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RESEARCH AND DEVELOPMENT OF RAPID HYDROGENATION FOR COAL CONVERSION TO SYNTHETIC MOTOR FUELS (RISER CRACKING OF COAL)

Final Report for the Period April 1, 1976—September 30, 1980

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By
Dennis A. Duncan
Justin L. Beeson
R. Donald Oberle

February 1981
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Work Performed Under Contract No. AC21-76ET10520

Institute of Gas Technology
Chicago, Illinois

U. S. DEPARTMENT OF ENERGY

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RESEARCH AND DEVELOPMENT OF RAPID HYDROGENATION FOR COAL CONVERSION TO SYNTHETIC MOTOR FUELS

(RISER CRACKING OF COAL)

Project 61001
Final Report for the Period
April 1, 1976, Through September 30, 1980

Dennis A. Duncan
Justin L. Beeson
R. Donald Oberle

Prepared by

Institute of Gas Technology
IIT Center, 3424 S. State Street
Chicago, Illinois 60616

Date Published — February 1981

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UNITED STATES DEPARTMENT OF ENERGY

Under Contract No. DE-AC21-76ET10520
(Formerly EX-76-C-01-2307)

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EXECUTIVE SUMMARY

This is the final report on the project "Research and Development of Rapid Hydrogenation for Coal Conversion to Synthetic Motor Fuels" (Riser Cracking of Coal) performed under contract number EX-76-C-01-2307 with the U.S. Department of Energy. The project was begun in April, 1976, and was scheduled to be completed in 50 months. The technical program was divided into the following tasks:

1. Planning
2. Construction and Operation of a Bench-Scale Unit
3. Design of a Process Development Unit
4. Construction of a Process Development Unit
5. Operation of a Process Development Unit
6. Process Assessment

In the process under investigation, feed coal was entrained in hydrogen or other gas at high pressure and heated cocurrently with the gas to pyrolysis temperatures for a few seconds in an entrained flow reactor followed by cooling and separation of products. A number of experiments were made in which hydrogen was preheated to pyrolysis temperatures prior to contact with feed coal. The spent char was easily separated from the hot process gases as a dry, free-flowing material.

In the bench-scale unit program 143 runs were made investigating the effects of temperature, pressure, heating rate, temperature profile, and particle size, using North Dakota lignite and Illinois No. 6 coal. With North Dakota lignite and Illinois No. 6, temperatures between 1400° and 1500°F and operating pressures above 1500 psig were required to obtain carbon conversions of interest. Hydrocarbon liquid yields were found to increase with both operating pressure and hydrogen-to-coal ratio. Within the range of 120°F/s to 1275°F/s, heating rate did not have any strong effect on the distribution of carbon among products. Preheating hydrogen to pyrolysis temperature prior to contacting the feed coal also did not have any strong effect on the carbon distribution.

The kinetics of the pyrolysis of coals have been investigated by J.L. Johnson.[1] In Figure ES-1, the methane plus ethane yields, hydrocarbon liquid yields, total carbon conversion, and carbon oxide yields obtained from North Dakota lignite processed in hydrogen are compared with the expected values calculated from Johnson's model, here shown as a function of severity ($K\theta$). Methane plus ethane yields (around 25 wt % of feed carbon) are in reasonable agreement with the model. Hydrocarbon liquid yields appear to go through a poorly defined maximum (about 15 wt % on C) in the vicinity of a value of 0.6 for $K\theta$. Carbon conversions appear to exceed the expected values, peaking out at about 50 wt %, and carbon oxide yields (10 wt %) are in reasonable agreement with the model.

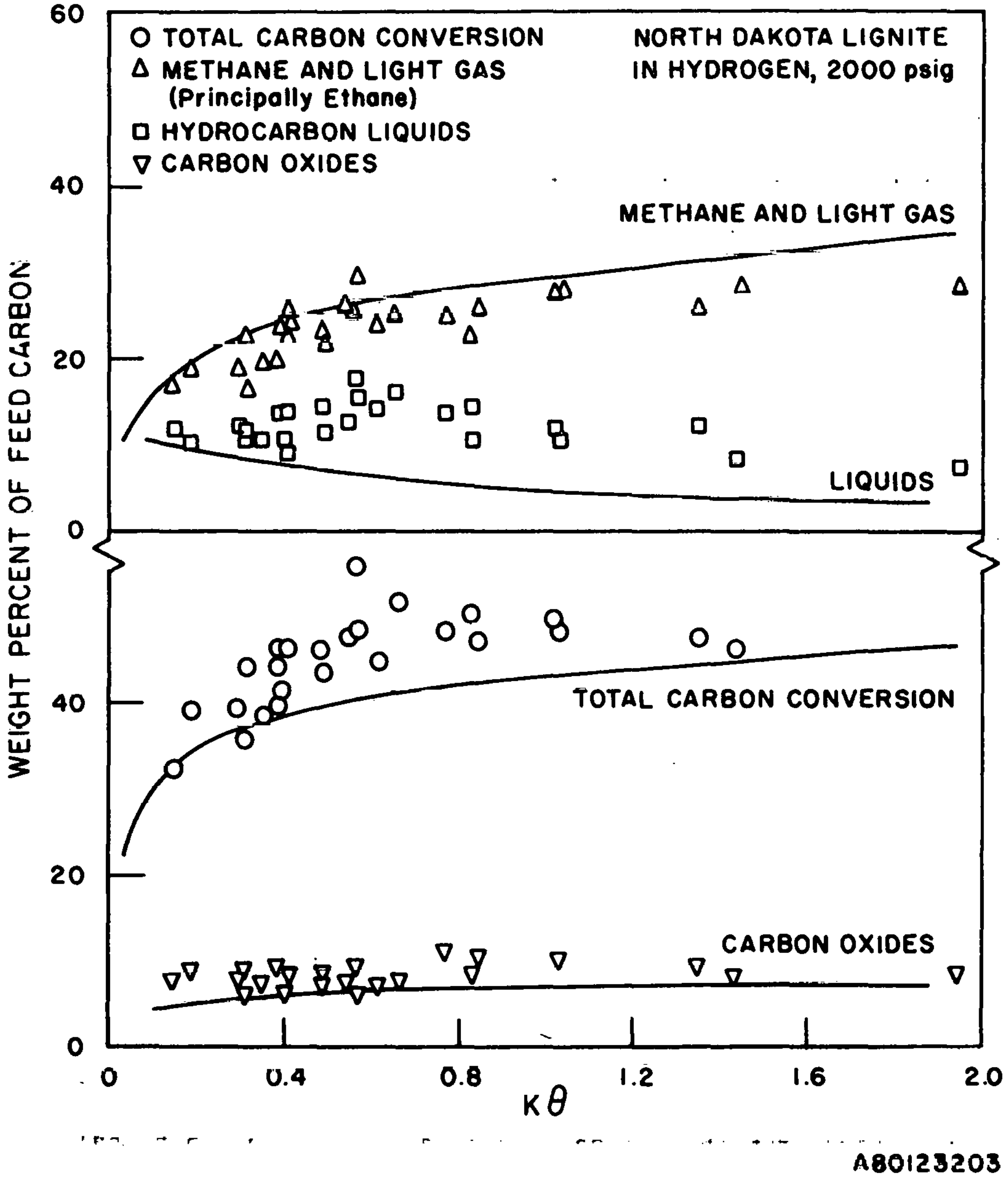

Figure ES-1. TOTAL CONVERSION AND CARBON DISTRIBUTIONS FROM NORTH DAKOTA LIGNITE. P, TP, RT AND HR SERIES COMPARED TO JOHNSON MODEL (SOLID LINE)

Measurements of average particle residence time were made by dividing hold-up in a coiled tube by the solids flow rate. The coiled tube was of the same diameter as the bench-scale unit reactor. From these measurements it was found that in the bench-scale unit, the average solids particle residence time was 2-3 times longer than the gas residence time. Thus, the deviations in carbon conversion from the Johnson model shown in Figure ES-1 may be caused by the longer residence time of the solids rather than a difference in reactivity. The principal sources of scatter in the data are believed to be caused by changes in hydrogen partial pressure through dilution by volatile material released in the pyrolysis, error in material balances, and differences in gas and solids residence times.

