MOUNTAIN FUEL RESOURCES 30 TONS PER DAY ENTRAINED FLOW COAL GASIFICATION PROCESS DEVELOPMENT UNIT

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INTRODUCTION

Pressurized gasification of coal in experimental entrained flow gasifiers was studied rather extensively during the period between 1953 and 1962 at the U.S. Bureau of Mines Morgantown Coal Research Center (1,2). A laboratory-scale gasifier with some similarity to the Bureau of Mines unit was operated by the Eyring Research Institute (MFI) between 1974 and 1978 (3,4). This work was followed by extensive process design studies carried out by Mountain Fuel Resources (5) which also led to the issuance of a U.S. patent (6). One of the important conclusions from this study was that feeding the dry coal to an entrained flow gasifier with recycle product gas was inherently more efficient than feeding the coal as a water slurry.

A 30 tons per day process development unit (PDU) was designed, constructed and operated between 1980 and 1984 to provide data for further scale-up of system components. Controlled continuous dry-feeding of pulverized coal into the gasifier at pressures between 100 and 260 psia (600 and 1700 kPa) was achieved. The unit was operated for more than 2000 hours on six different feedstocks. Most of the tests were conducted with Utah bituminous coal, achieving above 90 percent carbon conversion without char recycle.

DESCRIPTION OF PDU

Coal, 2" x 0" in size, was brought to the PDU site by trucks and piled on asphalt pads. The coal was reduced to less than 1/4" in size in a hammer mill, then pulverized to 70 percent minus 200 mesh in a roller mill. The pulverized coal was carried by hot gas into a cyclone where 90 to 95 percent of the coal was separated and dropped into a 20 ton storage bin. The remaining fine coal carried over from the cyclone was collected in a baghouse and also stored in the storage bin.

Coal was conveyed from the storage bin to a 3 ton lock hopper with nitrogen and, after being filled with coal, the lock hopper was pressurized with recycled product gas to the same pressure as the coal feed hopper below and the coal was discharged into the feed hopper. From the feed hopper the coal was fed into the coal feed line and carried to the gasifier by recycled product gas. Approximately 8 to 10 percent of the product gas was recycled to carry the pulverized coal. Twin augers located in the bottom of the coal feed tank were used to regulate the rate of coal flow into the feed line. Figure 1 presents a simplified process flow diagram of the PDU.

The gasification reactions were carried out at pressures up to 260 psia and at temperatures around 1565°C (2850°F) in a refractory-lined chamber approximately 2.3 cubic feet (0.065 cubic meters) in volume. Both heated oxygen and superheated steam were fed to the reactor. The reactor residence time was in the range of 0.5 to 1 second for most of the tests conducted. A radiant heat exchanger is located immediately below the gasifier in the same pressure vessel. The raw product gas leaves the vessel at a temperature about 670°C (1240°F). Approximately 50 to 60 percent of the ash in the form of slag droplets and char is collected at the base of the vessel. A water spray is used to cool the slag. Periodically, the slag and char are discharged into a slag lock hopper. Then the lock hopper is depressurized and the contents discharged into the slurry discharge tank where they are combined with fly ash, soot, and water discharged from the scrubber. This mixture is then pumped to a hydroclone. The underflow from the hydroclone is discharged to the waste water pond and the overflow to the recycle water pond.

The hot product gas from the radiant heat exchanger vessel passes through a section of double-wall pipe heat exchanger and into a scrubber and packed tower. The gas is metered and sampled on-line for analysis downstream of the scrubber and then is flared.

GASIFIER

A schematic drawing of the pressure vessel containing the gasification chamber, the heat exchanger internals, and slag quench section is presented in Figure 2. This vessel is 48 inches in diameter and 20.5 feet in length. The diameter of the refractory-lined reaction chamber is 16 inches. The refractory is supported by a water-jacketed cylinder. Coal, oxygen and steam are injected into the gasifier at the top of the chamber. Coal is injected through a water-cooled 1-1/2 inch feed nozzle and oxygen and steam mixture is injected through an annular space around the coal feed injector. Figure 3 shows a schematic drawing of the injector nozzle and head assembly. The head is fabricated from beryllium copper alloy, which is cooled by passing water through a slot parallel to the surface facing the reactor.

