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FLASH HYDROLYSIS OF COAL

QUARTERLY REPORT NO. 1
FOR THE PERIOD JANUARY 1 TO MARCH 31, 1977

April 1977

PROCESS TECHNOLOGY DIVISION
DEPARTMENT OF APPLIED SCIENCE

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

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ABSTRACT

The 1 lb/hr Flash Hydropyrolysis experimental equipment has been completed and is in operation. The unit was originally designed for the maximim operating conditions of 4000 psi and 800°C. To date it has been successfully operated at up to 3000 psi and 815°C with coal feed rates in excess of 2 lbs/hr. Product analysis is accomplished with the use of an on-line process gas chromatograph designed to measure CO, CO₂, H₂O, CH₄, C₂H₄, C₂H₆, C₆H₆, C₇H₈, C₈H₁₀ and all hydrocarbons $\geq$ C₉, every 6 minutes. Samples of the chromatograph can be taken from any of 6 sample taps including three located at 2 foot intervals along the 8 foot reactor. Carbon conversions in excess of 40% to gaseous products and 20% to liquid products have been observed. Preliminary process design and economic evaluations show the process to be both technically and economically feasible for commercial application.

I. OBJECTIVE AND SCOPE OF WORK

The program objective is to obtain process chemistry and design information on the Flash Hydropyrolysis Process (FHP), a rapid gas-phase, non-catalytic coal hydrogenation technique developed at BNL (1). The work entails the design, construction and operation of a 1 lb/hr down flow entrained reactor system capable of operating at up to 800°C and 4000 psi and incorporating on-line product analysis. This is to be used to study the effect of such process variables as temperature, pressure, feed rates, residence time, and coal type on liquid and gaseous yields.

II. SUMMARY OF PROGRESS TO DATE

The experimental equipment used in these studies has been completed and is in operation. The design capacity of the unit is 1 lb/hr and 10 lb/hr of hydrogen with sufficient capacity to operate for up to two hours. All components in contact with hydrogen at elevated pressures and temperatures are constructed of Inconel 617. The coal feeder, developed at BNL, is of a unique design, constructed of a helical vibrator feeder, a coal hopper and a load cell to monitor the weight of the coal hopper all assembled inside a high pressure vessel attached to the top of the reactor.

The analytical system is capable of measuring CO_x , hydrocarbons of C_8 and less ($\leq \text{C}_8$) and making an intergrated measurement of all hydrocarbons greater than C_9 ($> \text{C}_9$), each analysis taking approximately 6 minutes.

The experimental equipment has been operated successfully at pressures up to 3000 psi and temperatures to 815°C with coal feed rates up to 2 lb/hr.

Using the preliminary data from the system, a process design and economic evaluation shows the process to be technically and economically feasible.

A detailed report on the progress made in the first quarter of FY 1977 plus a full description of the experimental equipment and on-line process gas chromatograph analytic train is given in "Flash Hydropyrolysis of Coal, The Design, Construction, Operation and Initial Results of a Flash Hydropyrolysis Unit", by P. Fallon and M. Steinberg published in January 1977 (2).

III. DETAILED DESCRIPTION OF TECHNICAL PROGRESS

A. Task 1. Design and Order Equipment for 1 lb/hr Unit

1. Work Accomplished

The experimental equipment was designed and all materials recieved.

2. Work Forecast

None. Task 1 has been completed.

B. Task 2. Construction of 1 lb/hr Unit

1. Work Accomplished

All construction of the experimental equipment has been completed and the system is operational. Modifications are being made as necessary to improve the safety, reliability and ease of data gathering.

A method by which 300 ml grab samples of the process gas stream can be taken remotely during a run has recently been added to the system. This is to be used for verification of the results of the on-line process gas chromatograph and to allow the analysis of the gas by other means for such products as H_2S present in concentrations below the detectable limits of the chromatograph.

A 1-inch ball valve was installed on the bottom of the char trap and a stainless steel sheetmetal cone was placed inside the trap to direct all the char to the center of the valve. This allows all the char to be collected and weighed after a run without the need to remove the char trap. This eliminates problems previously encountered with resealing the trap for the high pressures and temperatures operation of the unit.

An alternate to part of the coal feeder system is being studied to replace the vibrator feeder. Plans are to maintain the hopper and load cell which allows continuous monitoring of coal supply and just to replace the helical vibrator feed located below the hopper. Although the present feeder system is functioning, it is not as positively reliable or reproducible as that desired.

2. Work Forecast

A coal feeding device will be developed and bench tested for replacement of the vibrator portion of the present feeder. This is to be an alternate to the present feeder if reliability and reproducibility cannot be increased.

