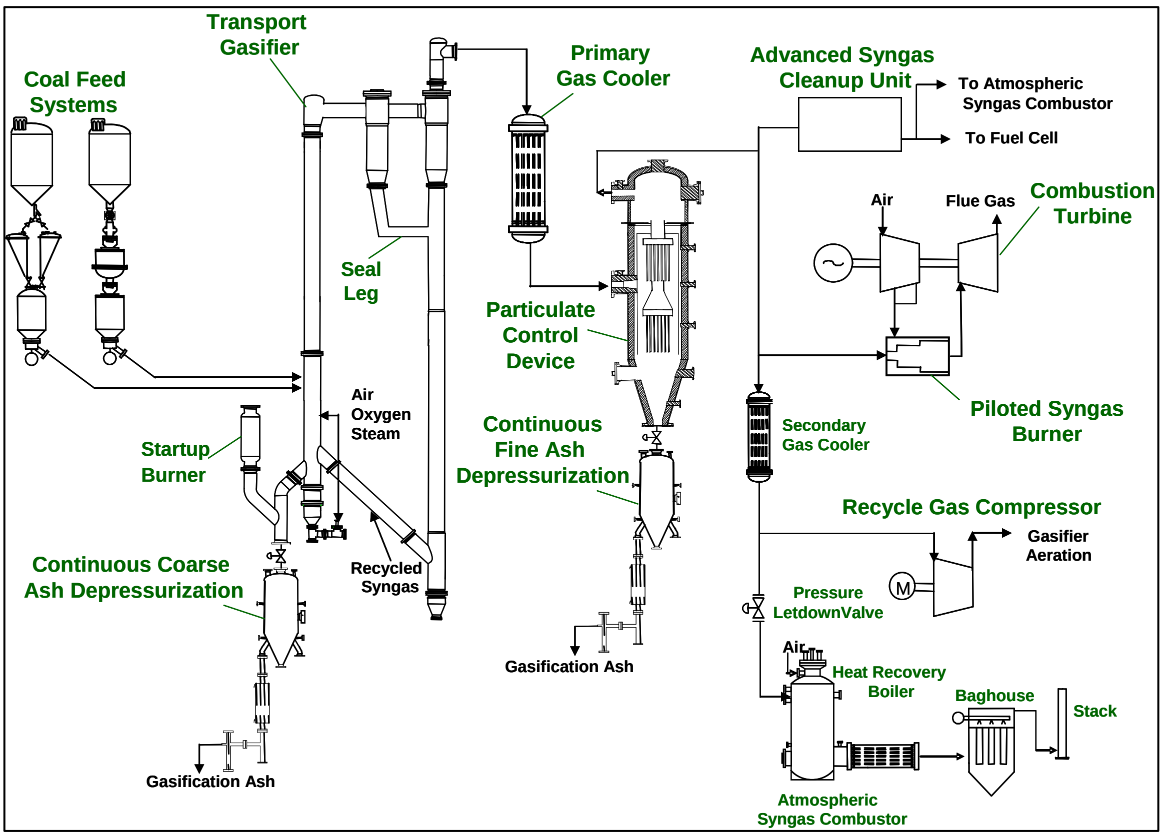

Figure 1. PSDF Gasification Process Flow Diagram.

A portion of the filtered syngas can be utilized in a slipstream syngas cleanup unit to test various pollutant control technologies or it can be combusted in a piloted syngas burner coupled with a gas turbine. Some of the syngas is compressed and sent to the gasifier for aeration to aid in circulation. The remaining syngas passes through a pressure control valve and flows to an atmospheric syngas combustor, a heat recovery boiler, a baghouse, and then out a stack. A flow diagram of the PSDF gasification process is. A detailed process description can be found on the PSDF web site, http://psdf.southernco.com.

The lignite coal used for test campaign TC22 was from the Red Hills mine in Mississippi. Table 1 gives the average, standard deviation, minimum, and maximum of the as-fed coal properties.

Table 1. Mississippi Lignite As-Fed Coal Properties.

	Average Value	Standard Deviation	Minimum Value	Maximum Value
Moisture, wt%	28.1	1.8	25.0	30.6
Carbon, wt%	39.1	1.3	37.2	44.3
Hydrogen, wt%	5.2	0.6	4.0	6.3
Nitrogen, wt%	0.8	0.0	0.7	0.8
Oxygen, wt%	37.1	1.6	34.3	39.9
Sulfur, wt%	0.9	0.2	0.8	1.8
Ash, wt%	16.8	1.0	13.8	19.0
Volatiles, wt%	29.4	0.9	27.8	31.2
Fixed Carbon, wt%	25.6	0.9	24.0	28.6
Higher Heating Value, Btu/lb	6,616	181	6,338	7,157
Lower Heating Value, Btu/lb	6,138	196	5,863	6,719
CaO, wt % in Ash	14.1	0.8	12.0	16.4
SiO_2, wt % in Ash	39.5	1.7	35.6	44.4
Al_2O_3, wt % in Ash	21.0	0.6	20.0	22.1
MgO, wt % in Ash	3.0	0.3	2.5	3.5
Na_2O, wt % in Ash	0.3	0.3	0.0	0.7
SO_3, wt % in Ash	12.0	0.9	9.6	15.2
Ca/S, mole/mole	1.5	0.2	0.8	1.9

Notes:
1. All analyses are as-sampled at original coal feeder FD0210 or secondary coal feeder FD0200.
2. Hydrogen in coal is reported separately from hydrogen in moisture.

The gasifier performed well with the Mississippi lignite, achieving carbon conversions up to 98.9 percent and projected syngas lower heating values of 119 Btu/SCF at the turbine inlet. The PCD and other downstream supporting equipment operated reliably with no problems associated with lignite operation. However, there were significant operating problems with the coal feed system due to the high coal moisture content. Although there were numerous coal feeder trips, recovery from trips was rapid and prevented significant downtime. After completing all planned testing that was feasible, the system was shut down to prevent damage caused by a ruptured filter bag in the ash transport system.

During the test campaign, 40 steady state operating periods were identified. The operating periods and major operating parameters are shown in Appendix 1. The following report presents the operational data and preliminary results of gasification technology development at the PSDF during TC22, compiled in the sections listed below. Inspection results are also included.

- Coal feed systems — Discusses operations of both the original and the secondary coal feed systems and presents coal moisture values and particle sizes and their effect on coal feed performance.
- Transport Gasifier — Includes the major gasifier operating parameters and the gasifier performance as indicated by preliminary solids and gas analyses. Also includes the results of parametric testing, such as the effects of varying temperatures and air-to-coal ratios on gasifier performance.
- Sensor development — Discusses testing of various gasifier instrumentation improvements, as well as testing by outside researchers (Babcock & Wilcox and Sensor Research and Development) utilizing the PSDF facilities to support the development of sensors for future commercial applications.
- Particulate control device — Describes the hot gas filter particulate characteristics, performance, and failsafe and filter element testing.
- Advanced syngas cleanup — Details various testing to support emissions control studies, as well as testing of trace metals removal by TDA Research.
- Recycle Syngas System — Describes operations of the recycle syngas system used to provide gasifier aeration.

2.0 TECHNOLOGY DEVELOPMENT

2.1 Coal Feed Systems

The high moisture Mississippi lignite was the highest moisture coal fed to the PSDF Transport Gasifier to date. Although previous coal preparation system modifications enabled effective processing of subbituminous and other lignite coals tested at the PSDF, the coal preparation system was not capable of decreasing the moisture content in the Mississippi lignite to a sufficiently low content for reliable handling.

The as-received coal moisture value ranged from 40.0 to 45.2 weight percent, averaging 42.9 weight percent. Although a considerable amount of moisture was removed in coal preparation, the as-fed moisture content was consistently above 25 weight percent, and often above 30 weight percent. Figure 2 gives the as-fed coal moisture values.

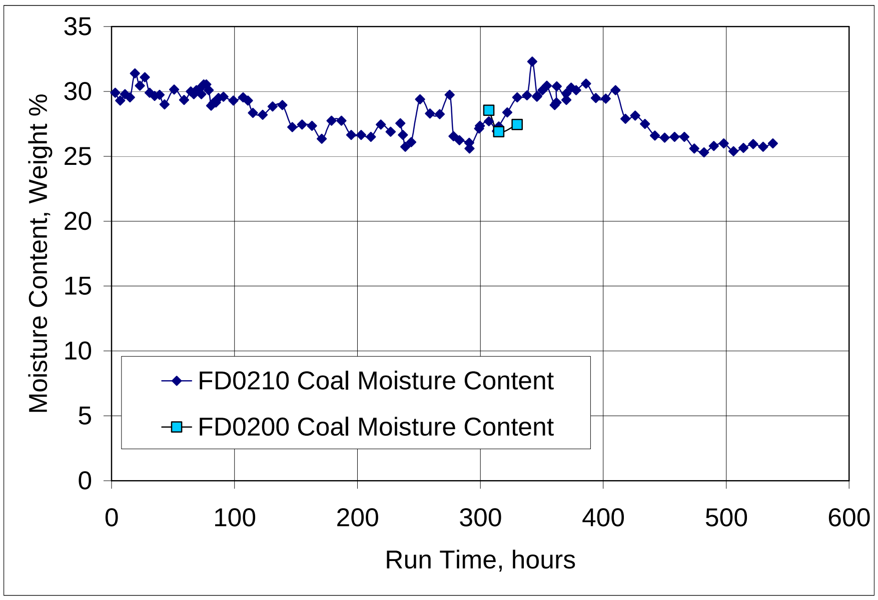

Figure 2. As-Fed Coal Moisture Content.

The original coal feeder, a Clyde lock hopper system, ran for a total of 540 hours at rates from 2,600 up to 5,200 lb/hr and particle sizes varying from 255 to 760 microns (mass median diameter). The feeder experienced numerous operating problems. Most of these problems were associated with the coal feeder discharge line plugging. Increasing the coal transport gas velocity improved feeder performance some and did not adversely affect gasifier operations. The feeder also experienced problems with lock vessel packing due to the presence of fines in the system. Operating parameters were adjusted in an effort to minimize the concentration of fines in the feed material. The fluidization of the lock vessel was increased during fill cycles to further improve feeder performance. Nitrogen was used as coal transport gas for the entire test campaign since the higher transport gas velocity requirement of the high moisture lignite was beyond the capability of the transport air system.