The heat exchanger internals inside the pressure vessel consist of three separate sections. The first section, the radiant heat exchanger, is a cylindrical membrane wall manufactured from steam tubes with strips of metal welded between them. Saturated water from the steam drum enters the tubes from the bottom and flows up through the tubes producing steam. The tube wall is also equipped with four soot blowers. The second section is a coil that cools the lower portion of the pressure vessel and protects it from the hot product gas. A small amount of steam is generated in this coil through convective heat transfer. The third section is located in the bottom of the vessel and consists of the slag quench equipment. A spray ring is installed in the bottom of the exchanger. Cooling water from the recycle water pond is sprayed through nozzles on this ring to form a pool of water in the bottom of the vessel.

Corrosion tests were conducted by IIT Research Institute (7) by installing test coupons in the slag quench pool. Test results show that at the bottom of the radiant heat exchanger, where corrosion coupons were submerged in the slag quench pool most of the time and the temperature scarcely exceeded 220°F, materials like A515 carbon steel, aluminized carbon steel, 2 1/4Cr-1Mo, 1 1/4Cr-1Mo, 9CR-1Mo, and 410 SS suffered from heavy corrosion. Types 304 SS and 316 SS exhibited acceptable overall corrosion, but they have a tendency to pit in this environment. The Incoloy 800 specimens showed excellent resistance to general corrosion and pitting.

TEST RESULTS WITH UTAH BITUMINOUS COAL

Extensive tests were conducted with Utah bituminous coal from Southern Utah Fuel Company's (SUFCO) Mine No. 1 located near Salina, Utah. Table 1 presents typical proximate and ultimate analyses of the pulverized coal. The coal received at the plant usually contained about 8 to 10 percent moisture.

The range of the principal operational parameters and test results from July through September 1984 are presented in Table 2. Figure 4 presents product gas rate, and gas composition versus coal feed rate. The gas production rate averaged 29.3 SCF/lb of coal. For the range of coal feed tested, carbon monoxide was found to increase and carbon dioxide to decrease slightly with coal feed rate, while hydrogen seemed to reach a maximum at about 1400 pounds per hour coal rate. The ranges of the dry volume percent of the major gas components are 51 to 60 percent for CO, 30 to 36 percent for H_2, and 6 to 12 percent for CO_2. The cold gas efficiency and fraction carbon gasified increase with oxygen/coal ratio and coal feed rate for the range of conditions tested. It is obvious that the fraction of carbon gasified will increase toward a value of 1 with increasing oxygen to coal ratio;

however, the cold gas efficiency is expected to reach a maximum value then start to fall as hydrogen and carbon monoxide react with oxygen and reduce the heating value of the product gas.

COMPUTER MODEL PREDICTIONS

Several sets of computations were made with a theoretical gasifier model to assess the effect of systematic variations in reactor conditions on performance of the gasifier and product gas composition. Model parameters were empirically determined from fitting the experimental data. Table 2 also presents a range of predicted performance by computer model. The variations examined were: (1) oxygen/coal feed ratio, (2) steam/coal feed ratio, (3) recycle gas/coal ratio, and (4) reactor heat loss. Results from these computations are presented in Figures 5 through 8. The cases were run using the model parameters as optimized for the July-September SUFCO coal data. The predicted product gas volume and product gas composition are plotted versus the oxygen coal feed ratio, with other variables as parameters.

It was found that the heating value of the product gas is at a maximum for an oxygen/coal ratio of between 0.8 and 0.9. Variations in the recycle gas to coal ratio were calculated to have only a weak influence on the product gas composition and volume. The steam/coal ratio, Figure 6, demonstrates a strong influence on the product gas composition with little effect in the product gas volume. The carbon monoxide concentration is highest for a lower steam/coal ratio. For lower oxygen feed rates, the temperature is a strong factor in the product gas volume. However, at an oxygen/coal ratio between 0.8 and 0.9, the cold gas efficiency is unaffected by the steam feed rate.

