POWER SYSTEMS DEVELOPMENT FACILITY

TOPICAL REPORT

GASIFICATION TEST CAMPAIGN TC22

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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 TC22, the first test campaign using a high moisture lignite from Mississippi as the feedstock in the modified Transport Gasifier configuration. TC22 was conducted from March 24 to April 17, 2007. The gasification process was operated for 543 hours, increasing the total gasification operation at the PSDF to over 10,000 hours.

The PSDF gasification process was operated in air-blown mode with a total of about 1,080 tons of coal. Coal feeder operation was challenging due to the high as-received moisture content of the lignite, but adjustments to the feeder operating parameters reduced the frequency of coal feeder trips. Gasifier operation was stable, and carbon conversions as high as 98.9 percent were demonstrated. Operation of the PCD and other support equipment such as the recycle gas compressor and ash removal systems operated reliably.

ACKNOWLEDGEMENT

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1.0 EXECUTIVE SUMMARY

Test campaign TC22 was the first demonstration of the Power Systems Development Facility (PSDF) gasification process with high moisture lignite from the Red Hills mine, located in Ackerman, Mississippi. TC22 occurred from March 24 to April 17, 2007, comprising 543 hours of gasification operation in air-blown mode and increasing the total PSDF gasification operation to over 10,000 hours. In addition to characterizing operation and performance of the modified gasifier and related equipment with the high moisture lignite, test objectives involved testing of coal feeders, hot gas filter elements and failsafes, instrumentation enhancements, and advanced syngas cleanup.

1.1 PSDF Overview

The PSDF, located near Wilsonville, Alabama, was established to support the U.S. Department of Energy's effort to develop cost-competitive and environmentally acceptable coal-based power generation technologies. This effort promotes fuel diversity—a key component in maintaining national security—while meeting the highest environmental standards. The PSDF is developing environmentally friendly technologies that will allow the continued use of coal, the United States' most abundant and least expensive fuel source.

The PSDF is operated by Southern Company Services. Other project participants currently include the Electric Power Research Institute, Siemens Power Generation, KBR (formerly Kellogg Brown & Root), the Lignite Energy Council, Burlington Northern Santa Fe Railway, and Peabody Energy. The facility is a highly flexible test center where researchers can evaluate innovative power system components on a semi-commercial scale at a low cost. Development of advanced power systems at the PSDF is focused specifically on identifying ways to reduce capital cost, enhance equipment reliability, and increase efficiency while meeting strict environmental standards. Current testing involves pressurized feed systems, coal gasifier optimization using a variety of fuels, sensor development, hot gas particulate removal, and advanced syngas cleanup.

1.2 Process Description

The PSDF gasification process, shown in Figure 1-1, features key components of an integrated gasification combined cycle (IGCC) power plant. These include high pressure solids feed systems; a KBR Transport Gasifier; syngas coolers; a hot gas filter vessel, the particulate control device (PCD); continuous ash depressurization systems developed at the PSDF for ash cooling and removal; a novel piloted syngas burner; a slipstream syngas cleanup unit to test various pollutant control technologies; and a recycle syngas compressor.

The coal used as the gasifier feedstock is processed on site, first crushed and then pulverized to a nominal particle diameter between 250 and 400 microns. Coal may be fed to the gasifier using two systems, the original coal feed system and a secondary coal feed system. The original coal feed system is a lock hopper, horizontal pocket feeder design with a "rotofeed" dispenser. It consists of two pressure vessels, with the coal pressurized in the upper lock vessel and then

gravity fed into a dispense vessel, which is always pressurized. The material is fed out of the dispense vessel by the rotofeed dispenser, which is driven by a variable speed electric motor and delivers the material into the discharge line where it is conveyed by air or nitrogen into the gasifier. The secondary coal feeder is a developmental test unit designed to evaluate different feeder mechanisms. Types of mechanisms that can be tested with this system include auger-style, fluid bed, and a higher pressure rotary feeder. Coal is fed at a nominal rate of 4,000 lb/hr.

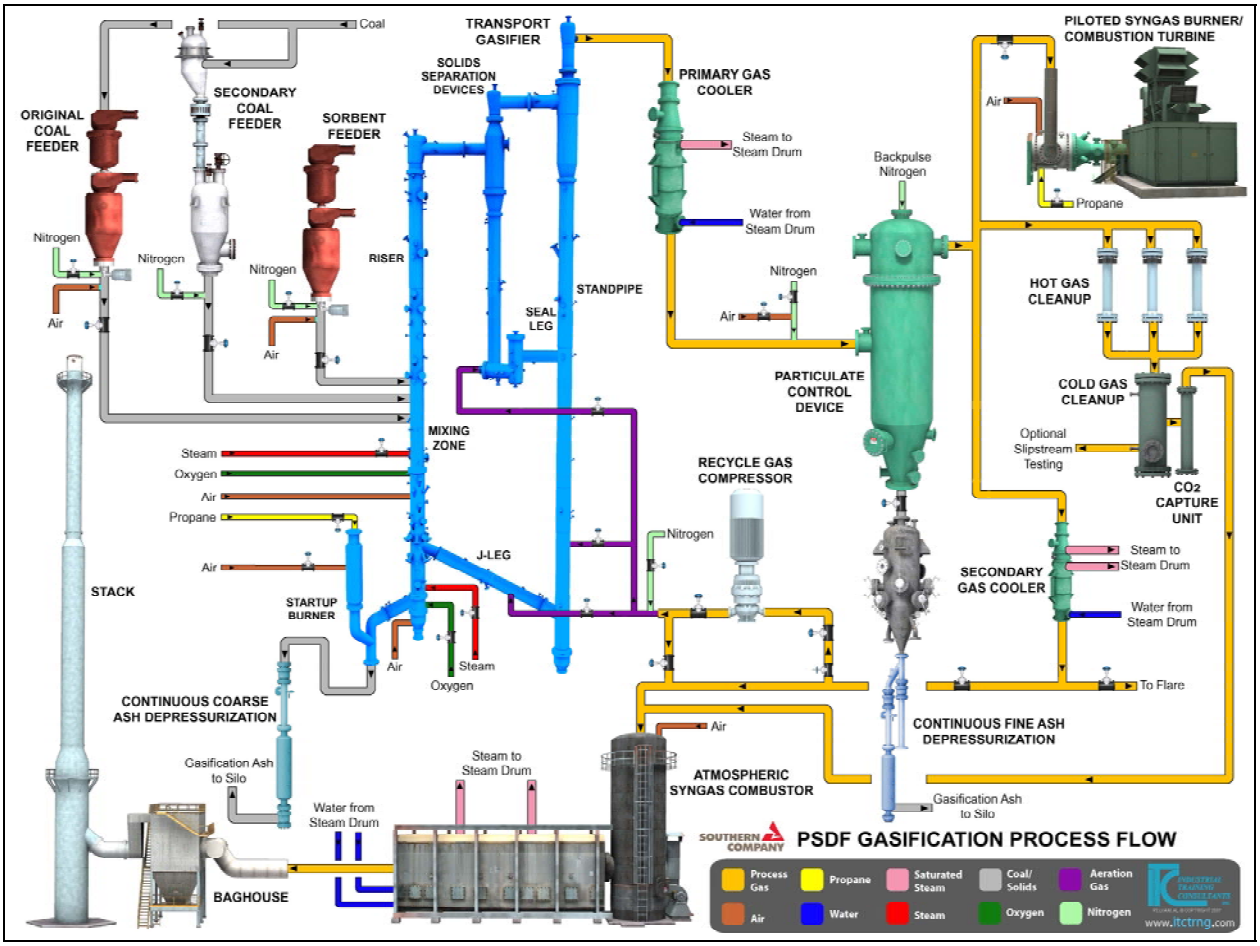

Figure 1-1. PSDF Gasification Process Flow Diagram.

A sorbent feeder is available to feed material into the gasifier for in-situ sulfur capture or to address ash chemistry issues. For sulfur capture, either limestone or dolomite is fed after being crushed and pulverized to a nominal particle diameter of 10 to 100 microns. The sorbent feeder utilizes the same design as the original coal feeder, but for a lower feed rate of nominally 100 lb/hr.

The start-up burner is a direct propane-fired burner operated to heat the gasifier to about 1,200^{o}F. The burner is typically started at a system pressure of 60 psig, and can operate at pressures up to 135 psig.

The Transport Gasifier, a pressurized, advanced circulating fluidized bed reactor, consists of a mixing zone, riser, solids separation unit, seal leg, standpipe, and J-leg. The gasifier is equally capable of using air or oxygen as the gasification oxidant. Steam and either air or oxygen are mixed together and fed into the mixing zone at different elevations and orientations to evenly distribute heat generated from the partial combustion of the circulating solids. The oxygen from the air or pure oxygen feed is completely consumed in this section of the gasifier. The coal and sorbent are fed at a higher elevation in the mixing zone where the atmosphere is reducing, or oxygen-free.

As the coal devolatilizes and chemical reactions occur to generate syngas, the gas and solids move up the riser and enter the solids separation unit. This unit contains two solids separation devices, which use cyclonic action to remove particles. Between the first and second solids separation devices is the seal leg, which prevents backflow of solids. The solids collected by the solids separation unit are recycled back to the gasifier mixing zone through the standpipe and J-leg. The gasifier solids inventory is controlled by removing gasification ash through the continuous course ash depressurization (CCAD) system, which cools and depressurizes the solids. The nominal gasifier operating temperature is 1,800°F, and the gasifier system is designed to have a maximum operating pressure of 294 psig with a thermal capacity of about 41 MBtu/hr.

The syngas exits the Transport Gasifier, passes through the primary gas cooler where the gas temperature is reduced to about 750°F, and enters the PCD for final particulate removal. The metal or ceramic filter elements used in the PCD remove essentially all the dust from the gas stream. The PCD utilizes a tube sheet holding up to 91 filter elements, which are attached to one of two plenums. Process gas flows into the PCD through a tangential entrance, around a shroud, and through the filter elements into the plenums. Failsafe devices are located downstream of the filter elements to stop solids leakage by plugging in the event of element failures. High pressure nitrogen back-pulsing, typically lasting 0.2 seconds, is used to clean the filters periodically to remove the accumulated gasification ash and control the pressure drop across the tube sheet. The solids fall to the bottom of the PCD and are cooled and removed through the continuous fine ash depressurization (CFAD) system.

After exiting the PCD, a small portion of the syngas, up to 100 lb/hr, can be directed to an advanced syngas cleanup system downstream of the PCD. The syngas cleanup system is a specialized, flexible unit, capable of operating at a range of temperatures, pressures, and flow rates, and provides a means to test various pollutant control technologies, including removal of sulfur, nitrogen, chlorine, and mercury compounds. The syngas cleanup slipstream can also be used to test other power technologies such as fuel cells.

A portion of the syngas can also be directed to the piloted syngas burner (PSB), a gas turbine combustor designed to burn coal-derived syngas with a lower heating value below 100 Btu/SCF. After syngas combustion in the burner, the flue gas passes through a 4 MWe turbine before exiting the turbine stack. An associated generator can supply power from the turbine to the electric transmission grid.

The main stream of syngas is then cooled in a secondary gas cooler, which reduces the temperature to about 450°F. Some of this gas may be compressed and sent to the gasifier for

aeration to aid in solids circulation. The recycle gas compressor is a vertically mounted centrifugal compressor which operates at high temperature, nominally 500 to 600°F, and was designed for a throughput of about 2,000 to 3,000 lb/hr.

The remaining syngas is reduced to near atmospheric pressure through a pressure control valve. The gas is then sent to the atmospheric syngas combustor which burns the syngas components. The flue gas from the atmospheric syngas combustor flows to a heat recovery boiler, through a baghouse, and then is discharged out a stack. A flare is available to combust the syngas in the event of a system trip when the atmospheric syngas combustor is offline.

A brief description of gasification testing history can be found in Appendix A.

1.3 Major Test Objectives

Evaluation of High Moisture Lignite Operation. The Mississippi lignite was used exclusively as the gasifier feed stock for TC22. The Transport Gasifier operation was stable, demonstrating high carbon conversions of up to 98.9 percent and projected syngas lower heating values at the turbine inlet of 119 Btu/SCF. The PCD and other downstream supporting equipment operated reliably with no problems associated with lignite operation.

Several parametric tests were performed to evaluate gasifier operation at various operating conditions and to optimize performance. Positive correlations were demonstrated for carbon conversion and gasifier temperature; syngas heating value and coal feed rate; syngas methane concentration and operating pressure; and solids circulation rate and standpipe level.

Coal Feeder Testing. Both the original and developmental coal feeders were tested using high moisture lignite at various feed rates. The original coal feed system ran for 540 hours at rates varying from 2,600 to 5,400 lb/hr and particle sizes varying from about 250 to 760 microns. The original coal feeder experience operational difficulties due to the coal feed discharge line plugging frequently and fine material packing in the lock vessel. Feeder operation improved after several operating parameters were adjusted and the fine particle size content was reduced. The secondary coal feeder ran for 33 hours at feed rates up to 2,200 lb/hr but experienced frequent discharge line plugging due to the flow path which has a high resistance due to the physical configuration.

Filter Element and Failsafe Testing. For TC22, the PCD was equipped with 36 iron aluminide elements in the top plenum and 36 HR-160 elements in the bottom plenum. This arrangement was used to allow a direct comparison of the gas flow distribution between the two types of elements. With this arrangement, the PCD performed well with acceptable pressure drop and particulate collection throughout TC22. On-line failsafe testing was conducted with one of the new prototype Pall reverse-media, sintered-fiber fuses. The failsafe worked very well with no measurable particulate penetration either in the first hour of testing or long-term. Real-time particulate monitoring indicated that the failsafe plugged almost immediately.

Advanced Syngas Cleanup Testing. Carbonyl sulfide (COS) hydrolysis tests with two catalysts were successfully performed, resulting in COS conversion efficiencies ranging from 82.1 to 96.2 percent. The hydrolyzed syngas was then treated to remove sulfur so that the gas could be utilized in the TDA Research trace metals removal test unit. TDA testing was successfully completed and showed promise for high removal efficiencies of mercury. The syngas cooler operation resulted in no exchanger tube fouling from organics.

1.4 Secondary Test Objectives

Recycle Gas Compressor Testing. The recycle gas compressor supplied recycle syngas for gasifier aeration for over 256 hours. When recycled syngas was used to replace nitrogen aeration, the raw syngas lower heating value was about 5 percent higher. The percentage increase was lower than previous testing due to the very low aeration flows required for the Mississippi lignite ash.

Gas Sampling in the Gasifier. Several gas samples were taken in the mixing zone and riser to provide gas composition data at different gasifier elevations. The data was provided to researchers on the computational modeling team, the Device Scale Modeling Group, at the National Energy Technology Laboratory (NETL) in Morgantown, West Virginia. The Device Scale Modeling Group utilized a Multiphase Flow with Interphase Exchanges (MFIX) software developed in-house at NETL to accurately simulate the hydrodynamics, heat transfer, and chemical reactions in the Transport Gasifier. The ability to predict gas composition and fluidization regimes in a fluid-solid system with complex physics and chemical reactions will ultimately be used to reduce cost in development of clean-coal technologies.

In-situ Sulfur Removal. Dolomite, a calcium based sulfur sorbent, was injected at various rates into the gasifier, achieving a sulfur removal of up to 35 percent.

Continued Sensor Development. The early-stage development of the Process Particle Counter real-time particulate monitor continued, and modifications to the system proved successful in mitigating condensation problems. The instrument showed improved performance and successfully detected changes in particulate concentrations. Evaluation of gasifier instrumentation enhancements continued, and reliable performance of ceramic and metal thermowells and ceramic-tipped pressure differential taps was demonstrated.

A prototype sensor system for in-situ real time detection and identification of coal combustion gases developed by Sensor Research and Development (SRD) in partnership with the Department of Energy (DOE) was successfully tested at the exit of the atmospheric syngas combustor. High speed pressure fluctuation data on the Transport Gasifier was taken to utilize with the advanced nonlinear signal analysis techniques developed by Oak Ridge National Lab (ORNL) and Babcock and Wilcox (B&W) under sponsorship by the Electric Power Research Institute (EPRI). The data was used to confirm that changes in pressure fluctuations can be correlated to changes in gasifier fluidization operating regimes.

Ash Removal Systems Evaluation. Both ash removal systems, CFAD and CCAD, performed well during TC22, cooling and depressurizing the ash from operating pressures up to 185 psig to near atmospheric pressure. The CFAD system smoothly discharged fines from the PCD at rates of up to 750 lb/hr. The CCAD system operated at ash removal rates from 85 to 475 lb/hr and inlet

temperatures of up to 1750°F. Testing was focused on enhancing instrumentation to automate the standpipe level control and improve the control of the ash removal rate.

1.5 Report Structure

The following report presents the operational data and results of gasification technology development at the PSDF during TC22, compiled in the sections listed below.

Section 2 Coal Feed — Discusses operation of the original coal feed and secondary coal feed systems and presents coal moisture values and particle sizes and their effect on coal feed system performance.

Section 3 Transport Gasifier — Includes the major gasifier operating parameters and the gasifier performance as indicated by solids and gas analyses. Also includes the results of parametric testing such as the effects of varying temperature and pressure on gasifier performance. Inspection results are included.

Section 4 Sensor Development — Discusses recent operation of real-time particulate monitors, results of gasifier instrumentation improvements, and sensor testing by outside researchers.

Section 5 Particulate Control Device — Describes the hot gas filter particulate characteristics, PCD performance, and filter element testing.

Section 6 Advanced Syngas Cleanup — Describes various testing to support emissions control studies, as well as testing trace metals removal.

Section 7 Conclusions — Lists the major conclusions and lessons learned from TC22 operation.

Appendix A gives a brief history of gasification operation at the PSDF. Appendix B shows the steady state operating periods and the major system operating conditions for each period. Material and energy balances are shown in Appendix C, and Appendix D lists the abbreviations and units used in this report.

2.0 COAL FEED

A high moisture lignite from the Red Hills Mine in Ackerman, Mississippi, was tested exclusively in TC22. Both the original and secondary coal feed systems were operated. The two systems combined fed about 1,080 tons of lignite to the gasifier.

