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## Gas-phase measurements of a bituminous coal in a pressurized entrained-flow gasifier

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A pressurized stand-alone gas-phase sampling system has been designed and fabricated at the University of Utah's Industrial Combustion and Gasification Research Facility. The system is constructed of three parts: a probe extension through which the gases travel, a pneumatic cylinder that controls the radial sampling location, and the control system. The probe extension is constructed of stainless steel and includes a cooling jacket and a pressure seal housed in a flange assembly. The pneumatic cylinder is capable of traversing the diameter of the gasifier reaction zone with a stroke length of 18 inches. OPTO 22 components and software comprise the distributive control system that controls the various solenoids and hardware in the sample gas line as well as the setpoint of the cylinder. The probe has been operated in pressures up to 150 psig and temperatures in excess of 2800 °F in the facility's pilot-scale entrained-flow gasifier for characterization and initial testing. Samples were run through a gas chromatograph for analysis of major gas species. It was found that as gasifier temperature increased, the gas compositions showed a decrease in both hydrogen and carbon monoxide, but an increase in carbon dioxide. In addition to the gas composition trends, it was found that the heating value decreased with increasing temperature and the syngas outlet HHV was higher than the extracted reaction zone samples. No significant trends were determined correlating radial sample location to gas composition. The molar ratio of CO/CO<sub>2</sub> was also found to decrease with temperature increase.

### **1. Introduction**

With increased utilization of coal and coal/petcoke blends at power generation facilities worldwide, it is important to understand what is happening within a gasifier and how to maximize the worthy attributes of gasification. IGCC plants require a clean synthesis gas for combustion that is rich in carbon monoxide and hydrogen. With an increased empirical knowledge of what these mechanisms and pathways are, more efficient regulatory policy and environmental standards can be created.

This paper presents a novel extractive gas-phase sampling system for use in a Texaco-style entrained-flow gasifier and offers the first data obtained from the sampling system to date. While other entrained-flow gasifiers have been used for extractive sampling (Skinner and Smoot 1980; Wiinikka et al. 2010; Alexander Tremel et al. 2012; A Tremel et al. 2012), this is the first known application to a slurry-fed, refractory-lined, entrained-flow gasifier. The aim of sampling the gas compositions within the reaction zone serves to supply numerous models with empirical data for validation and to increase the accuracy and precision of those models. Continued use of this extractive sample system will leverage more accurate models for use in IGCC application and industry in general.

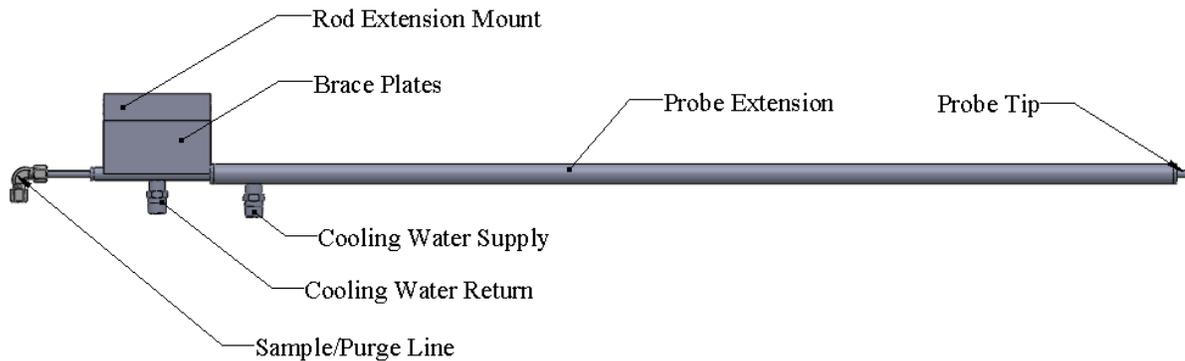
## 2. Methods

Through the use of an extractive gas phase sample system, measurements were made on the Texaco-style entrained-flow gasifier housed at the University of Utah Industrial Combustion and Gasification Research Facility. The gasifier stands at an overall height of 17.5 feet, including the reaction and quench zones and is 2.5 feet in diameter. The reaction zone itself is 8 inches in diameter and 68 inches in length. Water-coal slurry is fed to the top of the reactor via a progressive cavity pump along with oxygen to atomize the fuel. The solids concentration of the water-coal slurry is typically targeted at 55%. The coal used for tests described herein is a Utah bituminous coal with ultimate and proximate analyses shown in Table 1.

