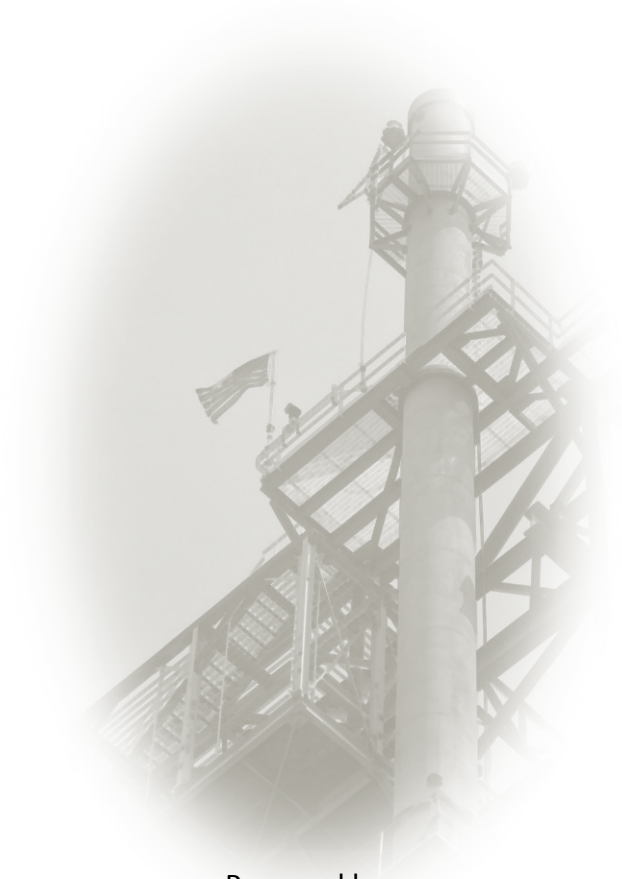
The National Carbon Capture Center
at the Power Systems Development Facility

Test Run Summary Report

Test Run R11
August 1, 2013 – September 2, 2013

DOE Cooperative Agreement
DE-NT0000749



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List of Abbreviations

CCAD	Continuous Coarse Ash Depressurization
DOE	Department of Energy
MTR	Membrane Technology & Research
NCCC	National Carbon Capture Center
PDAC	Pressure Decoupled Advanced Coal
PCD	Particulate Control Device
ppmw	Part per million by weight
R01 through R12	Test Runs 1 through 12
WGS	Water Gas Shift

1.0 EXECUTIVE SUMMARY

The National Carbon Capture Center (NCCC) at the Power Systems Development Facility supports the Department of Energy (DOE) goal of promoting the United States' energy security through reliable, clean, and affordable energy produced from coal. As part of its mission to develop technologies for clean coal power generation, the NCCC conducts testing of advanced gasification and CO_2 capture processes.

Gasification run R11 commenced from August 1 through September 2, for 770 hours of on-coal operation. The run was stable and demonstrated high carbon conversion while using high moisture Mississippi lignite as the feedstock. Mississippi lignite previously tested at the NCCC was from the Red Hills mine in Choctaw County, and R11 was the first test of lignite from the Liberty Fuels mine in Kemper County.

The R11 test objectives related to gasification technologies included further development and evaluation of coal feeders, gasifier automatic controls, sensors, hot gas filter elements and failsafes, and advanced materials with coupon testing. Test objectives involving pre-combustion CO_2 capture technologies consisted of operation of gas separation membranes and a water-gas shift (WGS) catalyst.

2.0 GASIFICATION SUPPORT TECHNOLOGIES

2.1 Coal Preparation and Feed

Table 1 lists the as-received and as-fed properties of the Liberty Fuels mine lignite used in R11. The average mass median diameter of the processed lignite was about 360 microns. A fluid bed coal dryer was utilized to reduce moisture levels from greater than 40 wt% to less than 20 wt%. The coal dryer processed about 1,850 tons of lignite over a range of flow rates from 5,000 to 10,000 lb/hr. Dryer operation was interrupted several times by plugging of heat exchangers with gravel originating from the coal delivery trucks.

