LOW-RANK COAL GASIFICATION STUDIES USING THE PSDF TRANSPORT GASIFIER

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ABSTRACT

The Power Systems Development Facility (PSDF) is an engineering scale demonstration of advanced coal based power systems, including the KBR Transport Gasifier, a high-temperature, high-pressure syngas filtration system, and a gas cleanup unit. Designed to be at a sufficient scale to test advanced power systems and components in an integrated fashion, the PSDF provides data necessary for commercial scale-up.

The Transport Gasifier is a circulating fluidized bed reactor designed to operate at higher circulation rates and riser densities than conventional circulating bed units. The high circulation rates result in higher throughput, better mixing, and higher mass and heat transfer rates. Since the gasifier uses a dry feed system and does not slag the ash, it is particularly well-suited for high moisture fuels such as subbituminous coal and lignite. As of September 2006, the gasifier has achieved over 7,100 hours of gasification using subbituminous Powder River Basin (PRB) coal and over 700 hours of gasification using lignite. The gasifier has operated in both air blown and oxygen blown modes with both fuels.

Using PRB coal in previous test runs, the gasifier yielded raw wet lower heating values of up to 71 BTU/SCF in air blown mode and up to 100 BTU/SCF in oxygen blown mode. These values translate into commercially projected syngas heating values of up to 147 Btu/SCF in air blown mode and up to 299 BTU/SCF in oxygen blown mode. Historically, the gasifier has maintained carbon conversions of around 95% using PRB coal. Recent gasifier configuration modifications have resulted in improvements to both the heating value and the carbon conversion. Preliminary data for PRB coal during air blown mode suggest an increase in the raw wet lower heating value to as high as 87 BTU/SCF, while the average carbon conversion increased to over 98%. This paper compares the performance of the gasifier during early testing with subbituminous coal and lignite to the preliminary results of the new gasifier configuration.

INTRODUCTION

The Power Systems Development Facility (PSDF) is an engineering scale demonstration of advanced coal fired power systems. At a sufficient scale to test advanced power systems and components in an integrated fashion, the PSDF provides data necessary for commercial scale-up. The United States Department of Energy, the Electric Power Research Institute, Southern Company, Kellogg Brown & Root, Inc. (KBR), Siemens Power Generation, Inc., Peabody Energy, the Lignite Energy Council, and Burlington Northern Santa Fe Corporation are current project participants.

Current clean coal technology development at the PSDF focuses on the Transport Gasification Process, a system including the KBR Transport Gasifier, a particulate control device (PCD), a gas cleanup test skid, and a number of auxiliary systems essential for any coal gasification process. The Transport Gasifier, a pressurized circulating fluidized bed system, provides an ideal system for gasifying high moisture, high ash coals, since it uses a dry feed system and does not slag the ash. A versatile system, the Transport Gasifier can operate in air or oxygen blown modes.

A primary goal of the PSDF is studying and improving the operability and performance of the Transport Gasification Process. Major indicators of process performance include the syngas heating value and the gasifier carbon conversion. A sufficient syngas heating value is critical for reliably operating a combustion turbine, while higher carbon conversions improve the gasifier efficiency and reduce operating costs. PSDF studies have resulted in major improvements in gasifier operability and performance.

Auxiliary system testing is another major goal of the PSDF. During operation, a particulate control device (PCD) filters the particulate matter from the syngas created in the Transport Gasifier to make the gas suitable for use in a combustion turbine or fuel cell. A slipstream gas cleanup system allows testing of various catalysts and sorbents for removing a wide range of pollutants at a variety of conditions. Other systems, such as pressurized coal feeders, recycle gas systems, advanced instrumentation, process automation, gasification ash cooling and depressurization, and syngas coolers are all important items of development at the PSDF.

PROCESS DESCRIPTION

Figure 1 illustrates the general flow diagram used for testing the Transport Gasification Process at the PSDF. A lock hopper assembly supplies fuel to the pressurized gasifier, while a separate assembly supplies sorbent, if necessary, to capture sulfur in the fuel as calcium sulfide. A burner is available to heat the gasifier from ambient conditions to a temperature suitable for adding fuel, but is only necessary during startup. The continuous coarse ash depressurization system (CCAD), located beneath the gasifier, allows for the removal of bed material to control the gasifier bed inventory.