2.1 Coal Characteristics

The as-received moisture content of the lignite ranged from 40 to 45 weight percent, which was the highest coal moisture content tested at the PSDF 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. 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 2-1 gives the as-fed coal moisture values as sampled from the original coal feed system. The as-fed moisture content varied due to variations in the as-received moisture content.

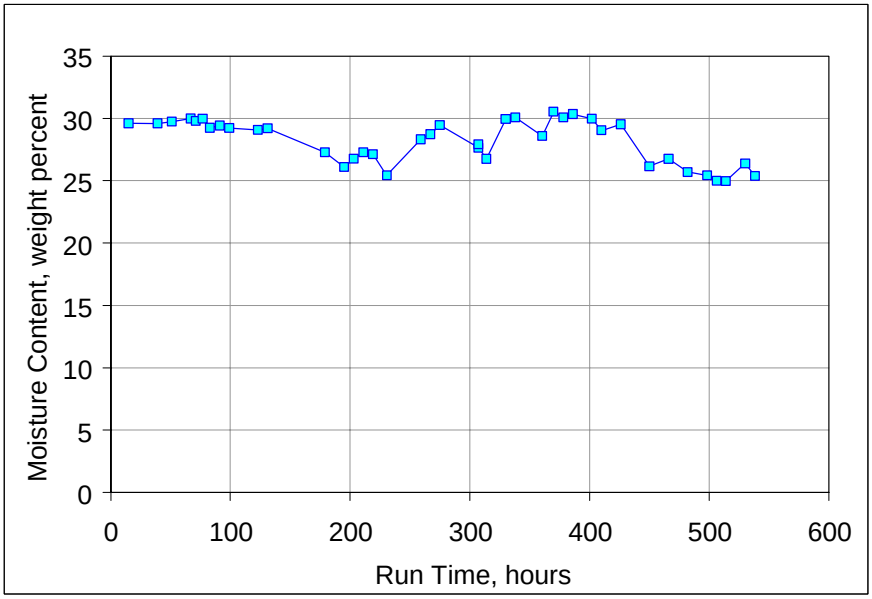

Figure 2-1. As-Fed Coal Moisture Content.

Table 2-1 shows the ultimate and proximate analysis including the ash mineral analysis of the as-fed lignite as sampled from the original and secondary (when operating) coal feed systems. Hydrogen in the coal is reported separately from hydrogen in the moisture. The ash content of about 17 percent and sulfur content of about 0.9 weight percent were typical for lignite from this seam. Because of the high moisture and ash content, the heating values were the lowest of the coals tested at the PSDF to date.

Table 2-1. Mississippi Lignite As-Fed Characteristics.

	Average Value	Minimum Value	Maximum Value	Standard Deviation
Moisture, wt %	28.1	25.0	30.6	1.8
Carbon, wt %	39.1	37.2	44.3	1.3
Hydrogen, wt %	5.2	4.0	6.3	0.6
Nitrogen, wt %	0.8	0.7	0.8	0.0
Oxygen, wt %	37.1	34.3	39.9	1.6
Sulfur, wt %	0.9	0.8	1.8	0.2
Ash, wt %	16.8	13.8	19.0	1.0
Volatiles, wt %	29.4	27.8	31.2	0.9
Fixed Carbon, wt %	25.6	24.0	28.6	0.9
Heating Value, As Received, Btu/lb	6,138	5,863	6,719	196
CaO, wt % in Ash	14.1	12.0	16.4	0.8
SiO_2, wt % in Ash	39.5	35.6	44.4	1.7
Al_2O_3, wt % in Ash	21.0	20.0	22.1	0.6
Fe_2O_3, wt % in Ash	7.3	6.5	9.2	0.7
MgO, wt % in Ash	3.0	2.5	3.5	0.3
Na_2O, wt % in Ash	0.3	0.0	0.7	0.3

2.2 Original Coal Feeder System Operation and Performance

The original coal feeder operated for a total of 540 hours at rates from 2,600 up to 5,400 lb/hr. The feeder experienced numerous operating problems, mostly 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. Nitrogen was used as coal transport gas for the entire test campaign since the higher transport gas velocity requirement of the high moisture Mississippi lignite was beyond the capability of the transport air system. The feeder also experienced problems with lock vessel packing due to the presence of fines in the system. Mill operating parameters were adjusted in an effort to minimize the concentration of fines in the feed material. Several coal feeder operating parameters were also adjusted to improved feeder performance. The surge bin fluidization was increased and the fill cycle weight was reduced. The fluidization of the lock vessel was also increased during fill cycles. The recently installed pressure balance line operated satisfactorily.

Figure 2-2 gives the as-fed coal particle sizes (MMD) as sampled from the original feeder. The coal particle size MMD varied from 246 to 757 microns with an average MMD of 437 microns and a standard deviation of 100 microns. The large deviation in MMD was due to the variation in as-received coal properties and differences in operation of the two coal mill systems.

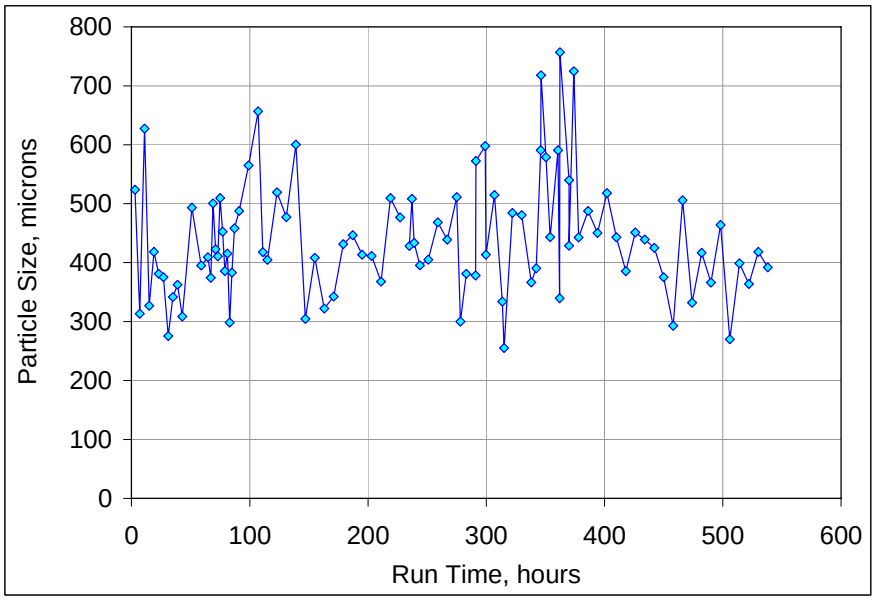

Figure 2-2. Coal Particle Sizes.

Figure 2-3 gives the percentage of coal particles above 1,180 microns, considered oversize coal, and the percentage of fine coal, that below 45 microns, for the coal sampled from the original coal feeder. The oversize particles above 1,180 microns ranged between 9 to 34 percent, averaging 19 percent. The percentage of fine coal varied between 6 and 16 percent with an average of 11 percent.

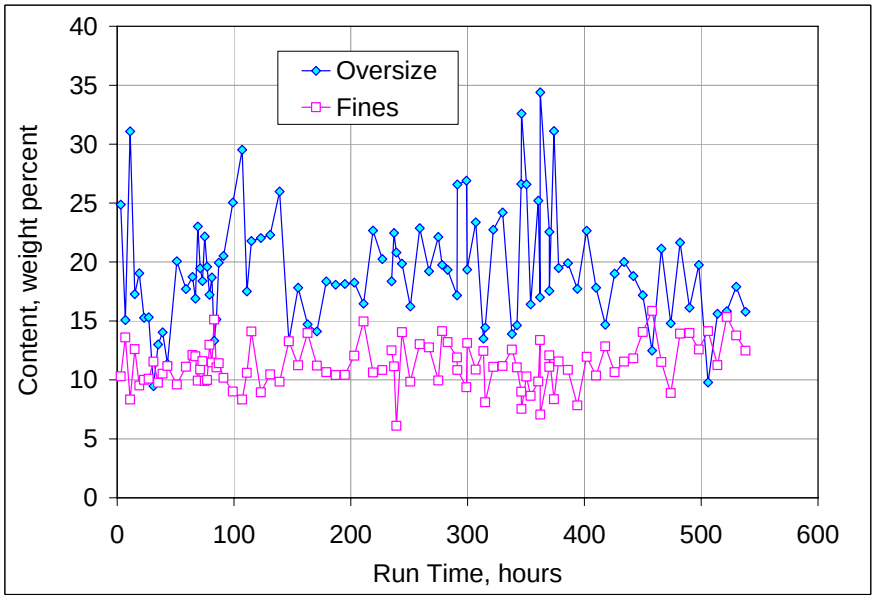

Figure 2-3. Coal Oversize and Fine Particles.

Coal Feeder Operating Envelope. Based on TC22 operation, the original coal feeder operating envelope for coal moisture content and particle size was developed. Figure 2-4 shows the range

of moisture and particle sizes for acceptable feeder operation. The area of overlap indicates conditions at which the coal feeder may operate acceptably for some time, but may trip if factors such as excessive fines or oversize coal exist or the moisture content is high.

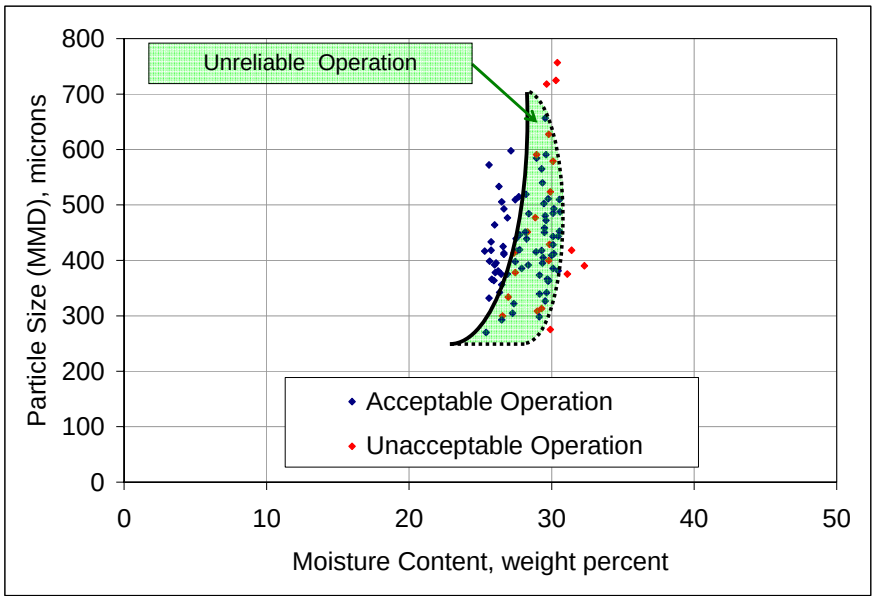

Figure 2-4. Coal Feeder Operating Envelope.

2.3 Secondary Coal Feeder Operation and Performance

The secondary coal feeder ran for a total of 33 hours at feed rates as high as 2,200 lb/hr. The lignite moisture content as sample from the secondary feeder was about 28 weight percent, and the particle size MMD was approximately 380 microns. 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.

3.0 TRANSPORT GASIFIER

Test campaign TC22 was the first demonstration of the PSDF gasification process operating with high moisture lignite from Mississippi. The major objective for this test was to evaluate the gasifier operational stability and performance using this coal.

The gasifier operated for 543 hours in air-blown mode. The gasifier performed well with the Mississippi lignite, achieving carbon conversions up to 98.9 percent and projected lower heating values of 119 Btu/SCF at the turbine inlet. 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 down time. There were 40 steady state operating periods during TC22. The steady state operating periods and major operating parameters are shown in Appendix B.

3.1 Operating Parameters

Figure 3-1 gives the average gasifier outlet temperature and pressure for each of the steady state periods. The gasifier outlet temperature varied between 1,540 to 1,660ºF, and the gasifier outlet pressure varied from 124 to 185 psig. The gasifier operating pressure was limited due to the maximum operating pressure of the coal feed system. The coal feed system was operating at a higher than normal pressure because of the high coal feed line pressure differential required to feed the high moisture lignite.

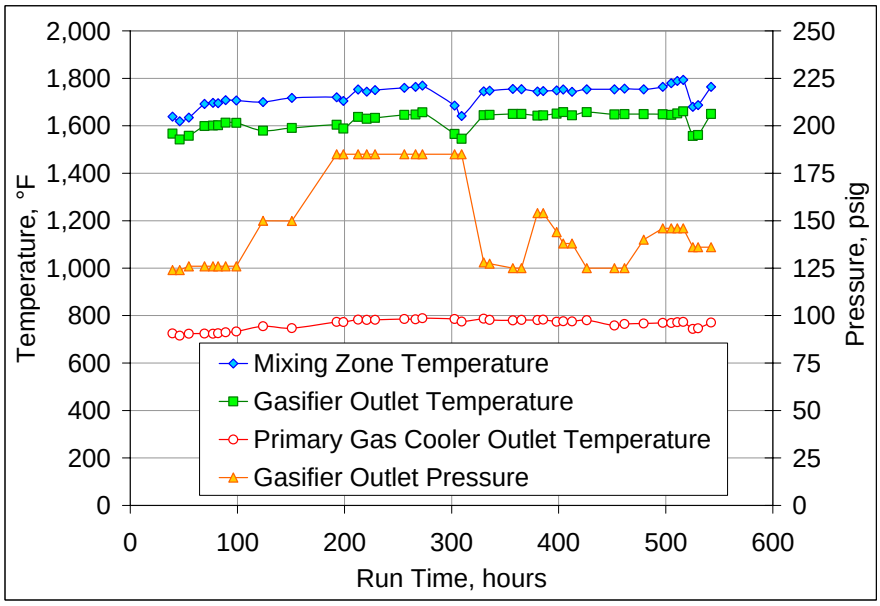

Figure 3-1. Gasifier Outlet Temperature and Pressure.

Flow rates of the major feed streams to the gasifier are shown in Figure 3-2. The coal feed rates were calculated from the feeder weigh cells, and the air, nitrogen, and recycle gas were taken from the flow indicators. The steam flow rates were derived from a system hydrogen balance.

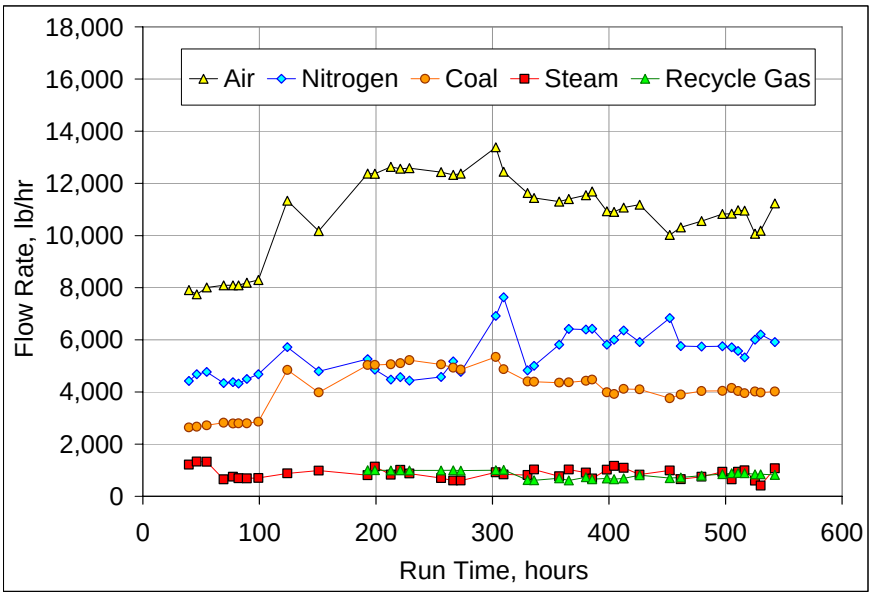

Figure 3-2. Flow Rates of the Major Feed Streams to the Gasifier.

Figure 3-3 shows the standpipe levels (as differential pressure) and the riser differential pressure. The standpipe level was held constant at about 150 inH_2O for most of TC22, with one steady period at 85 inH_2O, three periods at around 65 inH_2O, and three 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.

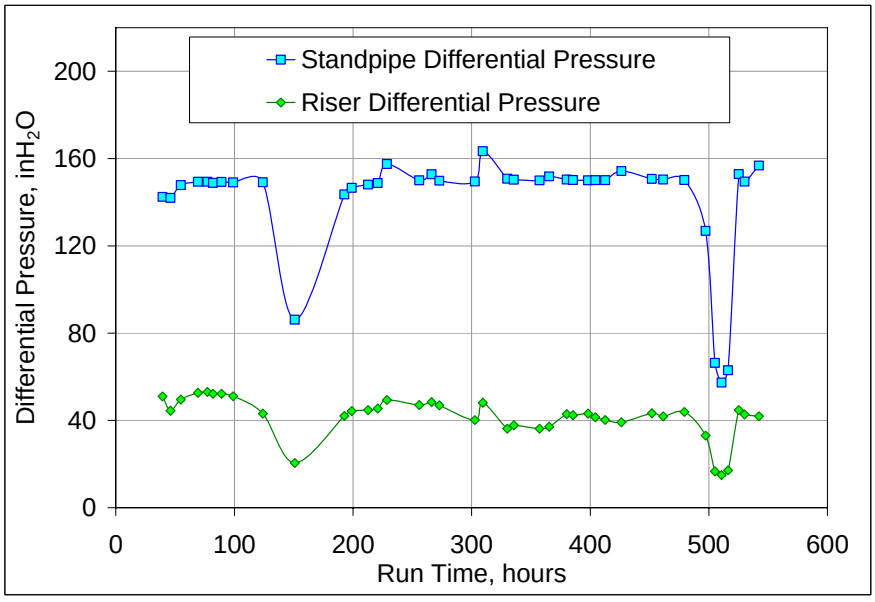

Figure 3-3. Gasifier Differential Pressures.

3.2 Gasifier Performance, Solids Analysis

The gasifier solids chemical composition and particle size analyses presented in the following sections represent both the circulating gasifier solids sampled from the gasifier standpipe and the solids exiting the gasifier, filtered in the PCD, and sampled from the CFAD system.