Table 1. Liberty Fuels Mine Lignite Properties

Property	As-Received	As-Fed
Carbon, wt %	34.4	49.1
Hydrogen, wt %	2.3	3.9
Nitrogen, wt %	0.6	0.9
Sulfur, wt %	1.0	1.8
Ash, wt %	8.7	14.0
Oxygen, wt % (by difference)	7.86	17.6
Volatiles, wt %	23.4	41.9
Fixed Carbon, wt %	22.8	31.4
Heating Value, Btu/lb	5750	8370
Moisture, wt%	41.8	17.5

Both the original coal feeder and the developmental Pressure Decoupled Advanced Coal (PDAC) feeder operated consistently in R11 without any forced downtime. The original feeder operated for a total of 757 hours with flow rates ranging from 1,000 to 2,500 lb/hr. The PDAC feeder operated for 400 hours at flow rates ranging from 1,100 to 4,000 lb/hr, and the PDAC trim logic controller maintained a consistent feed rate by varying conveying nitrogen.

PDAC Instrumentation

Measurements from the DensFlow coal flow meter continued to show discrepancy in coal feed rates with flow rates calculated from the feeder weigh cells. Collaboration with the flow meter supplier is ongoing to improve instrument performance.

The solids level probes in the PDAC system continued to perform reliably. The Dynatrol vibration level probes have accumulated 7,185 hours of operation, and the Drexelbrook point sensitive probe has accumulated 5,985 hours of operation.

2.2 Transport Gasifier

R11 consisted of 65 steady state periods encompassing over 450 hours of operation. Figure 1 plots major operating parameters for the run. Steady state carbon conversion ranged from 98.2 to 99.9 percent, averaging 98.6 percent.

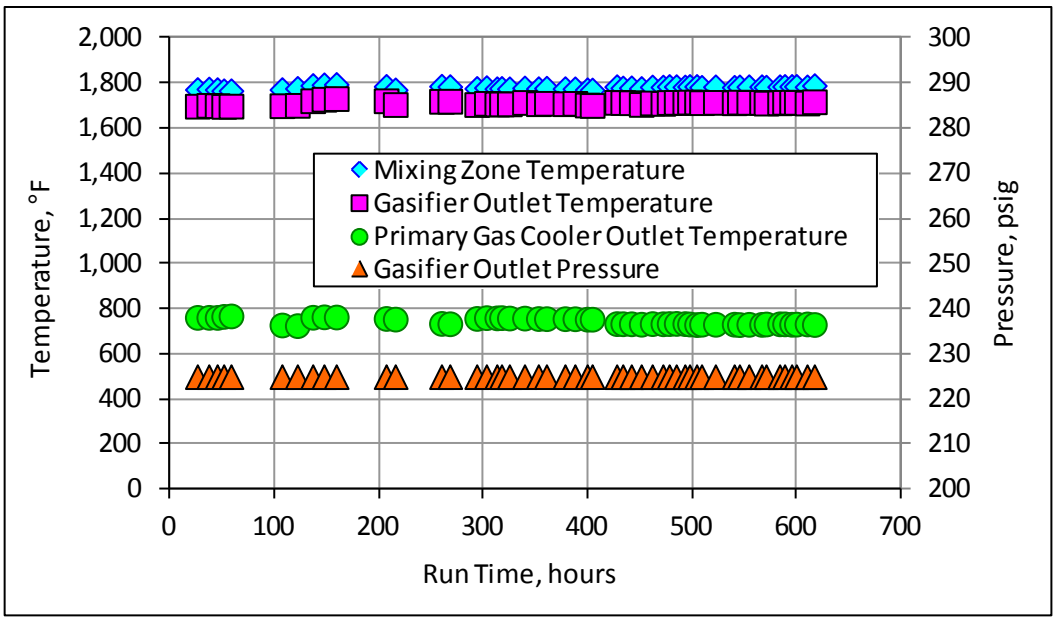

Figure 1. Steady State Operating Conditions

The gasifier automated temperature control performed well during R11. The controller incrementally adjusts the air flow to the upper and lower mixing zone in response to the coal feed rate fluctuations. As shown in Figure 2, the controller maintained the temperature within 5°F. During the run, some tuning was made to the airflow split between the lower and upper mixing zone to stabilize the temperature profile.