The secondary coal feeder ran for a total of 33 hours at feed rates up to 2,200 lb/hr. The feeder experienced discharge line plugging while transporting the high moisture lignite. The outlet piping from the secondary feeder comprises a flow path with higher resistance than that of the original feeder, and thus increasing transport gas velocity did not improve performance of this feeder.

Figure 3 gives the coal particle sizes in both mass median diameter (MMD) and Sauter mean diameter (SMD). The particle sizes for the original feeder, FD0210, and the secondary feeder, FD0200, are shown separately. The coal particle size MMD varied from 246 to 757 microns with an average MMD of 437 microns and standard deviation of 100 microns. The SMD only varied between 148 and 274 microns with an average particle size of 194 microns and a standard deviation of 23 microns. The SMD was nearly constant except for a few periods around hour 100 and between hours 346 and 374. The differences between the MMD and SMD were due to the large amounts of oversize material (greater than 1180 microns) in the feed samples. The oversize influences the MMD greater than the SMD since the SMD diameter is a particle surface area average which gives less influence to the larger particles.

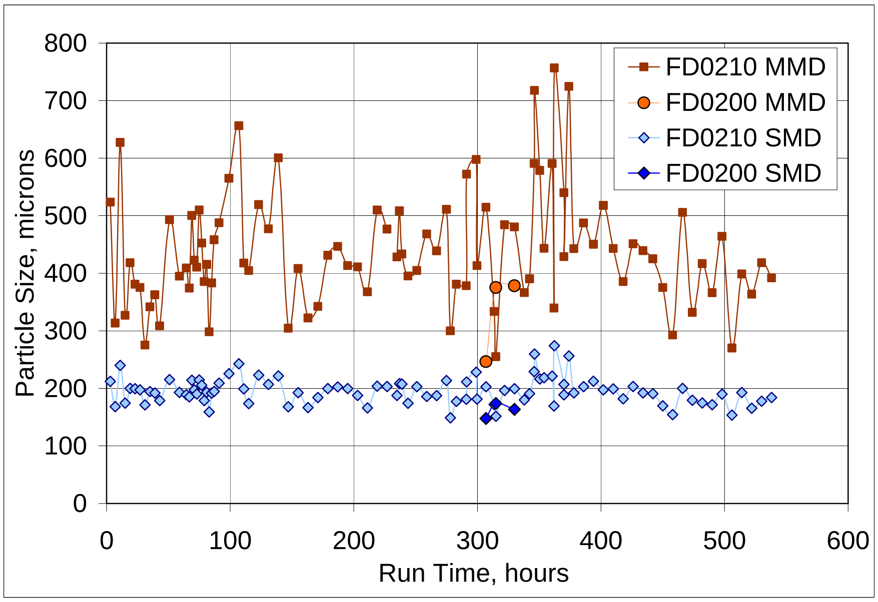

Figure 3. Coal Particle Sizes.

The percentage by weight of coal particles above 1,180 microns and the percentage by weight of coal particles below 45 microns are shown in Figure 4. The oversize particles above 1,180 microns were between 9 to 34 percent with an average of 19 percent. The coal fines less than 45 microns were between 6 and 16 percent with an average of 11 percent.

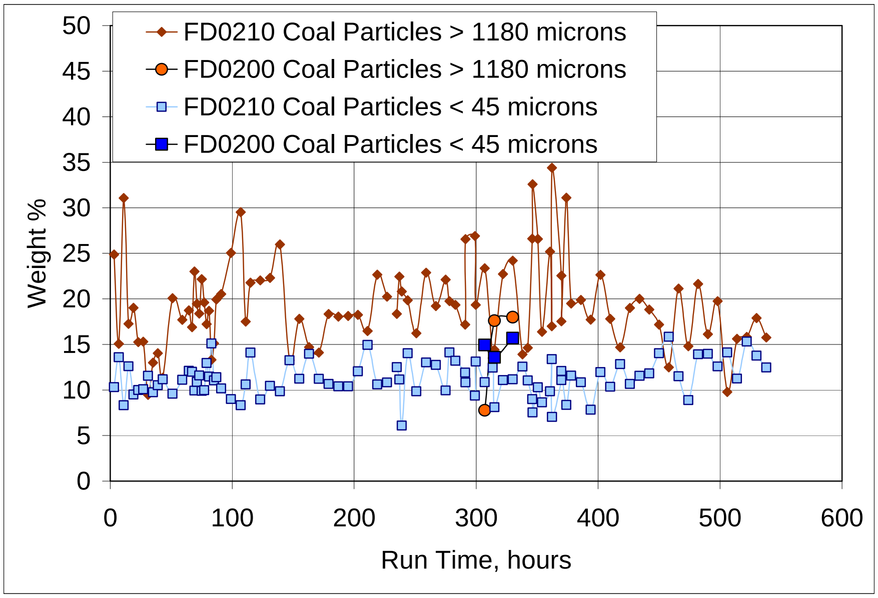

Figure 4. Percent Oversize and Fine Coal.

Based on TC22 operations, the coal feeding operating envelope for coal moisture content and particle size was developed. Figure 5 shows the range of moisture and particle sizes for acceptable feeder operation. The area of overlap indicates conditions at which the coal feeder may run acceptably for some time, but may trip if factors such as excessive fines or oversize coal exist.

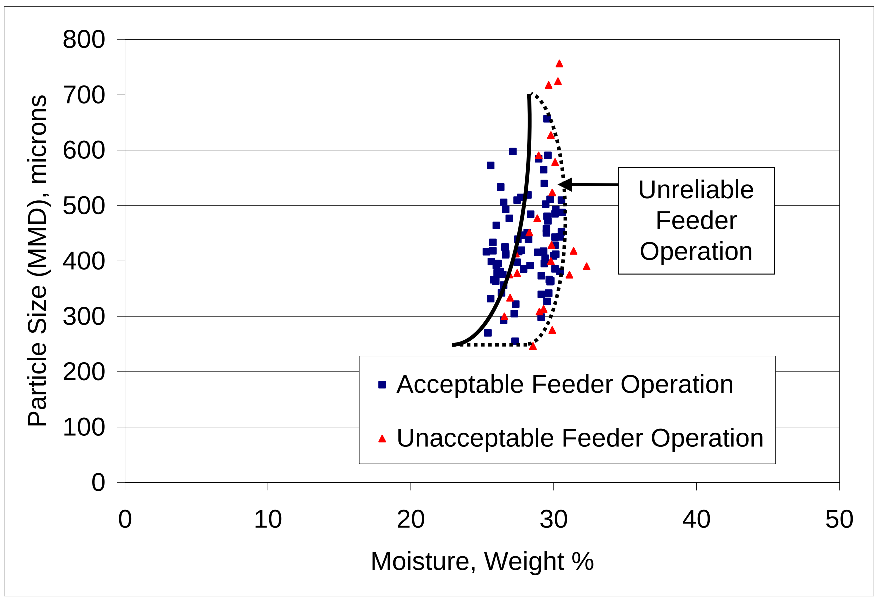

Figure 5. Coal Feeder Operating Envelope.

2.2 Transport Gasifier

2.2.1 Gasifier Operating Parameters

The average gasifier temperatures and pressures for each of the steady state periods are shown below in Figure 6. The gasifier outlet temperature varied between 1,540 and 1,660ºF, and the gasifier outlet pressure varied from 124 to 185 psig. Gasifier operating pressure was limited to 185 psig because of the high coal feed line pressure drop required to maintain coal feed with the Mississippi lignite.

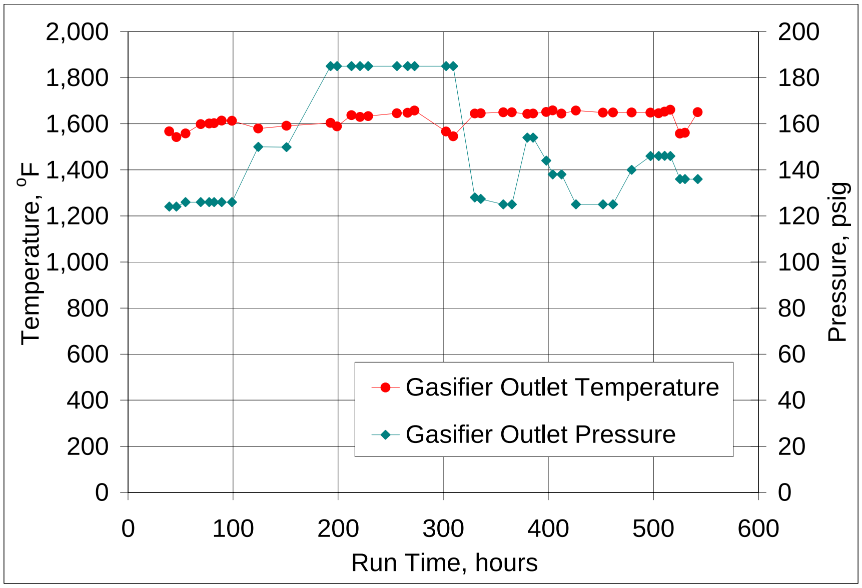

Figure 6. Gasifier Outlet Temperature and Pressure.

Figure 7 shows the air, nitrogen, coal, steam, and aeration recycle gas flow rates to the gasifier for the TC22 steady state periods. The air, nitrogen, and recycle gas flow rates shown were rates measured from flow indicators, and the coal feed rates were calculated from the feeder weigh cell output. The steam flow rates were derived from the system hydrogen balance, as the steam flow indicator was not reliable during the test campaign.

