NATIONAL CARBON CAPTURE CENTER
AT THE
POWER SYSTEMS DEVELOPMENT FACILITY

TEST RUN SUMMARY REPORT

TEST RUN R02
AUGUST 31, 2009 – SEPTEMBER 22, 2009

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Recipient: Southern Company Services (SCS), Inc.
SCS Project Director: Kerry Bowers

Prepared by:
Southern Company Services, Inc.
Power Systems Development Facility
P.O. Box 1069
Wilsonville, AL 35186
Tel: 205-670-5840
Fax: 205-670-5843
http://www.nationalcarboncapturecenter.com

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LIST OF ABBREVIATIONS

CCAD—Continuous Coarse Ash Depressurization
CFAD— Continuous Fine Ash Depressurization
DOE—Department of Energy
MCA—Multi Cell Array
MMD—Mass Median Diameter
NCCC—National Carbon Capture Center
NETL—National Energy Technology Laboratory
PDAC—Pressure Decoupled Advanced Coal
PRB—Powder River Basin
PCD—Particulate Control Device
PDAC—Pressure Decoupled Advanced Coal
PSDF—Power Systems Development Facility
R02—Run 2
SCU—Syngas Cleanup Unit
TCA—Total Carbonate Analysis

R02 SUMMARY REPORT

The DOE-sponsored National Carbon Capture Center (NCCC) at the Power Systems Development Facility (PSDF) has continued to support the advancement of clean coal technologies through testing under realistic industrial conditions. In August and September 2009, the PSDF operated its gasification process in test run R02, with the major objective of testing pre-combustion CO_2 capture technologies, including batch reactor CO_2 absorption and regeneration. Water-gas shift reaction of the syngas was also tested. The run included gasification operation in air-blown as well as oxygen-blown mode with Powder River Basin (PRB) coal.

1.0 EXECUTIVE SUMMARY

R02, the second test campaign under the NCCC/PSDF cooperative agreement, began in August 2009, with coal feed initiated on August 31, 2009. The test run ended on September 22, 2009, after 477 hours of on-coal operation, including 47 hours in oxygen-blown mode. In addition to CO_2 capture and water-gas shift testing, test objectives included:

- Fully assessing the modified gasifier performance in oxygen-blown operation
- Evaluating operation of the developmental Pressure Decoupled Advanced Coal (PDAC) feeder with its recent design changes
- Assessing new filter elements constructed of coated sintered fiber material
- Supporting testing of the DOE National Energy Technology Laboratory (NETL) solid oxide fuel cell

To meet the major test objectives, the test matrix included the parameters listed in Table 1. Gasifier-related parametric tests were completed during air-blown mode, and operations were held steady for long periods to facilitate testing at the syngas cleanup unit (SCU). All the test objectives were met with the exception of the full assessment of gasifier performance in oxygen-blown mode. The oxygen-blown operation, while stable, was cut short due to a coal supply shortage, and complete data analysis was not possible.

Table 1. Parametric Testing.

Parameter Tested	Purpose	Conditions
Transport Air and Nitrogen Dilution Minimization	Provide syngas with highest possible heating value for water-gas shift testing	Use recycle syngas for gasifier aeration; use air in place of nitrogen for conveying coal through original coal feeder; minimize miscellaneous nitrogen additions
Increased Pressure/ Reduced Riser Velocity	Simulate high-load conditions	Increase system pressure while maintaining other operating parameters
Solo PDAC Feeder Operation and PDAC Feed Rate	Evaluate effectiveness of modifications to PDAC feed system	Operate PDAC feeder only; vary feed rate
Reduced Steam-to-Oxygen Feed Ratio	Optimize steam addition in oxygen-blown gasification	Lower steam feed rate while maintaining low coal feed rate (~2,500 lb/hr)

2.0 COAL PREPARATION

The coal was processed in the coal mill system to reduce the moisture content and control the particle size distribution. Table 2 lists the as-received coal moisture value and the coal moisture and size values after mill processing (as-fed). The coal characteristics are given in Appendix A.

Table 2. Coal Properties before and after Milling.

	Average
As-Received Coal Moisture Content, wt %	29
As-Fed Coal Moisture Content, wt %	21
Moisture Content Reduction, %	28
As-Fed Coal MMD, micron	409
As-Fed Coal Oversize (>1,180 micron) Content, wt %	9
As-Fed Coal Fine (<45 micron) Content, wt %	11

3.0 COAL FEEDING

Both the developmental and the original coal feeders operated without major coal stoppages.