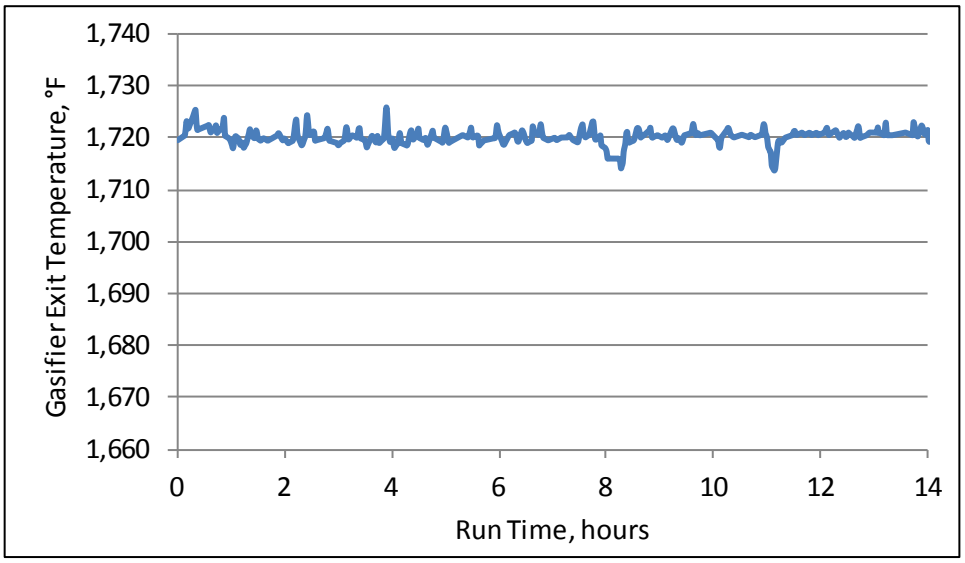

Figure 2. Gasifier Temperature Control Performance

Following the run, inspections and data analysis were completed. Gasifier refractory inspections did not reveal any areas of concern.

Sapphire Thermowell

Testing resumed on the Rosemount sapphire thermowell assembly, which has been tested in previous runs. In R11, the temperature indication from the sapphire assembly was slightly lower, about 10°F, than a nearby reference thermocouple with a conventional thermowell, although the difference was consistent throughout the run.

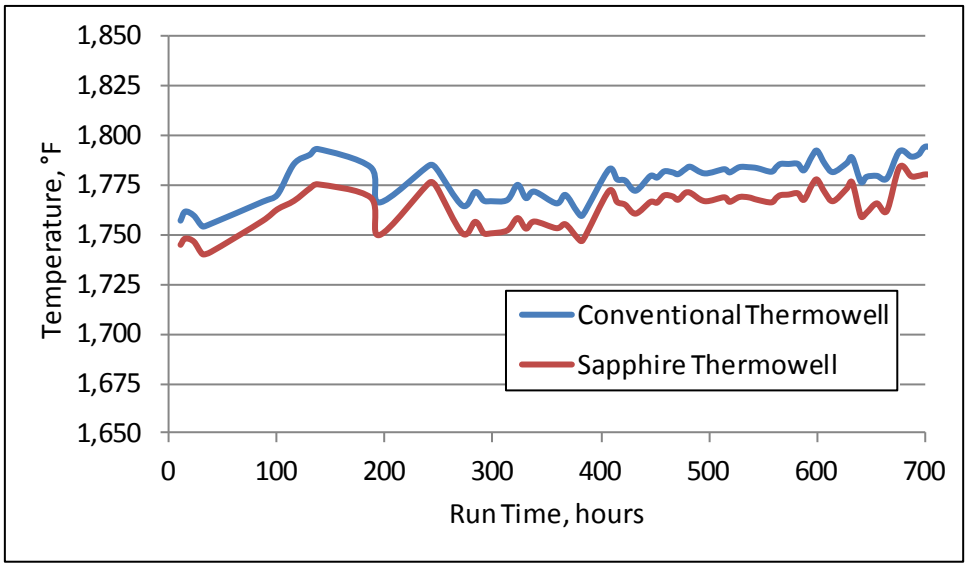

Figure 3. Comparison of Gasifier Temperature Indications Using Conventional and Sapphire Thermowells

2.3 Particulate Control Device

The particulate control device (PCD) operated with stable pressure drop and excellent filtration performance during the run, with particulate outlet loading consistently below the sampling detection limit, which is 0.1 part per million by weight (ppmw). Long-term material evaluation continued for the PCD filter elements and failsafes. The Iron Aluminide elements are the most extensively tested type, with several of these having around 16,000 hours of operation, and they continued to demonstrate acceptably low pressure drop across the filter media.

Filter element manufactures Mott Corporation and Bekaert continued long-term material testing using coupons installed in the PCD downstream of the filter elements. Mott has been testing 65 coupons originally installed in May 2007 made of sixteen different alloys including two types of Inconnel, four Hastelloy materials, three of Iron Aluminide, three of 310 stainless steel, one Silcolloy coated material, and three experimental alloys. Bekaert's coupons were initially installed in July 2010, and these consist of five coupons using Fecralloy, Inconnel, Hastelloy, Nicrofer, and an experimental alloy. All these coupons were left installed following R11 for additional syngas exposure in future runs.