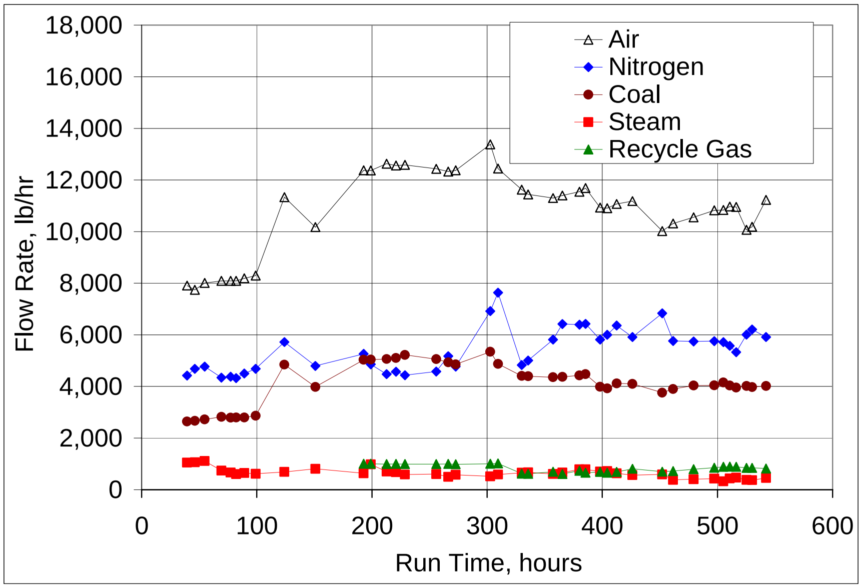

Figure 7. Air, Nitrogen, Coal, Steam, and Recycle Gas Flow Rates to Gasifier.

Figure 8 shows the standpipe levels (measured as differential pressures) and the riser differential pressures. The standpipe level was held constant at about 150 inH_2O for most of TC22, with one steady period at 85 inH_2O, three steady periods at around 65 inH_2O and three steady periods at around 160 inH_2O. The riser differential pressure tracked the standpipe level, and for most of TC22, the riser differential pressure was at 40 to 55 inH_2O with the lowest value at about 18 inH_2O.

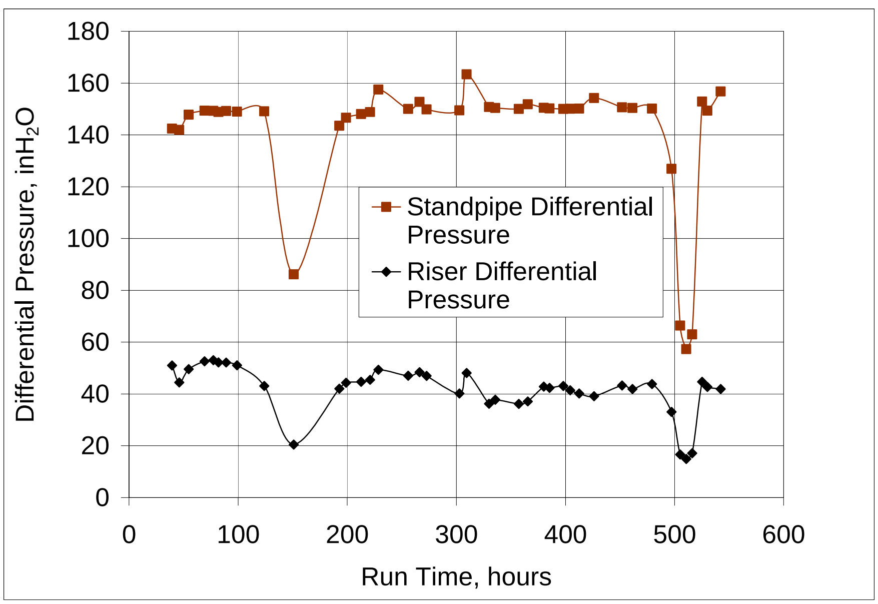

Figure 8. Gasifier Standpipe and Riser Differential Pressures.

2.2.2 Gasifier Performance, Solids Analysis

The average particle sizes (SMD) for the circulating solids sampled from the standpipe and for the seal leg solids are shown in Figure 9. The standpipe and seal leg particle sizes were all similar. They decreased from the startup solids particle size of 140 microns, and generally varied between 70 and 120 microns after about 50 hours.

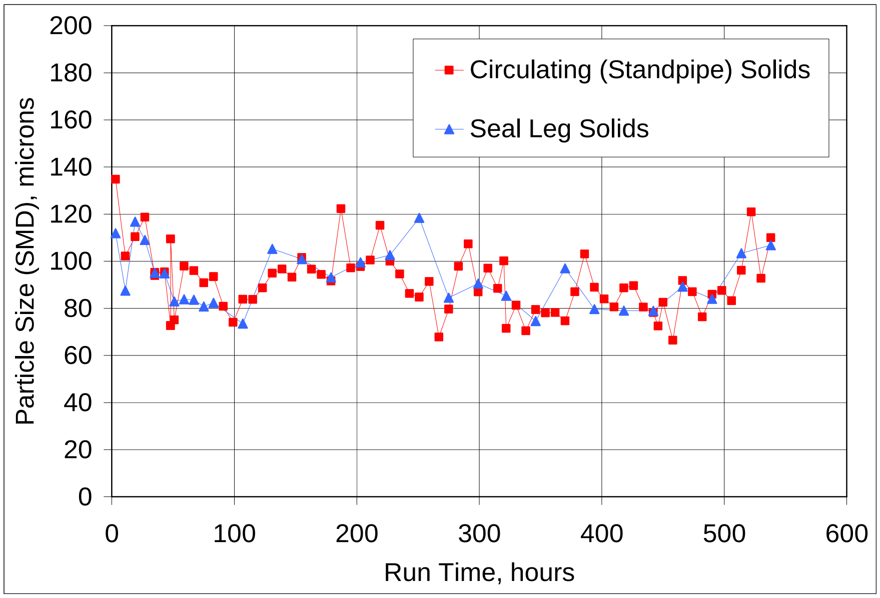

Figure 9. Gasifier Solids Particle Size.

Figure 10 gives carbon content for the coarse gasifier solids, which are sampled from the standpipe and seal leg. The maximum standpipe carbon was 3.5 weight percent, and the maximum carbon for the seal leg was 1.7 weight percent.

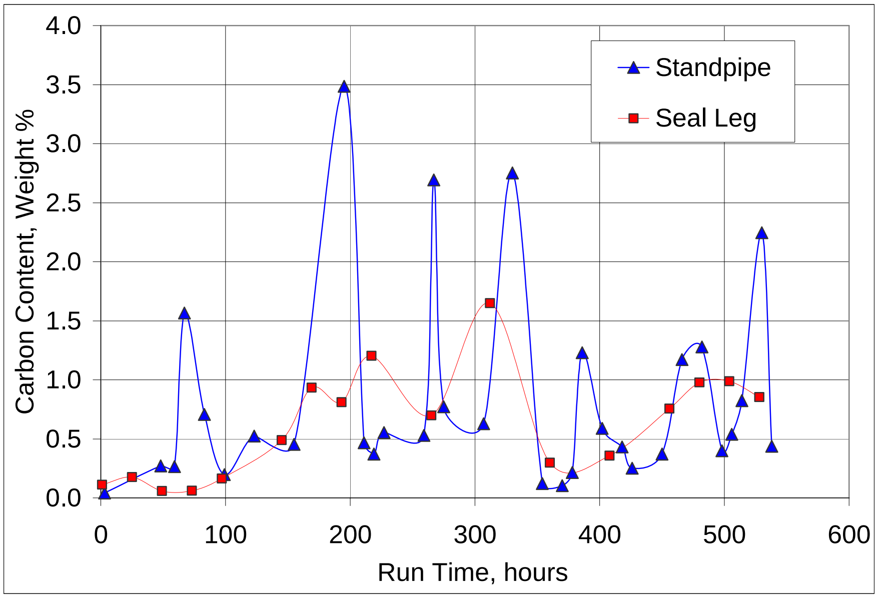

Figure 10. Gasifier Solids Carbon Content.

Figure 11 shows the solids rates for the gasification ash removed from the PCD by the Continuous Fine Ash Depressurization (CFAD) system and the coarse gasification ash removed from the gasifier standpipe by the Continuous Course Ash Depressurization (CCAD) system. The PCD solids rates are determined from the PCD inlet solids concentration, and the CCAD rates are determined by a system ash balance. The CFAD system discharged fines from the PCD at rates up to 730 lb/hr, cooling the solids from 600°F to under 200°F. The CCAD system withdrew hot ash from the gasifier at rates from 110 to 500 lb/hr at up to 1,750°F and cooled the ash to about 200°F. Between 10 and 53 percent of the solids were removed by the CCAD system.

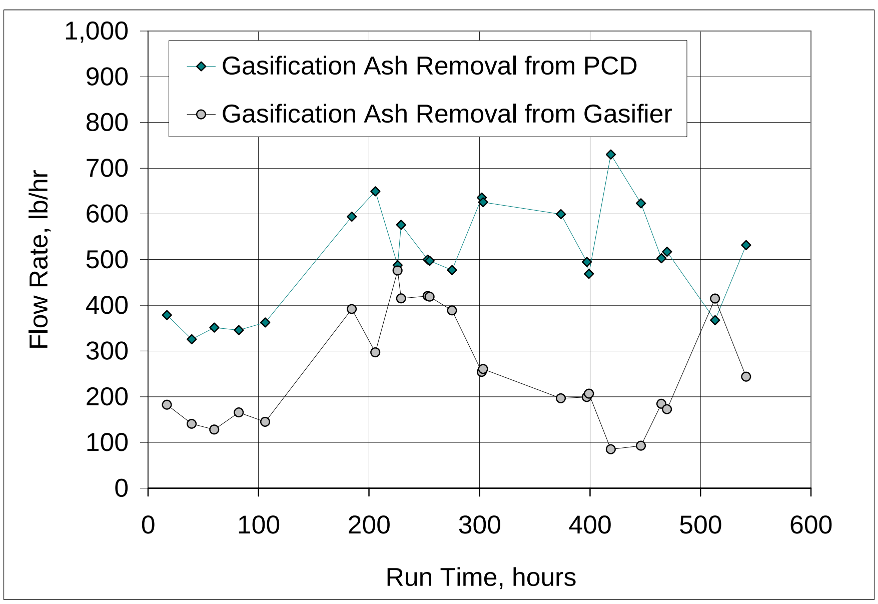

Figure 11. Gasification Ash Removal from PCD and Gasifier.

2.2.3 Gasifier Performance, Gas Analysis

Gasifier carbon conversion and dry syngas lower heating value (LHV) are shown in Figure 12. The carbon conversion was between 94.6 and 98.9 percent and averaged 97.2 percent. The dry LHV was between 39 and 66 Btu/SCF. The heating values obtained early in the test campaign were on the low end of the range and corresponded to lower coal feed rates.

