Table 2-4. COMPARISON OF FMC CHAR AND PARTIALLY HYDROGASIFIED IRELAND MINE BITUMINOUS COAL CHAR HYDROGASIFICATION RESULTS

Run No.	HT-111A	HT-221
Feed	Ireland Char	FMC Char
Feed Gas	Hydrogen-Steam	
Bed Temperature, Average, °F	1715	1550
Bed Height, ft	3.5	3.5
Char Feed Rate, lb/hr	28.7	42.78
Steam Rate, lb/hr	25.00	26.00
Hydrogen/Char Ratio, % of stoichiometric	36.9	28.4
Steam Concentration, mole %	51.3	48.5
Steam Decomposition, % of steam fed	13.8	16.0
Carbon Gasified, %	20.9	17.4
MAF Char Gasified, %	23.1	16.6
Hydrocarbon Yield, SCF/lb	3.14	2.84
Carbon Oxides Yield, SCF/lb	1.98	1.33

A7506 1527

2.3.3.4.13 West Virginia Medium-Volatile Content Bituminous Coal

The reactivity of a West Virginia medium-volatile-content bituminous coal to hydrogasification with hydrogen and steam was studied in a 3.5-foot fluidized bed, at a nominal reactor pressure of 1000 psig, and at varying hydrogen/coal ratios and steam concentrations (Table 2-A7, appendix). This coal, from the Sewell seam, Sewell No. 1 mine, Nicholas County, West Virginia, was lightly pretreated before hydrogasification.

The feed for run HT-230 (Table 2-A8, appendix) was prepared by light pretreatment of the crushed and screened coal with air at 850° to 900°F in the PDU fluidized-bed coal pretreatment unit. The pretreated coal was fed at a rate of 41 pounds per hour into the reactor where the temperatures were controlled to 1200° to 1300°F in the free-fall section and to 1700°F in the 3.5-foot fluidized coal bed. Hydrogen was fed at a rate of 596 standard cubic feet per hour; steam was fed at a rate of 15.9 pounds per hour. At these conditions, the hydrogen/coal ratio was 33.5% of stoichiometric, and the steam concentration in the feed gas was 36.0%. A carbon gasification of 31.7% was achieved, as well as a moisture- and ash-free coal conversion of 41.9% at an average coal bed temperature of 1345°F.

In run HT-231, the coal was gasified using a lower hydrogen-to-coal ratio of 20.5% of stoichiometric, but a higher steam concentration of 53.2% in the feed gas. The coal was fed at a rate of 57 pounds an hour, the hydrogen at a rate of 506 standard cubic feet per hour, and the steam at a rate of 27.3 pounds per hour. At these conditions, 26.7% of the carbon was gasified, and 35.2% of the moisture-, ash-free coal was converted to gaseous products.

Key hydrogasification results of runs HT-230 and HT-231, as well as those of a third test, run HT-233, performed at a hydrogen/coal ratio and a steam concentration similar to those of run HT-231, are summarized in Table 2-5.

The largest carbon gasification of 31.7%, the largest obtained in this set of tests, was recorded in run HT-230 when the Sewell No. 1 mine medium-volatile-content bituminous coal was hydrogasified with hydrogen at a hydrogen-to-coal ratio of 33.5% of stoichiometric ratio, and with steam at a steam-coal ratio of 0.389 pound per pound. A somewhat lower carbon gasification of 26.7% was obtained in runs HT-231 and HT-233 when the hydrogen-to-coal ratio was in the range of 20.5 to 23.7% of the stoichiometric ratio. The heating value of run HT-230 is lower than those of runs HT-231 and HT-233 because of the greater dilution of the gas by unconverted hydrogen from the higher feed hydrogen-to-coal ratio. The hydrogasification results obtained with this medium-volatile-content bituminous coal are not significantly different from those obtained with Ireland mine high-volatile-content bituminous coal at similar operating conditions.

2.3.3.4.14 New Mexico Subbituminous Coal

The experimental investigation of the hydrogasification behavior of Western subbituminous coals in the high-temperature, balanced-pressure

Table 2-5. COMPARISON OF SEWELL NO. 1 MINE BITUMINOUS COAL HYDROGASIFICATION RESULTS

Run No.	HT-230	HT-231	HT-233
Reactor Pressure, psig	996	1045	1016
Coal Bed Temp Average, °F	1345	1330	1490
Coal Bed Height, ft	3.5	3.5	3.5
Coal Feed Rate, lb/hr	40.97	56.58	46.21
Hydrogen Feed Rate, SCF/hr	596.3	506.0	485.5
Steam Feed Rate, lb/hr	15.94	27.33	25.36
Steam/Coal Ratio, lb/lb	0.389	0.483	0.549
Hydrogen/Coal Ratio, % of stoichiometric	33.5	20.5	23.7
Steam Concentration in Feed Gas, mole %	36.0	53.2	52.3
Steam Decomposed, % of total equivalent steam fed	35.4	28.6	26.0
Carbon Gasified, %	31.7	26.7	26.7
MAF Coal Gasified, %	41.9	35.2	32.8
Hydrocarbon Yield, SCF/lb	4.88	4.05	4.39
CO + CO_2 Yield, SCF/lb	2.68	2.27	2.05
Product-Gas Composition, nitrogen-free, mole %			
Carbon Monoxide	10.6	11.0	9.5
Carbon Dioxide	4.3	6.2	5.1
Hydrogen	57.7	51.7	53.9
Methane	26.6	30.1	30.6
Ethane	0.4	0.4	0.4
Propane	0.1	0.1	0.1
Benzene	0.3	0.4	0.3
Hydrogen Sulfide	--	0.1	0.1
Total	100.0	100.0	100.0
Product Gas Heating Value, nitrogen-free, Btu/SCF	503	525	529

A7506 1528

PDU was extended to tests with New Mexico subbituminous coal from several seams in the Farmington area. The dried, but otherwise untreated coal was gasified in a 3.5-foot fluidized bed with hydrogen and steam at a pressure of 1000 psig, and at coal-bed temperatures of 1300° to 1700°F (Table 2-A7, appendix).

In our initial tests with the untreated coal from one of the seams (Pit "A"), we experienced agglomeration of the coal. In test run HT-249, agglomeration occurred in the reactor bed after 2 hours of normal feeding. In two other tests designated runs HT-250 and HT-251, agglomeration started at the outlet of the coal feed one-half hour after coal feeding was started. These difficulties are attributed to an inoperative reactor heating section at the top of the reactor that limited our control of the coal heat-up rate. To provide for more rapid coal heat-up in the reactor, the 1-inch-diameter coal feed tube was lengthened by 30 inches for the next hydrogasification test, run HT-252. With the longer feed tube, the coal entered the reactor at the top of heating Zone No. 2, where temperatures of at least 1300°F could be maintained. With this change, run HT-252 was successfully completed in two parts, initially without steam feed in run HT-252A, and then with steam feed in run HT-252B.

The coal used in run HT-252 was from Pit "B". There is no significant difference in the compositions of the coals from Pit "A" and from Pit "B" (Table 2-A8, appendix). In run HT-252A, the coal was gasified in a fluidized bed with hydrogen only; in run HT-252B, the coal was gasified in a fluidized bed with hydrogen and steam. The coal feed rate in both tests was nearly the same, at 33.8 pounds per hour. In run HT-252A, 43.2% of the carbon was gasified, as the coal was allowed to react with hydrogen only at a hydrogen-to-coal ratio of 42.9% of the stoichiometric ratio. With the addition of 31.4 mole percent steam to the reactor in run HT-252B, and nearly the same hydrogen-to-coal ratio as in run HT-252A, the carbon gasification increased to 53.5%. The addition of steam also resulted in a moderation of the coal-bed temperature. With no steam, the average coal-bed temperature was 1675°F, and the maximum temperature was 1870°F. When the feed gas was a hydrogen-steam mixture, the average coal-bed temperature was 1485°F; the maximum temperature was 1770°F. Except for larger carbon oxides concentrations in run HT-252B, the product gas compositions in both tests were similar.

The gasified coal residue analyses reflect the larger amount of coal converted in run HT-252B. Carbon content of the residue was 59.1%, compared to 66.1% in run HT-252A; the ash content was 39.1%, compared to 31.9% (Table 2-A8, appendix).

Gasification results of runs HT-249 and HT-251, two of the partially successful tests in which the coal agglomerated, show carbon gasifications of 31.8% and 45.5% respectively. The greater carbon conversion of run HT-251 is due principally to the larger hydrogen-to-coal ratio, 47.9% of stoichiometric, compared to 23.1% of stoichiometric. Other contributing reasons are a lower coal throughput rate of 30.8 pounds per hour, compared to 63.00 pounds per hour, and a higher average bed temperature of 1560°F, compared to 1345°F.

The differences in the hydrogasification results obtained with the Pit "A" feed in, run HT-249, and with Pit "B" feed in run HT-251, are due mainly to different operating conditions in the two tests and not to differences in the composition or behavior of the coals.

The results of these tests establish the feasibility of gasifying New Mexico subbituminous coal in a fluidized bed with hydrogen and steam with no prior pretreatment of the coal. Reactivity of this coal is generally the same as the Montana and Colorado subbituminous coals, which had been also processed in the development unit.

2.3.3.5 Effect of Synthesis Gas on Coal Gasification

The hydrogasification of selected feeds, in a fluidized bed, with a synthesis gas and steam feed, was studied in a series of tests in the PDU. These feeds were: 1) Pittsburgh No. 8 seam bituminous coal, 2) Montana subbituminous coal, 3) Montana lignite, 4) North Dakota lignite, and 5) Illinois bituminous coal char.

The use of synthesis gas instead of hydrogen is of interest as it would eliminate the need for carbon monoxide shifting and carbon dioxide removal following the hydrogen production step of a complete coal hydrogasification process, whether the hydrogen was generated in a conventional char producer or in an electrothermal char gasifier. To be of any promise, carbon conversion rates to methane would not have to be unduly reduced by the lower hydrogen concentration in the feed gas, at least up to about 40% carbon conversion. To maintain adequate conversions with synthesis gas, moderate increases in coal residence time and in coal bed temperatures could be tolerated.

A synthesis gas mixture, simulating a gas composition expected from an electro-thermal char gasifier, was prepared by mixing hydrogen, carbon monoxide, and carbon dioxide into high-pressure storage. Mole fractions of these gases were as follows: hydrogen, 58%; carbon monoxide, 37%; and carbon dioxide, 5%. Pittsburgh No. 8 seam bituminous coal from the Ireland mine was the first feed selected for these tests as it had been previously hydrogasified in the demonstration unit over a wide range of conditions. As in tests with hydrogen feed gas, the coal was given the standard light pretreatment with air before hydrogasification.

Operating conditions and results of the first three tests performed with Pittsburgh No. 8 seam bituminous coal, runs HT-168, HT-169 and HT-171, are given in Table 2-A7, appendix. These tests were performed in a 3.5 foot fluidized-bed at a nominal reactor pressure of 1000 psig.

In run HT-168, the coal bed height was increased from 3.5 feet (Part A) after 1 hour of operation to 7.0 feet (Part B) to observe how the various bed depths affect hydrogasification. The results show only a small increase in carbon gasification and no perceptible change in product gas composition. A substantial shifting of the carbon monoxide in the feed gas to hydrogen is indicated by the sharp decrease in carbon monoxide content from the feed gas to the product gas, and by the corresponding increase in carbon dioxide content of the product gas over that of the feed gas. (Table 2-A7, appendix)

Run HT-169 was conducted at conditions similar to those of run HT-168, but the position of the coal bed was different. The feed gas distributor was set 62 inches from the bottom of the reactor furnace, in contrast to 31 inches in run HT-168. The coal bed, therefore, was higher in the reactor tube, so that heat losses to the bottom end were lessened. The effect of this change is shown by the increase in the average coal bed temperature from 1480° to 1515°F of run HT-168 to 1615°F. This increase in the average bed temperature partly accounts for the increase in the carbon gasified from the 18 to 21% of run HT-168, to 24% for run HT-169.

The hydrogen/coal ratio of run HT-171 was relatively high at 33.6% of the stoichiometric ratio. This does not include the carbon monoxide equivalent of hydrogen in the feed gas. Carbon gasification improved substantially over that in the first two runs (HT-168 and HT-169), from a range of 18 to 24%, up to 38%. However, the net heat release in run HT-171 could only maintain an average bed temperature of 1575°F, even with maximum furnace heat input from zones 5 and 6. The lowest furnace heating section, zone 7, was inoperative

To determine to what extent the coal bed temperatures of the tests with synthesis gas were influenced by the inoperation of zone 7, run HT-173 was conducted with the same Pittsburgh seam bituminous coal used in the tests with synthesis gas, but with a steam-hydrogen feed gas (Table 2-A7, appendix). The desired coal bed temperatures of 1700°F and above were achieved. Run HT-173 thus demonstrated that the low coal-bed temperatures in the tests conducted with synthesis gas resulted principally from the low heat release. The results of the tests with synthesis feed gas indicate that reduced hydrogen pressure that results from the presence of the carbon monoxide, reduces heat release. This occurred even through 70.5% of the carbon monoxide was shifted in run HT-171, based on the reduction of the carbon monoxide content between the feed gas and the product gas. Thus, even though carbon monoxide and hydrogen are equivalent through the shift reaction, the heat release is apparently affected by the partial pressure of the hydrogen.

Improved coal and carbon conversions of the Pittsburgh seam bituminous coal were obtained in the later test, run HT-210, performed in a 7-foot fluidized bed, at an average char-bed temperature of 1560°F, and at a reactor pressure of 987 psig (Table 2-A7, appendix). In this test, 51.6% of the moisture-, and ash-free coal, and 41.7% of the carbon in the coal were gasified with a hydrogen/coal ratio of 49.3% of stoichiometric, and a steam concentration of 51.1% in the feed gas mixture.

Results of run HT-242 (Table 2-A7, appendix) performed in a 3.5-foot fluidized bed at an average char-bed temperature of 1310°F, and a reactor pressure of 1556 psig show a carbon gasification of 24.5%, and a moisture-, and ash-free coal conversion of 29.2%. The hydrogen/coal ratio in this test was 24.8% of stoichiometric, and the steam concentration in the feed gas mixture was 50.3%. The lower carbon conversion in this test, compared to that of run HT-210, resulted from 1) the lower hydrogen/coal ratio, and 2) the lower char-bed temperature.

In these series of tests – generally – HYGAS researchers found that the use of synthesis gas results in 1) a lower char-bed temperature, particularly in the shorter fluidized bed, and 2) a lower degree of gasification than when hydrogen is used.

A synthesis gas-steam feed-gas mixture was also used in two tests in which researchers simulated, separately, the upper low-temperature zone and the lower high-temperature zone of a two-stage hydrogasification operation. The simulation was based on using a synthesis gas-steam feed, and lightly pretreated Pittsburgh No. 8 seam bituminous coal from the Ireland mine. Feed to the upper zone simulation in run HT-200, was lightly pretreated coal. Residue from this test was used as feed for the lower zone simulation in run HT-201 (see Table 2-A8, appendix). In run HT-200, the lightly pretreated coal was gasified in a 3.5-foot fluidized bed at an average bed temperature of 1380°F, a reactor pressure of 1012 psig, and with a synthesis gas-methane-steam feed gas. The dry feed gas was a prepared mixture of hydrogen, carbon monoxide, carbon dioxide and natural gas. The composition of this gas simulated that of a gas coming from the lower high-temperature zone of a two-stage reactor. Steam was premixed with the gas mixture when fed to the reactor, and constituted 32.9 mole percent of the total feed gas. The results of run HT-200 showed that 14.5% of the carbon in the coal was gasified, and that there was no net steam decomposition (see Table 2-A7, appendix).

In run HT-201, the residue from run HT-200 was gasified in a 7-foot fluidized bed at an average bed temperature of 1565°F and a reactor pressure of 1005 psig in a simulation of a lower, high-temperature reactor zone. Feed gas was a mixture of synthesis gas and steam. Steam concentration in the feed gas was 54.8 mole percent. The ratio of hydrogen plus carbon monoxide in the feed gas to the feed char was 11.3 standard cubic feet per pound. At these conditions, 19.3% of the carbon in the feed char was gasified and 29.7% of the equivalent steam fed was converted. The total carbon gasification in runs HT-200 and HT-201 was 31%, based on the feed to run HT-200.

Results from hydrogasification tests using pretreated Pittsburgh No. 8 seam and synthesis gas-steam mixtures have shown that the reaction rates are quite sensitive to the hydrogen partial-pressure in the system. Therefore, carbon monoxide and hydrogen in the synthesis gas cannot be considered as the equivalent of hydrogen. The use of synthesis gas in place of hydrogen will require operating adjustments in order to maintain the necessary conversion levels of carbon and steam. These adjustments may consist of 1) longer residence time, and 2) higher steam concentration to increase water-gas shift reaction, 3) higher synthesis gas-to-coal ratio, 4) higher system pressure to increase hydrogen partial pressure, 5) multistage contacting to improve countercurrency, or combinations thereof.

Gasification of a North Dakota lignite with a synthesis gas plus steam feed gas was studied in a series of tests to determine the reactivity of the lignite to lower concentrations of hydrogen in the feed gas. Another major purpose of the tests was to obtain experimental data on the concentration of carbon dioxide in the product gas and on the quantity of carbon dioxide produced with a high-oxygen-content feed and a feed gas containing carbon monoxide. In test run HT-196, (Table 2-A7, appendix) 47.3% of the carbon in the lignite was gasified and 49.7% of the total equivalent steams were converted at an average bed temperature of 1615°F and with a hydrogen plus carbon monoxide ratio of 13.3 standard cubic feet per pound of lignite. For purposes of comparison, key results of run HT-196, and three other lignite hydrogasification tests in which the gasifying medium was a synthesis gas-steam mixture, are tabulated in Table 2-6.

Table 2-6. COMPARISON OF NORTH DAKOTA LIGNITE-SYNTHESIS GAS TESTS IN FLUIDIZED BEDS

Run No.	HT-192	HT-195	HT-196	HT-197	Predicted From Model
Reactor Pressure, psig	1004	1031	1069	999	1000
Bed Temperature, Average	1430	1610	1615	1615	1700
Bed Height, ft	3.5	3.5	3.5	3.5	--
Bottom of Lignite Bed, in. above furnace bottom	62	62	62	62	--
Lignite Feed Rate, lb/hr	36.88	36.64	33.17	47.03	--
Steam Rate, lb/hr	22.44	18.88	25.60	19.02	--
Hydrogen/Lignite Ratio, % of stoichiometric	21.0	17.5	24.4	12.4	--
Hydrogen + Carbon Monoxide/ Lignite Ratio, SCF/lb	12.64	10.37	13.32	7.51	7.8
Steam Concentration, mole %	48.4	49.7	51.1	49.7	50
Steam Decomposition, % of steam fed	9.23	27.6	32.0	26.4	26.4
Carbon Gasified, %	33.9	40.8	47.3	43.8	46.4
MAF Lignite Gasified, %	49.9	58.8	62.2	65.2	--
Hydrocarbon Yield, SCF/lb	5.56	4.46	4.54	4.16	--
Carbon Oxides Yield, SCF/lb	0.756	3.28	4.33	4.22	--

Gas Analysis, mole % (nitrogen-free)

	Feed	Product	Feed	Product	Feed	Product	Feed	Product	Feed	Product
Carbon Monoxide	43.9	9.7	41.8	16.0	39.4	15.2	38.5	17.2	41.3	19.5
Carbon Dioxide	4.8	34.8	5.4	27.4	4.9	26.8	4.9	27.9	4.9	25.2
Hydrogen	51.3	21.4	52.8	33.6	55.7	40.0	56.6	30.4	53.8	24.6
Methane	--	31.8	--	20.8	--	16.4	--	22.4	--	28.3
Ethane	--	1.5	--	1.3	--	1.0	--	1.3	--	1.4
Propane	--	0.5	--	0.6	--	0.5	--	0.7	--	0.5
Benzene	--	0.3	--	0.3	--	0.1	--	0.1	--	0.2
Hydrogen Sulfide	--	--	--	--	--	--	--	--	--	0.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The significantly different results of run HT-192, compared to those of the other three tests presented in Table 2-6, may be partially explained by the lower average bed temperature of 1430°F. The carbon gasification, steam decomposition, and carbon oxides yield were well below those of the other three tests, and particularly below those of run HT-196, which was conducted at similar flow conditions but at an average bed temperature of 1615°F. Because of the comparatively low carbon oxides yield in run HT-192, however, a much greater fraction of the total carbon gasified went into the production of methane, so that hydrocarbon yield per pound of lignite fed (5.56 standard dubic feet per pound) was greater than in the tests where more carbon was gasified. As expected, the concentration of methane in the product gas of run HT-192 was higher than that of the other three tests, because lower temperatures favor equilibrium methane concentration.

A comparison of the results of runs HT-196 and HT-197 shows that reducing the ratio of synthesis gas to lignite by about 50% resulted in only small reductions in the total carbon gasification and steam decomposition. The lower carbon gasification is reflected in the lower hydrocarbon and carbon oxides yields per pound lignite. However, the conversion in run HT-197 was still high enough so that the carbon remaining was just enough to meet the requirements for feed synthesis gas production, and thus allow for balanced hydrogasification production.

The last column in Table 2-6 shows the key parameters calculated for a lignite hydrogasification model under the following assumptions:

a) A carbon activity of 2 at 1700°F,

b) Water-gas shift equilibrium, and

c) The hydrogen evolved from the lignite is divided equally between the low- and high-temperature zones.

The close agreement between HT-197 and the mathematical model gives confidence that the model and a sound basis for the economic evaluation of hydrogasification plants using lignite feed. The minor differences between the model prediction and run HT-197 can be attributed mostly to the heat losses encountered in run HT-197.

The hydrogasification reactivity of lignite with a synthesis gas and steam feed gas was also studied at a system pressure of 500 psig in run HT-241 (Table 2-A7, appendix). Hydrogasification of the lignite in a 3.5-foot fluidized bed with synthesis gas and steam, at an average lignite bed temperature of 1590°F and a reactor pressure of 498 psig, resulted in the gasification of 51.6% of the moisture-, and ash-free lignite, and of 36.0% of the carbon in the lignite. These conversions were obtained with a synthesis-gas rate giving a hydrogen to lignite ratio of 16.9% of the stoichiometric ratio, and a steam concentration of 49.8% in the feed gas. Additional lignite was converted to liquid products containing oil that included 2.72% of the carbon in the lignite. Based on an ash balance, 0.531 of a pound of lignite residue was recovered for every pound of lignite fed.

The series of tests with synthesis gas have shown that lignite, being highly reactive compared to pretreated bituminous coals, can be gasified as well with synthesis gas as with hydrogen. The high reactivity of lignite insensitizes the effect of substituting carbon monoxide for hydrogen in the synthesis gas. Thus, with lignite, the full benefit of hydrogasifying with a synthesis gas instead of hydrogen can be realized without any offsetting penaly.

The hydrogasification behavior of the Montana subbituminous coal with synthesis gas and steam was tested in run HT-214 in a 3.5-foot fluidized bed with a synthesis gas containing 58.6% hydrogen, 36.9% carbon monoxide, and 4.5% carbon dioxide. The ratio of hydrogen plus carbon monoxide to coal was 9.9 standard cubic feet per pound, and the steam concentration in the feed gas was 47.5 mole percent. Temperatures in the coal bed were controlled to a nominal 1700°F, and those above the coal bed to 1300°F. Reactor pressure was 1111 psig. The coal feed rate was 58.6 pounds per hour.

The results of run HT-214, (Table 2-A7, appendix) show that 29.6% of the carbon in the feed was gasified when the Montana subbituminous coal reacted with synthesis gas at a hydrogen to coal ratio of 17.7% of the stoichiometric ratio. Including the carbon monoxide equivalent of hydrogen in the feed gas, the hydrogen to coal ratio was 29% of the stoichiometric ratio.

The reaction of the Montana subbituminous coal to hydrogasification with synthesis gas is similar to that exhibited by Pittsburgh No. 8 seam bituminous coal to synthesis gas. For example, in run HT-209 (Table 2-A7, appendix), 29.2% of the carbon in a pretreated Pittsburgh seam bituminous coal was hydrogasified when the coal reacted with synthesis gas at a hydrogen to coal ratio of 18.2% of the stoichiometric ratio.

Hydrogasification of the Montana subbituminous coal with synthesis gas and steam at a system pressure of 489 psig was studied in run HT-243. The coal was gasified in a 3.5-foot fluidized bed at an average bed temperature of 1550°F using 14.2 standard cubic feet of hydrogen plus carbon monoxide per pound of coal. At these conditions, 30.0% of the carbon in the coal was gasified. In a similar test, run HT-248, performed at a pressure of 594 psig, an average bed temperature of 1295°F, and using 8.48 standard cubic feet of hydrogen plus carbon monoxide per lb of coal, 27.4% of the carbon in the coal was gasified.