Solids Chemical Analyses. The solids chemical analyses were used to monitor transition of the solids inventory from the start-up bed material, sand, to gasification ash and to characterize operation of the gasifier solids collection devices. The chemical analyses of the gasifier circulating solids ash and the solids captured by PCD are given in Table 3-1 and Table 3-2, respectively. During the initial 50 hours of gasification operation, the gasifier circulating solids were composed of mainly silicon dioxide (SiO_2) from the sand. The SiO_2 content decreased from around 90 percent to about 50 weight percent as gasification ash replaced the sand. The gasifier solids organic carbon content was essentially zero, and the solids heating value was below the lowest measurement limit of 100 Btu/lb. The PCD solids were composed mainly of SiO_2, about 39 percent, and aluminum oxide (Al_2O_3), about 20 percent. The heating value of the PCD solids ranged from 530 to 2,570 Btu/lb, which was the lowest value obtained to date.

Table 3-1. Gasifier Circulating Solids Analysis.

	Average	Standard Deviation	Minimum Value	Maximum Value
SiO_2, wt%	48.5	1.7	45.7	51.5
Al_2O_3, wt%	24.7	0.9	22.7	25.7
Fe_2O_3, wt%	6.7	0.5	5.9	7.5
Other Inerts (P_2O_5, Na_2O, K_2O, & TiO_2), wt%	2.7	0.4	2.1	3.5
CaS, wt%	0.6	0.3	0.2	1.8
CaO, wt%	12.0	1.7	45.7	51.5
MgO, wt%	12.0	0.7	10.6	13.1
Organic Carbon, wt%	0.9	0.9	0.1	3.5

Table 3-2. PCD Solids Analysis.

	Average	Standard Deviation	Minimum Value	Maximum Value
SiO_2, wt%	38.7	2.6	33.4	41.9
Al_2O_3, wt%	20.5	1.0	18.7	22.4
Fe_2O_3, wt%	7.3	0.6	5.8	8.4
Other Inerts (P_2O_5, Na_2O, K_2O, & TiO_2), wt%	2.6	0.4	1.8	3.5
CaS, wt%	2.4	0.9	1.2	4.3
CaO, wt%	13.4	1.6	10.5	16.1
MgO, wt%	3.4	0.4	2.7	4.0
Organic Carbon, wt%	8.9	3.7	3.3	16.3
Heating Value, As Received, Btu/lb	1,394	577	532	2,569

Solids Physical Analyses. The TC22 particle sizes measured in MMD of the gasifier circulating solids and PCD solids are shown in Figure 3-4. The MMD of the gasifier circulating solids gradually decreased as gasification ash replaced the initial bed inventory of sand, which has a MMD of about 145 microns. After this initial decrease during the first 50 hours of operation, the MMD varied from about 70 to 120 microns. The PCD solids particle sizes were smaller than typical and averaged 10.5 microns MMD. The range of particle size distributions (PSDs) for the gasifier circulating solids and the PCD solids are provided in Figure 3-5.

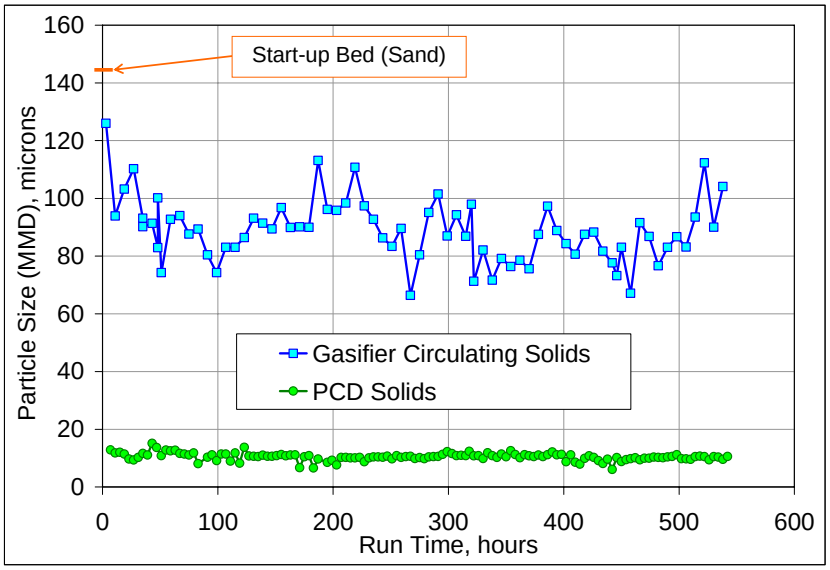

Figure 3-4. Particle Sizes of Gasifier Circulating Solids and PCD Solids.

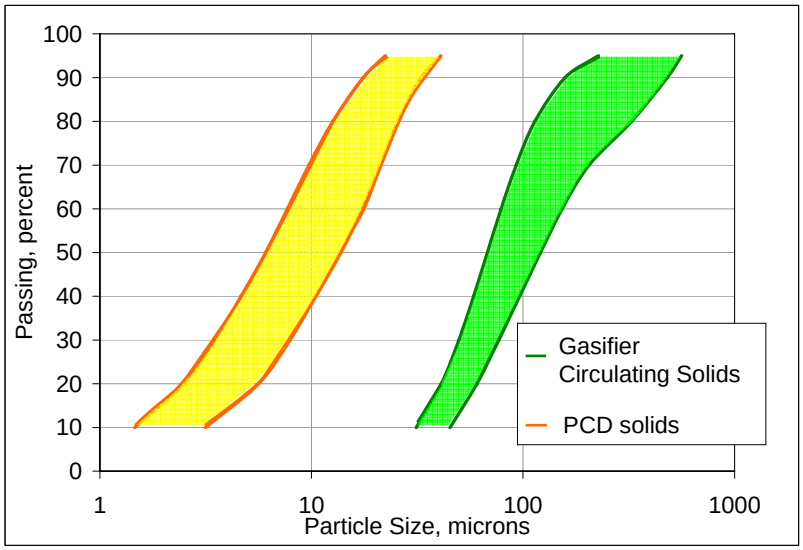

Figure 3-5. Particle Size Distribution Data for Gasifier Circulating Solids and PCD Solids.

Bulk densities of the gasifier circulating solids and PCD solids are shown in Figure 3-6. The bulk density of the circulating gasifier solids gradually decreased from 93 lb/ft^3, the bulk density of the start-up sand, to 45 lb/ft^3 due to the replacement of bed start-up material with gasification ash. The PCD solids bulk density varied from about 19 to 32 lb/ft^3.

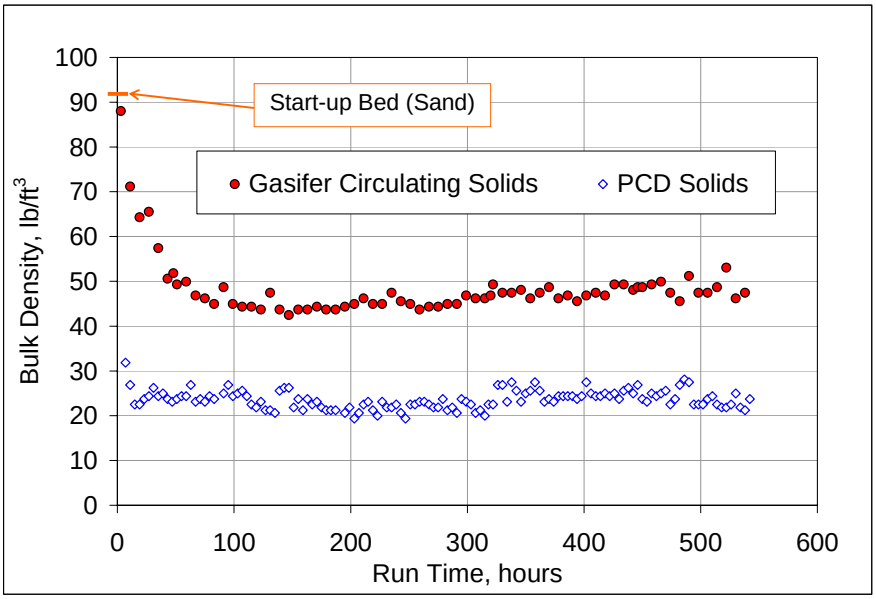

Figure 3-6. Bulk Densities of Gasifier Circulating Solids and PCD Solids.

Photomicrographs of the gasifier circulating solids are shown in Figure 3-7. The solids were fairly uniform in size and color and did not show indications of particle agglomeration.

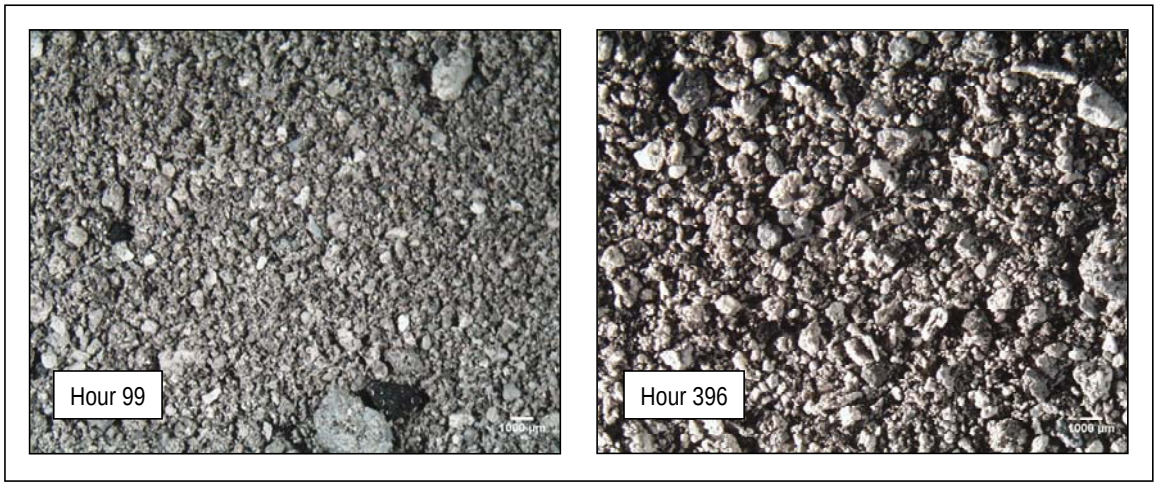

Figure 3-7. Photomicrographs of Gasifier Circulating Solids.

Gasification Ash Removal. Figure 3-8 shows the rates for the fine gasification ash removed from the PCD by the CFAD system and for the coarse gasification ash removed from the gasifier by

the CCAD system at times corresponding to the PCD inlet in-situ sampling. The PCD solids rates were determined from the PCD inlet in-situ sampling, and the ash removal rates for CCAD were determined by a system ash balance. The CCAD system withdrew hot ash from the gasifier at rates from 85 to 475 lb/hr. The CFAD system discharged fines from the PCD at rates up to 750 lb/hr. Between 10 and 53 percent of the solids were removed by the CCAD system.

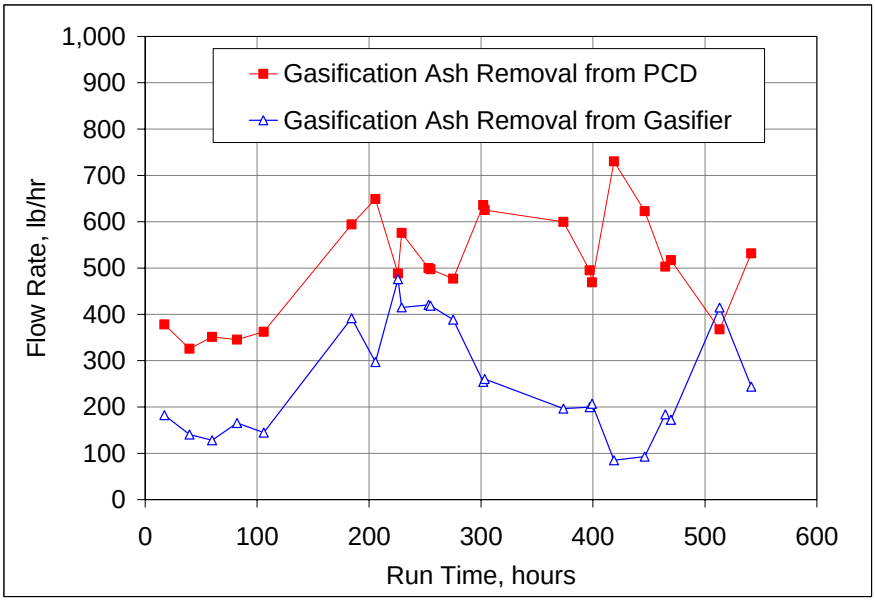

Figure 3-8. Gasification Ash Removal from the Gasifier and PCD.

3.3 Gasifier Performance, Gas Analysis

Continuous extractive syngas sampling was performed between the primary gas cooler and the PCD inlet, and the syngas constituents were analyzed using continuous analyzers and gas chromatography (GC). A Fourier Transform Infrared Analyzer (FTIR), located on the advanced syngas cleanup slipstream, was used to measure the syngas water (H_2O), ammonia (NH_3), and hydrocarbon concentrations. Manual in-situ samples of syngas moisture were also made at the PCD outlet during the particulate sampling.

Syngas Composition. Molar concentrations of the major syngas components for the steady state operating periods are given in Figure 3-9. The H_2, CO, CO_2, and CH_4 concentrations were measured by a GC on a moisture-free basis and converted to wet gas concentrations using the water concentration. During the first few steady state periods, the H_2O concentrations were high due to high steam flow rates. The CO was about 10 mole percent for the majority of the test campaign, and H_2 ranged from about 6 to 8 mole percent. The water concentration for steady state periods was estimated based on the PCD outlet sampling and a mathematical correlation based on the water gas shift reaction equilibrium

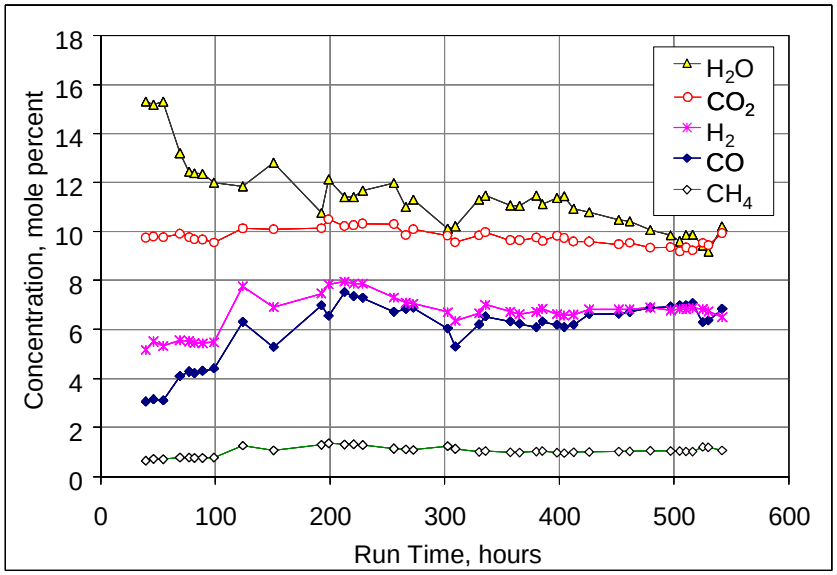

Figure 3-9. Concentrations of Major Syngas Components.

Figure 3-10 plots the syngas water concentrations determined by in-situ measurements at the PCD outlet and by the FTIR gas analyzer. It also plots the water concentration based on a mathematical correlation utilizing the water gas shift reaction. During the middle of TC22 (Hours 82 to 399), there was very good agreement between the measurements.

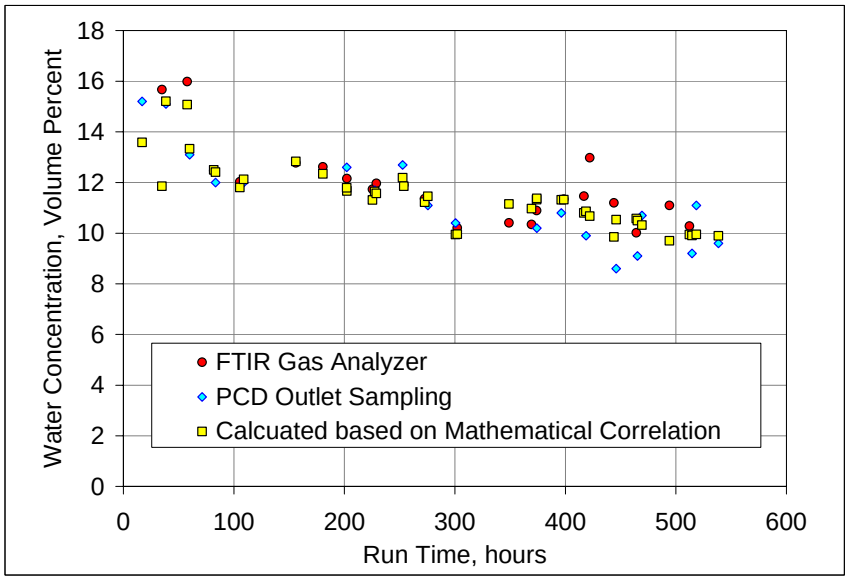

Figure 3-10. Syngas Water Concentrations.

Minor constituents in the syngas include reduced sulfur compounds such as hydrogen sulfide (H_2S), and COS, and reduced nitrogen compounds such as NH_3 and hydrogen cyanide (HCN). The H_2S and COS concentrations during steady state periods are shown in Figure 3-11. Before

the dolomite injection, the H_2S concentrations were between 1,100 and 1,700 ppm and averaged 1,375 ppm on a wet molar basis, and the COS concentrations were between 17 and 82 ppm and averaged 40 ppm. The addition of dolomite resulted in an average H_2S capture of 32 percent, with H_2S concentrations between 760 and 800 ppm.