Variations in the reactor heat loss were calculated to significantly affect the product gas volume and composition, mainly through lowering the reactor temperature. Figure 7 shows significantly lower product gas volume and quality with a higher reactor heat loss. Figure 8 again presents the effect of reactor heat loss; however, here the oxygen/coal feed ratio was adjusted to yield the desired reactor temperature. For a constant reactor temperature, a higher reactor heat loss deteriorates the product gas quality only slightly.

The oxygen/coal feed ratio is the controlling parameter on reactor temperature and performance. The effect of variations in steam, recycle gas ratio and the reactor heat loss on the cold gas efficiency are relatively small compared with the effects of varying the oxygen/coal ratio.

Table 3 presents a direct comparison of PDU data with the design assumptions for a scale-up unit utilizing SUFCO Utah bituminous coal.

CONCLUSIONS

The dry-feed, entrained coal gasification PDU was operated successfully for a total of about 2200 hours. Controlled continuous dry-feeding of pulverized coal into the gasifier at pressures up to 260 psia was achieved. Reactor throughputs of up to 754 $lbs/hr/ft^2$ or 317 $lbs/hr/ft^3$, gas yields of about 32 SCF/lb coal and gas heating values of 294 BTU/SCF were achieved. Carbon conversion efficiencies above 90 percent without char recycle were achieved with Utah bituminous, Wyoming subbituminous, and North Dakota lignite coals. Cold gas efficiencies as high as 80 percent were achieved with SUFCO coal. Sufficient reproducible data were obtained for scale-up design for applications utilizing Utah bituminous coal from SUFCO Mine No. 1.

ACKNOWLEDGEMENT

The authors gratefully acknowledge support of this work by the Department of Energy under Contract No. DE-AC21-81FE05121, Gary R. Friggens, Contractor Monitor.

REFERENCES

1. Holden, J.H., et al., "Operation of Pressure-Gasification Pilot Plant Utilizing Pulverized Coal and Oxygen: A Progress Report," Report of Investigations 5573, U.S. Dept. of the Interior, Bureau of Mines (1960).

2. Holden, J.H., Plants, K.D., et al., "Operating a Pressurized Gasification Pilot Plant Using Pulverized Coal and Oxygen: Effect of Heat Loss on Economy," Report of Investigations 5956, U.S. Dept. of the Interior, Bureau of Mines (1962).

3. Coates, R.L., "High Rate Coal Gasification," in Volume 3, "Coal Processing Technology," American Institute of Chemical Engineers, New York, N.Y., 1977, pp. 89-94.

4. McIntosh, M.J., and Coates, R.L., "Experimental and Process Design Study of a High Rate Entrained Coal Gasification Process," Final Report under Contract No. EX-76-C-01-1548, Eyring Research Institute, Provo, Utah, 1978.

5. Coates, R.L., and Mantyla, R.G., "Process Design Studies for High-Rate, Entrained-Flow Coal Gasification," Proceedings of the First International Gas Research Conference, June 1980, Chicago, Illinois, published by Government Institutes, Inc., Rockville, Md., October 1980, pp. 224-242.

6. U.S. Patent No. 4,272,255, "Apparatus for Gasification of Carbonaceous Solids."

7. Yurkewyez, R., "Corrosion and Degradation of the Test Materials in the Mountain Fuel Resources 30 Ton/Day Coal Gasification Process Development Unit," Report of Materials Evaluation conducted in 1983-1984 by IIT Research Institute for the Metal Properties Council, Inc., support by the U.S. Department of Energy, Morgantown Energy Technology Center, Report No. MPCI-22241-2, January 31, 1985.