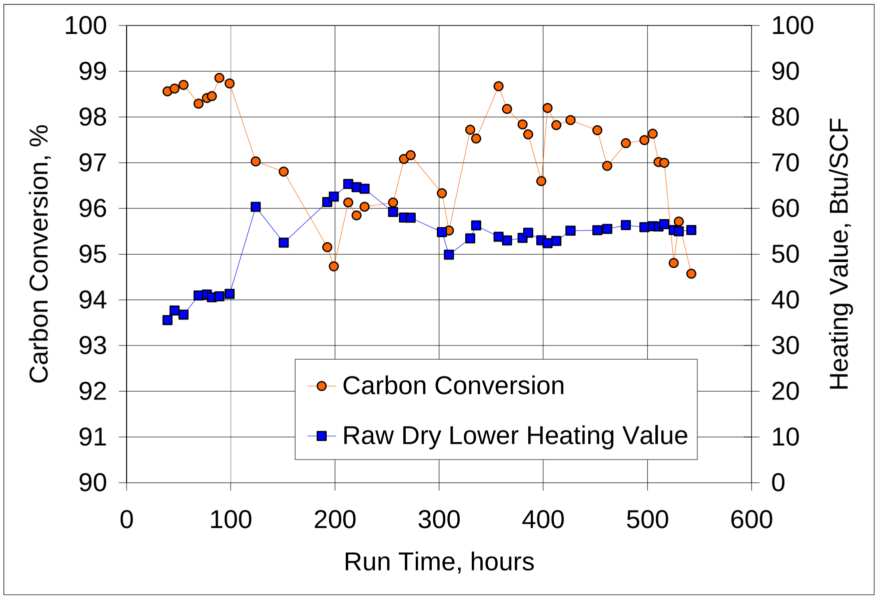

Figure 12. Carbon Conversion and Dry Syngas Lower Heating Value.

The sulfur species hydrogen sulfide (H_2S) and carbonyl sulfide (COS) concentrations (dry basis) during steady state periods are shown in Figure 13 below. The H_2S concentrations without dolomite addition were between 1,100 and 1,700 ppm and averaged 1,375 ppm. The H_2S concentrations with dolomite were between 760 and 800 ppm and averaged 780 ppm. The COS concentrations without dolomite addition were between 17 and 82 ppm and averaged 40 ppm.

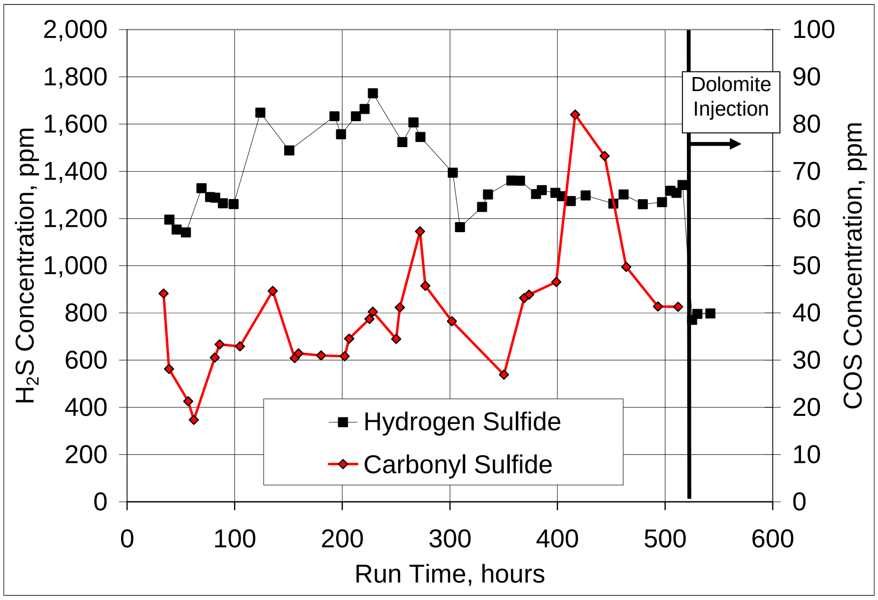

Figure 13. Syngas Hydrogen Sulfide and Carbonyl Sulfide Concentrations.

Figure 14 shows the syngas ammonia concentration (dry basis) and the percent conversion of coal nitrogen to ammonia. The ammonia concentrations varied between 960 and 1,950 ppm. The ammonia concentrations indicate that the fuel nitrogen converted to ammonia varied between 30 and 75 percent and averaged 47 percent.

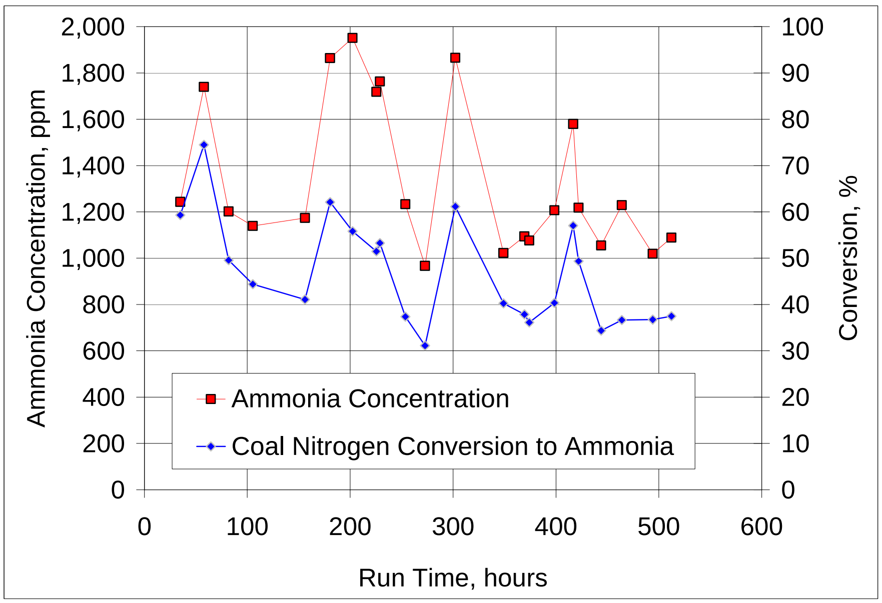

Figure 14. Syngas Ammonia and Conversion of Coal Nitrogen to Ammonia.

Figure 15 shows the syngas hydrogen cyanide and hydrogen chloride concentrations, reported on a dry basis. The hydrogen cyanide concentrations varied between about 4 and 13 ppm. The hydrogen chloride concentrations varied from below detection limits up to 4 ppm. Data indicate that over 50 percent of hydrogen chloride in the coal was retained in the gasification ash.

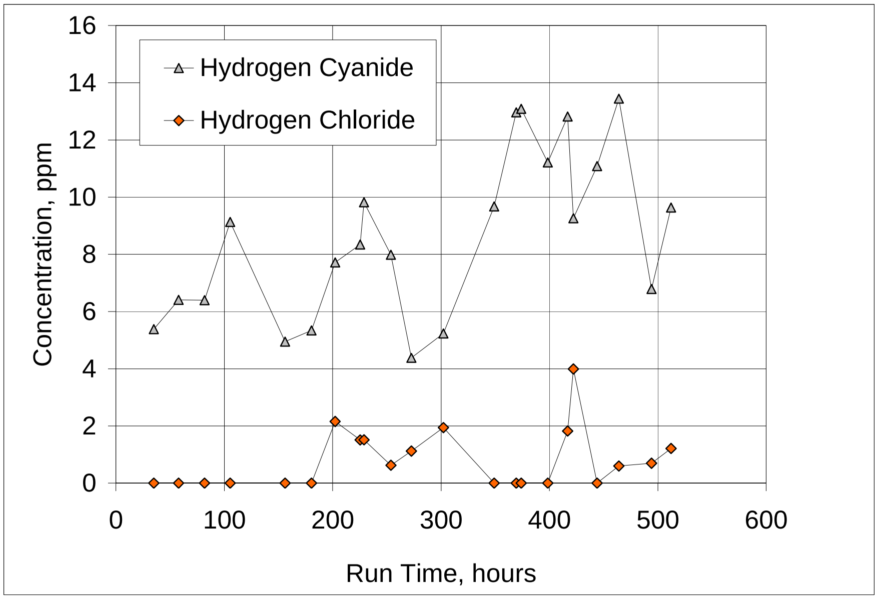

Figure 15. Syngas Hydrogen Cyanide and Hydrogen Chloride Concentrations.

Figure 16 plots the syngas water concentrations determined by in situ measurements at the PCD outlet and by the FTIR (Fourier Transform Infrared) gas analyzer. During the middle of TC22 (hours 82 to 399), there was very good agreement between the measurements.

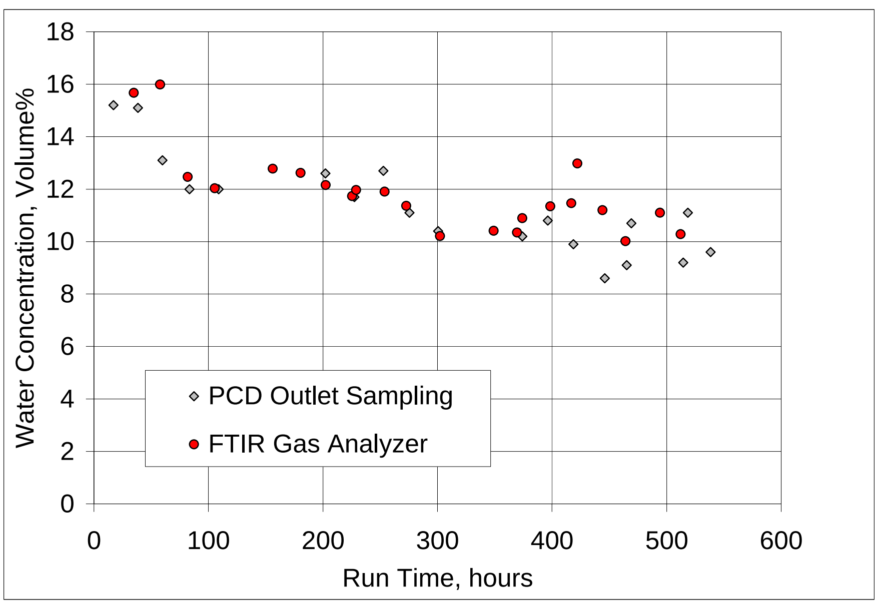

Figure 16. Syngas Water Concentrations.