C. Task 3. Development of Analytical System

1. Work Accomplished

a. On-Line Gas Chromatograph

The major effort in this task was the development of the on-line process gas chromatograph system. In its present state of development, it can measure CO , CO_2 , H_2O , CH_4 , C_2H_4 , C_2H_6 , C_6H_6 , C_7H_8 , C_8H_{10} and all hydrocarbons $\geq C_9$.

b. Material Balance

Coal and char analysis are performed routinely and the information used to calculate material balances. To date, when all the char from a run is collected, weighed and analyzed, the carbon balance has been closed to within 2%. This is well within the combined limits of precision of the instrument measurements.

The present effort is to close the sulfur balance. This has presented some difficulty since the sulfur content of the lignite being studied is only approximately 1% and dilution in the process stream brings the concentration to below the detectable limits of the analytical system. It is planned to analyze the aqueous part of the condensate from the condensers for C, S and N.

c. Product Analysis

A 32 mg sample of liquid removed from the water cooled trap was subjected to thermo-gravimetric analysis (TGA) and the results are shown in Figure 1. This trap is located right after the char trap and the gases entering it contain all the products from the reaction. The plot shows there are three distinct fractions; 1) 42.5% of the sample having a boiling range of 40-130°C, 2) 30% of the sample having a boiling range of 160-370°C, and 3) the remainder or 37.5% of the sample coking above 370°C.

2. Work Forecast

Efforts will continue to close the material balances, particularly with regard to sulfur. Further identification of the liquid product will be done on a second gas chromatograph and coal and char analyses will continue.

D. Task 4. Testing of Assembled Unit Including Analytic System

1. Work Accomplished

Before hydrogen was used in the system, it was pressurized to approximately 5000 psi using nitrogen and the 30,000 psi Corblin compressor. This was to insure the integrity of the system and to set and test a number of safety devices. The preheater was also tested at 800°C at this time. Once all the pressure and temperature safeties had been tested and system void of leaks, it was pressurized to 1500 psi with hydrogen. The first attempts to operate the equipment were unsuccessful as both the sample lines and the flow control valve plugged with product. It wasn't until these plus pressure regulator up-stream of the control valve were wrapped with heating tap did the system function satisfactorily.

2. Work Forecast

None. This task is completed.

E. Task 5. Study the Effect of Process Variables on Product Distribution and Yields

1. Work Accomplished

a. Effect of Temperature and Pressure

Figure 2 shows a plot of the fractional carbon conversion to products as a function of temperature at 1500 psi and a hydrogen flow rate of 1.25-1.45 lb/hr (velocity of 0.32-0.54 ft/sec in reactor). The graph indicates a maximum conversion to BTX liquids at approximately 765°C and as expected, the conversion to methane continues to rise although at a decreasing rate. In these experiments it was noted that except for those conducted at 650°C, the BTX yield was almost exclusively benzene while at 650°C, the toluene and xylene yield exceeded that of the benzene. Although the heavier liquid hydrocarbons or light oils were not measured for each run, experience has shown these products to always be approximately two-thirds of the BTX yield. When this is added to the BTX and to the total observed conversions, the estimated maximum liquid yield increases to approximately 20% and the total maximum conversion to approximately 65% at these conditions.

Figure 3 is a plot of the results of a number of runs conducted at 2000 psi and 700 to 805°C using North Dakota lignite. In all runs, the hydrogen flow rate was approximately 1 lb/hr giving a gas velocity in the 1 in. I. D. reactor of approximately 0.24 ft/sec. The results show the yield of all products except CO, to continue to increase with temperature to the maximum operating temperature of 805°C. Since the total hydrocarbon (HC) yield plot and total yield plot are approximately parallel (the difference being CO), the CO yield appears to be constant throughout this range of temperatures. The total liquid yield shown is the sum of the benzene, toluene, and xylene (BTX) plus the light oils ($\geq C_9$). The increase with temperature of this product is attributed almost exclusively to an increase in the light oils, the BTX yield remaining almost constant at 7-9%.

When these results are compared to the results of similar experiments conducted at 1500 psi, a number of differences are observed. First, at 1500 psi, the liquid yield appeared to maximize at approximately 765°C while at 2000 psi it continues to increase beyond 805°C. Second, as previously mentioned, the CO yield at 2000 psi appears to be relatively independent of temperature remaining at approximately 7.5% over the range explored, while at 1500 psi there was approximately a 30% increase in CO yield over this same temperature range.

