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HIGH-PRESSURE GASIFICATION OF MONTANA SUBBITUMINOUS COAL

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IGT

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ABSTRACT

A data base for the fluidized-bed gasification of different coals at elevated pressures has been developed at the Institute of Gas Technology (IGT) with different ranks of coal at pressures up to 450 psig and at temperatures dictated by the individual coals. Adequate data have been obtained to characterize the effect of pressure on the gasification of Montana Rosebud subbituminous coal and North Dakota lignite. The results obtained with Montana Rosebud subbituminous coal are presented here. This program was funded by the Gas Research Institute.

INTRODUCTION

The Institute of Gas Technology has developed an advanced single-stage, ash-agglomerating fluidized-bed coal gasification process -- the U-GAS process -- to produce a low- to medium-Btu gas from a variety of feedstocks, including highly caking, high-sulfur, and high-ash coals as well as peat and oil shale. The development of the process has been based on extensive testing in a low-pressure (50-psig) pilot plant conducted over a period of several years. Tests with different feedstocks (coals and other carbonaceous feedstocks) have achieved 98% coal utilization with long-term steady-state operation. Reliable techniques have been developed for start-up, shutdown, and process control. Operation of the pilot plant has firmly established the process feasibility and has produced a wealth of design data for various coals from many parts of the world. A detailed description of the process and the development program is given by Patel (1980), Leppin and Goyal (1981), and Goyal and Rehmat (1985).

The U-GAS pilot plant has an operating pressure limitation of 50 psig. However, the process economics of several coal gasification applications, including the production of SNG, chemicals, and combined-cycle power generation, favor the operation of the ash-agglomerating gasifier at a higher pressure, in the range of 300 to 500 psig. In the literature, data were available at pressures up to 230 psig only. Thus, IGT decided to construct and operate a gasification unit that would be capable of operating at pressures up to 500 psig.

The nominal capacity of the 3-foot-diameter low-pressure pilot plant is 30 tons per day. Its operation is expensive because of manpower needs for plant operation and utilities as well as data analysis. Thus, IGT constructed an 8-inch-diameter (ID) process development unit (PDU); it has a nominal capacity of 10 tons per day at 450 psig operation. The funding for this testing has been provided by the Gas Research Institute (GRI).

PDU DESCRIPTION

The PDU is located adjacent to the 3-foot-diameter low-pressure unit in the U-GAS pilot plant building because of the advantages of sharing the utilities, such as electric power, natural gas, oxygen, steam, and nitrogen; joint use of the pilot plant's coal drying, handling, storage, and weighing system; and the availability of an area for a control room that can accommodate a standard control panel. Figure 1 is a flow diagram of the high-pressure PDU system. It consists of 10 sections that perform all the functions necessary for integrated operations: 1) coal drying, 2) dry coal handling and storage, 3) coal/coke weight hoppers, 4) pressurized coal-feed lockhoppers, 5) coal-feed injection, 6) PDU gasifier, 7) product-gas quencher, 8) product-gas cyclone dust collector, 9) pressurized ash lock-hoppers, and 10) gasifier control system.

The coal dryer is a cocurrent, single-shell rotary drum unit with a nominal capacity of 1 ton/h when drying coal. The coal discharged from this dryer has the +1/4-inch (or 6-mesh) oversize scalped off by a screen. The 1/4-inch X 0 coal is conveyed by a bucket elevator to the top of either an 80-ton or a 120-ton storage silo. Each silo has a built-in 5-ton hopper at its top with variable-speed-drive feed screw to discharge coal. Because the process is initiated by using metallurgical coke as a start-up feed material, one silo is set aside for coke storage regardless of the feed coal being processed. Each pilot feed hopper discharges to a batch weigh system, which feeds preweighed amounts of coal and coke into the feed lockhoppers. The coal weigh hopper operates at atmospheric pressure.

The feed lockhopper system consists of two lockhoppers, each having a capacity of half a ton of coal. These are operated sequentially to pressurize the feed coal to the gasifier operating pressure.