Run HT-220, (Table 2-A7, appendix) was designed to investigate the hydrogasification of an untreated lignite from Savage, Montana. A mixture of synthesis gas and steam was used in a 3.5-foot fluidized bed at an average char-bed temperature of 1580°F, and at a reactor pressure of 986 psig.

In this test, the dried lignite was fed at a rate of 66 pounds per hour for reaction with synthesis gas fed at a rate of 547 standard cubic feet per hour, and with steam fed at a rate of 27 pounds per hour. Synthesis gas was of the standard composition used in previous hydrogasification tests containing 57 mole percent hydrogen, 38 mole percent carbon monoxide, and 5 mole percent carbon dioxide. Flow rates were set so that the hydrogen and carbon monoxide to lignite ratio was 25% of the stoichiometric hydrogen to lignite ratio. The steam concentration in the feed gas was 51 mole percent.

The gasification results of run HT-220 may be compared with those of runs HT-219, performed at similar conditions, but with hydrogen and steam (Table 2-A7, appendix). (Results of run HT-219 were discussed in the section on Montana lignite gasification.) The results of these two tests are a good guide to the reactivity of the lignite to hydrogen compared to its reactivity to synthesis gas having the carbon monoxide equivalent of hydrogen. The net moisture- and ash-free lignite gasified was nearly identical in both tests at 49%; however, 42% of the carbon was gasified when hydrogen was used, compared with only 33% when synthesis gas was used. This higher carbon gasification is reflected in the 25% higher hydrocarbon and carbon oxides yields per pound of lignite in run HT-219, as compared with run HT-220. Liquid yields of the two tests are also significantly different, paralleling the differences in carbon gasification (Table 2-A9, appendix). More than 9% of the carbon in the lignite was converted to oil in the test with hydrogen, compared with only 4.3% conversion to oil in the test with synthesis gas. Steam decompositions were similar in both tests. With hydrogen feed gas, 22% of the steam fed was reacted; with synthesis gas, 20% of the steam fed was consumed. The latter figure, of course, includes steam reacted in the water-gas shift reaction of carbon monoxide in the synthesis gas.

These studies show that Montana lignite conversions, at levels acceptable for certain pipeline gas processes, can be obtained with a synthesis feed gas. A beneficial effect of using synthesis gas for lignite hydrogasification is the apparent suppression of oil production. This leaves more carbon available to react with the gaseous products, or to be retained in the lignite residue with subsequent conversion to hydrogen in the hydrogen production stage.

The reactivity of Montana lignite was found to be similar to that of North Dakota lignite in that both can be gasified to the desired extent with either hydrogen-steam or synthesis gas-steam mixtures.

The reactivity in hydrogasification of a bituminous coal char from the FMC Corporation's Project COED, with a synthesis gas-steam mixture, was investigated in two tests. The purpose of these tests was to determine if this char, produced from an Illinois No. 6 seam, Crown mine high-volatile C bituminous coal, is sufficiently reactive to be used as a feed material for hydrogasification and methane production.

In both test runs HT-222 and HT-223, (Table 2-A7, appendix) the FMC Illinois No. 6 char was gasified with the standard composition synthesis gas and steam in a 3.5-foot fluidized bed, a nominal reactor pressure of 1000 psig; the average char-bed temperature was 1455°F in run HT-222 and 1590°F in run HT-223. Steam concentration in the feed gas was 50 to 51% in both tests. In run HT-222, with a hydrogen to char ratio of 23.8% of stoichiometric, 12,3% of the carbon was gasified. In run HT-223, with a hydrogen/char ratio of 18.3% of stoichiometric, 14.5% of the carbon was gasified. The lower of these two carbon conversions was apparently due to the lower reactor bed temperature in run HT-222. Both carbon conversions are somewhat lower than the 17.4% carbon gasification achieved in Run HT-221 when the FMC char was gasified with hydrogen and steam.

2.3.3.6 1500-psig Hydrogasification Tests

Standard hydrogasification pressure in PDU testing was 1000 psig. However, in order to study how 1500 psig pressure would affect carbon conversion and gas composition, four tests were conducted at the higher pressure with a lightly pretreated Ireland mine bituminous coal. Some of the advantages of hydrogasification at higher pressures are evident, including: 1) higher hydrogen partial pressures in the feed gas, 2) longer feed-gas residence time, and 3) a more favorable equilibrium methane concentration in the product gas.

At 1500 psig, run HT-129, (Table 2-A7, appendix), was the first hydrogasification test conducted in the balanced-pressure reactor at a pressure substantially above 1000 psig. To maintain an adequate fluidization velocity, the feed-gas rates were increased to 750 standard cubic feet per hour of hydrogen and 35.8 pounds per hour of steam. Proportionally, the coal feed rate was increased to a nominal 75 pounds per hour to maintain the hydrogen to coal ratio at 25% of the stoichiometric ratio.

Run HT-129 was conducted with the coal bed controlled to 1700°F. A carbon conversion to gaseous products of 37% was realized while producing a product gas of 582 Btu per standard cubic foot on a nitrogen-free basis. To obtain these results, a hydrogen to coal ratio of 32% of the stoichiometric ratio, and a steam concentration of 50 mole percent in the feed gas were required.

Run HT-154, (Table 2-A7, appendix), was a check run to confirm earlier results of hydrogasification at 1500 psig. Like the initial 1500-psig test in run HT-129, run HT-154 also was made with a Pittsburgh seam bituminous coal from the Ireland mine. Operating conditions of this test were similar to those of run HT-129. The coal was fed at a nominal rate of 75 pounds per hour and reacted in a 3.5-foot bed with 750 standard cubic feet per hour of hydrogen and 36 pounds per hour of steam. The solids-bed temperature was controlled at a nominal 1700°F, while the free-fall reactor section above the coal bed was held at a nominal 1300°F.

Results of run HT-154 tend to be somewhat erratic because the steady-state operating period was marred by intermittent coal flow in the feed tube. For purposes of comparison, the key operating conditions and results of the two tests are summarized in Table 2-7.

Two tests were performed at a nominal pressure of 1500 psig in which the Ireland mine bituminous coal was gasified with a synthesis gas-steam feed gas. Test runs HT-225 and HT-242 (Table 2-A7, appendix), were both performed in a 3.5-foot fluidized bed. Char-bed temperatures in both tests were relatively low because the lower reactor heating zone shorted out in both tests. These low temperatures limited the carbon gasification in both tests. In run HT-225, with an average bed-temperature of 1365°F, 17.4% of the carbon was gasified, and in run HT-242, at 1310°F, 24.5% of the carbon was gasified.

For purposes of comparison, the key results of runs HT-225 and HT-242 are presented in Table 2-8 with those of run HT-169, a synthesis gas test conducted at 1000 psig. A higher percentage of carbon gasification was

Table 2-7. OPERATING CONDITIONS AND RESULTS OF HYDROGASIFICATION PDU TESTS AT 1500-psig

Pittsburgh No. 8 Seam, Ireland Mine, Bituminous Coal

Run No.	HT-129	HT-154
Reactor Pressure, psig	1502	1500
Reactor Tube Temperature, average, °F	1650	1495
Coal Bed Height, ft	3.5	3.5
Coal Feed Rate, lb/hr	63.51	65.78
Hydrogen Feed Rate, SCF/hr	776.7	769.9
Steam Feed Rate, lb/hr	36.1	37.7
Hydrogen/Coal Ratio, % of stoichiometric	32.1	30.3
Steam Concentration in Feed Gas, mole %	49.5	50.7
Steam Decomposed, % of steam fed	5.01	2.84
Steam Decomposed, % of total equivalent steam fed	25.0	23.3
Carbon Gasified, %	37.3	24.6
MAF Coal Gasified, %	45.4	26.9
Hydrocarbon Yield, SCF/lb	5.55	4.06
CO + CO_2 Yield, SCF/lb	2.26	1.15
Carbon in Oil Products, % of carbon in coal	1.23	0.707
Product Gas Composition, mole %		
Nitrogen	26.4	17.7
Carbon Monoxide	6.4	4.0
Carbon Dioxide	5.3	4.4
Hydrogen	32.9	44.2
Methane	28.1	28.7
Ethane	0.5	0.7
Propane	0.1	0.2
Butane	0.0	0.0
Benzene	0.3	0.1
Product Gas Heating Value, Btu/SCF	428	461

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Table 2-8. COMPARISON OF IRELAND MINE BITUMINOUS COAL HYDROGASIFICATION PDU TEST RESULTS WITH SYNTHESIS GAS AT 1000- AND 1500-psig SYSTEM PRESSURES

Run No.	HT-225	HT-169	HT-242
Feed Gas	Synthesis Gas		
Reactor Pressure, psig	1478	1026	1556
Coal Bed Temp Average, °F	1365	1615	1310
Coal Feed Rate, lb/hr	63.49	46.05	42.58
Synthesis Gas Rate, SCF/hr	626.5	512.6	674.0
Steam Feed Rate, lb/hr	33.06	25.06	32.41
Hydrogen/Coal Ratio, % of stoichiometric	13.0	15.4	24.8
Equivalent Hydrogen/Coal Ratio, % of stoichiometric	25.0	28.8	40.9
Steam Concentration in Feed Gas, mole %	52.6	50.7	50.3
Steam Decomposed, % of total equivalent steam fed	36.5	27.08	45.2
Carbon Gasified, %	17.4	23.8	24.5
MAF Coal Gasified, %	22.1	37.3	29.2
Hydrocarbon Yield, SCF/lb	2.69	4.12	3.46
CO + CO_2 Yield, SCF/lb	0.662	0.767	0.929
Product Gas Composition (nitrogen-free), mole %			
Carbon Monoxide	19.9	15.7	17.8
Carbon Dioxide	27.0	28.3	23.7
Hydrogen	30.5	26.0	39.3
Methane	21.0	28.5	17.8
Ethane	0.5	0.8	0.7
Propane	0.4	0.2	0.1
Benzene	0.4	0.3	0.6
Hydrogen Sulfide	0.3	0.2	0.0
Total	100.0	100.0	100.0
Product Gas Heating Value (nitrogen-free), Btu/SCF	404	447	396

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attained in run HT-242 (24.5%) than in run HT-225 (17.4%) at 1500 psig, principally because of the larger 24.8% hydrogen-to-coal ratio of stoichiometric compared to 13.0% of stoichiometric. Product-gas compositions of the two tests are not significantly different. At a system pressure of 1000 psig in run HT-169, a carbon gasification of 23.8%, nearly equal to that of run HT-242, was obtained with a significantly lower hydrogen-to-coal ratio (15.4%) than in run HT-242. The product gas of run HT-169 has a larger methane concentration and a lower hydrogen concentration than either run HT-225 or HT-242. The poorer results at a system pressure of 1500 psig are attributed to the relatively low average coal-bed temperatures of, 1365°F in run HT-225 and 1310°F in run HT-242,* compared to 1615°F in run HT-169.

2.3.3.7 500-psig Hydrogasification Tests

Hydrogasification of selected feeds at a reactor pressure of 500 psig was studied to determine the effect of the lower pressure on carbon conversion. Coal feeds gasified at 500 psig included Pittsburgh No. 8 seam coal from the Ireland mine, a North Dakota lignite, and a Montana subbituminous coal. The principal advantages of gasification at a lower pressure are a reduced capital investment in the plant equipment and a simpler and more easily operable coal feeding and spent char removal systems. These advantages would have to outweigh:

1) the reduced carbon conversion at the lower pressure because of the lower hydrogen partial pressure in the feed gas and the shorter feed gas residence time, and

2) the reduced methane production because of the less favorable equilibrium methane concentration at the lower pressure.

Feeds of relatively high reactivity, such as lignite and subbituminous coal, showed the best promise of hydrogasification at 500 psig with acceptable carbon conversions. All three of the feeds were gasified with hydrogen and steam. The lignite and the subbituminous coal were also gasified with synthesis gas and steam at selected conditions.

Lightly pretreated Pittsburgh seam high-volatile content bituminous coal from the Ireland mine was gasified in run HT-224, (Table 2-A7, appendix), in a 3.5-foot fluidized bed at a pressure of 534 psig, and at an average coal bed temperature of 1660°F. The hydrogen-to-coal ratio was 23.8% of stoichiometric, and the steam concentration in the feed gas was 37.2 mole percent. At these conditions, 26.3% of the carbon was gasified and a product gas with a heating value of 510 Btu per standard cubic foot was produced.

Key hydrogasification results of run HT-224 are summarized in Table 2-9 for comparison with those of the two earlier test runs HT-119 and HT-128. The earlier runs were conducted at similar conditions but at 1000 psig to show the effect of system pressure. The carbon gasification of

---

* The temperature level attained in run HT-242 was limited by the heat input capacity of the reactor electrical heaters.

Table 2-9. COMPARISON OF IRELAND MINE BITUMINOUS COAL HYDROGASIFICATION PDU TEST RESULTS AT 500 AND 1000-psig SYSTEM PRESSURES

Run No.	HT-224	HT-119	HT-128
Reactor Pressure, psig	534	1035	1070
Coal Bed Temp Average, °F	1660	1735	1765
Coal Bed Height, ft	3.5	3.5	3.5
Coal Feed Rate, lb/hr	37.17	54.70	66.81
Hydrogen Feed Rate, SCF/hr	327.7	448.1	708.9
Steam Feed Rate, lb/hr	9.22	10.25	15.62
Steam/Coal Ratio, lb/hr	0.248	0.187	0.234
Hydrogen/Coal Ratio: % of stoichiometric	23.8	21.2	28.0
Steam Concentration in Feed Gas, mole %	37.2	32.5	31.6
Steam Decomposed, % of total equivalent steam fed	48.6	41.2	44.0
Carbon Gasified, %	26.3	27.5	37.0
MAF Coal Gasified, %	32.5	34.5	46.4
Hydrocarbon Yield, SCF/lb	3.24	4.18	4.97
CO + CO_2 Yield, SCF/lb	2.08	1.83	2.72
Product Gas Composition, nitrogen-free, mole %			
Carbon Monoxide	13.1	12.9	14.7
Carbon Dioxide	5.0	3.6	4.8
Hydrogen	53.5	45.4	44.7
Methane	27.5	36.9	34.8
Ethane	0.5	0.6	0.5
Propane	0.1	0.3	0.1
Benzene	0.3	0.3	0.4
Total	100.0	100.0	100.0
Product Heating Value, nitrogen-free, Btu/SCF	510	579	564

A7506 1532

run HT-224 is only somewhat lower than that of run HT-119, but it was appreciably lower than that of run HT-128. The higher carbon gasification of run HT-128 is due partially to the higher hydrogen-to-coal ratio (28% of stoichiometric) compared to that of run HT-224 (23.8% of stoichiometric). The product gas composition shows the effect of the lower operating pressure on the lower methane concentration in run HT-224.

In a test performed with a North Dakota lignite at a nominal reactor pressure of 500 psig (run HT-239, Table 2-A7, appendix), the hydrogasification reactivity of lignite with hydrogen and steam was shown to remain relatively high at the lower pressure. On a moisture- and ash-free basis, more than 54% of the lignite was gasified, and 41.4% of the carbon in the lignite was converted to gaseous products at an average bed temperature of 1535°F, and with a hydrogen-to-lignite ratio of 34.2% of stoichiometric.

For purposes of comparison, key results of test HT-239 are presented in Table 2-10 with those of run HT-145, conducted at generally similar conditions, but at a system pressure of 1000 psig. Carbon gasification at 500 psig was only somewhat less than the 42.1% obtained at 1000 psig. However, there was a shift in the proportion of the carbon in the lignite converted to hydrocarbons and to carbon oxide, as shown by the standard cubic foot-per-pound yield data for these gaseous products. The hydrocarbon yield at 500 psig was only 86% of that at 1000 psig, while the carbon oxides yield at the lower pressure was 115% of that at the higher pressure. The higher hydrogen-to-lignite ratio of run HT-239 (34.2% of stoichiometric), compared to that of run HT-145 (24.7% of stoichiometric) is partially responsible for the lignite gasification at 500 psig being similar to that at 1000 psig. Sixty-four percent less carbon in lignite was converted to oil at 500 psig (4.75% of the carbon in the lignite) than at 1000 psig (7.39% of the carbon in the lignite). A lower methane concentration in the product gas of the test at 500 psig was as expected, because of lower equilibrium methane concentration at this pressure compared with that at 1000 psig.

The hydrogasification of North Dakota lignite in run HT-241, at 500 psig with synthesis gas and steam, was discussed in the section on the effect of synthesis gas on coal gasification. Carbon gasification was not unduly affected by the lower pressure when compared with the results of run HT-195, performed at similar conditions, but at a pressure of 1031 psig. In run HT-241 carbon gasified was 36% of that in the feed lignite with a hydrogen-to-lignite ratio of 16.9% of stoichiometric. In run HT-195, with a hydrogen-to-lignite ratio of 17.5% of stoichiometric, 40.8% of the carbon was gasified.

The effect of pressure on Montana subbituminous coal hydrogasification, with hydrogen and steam, was studied in test runs HT-244 and HT-247 (Table 2-A7, appendix), which were performed at a nominal reactor pressure of 500 psig. Results of these two tests are compared in Table 2-11 with those of run HT-216, which was conducted at similar conditions, but at 1000 psig.

The results of runs HT-244 and HT-247 as shown in Table 2-11, are similar, indicating good reproducibility. Carbon gasification was 24% in run HT-244 and 26% in run HT-247. Carbon conversion to oils was only somewhat larger in run HT-247, with 5.43% of the carbon in the coal converted to oil, compared to 4.33% for run HT-244. Partially responsible

Table 2-10. COMPARISON OF NORTH DAKOTA LIGNITE HYDROGASIFICATION PDU TEST RESULTS AT 500 AND 1000-psig SYSTEM PRESSURES

Run No.	HT-145	HT-239
Reactor Pressure, psig	1048	478
Lignite Bed Temp Average, °F	1675	1535
Lignite Bed Height, ft	3.5	3.5
Lignite Feed Rate, lb/hr	85.76	32.07
Hydrogen Feed Rate, SCF/hr	710.3	368.8
Steam Feed Rate, lb/hr	15.35	8.69
Steam/Lignite Ratio, lb/lb	0.179	0.271
Hydrogen/Lignite Ratio, % of stoichiometric	24.7	34.2
Steam Concentration in Feed Gas, mole %	31.2	33.1
Steam Decomposed, % to total equivalent steam fed	75.9	56.9
Carbon Gasified, %	42.1	41.4
MAF Lignite Gasified, %	58.1	54.2
Hydrocarbon Yield, SCF/lb	5.06	4.33
CO + CO_2 Yield, SCF/lb	3.22	3.68
Carbon in Oil Fraction, % of carbon in lignite	7.39	4.75
Product-Gas Composition (nitrogen-free), mole %		
Carbon Monoxide	11.2	12.5
Carbon Dioxide	14.2	10.1
Hydrogen	34.9	50.2
Methane	37.1	24.9
Ethane	1.6	1.2
Propane	0.8	0.5
Benzene	0.2	0.5
Hydrogen Sulfide	--	0.1
Total	100.0	100.0
Product-Gas Heating Value (nitrogen-free), Btu/SCF	574	501

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Table 2-11. COMPARISON OF MONTANA SUBBITUMINOUS COAL HYDROGASIFICATION RESULTS WITH HYDROGEN AND STEAM AT 500 AND 1000-psig SYSTEM PRESSURES

Run No.	HT-216	HT-244	HT-247
Reactor Pressure, psig	1052	488	549
Coal-Bed Temp Average, °F	1615	1385	1460
Coal Feed Rate, lb/hr	53.74	69.45	54.60
Hydrogen Rate, SCF/hr	461.3	343.8	377.9
Steam Feed Rate, lb/hr	11.80	9.22	8.90
Hydrogen/Coal Ratio, % of stoichiometric	24.80	14.2	19.9
Steam Concentration in Feed Gas, mole %	34.9	36.0	33.1
Steam Decomposed, % of total equivalent steam fed	63.1	59.8	50.4
Carbon Gasified, %	43.1	23.5	26.1
MAF Coal Gasified, %	56.3	34.7	36.2
Hydrocarbon Yield, SCF/lb	5.12	1.88	2.80
CO + CO_2 Yield, SCF/lb	3.37	2.72	2.22
Product-Gas Rate (nitrogen-free), SCF/hr	664.2	585.4	561.3
Carbon Monoxide	16.4	24.7	13.5
Carbon Dioxide	10.9	7.6	8.1
Hydrogen	30.7	45.0	50.7
Methane	39.0	20.4	25.2
Ethane	1.8	1.2	1.4
Propane	0.6	0.7	0.6
Benzene	0.6	0.4	0.5
Hydrogen Sulfide	--	--	--
Total	100.0	100.0	100.0
Product-Gas Heating Value (nitrogen-free), Btu/SCF	608	479	514

A7506 1534

for the somewhat larger carbon conversions of run HT-244 are the higher average coal-bed temperature (1460°F compared to 1385°F) and the larger hydrogen-to-coal ratio (19.9% of stoichiometric versus 14.2% of stoichiometric).

How pressure affects Montana subbituminous coal hydrogasification results is shown by a comparison of the key results of runs HT-244 and HT-247 with those of run HT-216, conducted earlier at similar conditions except for 1000 psig. The carbon gasification, hydrocarbon yield, and product-gas heating values are significantly greater at 1000 psig than at 500 psig. This indicates that system pressure should be in the 1000-psi range to maximize methane formation in the hydrogasifier.

The hydrogasification of Montana subbituminous coal at a nominal pressure of 500 psig with synthesis gas and steam in test runs HT-243 and HT-248, was discussed in the section that describes how synthesis gas affects coal gasification. The weight percentage of carbon gasified in these two tests, 30.0% (run HT-243) and 27.4% (run HT-248), compare favorably with 29.6% obtained in run HT-214, performed at similar conditions with synthesis gas and steam, but at a system pressure of 1111 psig.

2.3.3.8 Product Gas Composition and Trace Components

The major constituents of the product gases produced by the hydrogasification of coal and lignite with hydrogen and steam in the PDU tests discussed are: methane, carbon oxides (carbon monoxide and carbon dioxide), and hydrogen. Methane concentration is determined by the degree of coal conversion and may also be controlled by the reactor temperature that sets the equilibrium composition of the product gas. The amount of carbon oxides formed is dependent on the oxygen content of the coal feeds and the steam-to-coal ratio. Feeds high in oxygen content such as subbituminous coal and lignite, when gasified, produce more carbon oxides than bituminous coals produce at similar conditions. In addition, the higher the steam-to-coal ratio, the greater will be the carbon oxides production, other conditions being equal. The ratio of carbon monoxide to carbon dioxide is set by the water-gas shift reaction, which is temperature controlled. Hydrogen content of the product gas is determined largely by the quantity of unreacted hydrogen remaining after the reaction. The concentration of hydrogen is related directly to the feed hydrogen-to-coal ratio, but not linearly. As the stoichiometric hydrogen-to-coal ratio is increased, concentration in the product gas tends to increase at a greater rate.

In addition to methane, small quantities of other saturated hydrocarbons are produced. Typical concentrations of these components are, ethane, 1.5%; propane, 0.5%; and butane, 0.2%. The principal aromatic in the product gas, generally less than 1%, is benzene.

A portion of the nitrogen in the coal is gasified. A substantial part — if not all — of the gasified nitrogen appears in the reactor product gas as ammonia; the ammonia dissolves in the water condensate.

Sulfur removal in hydrogasification was calculated from analyses of the coal feeds and residues with the results shown in Figure 2-14. While data are considerably scattered, it is evident that sulfur removal tends to increase as gasification proceeds, and that the sulfur is preferentially gasified, i.e. the percent of feed sulfur converted is always higher than the percent of coal converted, on a moisture- and ash-free basis. Conversion of sulfur in two low-sulfur Sewell seam coals, one low-volatile bituminous and the other medium-volatile bituminous, may be significantly higher than that of lower-rank coals. Scatter of data points for a single coal — the Pittsburgh No. 8 seam — was not significantly reduced by attempted correlation with gasification conditions.

Most of the sulfur appears in the reactor product gas as hydrogen sulfide, accompanied by small amounts (probably <200 ppm) of carbonyl sulfide (COS) and traces of organic sulfur compounds. Upon cooling of the gas, a substantial part of the hydrogen sulfide is absorbed by the water condensate along with the ammonia.