A series of runs have been initiated at 3000 psi to study the effect of temperature on product distribution and yield at this pressure. As with previous experiments conducted at 1500 psi and 2000 psi, the temperature range of most interest is from 700°C to 800°C. Although there is insufficient data to report fully on these runs, there does not appear

to be any great improvement in yield as compared to runs conducted at 2000 psi and the yield appear to increase beyond 800°C as in the 2000 psi runs.

b. Effect of Residence Time

In three runs conducted at 2000 psi and temperatures of 735, 770 and 800°C, product stream samples were taken both at the first sample tap on the reactor located two feet from the entrance of the hydrogen and at the sample tap located on the char trap effluent. These samples represent both the shortest and longest residence times measurable during any one run. In all of these experiments, it appeared that most of the reaction takes place in the first 2 feet of the reactor. This indicates a relatively short residence time is sufficient (~ 3 sec) and that little reaction takes place in the lower portion of the reactor.

2. Work Forecast

The series of runs being conducted at 3000 psi will be continued. Once sufficient data has been collected, the reactor pressure will be increased to 4000 psi and further studies made.

Since problems with reproducibility of the coal feed rate have been encountered in a number of runs conducted to date, once this problem is solved, some of these runs will be duplicated.

Shorter residence times than the present 3 second minimum will be studied by use of the reactor sample taps and higher gas velocities.

F. Task 6. Process Design and Economic Evaluation

1. Work Accomplished

a. Economic Evaluation

An economic study was made of incorporating flash hydrolysis FHP into an integrated coal refinery process for the production of fuels and chemical feedstocks from lignite (3). These preliminary results based on previous experimental results indicate a favorable return on the investment. The present results have already surpassed the early results indicating an incentive for further work. An economic computer model has been developed so that the experimental data may be evaluated currently with regard to process economics.

Under contract to ERDA, Mechanics Research, Inc. (4) also performed a techno-economic study on the Flash Hydrolysis Process. Their results indicate the process to be economically feasible and to be competitive with other processes such as Fisher-Tropsch which is much further along in development. This was found to be true even for carbon conversions as low as 60% since the unreacted char is assumed to be used

for the production of hydrogen utilized in the process.

b. Process Design

A study was made of the hydrogen requirements for a coal conversion process using Flash Hydropyrolysis assuming the following:

1) Coal Analysis

Carbon	60%
Hydrogen	4
Oxygen	24%
Nitrogen	1%
Sulfur	1%
Ash	10%
	<u>100%</u>

2) Carbon Distribution in Products at All Conditions and Total Yields

CO	13%
CO ₂	4%
CH ₄	36%
C ₂ H ₆	17%
BTX	17%
Light Oils	13%
	<u>100%</u>

3) All the oxygen is consumed to produce oxides of carbon or water.

4) All the hydrogen contained in the coal is available for products.

The calculations were made for up to 60% conversion of the carbon contained in the coal to products in the reactor. This limit was chosen because under the conditions assumed, at 58.5% conversion in the reactor, there is just sufficient carbon remaining in the char produced for the production of the hydrogen needed for hydrogenation. This represents total utilization of all the carbon contained in the coal. Beyond 58.5% conversion in the reactor, theoretically the overall conversion in the system (lbs of product/lbs of coal) remains constant. This is again assuming the above conditions.

At total utilization or 58.5% conversion, the net consumption of hydrogen is 3.3 lbs/100 lbs of coal. This would require approximately 30 lbs of water. Since the lignite used contains over 30% moisture as mined, no additional water would be needed. The net hydrogen requirement for lower yields is proportionally lower. For example, at 40% conversion in the reactor, only 1 lb of hydrogen or 9 lbs of water are required but only 66% of the available carbon is utilized.

2. Work Forecast

The economic evaluation and process design will be periodically re-evaluated with regard to current experimental results.

IV. CONCLUSIONS

Aside from the usual problems associated with the start-up of a new facility, the design, construction, and operations of the nominal 1 lb/hr Flash Hydropyrolysis experiment has been successfully completed and all systems are functioning properly. In addition to the process chemistry information being gained in the operation of the facility, a great deal of knowledge was acquired in its design and construction, particularly in the development of the on-line process gas analytic system.

The unit has been successfully operated at coal feed rate exceeding the design capacity up to 2 lbo/hr and at temperatures of 800°C and pressures of 3000 psi.

Carbon balances have been closed to within 2% and liquid yield in excess of 20% have been obtained. Much additional process chemistry information will be forthcoming with the continued operation of the facility.

Indications are that the Flash Hydropyrolysis Process is economically feasible for commercial application even at this early stage in its development.