2.2.4 Gasifier Performance, Parametric Testing

A number of tests were performed to evaluate operations with Mississippi lignite. Some planned tests, such as operation without steam to the gasifier shroud and coal transport with air, were not completed due to operating constraints caused by the coal feed system problems. The parametric testing completed included the following:

- Temperature, air-to-coal ratio, pressure/riser velocity, air distribution, fluidization flow, and coal feed rate effects on gasifier performance.
- Effect of dolomite sorbent addition on syngas sulfur capture efficiency.
- Standpipe level effect on gasifier circulation rate.

Partial analyses of these parametric tests are presented below. Further analysis is ongoing, and results will be included in the final TC22 topical report. To obtain meaningful analyses, data were analyzed using selected steady state periods which held other variables nearly constant to focus on the variable of interest.

Figure 17 gives the effect of temperature on carbon conversion at a fixed gasifier pressure of 185 psig, air-to-coal mass ratios between 2.4 and 2.55, and coal feed rates ranging from 4,850 to 5,200 lb/hr. As expected, the data shows a strong linear correlation between carbon conversion and temperature.

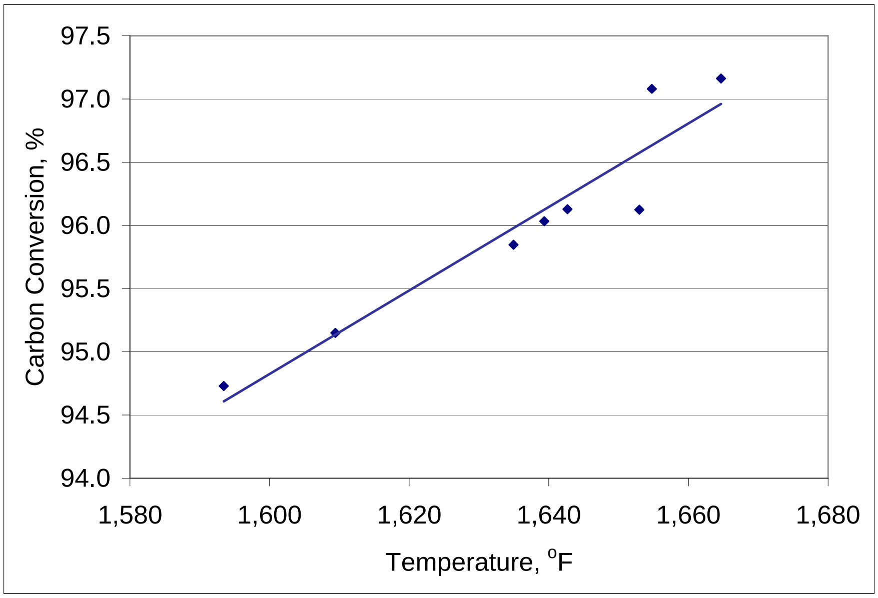

Figure 17. Carbon Conversion as a Function of Temperature.

Gasifier pressure (which directly controls riser velocity) was varied to quantify its effects on gasifier performance. Figure 18 below shows the effect of pressure on the syngas methane content, represented by a relative value, the methane factor. During the steady state periods from which the data was extracted, the air-to-coal mass ratios were maintained at about 2.5 to 2.7, the gasifier temperature ranged from 1,650 to 1,670°F, and carbon conversions were between 97 and

98 percent. A linear relationship correlating to an increase in methane content with increasing pressure is indicated, although some scatter exists in the data. The relationship between riser velocity and gasifier solids separation efficiency was also examined, although no clear correlation was seen for the operating conditions during TC22.

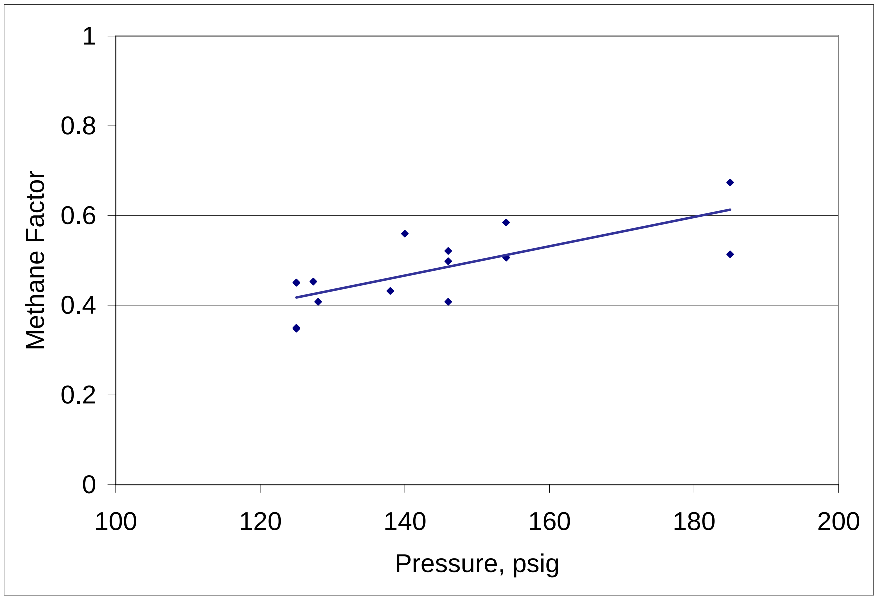

Figure 18. Methane Content as a Function of Gasifier Pressure.

Another area of parametric testing was the effect of air distribution on gasifier performance. Part of this testing including varying the air flow rate to the lower mixing zone (LMZ). Figure 19 shows the effect of LMZ air flow rate on the gasifier temperature profile. For this analysis, data was taken when the standpipe level was maintained at 150 inH_2O and the coal feed rate was constant at 4,000 lb/hr. The y-axis in the chart below represents the difference between the maximum gasifier temperature (normally in the upper mixing zone section) and the LMZ temperature. As the air flow to the LMZ increases, the carbon content in the LMZ decreases. The temperature decreases, thus causing a larger temperature differential.

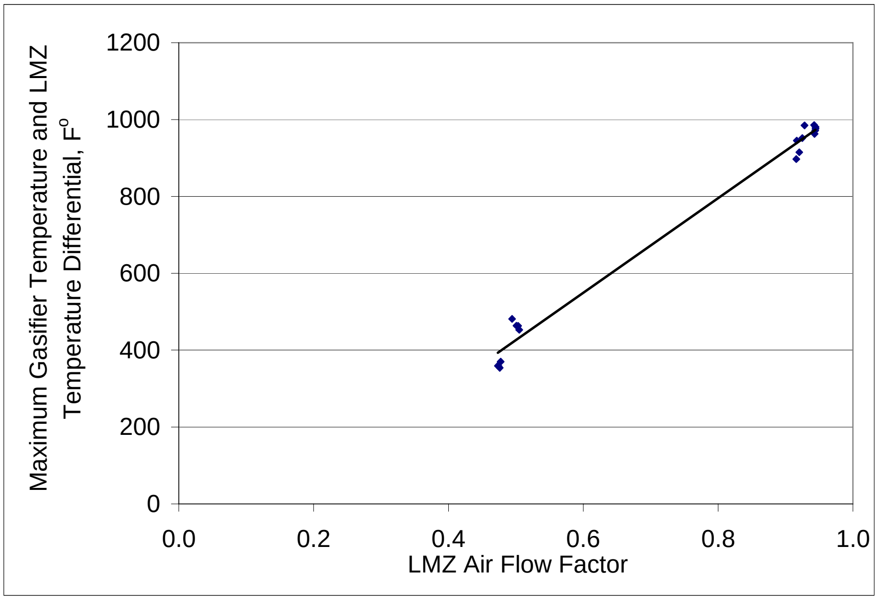

Figure 19. Gasifier Temperature Differential as a Function of LMZ Air Flow Rate.

Figure 20 below shows the raw dry syngas heating value as a function of coal feed rate for two different temperature ranges. This plot included the steady state data taken when the air-to-coal mass ratio was between 2.3 and 3.0. As shown in the figure, a positive correlation exists between the syngas heating value and coal feed rate.

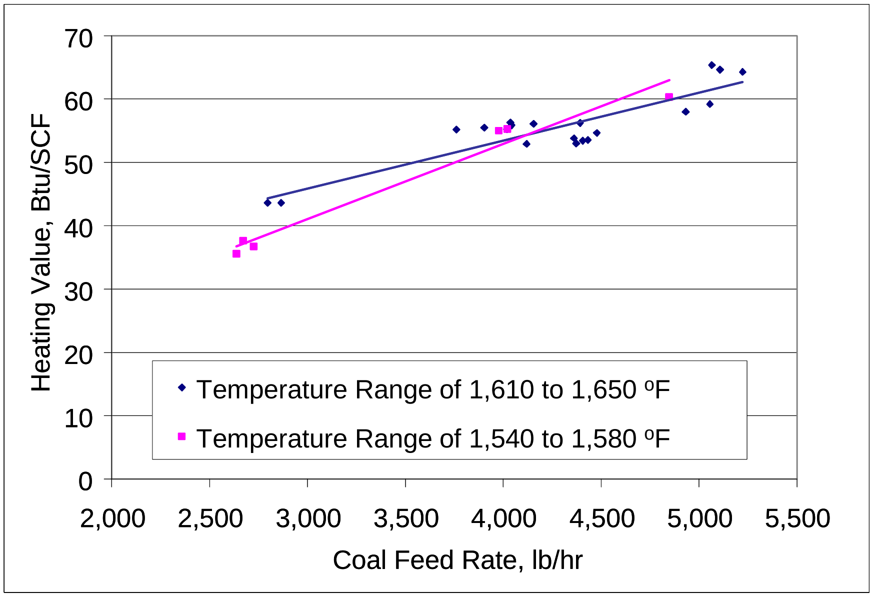

Figure 20. Dry Syngas Heating Value as a Function of Coal Feed Rate.