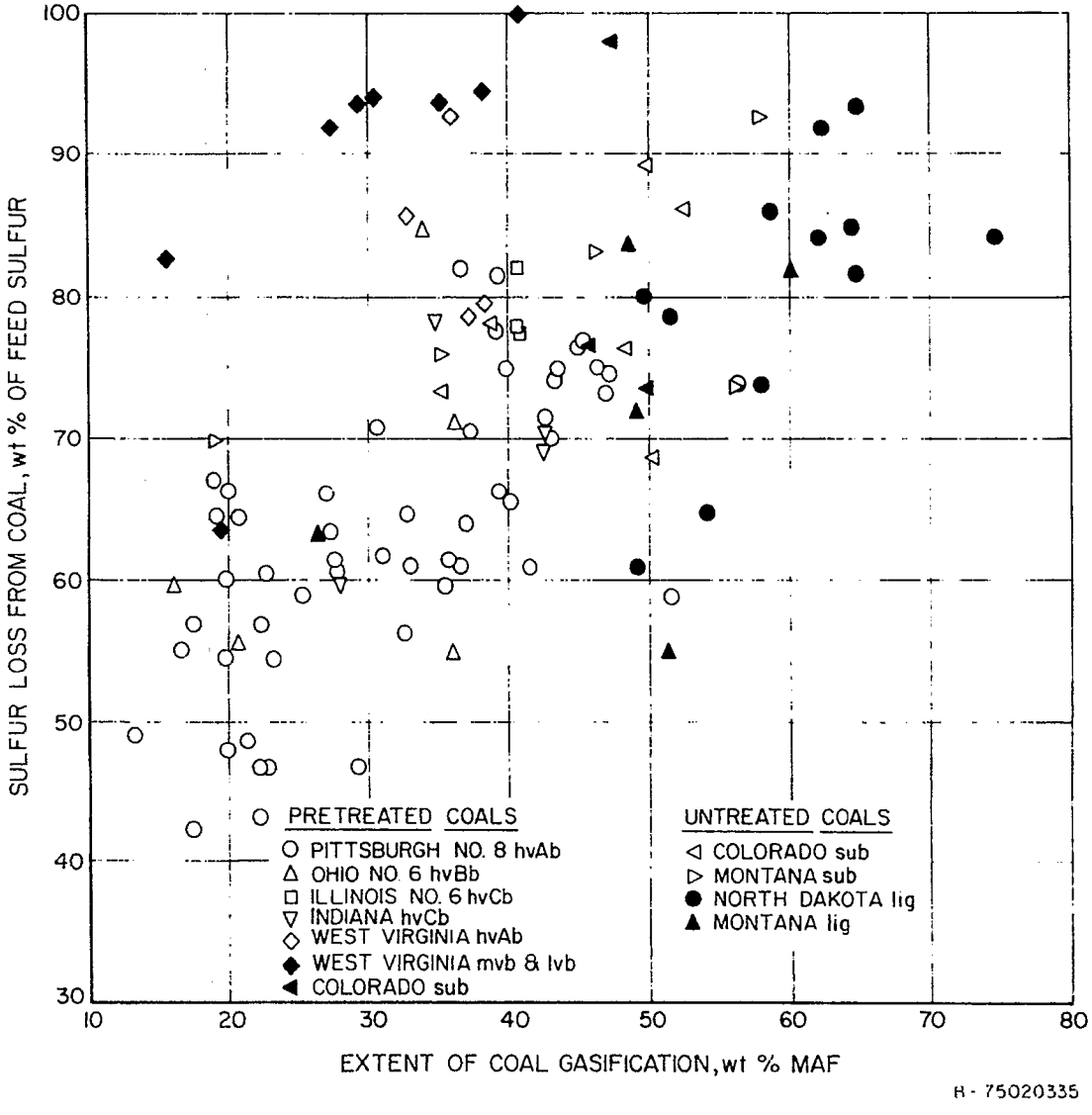

Figure 2-14. SULFUR LOSS FROM COAL DURING HYDROGASIFICATION

2.3.3.9 Char Compositions

Char rates and compositions reflected the degree of conversion of the feeds to gaseous and liquid products. Volatile matter contents of bituminous coals were generally reduced to 3% or less, and to less than 7% for subbituminous coal and for lignite. The reduction in hydrogen content tended to parallel the reduction in volatile matter content. Hydrogen concentration in the residue was reduced to less than 1.5% for all feeds. Gasification of the bituminous coals resulted in nearly complete consumption of the oxygen in the coal to produce carbon oxides and water. The residues produced from subbituminous coal and lignite gasification still contained from 3-6% oxygen by weight. Carbon concentration, in all cases, is significantly higher in the residue than in the feed.

There was no observable trend in the change in size distribution of the coal feeds after hydrogasification. Any breakdown in particle size due to attrition, or fracture, induced by the reaction, appeared to be balanced by particle growth due to coalescence.

Gasification of the coals and lignite resulted in a sizeable reduction in the bulk density. Lightly pretreated bituminous coal bulk densities were reduced from a range of 20 to 25 pounds per cubic foot, to a range of 15 to 20 pounds per cubic foot. Bulk densities of dried, untreated subbituminous coal and lignite were of the order of 45 pounds per cubic foot. After gasification, the subbituminous coal bulk density was reduced to 28 pounds per cubic foot, while the lignite bulk density was reduced to 20 pounds per cubic foot.

2.3.3.10 Liquid Products

Condensed liquids resulting from the hydrogasification of coals and lignite, consisted mainly of water and light oil fraction. Small quantities of ammonia and unidentified sulfur compounds were generally dissolved in the liquids. The relative quantities of water and oil were dependent mainly on the amount of steam fed and steam decomposed, and on the nature of the coal feed. Feeds high in volatile matter content, such as subbituminous coal and lignite, produced more oils then bituminous coals, other conditions being equal. Oil production was also influenced by reactor temperature, being higher at lower temperatures than at higher temperatures.

Specific gravity of the by-product oils was in the range of 1.001 to 1.010. Typically, the oil composition was 90 weight percent carbon and 6 weight percent hydrogen, the remainder of content being small quantities of oxygen, nitrogen, and sulfur. The principal compounds in the oil are benzene and toluene.

APPENDIX 2-A

Hydrogasification Data

APPENDIX 2-A CONTENT

Table 2-A1, Part 1. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: CONSOLIDATION COAL COMPANY, BITUMINOUS COAL CHAR, PITTSBURGH SEAM, MONTOUR NO. 10 MINE, HYDROGEN STEAM FEED GAS (Runs HT-42, -43, -44, -46, and -47)

Coal	Bituminous Coal Char	Bituminous Coal Char	Bituminous Coal Char	Bituminous Coal Char	Bituminous Coal Char
Source	Consolidation Coal Co.	Consolidation Coal Co.	Consolidation Coal Co.	Consolidation Coal Co.	Consolidation Coal Co.
Sieve Size, USS	35/80	35/80	35/80	35/80	35/80
Feed Gas	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam
Run No.	HT-42	HT-43	HT-44	HT-46	HT-47
Duration of Test, hr	5	6	3-3/4	7-1/4	6-1/4
Steady-State Operating Period, min[a]	177-300	115-354	169-207	253-355	302-395
OPERATING CONDITIONS					
Bed Height, ft	7	7	9.5[n]	3.5	8.2[n]
Reactor Pressure, psig	1046	1030	1114	1072	1159
Bed Temperatures, °F					
Bottom	1760	1725	1625	1670	1550
10-1/4 in.	1755	1715	1625	1740	1640
20-3/4 in.	1725	1720	1620	1725	1630
31 in.	1720	1715	1630	1720	1640
41-1/4 in.	1730	1720	1660	1715	1645
51-3/4 in.	1720	1710	1625	----	1660
62 in.	1690	1560	1610	----	1690
72-1/4 in.	1760	1750	1630	----	1695
82-3/4 in.	1825	1810	----	----	----
93 in.	1860	1840	1685	----	1725
103-1/4 in.	----	----	1710	----	1740
Average	1755	1725	1640	1715	1660
Coal Rate, lb/hr[b]	9.53	16.39	15.62	10.30	10.23
Hydrogen Rate, SCF/hr	204.3	234.0	291.1	284.3	323.8
Steam Rate, lb/hr	5.98	7.11	9.31	5.68	6.26
Steam, mole % of hydrogen-steam mixture	38.1	39.0	40.2	29.6	28.9
Hydrogen/Coal Ratio, % of stoichiometric[c]	48.8	32.7	43.2	63.6	73.5
Hydrogen/Steam Ratio, mole/mole	1.626	1.567	1.489	2.383	2.462
Bed Pressure Differential, in. wc	45.0	60.0	----	63.0	91.0
Coal Space Velocity, lb/cu ft-hr	15.40	26.49	22.19	33.28	14.11
Hydrogen-Steam Residence Time, min[d]	1.901	1.632	1.893	0.810	1.863
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0614	0.0715	0.0808	0.0720	0.0734

(Continued)

OPERATING RESULTS					
Product Gas Rate, SCF/hr	313.2	399.1	426.1	332.3	375.6
Net Btu Recovery, 1000 Btu/lb	7.626	5.981	7.861	7.629	9.263
Product Gas Yield, SCF/lb	32.87	24.34	27.27	32.27	36.72
Hydrocarbon Yield, SCF/lb	8.22	6.45	8.65	10.88	12.78
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[f]	126.5	170.9	160.9	362.2	180.3
Carbon Oxide Yield, SCF/lb	5.32	3.34	5.73	3.65	4.85
Net Reacted Hydrogen, SCF/lb	6.13	4.05	6.88	13.25	14.95
Residue, lb/lb coal[g]	0.568	0.569	0.614	0.561	0.572
Liquid Products, lb/lb coal[h]	0.415	0.321	0.371	0.339	0.404
Net MAF Coal Hydrogasified, wt %[i]	52.0	50.6	46.9	46.4	61.5
Carbon Gasified, wt %[j]	54.5	39.4	58.0	58.5	71.4
Steam Decomposed, lb/hr[j]	2.03	1.84	3.51	2.18	2.13
Steam Decomposed, % of steam fed[j]	33.9	25.9	37.7	38.4	34.0
Steam Decomposed, % of total equivalent fed[k]	43.3	40.0	47.2	47.5	43.2
Overall Material Balance, %	98.4	101.2	101.4	98.9	106.0
Carbon Balance, %	108.5	100.2	124.1	117.7	133.6
Hydrogen Balance, %	101.0	103.1	101.1	97.9	100.5
Oxygen Balance, %	----	----	----	----	97.1
PRODUCT GAS PROPERTIES					
Gas Composition, mole %					
Nitrogen	12.2	17.8	4.2	10.4	6.5
Carbon Monoxide	12.1	9.6	15.1	8.5	9.8
Carbon Dioxide	4.1	4.1	5.9	2.8	3.4
Hydrogen	46.6	42.0	43.1	44.5	45.5
Methane	25.0	26.5	31.7	33.7	34.8
Hydrogen Sulfide	----	----	----	0.1	----
Total	100.0	100.0	100.0	100.0	100.0
Heating Value, N_2-free, Btu/SCF[m]	497	522	523	565	559
Specific Gravity, Air = 1.00	0.469	0.505	0.483	0.445	0.434
Nitrogen Purge Rate, SCF/hr	48.2	62.8	52.8	43.2	38.2

a. From Start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Percent of the stoichiometric hydrogen/char ratio. The stoichiometric hydrogen/char ratio is the net feed hydrogen/char ratio required to convert all the carbon to methane

d. $\frac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

e. $\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

f. Reactor volume of 0.619 cu ft for Run HT-42 and HT-43; 0.840 cu ft for Run HT-44; 0.309 cu ft for Run HT-46; 0.725 cu ft. for Run HT-47

g. By ash balance

h. Includes condensed undecomposed steam

i. $100\left[\frac{\text{Wt of Product Gas-Wt Hydrogen in-Wt Decomposed Steam}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor.

m. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF:dry gas volume in SCF at 60°F, 30-in. Hg pressure

n. Average bed height

Table 2-A1, Part 1, Cont. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: CONSOLIDATION COAL COMPANY, BITUMINOUS COAL CHAR, PITTSBURGH SEAM, MONTOUR NO. 10 MINE, HYDROGEN + STEAM FEED GAS (Runs HT-50, -51, -52, -53, and -55)

Coal	Bituminous Coal Char	Bituminous Coal Char	Bituminous Coal Char	Bituminous Coal Char	Bituminous Coal Char
Source	Consolidation Coal Co.	Consolidation Coal Co.	Consolidation Coal Co.	Consolidation Coal Co.	Consolidation Coal Co.
Sieve Size, USS	10/40	10/40	10/40	10/40	10/40
Feed Gas	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam
Run No.	HT-50	HT-51	HT-52	HT-53	HT-55
Duration of Test, hr	5	5-3/4	4-1/2	4	4-1/4
Steady-State Operating Period, min[a]	178-309	265-327	169-271	145-233	184-252
OPERATING CONDITIONS					
Bed Height, ft	14.4	15.3	11.1[n]	7.7	7.1
Reactor Pressure, psig	1035	1043	1029	1006	1013
Reactor Temperatures, °F					
Bottom	1080	975	1030	890	620
10-1/4 in.	1705	1665	1710	----	----
11 in.	----	----	----	975	875
16 in.	----	----	----	1200	1000
20-3/4 in.	1520	1495	1520	----	----
21 in.	----	----	----	1365	1115
31 in.	1595	1565	1610	----	----
31-1/2 in.	----	----	----	1475	1080
42 in.	----	----	----	1575	1045
51-3/4 in.	1750	1720	1735	----	----
52 in.	----	----	----	1580	1105
62 in.	1760	1755	1765	----	----
62-1/2 in.	----	----	----	1725	1460
72-1/4 in.	1740	1730	1745	----	----
73 in.	----	----	----	1755	1645
82-3/4 in.	----	1710	1710	----	----
83 in.	----	----	----	1785	1815
93 in.	1740	1720	1680	----	----
94-1/2 in.	----	----	----	1760	1800
103-1/4 in.	1745	1735	1705	----	----
104 in.	----	----	----	1735	1790
113-3/4 in.	1755	1730	1715	----	----
124 in.	1755	1715	1715	----	----
134-1/4 in.	1730	1700	1725	----	----
144-3/4 in.	1735	1705	----	----	----
155 in.	----	1710	----	----	----
165-1/4 in.	1660	1690	----	----	----
175-3/4 in.	1655	1660	----	----	----
Average	1660	1645	1645	1485	1280
Coal Rate, lb/hr[b]	13.21	12.73	14.03	14.72	12.18
Hydrogen Rate, SCF/hr	305.0	243.8	224.1	259.1	251.5
Steam Rate, lb/hr	6.48	5.97	7.59	7.08	7.05
Steam, mole % of hydrogen-steam mixture	30.9	34.0	41.6	36.4	37.05
Hydrogen/Coal Ratio, % of stoichiometric[c]	54.0	45.6	35.1	41.1	48.1
Hydrogen/Steam Ratio, mole/mole	2.241	1.943	1.405	1.742	1.699
Bed Pressure Differential, in. wc	86.6	79.8	55.6	29.9	23.0
Coal Space Velocity, lb/cu ft-hr	10.37	9.41	15.21	21.68	19.47
Hydrogen-Steam Residence Time, min[d]	3.01	3.48	2.62	1.90	1.96
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0798	0.0691	0.0706	0.0693	0.0602

(Continued)

OPERATING RESULTS					
Product Gas Rate, SCF/hr	472.4	450.1	416.3	414.0	395.1
Net Btu Recovery, 1000 Btu/lb	9.668	9.053	7.304	7.360	7.708
Product Gas Yield, SCF/lb	35.75	35.35	27.69	28.10	32.43
Hydrocarbon Yield, SCF/lb	10.15	9.37	6.89	7.46	7.85
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[f]	105.3	88.19	104.8	162.0	152.8
Carbon Oxide Yield, SCF/lb	7.15	6.58	6.02	5.19	5.77
Net Reacted Hydrogen, SCF/lb	7.85	6.49	3.97	5.66	5.47
Residue, lb/lb coal[g]	0.525	0.534	0.652	0.583	0.624
Liquid Products, lb/lb coal[h]	0.265	0.167	0.221	0.282	0.495
Net MAF Coal Hydrogasified, wt %[i]	73.1	66.8	56.1	41.1	51.5
Carbon Gasified, wt %	70.2	66.6	52.9	51.6	55.8
Steam Decomposed, lb/hr[j]	2.98	3.85	4.79	2.92	1.01
Steam Decomposed, % of steam fed[j]	46.0	64.5	56.5	56.0	14.4
Steam Decomposed, % of total equivalent fed[k]	56.2	70.7	63.9	52.0	28.1
Overall Material Balance, %	109.9	105.8	104.5	104.5	103.4
Carbon Balance, %	127.3	122.3	122.2	114.0	122.6
Hydrogen Balance, %	104.0	99.1	97.5	102.6	109.9
Oxygen Balance, %	109.8	95.4	91.3	101.5	124.2
PRODUCT GAS PROPERTIES					
Gas Composition, mole %					
Nitrogen	9.0	19.1	14.1	12.5	11.1
Carbon Monoxide	16.7	14.6	17.9	15.0	14.6
Carbon Dioxide	3.3	4.0	3.7	3.5	3.3
Hydrogen	42.6	35.8	39.6	42.4	46.8
Methane	28.4	26.5	24.7	26.5	24.2
Ethane	----	----	----	0.1	----
Total	100.0	100.0	100.0	100.0	100.0
Heating Value, N_2-free, Btu/SCF[m]	519	525	499	513	492
Specific Gravity, Air = 1.00	0.486	0.560	0.531	0.497	0.466
Nitrogen Purge Rate, SCF/hr	53.8	87.3	64.4	51.8	80.9

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane

d. $\frac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

e. $\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-sectional Area of Reactor}}$

f. Reactor volume of 1.274 cu ft for Run HT-50; 1.353 cu ft for Run HT-51; 0.981 cu ft for Run HT-52; 0.680 cu ft for Run HT-53; 0.626 cu ft for Run HT-55

g. By ash balance

h. Includes condensed undecomposed steam

i. $100\left[\frac{\text{Wt of Product Gas - Wt Hydrogen in - Wt Decomposed Steam}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

m. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

n. Average bed height

B7506 1535A

Table 2-A1, Part 2. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PRETREATED PITTSBURGH NO. 8 SEAM, MONTOUR NO. 4 MINE, BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Run HT-58)

Coal	Montour 4 Bit. Coal
Source	IGT Pretreater[n]
Sieve Size, TSS	35x80
Feed Gas	Hydrogen - Steam
Run No.	HT-58
Duration of Test, hr	2
Steady-State Operating Period, min[a]	105-118
OPERATING CONDITIONS	
Bed Height, ft	11.3
Reactor Pressure, psig	1020
Reactor Temperatures, F	
Bottom	660
11 in.	1020
16 in.	1185
21 in.	1242
31-1/2	1215
42 in.	1180
52 in.	1165
62-1/2 in.	1190
73 in	1260
83 in.	1335
94-1/2 in.	1355
104 in.	1370
114 in.	1365
124-1/2 in.	1375
135 in.	1350
Average	1215
Coal Rate, lb/hr[b]	14.98
Hydrogen Rate, SCF/hr	204.0
Steam Rate, lb/hr	6.00
Steam, mole % of hydrogen-steam mixture	38.20
Hydrogen/Coal Ratio, % of stoichiometric[c]	57.1
Hydrogen/Steam Ratio, mole/mole	1.618
Bed Pressure Differential, in. wc	----
Coal Space Velocity, lb/cu ft-hr	14.51
Hydrogen-Steam Residence Time, min[d]	3.97
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0478

(Continued)

OPERATING RESULTS	
Product Gas Rate, SCF/hr	378.1
Net Btu Recovery, 1000 Btu/lb	3.945
Product Gas Yield, SCF/lb	26.09
Hydrocarbon Yield, SCF/lb	5.24
Gaseous Hydrocarbon Space Time Yield, SCF/cu ft-hr[f]	76.1
Carbon Oxide Yield, SCF/lb	0.86
Net Reacted Hydrogen, SCF/lb	5.44
Residue, lb/lb coal[g]	0.681
Liquid Products, lb/lb coal[h]	0.352
Net MAF Coal Hydrogasified, wt %[i]	23.7
Carbon Gasified, wt %	28.1
Steam Decomposed, lb/hr[j]	0.968
Steam Decomposed, % of steam fed[j]	16.2
Steam Decomposed, % of total equivalent fed[k]	34.4
Overall Material Balance, %	95.5
Carbon Balance, %	105.4
Hydrogen Balance, %	93.8
Oxygen Balance, %	79.7
PRODUCT GAS PROPERTIES	
Gas Composition, mole %	
Nitrogen	44.2
Carbon Monoxide	2.1
Carbon Dioxide	1.2
Hydrogen	32.4
Methane	19.2
Ethane	0.6
Propane	0.2
Benzene	0.1
Total	100.0
Heating Value, N_2-free, Btu/SCF[m]	575
Specific Gravity (Air = 1.00)	0.609
Nitrogen Purge Rate, SCF/hr	167.0

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Percent of the stoichiometric hydrogen-char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane

d. $\dfrac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

e. $\dfrac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

f. Reactor volume of 0.999 cu ft

g. By ash balance

h. Includes condensed, undecomposed steam

i. $100\left[\dfrac{\text{Wt of Product Gas} - \text{Wt Hydrogen in} - \text{Wt Decomposed Steam} - \text{Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

m. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

n. Blend of pretreated coals of Runs PP-1, PP-2, PP-3, PP-4 and PP-7

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Table 2-A1, Part 3. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PRETREATED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Runs HT-59, -61c, -62, and -63)

Coal	Ireland Mine Bituminous Coal	Ireland Mine Bituminous Coal	Ireland Mine Bituminous Coal	Ireland Mine Bituminous Coal
Source	IGT Pretreater Run FP-22	IGT Pretreater, Run FP-23	IGT Pretreater, Run FP-24	IGT Pretreater, Run FP-25
Sieve Size, USS	10/40	10/60	10/60	10/60
Gas Feed	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam
Run No.	HT-59	HT-61c	HT-62	HT-63
Duration of Test, hr	3	7-3/4	3-1/4	5
Steady-State Operating Period, min[a]	94-175	182-467	121-190	157-293
OPERATING CONDITIONS				
Bed Height, ft	8.7	7.0	11.3	11.3
Reactor Pressure, psig	1056	1012	1018	1035
Reactor Temperatures, °F				
Bottom	585	1014	980	890
11 in.	970	1220	1175	1130
16 in.	1150	1320	1270	1230
21 in.	1210	1325	1290	1235
31-1/2	1130	1230	1210	1140
42 in.	1045	1140	1125	1055
52 in.	1070	1140	1170	1070
62-1/2 in.	1240	1185	1220	1180
73 in.	1325	1330	1270	1260
83 in.	1400	1460	1320	1335
94-1/2 in.	1405	1430	1360	1340
104 in.	1410	----	1390	1345
114 in.	1430	----	1400	1350
124-1/2 in.	----	----	1405	1355
135 in.	----	----	1345	1315
Average	1180	1255	1260	1215
Coal Rate, lb/hr[b]	11.37	9.69	12.29	11.11
Hydrogen Rate, SCF/hr	302.4	301.6	301.4	297.6
Steam Rate, lb/hr	6.00	5.96	5.91	5.97
Steam, mole % of hydrogen-steam mixture	29.42	29.3	29.2	29.7
Hydrogen/Coal Ratio, % of stoichiometric[c]	70.7	85.8	65.4	70.8
Hydrogen/Steam Ratio, mole/mole	2.399	2.410	2.428	2.372
Bed Pressure Differential, in. wc	----	----	----	----
Coal Space Velocity, lb/cu ft-hr	14.72	15.66	12.30	11.13
Hydrogen-Steam Residence Time, min[d]	2.49	1.84	2.98	3.13
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0585	0.0635	0.0632	0.0607

(Continued)

OPERATING RESULTS				
Product Gas Rate, SCF/hr	457.9	403.5	422.4	134.2
Net Btu Recovery, 1000 Btu/lb	4.616	2.037	3.026	2.925
Product Gas Yield, SCF/lb	40.27	41.84	34.37	34.08
Hydrocarbon Yield, SCF/lb	6.52	4.71	5.41	5.21
Gaseous Hydrocarbon Space Time Yield, SCF/cu ft-hr[f]	96.0	73.69	66.39	57.86
Carbon Oxide Yield, SCF/lb	1.69	1.00	1.37	1.76
Net Reacted Hydrogen, SCF/lb	8.43	10.26	9.43	9.51
Residue, lb/lb coal[g]	0.560	0.657	0.600	0.583
Liquid Products, lb/lb coal[h]	0.708	0.734	0.544	0.652
Net MAF Coal Hydrogasified, wt %[i]	30.1	30.6	36.6	39.3
Carbon Gasified, wt %[j]	38.5	28.9	32.2	33.2
Steam Decomposed, lb/hr[j]	0.0	nil	nil	nil
Steam Decomposed, % of steam fed[j]	0.0	nil	nil	nil
Steam Decomposed, % of total equivalent fed[k]	0.0	4.1	18.0	10.0
Overall Material Balance, %	100.4	100.7	99.1	101.3
Carbon Balance, %	104.6	110.3	103.4	104.5
Hydrogen Balance, %	104.3	92.0	92.1	93.6
Oxygen Balance, %	121.9	105.0	98.3	93.0
PRODUCT GAS PROPERTIES				
Gas Composition, mole %				
Nitrogen	34.5	36.2	36.3	38.0
Carbon Monoxide	3.4	1.7	2.6	3.2
Carbon Dioxide	0.8	0.7	1.4	1.3
Hydrogen	45.1	50.1	43.9	44.2
Methane	15.6	10.5	14.9	12.4
Ethane	0.4	0.6	0.6	0.7
Propane	0.1	0.1	0.1	0.1
Butane	----	----	----	----
Benzene	0.1	0.1	0.1	0.1
Hydrogen Sulfide	----	----	0.1	----
Total	100.0	100.0	100.0	100.0
Heating Value, N_2-free, Btu/SCF[m]	495	450	493	471
Specific Gravity (Air 1.00)	0.507	0.483	0.524	0.531
Nitrogen Purge Rate, SCF/hr	156.0	146.1	153.3	165.0