The composition of the gasoline boiling range liquids obtained from North Dakota lignite changed with severity as shown in Figure ES-2. At low severity, substantial fractions of phenols and cresols were present. With increase in severity, the fraction of phenols and cresols decreased with an attendant increase in BTX. The distribution of benzene, toluene, and xylene changed with severity as shown in Figure ES-3; at high severity, toluene and xylenes appear to be dealkylated to form benzene. Because of this, the problem of obtaining a maximum oil yield should be enlarged to include consideration of chemical species making up the oil.

When steam was substituted for half of the hydrogen in a series of runs with North Dakota lignite, the hydrocarbon liquid yields were reduced, apparently through steam reforming reactions, with an attendant increase in carbon oxides yield. Some runs were also made with Illinois No. 6 coal which had a free swelling index of 4-1/2. This coal was successfully processed by diluting it with silica sand and devolatilized char, and by chemical treatments which destroyed its tendency to agglomerate. Iron oxide was found to have beneficial catalytic properties, increasing depth of carbon conversion with improvement in both hydrocarbon gas and liquids yields. Bentonite clay was found to catalyze hydrotreating reactions, reducing the amounts of phenols and cresols found in the gasoline boiling range liquids.

A total of 16 runs were made in the PDU (Figure ES-4). In the PDU, coal and hydrogen were preheated to auto-ignition temperatures. Small quantities of oxygen were injected at two points in the riser to raise the temperature of the process stream to pyrolysis temperatures by combustion in two stages. The spent char was separated from hot process gases in the char trap as a dry material. The gases were then cooled to condense the liquids which were collected in a separate vessel. The operating data for these runs are summarized in Figure ES-5, where the methane and ethane, hydrocarbon liquids, and carbon oxide yields are compared with the expected conversions calculated from the Johnson model, and also two bench-scale unit runs, TP-11 and P-21. At a severity of 0.63, the liquid yield is less than 10% of feed carbon, the methane and ethane yield is low, and the carbon oxide yield is considerably higher than expected. Because of heat losses, the quantities of oxygen needed to raise the bulk riser stream temperature to pyrolysis temperatures were larger than planned, and combustion of a portion of the products occurred.

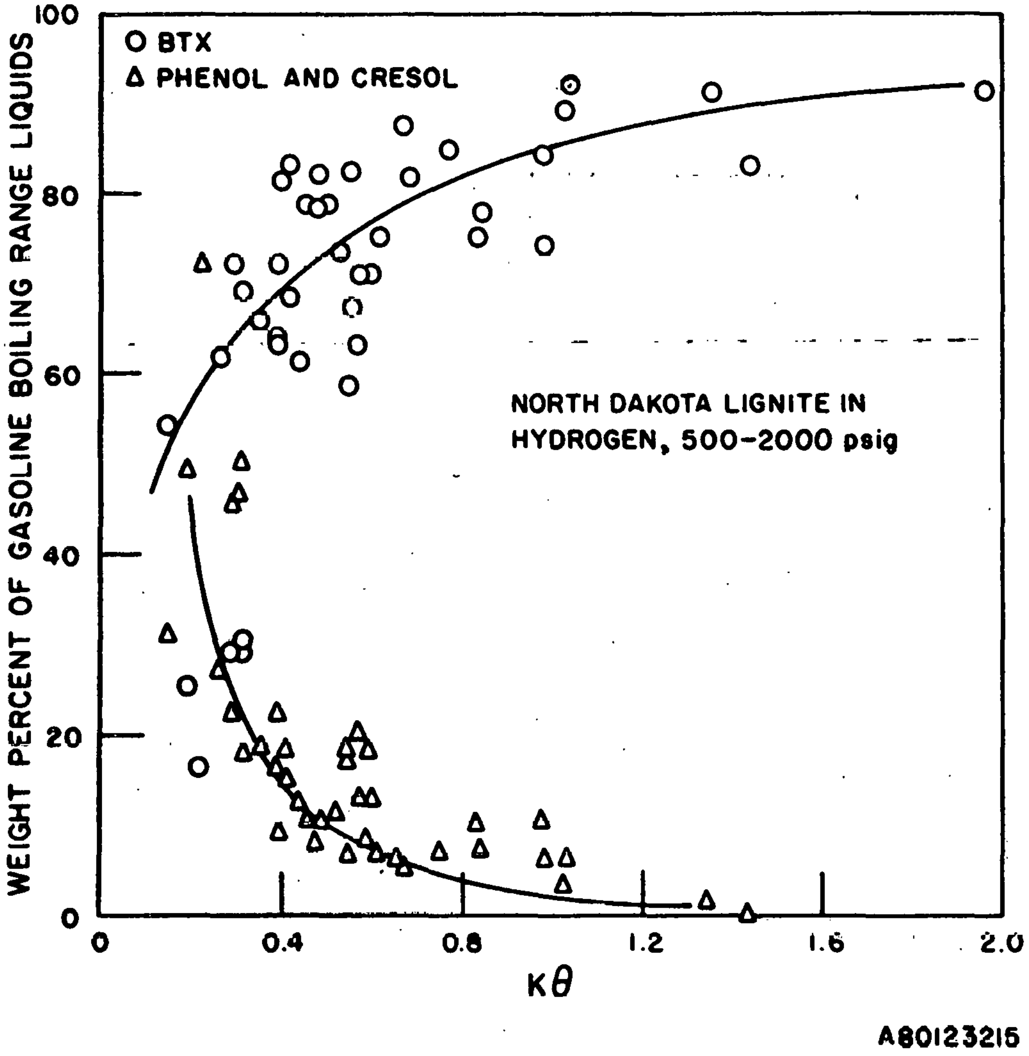

Figure ES-2. DISTRIBUTION OF BTX AND PHENOLS AND CRESOLS IN GASOLINE BOILING RANGE LIQUIDS OBTAINED FROM NORTH DAKOTA LIGNITE. P, TP, AT, PS, PP AND HR SERIES

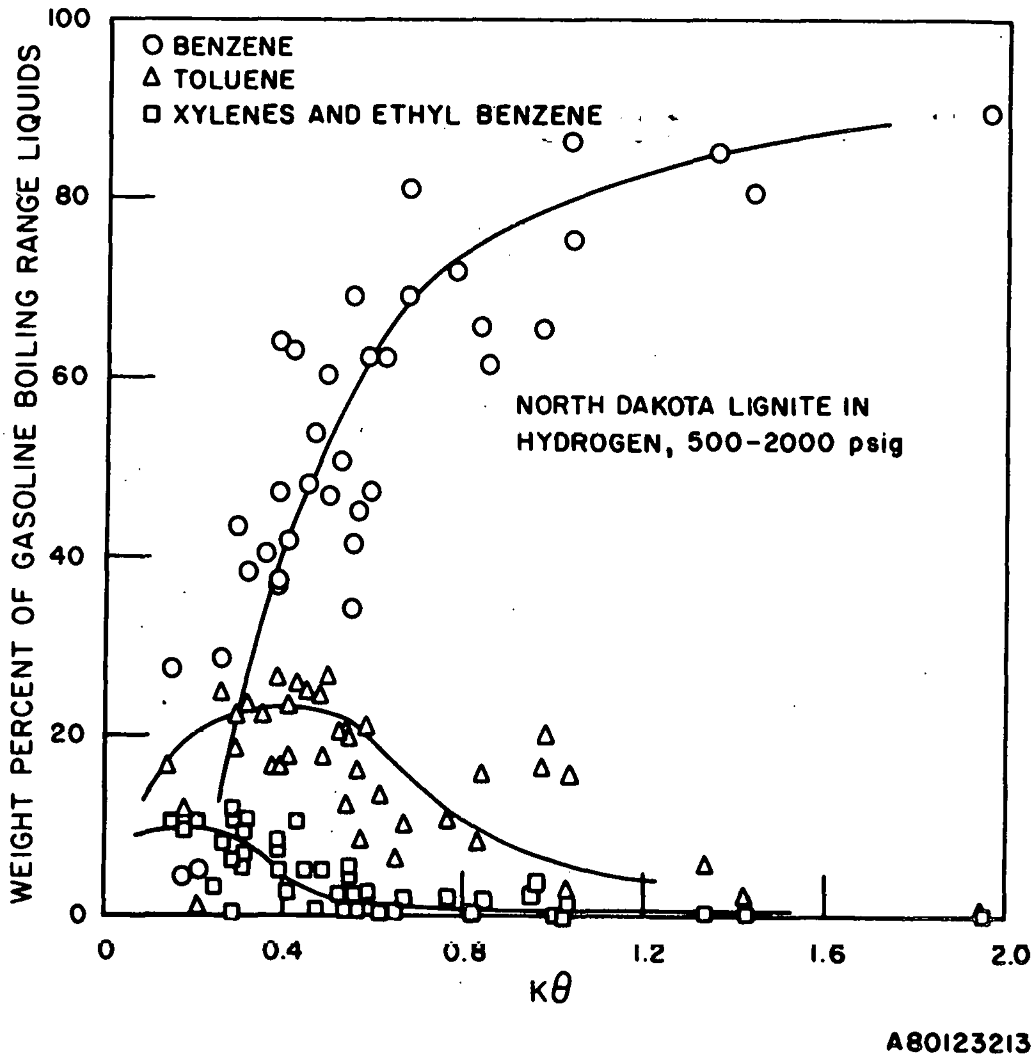

Figure ES-3. DISTRIBUTION OF BENZENE, TOLUENE AND XYLENES AND ETHYL BENZENE IN GASOLINE BOILING RANGE LIQUIDS OBTAINED FROM NORTH DAKOTA LIGNITE. P, TP, RT, PS, PP AND HR SERIES