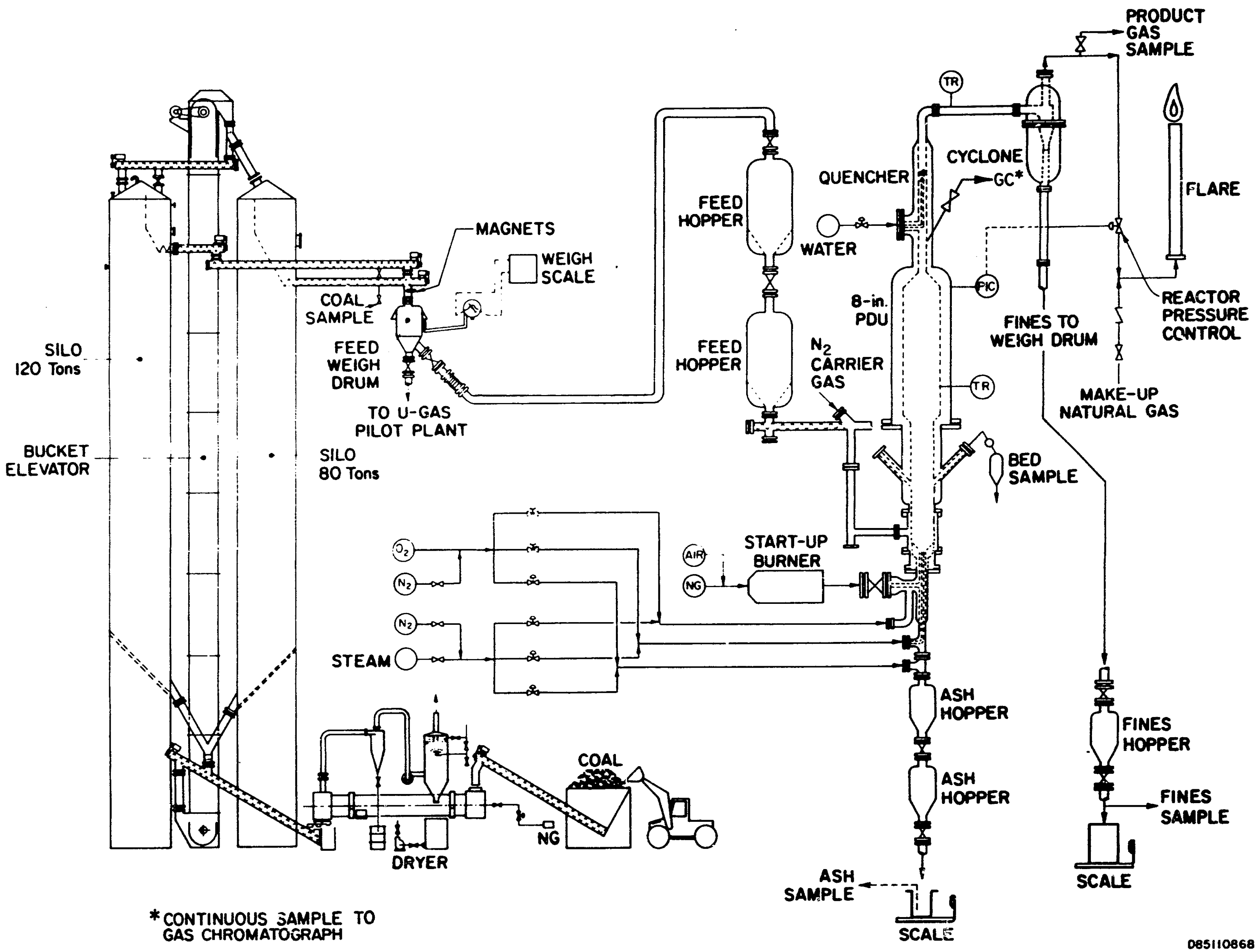

FIGURE 1 - FLOW DIAGRAM OF HIGH-PRESSURE PROCESS DEVELOPMENT UNIT

The coal-feed injection system uses a design based on the pilot plant's experience. The coal is injected pneumatically while the feed rate is controlled by a screw feeder.

The PDU reactor has an 8-inch-diameter X 5-1/4 foot-high fluidized-bed section and an 18-inch-diameter X 8-foot-high freeboard section. The hot inner wall is constructed of 310 SS and the outer wall of pressure-vessel-grade carbon steel.

At the bottom of the fluidized-bed reactor is a removable grid assembly. It is a one-piece weldment accommodating the standard U-GAS process grid with some internal components removable for alteration. In the same manner, the outer shell has been sectionalized to facilitate installation and dismantling for examination, modification, or repair.

The reactor gas leaving the freeboard directly enters the quencher through a refractory-lined tee piece. The direct quench cools the gas to about 1000°F, and the cooled gas then enters a 310 SS insulated cyclone. The cyclone discharges dust to a hopper; the collected dust is removed periodically in a scale-mounted drum. Similarly, the ash-lockhopper arrangement is designed to lower the ash from reactor pressure to ambient pressure and discharge it into a scale-mounted drum.

All process-gas flow streams are measured and recorded. Temperatures are recorded for all process and product-gas streams as well as at several locations within the reactor. The product-gas composition can be continuously monitored by on-line gas chromatography. The product-gas samples are also collected in gas bombs for later laboratory analyses. All solid streams are frequently sampled during runs and analyzed for both ultimate and proximate analysis and for particle-size distribution. Redundancy is provided for the reactor pressure taps used for bed density and height. Accordingly, all information required to calculate a material and energy balance for a steady-state operating period is obtained.

An HP 9845B computer system is used for automatic data acquisition. About 40 data points (temperature, pressure, flow, etc.) are collected every 3 minutes, and the reactor operating status, including various flows, pressures, temperatures, velocities (grid, venturi, bed, freeboard, cyclone), bed density, bed height, etc., is calculated and displayed on the computer CRT screen. These data are averaged every hour, and an hourly status report is printed automatically. All the data are also stored on a tape cartridge for later analysis.

TEST RESULTS

With construction essentially completed in September 1983 (Sandstrom and Bryan, 1984), the PDU has been operated to date with various feedstocks, including metallurgical coke, Australian bituminous coal, Western Kentucky bituminous coal, Pittsburgh No. 8 bituminous coal, Illinois No. 6 bituminous coal, Montana Rosebud subbituminous coal, North Dakota lignite, and Indiana New Albany oil shale (Goyal and Rehmat, 1985; Goyal et al., 1986; Patel et al., 1986; Goyal et al., 1990; Lau et al., 1987).

Several tests were conducted recently in the PDU with Pittsburgh No. 8 bituminous coal, Illinois No. 6 bituminous coal, Montana Rosebud subbituminous coal, and North Dakota lignite in a two-phase program (referred to here as Phase I and Phase II) under a contract with GRI. The test results obtained with North Dakota lignite have been reported earlier by Goyal et al. (1989). The test results obtained with Montana Rosebud subbituminous coal during both of these phases are presented in this paper.

Phase I Operation

During Phase I operation, three tests were conducted with Montana Rosebud subbituminous coal. The characteristics of the feedstock, including ultimate and proximate analyses, ash-fusion properties, ash elemental analysis, bulk density, heating value, and particle-size distribution, are given in Table 1. Steady-state data were obtained with this feedstock at 100, 200, and 300 psig operation. An overview of various set points achieved during this testing is provided in Table 2, while detailed data are given in Table 3. About 19,000 lb of this coal was gaisifed during these runs. Ash-discharge rates were continuous and controllable during these set-point operations. The PDU was operated at 200 psig in two different test runs, which confirmed the data reproducibility. The coal conversion attained during these set-point operations ranged from 83% to 92%. During 100-psig steady-state operation with the Montana Rosebud coal, many rounded particles appeared in the venturi discharge materials. These particles were ash agglomerates consisting of a number of 40 to 60-mesh ash particles cemented together. A number of these agglomerates, with some subangular shale and rounded char particles, are shown in Figure 2. The stucture of an agglomerate is shown in the photomicrograph of Figure 3, in which particles consisting mostly of high-reflectance sintered clay appear to be cemented together by a low-melting silicate probably containing both iron and calcium. Small unidentified crystals are present in the silicate.

Phase II Operation

Subsequent to operations at 300 psig, major unit upgrading was undertaken to enable operation up to 500 psig. These modifications included --

- Rerating of the PDU system to 500 psig. This included replacing a portion of the 8-inch reactor shell section with a 12-inch (ID) shell section (dual-diameter reactor) and

TABLE 1

MONTANA ROSEBUD SUBBITUMINOUS COAL-FEED CHARACTERISTICS

Sieve Analysis (mesh size) U.S.S., wt % retained on	Phase I	Phase II
3	0.0	0.0
6	0.1	0.0
12	23.5	20.9
20	29.3	32.4
40	20.5	21.9
70	14.2	14.3
140	8.2	6.0
270	2.4	1.9
Pan	1.8	2.6
	100.0	100.0
Proximate Anaylsis, wt % (as fed)		
Moisture	15.30	10.00
Ash	9.07	8.98
Volatile Matter	32.31	33.93
Fixed Carbon	43.32	47.09
	100.00	100.00
Ultimate Analysis, wt % (dry)		
Carbon	66.55	65.31
Hydrogen	4.61	4.35
Oxygen	16.19	18.34
Nitrogen	1.04	0.90
Sulfur	0.90	1.12
Ash	10.71	9.98
	100.00	100.00
Bulk Density, lb/ft^3	54.1	52.9
HHV, Btu/lb (dry)	11,244	11,059
Ash Fusion Temp. (reducing atm), °F		
Initial Deformation	2140	2255
Softening	2240	2325
Hemispherical	2280	2360
Fluid	2330	2480
Ash Analysis, wt %		
SiO_2	38.45	41.50
Al_2O_3	17.27	21.40
Fe_2O_3	9.30	5.06
TiO_2	0.62	0.82
CaO	13.91	8.07
MgO	3.95	3.68
K_2O	0.33	0.36
Na_2O	0.39	0.27
P_2O_5	0.33	0.44
SO_3	14.76	15.00