Developmental Feeder. The developmental PDAC feeder operated for 400 hours including independent operations for 124 hours. The feed rate varied from 500 to 4,000 lb/hr. The feed system operated well, providing a more stable feed rate control and improved reliability. The reduced variability in feed rate resulted in more stable gasifier temperatures. Figure 1 shows the gasifier temperature deviation during operation with the PDAC feeder operating prior to the modifications (test run TC25) and following the modifications (test run R02). The improved PDAC feed rate control resulted in a 50 percent reduction in gasifier temperature deviation.

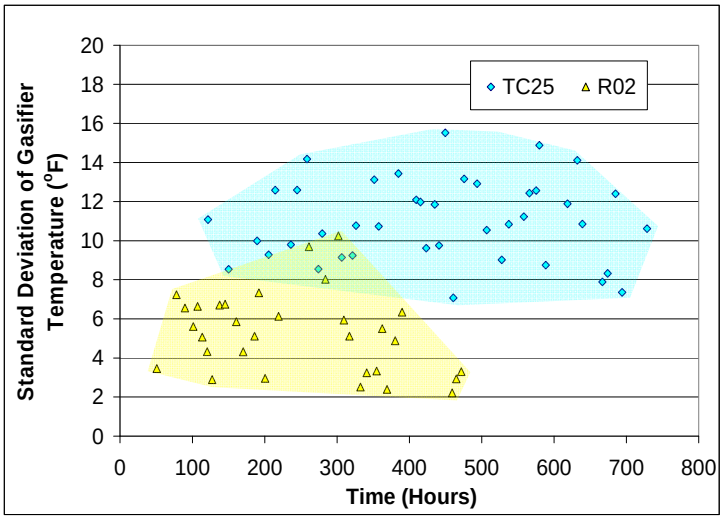

Figure 1. Comparison of Gasifier Temperature Deviation before and after PDAC Feeder Modifications.

Several modifications contributed to this improvement in feeder performance. During previous test campaigns, high pressure drop had been observed prior to coal feed entering the feeder discharge line due to a reduction in diameter of the components and due to complex geometry at the bottom of the feeder. The existing design was modified to create a smooth transition into the feeder discharge line eliminating the previously observed pressure drop. The discharge line itself was also modified to reduce the number of elbows and make the pipe inner diameter uniform from the feeder to the gasifier. In addition, the arrangement of nitrogen aeration in this section of the feeder was also modified to improve the gas distribution. This change resulted in much improved operability during feeder startup and low coal feed rate scenarios.

Logic modifications were also made to minimize the impact of lock vessel fill cycles on feed rate variability, and a feedback control was also implemented using a differential pressure transmitter on the feeder discharge line as an indication of instantaneous feed rate changes. Both logic changes helped enhance feeder operation but will require more tuning during off-line feeder testing. Further logic modifications are planned to continue improvement of feeder performance. New vibration probes, used to replace capacitance probes for level detection in the feeder lock vessel and dispense vessel, showed promising results. Future tuning of the lock vessel cycle will be possible if these probes continue to demonstrate high reliability.

Original Coal Feeder. The original coal feeder operated for 351 hours at feed rates varying from 800 to 3,550 lb/hr. The feed system was used in a secondary role for most of the test campaign and provided a stable feed rate. The system was operated utilizing transport air (i.e., air in place of nitrogen for coal transporting) for 98 hours.

4.0 TRANSPORT GASIFIER

Operations. There were 31 steady state operating periods in R02, all with recycle syngas utilized for gasifier aeration. Figure 2 plots the maximum gasifier temperature (mixing zone temperature), the outlet gasifier temperature and pressure, and the primary gas cooler outlet temperature during the R02 steady state periods. The primary gas cooler operated as designed, with an outlet temperature of about 800°F during the run. The last three operating periods, which consisted of oxygen-blown operation, occurred at lower system pressures due to the oxygen supply pressure limitation.