V. REFERENCES

1. Steinberg, M. and Fallon, P., "Coal Liquefaction by Rapid Gas Phase Hydrogenation", BNL Report 19507 (November 1974) presented at 169th National American Chemical Society Meeting, Philadelphia, Pa., (April 6-11, 1975).
2. Fallon, P. and Steinberg, M., "Flash Hydropyrolysis of Coal, The Design, Construction, Operation and Initial Results of a Flash Hydropyrolysis Experimental Unit", BNL Report 22519 (January 1977) presented at 173rd National American Chemical Society Meeting, New Orleans, La., (March 20-25, 1977).
3. Steinberg, M. Sheehan, T. V., and Lee, Q., "Flash Hydropyrolysis Process for Conversion of Lignite to Liquid and Gaseous Products", BNL Report 20915, (October 1975) presented at the American Chemical Society National Meeting, New York City, New York (April 4-9, 1976).
4. Boesch, L. P., Apte, A. A., Sarma, K. R., and Woo, J. W., "Flash Hydropyrolysis of Coal Techno-Economic Analysis and Comparison with Other Processes". (Draft Report). Prepared for ERDA by Mechanics Research, Inc., under contract No. EY-76-C-01-2345.

Figure 1. Thermogravimetric analysis (TGA) of 32 mg liquid sample.

Figure 2. Product yield vs temperature at 1500 psi.

Figure 3. Product yield vs. temperature at 2000 psi.

Figure 4. Milestone chart.

APPENDIX
Experimental Results of 2000 psi

RUN NO. 21

SAMPLE NO. 1

DATE 11 -5 - 1976

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED	8.000	SECONDS
CALCULATED	8.600	SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.7048	LB/HR	COAL FED	290.0	GRAMS
HYDROGEN FLOW RATE	.8700	LB/HR	CHAR	0.	GRAMS
HYDROGEN PRESSURE	2000.	PSI	LIGHT OILS	0.	GRAMS
REACTOR TEMP.	725.0	DEG C	BTX	0.	GRAMS
PREHEAT TEMP.	725.0	DEG C	WATER	0.	GRAMS

TOTAL ACCUMULATED WTS.

	COAL ANALYSIS, %	CHAR ANALYSIS, %
CARBON	59.40	0.
HYDROGEN	3.800	0.
OXYGEN	24.66	0.
NITROGEN	.8400	0.
SULFUR	1.200	0.
ASH	10.10	0.

	PRODUCT CONC. IN GAS, LB/C. FT	% CARBON CONV. TO PRODUCT	% MAF COAL CONV. TO PRODUCT
CARBON MONOXIDE	.4770E-03	8.026	12.37
CARBON DIOXIDE	.1600E-04	.1713	.4148
METHANE	.5080E-03	14.92	13.17
ETHYLENE	0.	0.	0.
ETHANE	.2430E-03	7.618	6.300
BENZENE	.2010E-03	7.277	5.211
TOLUENE	.4000E-05	.1432	.1037
XYLENE	0.	0.	0.
LIGHT OIL	.1270E-03	4.600	3.293
WATER	.4060E-03	0.	10.53
TOTAL		42.76	51.39

TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	12.0	15.7	0.	0.	0.	8.61
HYDROCARBON GASES	22.5	108.	0.	0.	0.	19.5
CARBON OXIDES	8.20	0.	26.9	0.	0.	12.8
WATER	0.	27.7	24.1	0.	0.	10.5
AMMONIA	0.	4.74	0.	100.	0.	1.13
HYDROGEN SULFIDE	0.	1.97	0.	0.	100.	1.42
CHAR	0.	0.	0.	0.	0.	0.
TOTAL	42.8	158.	61.0	100.	100.	53.9

HYDROGEN CONSUMPTION-	.2219E-01	LB HYDROGEN/LB COAL
	.4484	MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION-	42.76	PERCENT
EFFECTIVE ENERGY EFFICIENCY-	46.14	PERCENT

RUN NO. 22

SAMPLE NO. 1

DATE 1 -13 - 1977

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED.	0.	SECONDS
CALCULATED	11.40	SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.8199	LB/HR	TOTAL ACCUMULATED WTS.		
HYDROGEN FLOW RATE	1.080	LB/HR	COAL FED	417.0	GRAMS
HYDROGEN PRESSURE	2000.	PSI	CHAR	180.0	GRAMS
REACTOR TEMP.	750.0	DEG C	LIGHT OILS	0.	GRAMS
PREHEAT TEMP.	760.0	DEG C	BTX	0.	GRAMS
			WATER	0.	GRAMS