TABLE 2

DATA OVERVIEW WITH MONTANA ROSEBUD SUBBITUMINOUS COAL FEED

A. GRI Phase I Program

GRI Test No.	Press., psig	Bed Temp., °F	Coal Feed, lb/h	Steam, mol/h	Oxygen, mol/h	Steam/C Ratio, mol/mol	Oxygen/C Ratio, mol/mol	Superficial Velocity, ft/s	Set Point
2-6	96	1624	209	11.5	2.6	1.14	0.26	2.3	1
2-6	195	1576	259	19.8	3.7	1.58	0.30	2.0	2
3-1	283	1486	330	31.8	4.6	2.09	0.30	2.0	1
3-2	198	1561	357	23.8	4.8	1.42	0.29	2.3	1

B. GRI Phase II Program*

GRI Test No.	Press., psig	Bed Temp., °F	Coal Feed, lb/h	Steam, mol/h	Oxygen, mol/h	Steam/C Ratio, mol/mol	Oxygen/C Ratio, mol/mol	Superficial Velocity, ft/s	Set Point
5-1	201	1566	353	31.5	5.2	1.74	0.28	2.9	1
5-1	300	1565	537	41.6	6.8	1.52	0.25	2.7	2A
5-1	302	1549	480	42.5	5.8	1.81	0.25	2.6	2B
5-2	450	1501	500	59.8	8.2	2.41	0.33	2.5	1
5-2	450	1548	866	56.5	11.9	1.31	0.28	2.5	2
5-2	449	1553	662	56.8	9.8	1.71	0.29	2.5	3
5-3	449	1538	531	59.8	8.9	2.36	0.35	2.5	1
5-3	448	1456	379	59.8	6.8	3.28	0.37	2.4	3
5-3	448	1652	834	58.3	13.3	1.49	0.34	2.8	2

*Data Matrix Achievements During Phase II

- Three pressures at constant temperature and near-constant steam/C ratio, velocity. 5-1-S.P.1, 5-1-S.P.2B, 5-2-S.P.3.
- Two steam/C ratios at constant pressure, velocity, and near-constant temperature. 5-2-S.P.2, 5-3-S.P.1.
- Three temperatures at constant pressure, velocity; steam/C ratio varied. 5-3-S.P.1, 5-3-S.P.2, 5-3-S.P.3.

TABLE 3

OPERATING DATA SUMMARY
FEEDSTOCK: MONTANA ROSEBUD SUBBITUMINOUS COAL

GRI Run No.	2-6	2-6	3-2	3-1	5-1	5-1	5-1	5-2	5-2	5-2	5-3	5-3	5-3
Set Point	1	2	1	1	1	2A	2B	1	2	3	1	2	3
Pressure, psig	96	195	198	283	201	300	302	450	450	449	449	448	448
Bed Temperature, °F	1624	1576	1561	1486	1566	1565	1549	1501	1548	1553	1538	1652	1456
Freeboard Temeprature, °F	1600	1580	1575	1509	1580	1533	1461	1548	1633	1610	1590	1706	1491
Coal Feed Rate, lb/h	209.0	259.0	356.6	329.6	352.9	537.1	479.7	499.7	866.2	661.5	531.0	834.2	379.4
Steam Feed Rate, lb/h	207.1	356.0	428.9	573.5	568.2	749.4	766.4	1077.6	1016.9	1022.8	1076.4	1050.3	1077.0
Oxygen Feed Rate, lb/h	84.2	119.8	153.6	147.0	164.9	216.9	184.2	263.9	380.1	312.9	285.6	426.7	217.7
Fines Rate, lb/h	20.9	25.9	31.4	29.7	45.7	78.3	88.5	48.6	69.7	55.8	59.2	59.4	46.7
Ash Discharge Rate, lb/h	9.8	15.0	33.9	38.4	22.7	46.8	51.5	60.5	99.7	60.4	43.3	63.1	41.9
Bed Density, lb/ft^3	26.36	NA‡	24.86	15.16	26.34	15.88	18.07	16.66	13.02	12.17	14.11	12.87	15.76
Bed Height, ft	2.46	NA	2.79	1.84	2.22	3.30	2.50	2.68	3.77	3.24	3.12	2.71	4.44
Inlet Superficial Velocity, ft/s	2.50	2.11	2.53	2.17	2.94	2.66	2.62	2.45	2.52	2.47	2.53	2.80	2.35
Freeboard Velocity,* ft/s	0.88	0.69	0.82	0.67	0.95	0.83	0.81	0.79	0.97	0.84	0.81	1.03	0.71
Product Gas Rate,* mol/h	15.30	20.60	21.96	22.09	21.96	25.54	25.42	31.14	63.69	39.93	35.13	63.07	21.74
Product Gas Composition,* mol %													
CO	23.75	18.59	18.97	12.19	14.73	16.67	11.33	11.04	21.66	16.04	12.21	22.14	8.80
CO_2	25.14	30.07	30.22	38.23	36.35	27.26	36.90	40.10	30.35	15.52	41.47	30.12	43.14
H_2	45.16	44.71	42.99	40.55	41.67	45.49	42.27	39.26	39.23	39.20	37.61	39.14	38.27
CH_4	5.25	5.96	7.03	8.38	6.32	9.35	8.53	8.71	7.99	8.33	7.89	7.85	8.98
N_2	0.39	0.38	0.45	0.40	0.46	0.73	0.52	0.53	0.46	0.61	0.49	0.47	0.54
Product Gas HHV, Btu/SCF	278.2	267.2	273.9	257.3	249.6	299.2	262.9	253.4	279.9	265.1	243.4	279.5	245.2
MAF Coal Conversion, %	92.0	90.9	86.4	83.3	86.1	81.4	73.5	83.9	85.8	88.5	87.1	93.0	80.3

*Dry, purged N_2-free basis.

**Water, hydrogen, and total dry product gas in the reactor gas are determined by hydrogen, sulfur, and nitrogen balances, respectively.

‡Not available.