Dolomite sorbent was fed to the gasifier near the end of the test campaign to assess the sulfur capture. Figure 21 shows the sulfur (in the form of H_2S and COS) removal as a function of calcium-to-sulfur molar ratio (Ca/S) in the feed. Calcium from the coal ash was included. The data used for this figure was taken from steady state periods with mixing zone temperatures between 1620 and 1763°F, recycle gas in use for gasifier aeration, and the coal feed rate within a 250 lb/hr range. Without dolomite feed, at Ca/S values of about 1.5, an average of 13.2 percent sulfur removal was realized, presumably the result of sulfur reaction with the coal ash calcium. At higher Ca/S values reached with dolomite feed, the average sulfur removal was 30.9, with up to 35.3 percent removal achieved at the highest dolomite feed rate.

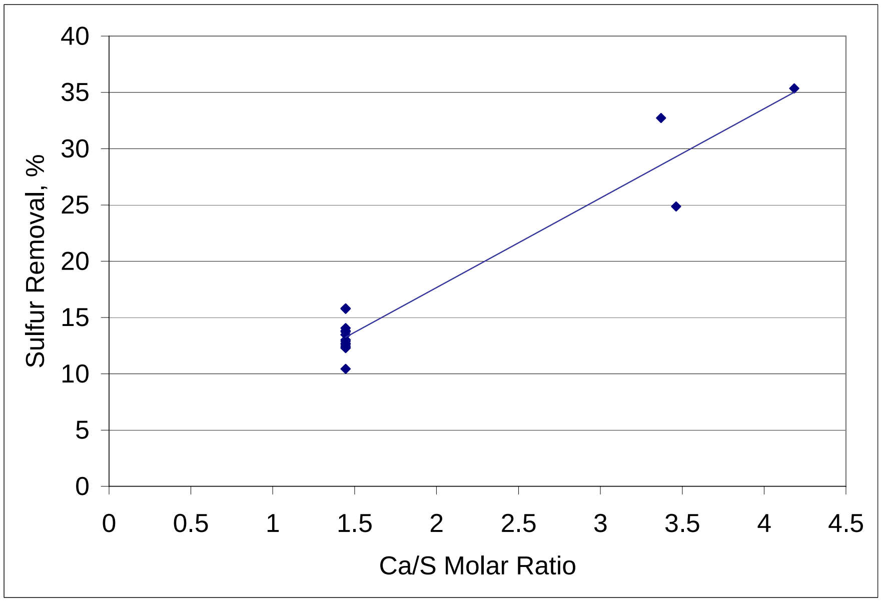

Figure 21. Sulfur Removal as a Function of Calcium-to-Sulfur Molar Ratio.

Figure 22 shows the relative solids circulation rate as a function of gasifier standpipe level. Since most of the steady state data for TC22 was at a constant standpipe level of 150 inH_2O, data at other periods when relatively stable conditions existed for short durations were used. Circulation rates were evaluated at 15 minute intervals at varying standpipe levels. The relationship indicated by the data is strongly linear.

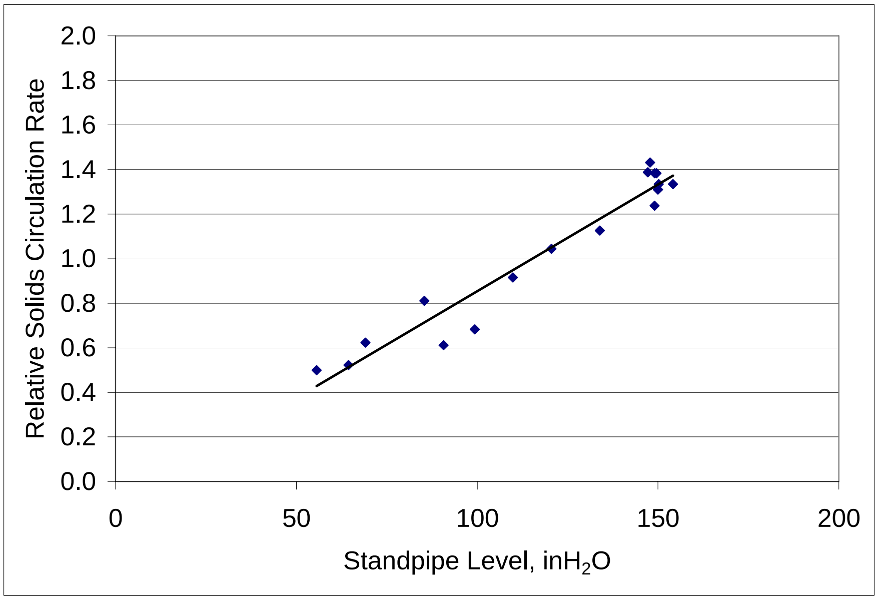

Figure 22. Effect of Standpipe Level on Circulation Rate.

2.2.5 Gasifier Inspections

Following shutdown, inspections of the system were performed. The gasifier refractory was in good condition. Due to blockage of purge flow by damaged ceramic thermowell material, ash deposition had occurred in the lower mixing zone. All other sections of the gasifier were clear upon inspection.

The primary syngas cooler was also inspected. As shown in Figure 23 below, the heat exchange tubes were free of deposition and fouling. The ceramic ferrules showed no signs of wear.

Figure 23. Primary Syngas Cooler Inlet Tubesheet.

2.3 Sensor Development

Sensor development continued in TC22 with material testing to improve instrument performance and longevity. The PSDF also provided a platform for outside researchers to test sensors for future applications.

2.3.1 Ceramic-Tipped Pressure Differential Measurements

To reduce instrument purge flow requirements and reduce plugging problems, ceramic inserts were installed on several gasifier pressure differential indicators (PDIs). These porous ceramic inserts prevent solids flow into the instrument, and thereby reduce the amount of required purge flow by over 50 percent. Testing of the inserts began in 2005 with installations in the riser and the solids collection device, and testing continued through TC22.

Figure 24 is a comparison of a ceramic-tipped measurement to a standard measurement without inserts during two days shortly after calibration. The measurements corresponded with an offset of the ceramic-insert PDI reading slightly lower than the standard PDI. The ceramic-tipped PDI measurement fluctuated widely further into the test campaign compared to the standard measurement, possibly the result of purge flow interruptions corresponding to coal feeder trips. The ceramic-tipped measurements often followed the standard measurements, but disagreed after significant pressure swings. One reason for the inconsistency of data may be poor flow control on existing ceramic-tipped instrument purge flow meters, since the meters are operating at the low end of their ranges. Following TC22, these purge flow meters will be replaced with meters having a lower flow operating range.

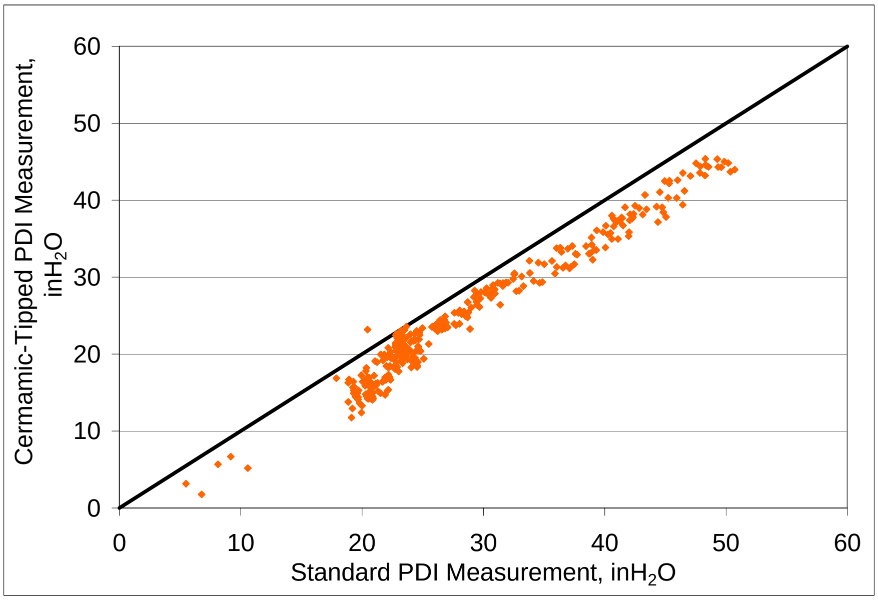

Figure 24. Comparison of Standard and Ceramic-Tipped PDI Measurements.

2.3.2 Thermowell Materials

To improve instrument longevity, testing of various thermowell materials was continued. Thermowell performance was good, with no failures during TC22. (Material from a ceramic thermowell had been damaged during the outage prior to TC22, and had fallen into the LMZ, causing ash deposition in that area during operation.) The HR-160 material continued to demonstrate good performance and ability to operate in the presence of high solids circulation. Following TC22, the gasifier thermowells were inspected and were found to be in good condition. Figure 25 shows the condition of thermowells in the LMZ, which was typical of the thermowell conditions seen throughout the gasifier. The use of HR-160 material will be expanded based on the improved thermowell durability and thermocouple longevity.

Figure 25. HR-160 Thermowells in Lower Mixing Zone.

2.3.3 Semi-Conducting Metal Oxide Analyzer Testing

Sensor Research and Development (SRD) Corporation is developing, with Department of Energy (DOE) funding, a prototype sensor system for in situ real time detection, identification, and measurement of coal combustion gases. The PSDF provided the testing site for the prototype in support of the DOE sensor program. The sensor system incorporates SRD's semi-conducting metal oxide (SMO) sensors and novel gas pre-filtration techniques. SRD has previously shown optimization of the gas delivery, sensor chamber, and data acquisition and control system for the testing of simulated flue gas.

SRD performed field testing on its chemical analyzer prototype at the PSDF during TC22, with the analyzer installed on the outlet of the atmospheric syngas combustor. The purpose of the test was to optimize the gas sampling times; to evaluate the accuracy of the hit-detection and classification algorithms used by SRD's prototype; and to determine the accuracy of concentration estimates made by SRD.

Performance criteria for the SRD chemical analyzer included a false positive rate, consisting of incorrect classification and false alarm due to noise, and a false negative rate. The SRD analyzer performed with 97 percent accuracy in detecting and classifying post-combustion gas constituents with a zero percent false negative rate. The false positives were entirely due to misclassification. In addition to evaluation of the classification and hit-detection algorithms, SRD had also developed algorithms to estimate the concentration of gases in the stream. SRD found that the concentration estimates were dependent on the magnitude of the training database used in classification and concentration estimates. For about 94 percent of tests, the estimates of the flue gas constituent concentrations were close to the concentrations measured by the PSDF on-line gas analyzers.