**Table 1: Ultimate and proximate fuel analyses.**

Ultimate, % ash-free					Proximate, % as received			
C	H	N	O	S	LOD	Ash	VM	FC
67.87	5.45	1.09	16.87	0.36	6.11	8.36	38.49	47.04

The sampling system consists of three main parts, the probe extension, pneumatic cylinder, and control system. The probe extension is made of stainless steel tubing and plates; a CAD rendering is shown in Figure 1.



**Figure 1: CAD drawing of the probe extension.**

The pneumatic cylinder is attached to the rod extension mount via the threaded rod extension on the nose-end of the cylinder. A U-shaped bracket supports the 3.6 pound cylinder with three 5/8" threaded rod pieces extending from the cooling water flange assembly attached to the gasifier. This whole assembly is shown in Figure 2 with the flange housing and probe extension cooling lines. The small tripod at the far right-hand side alleviates any additional stresses from cantilevering the cylinder from the U-shaped brace.



**Figure 2: Photograph of the entire probe assembly including (from left to right) flange assembly and cooling lines, stabilizer, probe extension and cooling lines, ball joint guide, threaded rod extensions and U-brace, pneumatic cylinder, support stand, and pneumatic control box.**

The sampling sequence is orchestrated using OPTO 22 hardware and software. Once a sample sequence is initiated, the probe is extended to the setpoint at which time the nitrogen purge in the sampling line is turned off and flow reverses, allowing the line to fill with syngas. This purge of nitrogen brings the sample to a bypassed solenoid that opens once the probe reaches the setpoint within the reaction zone. An inline cooling coil and 15-micron filter rid the sample of water and any significant particulate. Tedlar sample bags capture the syngas and are then analyzed using a Varian micro-gas chromatograph, model 4900. The limitation of the sample gas flow rate is a critical orifice installed immediately before the collection bag. This provides choked flow and thus a flow rate of gas at a determined pressure. A correlation was derived for the critical orifice based on gasifier pressure, desired sample flow rate, and orifice size. With a size 16 orifice, the target sample flow rate was 15 liters per minute, yielding five liters per 20 seconds, the desired sample time.

The run conditions of the entrained-flow gasifier were selected based on operating experience of the gasifier and probe and safety considerations of the pressure seal and flange housing of the sampling system. A pressure of 150 psig was chosen for operation and three temperatures of 2500, 2650, and 2800 °F were targeted for sampling. Temperature was determined from thermocouples lining the wall of the reaction zone and altered by varying the flow rates of oxygen and coal slurry. Three radial locations were sampled within the gasifier at each of the three temperatures; duplicates were obtained for each position and a triplicate at one position and temperature. These locations were the wall (W), centerline (C), and half way (H) between the two points. The solids percent of the water-coal slurry used was 56.5%.

### **3. Results and Discussion**

Nineteen samples were taken in total during operation of the gasifier; duplicates at each of nine locations and temperatures and one triplicate. The dry gas phase yields are shown in Figure 3 for carbon monoxide, hydrogen, and carbon dioxide.