COAL ANALYSIS, %

CARBON	59.70
HYDROGEN	3.800
OXYGEN	24.39
NITROGEN	.8400
SULFUR	1.170
ASH	10.10

CHAR ANALYSIS, %

72.22
2.750
0.
.6900
1.040
23.30

PRODUCT CONC. IN
GAS, LB/C. FT.% CARBON CONV.
TO PRODUCT% MAF COAL CONV.
TO PRODUCT

CARBON MONOXIDE	.4149E-03	7.413	11.48
CARBON DIOXIDE	0.	0.	0.
METHANE	.5428E-03	16.93	15.02
ETHYLENE	0.	0.	0.
ETHANE	.2415E-03	8.039	6.682
BENZENE	.2166E-03	8.326	5.993
TOLUENE	0.	0.	0.
XYLENE	0.	0.	0.
LIGHT OIL	.1757E-03	6.758	4.861
WATER	.3831E-03	0.	10.60

TOTAL

47.47

54.63

TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	15.1	19.8	0.	0.	0.	10.9
HYDROCARBON GASES	25.0	121.	0.	0.	0.	21.7
CARBON OXIDES	7.41	0.	24.2	0.	0.	11.5
WATER	0.	27.9	34.7	0.	0.	10.6
AMMONIA	0.	3.06	0.	64.5	0.	.732
HYDROGEN SULFIDE	0.	1.19	0.	0.	61.6	.852
CHAR	52.2	31.2	0.	35.5	38.4	36.8
TOTAL	99.7	204.	58.9	100.	100.	93.0

HYDROGEN CONSUMPTION-	.3961E-01	LB HYDROGEN/LB COAL
	.7962	MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION-	47.47	PERCENT
EFFECTIVE ENERGY EFFICIENCY-	53.61	PERCENT

RUN NO. 23

SAMPLE NO. 1

DATE 1 -25 - 1977

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED	0.	SECONDS
CALCULATED	12.20	SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.6348	LB/HR	COAL FED	215.0	GRAMS
HYDROGEN FLOW RATE	.9200	LB/HR	CHAR	0.	GRAMS
HYDROGEN PRESSURE	2000.	PSI	LIGHT OILS	0.	GRAMS
REACTOR TEMP.	785.0	DEG C	BTX	0.	GRAMS
PREHEAT TEMP.	785.0	DEG C	WATER	0.	GRAMS

TOTAL ACCUMULATED WTS.

	COAL ANALYSIS, %	CHAR ANALYSIS, %
CARBON	59.70	0.
HYDROGEN	3.800	0.
OXYGEN	24.39	0.
NITROGEN	.8400	0.
SULFUR	1.170	0.
ASH	10.10	0.

	PRODUCT CONC. IN GAS, LB/C. FT	% CARBON CONV. TO PRODUCT	% MAF COAL CONV. TO PRODUCT
CARBON MONOXIDE	.2680E-03	5.268	8.159
CARBON DIOXIDE	0.	0.	0.
METHANE	.4810E-03	16.51	14.64
ETHYLENE	0.	0.	0.
ETHANE	.1350E-03	4.944	4.110
BENZENE	.1630E-03	6.894	4.962
TOLUENE	0.	0.	0.
XYLENE	0.	0.	0.
LIGHT OIL	.2640E-03	11.17	8.037
WATER	.2660E-03	0.	8.098
TOTAL		44.79	48.01

TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	18.1	23.7	0.	0.	0.	13.0
HYDROCARBON GASES	21.5	107.	0.	0.	0.	18.8
CARBON OXIDES	5.27	0.	17.2	0.	0.	8.16
WATER	0.	21.3	26.5	0.	0.	8.10
AMMONIA	0.	4.74	0.	100.	0.	1.13
HYDROGEN SULFIDE	0.	1.92	0.	0.	100.	1.38
CHAR	0.	0.	0.	0.	0.	0.
TOTAL	44.8	158.	43.7	100.	100.	50.5

HYDROGEN CONSUMPTION-	.2214E-01	LB HYDROGEN/LB COAL
	.4451	MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION-	44.79	PERCENT
EFFECTIVE ENERGY EFFICIENCY-	52.22	PERCENT

RUN NO. 24

SAMPLE NO. 1

DATE 1 -27 - 1977

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED	0.	SECONDS
CALCULATED	11.50	SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.2909	LB/HR	TOTAL ACCUMULATED WTS.		
HYDROGEN FLOW RATE	1.050	LB/HR	COAL FED	155.0	GRAMS
HYDROGEN PRESSURE	2000.	PSI	CHAR	0.	GRAMS
REACTOR TEMP.	805.0	DEG C	LIGHT OILS	0.	GRAMS
PREHEAT TEMP.	805.0	DEG C	BTX	0.	GRAMS
			WATER	0.	GRAMS

COAL ANALYSIS, %

CARBON	59.70
HYDROGEN	3.800
OXYGEN	24.39
NITROGEN	.8400
SULFUR	1.170
ASH	10.10

CHAR ANALYSIS, %

0.
0.
0.
0.
0.
0.