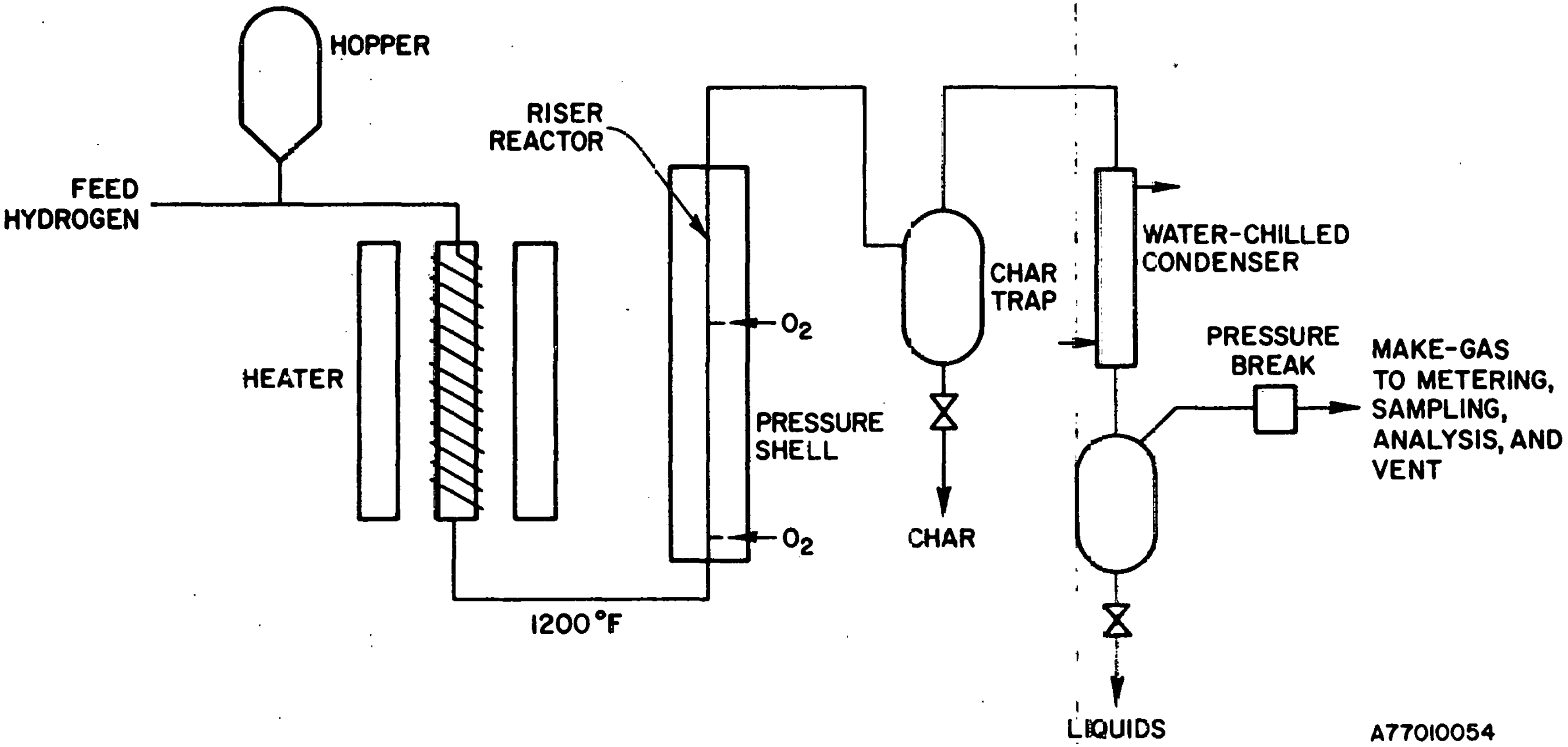

Figure ES-4. SIMPLIFIED FLOW DIAGRAM OF RISER REACTOR PDU

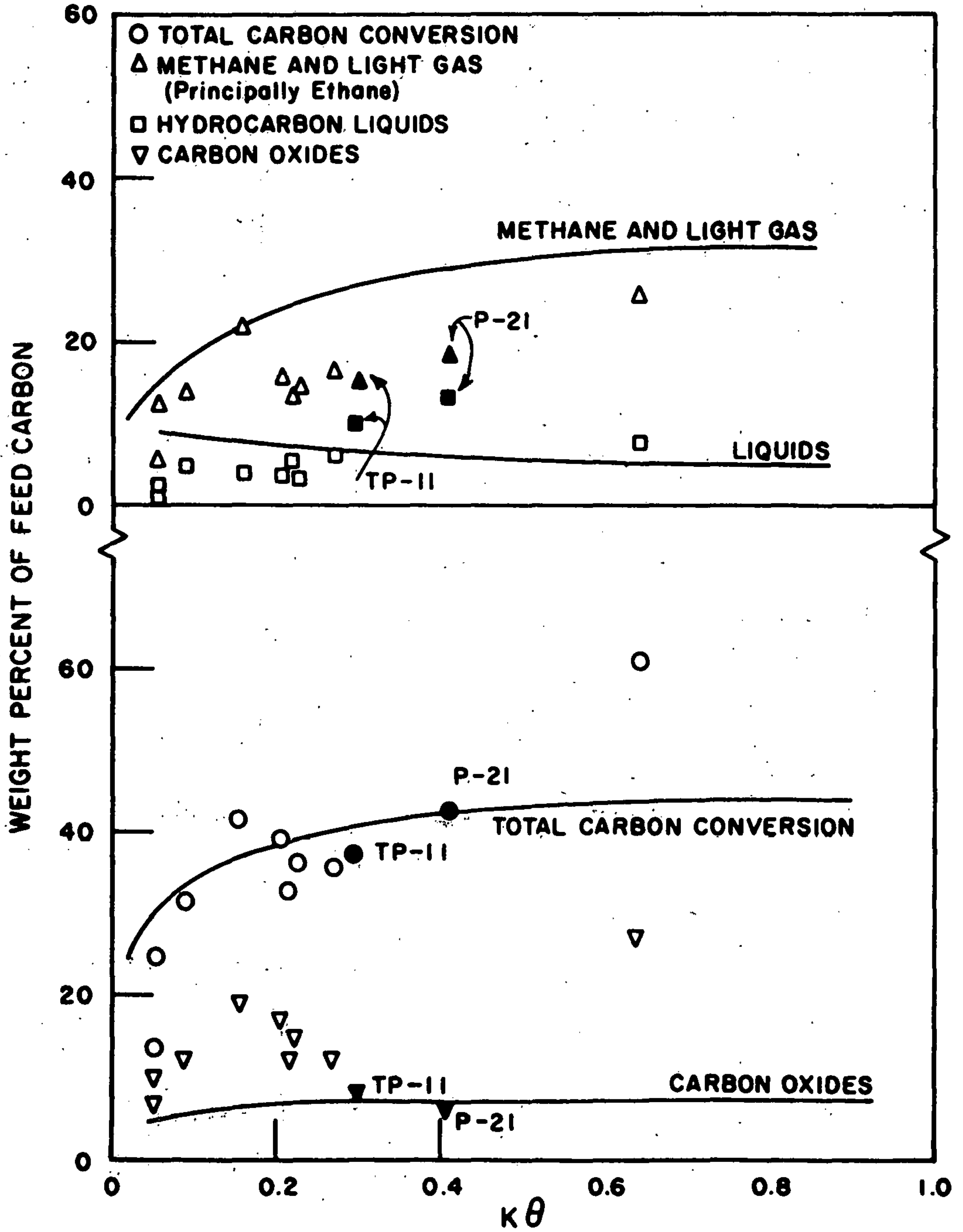

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Figure ES-5. COMPARISON OF PDU AND BENCH-SCALE UNIT METHANE AND LIGHT GAS, HYDROCARBON LIQUIDS AND CARBON OXIDE YIELDS

A complete summary of operating conditions and analytical data is given in the appendices to this report; Appendix A covers the BSU data and Appendix B, the PDU data.