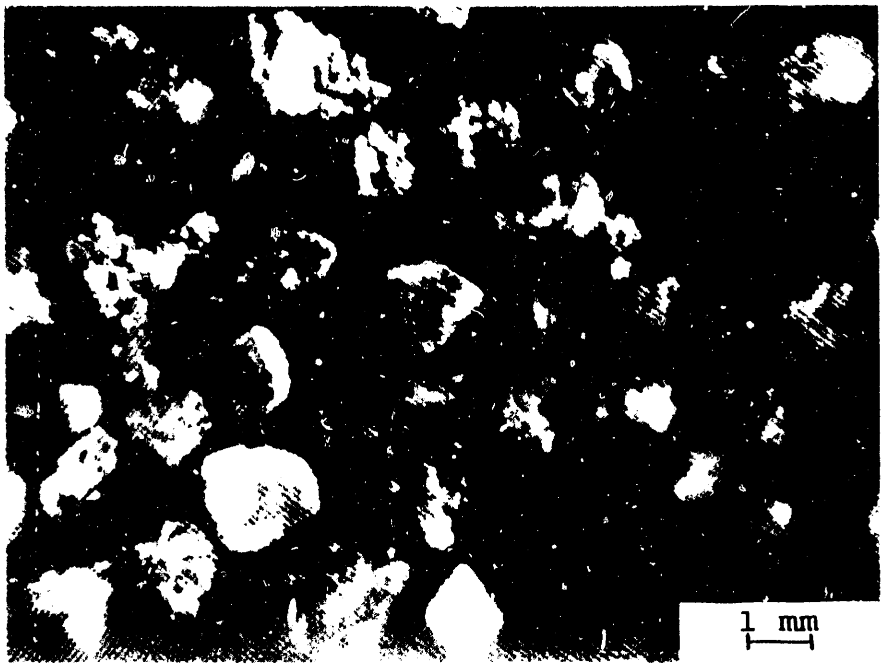

FIGURE 2 - ASH AGGLOMERATES AND OTHER PARTICLES IN RESIDUE FROM GASIFICATION OF MONTANA ROSEBUD SUBBITUMINOUS COAL

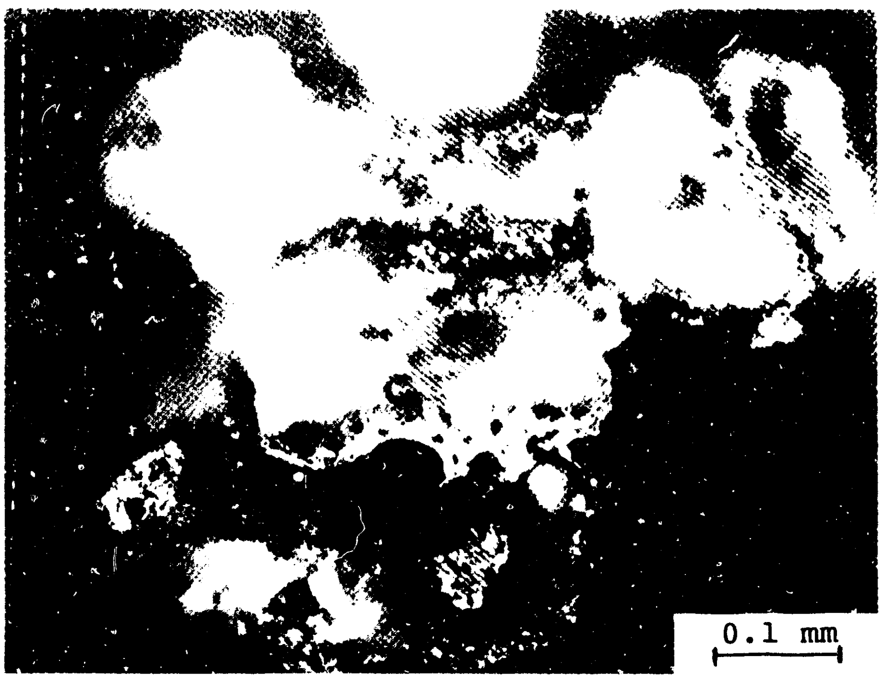

FIGURE 3 - PHOTOMICROGRAPH OF CEMENTED AGGLOMERATE IN ASH RESIDUE FROM GASIFICATION OF MONTANA ROSEBUD SUBBITUMINOUS COAL

reinforcing the freeboard section at critical nozzles. A schematic of the PDU is given in Figure 4.

- Automation of the coal-feed charging system and the ash-discharge system.
- Replacement of the existing feed and ash-discharge hoppers for 500-psi operation.
- Installation of a new steam-supply header and a steam superheater.
- Installation of an isokinetic char-fines sampling system employing a Royco optical counter for particle-size and rate determinations.
- Installation of a computer terminal near the control board for immediate availability of the unit operating status to the operations staff.
- Installation of an Oxford X-ray fluorescence ash analyzer.

After upgrading the PDU system for 500-psig operation, several tests were conducted with North Dakota lignite, Montana Rosebud subbituminous coal, and Illinois No. 6 bituminous coal. Three tests, consisting of nine set-points, were conducted with Montana Rosebud subbituminous coal, and steady-state data were obtained at 200, 300, and 450 psig operation. The characteristics of the feedstock are given in Table 1. Over 43,000 lb of this coal was processed during these runs. The MAF coal conversion attained during these set points ranged from 74% to 93% (fines carry-over, about 8% to 21% of the moisture-free feed, are not recycled to the gasifier in this PDU).

During these tests, nine steady-state operating periods were achieved (and complete material and energy balances were prepared); the operating data are given in Table 3. These set points represent data at (Table 2):

- Three pressure levels (200, 300, and 450 psi) at constant temperature and near-constant steam-to-carbon ratio
- Two steam-to-carbon feed ratios at constant pressure, velocity, and near-constant temperature
- Three temperatures at constant pressure and velocity.

This testing represents a parametric study conducted to determine the effect of operating variables (such as pressure, temperature, etc.) on the gasifier performance.