SRD will focus future efforts on augmenting the training database to increase the accuracy of the concentration estimator. In order to achieve this, SRD will collect data over longer periods of time and under differing operating conditions. Testing the sensor on syngas at the PSDF may proceed if initial development is successful.

2.3.4 High Speed Pressure Sensors

The Electric Power Research Institute (EPRI) has funded the development of advanced nonlinear signal analysis techniques and their application to coal combustion. Under sponsorship of EPRI, Oak Ridge National Laboratory (ORNL) and Babcock &Wilcox (B&W) have developed the Flame Doctor® diagnostic system for assessing combustion stability. ORNL has continued to apply these techniques for monitoring and controlling fluidized bed chemical reactors for industry and DOE. In all of these applications, it has been demonstrated that strong correlations exist between fluctuations in bed differential pressure signals and acoustic signals and the onset of undesirable bed conditions such as de-fluidization, slugging, and agglomeration.

EPRI funded ORNL and B&W to apply these advanced nonlinear techniques to develop a suite of diagnostic tools for monitoring gasifier performance. As none of the previous work was conducted in a gasification environment, a feasibility study was needed to confirm that these techniques could be extended to gasifiers. During TC22, B&W and ORNL personnel collected high speed pressure fluctuation data on the Transport Gasifier for the purpose of confirming that changes in pressure fluctuations could be correlated to changes in gasifier operating conditions. During this feasibility test, high speed Kistler piezotron pressure sensors were mounted on existing sensing lines at three locations on the gasifier: at the lower standpipe and above and below the coal feed nozzle. Changes in operating conditions were detected by the pressure sensors. These results confirm that a larger test is justified to collect more information with the goal of developing nonlinear techniques for predicting gasifier performance. A final report from B&W is available.

2.4 Particulate Collection Device (PCD)

2.4.1 PCD Performance

The PCD functioned reliably with a particle mass loading approximately 2.75 times higher with the Mississippi lignite than with Powder River Basin (PRB) coal tested in TC20. The higher solids carryover was expected due to the higher ash content of the Mississippi lignite. Table 2 shows results of the PCD inlet and outlet in situ sampling, which includes particle loading and characteristics. The PCD inlet average particle size with Mississippi lignite was 11.2 microns (MMD), indicating that the gasifier solids separation unit was operating as expected.

Table 2. PCD Inlet and Outlet In Situ Sampling Results.

PCD Inlet							PCD Outlet		
Test Date	Run No.	Particle Loading, ppmw	Particle Loading, lb/hr	Sample LOI,* %	Sample MMD, microns	PCD Drag**	Run No.	H_2O Vapor, vol %	Particle Loading, ppmw
3/25/07	1	21800	378	3.9	13.7	14.1	1	15.2	0.27
3/26/07	2	20000	325	1.9	12.2	19.8	2	15.1	0.59(1)
3/27/07	3	23000	352	7.1	11.0	21.5	3	13.1	0.33(1)
3/28/07	4	21800	345	3.8	12.5	19.0	4	12.0	<0.10
3/29/07	5	22400	360	4.0	14.5	15.1	5	12.0	0.16
4/01/07	6	24100	594	14.2	10.8	38.7	--	--	--
4/02/07	7	27200	643	16.4	10.1	42.4	6	12.6	<0.10
4/03/07	8	20800	487	10.8	12.5	39.9	7	11.7	<0.10
4/03/07	9	24500	577	13.9	8.9	38.3	--	--	--
4/04/07	10	21700	499	6.6	11.0	28.2	8	12.7	0.10
4/04/07	11	21500	496	7.5	10.9	27.6	--	--	--
4/05/07	12	20800	477	5.3	11.6	22.1	9	11.1	0.16
4/06/07	13	23600	636	13.3	10.3	28.8	10	10.4	0.16
4/06/07	14	23400	624	13.9	12.6	40.3	--	--	--
4/10/07	15	27100	600	6.4	11.6	25.7	11	10.2	0.21
4/11/07	16	24500	495	3.3	11.1	19.9	12	10.8	0.18
4/11/07	17	22900	468	2.9	11.6	20.2	--	--	--
4/12/07	18	34300	729	5.7	10.8	22.9	13	9.9	0.10
4/13/07	19	31200	623	6.0	10.7	28.0	14	8.6	0.11
4/14/07	20	25400	503	8.3	9.3	30.9	15	9.1	0.10
4/14/07	21	24500	517	5.9	9.4	20.5	16	10.7	< 0.10
4/16/07	22	17000	367	8.6	9.6	30.1	17	9.2	< 0.10
4/16/07	--	--	--	--	--	--	18	11.1	< 0.10(2)
4/17/07	23	24900	532	4.0	11.7	24.1	19	9.6	< 0.10(2)

Notes: 1. Some fraction of this mass appeared to be condensed organic matter.
2. Failsafe test on reverse media dynalloy fuse.
*Loss on Ignition, indication of carbon content
**Calculated transient drag at PCD conditions in units of inH_2O/(ft/min)/(lb/ft^2)

The PCD solids loss on ignition (approximately equal to carbon content) was low, ranging from about 2 to 16 weight percent for lignite versus 12 to 45 percent for PRB. The normalized PCD dust cake drag with the lignite gasification ash was lower than measured for PRB during TC20, consistent with lower carbon content in the lignite ash. Previous results have shown that drag is strongly affected by carbon content of the ash. Combined with the higher particle loading, the net effect would be a PCD transient pressure drop (differential pressure rise during filtering) about 1.6 times higher with the lignite.

As in previous tests, the PCD outlet particle loading was slightly elevated initially, with the highest level sampled at about 0.6 ppmw. After several days of filter element seasoning, the outlet loading was near 0.1 ppmw but still slightly higher than in previous tests with all iron aluminide elements. The slight increase in outlet loading was not surprising in view of the increased number of installed HR-160 sintered metal fiber elements, which have lower collection efficiency than do the iron aluminide sintered metal powder elements.

Figure 26 below shows the PCD normalized baseline pressure drop (i.e., the pressure drop following a backpulse cycle, normalized for a constant temperature and face velocity) for the test campaigns performed since the recent gasifier modifications were completed. Although changing system conditions (system pressure, coal feed rate, etc.) caused fluctuations in the baseline pressure drop, it has remained relatively stable in these recent test campaigns and not shown dramatic increases with time. The baseline pressure drop was slightly higher during TC22 than during recent test campaigns, which is consistent with the higher solids loading.

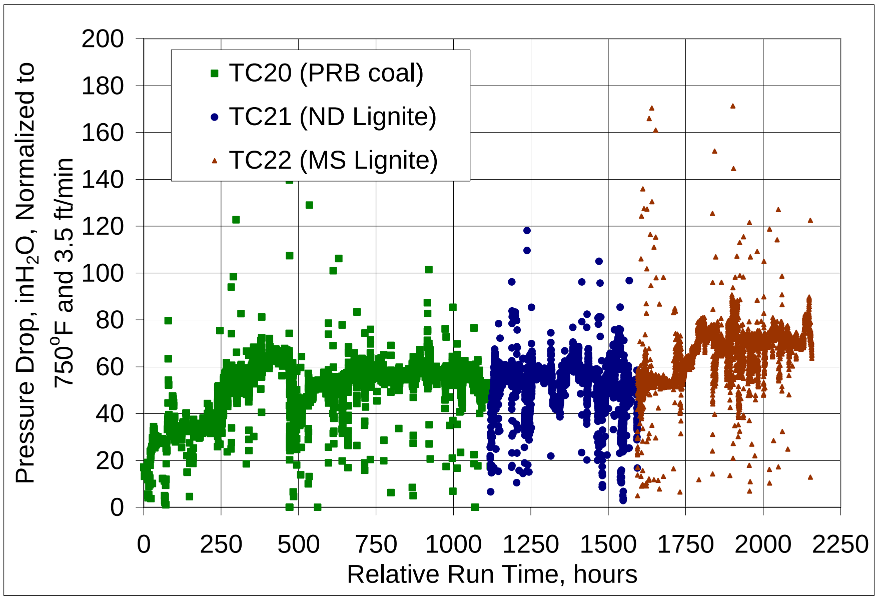

Figure 26. PCD Normalized Baseline Pressure Drop.

Near the end of the test campaign, an on-line failsafe test was conducted on a Pall HR-160 reversed-media failsafe, which showed very positive results. The reversed-media configuration was designed to cause the failsafe to plug up rapidly in high particle loading situations, thus limiting solids penetration in the event of upstream filter element failure. The test was conducted with the valve-activated failsafe tester, which opens a one inch hole to allow unfiltered syngas to flow to the failsafe. In situ samples at the PCD outlet did not indicate any measurable increase in particle concentration during the test.

2.4.2 PCD Inspections

At the conclusion of TC22, the PCD was shut down dirty (i.e., the filter elements were not backpulsed clean during the last few minutes of coal feed), preserving the transient dustcake. Measurements of the remaining dustcake indicated thicknesses of about 0.1 inches, about the same as past observations. Bulk dustcake samples were taken for analysis of chemical and physical properties.

Eight filter elements that were removed after TC22 were inspected with an optical microscope to evaluate their general condition and to monitor corrosion. The selected elements included six iron aluminide sintered metal powder elements with syngas exposures ranging from 1,801 to 9,478 hours and two HR-160 sintered metal fiber elements with exposures of 2,217 and 2,526 hours. As seen in the past, the iron aluminide elements exhibited a progressive corrosion characterized by reddish brown and black discoloration. The inspection did not reveal any evidence that the corrosion or loss of material was worse in the heat affected zones near the welds. The holes that were noted previously in the HR-160 elements did not appear to be any larger or any more numerous than seen in previous inspections. The holes did not appear to be related to any type of corrosion.

2.5 Advanced Syngas Cleanup

During TC22, COS hydrolysis, syngas cooler fouling, and trace metals removal testing continued in the syngas cleanup system. As shown in Figure 27, the COS hydrolysis testing resulted in COS conversion efficiencies ranging from 82.1 to 96.2 percent, with an average value of 88.8 percent. The catalyst used for this testing was an Alcoa F200 catalyst, which was tested previously in TC21. Syngas cooler operation resulted in no exchanger tube fouling from organics.