Economic studies were made, and complete design and cost estimates made for three processing scenarios. Two of these conceptual plants were for processing 16,000 tons/day of North Dakota lignite, recovering process hydrogen by oil absorption in the first scenario and by cryogenics in the second scenario. The third plant design was for processing Illinois No. 6 coal. The total capital requirements, and the projected selling prices for blending gasoline stock, fuel oil, and fuel gases on a "Utility" basis were as follows:

	Hydrogen Recovery by Absorption	Hydrogen Recovery by Cryogenics	Hydrogen Recovery by Cryogenics
Coal Type	N.D. Lignite	N.D. Lignite	Illinois No. 6
Total Capital, \$ Million (1979 dollars)	1319	1383	1436
Gasoline, \$/gal	0.88	0.86	0.91
Fuel Oil, \$/gal	0.61	0.59	0.69
Fuel Gas, \$/10^6 Btu	3.86	3.76	3.90

In view of the economics, which appear favorable in the current markets, the Riser Cracking of Coal process warrants further development in spite of the immediate technical shortcomings of the equipment used in this investigation.

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ABSTRACT

The objective of the program described in this report was to develop a noncatalytic process for the hydropyrolysis of lignite and coal to produce high-octane blending gasoline constituents, methane, ethane, and carbon oxides. The process would operate in a "balanced plant" mode, using spent char to generate process hydrogen by steam-oxygen gasification. The technical program included the construction and operating of a bench-scale unit (5-10 lb/hr), the design, construction, and operation of a process development unit (PDU) (100 lb/hr), and a final technical and economic assessment of the process, called "Riser Cracking of Coal".

In the bench-scale unit program, 143 runs were made investigating the effects of pressure, temperature, heating rate, residence time, and particle size, processing North Dakota lignite in hydrogen. Some runs were made in which the hydrogen was preheated to pyrolysis temperatures prior to contact with the coal, and, also, in which steam was substituted for half of the hydrogen. Attempts to operate the bench-scale unit at 1200 psig and 1475°F were not successful. Depth of carbon conversion was found to be influenced by hydrogen pressure, hydrogen-to-coal ratio, and the severity of the thermal treatment. The composition of hydrocarbon liquids produced was found to change with severity. At low severity, the liquids contained sizable fractions of phenols and cresols. At high severity, the fraction of phenols and cresols was much reduced, with an attendant increase in BTX.

In operating the PDU, it was necessary to use more oxygen than was planned to achieve pyrolysis temperatures because of heat losses, and portions of hydrocarbon products were lost through combustion with a large increase in carbon oxide yields. Economic studies, however, showed that selling prices for gasoline blending stock, fuel oil, and fuel gas are competitive in current markets, so that the process is held to warrant further development.

I. OBJECTIVE AND SCOPE OF WORK

The objective of the research and development program described in this report was to develop the technology of short-residence-time hydropyrolysis of lignite and coal to produce high-octane gasoline blending-stock constituents with coproducts of methane, ethane, and fuel oil. The process is to be operated in a "balanced plant" mode, using spent char to product hydrogen. The scope of the investigation includes the design, construction, and operation of both a bench-scale unit (5 to 10 lb/hr) and a process development unit (50 to 100 lb/hr). This work was performed under Contract No. DE-AC21-76ET10520 (formerly EX-76-C-01-2307) with the Department of Energy; the process developed is called "Riser Cracking of Coal."

Work on the bench-scale unit was performed over an operating temperature range from 1200° to 1500°F, pressures from 500 to 2000 psig, and residence times from 1 to 10 seconds. The development of the reactor was regarded as the principal task, so the subsystems needed for a self-contained process plant (slurry feed system and dryer, hydrogen recovery and recycle, etc.) were omitted.

The investigation conducted in this program was oriented toward establishing a process that can be scaled up to commercial size in terms of current materials of construction, equipment, and technology rather than to a fundamental study of the pyrolysis chemistry involved. The work is expected to augment and complement the work of other investigators.[2,4,5,7,8,9,12,15,17] In the final phase of the project, the technical and economic aspects of a commercial scale of operation were evaluated.

II. ACHIEVEMENT OF PROJECT OBJECTIVES

The status of the various tasks of the 50-month program is as follows:

Task 1, Work Plan: Completed in the second month of the program: Task report issued in May 1976.

Task 2, Construction and Operation of a Bench-Scale Unit: All planned work has been completed.

Task 3, Design of a Process Development Unit: Completed, and Task report issued in May 1978.

Task 4, Construction of a Process Development Unit: Completed in August 1979.

Task 5, Operation of a Process Development Unit: A total of 16 runs were made at system operating pressures of 1000, 1500, and 2000 psig and temperatures of 1200° to 1475°F.

Task 6, Process Assessment: Several processing scenarios have been reduced to three cases for detailed economic analysis. The Task report is being issued at this time.

A total of 142 runs were made in the bench-scale program processing North Dakota lignite and Illinois No. 6 bituminous coal at system operating pressures ranging from 500 to 2000 psig using hydrogen and mixtures of hydrogen and steam as the main carrier gas. Some trials using mixtures of syngas and steam were also made. In the program, the effects of operating pressure, temperature profile (time-temperature history), residence time, particle size, and heating rate were investigated. Successful methods for processing caking coals were demonstrated, and processing by cocurrently heating feed coal and carrier gas to pyrolysis temperatures was compared with processing in which hydrogen carrier gas was preheated to the 1000° to 1350°F range prior to conducting the feed coal.

In the PDU program (Task 5), 16 runs were made. Most of the problems with the combustion system, high pressure nitrogen start-up system, and other unanticipated problems have been resolved. The distribution of feed carbon among products has been characterized. Problems with occasional plugging remain not well understood.

In Task 6, a number of conceptual processing scenarios were considered and a detailed economic analysis made of the three most promising cases. The Task 6 report is being issued at this time.

III. SUMMARY OF TECHNICAL PROGRESS

A. Task 2. Build and Operate a Bench-Scale Unit

1. Bench-Scale Unit Program

In the planning phase the main variables were identified as temperature, pressure, residence time, particle size, and system operating pressure. These variables were handled by an organized approach using a test matrix comprised of system operating pressures of 500, 1000, and 2000 psig, reactor outlet temperatures of 1000°, 1250°, and 1500°F, and residence times of 1, 2, and 4 seconds. An extended experimental program was mapped out with provision to periodically review results as they were obtained and modifying the planned experimental program in the light of the experimental results. The design of the PDU was to be based upon results obtained from the bench-scale unit program. In addition to an investigation of basic processing parameters using North Dakota lignite, work with caking coals was also included in the experimental program. In addition, work with mixtures of hydrogen and steam, syngas and steam, and preheated hydrogen was planned, together with some work with catalysts.

2. Coal Feeder

Because is was doubtful that an auger-type feeder would work at 2000 psig, it was necessary to develop a coal feeder for the bench-scale unit. An entrained flow device was chosen and was piloted in Plexiglas at ambient pressure to develop a working device and establish operating characteristics. A schematic drawing of the equipment is shown in Figure 1.