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Percent of the stoichiometric hydrogen/char ratio — the net feed hydrogen/char ratio required to convert all the carbon to methane

d. $\frac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

e. $\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

f. Reactor volume of 0.773 cu ft for Run HT-59; 0.619 cu ft for Runs HT-61c, and HT-67; 0.999 cu ft for Runs HT-62 and HT-63

g. By ash balance for Runs HT-59, HT-62, HT-63 and HT-67; by weight of recovered residue for Run HT-61c

h. Includes condensed, undecomposed steam

i. $100\left[\frac{\text{Wt of Product Gas - Wt Hydrogen in - Wt Decomposed Steam - Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

m. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

n. Blend of pretreated coals of Runs PP-1, PP-2, PP-3, PP-4, and PP-7

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Table 2-A1, Part 3, Cont. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PRE-TREATED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + METHANE + STEAM FEED GAS (Runs HT-67, -68, -70, -71, and -78)

Coal Source	Ireland Mine Bituminous Coal IGT Pretreater Run FP-28	Ireland Mine Bituminous Coal IGT Pretreater Run FP-29	Ireland Mine Bituminous Coal IGT Pretreater Run FP-31	Ireland Mine Bituminous Coal IGT Pretreater Runs FP-28 and FP-29	Ireland Mine Bituminous Coal IGT Pretreater Run FP-37
Sieve Size, USS	10/60	10/60	10/80	10/80	10/80
Feed Gas	Hydrogen + Methane + Steam				
Run No.	HT-67	HT-68	HT-70	HT-71	HT-78
Duration of Test, hr	8	8	5-3/4	6	7
Steady-State Operating Period, min[a]	165-475	132-482	126-341	102-357	77-415
OPERATING CONDITIONS					
Bed Height, ft	7.0	7.0	7.0	7.0	7.0
Reactor Pressure, psig	1031	1041	1030	1031	1039
Reactor Temperature, °F					
Bottom	1105	1120	1090	1030	1035
11 in.	1255	1265	1180	1170	1145
16 in.	1320	1330	1225	1220	1200
21 in.	1395	1390	1265	1260	1250
31-1/2 in.	1340	1365	1230	1240	1260
42 in.	1290	1345	1075	1215	1265
52 in.	1240	1325	1160	1190	1270
62-1/2 in.	1155	1195	1175	1160	1185
73 in.	1065	1075	1190	1125	1095
83 in.	1085	1295	1320	1155	1095
94-1/2 in.	1185	1210	1345	1225	1215
Average	1220	1245	1205	1185	1185
Coal Rate, lb/hr[b]	13.61	12.73	23.26	22.72	17.97
Hydrogen Rate, SCF/hr[c]	302.0	306.8	479.9	465.5	314.1
Steam Rate, lb/hr	7.52	7.54	9.91	10.10	7.40
Steam, mole % of hydrogen-steam mixture	34.3	34.0	30.2	31.3	33.1
Hydrogen/Coal Ratio, % of stoichiometric[d]	33.0	36.7	33.8	33.7	26.8
Hydrogen/Steam Ratio, mole/mole	1.088	1.099	1.414	1.330	1.171
Bed Pressure Differential, in. wc	----	----	----	----	----
Coal Space Velocity, lb/cu ft-hr	21.99	20.58	37.58	36.72	29.03
Feed Gas Residence Time, min[e]	1.77	1.74	1.19	1.22	1.77
Superficial Feed Gas Velocity, ft/sec[f]	0.0659	0.0670	0.0978	0.0952	0.0659

(Continued)

OPERATING RESULTS

Product Gas Rate, SCF/hr	497.2	498.6	589.9	591.2	437.0
Net Btu Recovery, 1000 Btu/lb	3.103	2.952	1.949	2.432	2.242
Product Gas Yield, SCF/lb	36.54	39.18	25.37	26.02	24.33
Hydrocarbon Yield, SCF/lb	3.84	3.96	3.41	2.90	2.92
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[g]	84.38	81.35	128.1	106.7	84.82
Carbon Oxide Yield, SCF/lb	0.95	0.94	0.93	0.77	0.67
Net Reacted Hydrogen, SCF/lb	2.76	3.25	4.58	2.58	2.62
Residue, lb/lb coal[h]	0.680	0.736	0.732	0.734	0.724
Liquid Products, lb/lb coal[i]	0.648	0.686	0.521	0.554	0.538
Net MAF Coal Hydrogasified, wt %[j]	19.9	19.2	21.3	22.2	17.5
Carbon Gasified, wt %	19.8	21.7	19.0	18.1	16.1
Steam Decomposed, lb/hr[k]	nil	nil	nil	nil	nil
Steam Decomposed, % of steam fed[k]	nil	nil	nil	nil	nil
Steam Decomposed, % of total equivalent fed[m]	3.9	5.8	8.3	nil	nil
Overall Material Balance, %	98.1	99.8	99.5	100.6	99.6
Carbon Balance, %	97.7	104.8	101.3	99.9	100.6
Hydrogen Balance, %	101.0	103.0	102.9	104.1	101.3
Oxygen Balance, %	106.5	99.2	103.1	103.1	105.8

PRODUCT AND FEED GAS PROPERTIES

Gas Composition, mole %	Feed	Product	Feed	Product	Feed	Product	Feed	Product	Feed	Product
Nitrogen	3.0	35.6	3.7	36.5	1.2	20.8	1.2	18.0	1.6	25.1
Carbon Monoxide	---	1.6	---	1.5	---	2.1	---	1.9	0.0	1.6
Carbon Dioxide	0.1	1.0	0.1	0.9	0.2	1.6	0.3	1.3	0.2	1.3
Hydrogen	56.9	27.0	56.7	26.6	61.3	31.8	60.6	37.8	58.0	30.9
Methane	35.9	32.7	36.7	32.4	34.0	41.6	35.1	38.1	36.7	38.4
Ethane	2.4	1.9	2.3	1.7	2.2	1.8	2.0	2.5	2.5	2.4
Propane	1.5	0.1	1.3	---	0.7	0.1	0.6	0.2	0.8	0.2
Butanes	0.2	---	0.2	---	0.3	---	0.2	---	0.2	0.0
Benzene	---	0.1	---	0.3	---	0.2	---	0.2	0.0	0.1
Helium	---	---	---	0.1	0.1	---	---	---	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Heating Value, N_2-free, Btu/SCF[n]	634	710	641	715	608	712	605	687	632	717
Specific Gravity (Air = 1.00)	0.322	0.601	0.323	0.608	0.283	0.525	0.287	0.485	0.305	0.545
Nitrogen Purge Rate, SCF/hr	177.0		182.0		123.0		99.7		109.5	

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Hydrogen and methane mixture

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane

e. $\dfrac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

f. $\dfrac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

g. Reactor volume of 0.619 cu ft

h. By ash balance

i. Includes condensed, undecomposed steam

j. $100\left[\dfrac{\text{Wt of Product Gas - Wt Feed Gas in - Wt Decomposed Steam - Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

k. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

m. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char and the measured liquid water rate leaving the reactor

n. Gross – gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

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Table 2-A1, Part 3, Cont. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PRE-TREATED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + METHANE + STEAM FEED GAS (Runs HT-83, -84, -94, -97, and -98)

Coal	Ireland Mine Bituminous Coal	Ireland Mine Bituminous Coal	Ireland Mine Bituminous Coal	Ireland Mine Bituminous Coal	
Source	IGT Pretreater Run FP-28	IGT Pretreater Run FP-43	IGT Pretreater Run FP-46	IGT Pretreater Runs FP-51 and FP 54	
Sieve Size, USS	10/80	10/80	10/80	10/80	
Feed Gas	Hydrogen + Methane + Steam				
Run No.	HT-83	HT-84	HT-94	HT-97	HT-98
Duration of Test, hr	5-1/2	5-1/4	3-1/2	3-1/4	9-1/2
Steady-State Operating Period, min[a]	120-325	127-307	108-207	90-203	95-578
OPERATING CONDITIONS					
Bed Height, ft	7.0	7.0	3.5	7	7
Reactor Pressure, psig	1013	1029	1024	1036	1037
Reactor Temperatures, °F					
Bottom	965	950	----	----	965
11 in.	1200	1160	----	1065	1032
16 in.	1310	1260	----	1130	1065
21 in.	1295	1260	----	1290	1310
31-1/2 in.	1220	1300	----	1190	1245
42 in.	1150	1140	----	1090	1180
52 in.	1170	1195	----	1080	1247
62-1/2 in.	1210	1315	----	1220	1315
73 in.	1325	1405	----	1315	1330
83 in.	1430	1485	----	1400	1350
94-1/2 in.	1395	1440	----	1405	1345
114 in.	----	----	1340	----	----
124-1/2 in.	----	----	1370	----	----
135 in.	----	----	1275	----	----
145 in.	----	----	1315	----	----
155-1/2 in.	----	----	1355	----	----
Average	1245	1265	1330	1220	1215
Coal Rate, lb/hr[b]	14.60	17.82	24.60	20.65	22.56
Hydrogen Rate, SCF/hr[c]	144.2	176.7	350.4	350.0	353.1
Steam Rate, lb/hr	3.56	3.13	7.87	7.38	7.46
Steam, mole % of hydrogen-steam mixture[d]	34.1	27.1	32.1	30.7	30.8
Hydrogen/Coal Ratio, % of stoichiometric	15.4	15.8	21.6	25.9	24.0
Hydrogen/Steam Ratio, mole/mole	1.133	1.671	1.345	1.428	1.445
Bed Pressure Differential, in. wc	----	----	----	----	----
Coal Space Velocity, lb/cu ft-hr	23.59	28.80	79.52	33.35	36.46
Hydrogen-Steam Residence Time, min[e]	3.61	3.27	0.736	1.62	1.61
Superficial Hydrogen-Steam Velocity, ft/sec[f]	0.0323	0.0357	0.0793	0.0720	0.0724

(Continued)

OPERATING RESULTS

Product Gas Rate, SCF/hr	307.5	321.1	783.9	667.5	699.4
Net Btu Recovery, 1000 Btu/lb	3.269	3.141	2.004	1.892	1.337
Product Gas Yield, SCF/lb	21.07	18.02	31.86	32.32	31.00
Hydrocarbon Yield, SCF/lb	1.86	3.43	2.69	2.63	2.15
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr	43.81	98.86	213.9	87.73	78.35
Carbon Oxides Yield, SCF/lb	1.16	1.25	0.672	0.725	0.341
Net Reacted Hydrogen, SCF/lb	1.58	1.58	2.04	2.53	2.67
Residue, lb/lb coal[h]	0.630	0.642	0.732	0.786	0.863
Liquid Products, lb/lb coal[i]	0.330	0.235	0.373	0.417	0.379
Net MAF Coal Hydrogasified, wt %	27.5	27.2	19.0	17.4	13.27
Carbon Gasified, wt %	20.5	20.1	13.4	14.0	10.7
Steam Decomposed, lb/hr[k]	Nil	Nil	Nil	Nil	Nil
Steam Decomposed, % of steam fed[k]	Nil	Nil	Nil	Nil	Nil
Steam Decomposed, % of total equivalent fed[m]	----	----	7.4	5.21	9.88
Overall Material Balance, %	97.0	96.7	97.7	99.4	100.2
Carbon Balance, %	91.4	93.8	93.6	97.8	103.9
Hydrogen Balance, %	105.5	101.9	100.9	103.0	99.6
Oxygen Balance, %	----	90.4	104.3	106.8	95.7

PRODUCT AND FEED GAS PROPERTIES

Gas Composition, mole %	Feed	Product	Feed	Product	Feed	Product	Feed	Product	Feed	Product
Nitrogen	1.4	39.0	1.0	28.2	1.5	51.8	1.2	45.5	1.2	50.6
Carbon Monoxide	0.0	2.9	0.0	4.3	0.0	1.2	---	1.5	---	0.7
Carbon Dioxide	0.3	2.6	0.3	2.8	0.2	1.0	0.3	0.9	0.2	0.5
Hydrogen	38.7	20.0	62.1	25.4	63.5	22.0	63.3	25.4	64.2	23.8
Methane	37.0	34.4	34.0	38.4	32.1	23.2	32.5	25.7	31.7	23.1
Ethane	1.9	0.9	1.9	0.7	1.9	0.7	1.9	0.8	1.9	1.2
Propane	0.5	0.1	0.5	0.1	0.6	0.1	0.6	0.1	0.6	---
Butane	0.2	0.0	0.2	0.0	0.2	---	0.2	---	0.2	---
Benzene	0.0	0.1	0.0	0.1	---	---	---	0.1	---	0.1
Hydrogen Sulfide	0.0	0.0	0.0	0.0	---	---	---	---	---	---
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Heating Value, N_2-free, Btu/SCF[n]	618	718	596	691	587	664	558	664	583	679
Specific Gravity (Air = 1.00)	0.296	0.665	0.278	0.601	0.273	0.683	0.274	0.643	0.269	0.666
Nitrogen Purge Rate, SCF/hr	119.9		90.5		401		304		350	

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Hydrogen and methane mixture

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane

e. $$\frac{\text{Coal Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$$

f. $$\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-sectional Area of Reactor}}$$

g. Reactor volume of 0.619 cu ft. HT-83, HT-84, HT-97 and HT-98; 0.309 cu ft in Run HT-94

h. By ash balance

i. Includes condensed, undecomposed steam

j. $$100\left[\frac{\text{Wt of Product Gas - Wt Hydrogen in - Wt Decomposed Steam - Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$$

k. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

m. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

n. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

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Table 2-A1, Part 3, Cont. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PRE-TREATED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + METHANE + NITROGEN FEED GAS (Run HT-85)

Coal	Ireland Mine Bituminous Coal
Source	IGT Pretreater Run FP-43
Sieve Size, USS	10/80
Gas Feed	Hydrogen + Methane + Nitrogen
Run No.	HT-85
Duration of Test, hr	6-1/4
Steady-State Operating Period, min[a]	106-371
OPERATING CONDITIONS	
Bed Height, ft	7.0
Reactor Pressure, psig	1007
Reactor Temperature, °F	
Bottom	----
11 in.	1070
16 in.	1205
21 in.	1200
31-1/2 in.	1145
42 in.	1080
52 in.	1140
62-1/2 in.	1275
73 in.	1400
83 in	1515
94-1/2 in.	1455
Average	1250
Coal Rate, lb/hr[b]	18.77
Hydrogen Rate, SCF/hr[c]	218.8
Steam Rate, lb/hr	Nil
Steam, mole % of hydrogen-steam mixture	Nil
Hydrogen/Coal Ratio, % of stoichiometric[d]	15.0
Hydrogen/Steam Ratio, mole/mole	----
Bed Pressure Differential, in. wc	----
Coal Space Velocity, lb/cu ft-hr	30.33
Feed Gas Residence Time, min[e]	3.58
Superficial Feed Gas Velocity, ft/sec[f]	0.0326

(Continued)

OPERATING RESULTS

Product Gas Rate, SCF/hr	343.0
Net Btu Recovery, 1000 Btu/lb	2.570
Product Gas Yield, SCF/lb	18.28
Hydrocarbon Yield, SCF/lb	2.96
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[g]	89.76
Carbon Oxide Yield, SCF/lb	0.769
Net Reacted Hydrogen, SCF/lb	1.69
Residue, lb/lb coal[h]	0.711
Liquid Products, lb/lb coal[i]	0.1137
Net MAF Coal Hydrogasified, wt %[j]	20.0
Carbon Gasified, wt %	15.9
Steam Decomposed, lb/hr[k]	----
Steam Decomposed, % of steam fed[k]	----
Steam Decomposed, % of total equivalent fed[m]	----
Overall Material Balance, %	99.6
Carbon Balance, %	98.7
Hydrogen Balance, %	100.2
Oxygen Balance, %	71.5

PRODUCT AND FEED GAS PROPERTIES

Gas Composition, mole %	Feed	Product
Nitrogen	20.8	38.2
Carbon Monoxide	0.0	3.1
Carbon Dioxide	0.3	1.3
Hydrogen	50.2	22.8
Methane	26.6	33.7
Ethane	1.5	0.7
Propane	0.4	0.1
Butanes	0.2	0.0
Benzene	0.0	0.1
Helium	0.0	Trace
Total	100.0	100.0
Heating Value, N_2-free, Btu/SCF[n]	592	707
Specific Gravity (Air = 1.00)	0.415	0.635
Nitrogen Purge Rate, SCF/hr	85.5	

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Hydrogen and methane mixture

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane

e. $\frac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

f. $\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

g. Reactor volume of 0.619 ft

h. By ash balance

i. Includes condensed, undecomposed steam

j. $100\left[\frac{\text{Wt of Product Gas - Wt Feed Gas in - Wt Decomposed Steam - Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

k. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

m. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

n. Gross – gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

Table 2-A1, Part 4. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PARTIALLY HYDROGASIFIED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Runs HT-64, -69, -72, and -73)

Coal	Partially Hydrogasified Bituminous Coal	Partially Hydrogasified Bituminous Coal	Partially Hydrogasified Bituminous Coal	Partially Hydrogasified Bituminous Coal
Source	Runs HT-61c, HT-62, and HT-63	Runs HT-67 and HT-68	Run HT-71	Run HT-70
Sieve Size, USS	10/60	10/60	10/80	10/80
Gas Feed	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam	Hydrogen + Steam
Run No.	HT-64	HT-69	HT-72	HT-73
Duration of Test, hr	7-1/4	7-3/4	5	4-1/2
Steady-State Operating Period, min[a]	214-455	190-453	146-320	134-269
OPERATING CONDITIONS				
Bed Height, ft	7.0	7.0	7.0	7.0
Reactor Pressure, psig	1021	1041	1023	1006
Reactor Temperature, °F				
Bottom	1150	1405	----	----
11 in.	1320	1455	----	----
16 in.	1405	1480	----	----
21 in.	1480	1500	----	----
31-1/2 in.	1405	1485	----	----
42 in.	1340	1470	----	----
52 in.	1280	1460	----	----
62-1/2 in.	1210	1380	----	----
73 in.	1235	1295	----	----
83 in.	1415	1420	----	----
94-1/2 in.	1585	1530	----	----
114 in.	----	----	1805	1975
124-1/2 in.	----	----	1815	1950
135 in.	----	----	1825	1930
145 in.	----	----	1830	1970
155-1/2 in.	----	----	1830	2005
166 in.	----	----	1825	1930
176 in.	----	----	1830	1940
187-1/4 in.	----	----	1835	1950
197 in.	----	----	1830	1880
Average	1350	1445	1825	1950
Coal Rate, lb/hr[b]	8.02	7.95	16.74	17.22
Hydrogen Rate, SCF/hr	291.8	279.9	223.8	269.4
Steam Rate, lb/hr	9.88	13.15	6.70	3.97
Steam, mole % of hydrogen-steam mixture	41.6	49.7	38.6	23.6
Hydrogen/Coal Ratio, % of stoichiometric[c]	80.7	79.8	29.7	35.0
Hydrogen/Steam Ratio, mole/mole	1.406	1.013	1.590	3.234
Bed Pressure Differential, in. wc	----	----	----	22.0
Coal Space Velocity, lb/cu ft-hr	12.95	12.85	27.05	27.84
Hydrogen-Steam Residence Time, min[d]	1.50	1.31	1.64	1.57
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0777	0.0893	0.0715	0.0741

(Continued)

OPERATING RESULTS				
Product Gas Rate, SCF/hr	411.8	431.9	585.2	551.2
Net Btu Recovery, 1000 Btu/lb	1.716	2.482	7.254	5.330
Product Gas Yield, SCF/lb	51.37	54.32	34.96	32.42
Hydrocarbon Yield, SCF/lb	4.88	4.13	6.26	4.86
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[f]	63.22	53.04	169.29	135.38
Carbon Oxide Yield, SCF/lb	1.80	1.36	5.52	4.09
Net Reacted Hydrogen, SCF/lb	10.92	5.82	1.80	2.51
Residue, lb/lb coal[g]	0.806	0.793	0.460	0.671
Liquid Products, lb/lb coal[h]	1.198	1.565	0.119	0.0774
Net MAF Coal Hydrogasified, wt %[i]	31.5	30.1	52.0	43.6
Carbon Gasified, wt %	27.8	23.0	48.8	36.9
Steam Decomposed, lb/hr[j]	0.565	0.711	4.71	2.63
Steam Decomposed, % of steam fed[j]	5.7	5.4	70.4	66.4
Steam Decomposed, % of total equivalent fed[k]	6.9	6.0	71.9	69.3
Overall Material Balance, %	102.3	100.6	94.8	100.1
Carbon Balance, %	112.4	99.2	86.0	94.8
Hydrogen Balance, %	94.9	98.1	105.3	102.7
Oxygen Balance, %	103.8	99.7	101.4	112.1
PRODUCT AND FEED GAS PROPERTIES				
Gas Composition, mole %				
Nitrogen	37.4	35.8	33.2	31.9
Carbon Monoxide	1.9	1.3	13.0	11.6
Carbon Dioxide	1.6	1.2	2.8	1.0
Hydrogen	49.6	54.1	33.1	40.5
Methane	9.5	7.6	17.8	15.0
Ethane	----	----	----	0.0
Propane	----	----	----	0.0
Butanes	----	----	----	0.0
Benzene	----	----	----	0.0
Helium	----	----	----	0.0
Total	100.0	100.0	100.0	100.0
Heating Value, N_2-free, Btu/sec[n]	414	374	488	464
Specific Gravity (Air = 1.00)	0.493	0.459	0.614	0.549
Nitrogen Purge Rate, SCF/hr	154.0	149.0	194.0	176.0

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane

d. $\dfrac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

e. $\dfrac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

f. Reactor volume of 0.619 cu ft

g. By ash balance, except by weight recovered in Runs HT-64 and HT-73

h. Includes condensed, undecomposed steam

i. $100\left[\dfrac{\text{Wt of Product Gas-Wt Feed Gas in-Wt Decomposed Steam-Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

m. Gross – gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

Table 2-A1, Part 4, Cont. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PARTIALLY HYDROGASIFIED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Runs HT-80, -86, and -87)

Coal	Partially Hydrogasified Bituminous Coal	Partially Hydrogasified Bituminous Coal	Partially Hydrogasified Bituminous Coal
Source	Run HT-78	Runs HT-82 and HT-83	Runs HT-84 and HT-85
Sieve Size, USS	10/80	10/80	10/80
Feed Gas	Hydrogen - Steam	Hydrogen - Steam	Hydrogen + Steam
Run No.	HT-80	HT-86	HT-87
Duration of Test, hr	4-1/2	4-1/4	7-1/4
Steady-State Operating Period, min[a]	141-267	149-260	123-420
OPERATING CONDITIONS			
Bed Height, ft	3.5	3.5	3.5
Reactor Pressure, psig	1041	1023	1007
Reactor Temperatures, °F			
Bottom	----	----	----
114 in.	1680	1740	1710
124-1/2 in.	1675	1735	1695
135 in.	1670	1735	1710
145 in.	1705	1730	1720
155-1/2 in.	1740	1725	1735
Average	1695	1735	1715
Coal Rate, lb/hr[b]	11.20	12.44	17.10
Hydrogen Rate, SCF/hr	187.9	189.1	182.6
Steam Rate, lb/hr	4.34	4.34	3.78
Steam, mole % of hydrogen-steam mixture	32.7	32.5	30.33
Hydrogen/Coal Ratio, % of stoichiometric[c]	36.0	31.7	21.6
Hydrogen/Steam Ratio, mole/mole	2.058	2.075	2.300
Bed Pressure Differential, in. wc	----	----	----
Coal Space Velocity, lb/cu ft-hr	36.20	40.20	55.28
Hydrogen-Steam Residence Time, min[d]	1.150	1.105	1.174
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0507	0.0528	0.0497

(Continued)