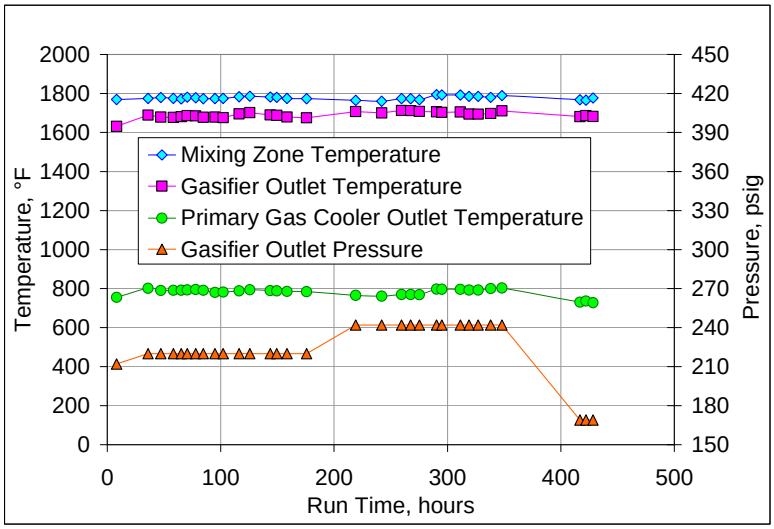

Figure 2. Gasifier and Primary Gas Cooler Operating Parameters.

Efforts to minimize nitrogen dilution around Hour 100 resulted in a 10 percent reduction in overall nitrogen addition to the gasifier. Other gasifier parametric tests were conducted during the run to validate previously collected operating data. The effect of reduced gasifier riser velocity on solids circulation rate was explored by increasing gasifier pressure. Figure 3 shows the relative solids circulation rate as a function of gasifier riser velocity during R02. The lowest riser velocity to date during gasifier coal feed operation was also achieved with no adverse effect on solids circulation.

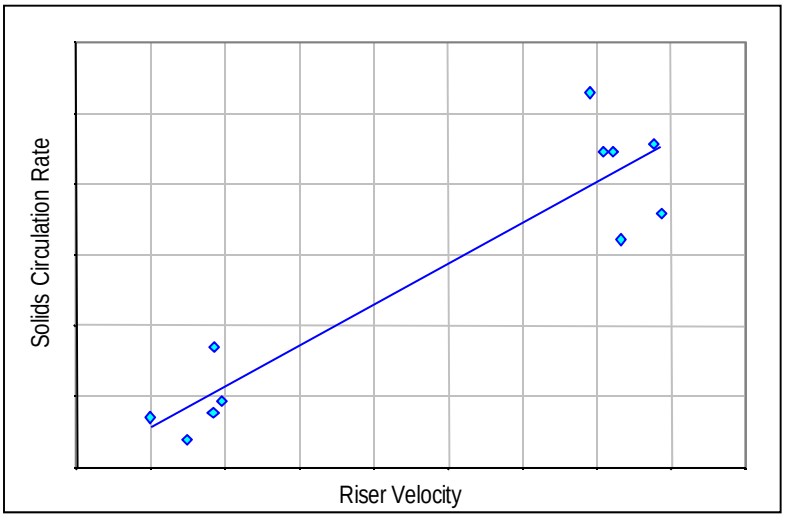

Figure 3. Solids Circulation Rate versus Riser Velocity.

Parametric testing to reduce steam-to-oxygen ratios during oxygen-blown operation was cut short due to a coal supply shortage. Operations were conducted at ratios ranging from 1.1 to 1.3 prior to the run ending. Gasifier performance was consistent with historical oxygen-blown testing in this range of steam-to-oxygen ratios.

Refractory Evaluation. During the gasifier inspection prior to R02, refractory damage was identified in the standpipe and entailed hot-face refractory loss on both sides of the J-leg / standpipe intersection, as shown in Figure 4. This hot-face refractory is 3 inches thick, and the deepest loss was about 1 ½ to 2 ½ inches. The refractory in the standpipe and J-leg was the refractory originally installed in the gasifier (Resocast 17EC).