During operation of the PDU, the knowledge of the ash content of the bed material and gasifier discharge is very useful and important due to the low bed inventory and rapid PDU responses to the process changes. Thus an Oxford X-ray

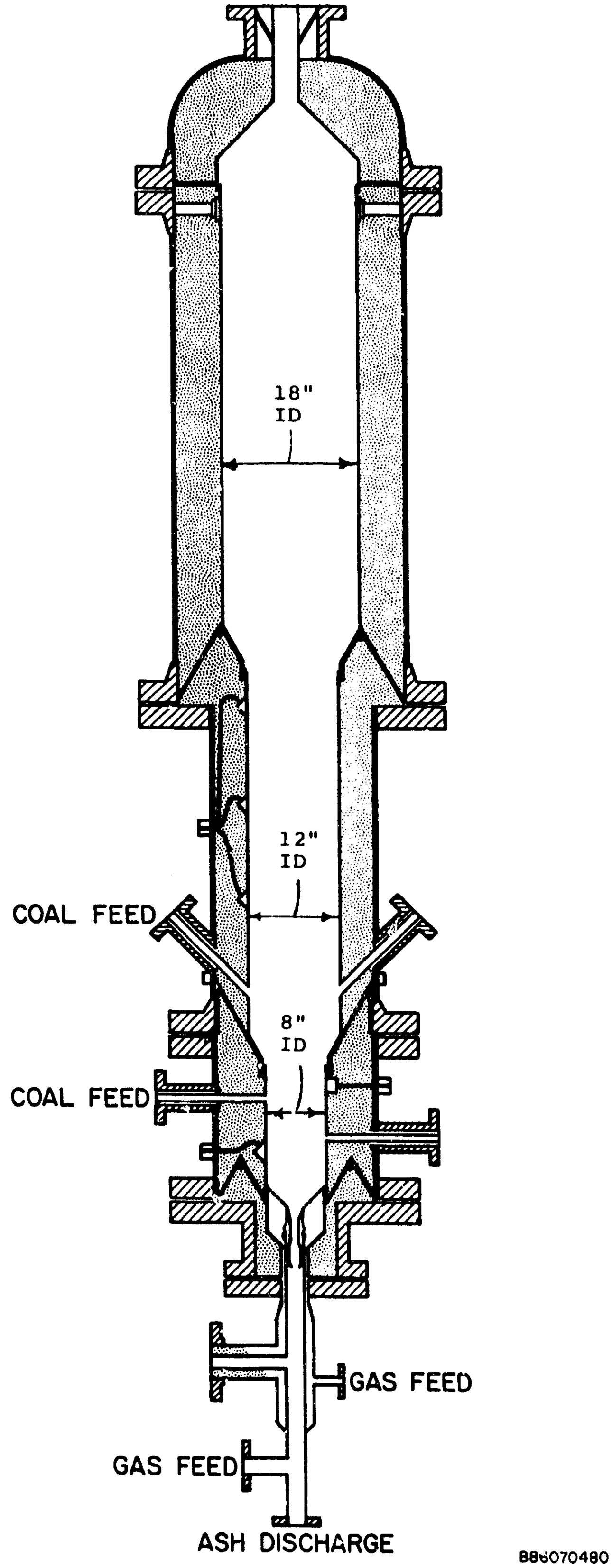

FIGURE 4 - HIGH-PRESSURE DUAL-DIAMETER PDU REACTOR

fluorescence ash analyzer was purchased and used during the last two tests. Designed originally for high accuracy on ground coal samples, our analyses were done with granular samples. The distinct advantage of the X-ray ash analyzer was a very rapid (1 minute) readout after a cooled sample (approximately 3 ounces) was placed in the holder and inserted into the analyzer. The operation of the analyzer is based on using the excited radiation emitted from the iron atom of the coal ash for ash concentration calibration. This device is used regularly in the coal industry for ash determination at the mine as coal cars are loaded and by electric power companies on coal cars received. Using this device for the ash determination on coal gasification solids is an extension of its present applications. In coal gasification, the solids contain a much higher ash concentration and may have undergone some fusion. In addition, the particle size and uniformity is much more diverse. Also, unlike ground coal, the gasification samples include distinctly separate coal-char particles and ash particles of various sizes from 20 mesh to 1/2 inch. Based upon the original calibrations, a 5% accuracy was anticipated. This accuracy was not achieved; however, the X-ray analyzer's usefulness during tests was considerable and a procedural learning curve was developed. The application of the Oxford Analyzer produced better results when the procedures were improved to include riffling and sample duplication. The timely analytical results obtained did enable more rapid response to gasifier process changes, which was the desired objective.

The data collected during the PDU operation do not necessarily represent maximum achievable coal conversion. Fines collected by the cyclone are not recycled to the gasifier in the PDU system; in a commercial gasifier these fines will be re-cycled, thus increasing the conversion. The fines are routinely recycled in the low-pressure pilot plant, thus establishing the feasibility of the fines recycle. Also, the amount of steam used in the PDU, most of which is required for fluidization, cannot be maintained at a desired constant ratio with respect to the carbon feed at different pressures because of PDU design limitations. This amount also invariably exceeds the amount envisaged for commercial operation. The use of this additional steam also reduces the efficiency of the PDU gasifier. Basically, the PDU's proportionally greater use of steam and coal transport gas along with the higher heat losses result in a higher oxygen demand than that expected for a commercial unit.

During the steady-state periods (Phase I as well as Phase II operation) all the operating conditions were maintained within the following limitations:

- Steam flow was maintained within 5% of the set-point conditions.

- Coal feed was maintained within a 5% variation throughout the set point.

- Reactor pressure was maintained within 5% of the set-point conditions.
- Reactor temperature was held to within 50°F of the set-point conditions.

As an example of the rigidity with which these steady-state criteria were maintained during the test runs, the process flow profiles and reactor condition profiles for Run GRI-5-3 (Set Point 1, 450 psig operation) are presented in Figures 5 and 6.

During the steady-state operation of the unit, ash-balanced operation was maintained by monitoring the amount and composition of fines and ash leaving the system. The expanded freeboard of the gasifier restricted the fines carry-over to about 8% to 21% of the coal feed (moisture-free basis). Ash discharge was adjusted by controlling the amount of gas flow entering the gasifier through the ash-discharge nozzle. The unit was operated for at least 4 hours at designated conditions during which both the product gas and solids discharges were monitored.

The normal test procedure for the PDU requires about 2 days for a test that includes 18 to 24 hours of steady-state operation with coal. Surprisingly, the PDU is much faster to start and shut down than the pilot plant. For example, the time required from heat-up to steady-state operation is only about 4 hours, compared with nearly 24 hours in the pilot plant. On the same basis, the PDU also responds much faster to changes in the operating conditions than the pilot plant.

DATA ANALYSIS

The operation of the PDU has demonstrated consistent and reproducible results. Also, at higher pressure, the fluidization is more stable, as observed from the uniformity of the bed density and the bed height chart traces. The thirteen steady-state periods obtained with Montana Rosebud subbituminous coal covered feed rates ranging from 209 to 866 lb/h, temperatures from 1456 to 1652°F, pressures of 100, 200, 300, and 450 psig, yielding MAF lignite conversions from 74% to 93%. These data were analyzed in terms of product-gas composition, methane make in the gasifier, and gasification rate. The results of the analysis are presented below.