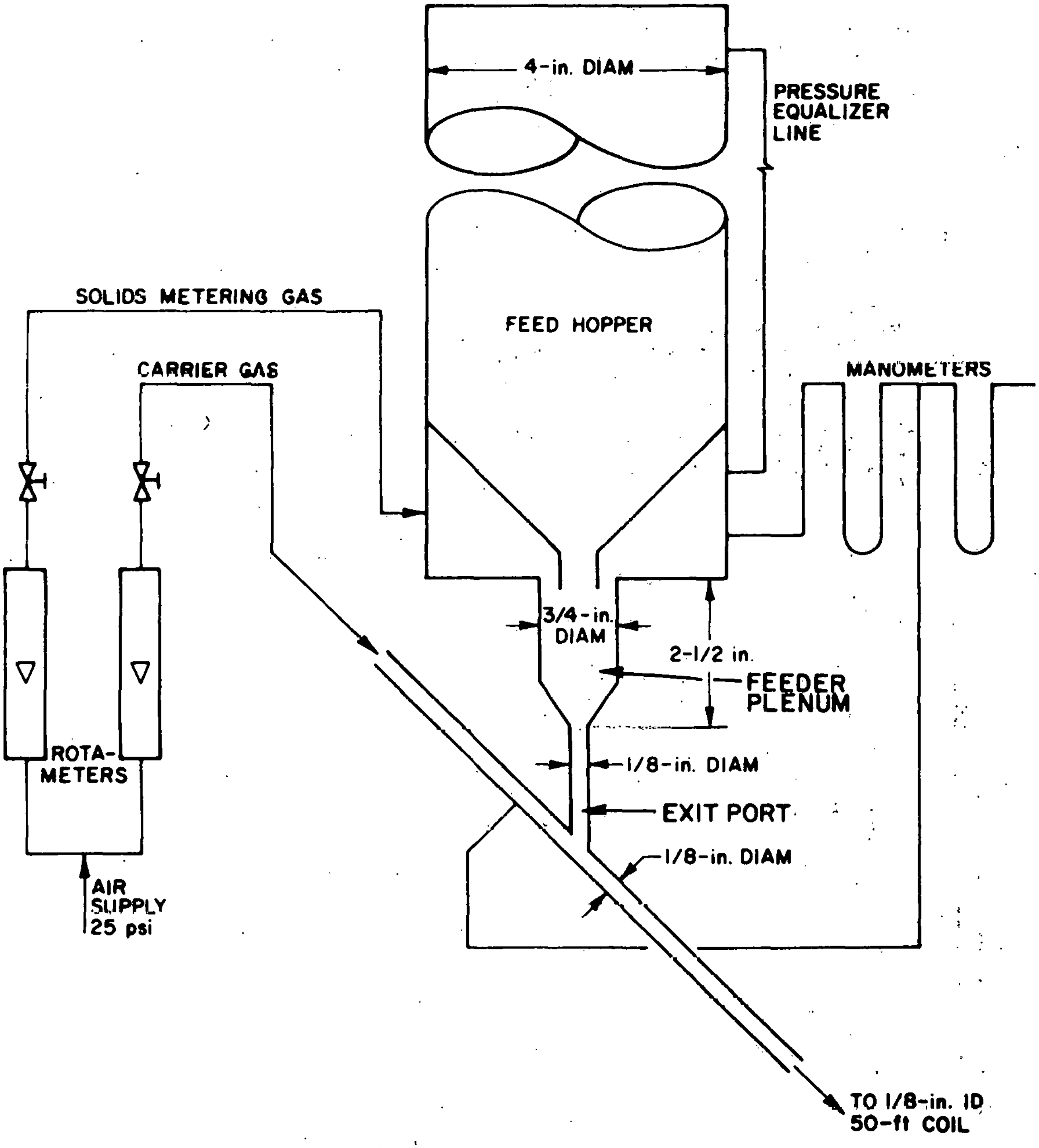

Figure 1. SCHEMATIC DRAWING OF ENTRAINED FLOW SOLIDS FEEDER SIMULATOR

In operating, test solids were charged to the feed hopper, which was then sealed. A predetermined carrier gas flow rate was then established. During this step, gas would enter the feed hopper, bringing the hopper pressure into equilibrium with the pressure established by the flow of carrier gas through the 50 ft coil attached to the feeder. Solids feeding was then started by introducing a flow of solids metering gas into the feeder plenum. This flow entrained the solids in the plenum, transporting them into the carrier gas line.

The addition of the feed solids to the carrier gas increased the pressure drop through the system so that a few minutes of operation were needed to bring the system to a steady-state operation. Three size ranges of North Dakota lignite were used in the study: a 60 x 100 mesh, a 100 x 200 mesh, and a 200 x 325 mesh. For a given size range, the coal feed rate was found to be related to the superficial velocity of the solids metering gas in the exit port as measured by the solids metering gas rotameter; i.e., the portion of solids metering gas required to replace the volume of solids withdrawn from the feed hopper was neglected. The data obtained for the three size ranges of North Dakota lignite are shown in Figures 2 and 3.

Coal feed rates were also found to be related to total system pressure drop as shown in Figures 4, 5, and 6. At a fixed carrier gas flow rate, the system pressure drop was observed to vary linearly with the coal feed rate. In the bench-scale unit, provision was made to meter the hopper gas rate by means of a high-pressure rotameter. Because of coal blowing back through the instrument lines, this method proved to be unsatisfactory, and solids feeding in the bench-scale unit was monitored by total system pressure drop using the correlation shown in Figure 7. The transient behavior of the Plexiglas simulator was evaluated, obtaining curves such as that shown in Figure 8, which shows the performance of the feeder system over a time interval of 1 hour.

3. Description of Equipment

A diagram showing the principal equipment of the bench-scale unit is shown in Figure 9. A more detailed description of the equipment and subsequent modifications is given in earlier reports. In operation, feed coal was metered from the feed hopper into a stream of carrier gas which transported the coal through the 70 ft long by 0.120-in. ID coiled tube reactor in which the process stream was subjected to a predetermined "temperature profile." The spent char was disengaged from the hot reactor effluent in the char trap. The gases were then cooled to condense liquids which drained from the demister into high-pressure sample bombs. Gases emerging from the demister were passed through a dry ice/methanol freeze-out train to remove uncondensed benzene and toluene. The dried gases were then metered, sampled, and vented.