TABLE 1

SUFCO UTAH BITUMINOUS COAL ANALYSIS

PROXIMATE ANALYSIS, Wt.%		ULTIMATE ANALYSIS, Wt.%	
Moisture	2.55	Moisture	2.55
Ash	9.23	Carbon	69.60
Volatile	39.37	Hydrogen	4.84
Fixed Carbon	48.85	Nitrogen	1.15
	100.00	Chlorine	0.02
		Sulfur	0.42
Btu/lb	12180	Ash	9.23
		Oxygen (diff.)	12.19
			100.00

TABLE 2

RANGE OF THE PRINCIPAL OPERATIONAL PARAMETERS AND SUMMARY OF THE RESULTS AND CORRELATIONS OF THE SUFCO COAL DATA, JULY - SEPTEMBER 1984

Range of Test Conditions		
Reactor pressures, psia	90.4 - 212	
Coal feed rates, lbs/hr	653 - 1812	
Oxygen/coal ratios	0.62 - 0.94	
Steam/coal ratios	0.11 - 0.22	
Recycle gas/coal ratios	0 - 0.33	
Range of Results	Actual	Predicted
Gas Yields, SCF/lb coal	23 - 36	24.5 - 35.4
Gas Composition, %		
Carbon monoxide	50.7 - 59.8	49.8 - 61.7
Hydrogen	27.5 - 36.8	29.9 - 40.7
Carbon dioxide	5.4 - 15.0	6.0 - 12.8
Methane	0.0 - 2.7	0.2 - 2.2
High Heating Values, BTU/SCF	266 - 307	282 - 313
Fraction Carbon Gasified	0.67 - 1.00	0.72 - 1.00
Cold Gas Efficiencies	0.53 - 0.85	0.60 - 0.85
Range of Calculated Balances		
Hydrogen Balance	0.626 - 1.176	
Mass Balance	0.980 - 1.039	

TABLE 3

COMPARISON OF SCALE-UP UNIT DESIGN ASSUMPTIONS WITH JULY-NOVEMBER 1984 PDU DATA

	Scale-Up Unit Design Assumptions	PDU Data Averages for SUFCO Coal Runs
Coal Rate, lbs/hr	11,686	1,055
Feed Ratios		
Oxygen/coal	0.80	0.849
Steam/coal	0.17	0.274
Recycle gas/coal	0.12	0.215
Reactor Pressure, psia	200	157
Reactor Throughput Rate		
$Lbs/hr/ft^2$	1,000	754
$Lbs/hr/ft^3$	190	317
Reactor Heat Loss		
BTU/lb coal	100	325
Product Gas Yield (net, dry)		
MSCFH	371	33.4
SCF/lb coal	31.7	31.5
Product Gas Composition		
Hydrogen	31.6	33.6
Carbon monoxide	56.0	51.3
Carbon dioxide	9.0	12.1
Methane	1.2	0.9
Nitrogen, argon	2.0	2.1
Hydrogen sulfide	0.2	-
Total	100.0	100.0

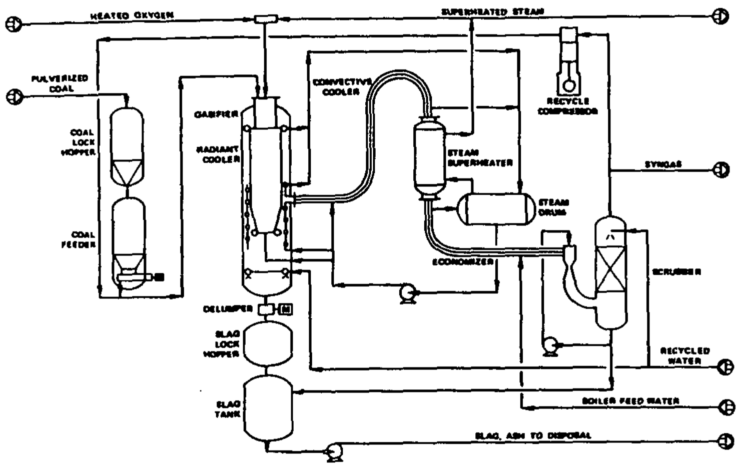
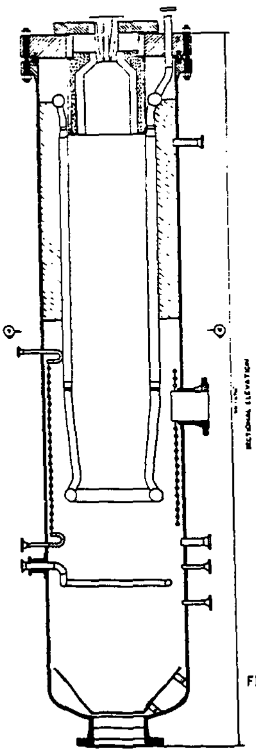