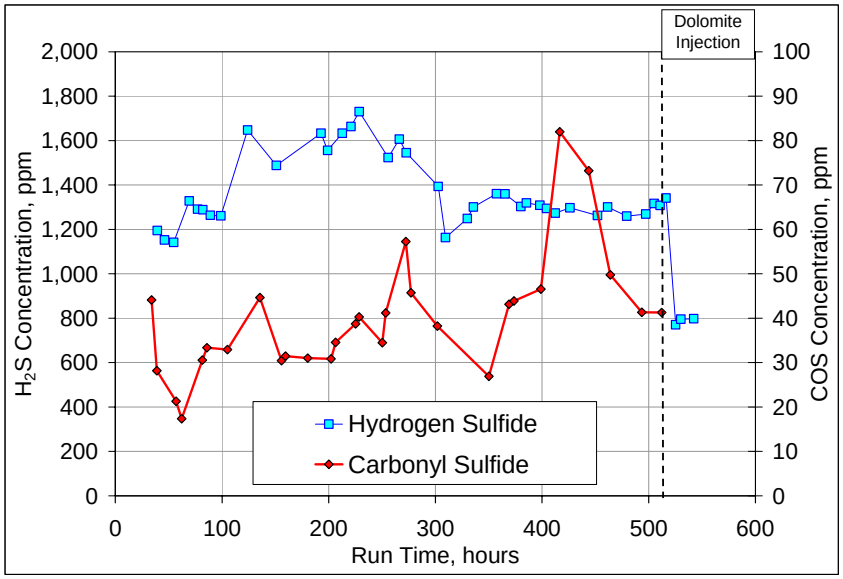

Figure 3-11. Syngas Hydrogen Sulfide and Carbonyl Sulfide Concentrations.

Figure 3-12 shows the syngas NH_3, and the percent conversion of coal nitrogen to NH_3. The NH_3 concentrations varied between 960 and 1,950 ppm, and indicated that the coal nitrogen conversion to NH_3 ranged from 30 to 75 percent and averaged 47 percent.

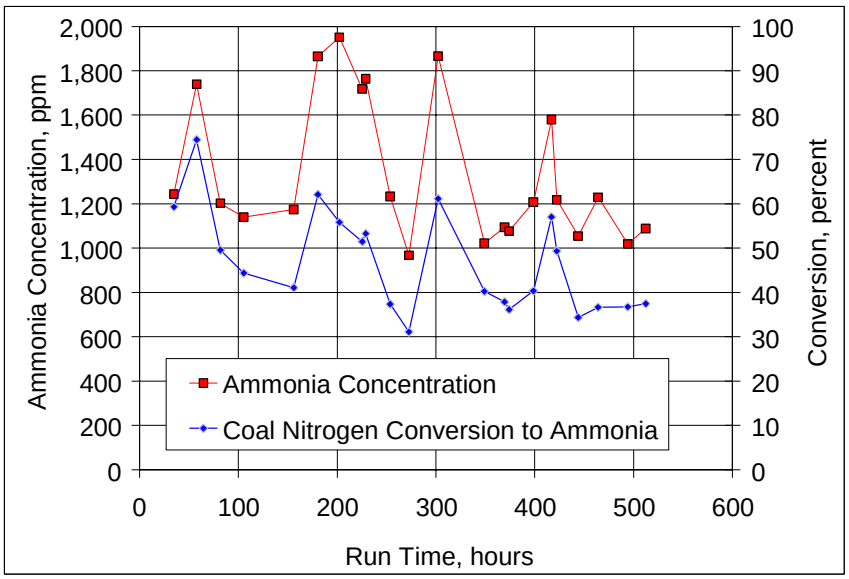

Figure 3-12. Syngas Ammonia Concentration and Conversion of Coal Nitrogen to Ammonia.

Syngas Heating Value. The dry syngas lower heating value (LHV) ranged from 36 to 66 Btu/SCF on a wet basis for the steady state periods during TC22. The heating values obtained early in the test campaign were on the low end of the range and corresponded to lower coal feed rates.

Carbon Conversion. The carbon conversion ranged from 94.6 and 98.9 percent and averaged 97.2 percent. Section 3.4 discusses the impacts of various operating conditions on carbon conversion.

Gasification Efficiency. The hot gasification efficiency ranged from 79 to 87 percent, which is slightly lower than operation with PRB under similar conditions due to the higher as-fed moisture content of the Mississippi lignite.

3.4 Gasifier Performance, Parametric Testing

A number of tests were performed to evaluate operation 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 feeder system problems. The parametric testing completed included temperature, air-to-coal ratio, pressure/riser velocity, fluidization flow, and coal feed rate effects on gasifier performance; effect of dolomite addition on syngas sulfur capture efficiency; and the standpipe level effect on gasifier circulation rate. 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 3-13 gives the effect of temperature on carbon conversion at a fixed pressure of 185 psig, air-to-coal mass ratios between 2.4 and 2.55, and coal feed rates of 4,850 to 5,200 lb/hr. As expected, the data show a linear correlation between carbon conversion and temperature.

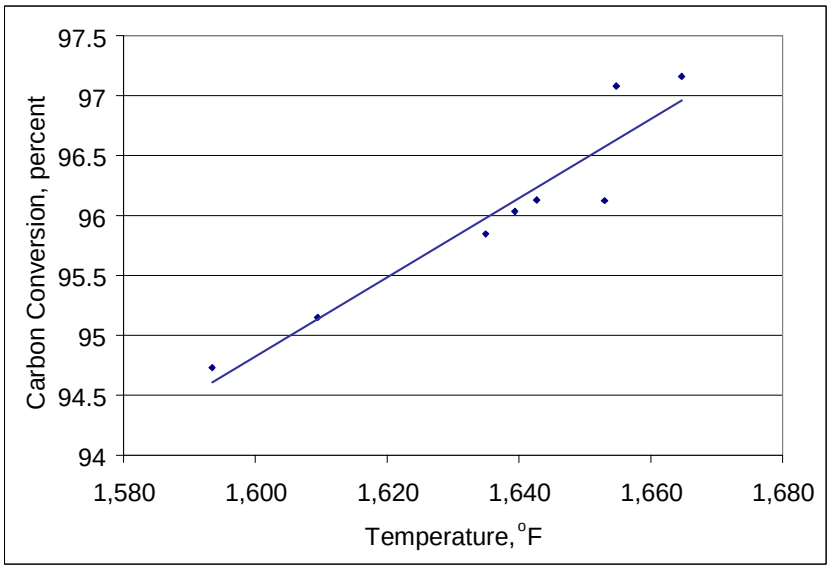

Figure 3-13. Carbon Conversion as a Function of Temperature.

Gasifier pressure (which directly controls riser velocity) was varied to quantify its effects on gasifier performance. Figure 3-14 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 lb/lb, the gasifier temperatures ranged from 1,650 to 1,670°F, and carbon conversions were between 97 and 98 percent. A linear relationship was indicated, although some scatter exists in the data.

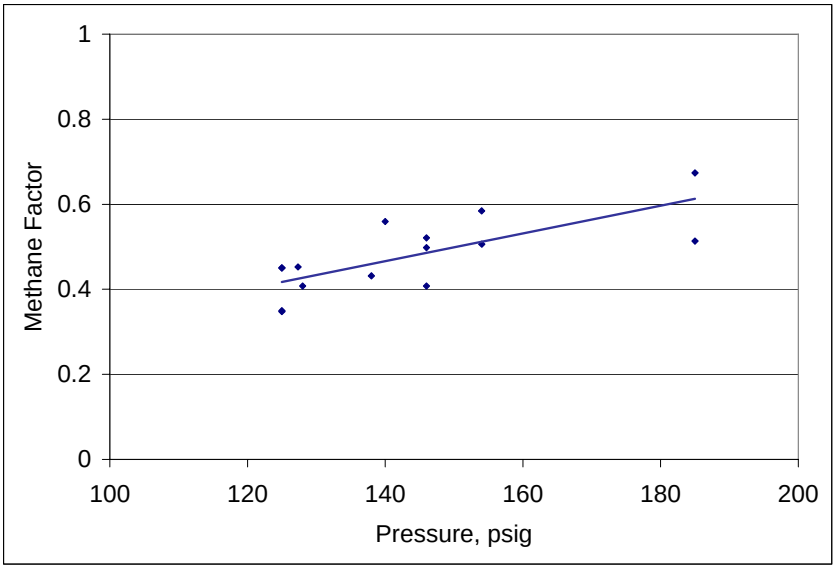

Figure 3-14. Syngas Methane Content as a Function of Gasifier Pressure.

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 3-15 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 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 due to consumption. Since less carbon is available to provide heat in the LMZ, and the LMZ temperature decreases, thus causing a larger temperature differential.

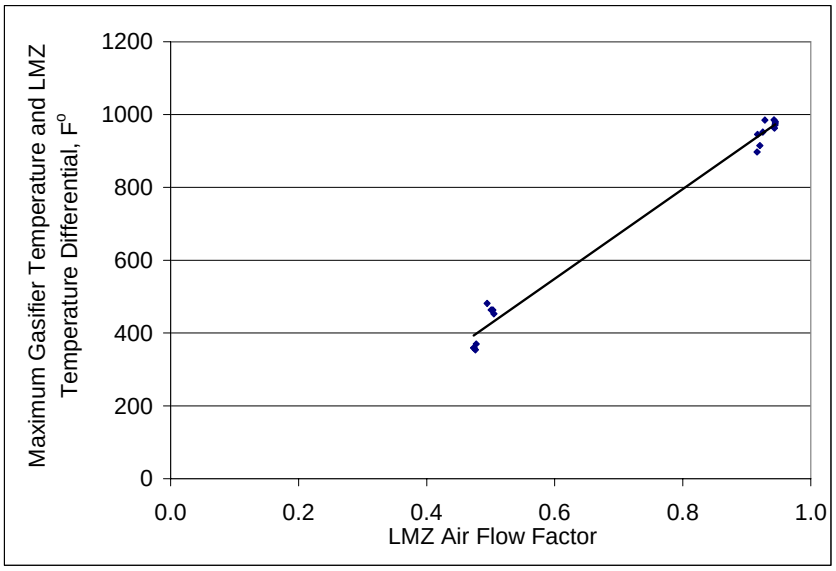

Figure 3-15. Gasifier Temperature Differential as a Function of LMZ Air Flow Rate.

Figure 3-16 shows the positive correlation of the raw dry syngas heating value and 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.

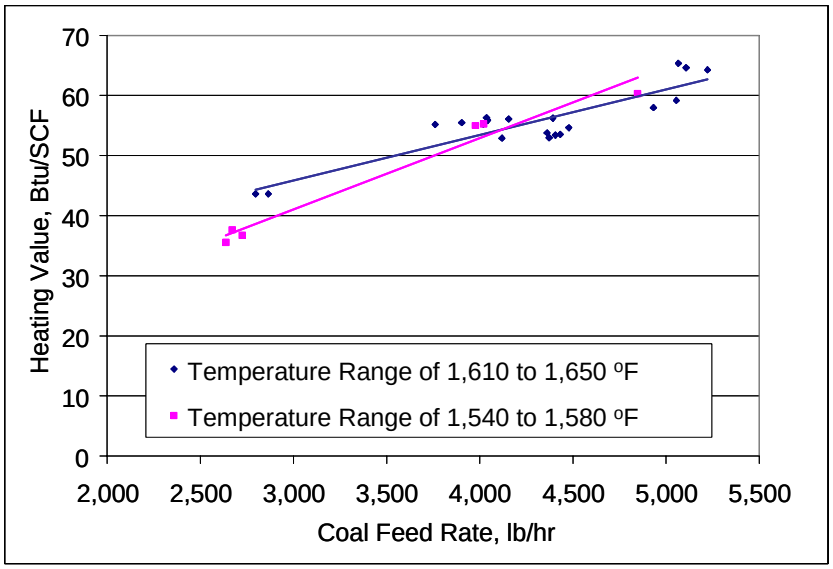

Figure 3-16. Syngas Heating Value as a Function of Coal Feed Rate.

Figure 3-17 shows the sulfur (in the form of H_2S and COS) removal as a function of calcium to sulfur molar ratio (Ca/S). Calcium originated from the coal ash and from dolomite, which was fed to the gasifier near the end of TC22. The data used were from steady state periods with mixing zone temperatures between 1,620 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, sulfur removal averaged 13.2 percent, the result of sulfur reaction with the coal ash calcium. At higher Ca/S values reached with dolomite feed, the average sulfur removal was about 32 percent, with up to 35 percent removal achieved at the highest dolomite feed rate.

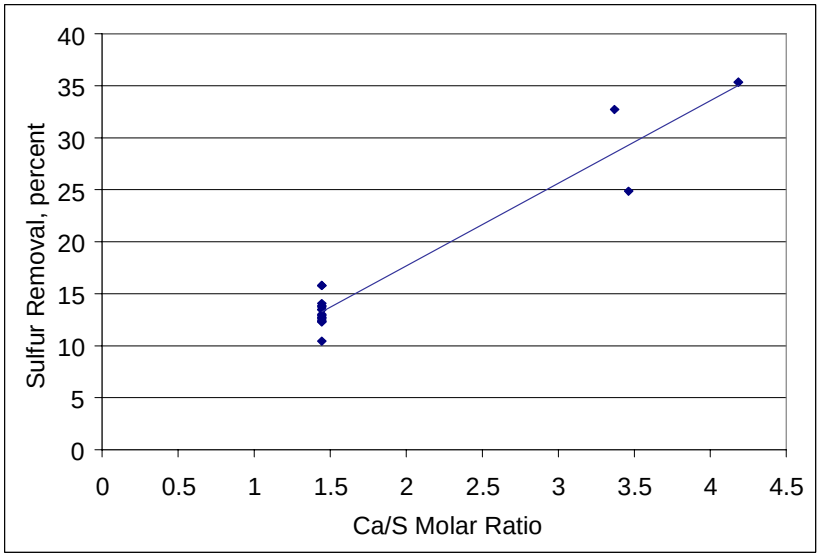

Figure 3-17. Sulfur Removal as a Function of Calcium-to-Sulfur Molar Ratio.

Figure 3-18 shows the linear relationship between solids circulation rate and gasifier standpipe level. Since most of the steady state data for TC22 were 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.

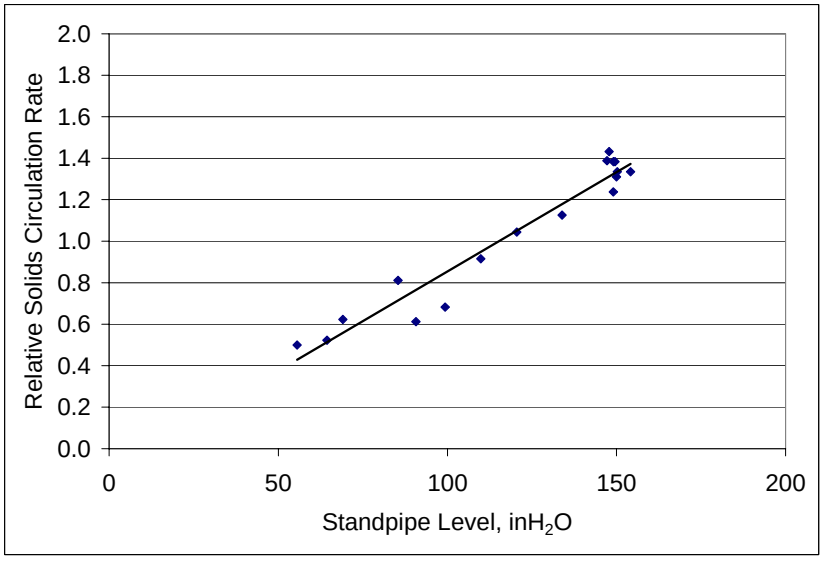

Figure 3-18. Effect of Standpipe Level on Circulation Rate.

3.5 Post-Test Inspections

Detailed inspections of the gasifier and related equipment were performed following TC22. Overall, the gasifier refractory was in good condition with no significant cracking or signs of excessive erosion, with the exception of the inlet of the first device in the solids separation unit, where some wear and cracking was observed.

Due to blockage of gas flow by damaged ceramic thermowell material, ash deposition occurred in the LMZ. Without proper aeration in the LMZ, hot spots may develop and cause the local temperature to exceed the ash melting temperature resulting in agglomeration of particles. Ash deposition was not observed in any other sections of the gasifier. Figure 3-19 shows the material found in the LMZ during the inspection.

Figure 3-19. Inspection of Lower Mixing Zone.

A photograph taken of the inlet of the primary syngas cooler during the inspection is included as Figure 3-20. The syngas cooler inlet was clean, and the exchanger tubes were free of deposition and fouling. The ceramic ferrules showed no signs of wear.

Figure 3-20. Inspection of Primary Syngas Cooler Inlet Tubesheet.

4.0 SENSOR DEVELOPMENT

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

4.1 Process Metrix Process Particle Counter

The heating of the window purge and cell coolant that were implemented prior to TC21 were successful in eliminating problems with window contamination in TC22. The PPC sample extraction and optical systems worked well in TC22, but the instrument was apparently not sensitive enough to detect the slight elevation of the baseline outlet particle loading.

There were two occasions when the PPC did indicate measurable particle concentrations during TC22. During the on-line failsafe test on April 16, 2007, the PPC detected an increase in concentration when the valve was opened to send particulate to the failsafe, and it detected another increase at the first backpulse after the failsafe tester was in service. However, the failsafe apparently plugged almost instantly. Because these events were of short duration a mass concentration could not be calculated from the PPC data.

The other occasion that the PPC detected a measurable concentration was during a test with high backpulse pressure in the PCD. For one hour on April 17, 2007, the PCD backpulse pressure was increased from 380 psig to 530 psig (from 250 to 400 psi above system pressure). During the lower pressure cleaning backpulses, the PPC did not detect a sufficient number of particles to calculate a result. However, during the higher pressure cleaning period, the particle concentration increased just after the backpulse, and the PPC detected particulate. The average of the PPC data over the hour long high pressure period was 0.12 mg/acm as opposed to under 0.01 mg/acm with lower pressure pulses. After the backpulse pressure was lowered to the previous level, no particulate was detected. Current coordination with the manufacturer involves identifying ways to increase the sensitivity of the instrument so the background particle level can be detected.