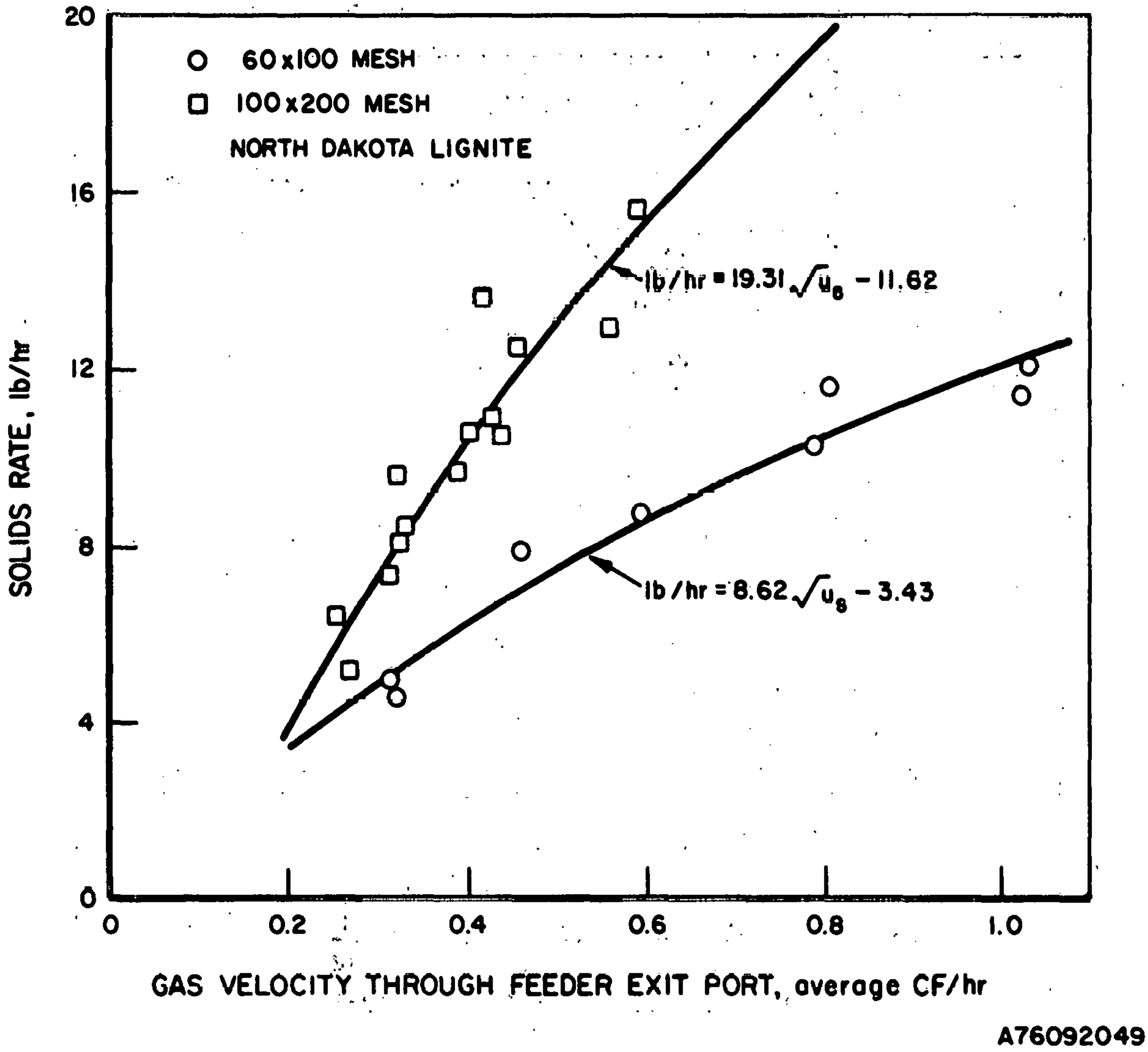

Figure 2. CHANGE IN SOLIDS FLOW RATE WITH SUPERFICIAL GAS VELOCITY IN THE FEEDER EXIT PORT

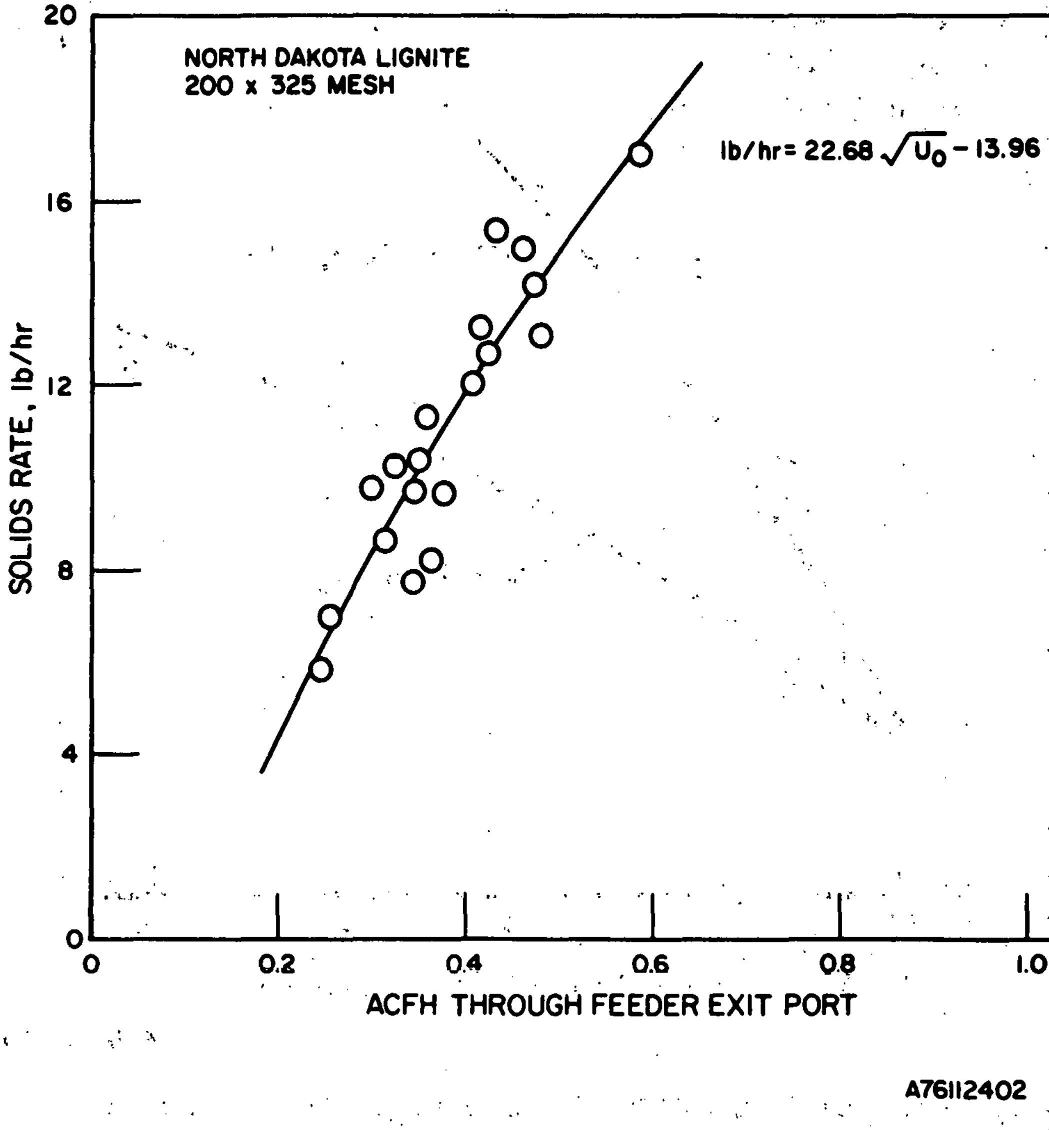

Figure 3. CHANGE IN SOLIDS FLOW RATE WITH SUPERFICIAL GAS VELOCITY IN THE FEEDER EXIT PORT

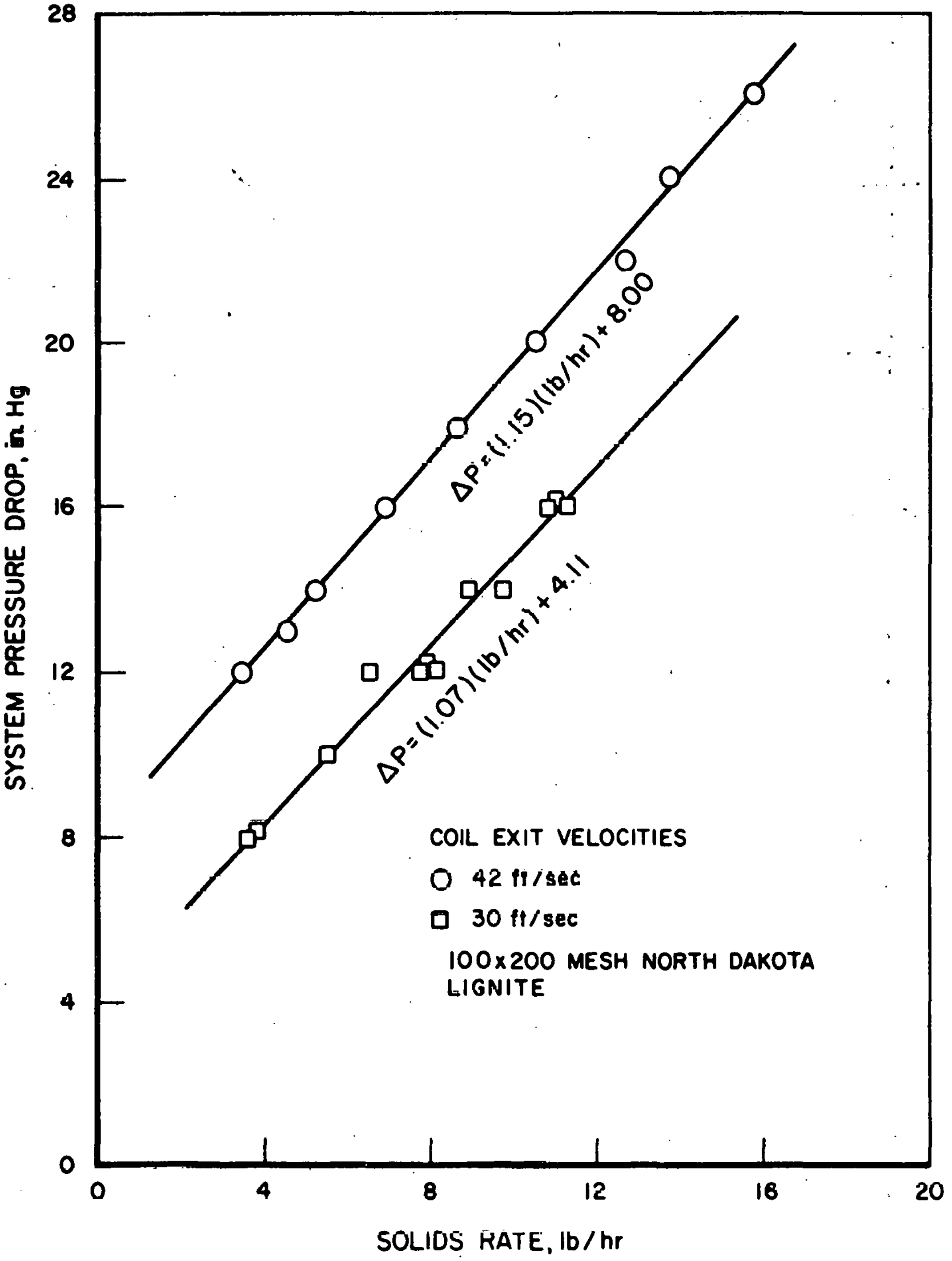

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Figure 4. INCREASE IN SYSTEM PRESSURE DROP WITH SOLIDS FLOW RATE (100 X 200 Mesh North Dakota Lignite)