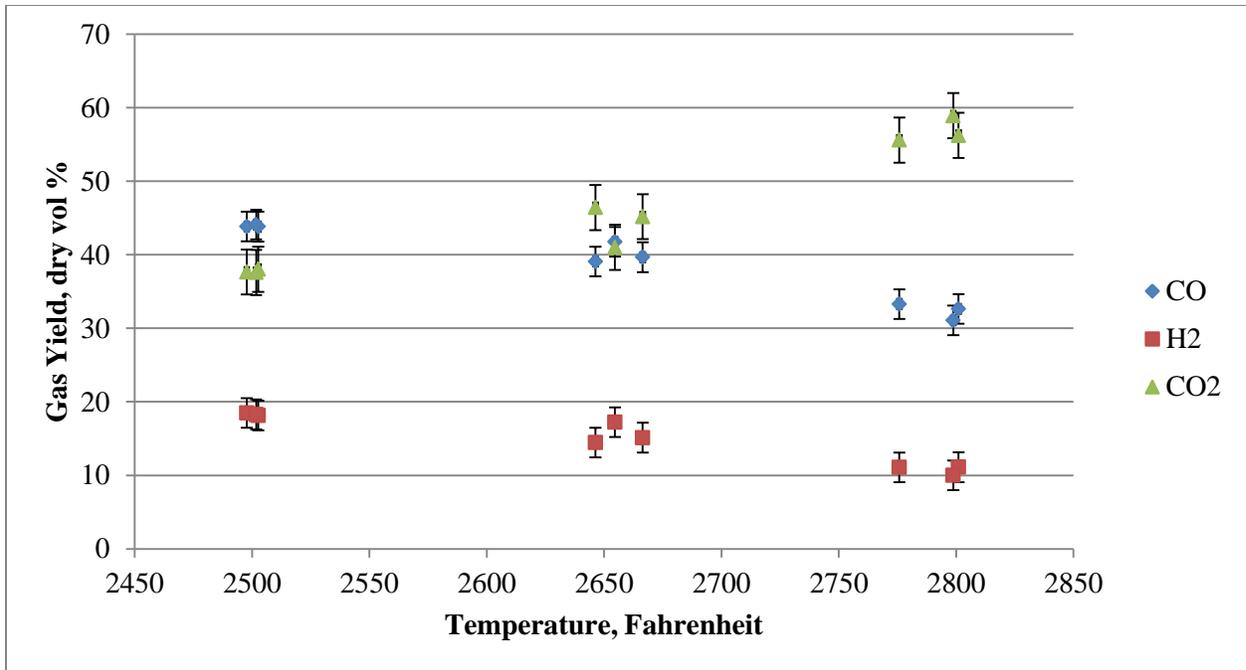


Figure 3: Gas yields for carbon monoxide (◆), hydrogen (■), and carbon dioxide (▲), dry volume percent.

All error values for the gas compositions are the standard error values of all 19 tests per component. The variation seen per target temperature is attributed to deviations of the gasifier temperature. The true temperature was retrieved and referenced in order to more accurately assess the gas composition values and trends. While the composition-temperature plot shows distinct trends, the significance of radial sample location is not as apparent. These effects can be seen in Figure 4 for carbon monoxide, hydrogen, and carbon dioxide with varying target temperature. The dimensionless diameter coordinate corresponds to the location at which the sample was taken in the gasifier. The value indicates how far the probe has traveled in the reaction zone (e.g. 0 corresponds to the wall location and 0.5 corresponds to the centerline).