4.2 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. The use of HR-160 material will be expanded based on the improved thermowell durability and thermocouple longevity.

4.3 Ceramic-Tipped Pressure Differential Indicators

To reduce instrument purge flow requirements and reduce plugging problems, ceramic inserts were installed in 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 4-1 is a comparison of a ceramic-tipped measurement with 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 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 instrument purge flow meters, since with the ceramic-tipped instruments; they are operating at the low end of their ranges. Following TC22, these purge flow meters may be replaced with meters having a lower flow operating range.

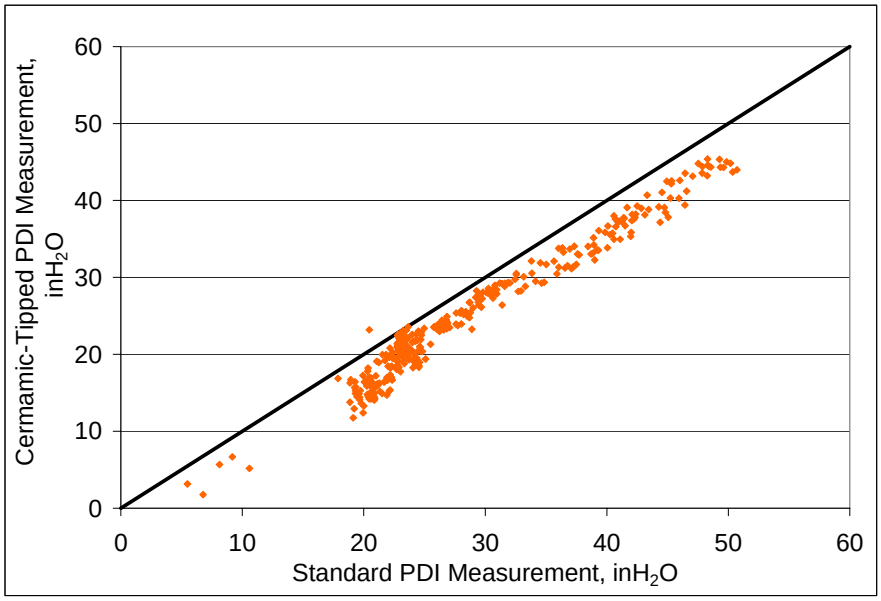

Figure 4-1. Comparison of Standard and Ceramic-Tipped PDI Measurements.

4.4 Sensor Research and Development Semi-Conducting Metal Oxide Sensors

Sensor Research and Development (SRD) Corporation developed, with DOE funding, a prototype sensor system for in situ real-time detection, identification, and measurement of coal-fired combustion gases. The PSDF provided the testing site for the SRD 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. 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.

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.

4.5 Babcock & Wilcox High Speed Pressure Sensors

EPRI has funded the development of advanced nonlinear signal analysis techniques and their application to coal combustion. Under sponsorship of EPRI, ORNL and 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 re-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.

5.0 PARTICULATE CONTROL DEVICE

The effects of high moisture and high ash lignite operation on PCD particulate characteristics and collection performance were quantified by in-situ particulate sampling at the inlet and outlet of the PCD and by physical and chemical analyses. Filter element testing continued with the exposure of 36 sintered-fiber Dynalloy HR-160 and 36 sintered-powder iron aluminide (FEAL) filter elements. On-line failsafe testing was conducted with one of the new prototype Pall reverse-media, sintered-fiber fuses using the new valve-actuated fail-safe tester that simulates a large leak in the main filter media. Further analyses of pressure drop performance and filter element condition were completed.

5.1 PCD Particulate Collection Performance

In-situ particulate sampling was performed at the PCD inlet and outlet using the in-situ batch sampling systems described in previous reports. The inlet particulate measurements were used to characterize PCD pressure drop performance and to calculate transient drag. The outlet measurements indicate the collection performance of the PCD. A new measurement technique was used on a TC22 sample to analyze the particles on the outlet filter and is described in that section.

5.1.1 PCD Inlet and Outlet In-Situ Measurements

The particulate concentrations measured at the PCD inlet and the corresponding mass rates are given in Table 5-1. Average particulate mass entering the PCD for the Mississippi lignite tests was 23,500 ppmw (501 lb/hr) with a range of 17,000 to 34,300 ppmw (325 to 729 lb/hr). Particulate concentrations measured at the PCD outlet are included in Table 5-1 and are plotted as a function of time in Figure 5-1. The graph also contains values measured during TC19, TC20, and TC21. Bars in the graph that are below the “Minimum Measurement Resolution” line are not actually measured values but merely placeholders to indicate the numbers of tests that had immeasurably low concentrations. As discussed in previous reports, it is common to see an elevated particulate concentration at the outlet of the PCD during the first few days of a test campaign. This may be due to seasoning of filter elements and plugging of gasket pores or to particulate from corrosion products and mechanical assembly of the PCD. During TC22, elevated outlet particulate loadings were observed throughout most of the test campaign. As discussed in the TC21 report, a fraction of these particles were determined by ignition or Energy Dispersive X-Ray Spectroscopy (EDS) to be iron sulfide.

Table 5-1. PCD Inlet and Outlet In-Situ Particulate Measurements.

	PCD Inlet					PCD Outlet				
Test Date	Run No.	Start Time	End Time	Particle Loading, ppmw	Particle Loading, lb/hr	Run No.	Start Time	End Time	H_2O Vapor, vol %	Particle Loading, ppmw[1]
3/25/07	1	16:00	16:15	21800	378	1	15:30	16:30	15.2	0.27
3/26/07	2	14:25	14:40	20000	325	2	12:30	14:30	15.1	0.59[2]
3/27/07	3	10:45	11:00	23000	352	3	10:00	11:47	13.1	0.33[2]
3/28/07	4	9:00	9:15	21800	345	4	8:30	12:30	12.0	<0.10
3/29/07	5	9:00	9:08	22400	360	5	8:45	13:43[3]	12.0	0.16
4/1/07	6	15:15	15:30	24100	570	--	--	--	--	--
4/2/07	7	12:15	12:30	27200	643	6	8:15	12:15	12.6	<0.10
4/3/07	8	8:45	9:00	20800	487	7	8:30	12:30	11.7	<0.10
"	9	12:00	12:15	24500	577	--	--	--	--	--
4/4/07	10	12:00	12:15	21700	499	8	9:45	13:45	12.7	0.10
"	11	13:45	14:00	21500	496	--	--	--	--	--
4/05/07	12	10:00	10:15	20800	477	9	8:30	12:30	11.1	0.16
4/06/07	13	12:55	13:10	23600	636	10	8:45	14:20[4]	10.4	0.16
"	14	14:10	14:25	23400	624	--	--	--	--	--
4/10/07	15	13:30	13:45	27100	582	11	13:05	15:05	10.2	0.21
4/11/07	16	13:00	13:08	24500	495	12	10:45	13:45	10.8	0.18
"	17	15:00	15:15	22900	468	--	--	--	--	--
4/12/07	18	10:45	10:56	34300	729	13	8:45	12:30	9.9	0.10
4/13/07	19	14:00	14:15	31200	600	14	13:00	15:00	8.6	0.11
4/14/07	20	8:30	8:45	25400	498	15	8:15	10:15	9.1	0.10
"	21	13:30	13:45	24500	496	16	12:30	14:05	10.7	< 0.10
4/16/07	22	9:00	9:15	17000	352	17	8:30	12:30	9.2	< 0.10
"	--	--	--	--	--	18	14:00	15:00	11.1	< 0.10[5]
4/17/07	23	13:15	13:30	24900	532	19	9:00	11:53	9.6	< 0.10[5]

Notes:
1. Some fraction of all measurable concentrations was iron sulfide.
2. Some fraction of this mass appears to be tar.
3. Sample stopped from 9:09 to 10:15 because of coal feeder trip.
4. Sample stopped from 8:59 to 12:20 because of coal feed problems.
5. Injection test of Pall Dynalloy prototype reverse media failsafe.

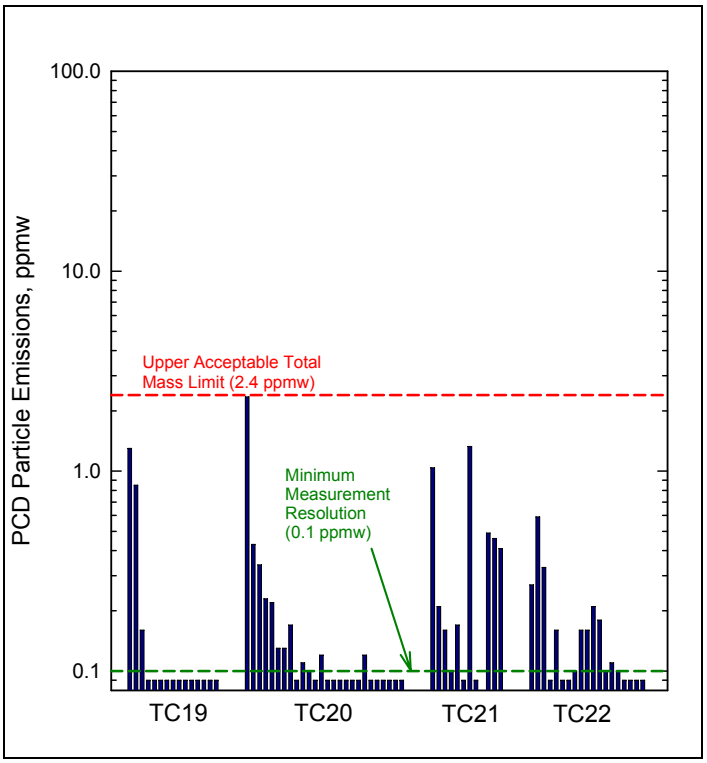

Figure 5-1. PCD Outlet Concentrations for Recent Gasification Test Campaigns.

There are several possible routes for the iron sulfide particulate to appear at the PCD outlet. A fine fume of iron sulfide particles generated in the gasifier could penetrate through the PCD filters, or the particles could be generated at the outlet of the PCD. Since some of the particles are as large as 5 microns, penetration through the PCD as a particulate seems unlikely. Penetration of a vapor through the PCD with downstream condensation during contact with cool back-pulse gas is possible, a mechanism for producing iron sulfide particles in this manner is not clear. Sources at the outlet of the PCD could include contaminated backpulse gas, contaminated instrument purge gas, or entrainment of corrosion products from the metal surfaces in the outlet of the PCD. This issue will be further evaluated during future test campaigns.

5.1.2 Failsafe Performance Tests

At the end of TC22, the background PCD outlet particulate concentrations were low enough that a failsafe test could be conducted. The failsafe installed was a Pall prototype, metal-fiber, reversed-media device similar to the one previously tested in TC20. A short-term test was conducted over the first hour of operation (Table 5-1, Outlet Run 18) and a second test was completed the next day after 19 hours of exposure. In neither test was a measurable particulate concentration observed.

5.2 PCD Solids Analysis

Important characteristics of the solids in assessing PCD performance include particle size distribution, bulk density, true density, porosity, surface area, composition, and flow resistance.

5.2.1 Particle Size Distributions

A Microtrac X-100 analyzer was used to measure the particle size distributions of the PCD hopper samples (sampled from the CFAD system) used for the laboratory drag measurements. The analysis of the hopper samples was important to confirm that they were representative samples for the laboratory flow resistance tests. Figure 5-2 compares the differential mass percentage distributions for the in-situ samples with the two hopper samples used for the TC22 lab drag measurements. The data almost perfectly overlay, indicating that the hopper samples selected are representative of the Mississippi lignite ash generated in TC22. The comparison also shows that there is very little difference in particle size distribution between the high- and low-carbon hopper samples selected for the lab drag measurements. Therefore, any difference in drag between these two samples can be attributed to the difference in carbon content.

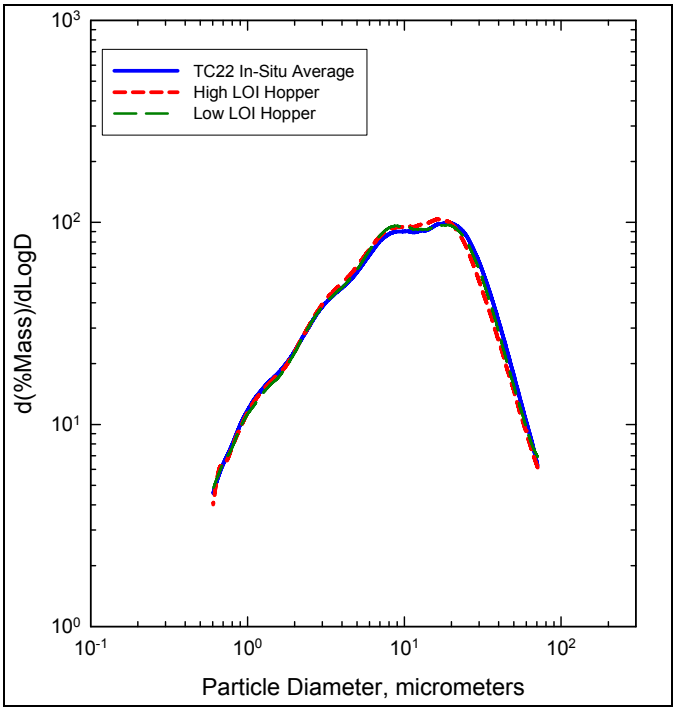

Figure 5-2. Comparison of Particle Size Distributions.

5.2.2 Dustcake Observations

At the conclusion of TC22, a dirty shutdown was performed, preserving the entire (transient plus residual) dustcake on the filter elements. The dustcake was generally smooth and fairly uniform on the HR-160 metal fiber elements and on the younger iron aluminide elements. However, the dustcake had a lumpy appearance on the older iron aluminide elements. The lumpy appearance may be related to the corrosion, sulfidation, and plugging of the iron aluminide with increasing syngas exposure. It appears that the lumpy areas are associated with plugged areas of the filter element that are no longer being effectively pulse cleaned.

The dustcake appeared to be thicker on the leading edge (i.e., the side of the element facing into the tangential gas flow). This effect has been noted in some previous runs and is a natural consequence of the swirling flow pattern created by the tangential entrance nozzle of the PCD.

Dustcake thickness measurements, which are summarized in Table 5-2, confirmed the variation in thickness between the leading and trailing edges of the elements.

Table 5-2. Dustcake Thickness Measurements.

Element Location	Element Type	PSDF No.	Mfr No.	Hrs Before TC22	Hrs After TC22	Leading Edge		Trailing Edge		General Appearance
						Top	Bottom	Top	Bottom	
B03	HR160	1731	75	1983	2526	---	---	0.0745	0.0772	Smooth
B06	HR160	1726	62	1983	2526	---	---	0.0678	0.0732	Smooth
B07	HR160	1725	61	1983	2526	0.1116	0.0976	---	---	Smooth
B13	HR160	1753	94	1674	2217	0.1185	0.0944	---	---	Smooth
T10	FEAL	2036	None	1777	2320	---	---	0.0789	0.0998	Smooth
T11	FEAL	2037	None	1258	1801	0.1052	0.1149	---	---	Smooth
T15	FEAL	1652	39128	6263	6806	---	---	0.0854	0.0652	Lumpy
T16	FEAL	1655	39131	6263	6806	0.0814	0.0832	---	---	Lumpy
Average						0.1042	0.0975	0.0767	0.0789	

5.2.3 Particulate Physical Properties and Chemical Compositions

Measurements of the physical properties and chemical composition were made on all of the in-situ samples collected at the PCD inlet, on hopper samples that were used for laboratory drag measurements and on the bulk and transient dustcake samples collected after TC22. The two hopper samples were selected to represent relatively low and high values of non-carbonate carbon (NCC) to examine the effect of NCC on surface area and drag.

In-situ Samples. Tables 5-3 and 5-4 give the physical properties and chemical compositions of the in-situ samples collected at the PCD inlet and the two hopper sample used for lab drag measurements. All of the in-situ samples had fairly consistent densities and porosities, but there were substantial variations in surface area and non-carbonate carbon (NCC) content. As observed in the past, the surface area increased with increasing NCC (see Figure 5-3). Compared to gasification ash from PRB coal, the gasification ash from the Mississippi lignite is generally lower in NCC and in surface area. In the past, this same trend has been noted with North Dakota lignite coals. Nevertheless, the surface area and NCC data from TC22 fall on the same trend line established previously for PRB gasification ash, as illustrated in Figure 5-3.

Table 5-3. Physical Properties of In-Situ Samples and Samples Used for Lab Measurements.

Sample ID	Run No.	Sample Date	Bulk Density, g/cc	True Density, g/cc	Bulk Porosity, %	Surface Area, m^2/g	Mass Median Particle Size, µm	Loss on Ignition, %
In-Situ Samples, Mississippi Lignite								
AB23035	1	03/25/07	0.45	2.71	83.4	33.9	13.7	4.38
AB23036	2	03/26/07	0.47	2.78	83.1	22.5	12.2	2.24
AB22865	3	03/27/07	0.45	2.67	83.1	49.8	11.0	7.06
AB23037	4	03/28/07	0.46	2.79	83.5	38.8	12.5	4.09
AB23038	5	03/29/07	0.45	2.78	83.8	31.7	14.5	4.10
AB23039	6	04/01/07	0.39	2.56	84.8	97.6	10.8	14.85
AB23003	7	04/02/07	0.41	2.54	83.9	100.0	10.1	16.35
AB23040	8	04/03/07	0.39	2.60	85.0	79.9	12.5	11.38
AB23041	9	04/03/07	0.40	2.59	84.6	92.7	8.9	13.73
AB23042	10	04/04/07	0.49	2.70	81.9	52.6	10.5	6.74
AB23043	11	04/04/07	0.42	2.67	84.3	58.8	10.9	7.60
AB23064	12	04/05/07	0.46	2.73	83.2	49.9	11.6	5.93
AB23111	13	04/06/07	0.38	2.47	84.6	84.7	10.3	14.05
AB23112	14	04/06/07	0.40	2.51	84.1	91.2	12.6	14.76
AB23154	15	04/10/07	0.49	2.66	81.6	50.0	11.6	6.25
AB23207	16	04/11/07	0.45	2.77	83.8	27.2	11.1	3.24
AB23208	17	04/11/07	0.44	2.74	83.9	29.7	11.6	3.57
AB23209	18	04/12/07	0.52	2.71	80.8	48.6	10.8	6.00
AB23263	19	04/13/07	0.48	2.75	82.5	46.4	10.7	6.12
AB23264	20	04/14/07	0.44	2.61	83.1	57.0	9.3	8.82
AB23265	21	04/14/07	0.44	2.70	83.7	45.0	9.4	5.87
AB23290	22	04/16/07	0.44	2.62	83.2	60.9	9.6	8.50
AB23294	23	04/17/07	0.47	2.75	82.9	41.9	11.7	4.36
Samples Used for Lab Drag Measurements								
AB23326	CFAD Composite	04/02/07	0.43	2.61	83.5	80.7	10.5	13.21
AB23327	CFAD Composite	04/15/07	0.43	2.66	83.8	54.6	10.6	7.18

Hopper Samples. For lab drag measurements, two composite hopper samples were prepared: one from April 2, when the NCC was 14.3 percent, and one from April 15, when the NCC was

7.8 percent. This difference in NCC would be expected to correspond to a significant difference in drag. Otherwise, the composite hopper samples appear to be similar to the in-situ samples in terms of physical properties and chemistry, and thus representative for the lab measurements.