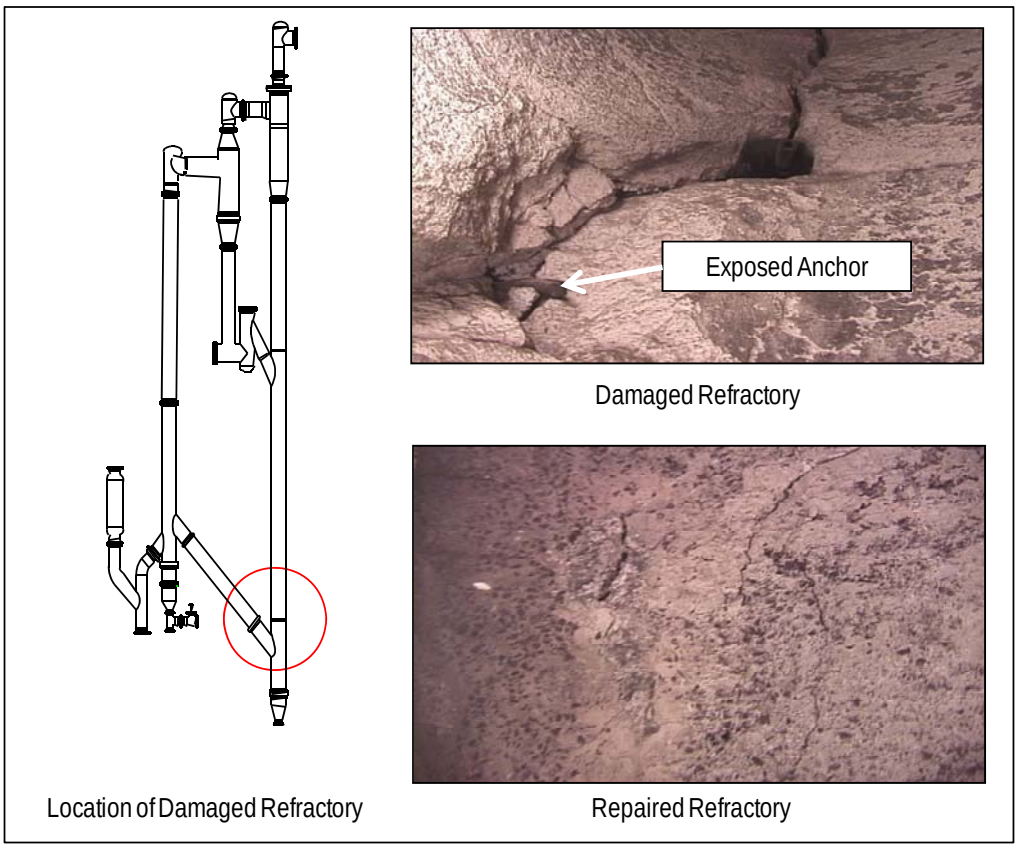

Figure 4. Refractory Damage in Gasifier Standpipe.

Repairs were completed prior to R02 using Resco Quikturn 60 RST refractory. During the run, this area was monitored using a thermal imaging camera and skin-mounted thermocouples. No temperature excursions were detected. Post-run inspections showed that the repaired refractory was in good condition.

5.0 PARTICULATE CONTROL DEVICE

Research related to the particulate control device (PCD) continued to focus on material testing. The failsafes installed included Pall Dynalloy devices constructed of forward (supporting screen on the inner surface of the failsafe) and reverse structures (supporting screen on the outer surface), as well as PSDF-designed devices constructed of HR-160 material. The filter elements installed consisted entirely of sintered fiber elements manufactured by Porvair. The installation of only one type of element allowed confident evaluation of the collection performance of these elements. Figure 5 shows a Porvair sintered fiber element.

Figure 5. Porvair Sintered Metal Fiber Filter Element.

The Porvair elements were designed with an outer screen to provide structural support and with a coating of inert material for corrosion resistance. Operation of the PCD with the sintered fiber elements yielded very good collection efficiency (>99.9999%), and further testing will be conducted to assess the corrosion resistance of these elements.

6.0 ASH REMOVAL SYSTEMS

The Continuous Coarse Ash Depressurization (CCAD) system reliably maintained the gasifier standpipe level through the run. Tuning of the standpipe level controller during the run improved controller stability and provided a more consistent level. Further optimization of this control was planned for future test runs.

Because of erosion of the Continuous Fine Ash Depressurization (CFAD) system discharge line and fittings, these components were replaced during the pre-R02 outage. Cross elbows were replaced with off-center elbows to reduce wear (see Figure 6), and the drainage system was improved to prevent damage caused by condensate buildup during startup. No plugging or significant pipe erosion occurred during R02.