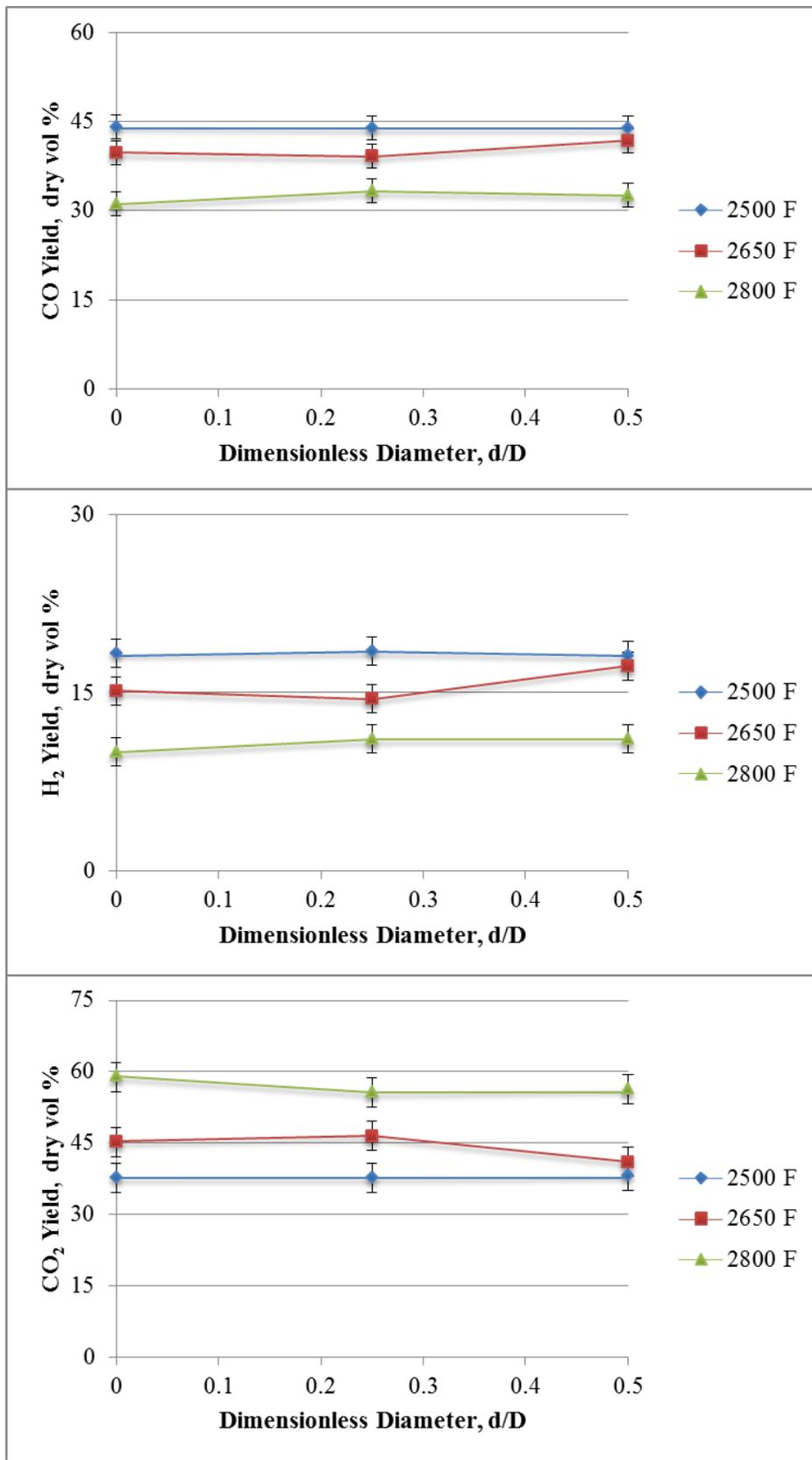


Figure 4: Radial gas compositions as a function of temperature, dry volume percent. Temperature trends are indicated as 2500 °F (◆), 2650 °F (■), and 2800 °F (▲).

The error represented in Figure 4 is the standard error calculated from the original 19 samples. The clear trends that emerge from Figure 3 are that as temperature increases, both carbon monoxide and hydrogen yield decrease, while carbon dioxide increases. The lower temperature samples show less of a deviation than the higher temperatures, most likely attributed to a more steady state operation of the gasifier in the beginning of the campaign. This is not the case, however, with the varying radial sample location as seen Figure 4. Here, any noticeable deviation in the yield is diminished by the fact that it is within the standard error of the sample taken. Two of the most significant deviations in radial location are the yields for carbon dioxide at 2800 °F and the yields of all three gases at the middle temperature of 2650 °F. This suggests that as temperature increases, to an undefined threshold, the carbon monoxide and carbon dioxide yields become closer. This evidence is supported by plotting the CO/CO<sub>2</sub> molar ratio versus actual gasifier temperature, and not target temperature, as seen in Figure 5.