FIGURE 1. Simplified Process Flow Diagram



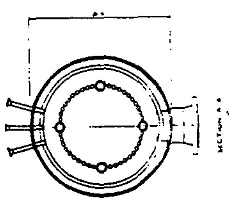


FIGURE 2. Schematic Drawing of Gasifier Vessel

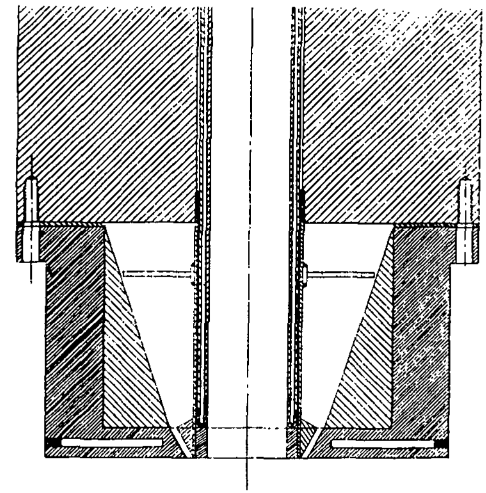


FIGURE 3. Schematic Drawing of Injector Nozzle and Head Assembly

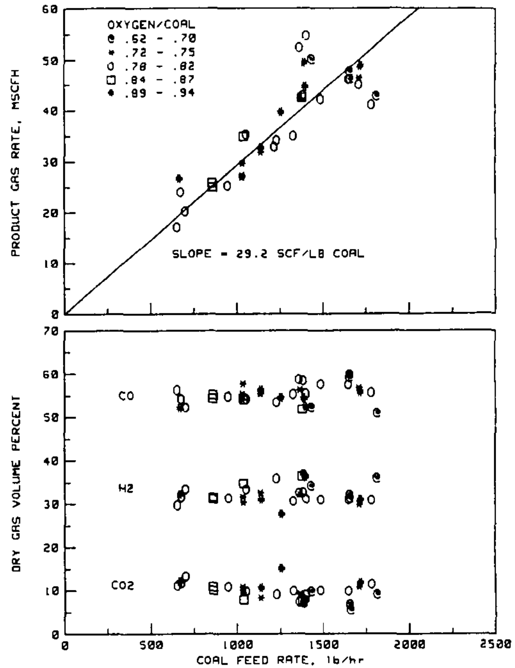


FIGURE 4. Gasifier Performance Data Gas Composition and Product Gas Rate Versus Coal Feed Rate

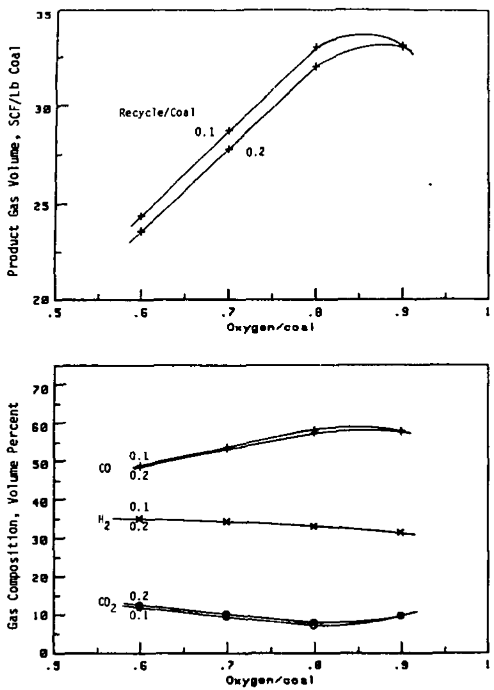


FIGURE 5. Predicted Performance of SUFCO Coal Using Best Fit Parameters from July - September 1984 Data Steam/Coal = 0.2, Reactor Heat Loss = 200 BTU/Lb Coal