Table 5-4. Chemical Composition of In-Situ Samples and Samples Used for Lab Measurements.

Sample ID	Run No.	Sample Date	$CaCO_3$ Wt %	CaS Wt %	CaO Wt %	Non-Carbonate Carbon Wt %	Inerts (Ash/Sand) Wt %	Loss on Ignition Wt %
In-Situ Samples - Mississippi Lignite								
AB23035	1	03/25/07	1.20	2.08	14.35	5.12	77.24	4.38
AB23036	2	03/26/07	0.84	0.65	16.10	2.38	80.03	2.24
AB22865	3	03/27/07	1.32	1.99	14.19	6.94	75.56	7.06
AB23037	4	03/28/07	1.07	1.57	15.06	4.62	77.68	4.09
AB23038	5	03/29/07	1.14	1.59	15.76	4.71	76.80	4.10
AB23039	6	04/01/07	2.70	4.31	10.47	14.78	67.74	14.85
AB23003	7	04/02/07	3.05	4.18	9.69	16.55	66.54	16.35
AB23040	8	04/03/07	2.14	3.38	11.65	11.42	71.41	11.38
AB23041	9	04/03/07	3.05	3.42	10.77	14.63	68.13	13.73
AB23042	10	04/04/07	1.30	1.77	14.54	7.25	75.14	6.74
AB23043	11	04/04/07	1.52	1.99	14.07	7.88	74.54	7.60
AB23064	12	04/05/07	1.27	1.95	14.73	6.65	75.40	5.93
AB23111	13	04/06/07	2.77	4.20	10.19	15.31	67.54	14.05
AB23112	14	04/06/07	2.89	4.32	9.75	14.69	68.35	14.76
AB23154	15	04/10/07	1.43	2.29	14.09	7.30	74.89	6.25
AB23207	16	04/11/07	1.00	1.30	15.91	3.80	77.99	3.24
AB23208	17	04/11/07	1.05	1.28	15.79	4.07	77.81	3.57
AB23209	18	04/12/07	1.43	1.63	13.83	6.48	76.63	6.00
AB23263	19	04/13/07	1.57	1.82	14.06	6.78	75.77	6.12
AB23264	20	04/14/07	2.09	2.40	12.31	9.69	73.51	8.82
AB23265	21	04/14/07	1.61	1.61	14.18	6.47	76.13	5.87
AB23290	22	04/16/07	2.16	2.22	13.38	9.55	72.70	8.50
AB23294	23	04/17/07	2.02	1.57	17.35	5.06	74.00	4.36
Samples Used for Lab Drag Measurements								
AB23326	CFAD Composite	04/02/07	1.20	3.71	11.85	14.25	68.99	13.21
AB23327	CFAD Composite	04/15/07	1.20	2.26	13.65	7.82	75.07	7.18

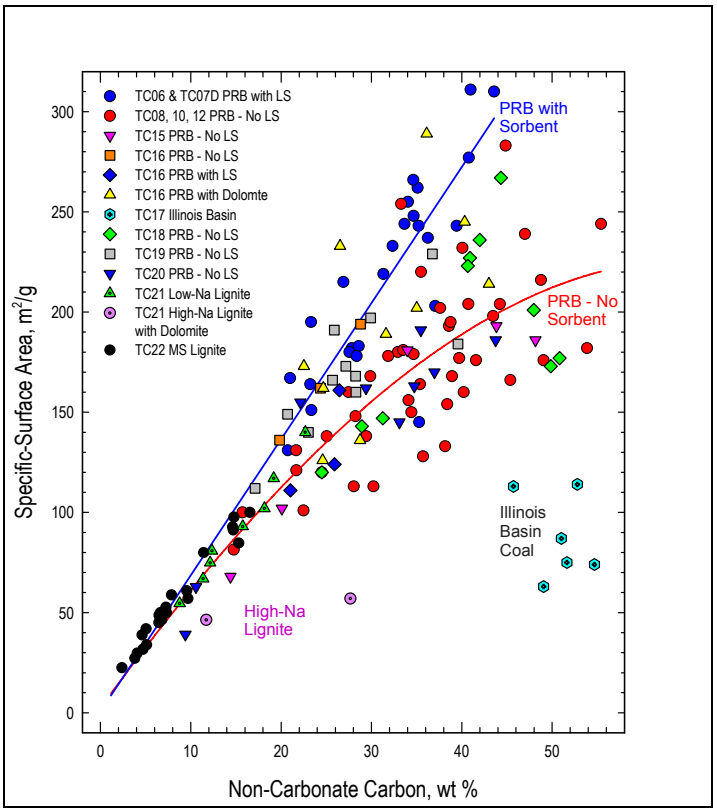

Figure 5-3. Effect of Carbon Content on Specific Surface Area of Gasification Ash.

Dustcake Samples. Tables 5-5 and 5-6 give the physical properties and chemical composition of the bulk and transient dustcake samples collected after the dirty shutdown at the end of TC22. The bulk and transient dustcake samples are very similar in terms of both physical properties and chemistry. This result is not surprising, considering that the bulk cake is primarily composed of transient cake. The cake samples are also very similar to the in-situ samples collected at the PCD inlet, suggesting that there is little effect of dropout ahead of the filter elements.

Table 5-5. Physical Properties of Dustcake Samples.

Sample ID	Sample Location	Bulk Density g/cc	True Density g/cc	Uncompacted Bulk Porosity %	Specific Surface Area m^2/g	Mass-Median Diameter μm	Loss on Ignition Wt %
AB23321	Top Plenum Bulk	0.41	2.79	85.3	39	10.2	4.82
AB23322	Bottom Plenum Bulk	0.44	2.79	84.2	37	11.7	3.86
AB23323	Top Plenum Transient	0.42	2.84	85.2	43	10.3	4.72
AB23324	Bottom Plenum Transient	0.40	2.80	85.7	39	11.9	3.96

Table 5-6. Chemical Composition of Dustcake Samples.

Sample ID	Sample Location	$CaCO_3$ Wt %	CaS Wt %	CaO Wt %	Non-Carbonate Carbon Wt %	Inerts (Ash/Sand) Wt %	Loss on Ignition Wt %
AB23321	Top Plenum Bulk	1.18	2.41	18.86	5.03	72.52	4.82
AB23322	Bottom Plenum Bulk	1.75	2.57	18.60	4.71	72.37	3.86
AB23323	Top Plenum Transient	1.43	2.46	18.73	5.01	72.37	4.72
AB23324	Bottom Plenum Transient	1.52	1.41	19.29	4.44	73.34	3.96

5.3 PCD Pressure Drop Performance

Transient PCD Drag. The pressure drop rise within a cleaning cycle of the PCD is a direct measure of the characteristics of the particulate being collected at that time. Under stable operation the vast majority of this particulate is removed from the filter elements during cleaning so this is referred to as the transient pressure drop. Since pressure drop is a function of the gas velocity, temperature (gas viscosity), particulate loading, and the flow resistance of the particulate, describing PCD operation in terms of pressure drop makes comparison of different conditions and particulates difficult. Therefore, a value of normalized drag is calculated, and is pressure drop that is normalized to 1 ft/min face velocity, 1 lb/ft^2 areal particulate loading, and viscosity of air at 70°F. The result is a fundamental parameter that describes the flow resistance of the collected dustcake, and it allows direct comparisons to the drag measurements made in the lab.

During each in-situ sampling run at the PCD inlet, the PCD transient drag was calculated using the measured particulate concentration along with the pressure drop increase and face velocity during the period of the in-situ test. All of the particulate measured at the PCD inlet is assumed to be collected on the filter elements and to contribute to pressure drop. The inputs and results of the drag calculations are shown in Table 5-7. The calculated transient drag at PCD conditions is listed under the column heading "PCD." The corresponding value of transient drag normalized for viscosity (air at room temperature) is listed under the heading "PCD@RT". These values are comparable to the lab drag measurements discussed in a later section and may also be compared directly to other test campaigns that operated at different temperatures.

Table 5-7. Transient Drag Determined from PCD Pressure Drop and from Lab Measurements.

Run No.	ΔP/Δt, inwc/min	Δ(AL)/Δt, lb/ft^2/min	FV, ft/min	MMD, μm	NCC, %	Drag, inwc/(lb/ft^2)/(ft/min)		
						PCD	PCD@RT	Lab
1	0.66	0.029	3.80	13.7	5.12	23	14	29
2	0.80	0.025	3.59	12.2	2.38	32	20	31
3	0.93	0.027	3.26	11.0	6.94	34	21	39
4	0.81	0.027	3.44	12.5	4.62	30	19	32
5	0.68	0.028	3.44	14.5	4.71	24	15	27
6	2.78	0.044	3.78	10.8	14.78	63	38	47
7	3.48	0.050	3.81	10.1	16.55	70	42	53
8	2.50	0.038	3.81	12.5	11.42	67	40	36
9	2.84	0.044	3.82	8.9	14.63	64	38	59
10	1.81	0.038	3.73	10.5	7.25	47	28	41
11	1.76	0.039	3.75	10.9	7.88	46	27	40
12	1.36	0.037	3.73	11.6	6.65	37	22	36
13	2.36	0.049	4.45	10.3	15.31	48	29	50
14	3.24	0.048	4.41	12.6	14.69	67	40	39
15	1.91	0.045	5.11	11.6	7.30	43	26	37
16	1.26	0.038	4.12	11.1	3.80	33	20	36
17	1.21	0.036	4.18	11.6	4.07	34	20	34
18	2.15	0.056	5.36	10.8	6.48	38	23	39
19	2.13	0.046	4.48	10.7	6.78	46	28	40
20	1.96	0.038	4.61	9.3	9.69	51	31	50
21	1.29	0.038	3.97	9.4	6.47	34	20	46
22	1.35	0.027	4.14	9.6	9.55	50	30	48
23	1.63	0.041	4.58	11.7	5.06	40	24	34
Avg	1.78	0.039	4.1	11.2	8.35	44	27	40
Lab drag data calculated from linear regression to MMD and NCC of lab drag samples.								

Nomenclature:

ΔP/Δt = rate of pressure drop rise during particulate sampling run, inwc/min.

Δ(AL)/Δt = rate of increase in areal loading during sampling run, lb/min/ft^2.

FV = average PCD face velocity during particulate sampling run, ft/min.

MMD = mass-median diameter of in-situ particulate sample, μm.

NCC = non-carbonate carbon. LOI = Loss On Ignition.

RT = room temperature, 77°F (25°C).

The TC22 data shown in the table indicate an average normalized drag value of 27 inwc/(ft/min)/(lb/ft^2). This is much lower than the TC20 value of 78 inwc/(ft/min)/(lb/ft^2) with PRB coal. The much lower drag with the lignite coal is attributable to the larger particle size distribution, lower surface area, lower carbon content of the particulate, and perhaps differences in particle morphology. Because of the reduced drag, the increased mass loading to

the PCD with the higher ash content of the lignite fuel should not result in significantly increased PCD pressure drop.

Normalized PCD transient drag is plotted as a function of carbon content in Figure 5-4. This graph has been simplified from that shown in previous reports in that only data points since TC20 are plotted. The dashed line is a linear regression to all previous PRB data for comparison with recent data. As seen in previous test campaigns, transient drag increases with increasing carbon content in the gasification ash. This correlation shows a lot of scatter in the data, particularly for the PRB data, because it does not take into account the effect of particle size and morphology. The Mississippi lignite data are nicely grouped below the average trend for the PRB. The TC22 data are somewhat higher than the North Dakota lignite tested in TC21.

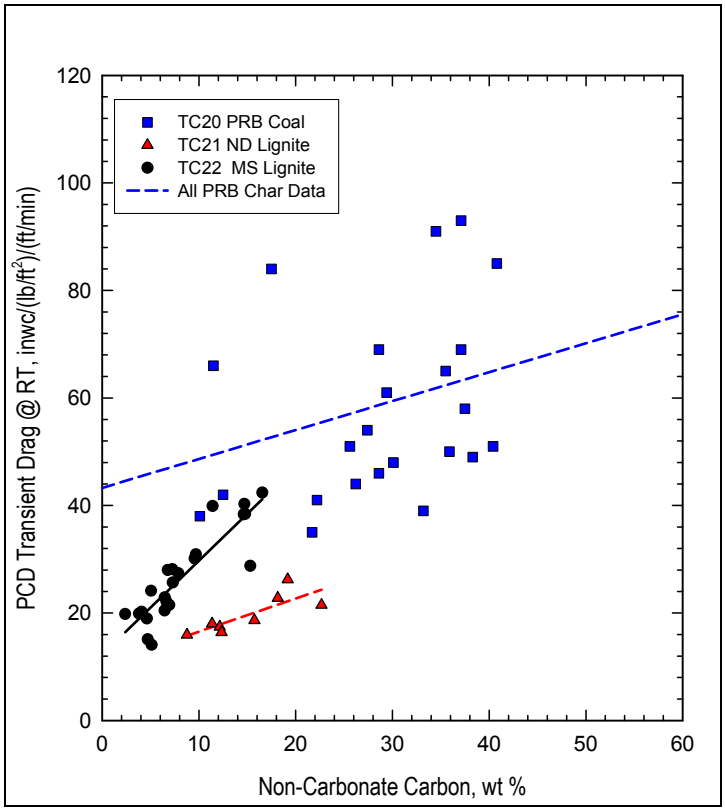

Figure 5-4. PCD Transient Drag versus Carbon Content of In-Situ Samples.

Baseline Pressure Drop Analysis. Figure 5-5 shows the PCD baseline pressure drop trends for the TC20 to TC22 test campaigns. The baseline pressure drop values have been unremarkable for the recent test campaigns. However, it does not appear that the pressure drop with the Mississippi lignite had fully stabilized by the end of the test campaign and was continuing to increase with time. A longer test in the future is indicated to determine if this value will stabilize at a reasonable level.

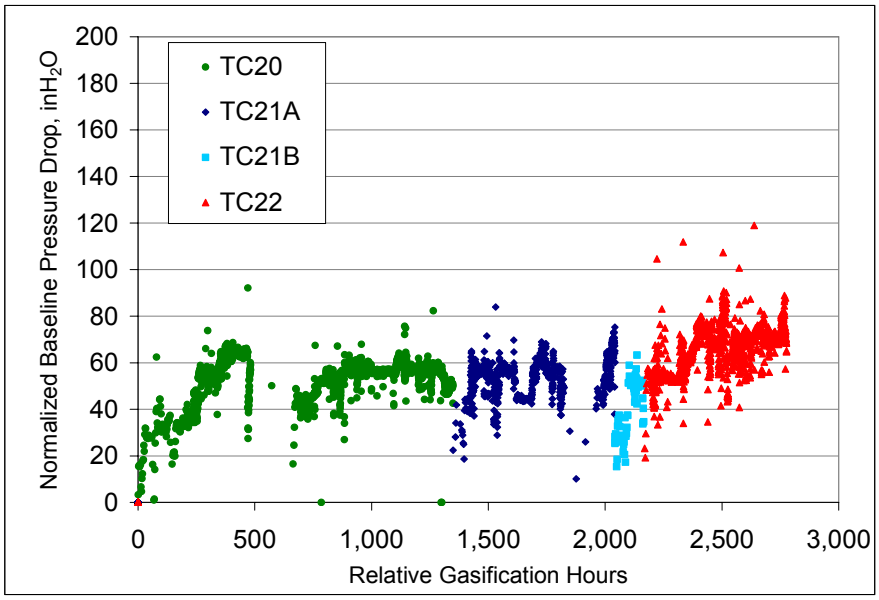

Figure 5-5. Normalized PCD Baseline Pressure from TC20 through TC22.

Prediction of PCD Drag and Pressure Drop. To fully characterize particulate, drag measurements were made in the lab flow resistance test device on the two hopper samples described previously. This lab apparatus uses a series of cyclones between the dust generator and the dustcake collection surface to vary the particle size distribution of the dustcake. The results are illustrated in Figure 5-6 with normalized drag plotted against the MMD of the collected dustcake. The actual lab data points are indicated by the triangles, while the solid lines are linear regressions to the data.

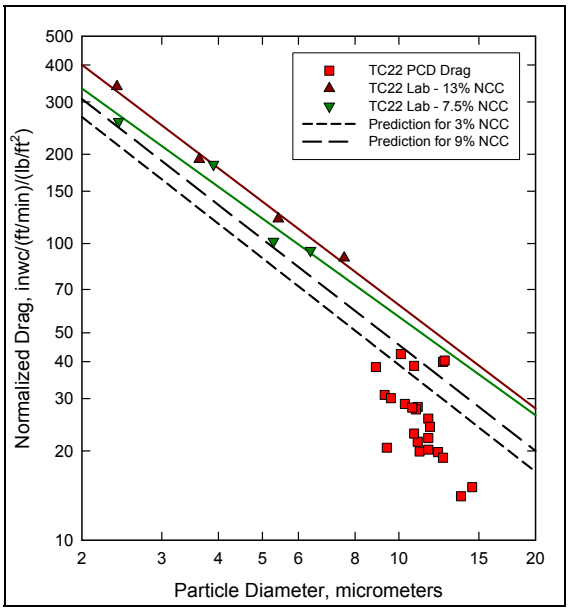

Figure 5-6. Lab-Measured Drag as a Function of Particle Size.