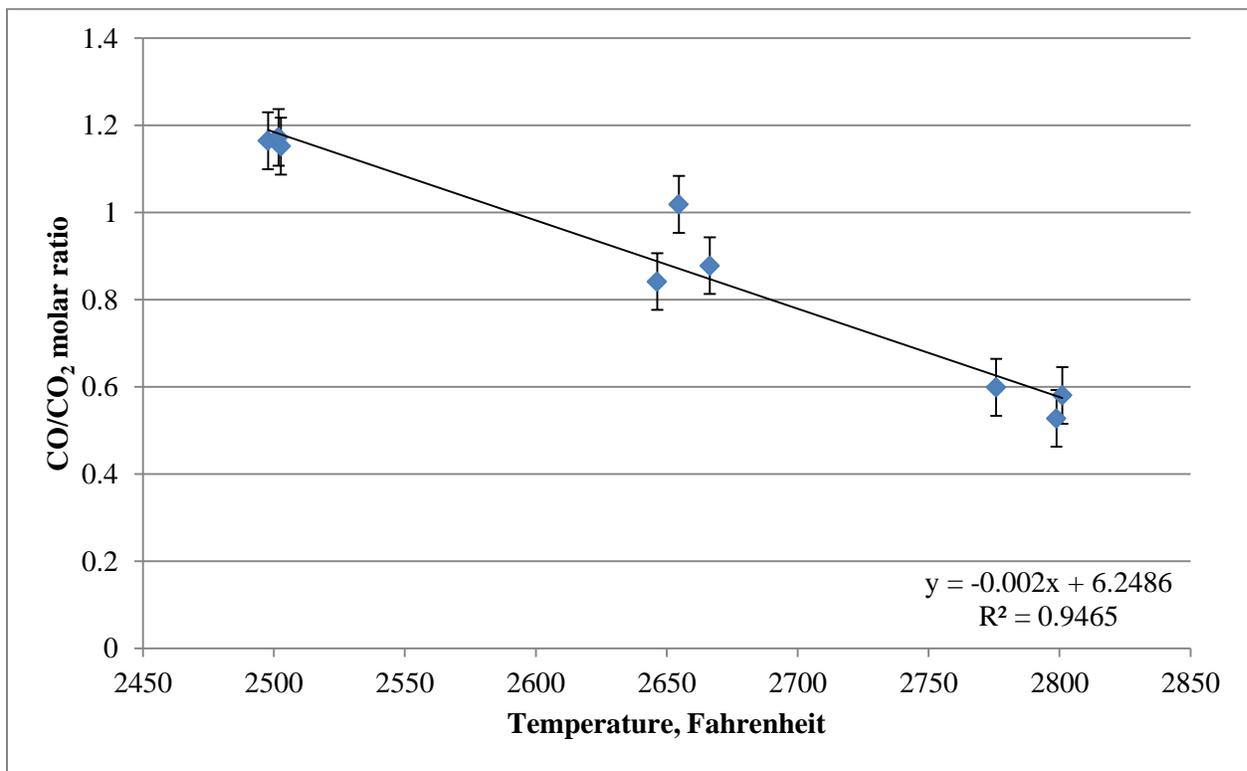


Figure 5: CO/CO<sub>2</sub> molar ratio versus temperature, dry basis.

This decrease in CO/CO<sub>2</sub> ratio also appears in dry-feed systems that alter the steam feed rate. Azuhata (Azuhata, Hedman, and Smoot 1986) showed that with an increase in oxygen flow rate, the CO/CO<sub>2</sub> ratio decreased in a pilot-scale dry-feed entrained-flow gasifier at Brigham Young University. As the temperature is raised in the University of Utah’s Texaco-style gasifier, the slurry flow rate decreases, introducing less water and coal to the system and increasing the oxygen to carbon feed ratio.

Gas chromatography analysis did yield other species, but are not presented above for a variety of reasons. The analyzer was not calibrated with sulfur containing component data at the time of initial analysis and post-processing of the individual chromatograms is necessary to determine yields of hydrogen sulfide and other species. This will be performed at a later date once the system is properly and fully calibrated. Hydrocarbon components, mainly methane, were also seen in the data,

but because of shifts in the retention times of the GC calibration, these species must also be recalibrated and post-processed. Oxygen was determined to be in the analyzed samples and ranged from approximately 0.25 mole percent to 0.5 mole percent. This higher value in oxygen was seen at the highest sampled temperature, evident by decreased slurry feed rate and prolonging the traditional combustion reactions within the gasifier reaction zone. Nitrogen was also seen in the sample and is attributed to a constant purge of the flame detectors near the water-coal injector. This value did not change significantly with temperature, as expected.

The heating value of the intermediate syngas from the gasifier and syngas outlet differ. Centerline gas composition and gasifier outlet higher heating values (HHV) are shown in Table 2.

**Table 2: Higher heating values (Btu/SCF) of intermediate and outlet syngas compositions.**

<b>Target Temperature (°F)</b>	<b>2500</b>	<b>2650</b>	<b>2800</b>
Centerline HHV (Btu/SCF)	196	187	138
Syngas Out HHV (Btu/SCF)	208	195	179

As the target temperature increases, the heating value decreases. This is likely from the higher production of carbon dioxide and less production of hydrogen and carbon monoxide as determined from Figure 3 and Figure 5.

#### **4. Conclusions**

A new extractive gas-phase sampling system has been fabricated and developed by the University of Utah. This paper presents the method and a portion of the abilities of the sample system by measuring gas compositions from a high temperature and high pressure environment. It has successfully sampled a Texaco-style entrained-flow gasifier at 150 psig and temperatures up to 2800 °F. The gas compositions were analyzed by gas chromatography and major trends in gas composition, temperature, and heating value were concluded. These are summarized below.

- As temperature increases from 2500 °F to 2800 °F, carbon monoxide and hydrogen yields decrease as carbon dioxide increases. This results in a decline of CO/CO<sub>2</sub> molar ratio as temperature increases.
- No discernible increase or decrease is determined for gas-phase compositions from variable radial sample locations ranging from the wall to the centerline of the reaction zone.
- Syngas heating values decrease as temperature increases for all radial sample locations as well as the syngas outlet. The magnitude of the heating value increases at the syngas outlet of the gasifier when compared to the mid-section of the reaction zone where the gas-phase samples are taken.

Further work is required to link the gas-phase results to the char collected from the quench zone. This work is targeted for summer 2013 in addition to injector performance for the test campaign described herein. During future test campaigns, it is anticipated that variable axial locations will be sampled in addition to the variable radial locations. This will either be accomplished by positioning the current probe at a different axial location or by fabricating another, similar probe system.

#### **Acknowledgements**

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