Cross Elbows Used Prior to R02

Off-Center Elbows Installed for R02

Figure 6. Redesign of CFAD Discharge Line Elbows.

7.0 ADVANCED SYNGAS CLEANUP

CO_2 Capture Testing. CO_2 capture testing continued during R02, and the primary objectives of the testing included:

- Establishing CO_2 mass balance with syngas
- Determining capture efficiency under various absorption and regeneration cycling conditions
- Investigating co-absorption of H_2S and COS with CO_2

Work to close the CO_2 mass balance involved the continued evaluation of gas and liquid analysis techniques. Previous testing had shown that the best results were obtained with total carbonate analysis (TCA), and this finding was confirmed during R02 testing. Figure 7 presents the results from titration and from TCA as compared to data from the plant historian, and shows better agreement with the TCA method.

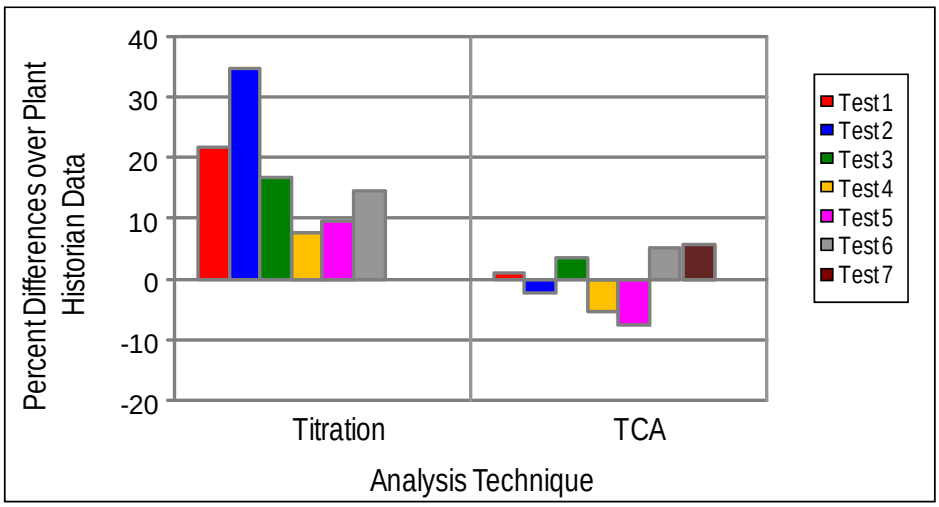

Figure 7. Comparison of Analysis Techniques for Total CO_2 in Solution.

A total of 24 absorption and 16 regeneration cycles were completed during R02. The operating parameters examined included solution concentration, absorption temperature, regeneration temperature and pressure, CO_2 concentration, and the cycling effect on performances and H_2S/COS co-absorption with CO_2. Figure 8 shows the CO_2 loading during one cycling test. The CO_2 loading at the end of absorption (rich loading), end of regeneration (lean loading) and net capacity (rich-lean) is shown as a function of cycles. As shown, the net loading for cycle 1 is higher than that of the subsequent cycles. This is dominated by the regeneration conditions which set the lean solution loading level and then the subsequent cycle's net loading capacity.

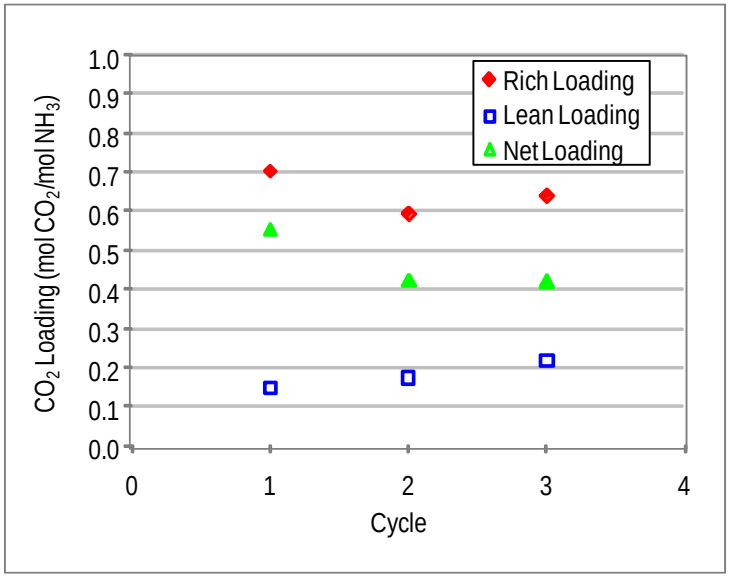

Figure 8. CO_2 Loading during Cycling.