The solid square symbols on the graph are the actual values of PCD transient drag calculated for each of the in-situ samples from Table 5-7. As seen in recent test campaigns, all of the PCD data points fall below the lab measurements partially because of differences in carbon contents. When the actual value of carbon in the lab samples was used (14 to 25 percent) instead of the bulk value of 7 to 16 percent, the following multiple regression equation was obtained:

Drag = 10^(2.762 – 1.192 • Log(MMD) + 0.00947 • NCC), with an $r^2 = 0.97$.

The regression was used to calculate drag versus particle size with two different carbon contents that are equal to the lowest and the average carbon contents of the in-situ samples, 3 and 9 percent NCC, respectively. These predictions are shown on Figure 5-6 as the dashed lines. Although not in perfect agreement, the predictions made from the regression technique match the PCD data reasonably well.

The results of regression predictions for each individual value of PCD transient drag are shown in the rightmost column of Table 5-7. These calculations use the MMD and NCC of each in-situ sample to predict the transient drag of the PCD during that test. The lab predictions are higher than the actual PCD data for most individual values and the average for TC22, but this still appears to be reasonable agreement.

5.4 Analysis of PCD Filter Element Condition

At the end of TC22, eight of the FEAL filter elements and four of the HR-160 filter elements were removed from the PCD for flow tests and inspection. This included the six iron aluminide reference elements and two HR-160 reference elements. Figure 5-7 shows the results of flow tests on the FEAL elements for both TC21 and TC22. The data continue to show significant increases in pressure drop with advanced age for these filter elements. Even after pressure washing, these older iron aluminide elements had pressure drops that were four to five times higher than the pressure drop of a virgin iron aluminide element.

The flow test results for the HR-160 elements (Figure 5-8) did not show that the pressure drop of the HR-160 filter elements was correlated with the length of syngas exposure. This graph shows dirty pressure drops for all HR-160 elements installed in TC21 plus the reference elements from TC22. However, these elements have accumulated only 2500 hours of gasification exposure.

Detailed inspection of the reference elements showed no evidence of corrosion in the HR-160 elements and a continuation of the progressive corrosion seen previously in the iron aluminide reference elements. The three oldest iron aluminide reference elements, with 9,478 hours; 8,064 hours; and 6,678 hours of syngas exposure, were covered with both reddish-brown and black corroded areas. The surfaces of these older iron aluminide elements were noticeably roughened, and pitted areas could be seen under the optical microscope. The pitted areas were surrounded by reddish-brown rims of iron oxide that was apparently transported out of the pit and deposited around the periphery.

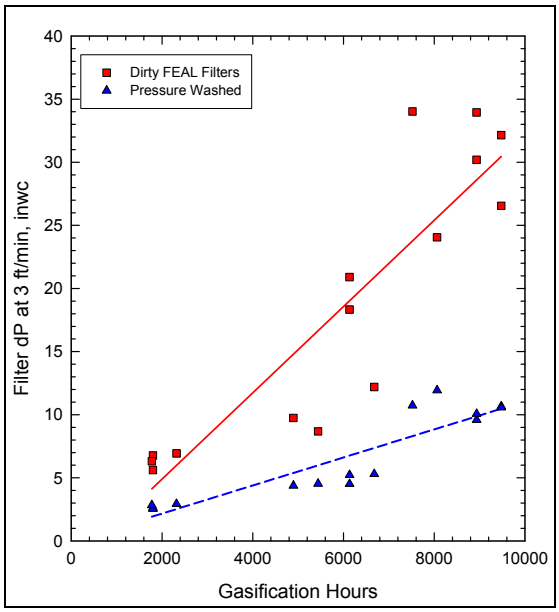

Figure 5-7. FEAL Filter Element Pressure Drop versus Gasification Hours.

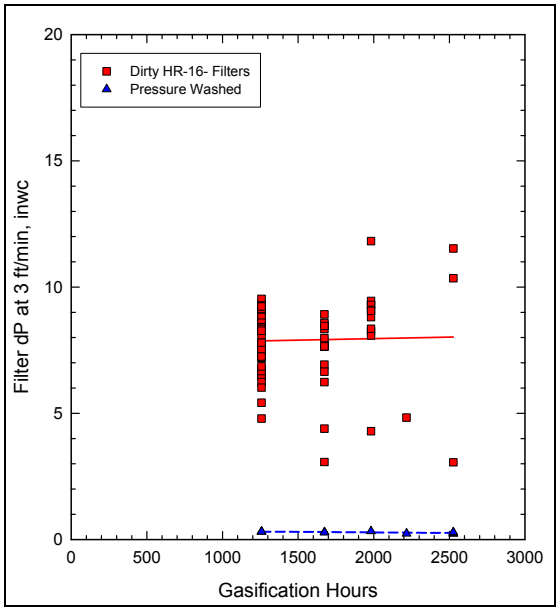

Figure 5-8. HR-160 Filter Element Pressure Drop versus Gasification Hours.

Past inspections have shown that the progressive corrosion of the iron aluminide begins as spots of reddish-brown iron oxide that first appear after about 2,000 to 3,000 hours of syngas exposure. As the corrosion progresses, the spots of iron oxide merge to form a continuous scale after about 5,000 to 5,500 hours of exposure. With additional exposure, a black scale containing iron sulfide also appears, and localized areas of sulfidation and plugging can be seen by SEM/EDS (Scanning Electron Microscopy/Energy Dispersive Spectroscopy) examination of element cross sections. The oldest iron aluminide elements removed after TC22 showed signs of all these effects.

While the iron aluminide corrosion has not yet resulted in any significant reduction in the tensile strength of the filter media, the corrosion may be playing a role in the gradual increase in filter element pressure drop with increasing syngas exposure. It is clear that even the pressure-washed iron aluminide elements are experiencing an increase in pressure drop with increasing syngas exposure. Based on microscopic examination of the element surface and element cross sections, it appears that the pressure washing effectively removed all of the ash from these elements; and there is very little ash penetration into the iron aluminide elements. Therefore, the curve for the pressure-washed elements represents the effects of the corrosion and sulfidation. As expected, higher pressure drops are obtained for the elements with the tightly bonded residual cake still in place. The rate of increase in the pressure drop becomes more rapid at longer exposure times, showing the effect of the corrosion and sulfidation. Based on these results, there appears to be an interaction between the corrosion products and the adherent dustcake that is accelerating the increase in pressure drop.

6.0 ADVANCED SYNGAS CLEANUP

The advanced syngas cleanup unit was used in TC22 to test a COS hydrolysis catalyst, trace metal sorbents, a sulfur removal sorbent, and syngas cooler fouling potential.

6.1 COS Hydrolysis

The Alcoa F200 catalyst, which was previously tested in TC21, was tested as the COS hydrolysis catalyst in TC22 for about 214 hours bringing the total time tested to 527 hours. The F200 catalyst is an aluminum oxide based catalyst with a proprietary active ingredient. The operating temperature ranged from 415 to 430°F and the pressure ranged from 100 to 125 psig. As shown in Figure 6-1, the COS hydrolysis testing resulted in COS conversions ranging from 82.1 to 96.2 percent, with an average value of 88.8 percent.

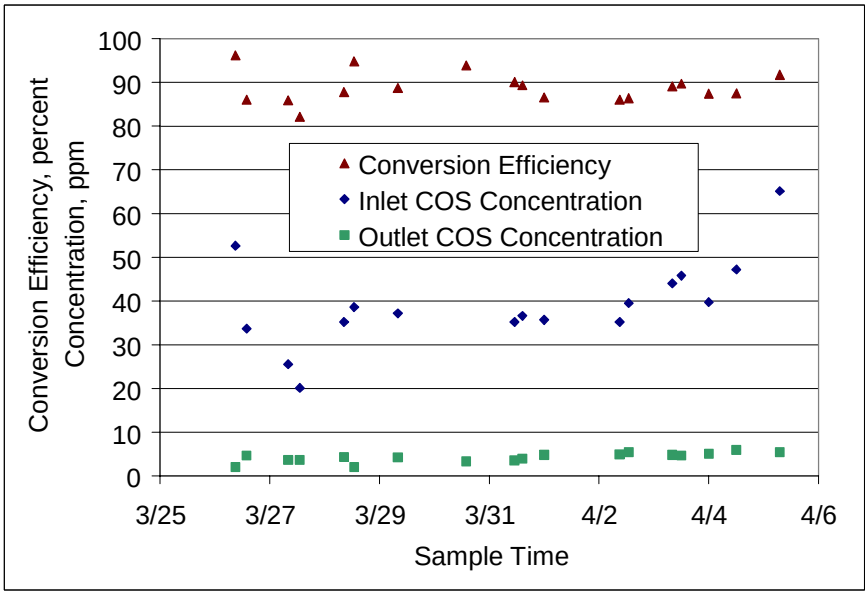

Figure 6-1. COS Inlet and Outlet Concentrations and COS Conversion Efficiency.

6.2 TDA Research Trace Metals Removal

The sorbent-based high temperature trace metal removal process being developed by TDA Research under sponsorship of DOE was tested in the advanced syngas cleanup unit at the PSDF during TC22. The process is designed to remove trace metals, including mercury, arsenic, selenium, and cadmium, from coal-derived syngas in a single step. Single step high temperature removal is potentially beneficial for future gasification power systems because of improved overall efficiency compared to cold gas cleanup systems and lower capital and operating cost due to the reduced amounts of sorbent required as compared to currently available trace metals removal technologies.

Initial testing by TDA Research began in late 2006, and continued throughout TC22. During TC22, over 200,000 SCF of syngas was treated. Post testing analysis indicated that the sorbent

may achieve high mercury removal efficiency. Results of the testing will be made available by TDA Research.

6.3 Sulfur Removal

Two sulfur sorbents from Synetix, Puraspec 2010 and Puraspec 2020, were used to reduce sulfur in the syngas supplied to TDA Research. The sorbents are composed mainly of zinc oxide with a proprietary active ingredient. The sorbents were effective in reducing the syngas sulfur levels below the detection limit, typically 1.5 ppm.

6.4 Fouling Potential in the Slipstream Syngas Cooler

The syngas cooler installed on the syngas slipstream unit was operated for 214 hours with a syngas flow from 18 to 25 lb/hr. The inlet temperature was 430°F and the outlet temperature was maintained at 130°F by plant cooling water. There was no exchanger tube fouling from organics observed. The condensate removed was clear and free of any heavy organic compounds.

7.0 SUPPORT EQUIPMENT

A ruptured bag in the ash transport system baghouse caused material carryover into the atmospheric syngas combustor, the combustor operations remained stable. However, the material eventually deteriorated the waste heat boiler performance of the waste heat boiler eventually forcing termination of the test run. In addition the main baghouse downstream of the atmospheric syngas burner and waste heat boiler also had several bags fail causing an intermittent discharge of particulate. This operating issue caused the annual compliance testing to be delayed until the next test campaign.

Recycle Gas Compressor. The recycle gas compressor supplied syngas for gasifier aeration for 256 hours during TC22. Steady state operating conditions at the recycle gas compressor outlet as well as the recycle syngas flow rate to the gasifier are shown in Figure 7-1. There were several compressor trips due interlock logic that shuts the compressor down under certain gasifier operating conditions that were caused due to coal feed interruptions. The recycle gas compressor was operated intermittently beginning at Hour 200. 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 recycle gas 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.

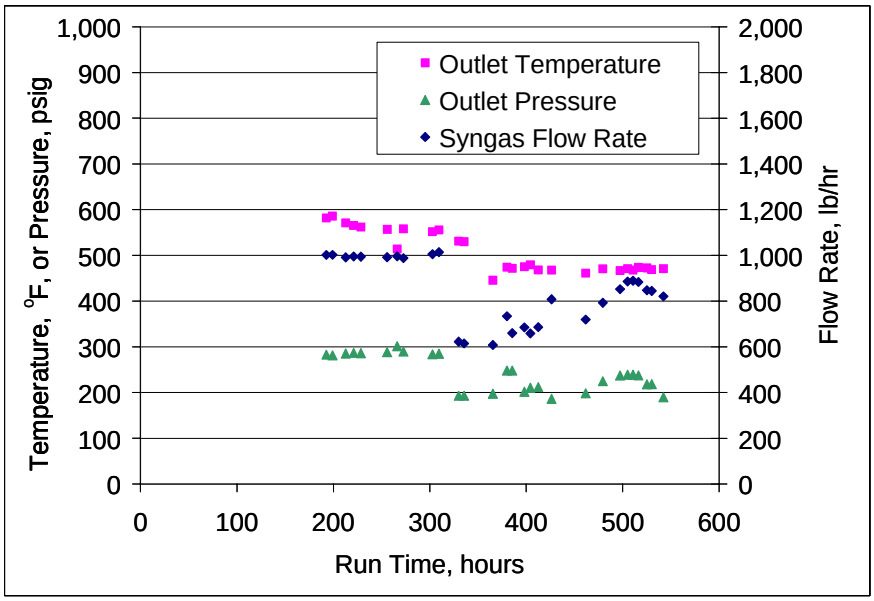

Figure 7-1. Recycle gas Compressor Operating Conditions.

8.0 CONCLUSIONS

The major focus of test campaign TC22 was characterization of the gasifier operation and performance with high moisture lignite from the Red Hills mine, located in Ackerman, Mississippi. TC22 began on March 24, 2007, and lasted until April 17, 2007, achieving 543 hours of gasification operation in air-blown mode and increasing the total PSDF gasification operation to over 10,000 hours. In addition to characterizing operation and performance of the modified gasifier and related equipment with the high moisture lignite, test objectives included testing of coal feeders, hot gas filter elements and failsafes, gasifier instrumentation enhancements, and advanced syngas cleanup.

Lessons Learned. The following list shows key lessons learned from TC22 operation.

- Higher conveying velocities are needed to prevent coal feeder discharge line plugging when feeding lignite with a particle size greater than 400 microns and an oversize percentage greater than 10 percent with moisture content greater than 25 weight percent. The moisture content should be less than 25 weight percent for reliable feeding. Conveying velocities of about 75 ft/s were effective in reducing the number of trips to about one per day as compared to eight per day; however, significant erosion occurred in the conveying line near the gasifier. A high percentage of fines (material smaller than 45 microns) caused lock hopper operational problems. Increasing the surge bin fluidization, decreasing the amount of material transferred during a cycle, and increasing the fluidization of the lock vessel during fill cycles improved feeder operation.
- Gasifier parametric tests confirmed several expected performance correlations.
    - The syngas heating value increased with increases in the coal feed rate.
    - The carbon conversion in the gasifier increased with the gasifier operating temperature. At high coal feed rates, carbon conversion was a weak function of temperature in the range tested.
    - There was very little tar in the syngas over the range of temperatures tested.
    - The carbon conversion increased and the syngas heating value decreased as the air-to-coal ratio was increased.
    - The methane content was higher at higher operating pressures in the pressure range tested.
    - The solids circulation showed a positive linear correlation with the standpipe level. Increasing the standpipe level increased the circulation rate, and as the circulation rate increased, the temperature difference from the mixing zone to the gasifer exit decreased.
    - The differential temperature from the LMZ to the gasifier maximum temperature increased as the air flow to the LMZ was increased due to carbon depletion in the solids in the LMZ.
- About 30 percent removal of sulfur from the syngas can be achieved by injecting dolomite into the gasifier at a calcium-to-sulfur molar ratio of about 4 mole/mole.
- About 30 to 75 percent of the fuel bound nitrogen was converted to ammonia.
- There was good agreement for the moisture content in the syngas between the in-situ measurements at the PCD outlet and the FTIR.
- Thermowell testing showed that while ceramic thermowells provide excellent longevity in the corrosive and erosive gasifier environment, they break easily during routine

maintenance activities. In addition, temperature measurements made with thermocouples inserted 2 and 4 inches into the gasifier showed that temperature was 8 to 10 degrees higher when measured at the longer insertion length.

- Density and pressure differential measurements gave evidence that the fluidization gas requirements for Mississippi lignite ash were less than for Powder River Basin coal or North Dakota lignite ash and that over-fluidization could prevent the solids from flowing smoothly from the separation devices into the standpipe.
- The failsafe injection test conducted on a Pall HR-160 reversed-media failsafe demonstrated very good results in that the failsafe plugged rapidly and limited particulate flow to downstream equipment. In-situ samples at the PCD outlet did not indicate any measurable increase in particulate concentration.

APPENDIX A OPERATING HISTORY

System commissioning of the KBR Transport Gasifier train and the first five test campaigns (TCs) were performed in combustion mode. Approximately 5,000 hours of combustion operation were completed from 1996 to 1999. The system was transitioned to gasification operation in late 1999. Four gasification commissioning tests (GCTs), each lasting nominally 250 hours, were completed by early 2001. At the conclusion of TC22, 17 gasification test campaigns were completed, each nominally 250 to 1,500 hours in duration, for a total of about 10,080 hours of coal gasification operation. Powder River Basin subbituminous coal is the most extensively tested fuel, although several bituminous and lignite coals have also been tested. The Transport Gasifier has operated successfully in both air-blown and oxygen-blown modes.

Table A-1 summarizes the gasification testing completed at the conclusion of TC22. The table lists the duration, number of hours on coal, fuel type, and major objectives of each test. More information about the individual test campaigns may be found in the test campaign reports, located on the PSDF website, http://psdf.southernco.com.

Table A-1. Gasification Operating History.