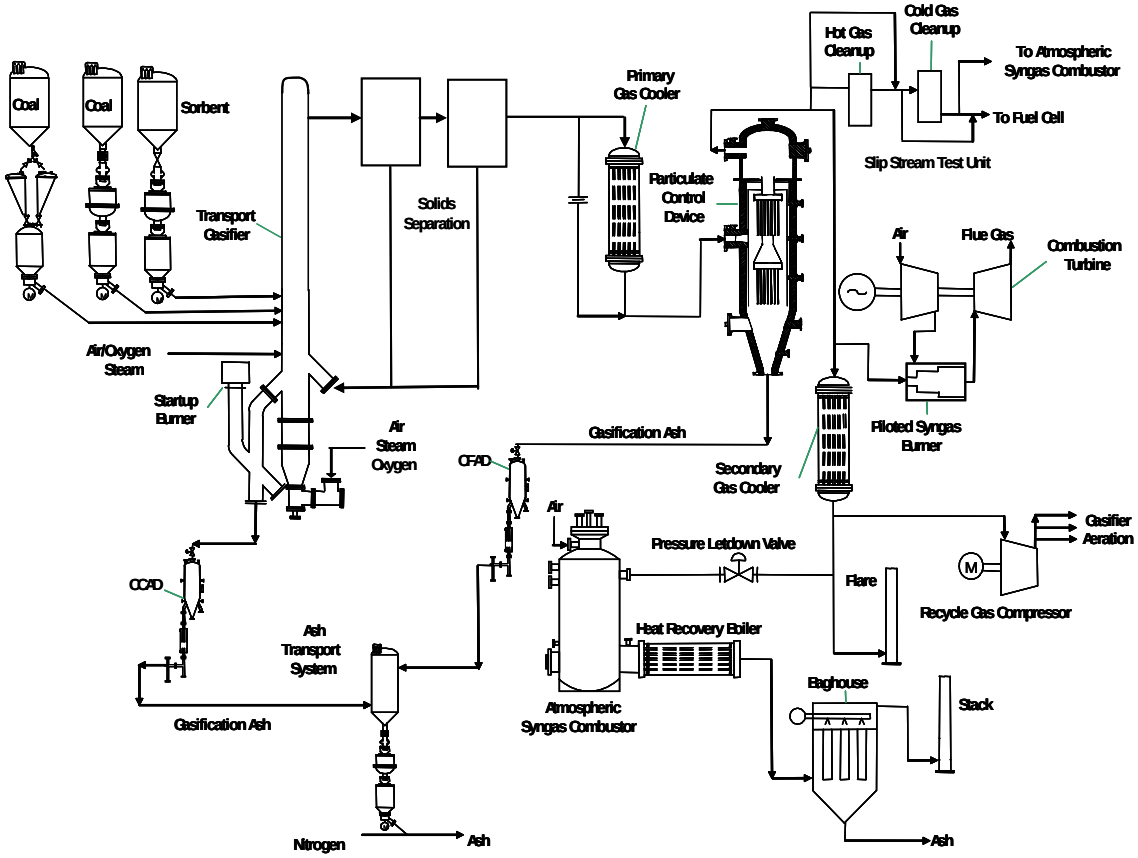

Fig.1. Transport Gasification Process at the PSDF.

The gasifier consists of an assembly of refractory-lined pipe that includes a mixing zone, a riser, a solids separation and collection unit, and a solids recycle section. The lower portion of the mixing zone is where the collected solids reenter the gasifier and combust to provide the heat necessary for the gasification reactions. The coal and sorbent enter the gasifier in the upper mixing zone, where the hot circulating solids traveling upward from the lower mixing zone provide the heat necessary to devolatilize and gasify the coal in the riser, producing syngas and gasification ash.