OPERATING RESULTS			
Product Gas Rate, SCF/hr	348.7	370.7	346.6
Net Btu Recovery, 1000 Btu/lb	4.950	5.187	3.514
Product Gas Yield, SCF/lb	31.13	29.80	20.27
Hydrocarbon Yield, SCF/lb	5.85	5.51	4.11
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[f]	211.9	221.7	227.4
Carbon Oxides Yield, SCF/lb	3.58	3.31	2.250
Net Reacted Hydrogen, SCF/lb	5.97	3.91	3.85
Residue, lb/lb coal[g]	0.678	0.734	0.789
Liquid Products, lb/lb coal[h]	0.194	0.176	0.104
Net MAF Coal Hydrogasified, wt %[i]	37.5	38.0	26.4
Carbon Gasified, wt %	38.1	34.9	24.7
Steam Decomposed, lb/hr[j]	2.17	2.14	2.00
Steam Decomposed, % of steam fed[j]	50.0	49.4	52.9
Steam Decomposed, % of total equivalent fed[k]	51.4	----	----
Overall Material Balance, %	99.1	101.9	100.9
Carbon Balance, %	102.5	97.2	103.9
Hydrogen Balance, %	97.1	105.7	102.7
Oxygen Balance, %	98.8	96.0	102.0
PRODUCT AND FEED GAS PROPERTIES			
Gas Composition, mole %			
Nitrogen	35.0	32.5	34.9
Carbon Monoxide	9.5	9.0	8.8
Carbon Dioxide	2.0	2.1	2.3
Hydrogen	34.7	37.9	33.7
Methane	18.8	18.5	20.2
Ethane	----	0.0	0.1
Propane	----	0.0	0.0
Butane	----	0.0	0.0
Benzene	----	0.0	0.0
Hydrogen Sulfide	----	0.0	0.0
Total	100.0	100.0	100.0
Heating Value, N_2-free, Btu/SCF[m]	505	495	521
Specific Gravity (Air = 1.00)	0.591	0.564	0.596
Nitrogen Purge Rate, SCF/hr	123.0	120.5	121.0

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Percent of the stoichiometric hydrogen/coal ratio – the net feed hydrogen/coal ratio required to convert all the carbon to methane

d. $\dfrac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

e. $\dfrac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

f. Reactor volume of 0.309 cu ft

g. By ash balance in Runs HT-80 and HT-87; by weight recovered in Run HT-86

h. Includes condensed, undecomposed steam

i. $100\left[\dfrac{\text{Wt of Product Gas} - \text{Wt Feed Gas in} - \text{Wt Decomposed Steam} - \text{Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

m. Gross – gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

Table 2-A1, Part 5. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PRETREATED OHIO NO. 6 SEAM, BROKEN ARO MINE, BITUMINOUS COAL, HYDROGEN + METHANE + STEAM FEED GAS (Runs HT-76, and -77)

Coal	Bituminous Coal Partially Hydrogasified	Bituminous Coal Partially Hydrogasified
Source	Ohio No. 6 Seam IGT Pretreater Runs FP-32, 33, and 34A	Ohio No. 6 Seam IGT Pretreater Runs FP-32, 33, and 34A
Sieve Size, USS	10/80	10/80
Feed Gas	Hydrogen + Methane + Steam	
Run No.	HT-76	HT-77
Duration of Test, hr	4-1/4	5
Steady-State Operating Period, min[a]	137-259	95-297
OPERATING CONDITIONS		
Bed Height, ft	7.0	7.0
Reactor Pressure, psig	1016	1021
Reactor Temperature, °F		
Bottom	----	1025
11 in.	975	1155
16 in.	1110	1220
21 in.	1235	1275
31-1/2 in.	1240	1275
42 in.	1240	1270
52 in.	1240	1275
62-1/2 in.	1165	1200
73 in.	1090	1125
83 in.	1075	1115
94-1/2 in.	1150	1170
Average	1150	1190
Coal Rate, lb/hr[b]	17.34	16.45
Hydrogen Rate, SCF/hr[c]	294.2	281.5
Steam Rate, lb/hr	7.61	7.67
Steam, mole % of hydrogen-steam mixture	35.2	36.4
Hydrogen/Coal Ratio, % of stoichiometric[d]	27.3	24.8
Hydrogen/Steam Ratio, mole/mole	1.175	1.006
Bed Pressure Differential, in. wc.	29.0	----
Coal Space Velocity, lb/cu ft-hr	28.02	26.58
Hydrogen-Steam Residence Time, min[e]	1.84	1.[illegible]
Superficial Hydrogen-Steam Velocity, ft/sec[f]	0.0632	0.0629

(Continued)

OPERATING RESULTS		
Product Gas Rate, SCF/hr	376.5	417.7
Net Btu Recovery, 1000 Btu/lb	1.594	2.280
Product Gas Yield, SCF/lb	21.71	25.40
Hydrocarbon Yield, SCF/lb	2.44	3.16
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[g]	68.35	83.96
Carbon Oxide Yield, SCF/lb	0.88	1.06
Net Reacted Hydrogen, SCF/lb	3.27	2.92
Residue, lb/lb coal[h]	0.660	0.724
Liquid Products, lb/lb coal[i]	0.537	0.582
Net MAF Coal Hydrogasified, wt %[j]	16.2	20.6
Carbon Gasified, wt %	14.3	17.3
Steam Decomposed, lb/hr[k]	Nil	Nil
Steam Decomposed, % of steam fed[k]	Nil	Nil
Steam Decomposed, % of total equivalent fed[m]	12.5	13.6
Overall Material Balance, %	94.2	99.8
Carbon Balance, %	92.6	103.6
Hydrogen Balance, %	97.8	100.9
Oxygen Balance, %	95.7	99.3

PRODUCT AND FEED GAS PROPERTIES

Gas Composition, mole %	Feed	Product	Feed	Product
Nitrogen	1.5	22.7	1.6	28.5
Carbon Monoxide	0.0	2.4	0.0	2.4
Carbon Dioxide	0.2	1.8	0.2	1.9
Hydrogen	63.8	34.8	57.6	27.3
Methane	31.5	25.7	36.9	37.8
Ethane	2.1	2.4	2.6	1.9
Propane	0.7	0.1	0.8	0.1
Butanes	0.2	0.0	0.3	0.0
Benzene	0.0	0.1	0.0	0.1
Helium	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0
Heating Value, N_2-free, Btu/SCF[n]	586	677	635	715
Specific Gravity (Air = 1.00)	0.274	0.523	0.309	0.582
Nitrogen Purge Rate, SCF/hr	85.4		118.9	

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Hydrogen and methane mixture

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane

e. $\dfrac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

f. $\dfrac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

g. Reactor volume of 0.619 cu ft

h. By ash balance

i. Includes condensed, undecomposed steam

j. $100\left[\dfrac{\text{Wt of Product Gas-Wt Feed Gas in-Wt Decomposed Steam-Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

k. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

m. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

n. Gross – gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

Table 2-A1, Part 6. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: PARTIALLY HYDROGASIFIED OHIO NO. 6 SEAM, BROKEN ARO MINE, BITUMINOUS COAL. HYDROGEN + STEAM FEED GAS (Run HT-81)

Coal	Partially Hydrogasified Bituminous Coal
Source	Ohio No. 6 Seam
Sieve Size, USS	Runs HT-76 and HT-77
Gas Feed	10/80
	Hydrogen + Steam
Run No.	HT-81
Duration of Test, hr	6-1/2
Steady-State Operating Period, min[a]	149-386
OPERATING CONDITIONS	
Bed Height, ft	3.5
Reactor Pressure, psig	992
Reactor Temperatures, °F	
Bottom	----
114 in.	1710
124-1/2 in.	1720
135 in.	1720
145 in.	1710
155-1/2 in.	1695
Average	1710
Coal Rate, lb/hr[b]	13.63
Hydrogen Rate, SCF/hr[c]	188.3
Steam Rate, lb/hr	4.46
Steam, mole % of hydrogen-steam mixture	33.2
Hydrogen/Coal Ratio, % of stoichiometric[c]	29.0
Hydrogen/Steam Ratio, mole/mole	2.011
Bed Pressure Differential, in. wc	16.0
Coal Space Velocity, lb/cu ft-hr	44.04
Hydrogen-Steam Residence Time, min[d]	1.076
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0542

(Continued)

OPERATING RESULTS	
Product Gas Rate, SCF/hr	413.2
Net Btu Recovery, 1000 Btu/lb	4.721
Product Gas Yield, SCF/lb	31.14
Hydrocarbon Yield, SCF/lb	5.39
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[f]	237.3
Carbon Oxides Yield, SCF/lb	2.99
Net Reacted Hydrogen, SCF/lb	4.61
Residue, lb/lb coal[g]	0.694
Liquid Products, lb/lb coal[h]	0.155
Net MAF Coal Hydrogasified, wt %[i]	33.1
Carbon Gasified, %	32.7
Steam Decomposed, lb/hr[j]	2.34
Steam Decomposed, % of steam fed[j]	52.6
Steam Decomposed, % of total equivalent fed[k]	54.2
Overall Material Balance, %	98.6
Carbon Balance, %	99.8
Hydrogen Balance, %	97.5
Oxygen Balance, %	94.9
PRODUCT AND FEED GAS PROPERTIES	
Gas Composition, mole %	
Nitrogen	43.5
Carbon Monoxide	7.5
Carbon Dioxide	2.1
Hydrogen	29.6
Methane	17.3
Total	100.0
Heating Value, N_2-free, Btu/SCF[m]	515
Specific Gravity (Air = 1.00)	0.644
Nitrogen Purge Rate, SCF/hr	184.6

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Percent of the stoichiometric hydrogen/coal ratio – the net feed hydrogen/coal ratio required to convert all the carbon to methane

d. $\dfrac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

e. $\dfrac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

f. Reactor volume of 0.309 cu ft

g. By ash balance

h. Includes condensed, undecomposed steam

i. $100\left[\dfrac{\text{Wt of Product Gas} - \text{Wt Feed Gas in} - \text{Wt Decomposed Steam} - \text{Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor

m. Gross – gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

Table 2-A1, Part 7. MOVING BED HYDROGASIFICATION TEST OPERATING RESULTS: NORTH DAKOTA LIGNITE, GLENHAROLD MINE, HYDROGEN + STEAM FEED GAS (Run HT-135)

Coal	North Dakota Lignite
Source	Glenharold Mine
Sieve Size, USS	10/80
Feed Gas	Hydrogen + Steam
Run No.	HT-135
Duration of Test, hr	7-1/4
Steady-State Operation Period, min[a]	179-356
OPERATING CONDITIONS	
Bed Height, ft	3.5
Reactor Pressure, psig	1001
Reactor Temperature, °F	
72-1/2 in.	1565
84-1/2 in.	1610
96-1/2 in.	1630
Average	1600
Coal Rate, lb/hr[b]	32.37
Feed Gas Rate, SCF/hr[c]	257.5
Steam Rate, lb/hr	12.68
Steam, mole % of hydrogen-steam mixture	50.8
Hydrogen/Coal Ratio, % of stoichiometric[d]	23.3
Hydrogen/Steam Ratio, mole/mole	0.967
Bed Pressure Differential, in. wc	70.0
Coal Space Velocity, lb/cu ft-hr	104.6
Feed Gas Residence Time, min[e]	0.308
Superficial Feed Gas Velocity, ft/sec[f]	0.0947

(Continued)

OPERATING RESULTS	
Product Gas Rate, SCF/hr	874.6
Net Btu Recovery, 1000 Btu/lb	6.809
Product Gas Yield, SCF/lb	27.02
Hydrocarbon Yield, SCF/lb	5.78
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[g]	604.9
Carbon Oxides Yield, SCF/lb	5.46
Net Reacted Hydrogen, SCF/lb	1.17
Residue, lb/lb coal[h]	0.335
Liquid Products, lb/lb coal[i]	0.541
Net MAF Coal Hydrogasified, wt %[j]	74.9
Carbon Gasified, wt %	57.0
Steam Decomposed, lb/hr[k]	Nil
Steam Decomposed, % of steam fed[k]	Nil
Steam Decomposed, % of total equivalent fed[m]	41.4
Overall Material Balance, %	97.7
Carbon Balance, %	99.7
Hydrogen Balance, %	107.1
Oxygen Balance, %	105.9
PRODUCT GAS PROPERTIES	
Gas Composition, mole %	
Nitrogen	33.1
Carbon Monoxide	10.0
Carbon Dioxide	10.2
Hydrogen	25.1
Methane	20.5
Ethane	0.6
Propane	0.3
Butane	0.0
Benzene	0.2
Hydrogen Sulfide	0.0
Total	100.0
Heating Value, N_2-free, Btu/SCF[n]	511
Specific Gravity (Air = 1.00)	0.722
Nitrogen Purge Rate, SCF/hr	289

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed

c. Hydrogen

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane

e. $\dfrac{\text{Coal Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

f. $\dfrac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-Sectional Area of Reactor}}$

g. Reactor volume of 0.309 cu ft

h. By ash balance

i. Includes condensed, undecomposed steam

j. $100\left[\dfrac{\text{Wt of Product Gas-Wt Hydrogen in-Wt Decomposed Steam-Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

k. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor

m. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of the feed char), and the measured liquid water rate leaving the reactor.

n. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure

Table 2-A2, Part 1. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN MOVING BED HYDROGASIFICATION TESTS: CONSOLIDATION COAL COMPANY, BITUMINOUS COAL CHAR, PITTSBURGH SEAM, MONTOUR NO. 10 MINE (Runs HT-42, -43, -44, -46, -47, -50, -51, -52, -53, and -55)

Run No. / Sample	HT-42		HT-43		HT-44		HT-46		HT-47	
	Feed	Residue	Feed	Residue	Feed	Residue	Feed	Residue	Feed	Residue
Proximate Analysis, wt %										
Moisture	1.6	0.6	1.5	1.4	1.9	4.4	1.2	0.7	1.6	0.2
Volatile Matter	15.2	2.3	16.8	1.8	16.6	3.4	16.6	2.1	16.4	0.9
Fixed Carbon	75.4	83.3	74.4	83.9	74.0	80.3	74.9	84.1	74.5	85.6
Ash	7.8	13.8	7.3	12.9	7.5	11.9	7.3	13.1	7.5	13.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %										
Carbon	78.9	83.9	78.9	84.4	78.6	84.6	78.7	83.0	78.3	85.1
Hydrogen	3.07	0.72	3.26	0.81	3.39	1.31	3.29	1.32	3.34	0.60
Nitrogen	1.59	0.40	1.77	0.43	1.74	0.76	1.75	0.79	1.74	0.28
Oxygen	7.71	1.01	7.69	1.22	7.74	0.78	7.92	1.60	8.08	0.65
Sulfur	0.82	0.04	0.92	0.02	0.92	0.15	0.92	0.07	0.89	0.00
Ash	7.91	13.93	7.46	13.12	7.61	12.40	7.42	13.22	7.65	13.37
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Gross Heating Value, Dry Basis, Btu/lb	13,040	12,470	13,070	12,640	----	----	----	----	----	----
Screen Analysis, USS, wt %										
+40	0.0	0.0	3.4	0.3	0.2	0.8	0.3	0.7	0.0	0.1
+60	27.9	5.1	30.4	18.4	36.3	3.4	35.7	15.9	28.4	7.5
+80	30.7	16.2	31.2	32.1	29.8	7.9	29.9	28.9	33.5	30.1
+100	21.4	22.6	20.2	23.5	22.6	13.4	21.0	23.4	23.0	27.8
+140	10.5	24.6	8.9	18.4	7.6	22.7	8.3	19.4	11.1	23.6
+200	3.8	15.4	2.6	5.0	2.1	20.5	2.4	6.3	2.1	7.5
+325	2.7	11.0	1.4	1.8	0.9	20.5	1.4	3.5	0.9	2.7
−325	3.0	5.1	1.9	0.5	0.5	10.8	1.0	1.9	1.0	0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

(Continued)

Run No. / Sample	HT-50 Feed	HT-50 Residue	HT-51 Feed	HT-51 Residue	HT-52 Feed	HT-52 Residue	HT-53 Feed	HT-53 Residue	HT-55 Feed	HT-55 Residue
Proximate Analysis, wt %										
Moisture	1.4	0.8	1.4	8.9	1.2	2.2	1.3	0.5	1.6	1.4
Volatile Matter	17.5	1.6	16.0	1.9	16.4	3.7	17.1	4.0	16.2	4.3
Fixed Carbon	74.2	84.4	72.7	72.0	74.0	81.4	73.2	81.0	74.1	82.3
Ash	6.9	13.2	9.9	17.2	8.4	12.7	8.4	14.5	8.1	12.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %										
Carbon	78.2	84.9	76.0	79.4	77.5	82.5	77.5	81.4	77.7	83.1
Hydrogen	3.49	0.75	3.16	0.72	3.23	1.38	3.18	1.86	3.24	1.82
Nitrogen	1.68	0.49	1.63	0.40	1.71	0.98	1.71	0.81	1.56	1.12
Oxygen	8.79	0.49	8.26	0.54	8.18	1.70	8.20	1.05	8.31	1.41
Sulfur	0.84	0.05	0.88	0.07	0.90	0.43	0.91	0.29	0.94	0.35
Ash	7.00	13.32	10.07	18.87	8.48	13.01	8.50	14.59	8.25	12.20
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Screen Analysis, USS, wt %										
+10	0.0	0.0	0.0	0.0	0.0	0.3	----	----	----	----
+12	1.0	0.2	0.6	0.2	0.9	1.0	----	----	----	----
+16	7.8	2.0	4.7	5.0	5.6	5.1	----	----	----	----
+20	19.4	7.7	13.7	14.0	14.5	12.0	14.4	8.4	14.5	9.4
+30	26.9	15.7	28.2	22.7	25.4	20.2	22.4	15.3	18.2	13.1
+40	25.9	19.1	35.0	26.0	30.4	26.1	28.0	22.8	29.6	22.8
+60	----	----	----	----	----	----	22.6	30.3	27.3	33.2
+80	----	----	----	----	----	----	3.3	6.3	2.2	6.2
+100	15.9	25.4	16.4	27.4	20.7	32.0	1.5	3.1	1.1	3.2
−100	3.1	29.9	1.4	4.7	2.5	3.3	----	----	----	----
+200	----	----	----	----	----	----	4.0	8.6	3.0	6.4
+325	----	----	----	----	----	----	1.5	3.1	1.7	3.0
−325	----	----	----	----	----	----	2.3	2.1	2.4	2.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2-A2, Part 2. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN MOVING BED HYDROGASIFICATION TESTS: PRETREATED PITTSBURGH NO. 8 SEAM, MONTOUR NO. 4 MINE, BITUMINOUS COAL (Run HT-58)

Run No. / Sample	HT-58 Feed	HT-58 Residue
Proximate Analysis, wt %		
Moisture	1.6	0.7
Volatile Matter	28.7	6.7
Fixed Carbon	60.1	77.0
Ash	9.6	15.6
Total	100.0	100.0
Ultimate Analysis (dry), wt %		
Carbon	73.4	78.5
Hydrogen	4.41	2.23
Nitrogen	1.67	1.27
Oxygen	8.52	0.66
Sulfur	2.34	1.67
Ash	9.66	15.67
Total	100.00	100.00
Screen Analysis, USS, wt %		
+20	0.0	20.5
+30	0.0	17.2
+40	0.2	19.0
+60	36.2	22.1
+80	23.2	8.8
+100	13.4	3.3
+200	22.5	7.3
+325	2.5	1.1
−325	2.0	0.7
Total	100.0	100.0

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Table 2-A2, Part 3. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN MOVING BED HYDROGASIFICATION TESTS: PRETREATED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL
(Runs HT-59, -61c, -62, -63, -67, -68, -70, -71, and -78)

Run No. / Sample	HT-59 Feed	HT-59 Residue	HT-61c Feed	HT-61c Residue	HT-62 Feed	HT-62 Residue	HT-63 Feed	HT-63 Residue
Proximate Analysis, wt %								
Moisture	0.7	0.5	1.1	0.6	1.0	0.7	1.1	0.5
Volatile Matter	25.3	2.4	22.9	2.9	26.8	3.5	25.6	2.5
Fixed Carbon	63.2	77.8	61.0	78.9	61.2	77.5	63.3	79.8
Ash	10.8	19.3	15.0	17.6	11.0	18.3	10.0	17.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %								
Carbon	71.4	78.0	68.6	78.2	71.1	76.7	71.7	78.2
Hydrogen	3.94	1.07	3.73	1.26	3.89	1.40	3.93	1.35
Nitrogen	1.43	0.47	1.24	0.72	1.38	0.32	1.55	0.70
Oxygen	8.50	0.68	7.62	0.42	9.14	1.36	9.46	1.26
Sulfur	3.84	0.34	3.67	1.71	3.40	1.74	3.26	1.17
Ash	10.89	19.44	15.14	17.69	11.09	18.48	10.10	17.32
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Screen Analysis, USS, wt %								
+20	19.4	33.0	18.7	18.5	25.4	35.7	21.6	26.1
+30	20.8	20.4	21.0	16.9	23.5	17.6	21.4	21.1
+40	33.1	23.3	33.5	27.3	31.3	19.4	31.3	24.5
+60	24.9	19.1	22.2	26.0	17.6	17.6	23.0	19.4
+80	1.0	2.1	2.0	4.5	0.9	4.0	1.2	3.4
+100	0.1	0.5	0.6	1.4	0.4	1.5	0.2	1.0
+200	0.3	1.0	1.4	3.8	0.4	3.1	0.4	2.6
+325	0.1	0.3	0.2	0.9	0.1	0.4	0.2	0.9
−325	0.3	0.3	0.4	0.7	0.4	0.7	0.7	1.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

(Continued)

Run No. / Sample	HT-67 Feed	HT-67 Residue	HT-68 Feed	HT-68 Residue	HT-70 Feed	HT-70 Residue	HT-71 Feed	HT-71 Residue	HT-78 Feed	HT-78 Residue
Proximate Analysis, wt %										
Moisture	0.5	1.9	0.5	0.6	2.1	1.3	2.1	1.1	1.3	0.9
Volatile Matter	23.7	4.6	23.3	4.6	21.2	3.9	22.6	7.7	24.9	5.0
Fixed Carbon	61.8	73.2	63.5	77.6	63.0	76.0	61.6	72.3	62.4	78.3
Ash	14.0	20.3	12.7	17.2	13.7	18.8	13.7	18.9	11.4	15.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %										
Carbon	70.2	73.7	70.1	76.9	69.0	76.1	68.5	73.0	71.4	78.5
Hydrogen	3.97	1.68	3.70	2.05	3.26	1.68	3.39	2.43	3.83	1.92
Nitrogen	1.36	0.91	1.37	1.01	1.28	0.77	1.08	1.05	1.43	1.06
Oxygen	6.58	0.75	8.30	0.65	9.15	0.33	9.45	1.83	8.11	0.38
Sulfur	3.82	2.27	3.80	2.09	3.34	2.04	3.57	2.59	3.68	2.18
Ash	14.07	20.69	12.73	17.30	13.97	19.08	14.01	19.10	11.55	15.96
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Gross Heating Value, Dry Basis, Btu/lb	----	----	----	----	----	----	11,670	12,080	12,120	12,590
Screen Analysis, USS, wt %										
+ 20	5.3	7.1	24.5	20.9	11.7	8.7	8.6	8.8	12.1	14.3
+ 30	20.0	19.9	22.4	23.4	19.0	19.1	18.8	16.5	18.8	23.6
+ 40	30.9	28.9	21.3	20.9	22.2	23.0	24.6	21.7	22.9	24.1
+ 60	28.6	26.7	19.8	20.3	28.4	26.5	28.3	28.1	24.1	21.5
+ 80	9.5	9.0	7.9	7.7	13.1	12.0	12.4	13.2	9.8	7.4
+ 100	3.1	3.3	2.1	3.0	4.1	5.0	4.1	5.2	4.0	2.9
+ 200	1.4	3.6	1.6	2.8	1.4	4.6	2.4	4.9	5.8	4.4
+ 325	0.3	0.8	0.2	0.7	0.1	0.7	0.3	1.0	1.4	1.0
−325	0.9	0.7	0.2	0.3	0.0	0.4	0.5	0.6	1.1	0.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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Table 2-A2, Part 3, Cont. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN MOVING BED HYDROGASIFICATION TESTS: PRETREATED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL (Runs HT-83, -84, -85, -94, -97, and -98)