PRODUCT CONC. IN
GAS, LB/C. FT% CARBON CONV.
TO PRODUCT% MAF COAL CONV.
TO PRODUCT

CARBON MONOXIDE	.1130E-03	5.532	8.567
CARBON DIOXIDE	0.	0.	0.
METHANE	.3260E-03	27.86	24.71
ETHYLENE	0.	0.	0.
ETHANE	.6100E-04	5.563	4.624
BENZENE	.7400E-04	7.794	5.610
TOLUENE	0.	0.	0.
XYLENE	0.	0.	0.
LIGHT OIL	.1210E-03	12.75	9.173
WATER	.1070E-03	0.	8.112

TOTAL

59.50

60.80

TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	20.5	27.0	0.	0.	0.	14.8
HYDROCARBON GASES	33.4	169.	0.	0.	0.	29.3
CARBON OXIDES	5.53	0.	18.0	0.	0.	8.57
WATER	0.	21.3	26.6	0.	0.	8.11
AMMONIA	0.	4.74	0.	100.	0.	1.13
HYDROGEN SULFIDE	0.	1.92	0.	0.	100.	1.38
CHAR	0.	0.	0.	0.	0.	0.
TOTAL	59.5	224.	44.6	100.	100.	63.3

HYDROGEN CONSUMPTION-

.4707E-01
.9462LB HYDROGEN/LB COAL
MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION-

57.87

PERCENT

EFFECTIVE ENERGY EFFICIENCY-

71.66

PERCENT

RUN NO. 25

SAMPLE NO. 1

DATE 1 -28 - 1977

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED	40.00	SECONDS
CALCULATED	11:10	SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.4893	LB/HR	COAL FED	185.0	GRAMS
HYDROGEN FLOW RATE	1.100	LB/HR	CHAR	0.	GRAMS
HYDROGEN PRESSURE	2000.	PSI	LIGHT OILS	0.	GRAMS
REACTOR TEMP.	725.0	DEG C	BTX	0.	GRAMS
PREHEAT TEMP.	725.0	DEG C	WATER	0.	GRAMS

TOTAL ACCUMULATED WTS.

COAL ANALYSIS, %

CARBON	59.70
HYDROGEN	3.800
OXYGEN	24.39
NITROGEN	.8400
SULFUR	1.170
ASH	10.10

CHAR ANALYSIS, %

0.
0.
0.
0.
0.
0.

PRODUCT CONC. IN GAS, LB/C. FT	% CARBON CONV. TO PRODUCT	% MAF COAL CONV. TO PRODUCT
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CARBON MONOXIDE	.2590E-03	7.898	12.23
CARBON DIOXIDE	0.	0.	0.
METHANE	.2410E-03	12.83	11.38
ETHYLENE	0.	0.	0.
ETHANE	.1150E-03	6.533	5.431
BENZENE	.9100E-04	5.970	4.297
TOLUENE	.5000E-05	.3244	.2361
XYLENE	0.	0.	0.
LIGHT OIL	.7000E-04	4.595	3.306
WATER	.2120E-03	0.	10.01

TOTAL	38.15	46.89
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TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	10.9	14.4	0.	0.	0.	7.84
HYDROCARBON GASES	19.4	95.5	0.	0.	0.	16.8
CARBON OXIDES	7.90	0.	25.8	0.	0.	12.2
WATER	0.	26.3	32.8	0.	0.	10.0
AMMONIA	0.	4.74	0.	100.	0.	1.13
HYDROGEN SULFIDE	0.	1.92	0.	0.	100.	1.38
CHAR	0.	0.	0.	0.	0.	0.
TOTAL	38.2	141.	58.6	100.	100.	49.4

HYDROGEN CONSUMPTION-	.1552E-01	LB HYDROGEN/LB COAL
	.3120	MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION-	38.15	PERCENT
EFFECTIVE ENERGY EFFICIENCY-	40.28	PERCENT

RUN NO. 26

SAMPLE NO. 1

DATE 1 -31 - 1977

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED	0.	SECONDS
CALCULATED	11.30	SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.5025	LB/HR	TOTAL ACCUMULATED WTS.		
HYDROGEN FLOW RATE	1.100	LB/HR	COAL FED	190.0	GRAMS
HYDROGEN PRESSURE	2000.	PSI	CHAR	0.	GRAMS
REACTOR TEMP.	700.0	DEG C	LIGHT OILS	0.	GRAMS
PREHEAT TEMP.	700.0	DEG C	BTX	0.	GRAMS
			WATER	0.	GRAMS

COAL ANALYSIS, %

CARBON	59.70
HYDROGEN	3.800
OXYGEN	24.39
NITROGEN	.8400
SULFUR	1.170
ASH	10.10

CHAR ANALYSIS, %

0.
0.
0.
0.
0.
0.