The resulting syngas and solids mixture then travel through the riser to the solids separation unit. The separation system removes the majority of solid particles and sends them via the recycle section to the lower mixing zone for combustion, while the syngas exits the solids separation unit and proceeds to the primary gas cooler and the PCD. Although the carbon content in the circulating spent solids is small, the high circulation rate ensures that enough carbon is present to provide the heat necessary to maintain gasifier temperatures. The gasifier requires either nitrogen or recycled syngas to fluidize the solids recycle sections of the unit to ensure that the circulating solids flow properly. Air or oxygen is necessary for combusting the recycled carbon, while steam provides a means for dispersing the oxidant and regulating the temperatures.

The nominal Transport Gasifier operating temperature for PRB coal and lignite is between 1,600 and 1,800°F. The PSDF gasifier has a maximum operating pressure of 294 psig in air

blown mode and 220 psig in oxygen blown mode with a thermal capacity of about 50 MMBtu/hr.

After leaving the solids collection unit of the gasifier, the syngas flows into the primary gas cooler at a temperature of approximately 1700°F. The primary gas cooler lowers the syngas temperature to 800°F before the gas enters the PCD. In the PCD, filter elements reduce the particulate loading in the syngas to less than 1.0 ppmw. When the differential pressure across the filter elements increases to a certain level, or a defined time elapses, a high pressure gas quickly back-pulses the system, forcing the filter cake to fall to the PCD cone and into the continuous fine ash depressurization system (CFAD) shown in Figure 1. A common ash silo collects the solids removed via the CCAD and CFAD for disposal.

The filtered syngas exiting the PCD continues to either a combustion turbine for producing electricity or to the secondary gas cooler and the atmospheric syngas combustor, where the gas is burned and all reduced sulfur compounds (H_2S, COS, CS_2) and reduced nitrogen compounds (NH_3, HCN) become oxidized. Upon leaving the syngas combustor, the flue gas flows through a heat recovery boiler to both cool the gas and generate steam. The cooled gas then passes through a baghouse and out the exhaust stack. A slipstream test unit is also available for testing various catalysts and sorbents for removing syngas contaminants before sending the syngas to the atmospheric syngas combustor or to a fuel cell. To improve heating value and reduce nitrogen consumption, a recycle gas system can send a portion of the syngas back to the gasifier to serve as fluidization gas.

EXPERIMENTAL METHOD

Since 1999, the Transport Gasifier has accumulated over 8,500 hours in four commissioning tests and 15 test campaigns. The campaign test plan dictates the process parameters to be tested during the run such as the gasifier temperature, pressure, steam flow rate, coal feed rate, and the type of oxidant, sorbent, and coal used. Most tests have featured low rank fuels, including lignite (over 750 hours of testing) and subbituminous coal from the Powder River Basin (over 7,400 hours). Although most of the testing has occurred during air blown mode, the gasifier has operated for over 1,700 hours in oxygen blown mode. The test campaigns have been greatly successful, particularly using high volatile fuels such as PRB coal and lignite.

Prior to 2006, the Transport Gasifier design was based on a combined combustor/gasifier design that limited its performance as a gasifier. In early 2006, changes to the gasifier provided new, more robust solids separation and recycle systems as well as a larger diameter riser. These changes consisted of replacing approximately 85% of the existing refractory-lined gasifier. The primary goals were to improve the solids collection efficiency and to increase the residence time in the gasifier as well as to generate a solids collection system better suited for commercial scale-up. Increasing the collection efficiency was necessary to improve the carbon conversion by retaining more of the carbon in the gasifier unit. Increasing the residence time also improves the carbon conversion as well as improves the breakdown of heavy organic compounds into desirable syngas components such as methane.

RESULTS AND DISCUSSION

On August 2, 2006, sand circulation tests began on the new gasifier design, followed by PRB coal gasification testing on August 8. The new design affected both gasifier operations as well as performance. Due to the time frame of the tests, most data are preliminary, but provide general insight into the results of the modifications.