Run No. / Sample	HT-83 Feed	HT-83 Residue	HT-84 Feed	HT-84 Residue	HT-85 Feed	HT-85 Residue	HT-94 Feed	HT-94 Residue	HT-97 Feed	HT-97 Residue	HT-98 Feed	HT-98 Residue
Proximate Analysis, wt %												
Moisture	1.0	1.0	1.0	0.8	1.3	0.3	1.3	1.2	1.3	2.3	1.5	0.6
Volatile Matter	23.3	4.2	23.3	3.5	24.0	2.1	15.8	3.6	16.3	5.6	14.5	3.7
Fixed Carbon	62.4	74.9	65.5	79.7	65.5	84.6	68.6	75.7	67.9	73.9	68.3	77.4
Ash	12.4	19.9	10.2	16.0	9.2	13.0	14.3	19.5	14.5	18.2	15.7	18.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %												
Carbon	70.6	76.0	72.8	79.9	73.3	83.8	74.2	78.2	73.9	76.5	73.2	78.2
Hydrogen	3.65	1.37	3.68	1.17	3.86	0.87	2.59	0.93	2.73	1.92	2.29	1.32
Nitrogen	1.04	0.72	1.37	0.74	1.26	0.69	1.06	0.61	1.13	1.00	1.04	0.57
Oxygen	8.45	0.00	8.49	0.20	9.02	0.00	4.97	0.00	4.73	0.00	4.82	0.00
Sulfur	3.63	2.22	3.31	1.88	3.23	1.53	2.70	1.21	2.85	2.09	2.73	1.61
Ash	12.63	20.06	10.35	16.11	9.33	13.12	14.48	19.77	14.66	18.64	15.92	18.45
Total	100.00	100.37	100.00	100.00	100.00	100.01	100.00	100.72	100.00	100.15	100.00	100.15
Screen Analysis, USS, wt %												
+20	10.0	6.1	12.0	7.3	12.3	8.4	11.4	13.8	11.8	14.4	9.3	3.2
+30	16.9	17.8	18.5	21.3	18.5	17.3	12.7	17.9	15.7	19.2	15.7	8.6
+40	20.0	25.7	22.6	30.3	24.5	25.2	23.2	22.2	23.8	21.6	24.3	25.4
+60	22.2	27.9	23.8	27.6	23.4	25.0	26.5	23.3	26.1	23.2	26.9	33.5
+80	10.5	10.3	10.8	7.4	9.1	10.1	11.6	10.0	10.9	9.9	11.1	14.6
+100	5.0	4.2	4.9	2.6	4.2	4.3	5.2	4.6	4.7	4.1	4.9	6.1
+200	9.3	5.7	5.9	2.9	5.6	7.1	6.6	6.0	0.7	0.2	5.9	7.1
+325	3.4	0.6	1.0	0.3	1.1	0.5	1.7	1.4	5.6	6.5	1.2	0.8
−325	2.7	1.7	0.5	0.3	1.3	2.1	1.1	0.8	0.7	0.9	0.7	0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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Table 2-A2, Part 4. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN MOVING BED HYDROGASIFICATION TESTS: PARTIALLY HYDROGASIFIED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL (Runs HT-64, -69, -72, -73, -80, -86, and -87)

Run No.	HT-64		HT-69		HT-72		HT-73	
Sample	Feed	Residue	Feed	Residue	Feed	Residue	Feed	Residue
Proximate Analysis, wt %								
Moisture	0.9	1.1	1.1	0.6	1.3	1.1	2.0	0.6
Volatile Matter	3.9	3.3	4.4	3.3	5.2	1.2	4.2	2.0
Fixed Carbon	75.9	74.1	75.2	71.6	76.6	60.8	75.1	64.0
Ash	19.3	21.5	19.3	24.5	16.9	36.9	18.7	33.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %								
Carbon	76.1	76.0	75.6	72.6	76.9	62.3	76.0	65.6
Hydrogen	1.52	1.23	1.76	1.08	1.85	0.30	1.69	0.43
Nitrogen	0.81	0.27	0.93	0.54	1.10	0.36	1.01	0.41
Oxygen	0.67	0.57	0.00	0.00	0.76	0.00	0.21	0.00
Sulfur	1.44	0.23	2.21	1.24	2.22	2.06	2.02	1.10
Ash	19.46	21.70	19.53	24.62	17.15	37.26	19.07	33.56
Total	100.00	100.00	100.03	100.08	100.00	102.28	100.00	101.10
Gross Heating Value, Dry Basis, Btu/lb	----	----	----	----	12,240	----	11,960	----
Screen Analysis, USS, wt %								
+20	15.7	11.2	6.3	5.0	11.9	4.4	7.7	6.5
+30	19.0	14.6	16.8	14.9	20.0	15.0	17.1	17.7
+40	28.0	25.5	25.0	24.5	23.6	27.2	22.0	25.2
+60	25.5	29.4	29.8	30.2	25.6	32.2	27.8	29.8
+80	4.4	6.1	11.6	12.0	10.3	12.7	12.9	11.6
+100	1.7	2.1	4.5	5.3	4.0	4.7	5.6	4.7
+200	3.7	5.2	4.5	6.1	3.8	3.4	5.8	4.1
+325	0.9	2.3	0.9	1.3	0.6	0.2	0.9	0.3
-325	1.1	3.6	0.6	0.7	0.2	0.2	0.2	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

(Continued)

Run No. / Sample	HT-80 Feed	HT-80 Residue	HT-86 Feed	HT-86 Residue	HT-87 Feed	HT-87 Residue
Proximate Analysis, wt %						
Moisture	1.1	4.6	1.1	0.3	0.9	0.1
Volatile Matter	4.4	1.9	3.7	1.7	2.8	1.0
Fixed Carbon	77.9	69.9	78.9	67.6	82.5	81.3
Ash	16.6	23.6	16.3	30.4	13.8	17.6
Total	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %						
Carbon	78.6	74.7	80.2	68.1	81.5	81.8
Hydrogen	1.55	0.53	1.36	0.58	1.02	0.43
Nitrogen	0.99	0.42	0.74	0.29	0.43	0.32
Oxygen	0.00	0.00	0.00	0.00	1.51	0.00
Sulfur	2.30	1.99	2.03	2.57	1.66	1.40
Ash	16.76	24.73	16.43	30.50	13.88	17.59
Total	100.20	102.37	100.76	102.04	100.00	101.54
Gross Heating Value, Dry Basis, Btu/lb	12,250	11,050	----	----	----	----
Screen Analysis, USS, wt %						
+20	10.1	7.3	7.1	4.0	9.0	5.0
+30	16.8	15.7	13.4	12.6	16.2	11.6
+40	22.6	24.3	21.1	28.2	25.2	21.7
+60	25.3	27.7	24.5	31.2	24.4	26.8
+80	10.6	11.3	11.5	11.1	9.9	13.7
+100	4.5	4.7	5.6	4.4	4.3	7.0
+200	7.0	6.7	10.3	6.1	7.7	12.1
+325	1.8	1.3	4.0	1.3	1.9	1.4
-325	1.3	1.0	2.5	1.1	1.4	0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0

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Table 2-A2, Part 5. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN MOVING BED HYDROGASIFICATION TESTS: PRETREATED OHIO NO. 6 SEAM, BROKEN ARO MINE, BITUMINOUS COAL (Runs HT-76, and -77)

Run No. / Sample	HT-76 Feed	HT-76 Residue	HT-77 Feed	HT-77 Residue
Proximate Analysis, wt %				
Moisture	3.3	1.0	3.3	1.0
Volatile Matter	24.5	6.0	24.5	5.1
Fixed Carbon	64.3	80.8	64.3	82.7
Ash	7.9	12.2	7.9	11.2
Total	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %				
Carbon	73.7	82.0	73.7	83.2
Hydrogen	3.59	2.49	3.59	2.05
Nitrogen	1.49	1.32	1.49	1.29
Oxygen	10.31	0.00	10.31	0.62
Sulfur	2.75	1.90	2.75	1.57
Ash	8.16	12.36	8.16	11.27
Total	100.00	100.07	100.00	100.00
Gross Heating Value, Dry Basis, Btu/lb	12,260	13,167	12,260	13.225
Screen Analysis, USS, wt %				
+20	11.3	20.4	11.3	18.3
+30	22.1	21.4	22.1	20.3
+40	22.0	20.9	22.0	19.7
+60	23.7	20.5	23.7	20.5
+80	10.7	8.1	10.7	9.0
+100	4.9	3.8	4.9	4.4
+200	4.3	4.3	4.3	6.3
+325	0.7	0.4	0.7	1.1
−325	0.3	0.2	0.3	0.4
Total	100.0	100.0	100.0	100.0

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Table 2-A2, Part 6. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN MOVING BED HYDROGASIFICATION TESTS: PARTIALLY HYDROGASIFIED OHIO NO. 6 SEAM, BROKEN ARO MINE, BITUMINOUS COAL (Run HT-81)

Run No. / Sample	HT-81 Feed	HT-81 Residue
Proximate Analysis, wt %		
Moisture	1.4	1.9
Volatile Matter	5.1	1.9
Fixed Carbon	80.1	77.1
Ash	13.4	19.1
Total	100.0	100.0
Ultimate Analysis (dry), wt %		
Carbon	81.2	78.5
Hydrogen	1.88	0.50
Nitrogen	1.14	0.40
Oxygen	0.42	0.00
Sulfur	1.82	1.88
Ash	13.54	19.51
Total	100.00	100.77
Gross Heating Value, Dry Basis, Btu/lb	12,840	11,710
Screen Analysis, USS, wt %		
+20	8.2	5.3
+30	17.9	13.3
+40	24.7	25.1
+60	27.0	28.8
+80	10.7	12.3
+100	4.8	5.5
+200	5.8	8.0
+325	0.7	1.0
−325	0.2	0.7
Total	100.0	100.0

Table 2-A2, Part 7. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN MOVING BED HYDROGASIFICATION TESTS: NORTH DAKOTA LIGNITE, GLENHAROLD MINE (Run HT-135)

Run No. / Sample	HT-135 Feed	HT-135 Residue
Proximate Analysis, wt %		
Moisture	18.2	4.5
Volatile Matter	35.8	13.2
Fixed Carbon	38.7	56.7
Ash	7.3	25.6
Total	100.0	100.0
Ultimate Analysis (dry), wt %		
Carbon	66.2	71.1
Hydrogen	4.03	0.77
Nitrogen	0.94	0.34
Oxygen	19.00	0.08
Sulfur	0.85	0.90
Ash	8.98	26.81
Total	100.00	100.00
Gross Heating Value, Dry Basis, Btu/lb	----	----
Screen Analysis, USS, wt %		
+20	3.1	7.5
+30	26.6	11.1
+40	29.9	29.0
+60	23.7	29.4
+80	10.9	12.8
+100	3.6	4.4
+200	2.0	5.4
+325	0.1	0.2
−325	0.1	0.2
Total	100.0	100.0

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Table 2-A3, Part 1. COMPOSITION OF LIQUID PRODUCTS IN MOVING BED HYDROGASIFICATION TESTS: CONSOLIDATION COAL COMPANY, BITUMINOUS COAL CHAR, PITTSBURGH SEAM, MONTOUR NO. 10 MINE (Runs HT-42, -43, -44, -46, -47, -50, -52, -53, and -55)

Run No.	HT-42	HT-43	HT-44	HT-46	HT-47
Sample	Condenser	Condenser	Condenser	Condenser	Condenser
Liquid Products,[a] lb/lb char	0.415	0.321	0.371	0.339	0.404
Composition of Liquid Products, wt %					
Water	100.0	100.0	100.0	100.0	100.0
Oil	Trace	Trace	Trace	Trace	Trace
Total	100.0	100.0	100.0	100.0	100.0
Composition of Oil Fraction, wt %					
Carbon	----	----	----	----	----
Hydrogen	----	----	----	----	----
Total	----	----	----	----	----
Carbon in Oil Fraction,					
lb/lb char	Trace	Trace	Trace	Trace	Trace
wt % of carbon in char	Trace	Trace	Trace	Trace	Trace

a. Includes condensed undecomposed steam

Run No.	HT-50	HT-51	HT-52	HT-53	HT-55
Sample	Condenser	Condenser	Condenser	Condenser	Condenser
Liquid Products,[a] lb/lb char	0.265	0.167	0.221	0.282	0.495
Composition of Liquid Products, wt %					
Water	100.0	100.0	100.0	100.0	100.0
Oil	Trace	Trace	Trace	Trace	Trace
Total	100.0	100.0	100.0	100.0	100.0
Composition of Oil Fraction, wt %					
Carbon	----	----	----	----	----
Hydrogen	----	----	----	----	----
Total	----	----	----	----	----
Carbon in Oil Fraction,					
lb/lb char	Trace	Trace	Trace	Trace	Trace
wt % of carbon in char	Trace	Trace	Trace	Trace	Trace

a. Includes condensed undecomposed steam

Table 2-A3, Part 2. COMPOSITION OF LIQUID PRODUCTS IN MOVING BED HYDROGASIFICATION TESTS: PRETREATED PITTSBURGH NO. 8 SEAM, MONTOUR NO. 4 MINE, BITUMINOUS COAL (Run HT-58)

Run No.	HT-58
Sample	Condenser
Liquid Products,[a] lb/lb char	0.352
Composition of Liquid Products, wt %	
Water	95.31
Oil	4.61
Total	100.0
Composition of Oil Fraction, wt %	
Carbon	86.1
Hydrogen	7.28
Total	93.38
Carbon in Oil Fraction, lb/lb char	0.0142
wt % of carbon in char	2.00

a. Includes condensed undecomposed steam

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Table 2-A3, Part 3. COMPOSITION OF LIQUID PRODUCTS IN MOVING BED HYDROGASIFICATION TESTS: PRETREATED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL (Runs HT-59, -61c, -62, -63, -67, -68, -70, -71, and -78)

Run No.	HT-59	HT-61c	HT-62	HT-63
Sample	Condenser	Condenser	Condenser	Condenser
Liquid Products,[a] lb/lb coal	0.708	0.734	0.544	0.652
Composition of Liquid Products, wt %				
Water	94.39	92.98	90.36	90.43
Oil	5.61	7.02	9.64	9.57
Total	100.00	100.00	100.00	100.00
Composition of Oil Fraction, wt %				
Carbon	87.8	92.0	87.5	88.2
Hydrogen	6.89	6.50	7.13	7.05
Total	94.69	98.50	94.63	95.25
Carbon in Oil Fraction, lb/lb coal	0.0349	0.0450	0.0463	0.0551
wt % of carbon in coal	4.88	6.56	6.51	7.68

a. Includes condensed undecomposed steam

Run No.	HT-67	HT-68	HT-70	HT-71	HT-78
Sample	Condenser	Condenser	Condenser	Condenser	Condenser
Liquid Products,[a] lb/lb coal	0.648	0.688	0.521	0.554	0.538
Composition of Liquid Products, wt %					
Water	93.26	94.58	96.88	94.79	92.02
Oil	6.74	5.42	3.12	5.21	7.98
Total	100.00	100.00	100.00	100.00	100.00
Composition of Oil Fraction, wt %					
Carbon	87.6	87.8	87.7	85.5	85.2
Hydrogen	6.66	6.31	6.17	6.25	6.49
Total	94.26	94.11	93.87	91.75	91.69
Carbon in Oil Fraction, lb/lb coal	0.0383	0.0327	0.0143	0.0247	0.0365
wt % of carbon in coal	5.45	4.67	1.48	2.58	5.12

a. Includes condensed undecomposed steam

Table 2-A3, Part 3, Cont. COMPOSITION OF LIQUID PRODUCTS IN MOVING BED HYDROGASIFICATION TESTS: PRETREATED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL (Runs HT-83, -84, -85, -94, -97, and -98)

Run No.	HT-83	HT-84	HT-85	HT-94	HT-97	HT-98
Sample	Condenser	Condenser	Condenser	Condenser	Condenser	Condenser
Liquid Products,[a] lb/lb coal	0.330	0.235	0.1137	0.373	0.417	0.379
Composition of Liquid Products, wt %						
Water	96.26	92.30	89.84	96.40	96.20	95.28
Oil	3.74	7.70	10.16	3.60	3.80	4.72
Total	100.00	100.00	100.00	100.00	100.00	100.00
Composition of Oil Fraction, wt %						
Carbon	84.8	87.4	86.4	86.9	84.3	82.1
Hydrogen	6.57	6.18	6.93	7.76	6.65	6.15
Total	91.37	93.58	93.33	94.66	90.95	88.25
Carbon in Oil Fraction, lb/lb coal	0.01045	0.0158	0.00998	0.0117	0.01336	0.01468
wt % of carbon in coal	1.48	2.17	1.36	1.58	1.81	2.00

a. Includes condensed, undecomposed steam

Table 2-A3, Part 4. COMPOSITION OF LIQUID PRODUCTS IN MOVING BED HYDROGASIFICATION TESTS: PARTIALLY HYDROGASIFIED PITTSBURGH SEAM, IRELAND MINE, BITUMINOUS COAL (Runs HT-64, -69, -72, -73, -80, -86, and -87)

Run No.	HT-64	HT-69	HT-72	HT-73
Sample	Condenser	Condenser	Condenser	Condenser
Liquid Products,[a] lb/lb coal	1.198	1.565	0.119	0.0774
Composition of Liquid Products, wt %				
Water	97.0	100.0	100.00	100.00
Oil	3.0	Trace	----	----
Total	100.0	100.0	100.00	100.00
Composition of Oil Fraction, wt %				
Carbon	85.0	----	----	----
Hydrogen	6.5	----	----	----
Total	91.5	----	----	----
Carbon in Oil Fraction, lb/lb coal	0.0305	----	----	----
wt % of carbon in coal	4.01	----	----	----

a. Includes condensed undecomposed steam

Run No.	HT-80	HT-86	HT-87
Sample	Condenser	Condenser	Condenser
Liquid Products,[a] lb/lb coal	0.194	0.1764	0.1041
Composition of Liquid Products, wt %			
Water	100.0	100.00	100.00
Oil	0.0	----	----
Total	100.0	100.00	100.00
Composition of Oil Fraction, wt %			
Carbon	----	----	----
Hydrogen	----	----	----
Total	----	----	----
Carbon in Oil Fraction, lb/lb coal	----	----	----
wt % of carbon in coal	----	----	----

a. Includes condensed undecomposed steam

Table 2-A3, Part 5. COMPOSITION OF LIQUID PRODUCTS IN MOVING BED HYDROGASIFICATION TESTS: PRETREATED OHIO NO. 6 SEAM, BROKEN ARO MINE, BITUMINOUS COAL (Runs HT-76, and -77)

Run No.	HT-76	HT-77
Sample	Condenser	Condenser
Liquid Products,[a] lb/lb coal	0.537	0.582
Composition of Liquid Products, wt %		
Water	96.00	91.54
Oil	4.00	8.46
Total	100.00	100.00
Composition of Oil Fraction, wt %		
Carbon	86.7	86.4
Hydrogen	6.39	6.51
Total	93.09	92.91
Carbon in Oil Fraction, lb/lb coal	0.0186	0.0425
wt % of carbon in coal	2.53	5.77

a. Includes condensed, undecomposed steam

Table 2-A3, Part 6. COMPOSITION OF LIQUID PRODUCTS IN MOVING BED HYDROGASIFICATION TESTS: PARTIALLY HYDROGASIFIED OHIO NO. 6 SEAM, BROKEN ARO MINE, BITUMINOUS COAL (Run HT-81)

Run No.	HT-81
Sample	Condenser
Liquid Products,[a] lb/lb coal	0.155
Composition of Liquid Products, wt %	
Water	100.0
Oil	0.0
Total	100.0
Composition of Oil Fraction, wt %	
Carbon	----
Hydrogen	----
Total	----
Carbon in Oil Fraction, lb/lb coal	----
wt % of carbon in coal	----

a. Includes condensed, undecomposed steam

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Table 2-A3, Part 7. COMPOSITION OF LIQUID PRODUCTS IN MOVING BED HYDROGASIFICATION TESTS: NORTH DAKOTA LIGNITE. GLENHAROLD MINE (Run HT-135)

Run No.	HT-135
Sample	Condenser
Liquid Products,[a] lb/lb coal	0.541
Composition of Liquid Products, wt %	
Water	89.6
Oil	10.4
Total	100.0
Composition of Oil Fraction, wt %	
Carbon	79.8
Hydrogen	7.26
Total	87.06
Carbon in Oil Fraction, lb/lb coal	0.0448
wt % of carbon in coal	6.76

a. Includes condensed, undecomposed steam

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Table 2-A4, Part 1. FREE-FALL HYDROGASIFICATION AND CARBONIZATION TEST OPERATING RESULTS: CONSOLIDATION COAL COMPANY, BITUMINOUS COAL CHAR, PITTSBURGH SEAM, MONTOUR NO. 10 MINE, HYDROGEN + STEAM FEED GAS (Run HT-48)

Coal	Bituminous Coal Char
Source	Consolidation Coal Co.
Sieve Size, USS	35/80
Feed Gas	Hydrogen + Steam
Run No.	HT-48
Duration of Test, hr	6-1/4
Steady-State Operating Period, min[a]	183-390
OPERATING CONDITIONS	
Bed Height, ft	Free-fall
Reactor Pressure, psig	1010
Reactor Temperatures, °F	
Bottom	860
10-1/4 in.	1710
20-3/4 in.	1585
31 in.	1685
41-1/4 in.	1330
51-3/4 in.	1740
62 in.	1740
72-1/4 in.	1740
93 in.	1740
103-1/4 in.	1745
113-3/4 in.	1740
124 in.	1740
134-1/4 in.	1730
155 in.	1720
165-1/4 in.	1685
175-3/4 in.	1670
186 in.	1765
196-1/4 in.	1660
Average	1645
Coal Rate, lb/hr[b]	18.16
Hydrogen Rate, SCF/hr	336.0
Steam Rate, lb/hr	7.16
Steam, mole % of hydrogen-steam mixture	32.1
Hydrogen/Coal Ratio, % of stoichiometric[c]	77.7
Hydrogen/Steam Ratio, mole/mole	2.232
Bed Pressure Differential, in. wc	0.0
Coal Space Velocity, lb/cu ft-hr	6.357
Hydrogen-Steam Residence Time, min[d]	7.10
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0890

(Continued)

OPERATING RESULTS	
Product Gas Rate, SCF/hr	441.7
Net Btu Recovery, 1000 Btu/lb	4.271
Product Gas Yield, SCF/lb	43.46
Hydrocarbon Yield, SCF/lb	4.69
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[f]	29.84
Carbon Oxide Yield, SCF/lb	0.869
Net Reacted Hydrogen, SCF/lb	2.115
Residue, lb/lb coal[g]	0.708
Liquid Products, lb/lb coal[h]	0.729
Net MAF Coal Hydrogasified, wt %[i]	20.6
Carbon Gasified, wt %	24.8
Steam Decomposed, lb/hr[j]	nil
Steam Decomposed, % of steam fed[j]	nil
Steam Decomposed, % of total equivalent fed[k]	6.85
Overall Material Balance, %	96.5
Carbon Balance, %	101.6
Hydrogen Balance, %	105.2
Oxygen Balance, %	97.3

PRODUCT GAS PROPERTIES	
Gas Composition, mole %	
N_2	16.0
CO	1.4
CO_2	0.6
H_2	71.2
CH_4	10.8
Total	100.0
Heating Value, N_2-free, Btu/SCF[m]	404
Specific Gravity (Air = 1.00)	0.288
Nitrogen Purge Rate, SCF/hr	81.2

a. From start of coal feed.

b. Operating conditions and results based on weight of dry feed.

c. Percent of the stoichiometric hydrogen/char ratio — the net feed hydrogen/char ratio required to convert all the carbon to methane.

d. $\frac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

e. $\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-sectional Area of Reactor}}$

f. Reactor volume of 1.598 cu ft.

g. By weight of residue recovered.

h. Includes condensed undecomposed steam.

i. $100\left[\frac{\text{Wt of Product Gas - Wt Hydrogen in - Wt Decomposed Steam}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor.

m. Gross, gas saturated at 60°F, 30 in. Hg pressure. SCF-dry gas volume in SCF at 60°F, 30 in. Hg pressure.

Table 2-A4, Part 2. FREE-FALL HYDROGASIFICATION AND CARBONIZATION TEST RESULTS: PRETREATED PITTSBURGH NO. 8 SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN FEED GAS (Run HT-60)

Coal	Ireland Bituminous Coal IGT Pretreated
Source	
Sieve Size, USS	10/40
Feed Gas	Hydrogen
Run No.	HT-60
Duration of Test, hr	7-1/2
Steady-State Operating Period, min[a]	80—447
OPERATING CONDITIONS	
Bed Height, ft	Free-fall
Reactor Pressure, psig	1025
Reactor Temperatures, °F	
Bottom	950
11 in.	1220
16 in.	1350
21 in.	1375
31-1/2	1320
42 in.	1265
52 in.	1380
62-1/2 in.	1430
73 in.	1440
83 in.	1440
94-1/2 in.	1420
104 in.	1410
114 in.	1390
124-1/2 in.	1365
135 in.	1335
145 in.	1310
155-1/2 in.	1285
166 in.	1300
176 in.	1150
187-1/4 in.	1110
197 in.	1090
207 in.	1080
217-1/2 in.	870
Average	1275
Coal Rate, lb/hr[b]	10.49
Hydrogen Rate, SCF/hr	309.0
Steam Rate, lb/hr	----
Steam, mole % of hydrogen-steam mixture	----
Hydrogen/Coal Ratio, % of stoichiometric[c]	78.9
Hydrogen/Steam Ratio, mole/mole	----
Bed Pressure Differential, in. wc	----
Coal Space Velocity, lb/cu ft-hr	6.56
Hydrogen-Steam Residence Time, min[d]	6.57
Superficial Hydrogen-Steam Velocity, ft/sec[e]	0.0459

(Continued)

OPERATING RESULTS	
Product Gas Rate, SCF/hr	448.5
Net Btu Recovery, 1000 Btu/lb	1.118
Product Gas Yield, SCF/lb	42.76
Hydrocarbon Yield, SCF/lb	3.16
Gaseous Hydrocarbon Space Time Yield, SCF/cu ft-hr[f]	20.7
Carbon Oxide Yield, SCF/lb	0.556
Net Reacted Hydrogen, SCF/lb	8.30
Residue, lb/lb coal[g]	0.744
Liquid Products, lb/lb coal[h]	0.1259
Net MAF Coal Hydrogasified, wt %[i]	22.7
Carbon Gasified, wt %	20.0
Steam Decomposed, lb/hr[j]	----
Steam Decomposed, % of steam fed[j]	----
Steam Decomposed, % of total equivalent fed[k]	----
Overall Material Balance, %	102.5
Carbon Balance, %	99.2
Hydrogen Balance, %	95.1
Oxygen Balance, %	106.0

PRODUCT GAS PROPERTIES	
Gas Composition, mole %	
N_2	41.8
CO	1.0
CO_2	0.3
H_2	49.5
CH_4	6.6
C_2H_6	0.5
C_3H_8	0.1
Benzene	0.2
Total	100.0
Heating Value, N_2-free, Btu/SCF[m]	422
Specific Gravity (Air = 1.00)	0.504
Nitrogen Purge Rate, SCF/hr	183.0

a. From start of coal feed

b. Operating conditions and results based on weight of dry feed.

c. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane.

d. $$\frac{\text{Char Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$$

e. $$\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-sectional Area of Reactor}}$$

f. Reactor volume of 1.598 cu ft.

g. By ash balance.

h. Includes condensed undecomposed steam.

i. $$100\left[\frac{\text{Wt of Product Gas - Wt Hydrogen in - Wt Decomposed Steam - Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$$

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor.

m. Gross, gas saturated at 60°F, 30 in. Hg pressure. SCF – dry gas volume in SCF at 60°F, 30 in. Hg pressure.

n. Pretreated in Run FP-22.