2.4 Ash Removal Systems

During the run, newly installed aeration for the Continuous Coarse Ash Depressurization (CCAD) was evaluated. The modification was made to allow improved control of the solids flow rate through the CCAD depressurization column. Previously, solids packing occurred when the CCAD was not operating continuously, and re-start of CCAD operation would necessitate fluidization, causing excess solids flow. The aeration modification successfully allowed re-fluidization of the solids bed prior to operation of the depressurization column and thus provided a better-controlled flow rate.

3.0 PRE-COMBUSTION CO_2 CAPTURE TECHNOLOGIES

3.1 Worcester Polytechnic Institute Membrane

Worcester Polytechnic Institute continued testing of its palladium-based membrane technology during R11. A single-tube membrane module was heated to 840°F in a nitrogen atmosphere, and initial testing was completed using a nitrogen/hydrogen mixture to establish baseline performance. On August 7, gas flow was transitioned to syngas with hydrogen enrichment from bottled gas to achieve 35 vol%. The membrane performed stably for 355 hours, producing hydrogen with over 99.5 percent purity until the test was ended on August 20 to change to the second membrane with a different composition. However, the stainless steel membrane tube support was damaged during installation. As a replacement was not immediately available, testing was concluded. The second membrane will be tested in R12 using a new support tube.

3.2 Membrane Technology & Research Membrane System

Membrane Technology & Research (MTR) previously tested its 500 lb/hr CO_2 membrane system during R10 and demonstrated high purity liquid CO_2 production. After R10, a number of minor modifications were made to improve system controls and data accuracy. Testing in R11 began on August 6 and continued until August 26 when MTR shut the system down to replace the membrane modules in both stages with a different design. This initial testing period consisted of 345 operating hours and demonstrated stable membrane performance, fourfold CO_2 enrichment in the first-stage membrane, and production of liquid CO_2 with over 97 percent purity. The liquid CO_2 production rate was about 35 to 40 lb/hr, which corresponds to about 60 to 70 percent CO_2 capture. There were a few interruptions arising from issues with the syngas conditioning system and trips of the MTR chiller.

The replacement membranes were designed with higher selectivity at reduced permeance. Although the second-stage membrane performed as expected, the first-stage membrane had unexpectedly high permeance, resulting in a higher flow rate with a lower CO_2 concentration than anticipated. Several process modifications were implemented, such as increasing the first-stage permeate pressure and reducing the compressor discharge pressure to avoid a compressor trip from high suction pressure. The lower pressure coupled with lower CO_2 concentration reduced liquid CO_2 production. The second membrane operated for about 82 hours and still provided valuable second-stage membrane performance data for further evaluation. After the run, the membrane modules were removed and returned to MTR for post-run analysis.

3.3 Media & Process Technology Membrane

Media & Process Technology's 86-tube catalytic membrane reactor was tested for over 350 hours in R11. During previous testing in run R10, several membrane tubes had failed because of stresses induced by the tightly packed WGS catalyst. For R11, less catalyst was used, and no membrane tubes failed.

On average, CO conversion was 50 percent with the moisture inherent in the syngas, and there was no reduction in membrane permeance. A steam line was added prior to the run but was not placed in service due to condensation. Additional heating and insulation will be applied to the steam line in preparation for R12. The main objective for the forthcoming run is to collect additional data in support of reactor scale-up.

In R10 when operating with sub-bituminous coal, gas analysis measurements indicated that the methane entering the reactor was being cracked to extinction. During R11 operation with lignite, no methane reduction was observed. This phenomenon will be investigated further in R12 when sub-bituminous coal will be used again.

3.4 Water-Gas Shift Catalyst

The WGS catalyst previously tested in runs R07 through R10 was further tested in R11 for around 720 hours, raising the total exposure time to over 3,000 hours. Though original plans

were to return the catalyst to the vendor for post-run analysis after R11, the vendor has decided to continue testing in R12 to accumulate more operating hours in syngas. During R11, 50 lb/hr of syngas was fed to the catalyst at 480°F and 195 psia without steam addition. On average, the catalyst achieved about 80 to 90 percent CO conversion with a steam-to-CO ratio of 1.5 to 3.5.