Gasifier Operations

Several operational parameters were significantly affected by the modifications, including the residence time, the riser gas velocity, and the solids collection efficiency. Proper solids collection is important to gasifier operations. With a higher collection efficiency, more solids remain in the gasifier loop, supplying a higher amount of carbon to heat the gasifier. Without a sufficient amount of carbon returning via the solids recycle loop, a portion of the volatiles in the coal will necessarily burn to keep the gasifier warm, thus decreasing the syngas heating value.

Figure 2 depicts the effect the modified system had on solids collection efficiency. As shown in the figure, the flow rate of solids leaving the gasifier in the syngas stream generally ranged from 200 to 500 pph. The modifications reduced this solids flow rate by roughly one-half due to the increased efficiency of the solids separators. The solids flow rate was also more consistent and more linearly dependent on coal feed rate than it was previously.

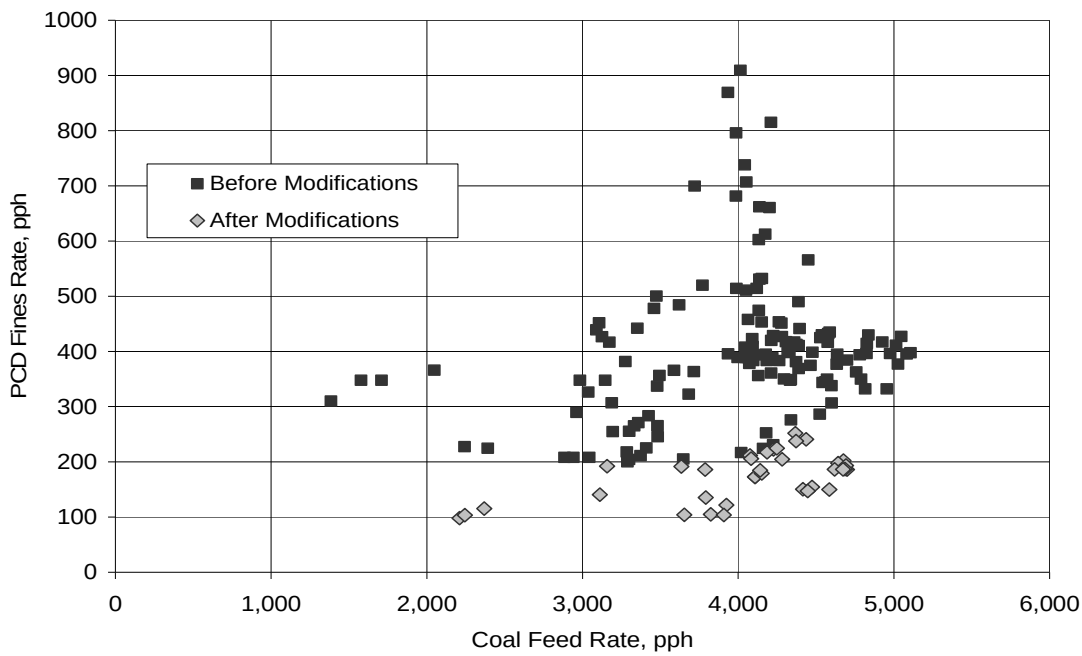

Fig. 2. PCD fines collection rate versus coal feed rate.

Based on preliminary calculations, the separation system efficiency increased from 99.93% to 99.97%, when the coal feed rate was between 4000 and 4500 pph. The increase in separator efficiency led to a decrease in the particle size of the solids filtered by the PCD,

since the improved system collected more of the smaller particles than the previous system. Consequently, the particle size and bulk density of the solids remaining in the gasifier also decreased. None of the changes, however, adversely affected gasifier operations.

Gasifier Performance

During the test run, gas analyzers measured the syngas constituents on a continuous basis. In addition, solids samples were taken at the coal feeders, the PCD inlet, the CCAD and CFAD systems, and from the gasifier. The samples and analyzers provided the information necessary to evaluate the gasifier performance by yielding the syngas heating value and gasifier carbon conversion.