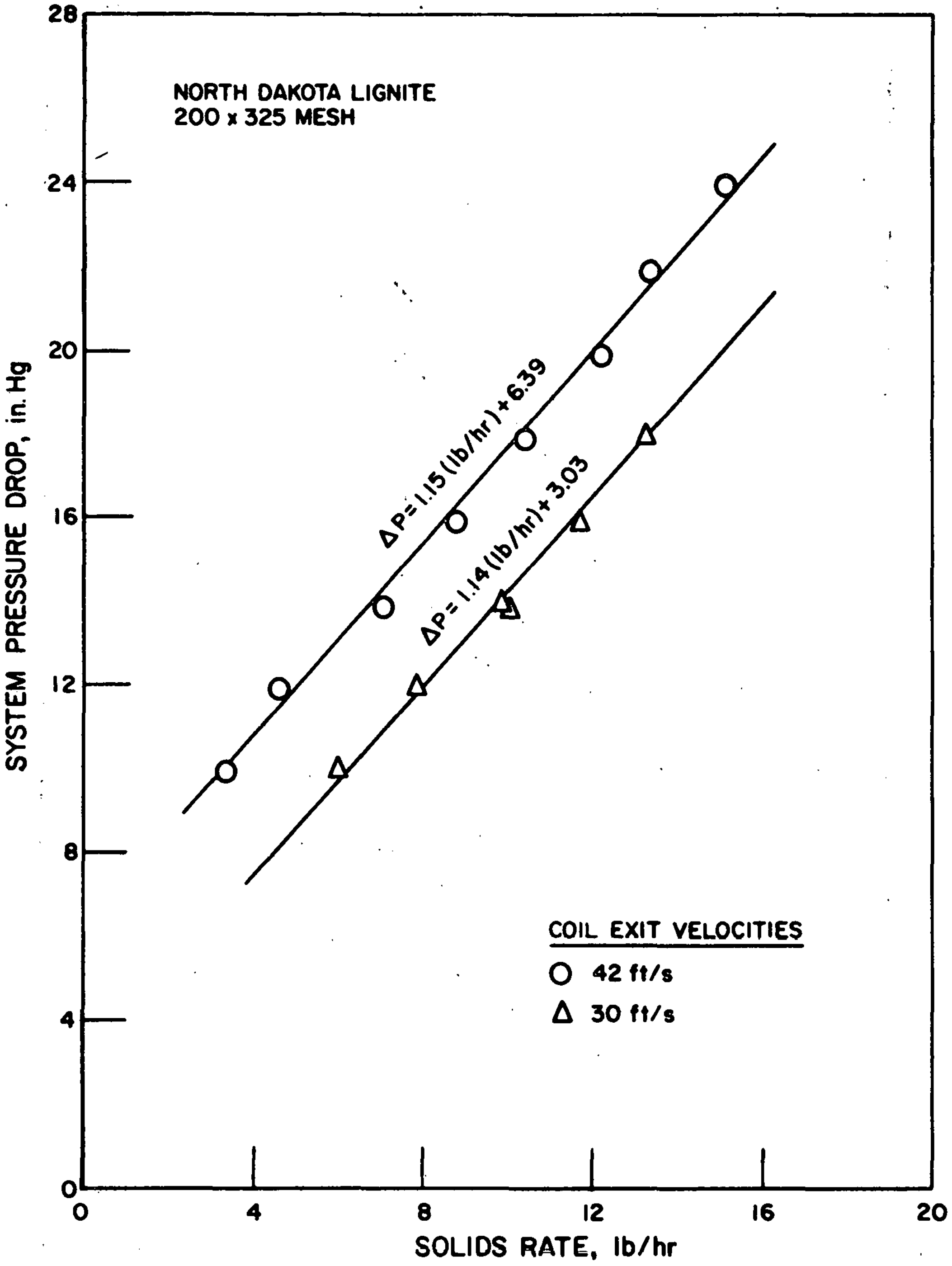

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Figure 5. INCREASE IN SYSTEM PRESSURE DROP WITH SOLIDS FLOW RATE (200 X 325 Mesh North Dakota Lignite)

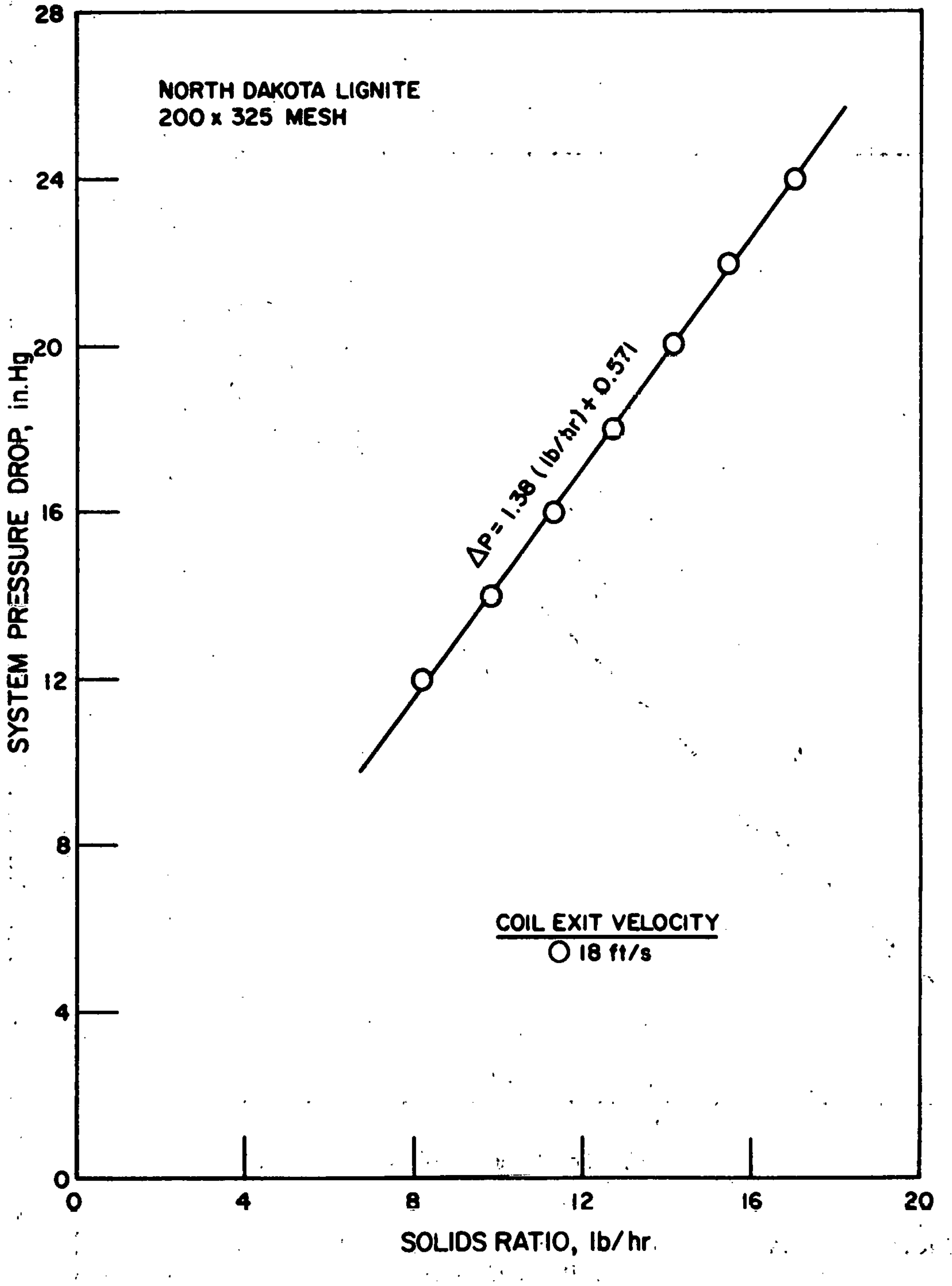

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Figure 6. INCREASE IN SYSTEM PRESSURE DROP WITH SOLIDS FLOW RATE AT LOW VELOCITY (200 X 325 Mesh North Dakota Lignite)