Product Gas Composition

The product gas from the gasifier contains primarily CO, H_2, CO_2, H_2O, and CH_4. Typically, a fraction of the carbon present in the feed converts to methane, while the balance of the carbon is oxidized to carbon monoxide and carbon dioxide. The water-gas shift reaction --

$$CO + H_2O \rightleftarrows CO_2 + H_2 \qquad (1)$$

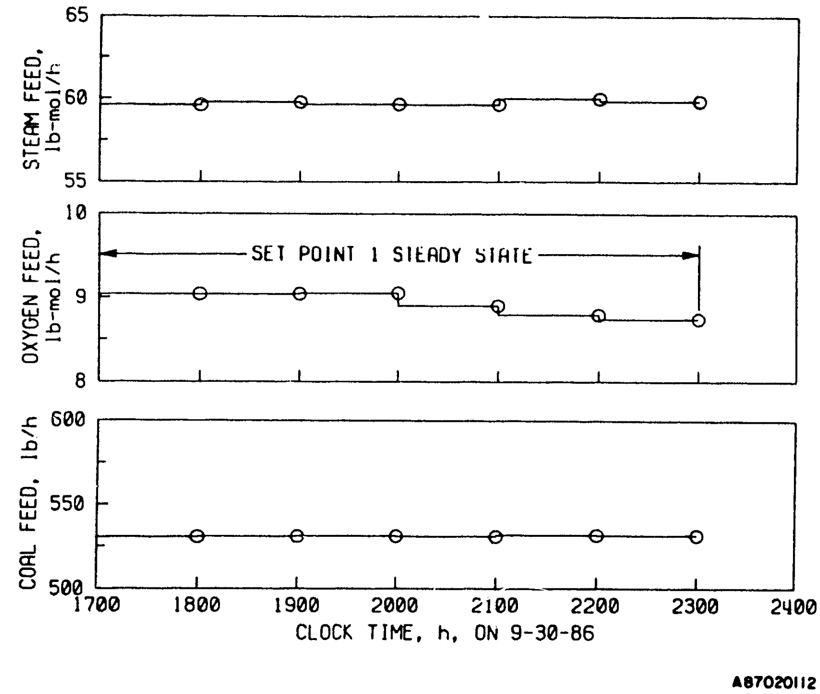

FIGURE 5 - PROCESS FLOW PROFILES (RUN GRI-5-3)

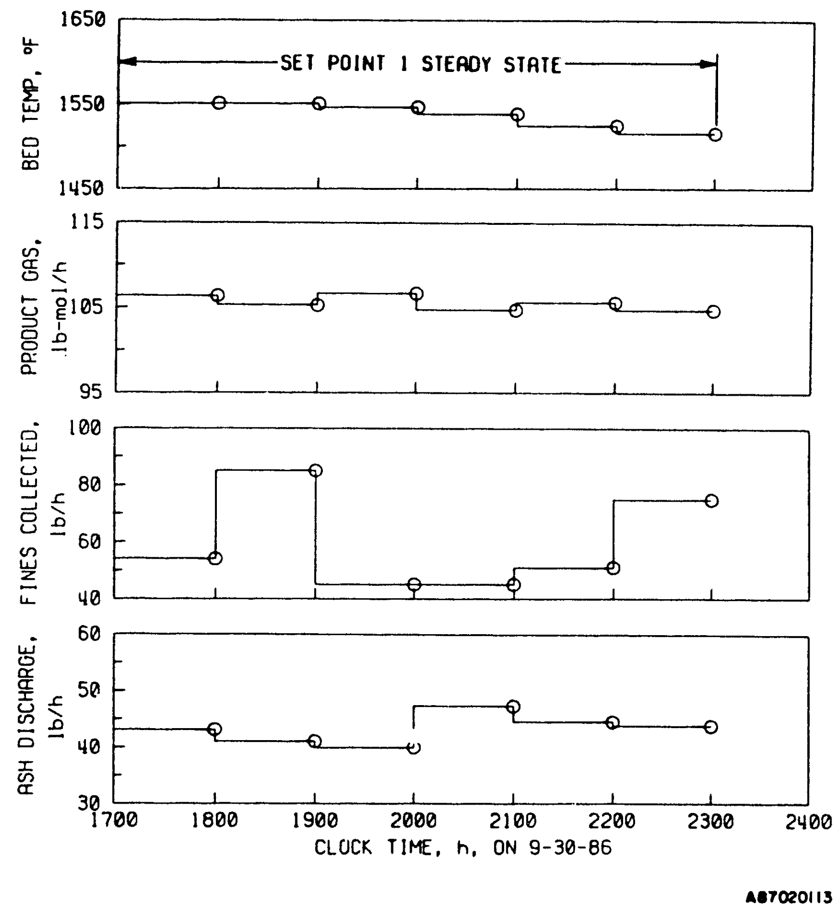

FIGURE 6 - REACTOR PRODUCT PROFILES (RUN GRI-5-3)

is known to proceed rapidly and reach equilibrium in the gasifier. To test this hypothesis, the ratio of $[(CO_2 \bullet H_2)/(CO \bullet H_2)]$ (mole fractions) in the product gas was plotted as a function of the gasifier freeboard temperature and compared with the theoretical values of the water-gas shift equilibrium (Figure 7). The experimental values were found to be remarkably close to the theoretical values of the water-gas shift equilibrium. The standard deviation of the difference between the freeboard and shift equilibrium temperatures was only 86°F. (The shift equilibrium temperature is the calculated temperature at which the actual gas composition corresponds to the shift equilibrium composition.) Therefore, it can be generalized that in the fluidized-bed reactor, the product gas reaches water-gas shift equilibrium within the range of temperature, pressure, and reactant feed gases used in these tests. A similar conclusion was drawn based on the data gathered in the PDU North Dakota lignite feedstock (Goyal et al., 1989).

Methane Yield

Methane is produced from the devolatilization products of coal and by a slow-rate methanation reaction. Methane yield is significantly influenced by the reactor pressure. Slow-rate methanation proceeds as follows:

$$C + 2H_2 \rightleftarrows CH_4 \qquad (2)$$

The partial pressure of methane relative to hydrogen found in the product gas during PDU operations has been related to bed temperature in Figure 8. This equilibrium relationship is defined as --

$$k_p = \frac{P_{CH_4}}{\left(P_{H_2}\right)^2} \qquad (3)$$

where P is partial pressure expressed in atmospheres. The equilibrium line on Figure 8 is based on graphite, the correlation of which is given by the following:

$$\ln k_p = -13.2665 + 19734.5/T \qquad (4)$$

where T is absolute bed temperature in °R.