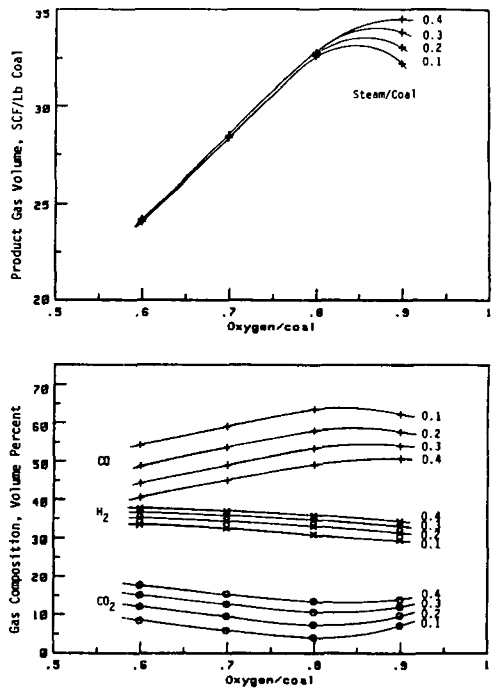


FIGURE 6. Predicted Performance of SUFCO Coal Using Best Fit Parameters from July - September 1984 Data Recycle/Coal = 0.12, Reactor Heat Loss = 200 BTU/Lb Coal

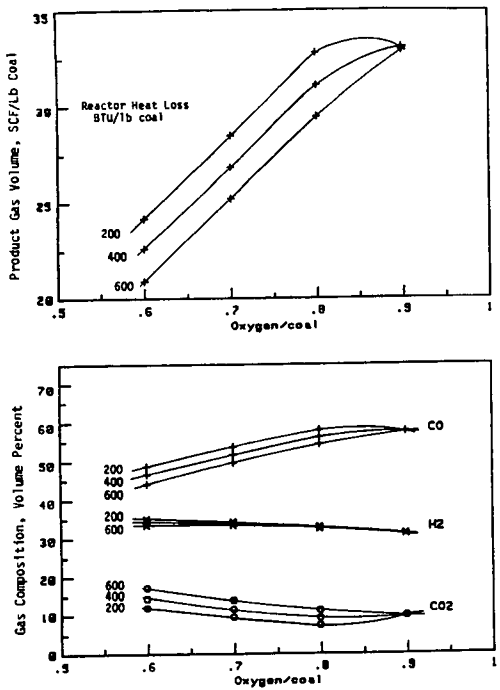


FIGURE 7. Predicted Performance of SUFCO Coal Using Best Fit Parameters from July - September 1984 Data Steam/Coal = 0.2, Recycle Coal = 0.12

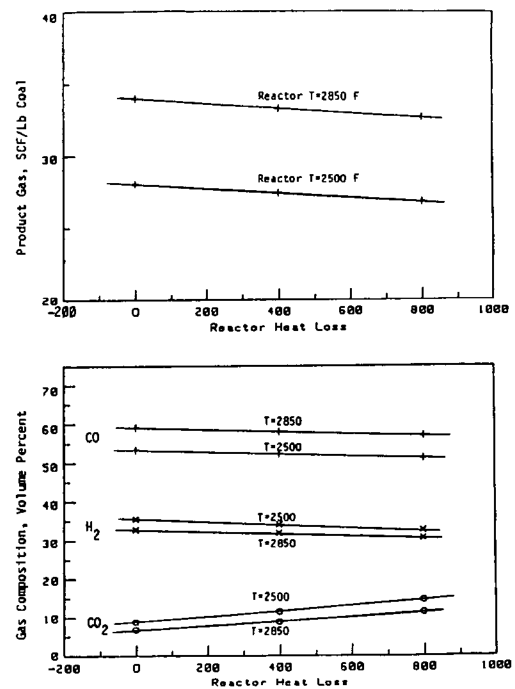


FIGURE 8. Predicted Effect of Heat Loss on Product Gas Steam/Coal = 0.2, Recycle Gas/Coal = 0.12