Co-absorption of hydrogen sulfide (H_2S), carbonyl sulfide (COS) and CO_2 was also evaluated during the test run. The preliminary results supported the possibility of co-absorption, as plotted in Figure 9, although the capture efficiency decreases as the free ammonia is consumed and CO_2 breaks through. More tests are planned to further understand the mechanisms behind such co-absorption.

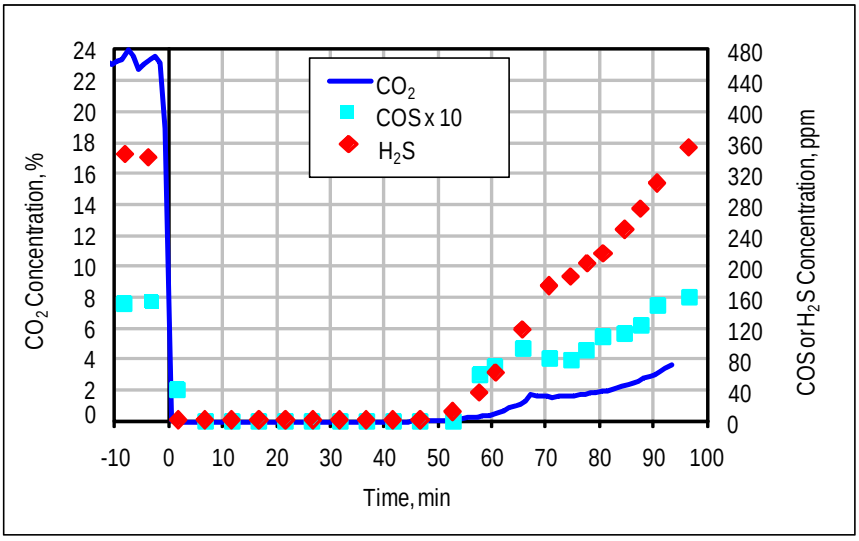

Figure 9. Co-Absorption of COS and H_2S during CO_2 Absorption.

Water-Gas Shift Testing. During R02, the SCU fixed bed reactor was utilized to test the water gas shift testing with pellet catalyst during air-blown and oxygen-blown gasifier operation. Operating conditions for the fixed bed reactor testing are included in Table 3.

Table 3. Fixed Bed Reactor Water-Gas Shift Catalyst Operating Parameters.

Pressure, psig	165
Reactor Inlet Temperature, ^{o}F	650
Syngas Flow Rate, lb/hr	40
Superheated Steam Flow Rate, lb/hr	0.2 to 1.4
Space Velocity, hr^{-1}	2,600 to 2,700
H_2O-to-CO Molar Ratio	1.4 to 1.9
Shift Conversion, percent	65 to 75

The fixed bed water-gas shift testing included varying the H_2O-to-CO molar ratio. Test results, plotted in Figure 10, indicated that acceptable CO conversions could be achieved at relatively low steam feed rates, which could provide significant capital and operating cost savings compared to high steam feed rate operation.

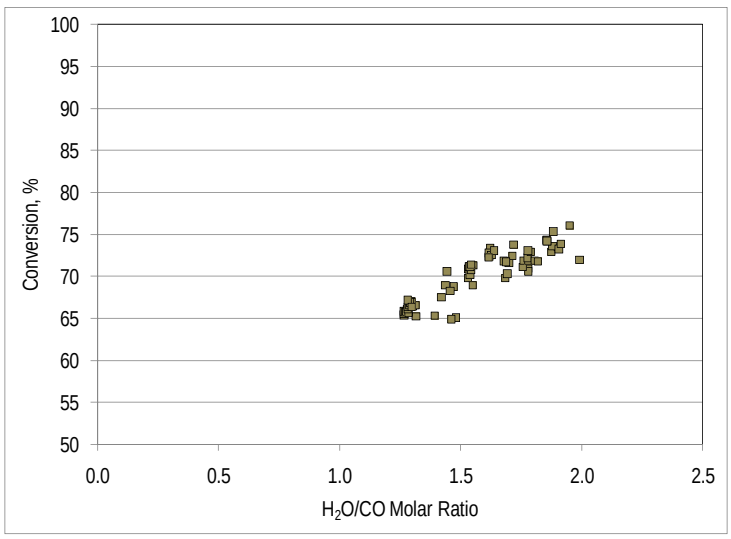

Figure 10. Syngas Shift Conversion versus H_2O-to-CO Molar Ratio.