Table 2-A4, Part 3. FREE-FALL HYDROGASIFICATION AND CARBONIZATION TEST RESULTS: PRE-TREATED SEWELL SEAM, LOCHGELLY NO. 2 MINE, WEST VIRGINIA LOW-VOLATILE CONTENT BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Run HT-165)

Coal	West Virginia Sewell Seam Bituminous Coal	
Source	IGT Pretreater Runs FP-115 and FP-116	
Sieve Size, USS	10/80	
Feed Gas	Hydrogen + Steam	
Run No.	HT-165	
	A	B
Part of Run	3	3
Duration of Test, hr	117-184	217-365
Steady-State Operating Period, min[a]		
OPERATING CONDITIONS		
Bed Height, ft	Free-fall[n]	2.0[q]
Reactor Pressure, psig	981	988
Reactor Temperature, °F[b]		
31-1/2 in.	1105	1170
36-3/4 in.	----	----
42 in.	1225	1325
47 in.	1445	1530
52 in.	1580	1635
57-1/4 in.	1605	1660
62-1/2 in.	1635	1690
67-3/4 in.	1670	1710
73 in.	1700	1705
78-1/4 in.	1670	1680
83-1/2 in.	1670	1670
89 in.	1670	1685
94-1/2 in.	1695	1680
100 in.	1710	1715
104 in.	1720	1715
114 in.	1710	1705
124-1/2	1600	1605
135 in.	1665	1660
145 in.	1580	1580
155-1/2 in.	1560	1560
166 in.	1515	1515
176 in.	1500	1495
187-1/2 in.	1395	1405
197 in.	1460	1465
207 in.	1460	1460
217-1/2 in.	1350	1355
Average	1555	1575
Coal Rate, lb/hr[c]	44.64	44.64
Feed Gas Rate, SCF/hr	531.6	522.5
Steam Rate, lb/hr	25.83	25.44
Steam, mole % of hydrogen-steam mixture	50.5	50.6
Hydrogen/Coal Ratio, % of stoichiometric[d]	24.8	24.4
Hydrogen/Steam Ratio, mole/mole	0.979	0.977
Bed Pressure Differential, in. wc	----	136.0
Coal Space Velocity, lb/cu ft-hr	32.58[p]	252.5
Feed Gas Residence Time, min[e]	1.333[p]	0.174
Superficial Feed Gas Velocity, ft/sec[f]	0.194	0.191

(Continued)

OPERATING RESULTS		
Product Gas Rate, SCF/hr	940.9	1032.3
Net Btu Recovery, 1000 Btu/lb	2.546	4.072
Product Gas Yield, SCF/lb	21.08	23.13
Hydrocarbon Yield, SCF/lb	2.80	3.91
Carbon Oxides Yield, SCF/lb	0.906	1.69
Net Reacted Hydrogen, SCF/lb	2.42	1.76
Residue, lb/lb coal[g]	0.743	0.757
Liquid Products, lb/lb coal[h]	0.530	0.511
Net MAF Coal Hydrogasified, wt %[i]	15.65	27.41
Carbon Gasified, wt %	15.43	22.60
Steam Decomposed, lb/hr[j]	2.706	2.630
Steam Decomposed, % of steam fed	10.47	10.34
Steam Decomposed, % of total equivalent fed[k]	21.64	21.67
Overall Material Balance, %	95.5	100.8
Carbon Balance, %	96.1	103.7
Hydrogen Balance, %	93.0	103.1
Oxygen Balance, %	90.6	98.1
PRODUCT GAS PROPERTIES		
Gas Composition, mole %		
Nitrogen	37.1	32.5
Carbon Monoxide	3.0	4.9
Carbon Dioxide	1.3	2.4
Hydrogen	45.0	43.0
Methane	13.0	16.6
Ethane	0.3	0.3
Propane	0.0	0.0
Butane	0.0	0.0
Benzene	0.3	0.3
Hydrogen Sulfide	0.0	0.0
Total	100.0	100.0
Heating Value, N_2-free, Btu/SEC[m]	475	496
Specific Gravity (Air = 1.00)	0.524	0.533
Nitrogen Purge Rate, SCF/hr	343	336

a. From start of coal feed.

b. Tube wall temperatures.

c. Operating conditions and results based on weight of dry feed.

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane.

e. Coal bed volume/(CF/min feed gas at reactor pressure and temperature).

f. (CF/sec feed gas at reactor pressure and temperature)/ cross-sectional area of reactor.

g. By ash balance.

h. Includes condensed, undecomposed steam.

i. 100 (wt of product gas-wt hydrogen in-wt decomposed steam-wt nitrogen in/wt of moisture-, ash-free coal).

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char) and the measured liquid water rate leaving the reactor.

m. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure.

n. Free-fall length of 15.5 ft.

p. Based on 1.3702 cu ft free-fall volume.

q. Bottom of bed 31 in. above furnace bottom.

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Table 2-A4, Part 4. FREE-FALL HYDROGASIFICATION AND CARBONIZATION TEST RESULTS: PRETREATED POCAHONTAS NO. 4 SEAM, LOW-VOLATILE CONTENT BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Run HT-167)

Coal	Pocahontas No. 4 Seam Bituminous Coal
Source	IGT Pretreater Run FP-96
Sieve Size, USS	10/80
Feed Gas	Hydrogen + Steam
Run No.	HT-167
Duration of Test, hr	4-1/2
Steady-State Operating Period, min[a]	176-229
OPERATING CONDITIONS	
Bed Height, ft	Free-fall[n]
Reactor Pressure, psig	995
Reactor Temperature, °F[b]	
31-1/2 in.	1205
36-3/4 in.	----
42 in.	1305
47 in.	1520
52 in.	1625
57-1/4 in.	1640
62-1/2 in.	1650
67-3/4 in.	1680
73 in.	1700
78-1/4 in.	1680
83-1/2 in.	1665
89 in.	1675
94-1/2 in.	1685
100 in.	1700
104 in.	1700
114 in.	1695
124-1/2 in.	1580
135 in.	1650
145 in.	1570
155-1/2 in.	1555
166 in.	1560
176 in.	1500
187-1/2 in.	1410
197 in.	1470
207 in.	1450
217-1/2 in.	1360
Average	1570
Coal Rate, lb/hr[c]	36.29
Feed Gas Rate, SCR/hr	529.6
Steam Rate, lb/hr	25.30
Steam, mole % of hydrogen-steam mixture	50.1
Hydrogen/Coal Ratio, % of stoichiometric[d]	29.4
Hydrogen/Steam Ratio, mole/mole	0.996
Bed Pressure Differential, in. wc	----[p]
Coal Space Velocity, lb/cu ft-hr	26.48[p]
Feed Gas Residence Time, min[e]	1.360[p]
Superficial Feed Gas Velocity, ft/sec[f]	0.190

(Continued)

OPERATING RESULTS	
Product Gas Rate, SCF/hr	961.2
Net Btu Recovery, 1000 Btu/lb	2.618
Product Gas Yield, SCF/lb	26.49
Hydrocarbon Yield, SCF/lb	2.73
Carbon Oxides Yield, SCF/lb	0.689
Net Reacted Hydrogen, SCF/lb	1.67
Residue, lb/lb coal[g]	0.767
Liquid Products, lb/lb coal[h]	0.725
Net MAF Coal Hydrogasified, wt %[i]	19.48
Carbon Gasified, wt %[i]	14.09
Steam Decomposed, lb/hr[j]	Nil
Steam Decomposed, % of steam fed	Nil
Steam Decomposed, % of total equivalent fed[k]	6.95
Overall Material Balance, %	99.2
Carbon Balance, %	93.0
Hydrogen Balance, %	107.9
Oxygen Balance, %	102.5

PRODUCT GAS PROPERTIES	
Gas Composition, mole %	
Nitrogen	38.1
Carbon Monoxide	1.8
Carbon Dioxide	0.8
Hydrogen	48.8
Methane	10.1
Ethane	0.2
Propane	0.0
Butane	0.0
Benzene	0.2
Hydrogen Sulfide	0.0
Total	100.0
Heating Value, N_2-free, Btu/SCF[m]	441
Specific Gravity (Air = 1.00)	0.497
Nitrogen Purge Rate, SCF/hr	366

a. From start of coal feed.

b. Tube wall temperatures.

c. Operating conditions and results based on weight of dry feed.

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane.

e. Coal bed volume/(CF/min feed gas at reactor pressure and temperature).

f. (CF/sec feed gas at reactor pressure and temperature)/cross-sectional area of reactor.

g. By ash balance.

h. Includes condensed, undecomposed steam.

i. 100 (wt of product gas-wt hydrogen in-wt decomposed steam-wt nitrogen in/wt of moisture-, ash-free coal).

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char) and the measured liquid water rate leaving the reactor.

m. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure.

n. Free-fall length of 15.5 ft.

p. Based on 1.3702 cu ft free-fall volume.

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Table 2-A4, Part 5. FREE-FALL HYDROGASIFICATION AND CARBONIZATION TEST RESULTS: COLORADO SUBBITUMINOUS COAL, LARAMIE NO. 3 SEAM, EAGLE MINE, HYDROGEN + STEAM FEED GAS (Runs HT-179, and -183)

Coal	Colorado Subbituminous Coal		Colorado Subbituminous Coal
Source	Laramie No. 3 Seam, Eagle Mine		Laramie No. 3 Seam, Eagle Mine
Sieve Size, USS	10/80		10/80
Feed Gas	Hydrogen + Steam		
Run No.	HT-179		HT-183
	A	B	
Duration of Test, hr	3	3	3
Steady-State Operating Period, min[a]	74-141	191-349	113-182
OPERATING CONDITIONS			
Bed Height, ft	Free-fall[p]	Free-fall[p]	Free-fall[p]
Reactor Pressure, psig	1030	1037	1035
Reactor Temperature, °F[b]			
31-1/2 in.	845	875	----
36-3/4 in.	----	----	----
42 in.	950	1090	870
47 in.	1285	1455	1225
52 in.	1450	1565	1310
57-1/4 in.	----	----	----
62-1/2 in.	1570	1550	1295
67-3/4 in.	1655	1655	1385
73 in.	1700	1695	1585
78-1/4 in.	1680	1680	1745
83-1/2 in.	1680	1675	1725
89 in.	1700	1695	1735
94-1/2 in.	1650	1660	1665
100 in.	1705	1710	1720
104 in.	1705	1710	1710
114 in.	1675	1685	1710
124-1/2 in.	1515	1545	1630
135 in.	1595	1590	1720
145 in.	1500	1490	----
155-1/2	1485	1405	1580
166 in.	1395	1305	1475
176 in.	1345	1290	1425
187-1/2 in.	1230	1195	1295
197 in.	1255	1245	1290
207 in.	1195	1200	1225
217-1/2 in.	1135	1155	1210
Average	1455	1465	1480
Coal Rate, lb/hr[c]	28.90	54.46	39.99
Feed Gas Rate, SCF/hr[d]	507.4	715.7	487.2
Steam Rate, lb/hr	15.28	15.18	25.12
Steam, mole % of hydrogen-steam mixture	37.9	30.7	52.0
Hydrogen/Coal Ratio, % of stoichiometric[e]	47.2	35.3	33.4
Hydrogen/Steam Ratio, mole/mole	1.580	2.245	0.923
Bed Pressure Differential, in. wc	----	----	----
Coal Space Velocity, lb/cu ft-hr	21.09[q]	39.74[q]	29.18[q]
Feed Gas Residence Time, min[f]	1.909[q]	1.533[q]	1.546[q]
Superficial Feed Gas Velocity, ft/sec[g]	0.135	0.169	0.167

(Continued)

OPERATING RESULTS			
Product Gas Rate, SCF/hr	992.0	1166.7	1093.6
Net Btu Recovery, 1000 Btu/lb	4.431	3.544	5.213
Product Gas Yield, SCF/lb	34.31	21.42	27.35
Hydrocarbon Yield, SCF/lb	4.29	3.94	4.46
Carbon Oxides Yield, SCF/lb	1.68	1.67	2.65
Net Reacted Hydrogen, SCF/lb	2.63	4.02	0.971
Residue, lb/lb coal[h]	0.592	0.612	0.518
Liquid Products, lb/lb coal[i]	0.608	0.412	0.703
Net MAF Coal Hydrogasified, wt %[j]	38.8	35.3	50.0
Carbon Gasified, wt %	29.3	27.7	34.1
Steam Decomposed, lb/hr[k]	Nil	Nil	Nil
Steam Decomposed, % of steam fed	Nil	Nil	Nil
Steam Decomposed, % of total equivalent fed[m]	19.1	24.6	19.8
Overall Material Balance, %	100.1	102.3	104.5
Carbon Balance, %	100.8	105.0	100.8
Hydrogen Balance, %	100.3	95.5	98.9
Oxygen Balance, %	99.1	103.1	103.1
PRODUCT GAS PROPERTIES			
Gas Composition, mole %			
Nitrogen	38.8	30.9	32.7
Carbon Monoxide	2.5	4.0	4.8
Carbon Dioxide	2.4	3.8	4.9
Hydrogen	43.5	42.6	41.0
Methane	11.5	16.8	15.2
Ethane	0.8	1.2	0.9
Propane	0.2	0.4	0.2
Butane	0.0	0.0	---
Benzene	0.3	0.3	0.3
Hydrogen Sulfide	0.0	0.0	---
Total	100.0	100.0	100.0
Heating Value, N_2-free, Btu/SCF[n]	477	518	490
Specific Gravity (Air = 1.00)	0.552	0.547	0.573
Nitrogen Purge Rate, SCF/hr	385	361	358

a. From start of coal feed.

b. Tube wall temperatures. Bottom of coal bed at 62 in. in Run HT-179.

c. Operating conditions and results based on weight of dry feed.

d. Hydrogen

e. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane.

f. Coal bed volume/(CF/min feed gas at reactor pressure and temperature).

g. (CF/sec feed gas at reactor pressure and temperature)/cross-sectional area of reactor.

h. By ash balance.

i. Includes condensed, undecomposed steam.

j. 100 (wt of product gas-wt hydrogen in-wt decomposed steam-wt nitrogen in/wt of moisture-, ash-free coal).

k. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

m. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char and bound water corresponding to oxygen content of feed char) and the measured liquid water rate leaving the reactor.

n. Gross, gas saturated at 60°F, 30-in.-Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in.-Hg pressure.

p. Free-fall length of 15.5 ft.

q. Based on 1.3702 cu ft free-fall volume.

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Table 2-A4, Part 6. FREE-FALL HYDROGASIFICATION AND CARBONIZATION TEST RESULTS: MONTANA LIGNITE, SAVAGE MINE, CARBONIZATION, NO FEED GAS (Run HT-229)

Coal	Montana Lignite
Source	Savage Mine
Sieve Size, USS	10/80
Feed Gas	None
Run No.	HT-229
Duration of Test, hr	4-3/4
Steady-State Operating Period, min[a]	34-288
OPERATING CONDITIONS	
Bed Height, ft	Free-fall
Reactor Pressure, psig	1004
Reactor Temperature, °F[b]	
Inches From Bottom	
62-1/2	840
67-3/4	1255
73	1410
78-1/4	1490
83-1/2	1540
89	1525
94-1/2	1520
100	1510
104	1425
114	1485
124-1/2	1340
135	1365
145	1305
155-1/2	1250
166	1210
176	1105
187-1/2	1040
197	1010
207	970
217-1/2	890
Average	1275
Lignite Rate, lb/hr[c]	21.24
Sweep Nitrogen Rate, SCF/hr	294.0
Superficial Sweep Nitrogen Velocity, ft/s[d]	0.0446
Lignite Space Velocity, lb/cu ft-hr[c]	15.50

(Continued)

OPERATING RESULTS	
Product Gas Rate (nitrogen-free), SCF/hr	67.59
Net Btu Recovery, 1000 Btu/lb	1.537
Product Gas Yield, SCF/lb	3.183
Hydrocarbon Yield, SCF/lb	0.923
Carbon Oxides Yield, SCF/lb	1.808
Residue, lb/lb lignite[f]	0.628
Liquid Products, lb/lb lignite	
Water	0.0861
Oil	0.0432
Net MAF Lignite Gasified, wt %[g]	26.34
Carbon Gasified, wt %	15.22
Overall Material Balance, %	99.4
Carbon Balance, %	95.5
Hydrogen Balance, %	99.1
Oxygen Balance, %	108.5
PRODUCT GAS PROPERTIES	
Gas Composition (nitrogen-free), mole %	
Carbon Monoxide	19.7
Carbon Dioxide	37.1
Hydrogen	13.2
Methane	24.6
Ethane	3.0
Propane	1.4
Benzene	1.0
Total	100.0
Heating Value, N_2-free, Btu/SCF[h]	475
Specific Gravity (Air = 1.00)	0.983
Nitrogen Purge Rate, SCF/hr	135.5

a. From start of lignite feed.

b. Tube wall temperatures. Heated reactor length of 15.5 ft. Sweep nitrogen inlet at 62-in. level.

c. Operating conditions and results based on weight of dry feed.

d. (CF/s sweep nitrogen at reactor pressure and temperature)/cross-sectional area of reactor.

e. Based on 1.3702-cu-ft heated reactor volume.

f. By weight of residue recovered.

g. 100 (wt product gas/wt of moisture-, ash-free lignite).

h. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure.

Table 2-A4, Part 7. FREE-FALL HYDROGASIFICATION AND CARBONIZATION TEST RESULTS: NORTH DAKOTA LIGNITE, GLENHAROLD MINE, CARBONIZATION, NO FEED GAS (Run HT-234)

Coal	North Dakota Lignite
Source	Glenharold Mine
Sieve Size, USS	10/80
Feed Gas	None
Run No.	HT-234
Duration of Test, hr	3-1/4
Steady-State Operating Period, min[a]	134-212
OPERATING CONDITIONS	
Bed Height, ft	Free-fall
Reactor Pressure, psig	282
Reactor Temperature, °F[b]	
Inches From Bottom	
62-1/2	955
67-3/4	1200
73	1280
78-1/4	1310
83-1/2	1380
89	1265
94-1/2	1190
100	1400
104	1300
114	1400
124-1/2	1265
135	1430
145	1280
155-1/2	1420
166	1425
176	1310
187-1/2	1360
197	1355
207	1255
217-1/2	1060
Average	1290
Lignite Rate, lb/hr[c]	19.68
Sweep Nitrogen Rate, SCF/hr	185.1
Superficial Sweep Nitrogen Velocity, ft/s[d]	0.0975
Lignite Space Velocity, lb/cu ft-hr[e]	14.37

(Continued)

OPERATING RESULTS	
Product-Gas Rate (nitrogen-free), SCF/hr	59.59
Net Btu Recovery, 1000 Btu/lb	1.404
Product-Gas Yield, SCF/lb	3.027
Hydrocarbon Yield, SCF/lb	0.902
Carbon Oxides Yield, SCF/lb	1.659
Residue, lb/lb lignite[f]	0.728
Liquid Products, lb/lb lignite	
Water	0.0711
Oil	0.0191
Net MAF Lignite Gasified, wt %[g]	24.48
Carbon Gasified, wt %	13.68
Overall Material Balance, %	103.1
Carbon Balance, %	104.3
Hydrogen Balance, %	89.3
Oxygen Balance, %	102.7
PRODUCT GAS PROPERTIES	
Gas Composition (nitrogen-free), mole %	
Carbon Monoxide	14.3
Carbon Dioxide	40.5
Hydrogen	15.4
Methane	25.0
Ethane	1.2
Propane	3.6
Benzene	Trace
Total	100.0
Heating Value, N_2-free, Btu/SCF[h]	456
Specific Gravity (Air = 1.00)	0.975
Nitrogen Purge Rate, SCF/hr	183.5

a. From start of lignite feed.

b. Tube wall temperatures. Heated reactor length of 15.5 ft. Sweep nitrogen inlet at 62-in. level.

c. Operating conditions and results based on weight of dry feed.

d. (CF/s sweep nitrogen at reactor pressure and temperature)/ cross-sectional area of reactor.

e. Based on 1.3702-cu-ft heated reactor volume

f. By weight of residue recovered.

g. 100 (wt product gas/wt of moisture-, ash-free lignite).

h. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure.

Table 2-A5, Part 1. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: CONSOLIDATION COAL COMPANY, BITUMINOUS COAL CHAR, PITTSBURGH SEAM, MONTOUR NO. 10 MINE (Run HT-48)

Run No.	HT-48	
Sample	Feed	Residue
Proximate Analysis, wt %		
Moisture	1.0	5.7
Volatile Matter	16.8	3.0
Fixed Carbon	74.6	79.5
Ash	7.6	11.8
Total	100.0	100.0
Ultimate Analysis (dry), wt %		
Carbon	77.7	84.2
Hydrogen	3.43	1.30
Nitrogen	1.66	0.75
Oxygen	8.62	0.91
Sulfur	0.91	0.33
Ash	7.68	12.51
Total	100.00	100.00
Screen Analysis, USS, wt %		
+40	0.1	0.0
+60	30.9	2.6
+80	32.9	9.5
+100	22.0	13.3
+140	11.0	20.5
+200	1.7	15.6
+325	0.7	14.1
−325	0.7	24.4
Total	100.0	100.0

Table 2-A5, Part 2. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: PRETREATED PITTSBURGH NO. 8 SEAM, IRELAND MINE, BITUMINOUS COAL (Run HT-60)

Run No.	HT-60	
Sample	Feed	Residue
Proximate Analysis, wt %		
Moisture	0.5	0.5
Volatile Matter	26.5	6.2
Fixed Carbon	61.4	68.6
Ash	11.6	24.7
Total	100.0	100.0
Ultimate Analysis (dry), wt %		
Carbon	70.5	68.5
Hydrogen	3.77	2.42
Nitrogen	1.28	1.27
Oxygen	9.30	0.47
Sulfur	3.53	2.53
Ash	11.62	24.81
Total	100.00	100.00
Screen Analysis, USS, wt %		
+ 20	19.1	27.7
+ 30	18.8	24.0
+ 40	33.9	27.1
+ 60	23.1	16.8
+ 80	1.8	1.9
+ 100	0.8	0.7
+ 200	1.3	1.4
+ 325	0.6	0.1
−325	0.6	0.3
Total	100.0	100.0

Table 2-A5, Part 3. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: PRETREATED SEWELL SEAM, LOCHGELLY NO. 2 MINE, WEST VIRGINIA LOW-VOLATILE CONTENT BITUMINOUS COAL (Run HT-165)

Run No.	HT-165		
Sample	Feed	Residue A[a]	Residue B[b]
Proximate Analysis, wt %			
Moisture	0.6	0.9	0.9
Volatile Matter	15.2	1.4	2.2
Fixed Carbon	81.3	93.8	93.1
Ash	2.9	3.9	3.8
Total	100.0	100.0	100.0
Ultimate Analysis (Dry), wt %			
Carbon	85.4	91.2	91.6
Hydrogen	3.13	1.18	1.22
Nitrogen	1.32	0.64	0.72
Oxygen	6.79	2.98	2.59
Sulfur	0.47	0.11	0.05
Ash	2.89	3.89	3.82
Total	100.00	100.00	100.00
Screen Analysis, USS, wt %			
+20	4.3	9.7	1.8
+30	12.5	15.9	9.1
+40	22.9	23.6	17.1
+60	29.6	26.6	25.3
+80	17.7	13.5	18.1
+100	6.2	4.7	7.5
+200	5.6	4.2	6.0
+325	0.7	0.9	3.6
−325	0.5	0.9	11.5
Total	100.0	100.0	100.0

a. Coal in free-fall.

b. 2.0-ft coal bed.