Syngas Heating Value

As mentioned above, one of the primary indices of gasifier performance is the syngas heating value. Commercial gas turbine manufacturers have suggested that a lower heating value (LHV) of greater than 100 Btu/SCF is necessary to operate an Integrated Gasification Combined Cycle (IGCC) unit. Using PRB coal, the Transport Gasifier has produced commercially projected lower heating values as high as 147 Btu/SCF during air blown gasification and as high as 299 Btu/SCF during oxygen blown mode. Both of these values are acceptable for operating a combustion turbine.

The actual heating value of the syngas produced by the PSDF gasifier, however, is lower than that of a commercial facility for several reasons. The small scale of the PSDF unit causes the system to have a higher amount of heat loss per pound of coal fed. Also, the system has a higher flow of instrument purge nitrogen per pound of coal fed than a commercial plant.

The use of recycled syngas at a commercial plant to fluidize the gasifier and the use of air to convey the coal will also dramatically improve the heating value. These systems have recently become available at the PSDF, but have only seen limited testing and none with the new gasifier configuration. Finally, unlike a commercial system, the PSDF does not use a cold gas cleanup system as a final contaminant removal system. Thus, the moisture content of the syngas at the PSDF is higher (and the wet heating value lower) than that of a commercial plant. Prior to the gasifier modifications in 2006, the wet lower heating values for PRB coal were typically only as high as 71 BTU/SCF in air blown mode and 100 BTU/SCF in oxygen blown mode.

The gasifier modifications substantially increased the syngas heating value during air blown operations. Syngas heating values after the modifications were the highest the Transport Gasifier at the PSDF has ever achieved. The raw lower heating values ranged as high a 87 BTU/SCF on a wet basis and occasionally exceeded 100 BTU/SCF on a dry basis. Commercial projections based on these values are yet to be evaluated, but should be at least 30-40% higher than the raw values, well in the acceptable range for operating a combustion turbine.

Figure 3 depicts the preliminary raw, wet lower heating value versus the air to coal ratio for the modified gasifier. The relationship is as expected: as the air to coal ratio increases, the

heating value decreases. Also plotted on the graph is a linear regression representing all finalized PRB data prior to the gasifier modifications. All of the recent preliminary data, with the exception of only a few data points, exhibit much higher heating values than did the previous data at the same air to coal ratios. The increase in heating value was due to the increased residence time and higher solids collection efficiency.

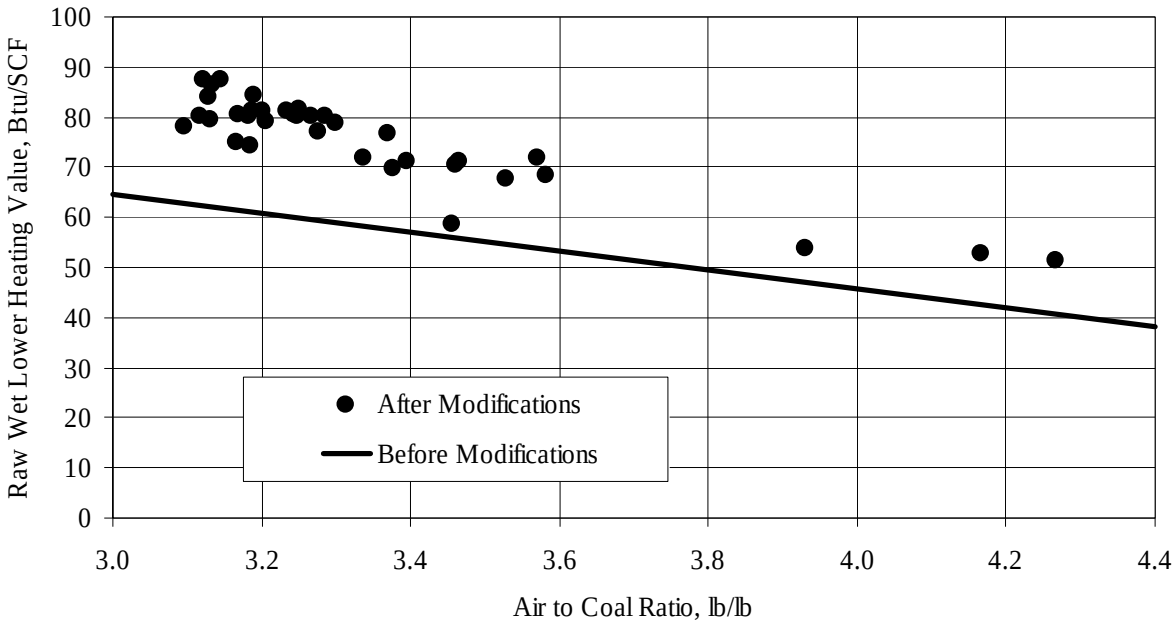

Fig. 3. Preliminary raw syngas lower heating value versus air to coal ratio.