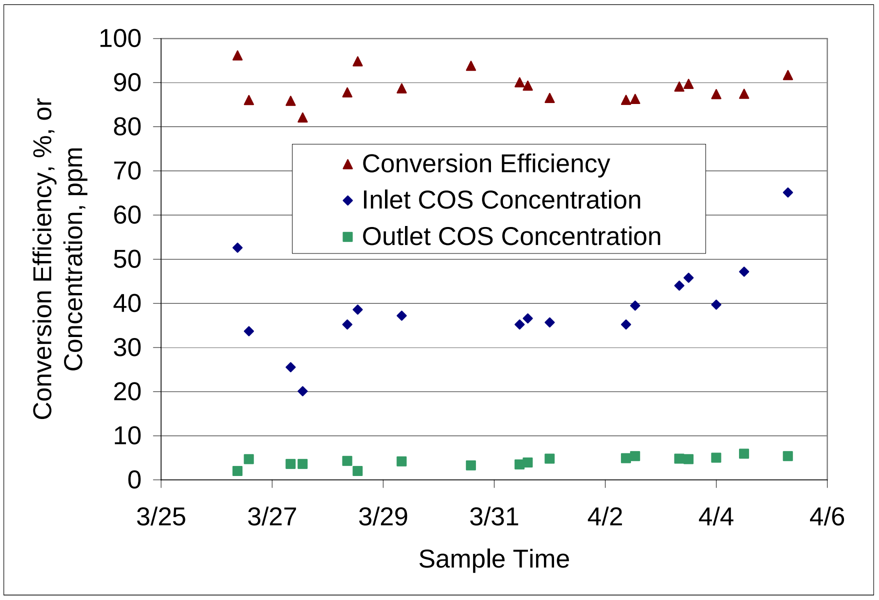

Figure 27. COS Conversion in Syngas Cleanup Unit.

Continuing development of a DOE sponsored project for sorbent based high temperature removal of trace metals from coal-derived syngas, TDA Research performed testing at the PSDF syngas cleanup skid. The sorbent based process is designed to remove trace metals, including mercury, arsenic, selenium, and cadmium. High temperature removal is potentially beneficial for future gasification power systems because of improved overall efficiency compared to cold gas cleanup systems. This process also has the benefit of reduced amounts of sorbent compared to currently available metals removal technologies.

Initial testing by TDA Research began in late 2006, and continued throughout TC22. Post reaction analysis has indicated that the sorbent may achieve high mercury removal efficiency. Further analysis is underway to determine the removal efficiencies of arsenic, selenium, cadmium, and other trace metals.

Sulfur sorbents from Sud Chemie were used to reduce sulfur in the syngas supplied to TDA Research. Syngas sulfur levels were reduced below the detection limit, typically 1 ppm.

2.6 Recycle Syngas System

The recycle syngas system supplied syngas for gasifier aeration for over 256 hours. The system ran well and experienced no major problems. Operating conditions at the recycle gas compressor outlet are shown in Figure 28 below. Recycle syngas was used as aeration intermittently beginning near hour 200 of the test campaign. Because feeding lignite to the gasifier required a higher feeder to gasifier differential pressure and therefore a lower than usual gasifier operating pressure, aeration flow requirements for Mississippi lignite operation were lower than typically seen with PRB. When recycled syngas was used to replace nitrogen aeration, the raw syngas lower heating value increased up to 5 percent, slightly less than that seen previously with PRB operation.

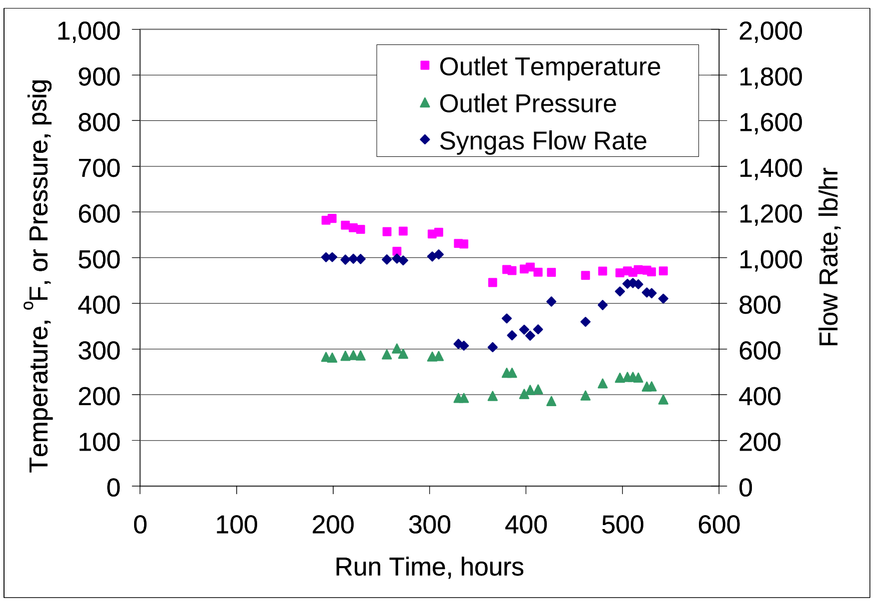

Figure 28. Recycle Syngas Compressor Operating Conditions.

3.0 CONCLUSIONS

Test campaign TC22 resulted in successful gasification operation, with high carbon conversions and syngas heating values adequate for gas turbine operation. Although coal feeding was problematic, the coal feeder operating envelope with this lignite was established to improve future operations. Preliminary results of parametric testing showed effects of temperature, pressure, air distribution, coal feed rates, and standpipe level on gasifier operations. Sulfur capture with dolomite sorbent was also demonstrated at different sorbent feed rates. Additional testing was continued with sensor development, PCD operations, advanced syngas cleanup, and supporting equipment. Final results of TC22 testing will be presented in the Gasification Test Campaign TC22 Topical Report.

APPENDIX 1

STEADY STATE OPERATING PERIODS

Table A-1 Steady State Operating Periods and Major Operating Parameters

Operating Period	Run Time hours	Gasifier Outlet Temperature °F	Gasifier Outlet Pressure psig	Coal Feed Rate lb/hr	Air Rate lb/hr	Recycle Syngas Rate lb/hr	Steam Rate lb/hr	Dolomite Feed Rate lb/hr	Nitrogen Rate lb/hr	Syngas Rate lb/hr	Standpipe Solids Removal Rate lb/hr	PCD Solids Rate lb/hr
TC22-1	39	1,567	124	2,638	7,908	0	1,209	0	4,421	16,509	146	328
TC22-2	46	1,542	124	2,671	7,742	0	1,325	0	4,682	16,500	131	333
TC22-3	55	1,558	126	2,725	8,009	0	1,321	0	4,771	16,971	121	345
TC22-4	69	1,599	126	2,823	8,090	0	644	0	4,343	16,183	149	349
TC22-5	77	1,601	126	2,793	8,088	0	747	0	4,375	16,112	129	347
TC22-6	82	1,602	126	2,796	8,089	0	687	0	4,321	16,043	165	346
TC22-7	89	1,614	126	2,797	8,190	0	681	0	4,498	16,334	147	350
TC22-8	99	1,613	126	2,866	8,295	0	699	0	4,680	16,649	140	357
TC22-9	124	1,580	150	4,848	11,336	0	870	0	5,721	21,642	244	587
TC22-10	151	1,591	150	3,987	10,173	0	975	0	4,792	19,931	251	489
TC22-11	193	1,604	185	5,037	12,374	1,002	942	0	5,263	24,921	411	608
TC22-12	199	1,588	185	5,040	12,368	1,003	1,282	0	4,861	25,070	382	609
TC22-13	213	1,637	185	5,065	12,632	992	965	0	4,476	24,145	267	612
TC22-14	221	1,629	185	5,107	12,562	995	1,153	0	4,570	23,947	341	616
TC22-15	229	1,634	185	5,224	12,585	994	1,014	0	4,433	23,723	443	576
TC22-16	256	1,646	185	5,056	12,430	992	835	0	4,576	23,395	416	498
TC22-17	266	1,648	185	4,933	12,329	996	734	0	5,177	23,798	388	491
TC22-18	273	1,657	185	4,856	12,374	988	733	0	4,767	23,423	377	485
TC22-19	303	1,566	185	5,343	13,380	1,006	1,045	0	6,919	27,119	272	629
TC22-20	309	1,545	185	4,876	12,441	1,014	961	0	7,630	26,413	206	625
TC22-21	330	1,645	128	4,406	11,626	622	890	0	4,826	22,615	206	537
TC22-22	336	1,646	127	4,392	11,439	615	1,101	0	5,006	21,916	222	535
TC22-23	357	1,650	125	4,362	11,300	0	1,034	0	5,812	22,992	208	532
TC22-24	365	1,650	125	4,372	11,401	608	1,097	0	6,419	22,901	205	533
TC22-25	380	1,643	154	4,432	11,545	734	1,002	0	6,394	23,331	228	540
TC22-26	386	1,644	154	4,478	11,688	659	761	0	6,424	23,481	201	545
TC22-27	398	1,651	144	3,992	10,930	685	1,106	0	5,814	21,446	188	490
TC22-28	404	1,658	138	3,926	10,904	658	1,245	0	6,005	21,321	152	482
TC22-29	413	1,644	138	4,120	11,068	686	1,171	0	6,362	21,755	227	504
TC22-30	426	1,658	125	4,104	11,183	808	931	0	5,912	21,618	167	502
TC22-31	452	1,648	125	3,761	10,019	0	1,261	0	6,837	21,695	234	463
TC22-32	462	1,649	125	3,903	10,314	719	744	0	5,764	20,018	233	479
TC22-33	479	1,649	140	4,037	10,552	793	844	0	5,742	21,365	267	495
TC22-34	497	1,648	146	4,043	10,823	852	1,041	0	5,758	21,882	248	495
TC22-35	505	1,646	146	4,156	10,835	886	753	0	5,714	21,942	320	508
TC22-36	511	1,652	146	4,036	10,972	889	1,042	0	5,573	22,004	292	495
TC22-37	516	1,661	146	3,953	10,956	884	1,101	0	5,326	21,745	249	485
TC22-38	525	1,557	136	4,021	10,067	847	695	165	6,006	21,464	104	579
TC22-39	530	1,561	136	3,977	10,188	845	510	170	6,209	21,667	42	578
TC22-40	542	1,650	136	4,020	11,230	821	1,170	235	5,914	21,868	192	616