Table 2-A5, Part 4. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: PRETREATED POCAHONTAS NO. 4 SEAM, LOW-VOLATILE CONTENT BITUMINOUS COAL (Run HT-167)

Run No.	HT-167	
Sample	Feed	Residue
Proximate Analysis, wt %		
Moisture	1.2	1.9
Volatile Matter	14.0	3.2
Fixed Carbon	79.1	87.5
Ash	5.7	7.4
Total	100.0	100.0
Ultimate Analysis (Dry), wt %		
Carbon	85.3	86.5
Hydrogen	2.23	1.82
Nitrogen	0.84	0.40
Oxygen	5.24	3.44
Sulfur	0.59	0.28
Ash	5.80	7.56
Total	100.00	100.00
Screen Analysis, USS, wt %		
+ 20	1.8	11.0
+ 30	12.0	16.0
+ 40	22.6	23.2
+ 60	29.9	25.8
+ 80	18.9	14.2
+ 100	8.0	5.3
+ 200	4.7	3.0
+ 325	1.7	0.8
−325	0.4	0.7
Total	100.0	100.0

Table 2-A5, Part 5. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: COLORADO SUBBITUMINOUS COAL, LARAMIE NO. 3 SEAM, EAGLE MINE (Runs HT-179 and -183)

Run No.	HT-179			HT-183	
Sample	Feed	Residue A	Residue B	Feed	Residue
Proximate Analysis, wt %					
Moisture	3.7	1.0	1.2	4.1	0.5
Volatile Matter	35.2	4.2	4.0	34.5	3.4
Fixed Carbon	56.5	86.9	87.2	56.7	86.7
Ash	4.6	7.9	7.6	4.7	9.4
Total	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (Dry), wt %					
Carbon	73.7	87.1	87.2	74.1	86.3
Hydrogen	4.92	1.75	1.70	5.44	1.30
Nitrogen	1.33	0.90	0.86	1.27	0.00
Oxygen	15.02	2.15	2.38	13.94	2.86
Sulfur	0.30	0.11	0.13	0.34	0.07
Ash	4.73	7.99	7.73	4.91	9.47
Total	100.00	100.00	100.00	100.00	100.00
Screen Analysis, USS, wt %					
+ 20	2.4	5.7	8.4	2.9	9.4
+ 30	15.3	12.3	15.6	19.3	15.2
+ 40	30.6	26.0	34.6	30.2	30.1
+ 60	28.7	43.5	26.0	26.1	25.3
+ 80	13.7	7.7	9.2	12.3	10.4
+ 100	4.9	2.2	2.8	4.4	3.5
+ 200	4.1	2.2	3.0	3.7	4.9
+ 325	0.2	0.2	0.2	0.5	0.8
−325	0.1	0.2	0.2	0.6	0.4
Total	100.0	100.0	100.0	100.0	100.0

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Table 2-A5, Part 6. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: MONTANA LIGNITE, SAVAGE MINE, CARBONIZATION, NO FEED GAS (Run HT-229)

Run No.	HT-229	
Sample	Feed	Residue
Proximate Analysis, wt %		
Moisture	2.7	0.8
Volatile Matter	37.6	12.4
Fixed Carbon	50.9	75.5
Ash	8.8	11.3
Total	100.0	100.0
Ultimate Analysis (dry), wt %		
Carbon	64.3	77.4
Hydrogen	3.89	2.40
Nitrogen	0.92	1.11
Oxygen	20.46	6.85
Sulfur	1.44	0.84
Ash	8.99	11.40
Total	100.00	100.00
Screen Analysis, USS, wt %		
+ 20	22.7	13.3
+ 30	24.9	22.8
+ 40	21.1	22.5
+ 60	19.2	23.2
+ 80	7.1	9.4
+ 100	2.0	3.2
+ 200	2.4	4.8
+ 325	0.5	0.7
−325	0.1	0.1
Total	100.0	100.0

Table 2-A5, Part 7. CHEMICAL AND SCREEN ANALYSES OF FEEDS AND RESIDUES IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: NORTH DAKOTA LIGNITE, GLENHAROLD MINE, CARBONIZATION, NO FEED GAS (Run HT-234)

Run No.	HT-234	
Sample	Feed	Residue
Proximate Analysis, wt %		
Moisture	1.1	0.2
Volatile Matter	40.0	11.9
Fixed Carbon	51.3	77.4
Ash	7.6	10.5
Total	100.0	100.0
Ultimate Analysis (dry), wt %		
Carbon	65.3	79.3
Hydrogen	4.35	2.35
Nitrogen	0.93	1.42
Oxygen	21.07	5.69
Sulfur	0.69	0.70
Ash	7.66	10.54
Total	100.00	100.00
Screen Analysis, USS, wt %		
+ 20	25.7	24.5
+ 30	19.0	11.6
+ 40	23.2	20.8
+ 60	20.4	22.3
+ 80	7.6	10.3
+ 100	2.1	3.5
+ 200	1.6	4.6
+ 325	0.2	1.1
−325	0.2	1.3
Total	100.0	100.0

Table 2-A6, Part 1. COMPOSITIONS OF LIQUID PRODUCTS IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: CONSOLIDATION COAL COMPANY, BITUMINOUS COAL CHAR, PITTSBURGH SEAM, MONTOUR NO. 10 MINE (Run HT-48)

Run No.	HT-48
Sample	Condenser
Liquid Products,[a] lb/lb char	0.729
Composition of Liquid Products, wt %	
Water	100.0
Oil	Trace
Total	100.0
Composition of Oil Fraction, wt %	
Carbon	----
Hydrogen	----
Total	----
Carbon in Oil Fraction,	
lb/lb char	Trace
wt % of carbon in char	Trace

a. Includes condensed, undecomposed steam

Table 2-A6, Part 2. COMPOSITIONS OF LIQUID PRODUCTS IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: PRETREATED PITTSBURGH NO. 8 SEAM, IRELAND MINE, BITUMINOUS COAL (Run HT-60)

Run No.	HT-60
Sample	Condenser
Liquid Products,[a] lb/lb coal	0.1259[b]
Composition of Liquid Products, wt %	
Water	64.92
Oil	35.08
Total	100.00
Composition of Oil Fraction, wt %	
Carbon	87.4
Hydrogen	7.18
Total	94.58
Carbon in Oil Fraction, lb/lb coal	0.0386
wt % of carbon in coal	6.05

a. Includes condensed, undecomposed steam

b. Also 0.00726 lb tar/lb coal

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Table 2-A6, Part 3. COMPOSITIONS OF LIQUID PRODUCTS IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: PRETREATED SEWELL SEAM, LOCHGELLY NO. 2 MINE, WEST VIRGINIA LOW-VOLATILE CONTENT BITUMINOUS COAL (Run HT-165)

Run No. / Sample	HT-165 Condenser A[b]	HT-165 Condenser B[c]
Liquid Products,[a] lb/lb coal	0.530	0.511
Composition of Liquid Products, wt %		
Water	97.7	97.7
Oil	2.3	2.3
Total	100.0	100.0
Composition of Oil Fraction, wt %		
Carbon	89.2	89.2
Hydrogen	3.90	3.90
Total	93.10	93.10
Carbon in Oil Fraction,		
lb/lb coal	0.0110	0.0106
wt % of carbon in coal	1.29	1.24

a. Includes condensed, undecomposed steam.

b. Coal in free-fall.

c. 2.0-ft coal bed.

Table 2-A6, Part 4. COMPOSITIONS OF LIQUID PRODUCTS IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: PRETREATED POCAHONTAS NO. 4 SEAM, LOW-VOLATILE CONTENT BITUMINOUS COAL (Run HT-167)

Run No.	HT-167
Sample	Condenser
Liquid Products,[a] lb/lb coal	0.725
Composition of Liquid Products, wt %	
Water	98.6
Oil	1.4
Total	100.0
Composition of Oil Fraction, wt %	
Carbon	90.4
Hydrogen	5.09
Total	95.49
Carbon in Oil Fraction, lb/lb coal	0.00938
wt % of carbon in coal	1.09

Table 2-A6, Part 5. COMPOSITIONS OF LIQUID PRODUCTS IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: COLORADO SUBBITUMINOUS COAL, LARAMIE NO. 3 SEAM, EAGLE MINE (Runs HT-179 and -183)

Run No.	HT-179		HT-183
	A	B	
Sample	Condenser	Condenser	Condenser
Liquid Products,[a] lb/lb coal	0.608	0.412	0.703
Composition of Liquid Products, wt %			
Water	98.0	89.0	91.9
Oil	2.0	11.0	8.1
Total	100.0	100.0	100.0
Composition of Oil Fraction, wt %			
Carbon	81.9	80.5	82.8
Hydrogen	6.27	5.40	5.41
Total	88.17	85.90	88.21
Carbon in Oil Fraction,			
lb/lb coal	0.0115	0.0363	0.0470
wt % of carbon in coal	1.56	4.93	6.34

a. Includes condensed, undecomposed steam.

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Table 2-A6, Part 6. COMPOSITIONS OF LIQUID PRODUCTS IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: MONTANA LIGNITE, SAVAGE MINE, CARBONIZATION, NO FEED GAS (Run HT-229)

Run No.	HT-229
Sample	Condenser
Liquid Products, lb/lb lignite	0.1293
Composition of Liquid Products, wt %	
Water	66.56
Oil	33.44
Total	100.00
Composition of Oil Fraction, wt %	
Carbon	81.6
Hydrogen	7.83
Total	89.43
Carbon in Oil Fraction, lb/lb lignite	0.0363
wt % of carbon in lignite	5.64

Table 2-A6, Part 7. COMPOSITIONS OF LIQUID PRODUCTS IN FREE-FALL HYDROGASIFICATION AND CARBONIZATION TESTS: NORTH DAKOTA LIGNITE, GLENHAROLD MINE, CARBONIZATION, NO GAS FEED (Run HT-234)

Run No.	HT-234
Sample	Condenser
Liquid Products, lb/lb lignite	0.0902
Composition of Liquid Products, wt %	
Water	78.79
Oil	21.21
Total	100.00
Composition of Oil Fraction, wt %	
Carbon	82.2
Hydrogen	7.63
Total	89.83
Carbon in Oil Fraction, lb/lb lignite	0.0157
wt % of carbon in lignite	2.41

B7506 1540F

Table 2-A7, Part 1. FLUIDIZED-BED HYDROGASIFICATION TEST OPERATING RESULTS: PRETREATED PITTSBURGH NO. 8 SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Runs HT-113, -115, -116, -118 and -119)

Coal Source	Ireland Mine Bituminous Coal IGT Pretreater Runs FP-60 and FP-61 10/80	Ireland Mine Bituminous Coal IGT Pretreater Run FP-63 10/80	Ireland Mine Bituminous Coal IGT Pretreater Run FP-63 10/80	Ireland Mine Bituminous Coal IGT Pretreater, Runs FP-63 and FP-64 10/80	Ireland Mine Bituminous Coal IGT Pretreater Run FP-67 10/80
Sieve Size, USS					
Feed Gas		Hydrogen + Steam			
Run No.	HT-113	HT-115	HT-116	HT-118	HT-119
Duration of Test, hr	5-3/4	3-1/2	3-1/2	3-1/4	3-1/4
Steady-State Operation Period, min[a]	131-383	173-210	178-201	130-164	140-190
OPERATING CONDITIONS					
Bed Height, ft	7.0	7.0	7.0	3.5	3.5
Reactor Pressure, psig	1017	1056	1024	1044	1035
Reactor Temperature, °F					
62-1/2 in.	1600	1565	1690	1630	1740
73 in.	1630	1615	1685	1650	1750
83 in.	1665	1665	1680	1670	1760
94-1/2 in.	1560	1560	1610	1655	1735
104 in.	1475	1460	1540	1650	1705
114 in.	1580	1570	1605	----	----
124-1/2 in.	1675	1685	1670	----	----
135 in.	1310	1325	1365	----	----
145 in.	1425	1475	1515	----	----
Average	1545	1545	1595	1650	1735
Coal Rate, lb/hr[b]	41.96	53.43	48.69	48.9	54.70
Feed Gas Rate, SCF/hr[c]	510.6	626.2	495.3	504.0	448.1
Steam Rate, lb/hr	25.83	28.50	26.03	25.10	10.25
Steam, mole % of hydrogen-steam mixture[d]	51.5	48.9	52.8	51.1	32.5
Hydrogen/Coal Ratio, % of stoichiometric	31.8	31.3	27.7	27.7	21.2
Hydrogen/Steam Ratio, mole/mole	0.941	1.045	0.906	0.956	2.081
Bed Pressure Differential, in. wc	124	----	----	----	----
Coal Space Velocity, lb/cu ft-hr	67.81	86.34	78.69	158.1	176.8
Feed Gas Residence Time, min[e]	0.639	0.568	0.635	0.319	0.471
Superficial Feed Gas Velocity, ft/sec[f]	0.182	0.206	0.184	0.183	0.124

(Continued)

OPERATING RESULTS					
Product Gas Rate, SCF/hr	987.5	1108	1073	1033	952.8
Net Btu Recovery, 1000 Btu/lb	4.844	4.539	4.946	4.849	3.886
Product Gas Yield, SCF/lb	23.53	20.73	22.03	21.12	17.42
Hydrocarbon Yield, SCF/lb	5.25	5.02	5.07	4.97	4.18
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[g]	356	433	396	785.0	739
Carbon Oxides Yield, SCF/lb	2.78	2.38	2.49	2.45	1.83
Net Reacted Hydrogen, SCF/lb	3.95	4.13	2.66	3.16	3.16
Residue, lb/lb coal[h]	0.580	0.615	0.622	0.550	0.686
Liquid Products, lb/lb coal[i]	0.583	0.479	0.474	0.470	0.174
Net MAF Coal Hydrogasified, wt %[j]	47.3	43.1	42.7	43.4	34.5
Carbon Gasified, wt %	35.9	34.7	34.9	35.7	27.5
Steam Decomposed, lb/hr[k]	2.29	3.45	3.37	3.13	1.12
Steam Decomposed, % of steam fed[k]	8.9	12.1	13.0	12.5	10.9
Steam Decomposed, % of total equivalent fed[m]	21.4	25.3	26.9	24.6	41.2
Overall Material Balance, %	100.6	99.4	99.6	96.8	99.0
Carbon Balance, %	98.5	98.5	101.9	95.6	98.9
Hydrogen Balance, %	98.0	94.0	98.6	97.2	91.8
Oxygen Balance, %	104.5	100.5	100.0	101.6	96.8
PRODUCT GAS PROPERTIES					
Gas Composition, mole %					
Nitrogen	30.6	27.3	31.6	30.7	36.3
Carbon Monoxide	7.1	6.6	6.3	7.0	8.2
Carbon Dioxide	4.7	4.9	5.0	4.6	2.3
Hydrogen	34.9	36.6	34.1	33.8	28.9
Methane	21.8	23.6	22.2	22.8	23.5
Ethane	0.5	0.6	0.6	0.6	0.4
Propane	0.0	0.0	0.0	0.1	0.1
Butane	0.0	0.0	0.0	----	0.0
Benzene	0.2	0.3	0.2	0.3	0.2
Hydrogen Sulfide	0.2	0.1	0.0	0.1	0.1
Total	100.0	100.0	100.0	100.0	100.0
Heating Value, N_2-free Btu/SCF[n]	529	543	538	550	579
Specific Gravity (Air = 1.00)	0.596	0.576	0.603	0.603	0.630
Nitrogen Purge Rate, SCF/hr	302	297	339	318	346

a. From start of coal feed.

b. Operating conditions and results based on weight of dry feed.

c. Hydrogen.

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane.

e. $\frac{\text{Coal Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

f. $\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-sectional Area of Reactor}}$

g. Reactor volume of 0.619 cu ft in Runs HT-113, HT-115, and HT-116; 0.309 cu ft in Run HT-119.

h. Based on moisture-, ash-free coal conversion to gas and liquids.

i. Includes condensed, undecomposed steam.

j. $100\left[\frac{\text{Wt of Product Gas-Wt Hydrogen in-Wt Decomposed Steam-Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

k. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

m. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor.

n. Gross, gas saturated at 60°F, 30 in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30 in. Hg pressure.

Table 2-A7, Part 1, Cont. FLUIDIZED-BED HYDROGASIFICATION TEST OPERATING RESULTS: PRE-TREATED PITTSBURGH NO. 8 SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Runs HT-121, -125, -126, -128, and -129)

Coal Source	Ireland Mine Bituminous Coal IGT Pretreater Runs FP-67 and FP-71	Ireland Mine Bituminous Coal IGT Pretreater Runs FP-72a, FP-73 and FP-74	Ireland Mine Bituminous Coal IGT Pretreater Run FP-74	Ireland Mine Bituminous Coal IGT Pretreater Runs FP-76 and FP-77	Ireland Mine Bituminous Coal IGT Pretreater Run FP-77
Sieve Size, USS	10/80	10/80	10/80	10/80	10/80
Feed Gas		Hydrogen + Steam			
Run No.	HT-121	HT-125	HT-126	HT-128	HT-129
Duration of Test, hr	6	3-1/2	6	5-3/4	5-3/4
Steady-State Operating Period, min[a]	211-355	147-172	151-359	176-346	162-337
OPERATING CONDITIONS					
Bed Height, ft	7.0	3.5	3.5	3.5	3.5
Reactor Pressure, psig	1014	1022	1025	1070	1502
Reactor Temperature, °F					
62-1/2 in.	1580	1610	1580	----	----
73 in.	1620	1680	1650	1795	1670
83 in.	1660	1720	1715	1785	1650
94-1/2 in.	1645	1715	1695	1755	1645
104 in.	1635	1685	1670	1730	1640
Average	1570	1680	1660	1765	1650
Coal Rate, lb/hr[b]	47.7	44.9	44.7	66.81	63.51
Feed Gas Rate, SCF/hr[c]	493.1	490.4	490.3	708.9	776.7
Steam Rate, lb/hr	25.65	26.26	26.82	15.62	36.1
Steam, mole % of hydrogen-steam, mixture	52.0	52.9	53.5	31.6	49.5
Hydrogen/Coal Ratio, % of stoichiometric[d]	27.1	27.7	28.1	28.0	32.1
Hydrogen/Steam Ratio, mole/mole	0.923	0.890	0.881	2.161	1.022
Bed Pressure Differential, in. wc	110	110	120	96.0	120
Coal Space Velocity, lb/cu ft-hr	154.1	145.2	144.5	215.9	205.3
Feed Gas Residence Time, min[e]	0.323	0.304	0.304	0.309	0.306
Superficial Feed Gas Velocity, ft/sec[f]	0.181	0.192	0.192	0.189	0.190

(Continued)

OPERATING RESULTS					
Product Gas Rate, SCF/hr	1037	1052	1048	1282	1227
Net Btu Recovery, 1000 Btu/lb	4.556	5.182	5.104	4.610	4.438
Product Gas Yield, SCF/lb	21.76	23.41	23.45	19.19	19.32
Hydrocarbon Yield, SCF/lb	4.92	5.10	5.20	4.97	5.55
Gaseous Hydrocarbon Space-Time Yield, SCF/cu ft-hr[g]	757.6	741.3	751.5	1072	1138
Carbon Oxides Yield, SCF/lb	2.28	2.83	2.70	2.72	2.26
Net Reacted Hydrogen, SCF/lb	3.66	2.90	3.45	4.35	5.87
Residue, lb/lb coal[h]	0.602	0.517	0.501	0.507	0.586
Liquid Products, lb/lb coal[i]	0.513	0.522	0.574	0.226	0.550
Net MAF Coal Hydrogasified, wt %[j]	39.1	45.0	47.2	46.4	45.4
Carbon Gasified, wt %	33.6	37.2	37.0	37.0	37.3
Steam Decomposed, lb/hr[k]	2.15	3.86	2.20	1.92	1.81
Steam Decomposed, % of steam fed[k]	8.4	14.7	8.20	12.3	5.01
Steam Decomposed, % of total equivalent fed[m]	23.8	27.7	23.1	44.0	25.0
Overall Material Balance, %	98.1	96.5	96.8	95.7	99.2
Carbon Balance, %	102.1	94.1	91.9	93.8	104.2
Hydrogen Balance, %	96.8	99.8	99.3	98.7	97.7
Oxygen Balance, %	100.8	99.6	103.2	101.8	96.7
PRODUCT GAS PROPERTIES					
Gas Composition, mole %					
Nitrogen	36.0	31.4	33.9	27.0	26.4
Carbon Monoxide	6.1	7.3	6.8	10.7	6.4
Carbon Dioxide	4.4	4.8	4.7	3.5	5.3
Hydrogen	30.7	34.3	32.1	32.6	32.9
Methane	21.8	21.2	21.5	25.4	28.1
Ethane	0.6	0.5	0.5	0.4	0.5
Propane	0.2	0.1	0.2	0.1	0.1
Butane	----	----	----	0.0	0.0
Benzene	0.2	0.3	0.3	0.3	0.3
Hydrogen Sulfide	----	0.1	----	Trace	0.0
Total	100.0	100.0	100.0	100.0	100.0
Heating Value, N_2-free Btu/SCF[n]	559	534	549	564	582
Specific Gravity (Air = 1.00)	0.633	0.607	0.625	0.600	0.593
Nitrogen Purge Rate, SCF/hr	373	330	355	346	324

a. From start of coal feed.

b. Operating conditions and results based on weight of dry feed.

c. Hydrogen.

d. Percent of the stoichiometric hydrogen/char ratio – the net feed hydrogen/char ratio required to convert all the carbon to methane.

e. $\frac{\text{Coal Bed Volume}}{\text{CF/min Feed Gas at Reactor Pressure and Temperature}}$

f. $\frac{\text{CF/sec Feed Gas at Reactor Pressure and Temperature}}{\text{Cross-sectional Area of Reactor.}}$

g. Reactor volume of 0.309 cu ft in Runs HT-118, HT-125, HT-126, HT-128, and HT-129; 0.619 cu ft in Run HT-121.

h. By ash balance.

i. Includes condensed, undecomposed steam.

j. $100\left[\frac{\text{Wt of Product Gas-Wt Hydrogen in-Wt Decomposed Steam-Wt Nitrogen in}}{\text{Wt of Moisture-, Ash-Free Coal}}\right]$

k. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

m. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char, and bound water corresponding to oxygen content of feed char), and the measured liquid water rate leaving the reactor.

n. Gross, gas saturated at 60°F, 30 in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30 in. Hg pressure.

Table 2-A7, Part 1, Cont. FLUIDIZED-BED HYDROGASIFICATION TEST OPERATING RESULTS: PRE-TREATED PITTSBURGH NO. 8 SEAM, IRELAND MINE, BITUMINOUS COAL, HYDROGEN + STEAM FEED GAS (Runs HT-138, -154, -173, and -224)

Coal	Ireland Mine Bituminous Coal IGT Pretreater, Runs FP-81, 82, 82c, and 83	Ireland Mine Bituminous Coal IGT Pretreater, Run FP-85	Ireland Mine Bituminous Coal IGT Pretreater, Runs FP-80, 81, and 83	Ireland Mine Bituminous Coal IGT Pretreater, Run FP-138
Source	10/80	10/80	10/80	10/80
Sieve Size, USS				
Feed Gas	Hydrogen + Steam			
Run No.	HT-138	HT-154	HT-173	HT-224
Duration of Test, hr	5-1/2	3-1/2	5-3/4	5-3/4
Steady-State Operating Period, min[a]	200-335	236-268	171-345	81-343
OPERATING CONDITIONS				
Bed Height, ft	3.5	3.5	3.5	3.5
Reactor Pressure, psig	1002	1500	1024	534
Reactor Temperature, °F[b]				
62 in.	----	----	1675	1470
67-3/4 in.	1510	1345	1655	1695
73 in.	1640	1470	1685	1700
78-1/4 in.	1615	1465	1700	1665
83-1/2 in.	1555	1450	1680	1715
89 in.	1630	1520	1700	1650
94-1/2 in.	1635	1560	1655	1590
100 in.	1625	1560	1705	1740
104 in.	1640	1595	1715	1700
Average	1605	1495	1685	1660
Coal Rate, lb/hr[c]	42.31	65.78	46.13	37.17
Feed Gas Rate, SCF/hr[d]	494.2	769.9	509.9	327.7
Steam Rate, lb/hr	26.17	37.68	25.18	9.22
Steam, mole % of hydrogen-steam mixture	52.7	50.7	50.9	37.2
Hydrogen/Coal Ratio, % of stoichiometric[e]	30.3	30.3	28.5	23.8
Hydrogen/Steam Ratio, mole/mole	0.899	0.973	0.964	1.692
Bed Pressure Differential, in. wc	72	----	----	40.5
Coal Space Velocity, lb/cu ft-hr	136.8	212.6	149.1	120.1
Feed Gas Residence Time, min[f]	0.299	0.325	0.305	0.325
Superficial Feed Gas Velocity, ft/sec[g]	0.189	0.180	0.191	0.179