Carbon Conversion

Another major performance indicator is the gasifier carbon conversion. Carbon conversion is the percentage of coal carbon entering the gasifier that leaves in the syngas stream. Typically, carbon conversion for the Transport Gasifier has been high for low rank coals such as PRB coal (averaging 95%) and lignite (averaging 97%). The conversion, however, is notably lower at lower gasifier temperatures and also with low volatile coals.

Operating at low temperatures is often a necessity. Many types of lignite contain sodium and potassium. These chemicals react with silica to form low melting point compounds that form agglomerates in the gasifier at normal operating temperatures and disrupt operations. Often operating at a lower temperature is necessary to prevent the agglomerates from forming. The reduced temperatures, however, result in a lower carbon conversion.

Table 1 lists the averages for the gasifier carbon conversion when using various fuels, including PRB coal, lignites from the Falkirk and Freedom Mines in North Dakota, and bituminous coal from Indiana and the Hiawatha seam in Utah. Also shown is the standard deviation for the carbon conversion for each of the fuels.

All of the values shown in Table 1 are for the original gasifier configuration, with the exception of the final PRB values. The original gasifier yielded the highest carbon conversion when using the two varieties of lignite. PRB coal produced a slightly lower carbon conversion than did the lignite. The high volatile bituminous Hiawatha coal delivered

a higher carbon conversion than that of the low volatile Indiana bituminous coal, but a lower carbon conversion than that of the subbituminous PRB.

Note that all of the carbon conversions shown on Table 1 were at similar gasifier temperatures with the exception of the specially noted Freedom Lignite. The low temperature yielded the lowest carbon conversion of all the fuels, despite the high volatility of the lignite. The low temperatures were desirable, however, when using the high sodium variety of the Freedom Mine lignite to prevent agglomeration.

Table 1. Average Carbon Conversions for the PSDF Gasifier in Air Blown Mode.

	Gasifier Configuration	Average Carbon Conversion	Standard Deviation
Falkirk Lignite	Original	97.0	0.9
Freedom Lignite	Original	95.1	3.1
Freedom Lignite – Low Temperature	Original	84.4	3.6
Hiawatha Bituminous	Original	90.4	2.0
Indiana Bituminous	Original	83.2	1.8
PRB	Original	95.4	1.6
PRB	Modified	98.1	0.61

As shown in Table 1, preliminary data indicate that the carbon conversion improved significantly after the gasifier modifications. Instead of averaging 95.4% for PRB coal and ranging from 93.4% to 97.0%, the conversion averaged 98.1%, and was consistently above 97%. The higher carbon conversion is consistent with the higher solids collection efficiency and higher syngas heating value. These values indicate that a higher amount of carbon remained in the gasifier loop and was available to heat the gasifier, reserving more of the coal volatiles for producing syngas. The larger riser diameter also likely played a role in that the residence time in the modified unit was longer. Since the carbon conversion for PRB coal was already high in previous test runs, however, operating at lower gasifier temperatures may yield more conclusive data.

CONCLUSIONS

Preliminary results show that the modified gasifier yielded higher heating values and higher carbon conversions than the previous design, without adversely affecting gasifier operations. By increasing the solids collection efficiency, the new unit was able to retain more carbon, and, as a result, less coal volatiles were used in providing heat to the gasifier. The larger riser diameter also aided by increasing the residence time of the coal in the gasifier. Future tests

are planned with bituminous coals and high sodium lignite at lower gasifier temperatures to evaluate the impacts on both carbon conversion and heating value.

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