It can be seen from Figure 8 that more methane is made in the gasifier for the subbituminous coal than the graphite equilibrium value dictates. A significant quantity of this methane is associated with the products of coal devolatilization. This methane yield can be predicted by the following pseudo-equilibrium correlation:

$$\ln k_p = -12.7991 + 19734.5/T \qquad (5)$$

where T is absolute bed temperature in °R.

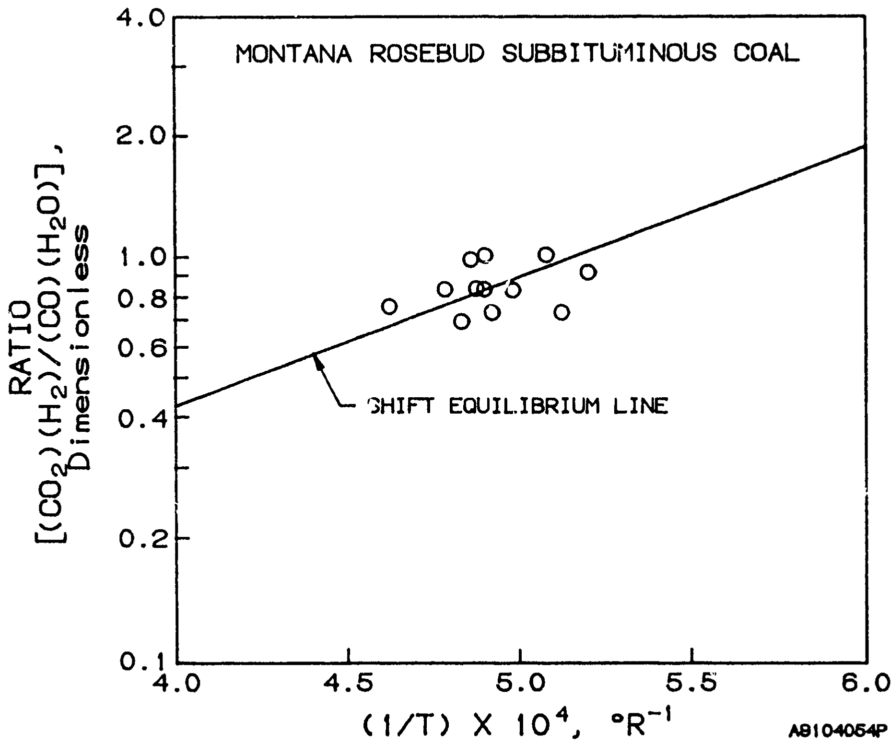

FIGURE 7 - APPROACH TO WATER-GAS SHIFT EQUILIBRIUM AT FREEBOARD TEMPERATURE

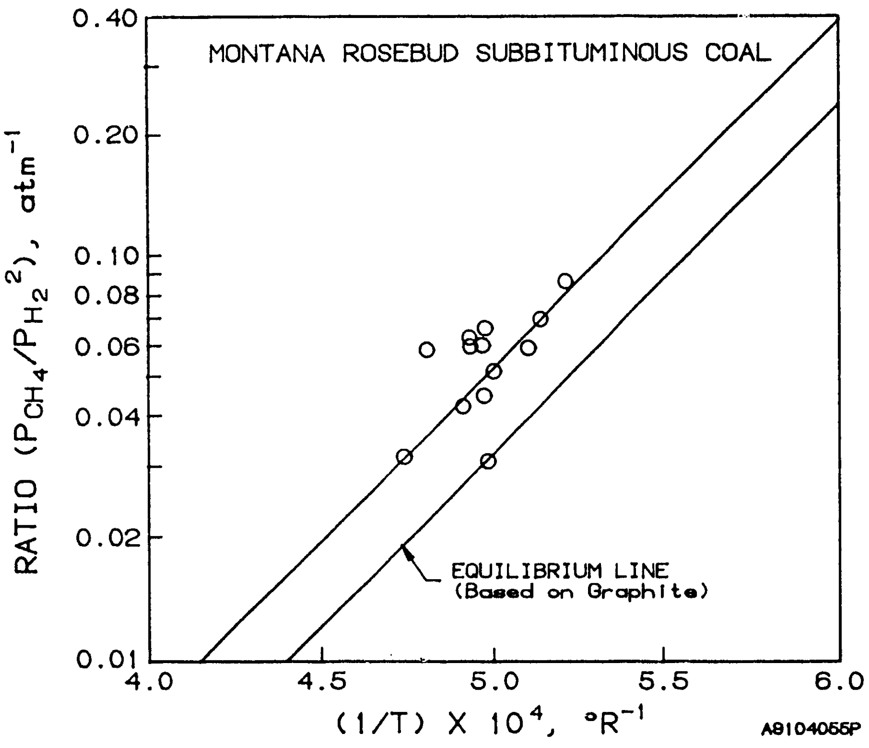

FIGURE 8 - PLOT OF $P_{CH_4}/\left(P_{H_2}\right)^2$ VERSUS BED TEMPERATURE

In Figure 9, the actual amount of feed carbon converted to methane is presented as a function of pressure. As expected, the methane yield increases as the pressure increases. The correlation for feed carbon being converted to methane is given by the following equation.

$$\text{The fraction of feed carbon converted to methane} = 1.1185\ P^{0.39} \qquad (6)$$

where P is absolute pressure in psia.

Gasification Rate

The effect on gasification rate has been assessed by analyzing the data for the amount of carbon gasified per unit amount of carbon in the bed at different pressures (Figure 10). Only the data from set points at about 1550°F bed temperature are plotted in the figure. The figure shows that the gasification rate increases with pressure. The data show scatter because the gasification rate depends on other factors such as surrounding gas composition, exact temperature, etc., which may be somewhat different for different set points.

CONCLUSIONS

The high-pressure gasification data were obtained with Montana subbituminous coal in a fluidized-bed reactor, and thirteen steady-state periods were obtained. The matrix of gasification conditions covered includes subbituminous coal-feed rates from 209 to 866 lb/h, bed temperatures from 1456 to 1652°F, and pressures of 100, 200, 300, and 450 psig, yielding coal covnersions from 74% to 93%. These data were analyzed to study the effects of pressure and temperature on the coal gasification. The following conclusions can be drawn:

- The product-gas composition is close to water-gas shift equilibrium at all pressures.
- The methane yield increases with pressure. It can be estimated using a pseudo-equilibrium approach.
- The gasification rate increases almost linearly with pressure.
- The gasification rate increases with temperature.