PRODUCT CONC. IN
GAS, LB/C. FT% CARBON CONV.
TO PRODUCT% MAF COAL CONV.
TO PRODUCT

CARBON MONOXIDE	.2530E-03	7.512	11.63
CARBON DIOXIDE	.2900E-04	.5480	1.333
METHANE	.1920E-03	9.953	8.828
ETHYLENE	0.	0.	0.
ETHANE	.9700E-04	5.366	4.460
BENZENE	.5900E-04	3.769	2.713
TOLUENE	.1300E-04	.8214	.5977
XYLENE	0.	0.	0.
LIGHT OIL	.1260E-03	8.053	5.793
WATER	.2120E-03	0.	9.748

TOTAL

36.02

45.11

TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	12.6	16.7	0.	0.	0.	9.10
HYDROCARBON GASES	15.3	73.7	0.	0.	0.	13.3
CARBON OXIDES	8.06	0.	28.1	0.	0.	13.0
WATER	0.	25.6	31.9	0.	0.	9.75
AMMONIA	0.	4.74	0.	100.	0.	1.13
HYDROGEN SULFIDE	0.	1.92	0.	0.	100.	1.38
CHAR	0.	0.	0.	0.	0.	0.
TOTAL	36.0	123.	60.0	100.	100.	47.6

HYDROGEN CONSUMPTION-	.8638E-02	LB HYDROGEN/LB COAL
	.1736	MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION-	36.02	PERCENT
EFFECTIVE ENERGY EFFICIENCY-	35.85	PERCENT

RUN NO. 27

SAMPLE NO. 1

DATE 2 -2 - 1977

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED	0.	SECONDS
CALCULATED	11.20	SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.5951	LB/HR	COAL FED	230.0	GRAMS
HYDROGEN FLOW RATE	1.100	LB/HR	CHAR	0.	GRAMS
HYDROGEN PRESSURE	2000.	PSI	LIGHT DILS.	0.	GRAMS
REACTOR TEMP.	735.0	DEG C	BTX	0.	GRAMS
PREHEAT TEMP.	735.0	DEG C	WATER	0.	GRAMS

TOTAL ACCUMULATED WTS.

	COAL ANALYSIS, %	CHAR ANALYSIS, %
CARBON	59.70	0.
HYDROGEN	3.800	0.
OXYGEN	24.39	0.
NITROGEN	.8400	0.
SULFUR	1.170	0.
ASH	10.10	0.

	PRODUCT CONC. IN GAS, LB/C. FT	% CARBON CONV. TO PRODUCT	% MAF COAL CONV. TO PRODUCT
CARBON MONOXIDE	.3230E-03	8.098	12.54
CARBON DIOXIDE	.1100E-04	.1755	.4271
METHANE	.2800E-03	12.26	10.87
ETHYLENE	0.	0.	0.
ETHANE	.1370E-03	6.399	5.319
BENZENE	.1160E-03	6.257	4.504
TOLUENE	.9000E-05	.4802	.3494
XYLENE	0.	0.	0.
LIGHT OIL	.9600E-04	5.181	3.727
WATER	.2470E-03	0.	9.590

TOTAL	38.85	47.33
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TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	11.9	15.8	0.	0.	0.	8.58
HYDROCARBON GASES	18.7	89.9	0.	0.	0.	16.2
CARBON OXIDES	8.27	0.	27.5	0.	0.	10.0
WATER	0.	25.2	31.4	0.	0.	9.59
AMMONIA	0.	4.74	0.	100.	0.	1.13
HYDROGEN SULFIDE	0.	1.92	0.	0.	100.	1.38
CHAR	0.	0.	0.	0.	0.	0.
TOTAL	38.8	138.	59.0	100.	100.	49.8

HYDROGEN CONSUMPTION-	.1427E-01	LB HYDROGEN/LB COAL
	.2869	MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION-	38.85	PERCENT
EFFECTIVE ENERGY EFFICIENCY-	40.16	PERCENT

RUN NO. 28

SAMPLE NO. 1

DATE 2 -3 - 1977

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED 0. SECONDS
CALCULATED 11.20 SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.4761	LB/HR	COAL FED	168.0	GRAMS
HYDROGEN FLOW RATE	1.100	LB/HR	CHAR	78.00	GRAMS
HYDROGEN PRESSURE	2000.	PSI	LIGHT OILS	0.	GRAMS
REACTOR TEMP.	770.0	DEG C	BTX	0.	GRAMS
PREHEAT TEMP.	770.0	DEG C	WATER	0.	GRAMS

TOTAL ACCUMULATED WTS.