Catalytic filter element testing was attempted during oxygen-blown operation. However, due to operational problems, such as inadequate vessel sealing, useful data from the filter element testing was not generated. Due to the vessel sealing problems, on-site engineers re-designed the vessel sealing system and modified the seal installation procedures. The sealing modifications appeared to be effective and will be used in future test runs.

NETL Multi-Cell Array Fuel Cell Skid. The NETL multi-cell array (MCA) fuel cell skid arrived on site and was re-assembled and connected to the gasification process for slipstream testing. Several design improvements, which had been identified as a result of previous testing at the PSDF, were implemented and tested at NETL prior to shipment of the unit. A backup MCA unit was also assembled for insertion into the skid in case of failure of the original MCA unit.

Prior to coal feed to the gasifier, the fuel cell unit was heated up with nitrogen and checked for cell integrity. Hydrogen gas was used to establish a baseline. During on-coal gasifier operation, syngas was desulfurized at warm gas conditions in the SCU prior to use in the MCA unit using the Johnson Matthey sulfur sorbent Puraspec 2010.

The MCA unit operated well with 10 of 12 cells indicating good performance. The cells operated stably, although noise levels increased modestly since testing first began. As water content in the syngas remained high, the MCA was flushed with pure hydrogen for a period of 10 to 20 minutes twice per day during operation. This produced cell voltage traces free from dropouts. The applied load was reduced in some instances in order to contend with apparent degradation.

8.0 SUPPORT EQUIPMENT

Main Air Compressor. During a routine inspection of the main air compressor prior to R02, tube leaks were found in the intercoolers. Since a full repair would entail replacing the bundles and would delay R02 operation, the leaking tubes were plugged prior to the run. Following the run, the intercooler tube bundles were replaced, and the exchanger shells were re-coated. Figure 11 includes photographs of the damaged tube bundles and the shell re-coating.

Leaking Intercooler Tube Bundles Re-Coated Intercooler Shells

Figure 11. Repairs to Main Air Compressor.

Baghouse. An inspection of the baghouse downstream of the syngas combustor after the R01 test run showed significant acid corrosion of both external and internal surfaces. The extent of damage required that all filter bags and cages be replaced. Figure 12 shows examples of the baghouse corrosion.

Figure 12. Baghouse Corrosion Damage.

The filtering side of the baghouse, where solids were present, had the greatest buildup of corrosion product. Analysis of corrosion product samples showed that the sample pH was nearly zero and consisted mainly of sulfate (spent sulfuric acid), iron (from baghouse metal surfaces), and aluminum (from filter bag cages and grounding straps). The buildup of high sulfur ash in the baghouse over time combined with water from the external leakage of rain and possible condensation during operation caused the corrosion. The seams of the filter bags were damaged, and many of the bags disintegrated upon removal. The baghouse tubesheet, housing, and adjacent duct were cleaned, and the corrosion products were properly disposed.

APPENDIX A COAL CHARACTERISTICS

The characteristics of the PRB coal used in R02 are listed in Table A-1.

Table A-1. As-Fed PRB Coal Characteristics.

	Average	Minimum	Maximum	Standard Deviation
Moisture, wt %	19.7	17.7	23.1	1.4
Carbon, wt %	55.3	54.1	56.7	0.8
Hydrogen, wt %	3.8	3.5	4.0	0.14
Nitrogen, wt %	0.9	0.8	0.9	0.02
Oxygen, wt %	14.1	12.7	14.9	0.56
Sulfur, wt %	0.4	0.3	0.4	0.03
Ash, wt %	5.8	5.5	8.5	0.66
Volatiles, wt %	35.0	33.3	36.6	0.8
Fixed Carbon, wt %	39.5	38.1	41.1	0.8
Heating Value, As Received, Btu/lb	9421	9016	9666	172