ACKNOWLEDGMENT

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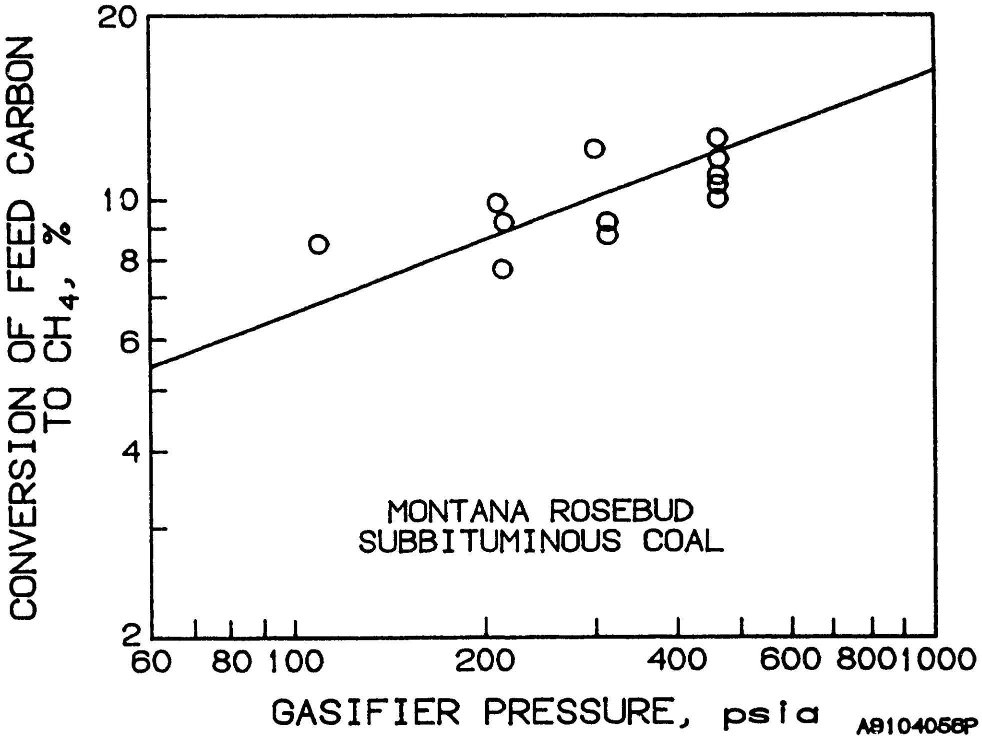

FIGURE 9 - METHANE YIELD AS A FUNCTION OF PRESSURE

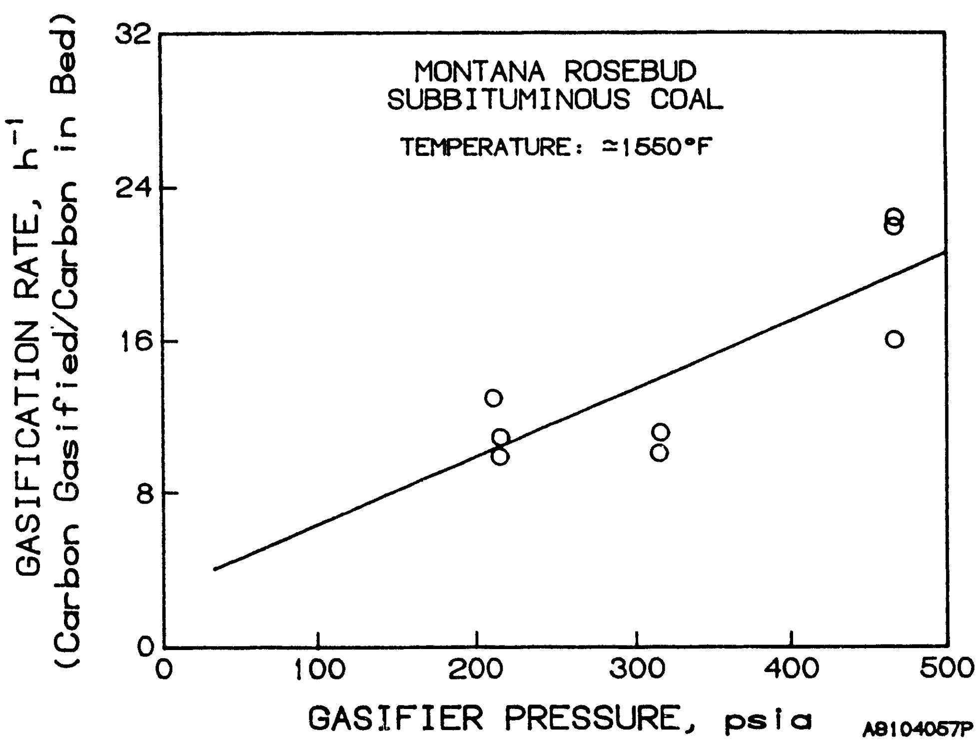

FIGURE 10 - GASIFICATION RATE AS A FUNCTION OF PRESSURE

REFERENCES

Goyal, A., Bryan, B., Rehmat, A., Patel, J. and Ghate, M., "In-Situ Desulfurization in a Fluidized-Bed Coal Gasifier," Energy Sources, 12, pp. 161-179 (1990).

Goyal, A., Bryan, B. and Rehmat, A., "Gasification of a Low-Rank Coal," in Proceedings of the Fifteenth Biennial Low-Rank Fuels Symposium, pp. 447-464, DOE/METC-90/6109, CONF-890573, May 1989.

Goyal, A. and Rehmat, A., "Recent Advances in the U-GAS Process," Paper presented at the AIChE Summer National Meeting, Seattle, WA, August 25-28, 1985.

Goyal, A., Rehmat, A. and Sandstrom, W. A., "Operation of a High-Pressure Ash-Agglomerating Coal Gasifier," in Third Annual Pittsburgh Coal Conference Proceedings, p. 450, Pittsburgh: University of Pittsburgh (1986).

Lau, F. S., Rue, D. M., Punwani, D. V. and Rex, Jr., R. C., "Fluidized Bed Gasification of an Eastern Oil Shale," in Proceedings: 1987 Eastern Oil Shale Symposium, p. 253, Kentucky: Kentucky Energy Cabinet Laboratory (1987).

Leppin, D. and Goyal, A., "U-GAS Technology Status -- II," in Symposium Papers: Advances in Coal Utilization Technology IV, p 387. Chicago: Institute of Gas Technology (1981).

Patel, J. G., "The U-GAS Process," Energy Research, 4, p. 149 (1980).

Patel, J. G., Goyal, A., Rehmat, A. and Leppin, D., "High-Pressure Ash-Agglomeration Gasification of United States Coals," Paper presented at the 1986 American Gas Association's Distribution/Transmission Conference, Chicago, April 28-30, 1986.

Sandstrom, W. A. and Bryan, B., "Design, Construction and Shakedown of a High-Pressure Ash-Agglomerating Process Development Coal Gasifier," Paper presented at the Eleventh Energy Technology Conference, Washington, DC, March 19-21, 1984.

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