Test	Start Date	Duration, hours	Fuel Type*	Comments
GCT1	September 1999	233	PRB, Illinois #6, Alabama	First gasification testing
GCT2	April 2000	218	PRB	Stable operations
GCT3	February 2001	184	PRB	Loop seal commissioning
GCT4	March 2001	242	PRB	Final gasification commissioning test
TC06	July 2001	1,025	PRB	First long duration test campaign
TC07	April 2002	442	PRB, Alabama	Lower mixing zone commissioning
TC08	June 2002	365	PRB	First oxygen-blown testing First on-line failsafe testing
TC09	September 2002	309	Hiawatha	New mixing zone steam system
TC10	October 2002	416	PRB	Developmental coal feeder
TC11	April 2003	192	Falkirk Lignite	First lignite testing
TC12	May 2003	733	PRB	Fuel cell testing
TC13	September 2003	501	PRB, Freedom Lignite	Syngas to combustion turbine
TC14	February 2004	214	PRB	Syngas to combustion turbine CFAD commissioning
TC15	April 2004	200	PRB	Improved oxygen feed distribution
TC16	July 2004	835	PRB, Freedom Lignite	Fuel cell testing High pressure O_2-blown operation
TC17	October 2004	313	PRB, Illinois Basin	Bituminous coal testing
TC18	June 2005	1,342	PRB	Recycle gas compressor Commissioning
TC19	November 2005	518	PRB	CCAD commissioning
TC20	August 2006	870	PRB	Gasifier configuration modifications
TC21	November 2006	388	Freedom Lignite	First lignite test following the gasifier modifications
TC22	March 2007	543	Mississippi Lignite	High moisture lignite testing

*Note: PRB is subbituminous coal; Illinois #6, Alabama, Hiawatha, Utah, and Illinois Basin coals are bituminous coals.

APPENDIX B STEADY STATE OPERATING PERIODS AND MAJOR OPERATING PARAMETERS

There were sixteen forty operating periods during TC22. These periods are given in Table B-1, along with the major operating parameters for each period. The steady state periods are defined based on maintaining gasifier operating conditions within defined ranges.

All of the steady state periods were in air-blown gasification mode with lignite feed. Recycle syngas operation was achieved in 75 percent of the operating periods. The coal feed rates were calculated from the feeder weigh cells; the air and recycle syngas flow rates were taken from flow indicators; and the steam flow rate was calculated from the hydrogen balance. The nitrogen flows are taken from a flow indicator and then decreased by 2,200 pounds per hour to account for ash transport nitrogen and increased by 2,000 pounds per hour to account for unmeasured secondary coal feeder coal transport nitrogen. The PCD solids rates were determined from the in-situ sampling at the PCD inlet, and the ash removal rates for CCAD were determined by a system ash balance.

Table B-1. Steady State Operating Periods and Major Operating Parameters.

Steady State Operating Period	Start Time	End Time	Run Time Hours	Gasifier Mixing Zone Temperature, ^{0}F	Gasifier Outlet Pressure, psig	Coal Feed Rate, lb/hr	Air Feed Rate, lb/hr	Steam Feed Rate, lb/hr	Nitrogen Flow Rate, lb/hr	Recycle Gas Flow Rate, lb/hr	Syngas Rate, lb/hr	PCD Inlet Temperature, ^{0}F	Gasifier Solids Removal Rate, lb/hr	PCD Solids Removal Rate, lb/hr
TC22-1	3/26/07 12:45	3/26/07 16:00	39	1,640	120	2,640	7,910	1,210	4,420	0	16,510	690	150	330
TC22-2	3/26/07 19:00	3/26/07 23:15	46	1,620	120	2,670	7,740	1,330	4,680	0	16,500	680	130	330
TC22-3	3/27/07 4:15	3/27/07 7:15	55	1,630	130	2,720	8,010	1,330	4,770	0	16,970	690	120	340
TC22-4	3/27/07 17:45	3/27/07 22:45	69	1,690	130	2,820	8,090	650	4,340	0	16,180	690	150	350
TC22-5	3/28/07 2:00	3/28/07 6:30	77	1,700	130	2,790	8,090	750	4,370	0	16,110	690	130	350
TC22-6	3/28/07 6:45	3/28/07 11:15	82	1,700	130	2,800	8,090	690	4,320	0	16,040	690	170	350
TC22-7	3/28/07 12:15	3/28/07 20:00	89	1,710	130	2,800	8,190	690	4,500	0	16,330	690	150	350
TC22-8	3/29/07 0:00	3/29/07 4:00	99	1,710	130	2,870	8,290	710	4,680	0	16,650	700	140	360
TC22-9	3/30/07 0:30	3/30/07 5:30	124	1,700	150	4,850	11,340	880	5,720	0	21,640	730	240	590
TC22-10	3/31/07 3:15	3/31/07 8:30	151	1,720	150	3,990	10,170	980	4,790	0	19,930	720	250	490
TC22-11	4/1/07 22:00	4/2/07 1:30	193	1,720	190	5,040	12,370	810	5,260	1,000	24,920	750	410	610
TC22-12	4/2/07 3:45	4/2/07 8:15	199	1,700	190	5,040	12,370	1,140	4,860	1,000	25,070	750	380	610
TC22-13	4/2/07 15:45	4/2/07 23:45	213	1,750	190	5,070	12,630	830	4,480	990	24,150	760	270	610
TC22-14	4/2/07 23:45	4/3/07 8:00	221	1,740	190	5,110	12,560	1,010	4,570	990	23,950	760	340	620
TC22-15	4/3/07 8:30	4/3/07 14:45	229	1,750	190	5,220	12,580	870	4,430	990	23,720	760	440	580
TC22-16	4/4/07 11:15	4/4/07 18:30	256	1,760	190	5,060	12,430	700	4,580	990	23,400	760	420	500
TC22-17	4/4/07 23:00	4/5/07 3:30	266	1,760	190	4,930	12,330	610	5,180	1,000	23,800	760	390	490

Steady State Operating Period	Start Time	End Time	Run Time Hours	Gasifier Mixing Zone Temperature, °F	Gasifier Outlet Pressure, psig	Coal Feed Rate, lb/hr	Air Feed Rate, lb/hr	Steam Feed Rate, lb/hr	Nitrogen Flow Rate, lb/hr	Recycle Gas Flow Rate, lb/hr	Syngas Rate, lb/hr	PCD Inlet Temperature, °F	Gasifier Solids Removal Rate, lb/hr	PCD Solids Removal Rate, lb/hr
TC22-18	4/5/07 5:00	4/5/07 10:30	273	1,770	190	4,860	12,370	610	4,770	990	23,420	760	380	480
TC22-19	4/6/07 12:30	4/6/07 15:00	303	1,680	190	5,340	13,380	920	6,920	1,010	27,120	760	270	630
TC22-20	4/6/07 19:00	4/6/07 22:00	309	1,640	190	4,880	12,440	840	7,630	1,010	26,410	750	210	630
TC22-21	4/8/07 15:00	4/8/07 21:00	330	1,750	130	4,410	11,630	810	4,830	620	22,610	760	210	540
TC22-22	4/8/07 21:30	4/9/07 1:45	336	1,750	130	4,390	11,440	1,020	5,010	620	21,920	750	220	540
TC22-23	4/9/07 19:00	4/9/07 23:30	357	1,760	130	4,360	11,300	770	5,810	690	22,300	750	210	530
TC22-24	4/10/07 3:30	4/10/07 7:15	365	1,750	130	4,370	11,400	1,030	6,420	610	22,900	750	200	530
TC22-25	4/10/07 17:30	4/10/07 22:45	380	1,740	150	4,430	11,540	910	6,390	730	23,330	750	230	540
TC22-26	4/10/07 22:45	4/11/07 4:15	386	1,750	150	4,480	11,690	680	6,420	660	23,480	750	200	540
TC22-27	4/11/07 12:00	4/11/07 16:15	398	1,750	140	3,990	10,930	1,020	5,810	680	21,450	740	190	490
TC22-28	4/11/07 18:15	4/11/07 22:15	404	1,750	140	3,930	10,900	1,160	6,000	660	21,320	740	150	480
TC22-29	4/12/07 0:30	4/12/07 8:30	413	1,740	140	4,120	11,070	1,090	6,360	690	21,750	740	230	500
TC22-30	4/12/07 15:45	4/12/07 20:45	426	1,750	130	4,100	11,180	830	5,910	810	21,620	750	170	500
TC22-31	4/13/07 18:00	4/13/07 22:00	452	1,750	130	3,760	10,020	990	6,840	700	21,000	730	230	460
TC22-32	4/14/07 3:30	4/14/07 7:30	462	1,760	130	3,900	10,310	660	5,760	720	20,020	730	230	480
TC22-33	4/14/07 21:15	4/15/07 1:30	479	1,750	140	4,040	10,550	750	5,740	790	21,360	730	270	490
TC22-34	4/15/07 15:00	4/15/07 19:30	497	1,760	150	4,040	10,820	940	5,760	850	21,880	740	250	500
TC22-35	4/15/07 22:15	4/16/07 4:00	505	1,780	150	4,160	10,830	650	5,710	890	21,940	740	320	510
TC22-36	4/16/07 4:00	4/16/07 9:30	511	1,790	150	4,040	10,970	940	5,570	890	22,000	740	290	490

Steady State Operating Period	Start Time	End Time	Run Time Hours	Gasifier Mixing Zone Temperature, °F	Gasifier Outlet Pressure, psig	Coal Feed Rate, lb/hr	Air Feed Rate, lb/hr	Steam Feed Rate, lb/hr	Nitrogen Flow Rate, lb/hr	Recycle Gas Flow Rate, lb/hr	Syngas Rate, lb/hr	PCD Inlet Temperature, °F	Gasifier Solids Removal Rate, lb/hr	PCD Solids Removal Rate, lb/hr
TC22-37	4/16/07 9:30	4/16/07 15:00	516	1,790	150	3,950	10,960	1,000	5,330	880	21,750	740	250	490
TC22-38	4/16/07 19:45	4/16/07 22:45	525	1,680	140	4,020	10,070	600	6,010	850	21,460	710	100	580
TC22-39	4/17/07 0:00	4/17/07 4:15	530	1,690	140	3,980	10,190	410	6,210	840	21,670	720	40	580
TC22-40	4/17/07 13:30	4/17/07 15:00	542	1,760	140	4,020	11,230	1,070	5,910	820	21,870	740	190	620

APPENDIX C MATERIAL AND ENERGY BALANCES

The material and energy balances showed reasonable accuracy given the diversity of the measurements used for their calculation. A gasifier mass balance for the TC22 steady state operating periods, shown in Figure C-1, documents the accuracy of the solids and gas rates at the gasifier inlet and outlet. The data generally showed agreement within 10 percent.

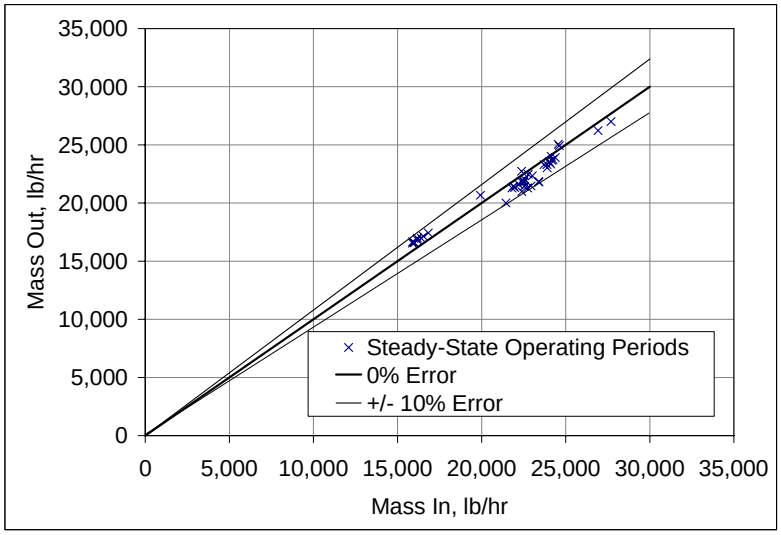

Figure C-1. Mass Balance.

The overall energy balance for the gasifier, plotted in Figure C-2, verifies the accuracy of the gasification efficiencies, and showed agreement within about 20 percent. A gasifier heat loss of 3.5 MMBtu/hr was assumed for the energy balance. The energy balance is biased high with more energy leaving the system than entering. Assuming a heat loss of 0.35 MMBtu/hr eliminates the bias and produces an energy balance within 10 percent.

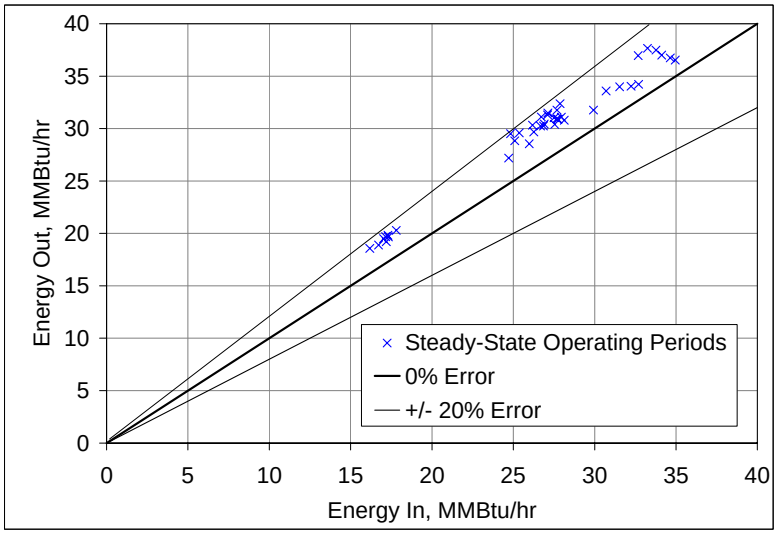

Figure C-2. Energy Balance.

The carbon balance documents the accuracy of the carbon conversions, and is shown in Figure C-3. The data showed good agreement within a 10 percent error range.

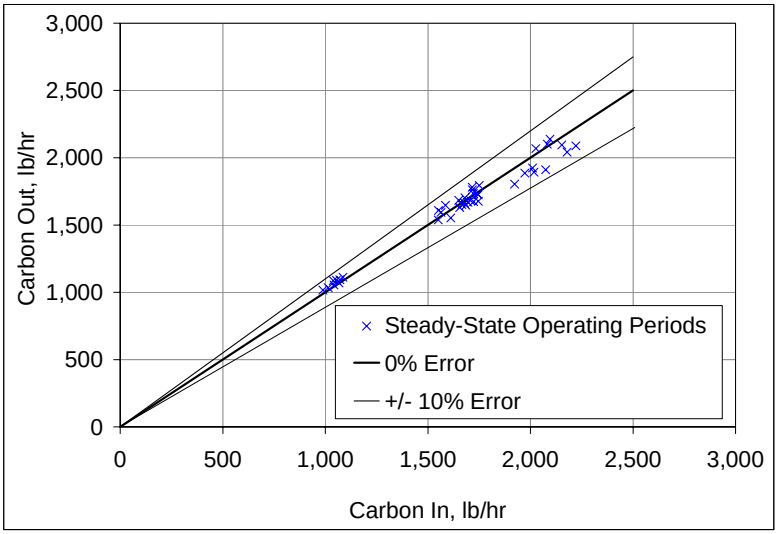

Figure C-3. Carbon Balance.

The sulfur balance supports the accuracy of the sulfur removal efficiencies and is plotted in Figure C-4. The balance showed reasonable agreement within a 30 percent error range, with one outlier.

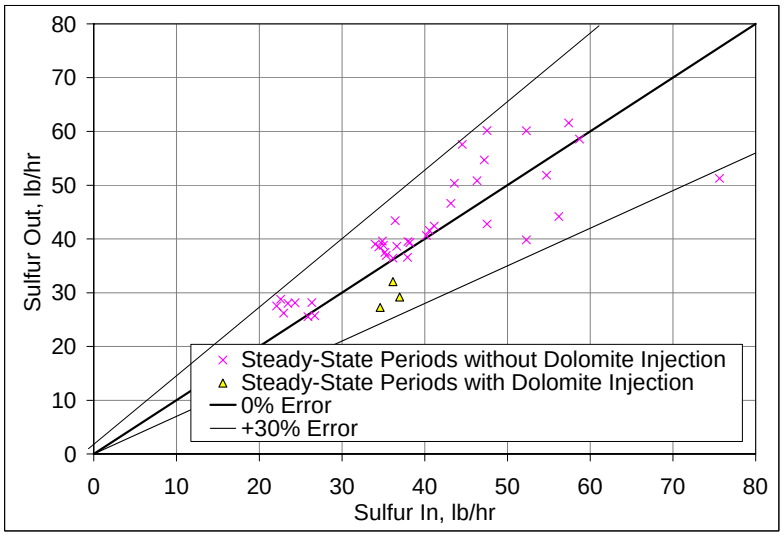

Figure C-4. Sulfur Balance.

APPENDIX D LIST OF ABBREVIATIONS AND UNITS

Abbreviations

CCAD—Continuous Coarse Ash Depressurization
CFAD—Continuous Fine Ash Depressurization
DOE—Department of Energy
EDS—Energy Dispersive X-Ray Spectrometry
FEAL—Iron Aluminide
FTIR—Fourier Transform Infrared
GCT—Gasification Commissioning Test
HHV—Higher Heating Value
IGCC—Integrated Gasification Combined Cycle
LMZ—Lower Mixing Zone
LOI—Loss on Ignition
MMD—Mass Median Diameter
PCD—Particulate Control Device
PDI—Pressure Differential Indicator
PPC—Process Particle Counter
PRB—Powder River Basin
PSDF—Power Systems Development Facility
SEM—Scanning Electron Microscope
SMD—Sauter Mean Diameter
SRD—Sensor Research and Development
SRI—Southern Research Institute
TC—Test Campaign
SMD—Sauter Mean Diameter

Units

Btu—British thermal units
dP—Differential Pressure
^{o}F—degrees Fahrenheit
ft—feet
ft^3—cubic feet
g/cm^3 or g/cc—grams per cubic centimeter
hr— hours
inH_2O—inches of water
in—inches
inwc—inches of water column
lb—pounds
min—minutes
mm—millimeters
MMBtu—million British thermal units
mol—mole
μm—microns or micrometers
MW—megawatts
ppm—parts per million
ppmv—parts per million by volume
ppmw—parts per million by weight
psi—pounds per square inch
psig—pounds per square inch gauge
s or sec—second
SCF—standard cubic feet
wt—weight