	COAL ANALYSIS, %	CHAR ANALYSIS, %
CARBON	59.70	74.30
HYDROGEN	3.800	2.760
OXYGEN	24.39	0.
NITROGEN	.8400	.5300
SULFUR	1.170	.8100
ASH	10.10	21.60

	PRODUCT CONC. IN GAS, LB/C. FT	% CARBON CONV. TO PRODUCT	% MAF COAL CONV. TO PRODUCT
CARBON MONOXIDE	.2420E-03	7.584	11.75
CARBON DIOXIDE	0.	0.	0.
METHANE	.3100E-03	16.96	15.05
ETHYLENE	0.	0.	0.
ETHANE	.1110E-03	6.481	5.387
BENZENE	.1320E-03	8.901	6.407
TOLUENE	0.	0.	0.
XYLENE	0.	0.	0.
LIGHT OIL	.5700E-04	3.846	2.766
WATER	.1950E-03	0.	9.464

TOTAL 43.77 50.82

TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	12.7	16.8	0.	0.	0.	9.17
HYDROCARBON GASES	23.4	115.	0.	0.	0.	20.4
CARBON OXIDES	7.58	0.	24.7	0.	0.	11.7
WATER	0.	24.9	31.0	0.	0.	9.46
AMMONIA	0.	3.35	0.	70.7	0.	.802
HYDROGEN SULFIDE	0.	1.31	0.	0.	67.9	.938
CHAR	57.8	33.7	0.	29.3	32.1	40.5
TOTAL	102.	195.	55.7	100.	100.	93.0

HYDROGEN CONSUMPTION- .3614E-01 LB HYDROGEN/LB COAL
.7264 MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION- 43.77 PERCENT
EFFECTIVE ENERGY EFFICIENCY- 48.85 PERCENT

RUN NO. 29

SAMPLE NO. 1

DATE 2 -3 - 1977

COAL TYPE- NORTH DAKOTA LIGNITE

COAL RESIDENCE TIME-MEASURED	0.	SECONDS
CALCULATED	10.50	SECONDS

NOMINAL CONDITIONS

COAL FEED RATE	.5157	LB/HR	COAL FED	235.0	GRAMS
HYDROGEN FLOW RATE	1.000	LB/HR	CHAR	0.	GRAMS
HYDROGEN PRESSURE	1500.	PSI	LIGHT OILS	0.	GRAMS
REACTOR TEMP.	770.0	DEG C	BTX	0.	GRAMS
PREHEAT TEMP.	770.0	DEG C	WATER	0.	GRAMS

TOTAL ACCUMULATED WTS.

	COAL ANALYSIS, %	CHAR ANALYSIS, %
CARBON	59.70	0.
HYDROGEN	3.800	0.
OXYGEN	24.39	0.
NITROGEN	.8400	0.
SULFUR	1.170	0.
ASH	10.10	0.

	PRODUCT CONC. IN GAS, LB/C. FT	% CARBON CONV. TO PRODUCT	% MAF COAL CONV. TO PRODUCT
CARBON MONOXIDE	.3230E-03	8.494	13.16
CARBON DIOXIDE	0.	0.	0.
METHANE	.2940E-03	13.50	11.97
ETHYLENE	0.	0.	0.
ETHANE	.1150E-03	5.635	4.684
BENZENE	.1090E-03	6.168	4.439
TOLUENE	0.	0.	0.
XYLENE	0.	0.	0.
LIGHT OIL	.3600E-04	2.038	1.466
WATER	.2480E-03	0.	10.10
TOTAL		35.84	45.82

TOTAL MATERIAL BALANCE, %

	CARBON	HYDROGEN	OXYGEN	NITROGEN	SULFUR	MAF COAL
LIQUIDS	8.21	10.8	0.	0.	0.	5.91
HYDROCARBON GASES	19.1	93.5	0.	0.	0.	16.7
CARBON OXIDES	8.49	0.	27.7	0.	0.	13.2
WATER	0.	26.5	33.1	0.	0.	10.1
AMMONIA	0.	4.74	0.	100.	0.	1.13
HYDROGEN SULFIDE	0.	1.92	0.	0.	100.	1.38
CHAR	0.	0.	0.	0.	0.	0.
TOTAL	35.8	137.	60.8	100.	100.	48.3

HYDROGEN CONSUMPTION-	.1424E-01	LB HYDROGEN/LB COAL
	.2863	MOLE HYDROGEN/MOLE CARBON

EFFECTIVE CARBON CONVERSION-	35.84	PERCENT
EFFECTIVE ENERGY EFFICIENCY-	37.42	PERCENT

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