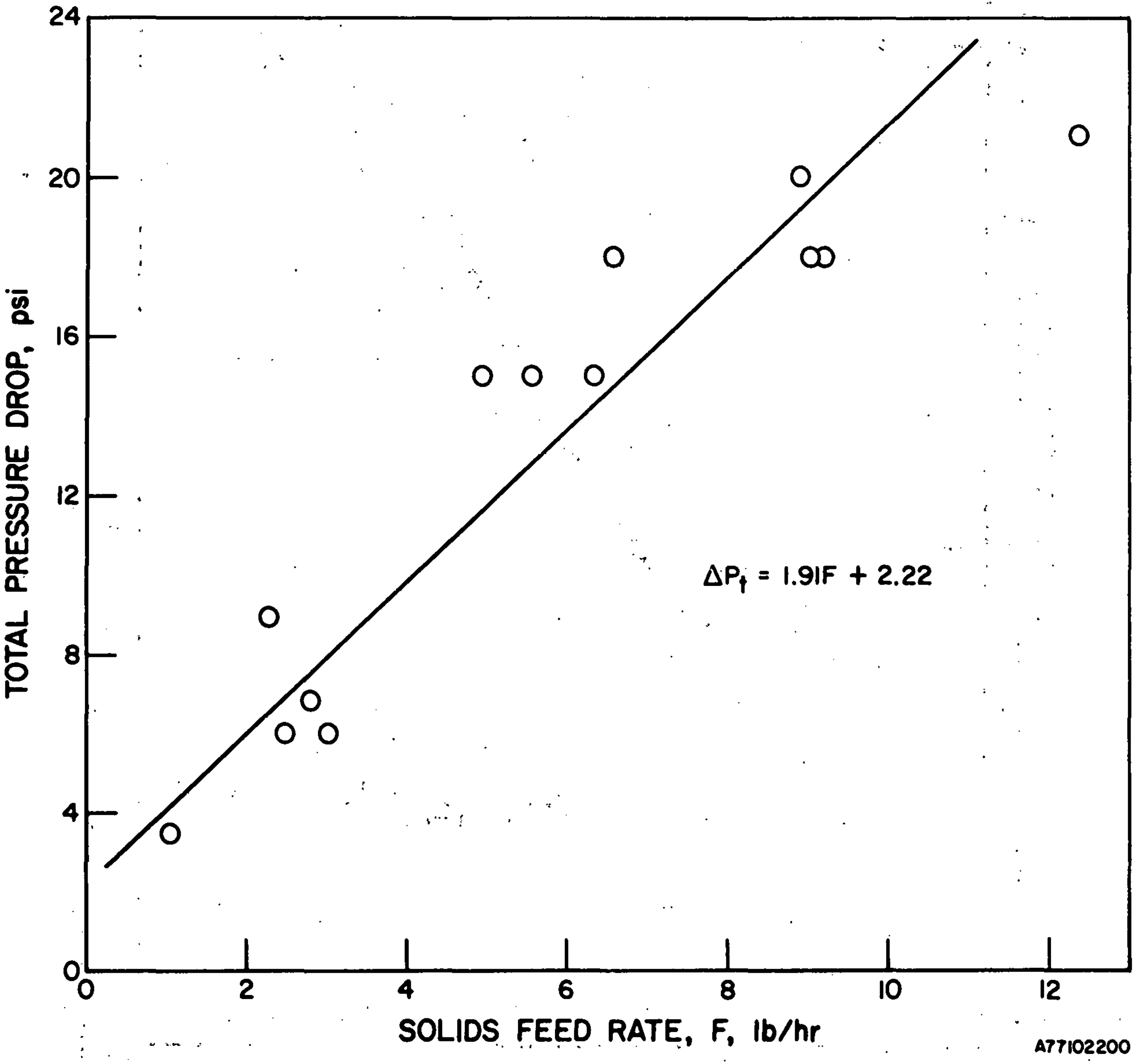

Figure 7. CHANGE IN BENCH-SCALE UNIT SYSTEM PRESSURE DROP WITH SOLIDS FEED RATE

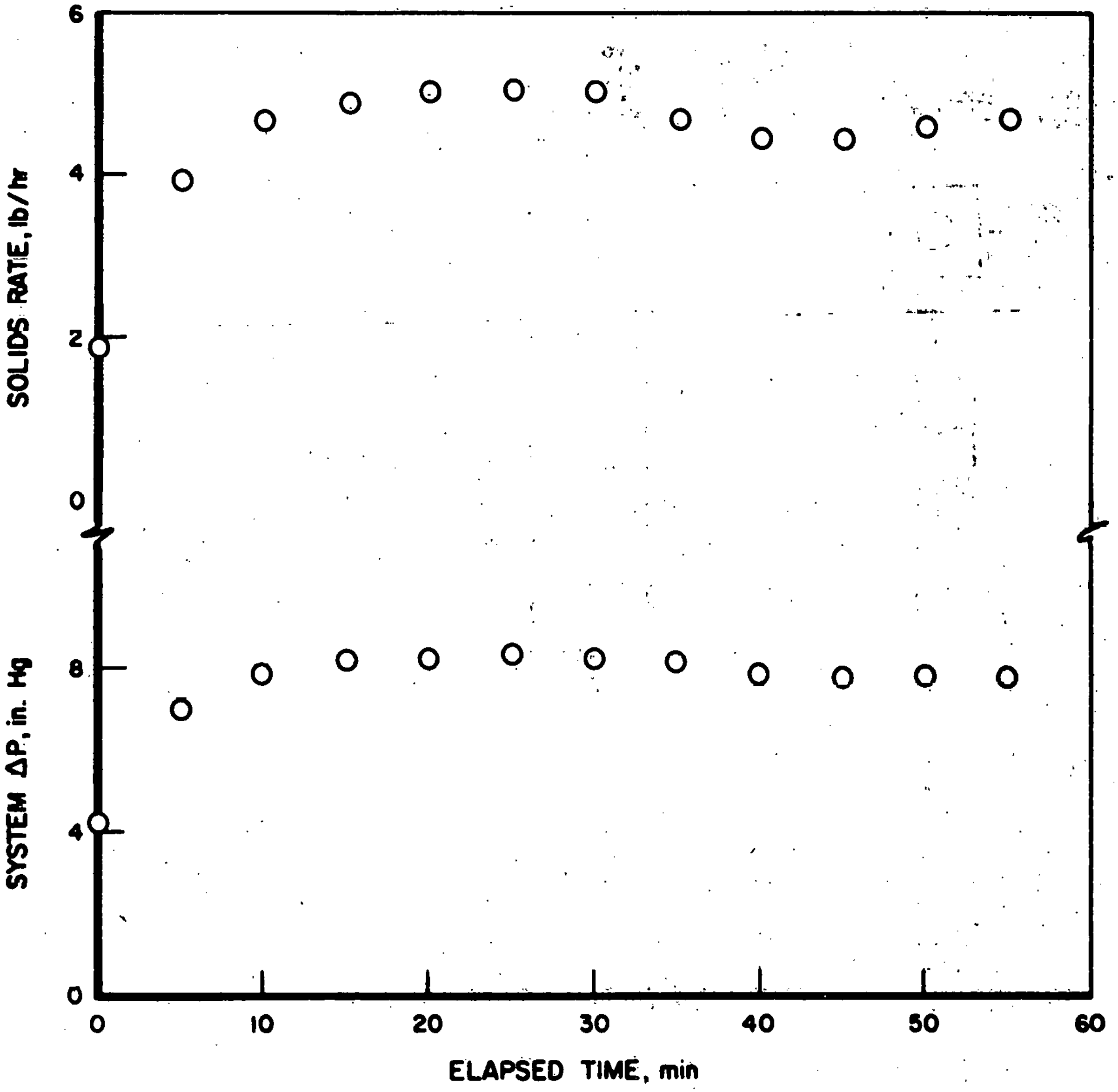

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Figure 8. TRANSIENT BEHAVIOR OF SOLIDS FEEDER WHEN OPERATED AT CONSTANT MASS FLOW

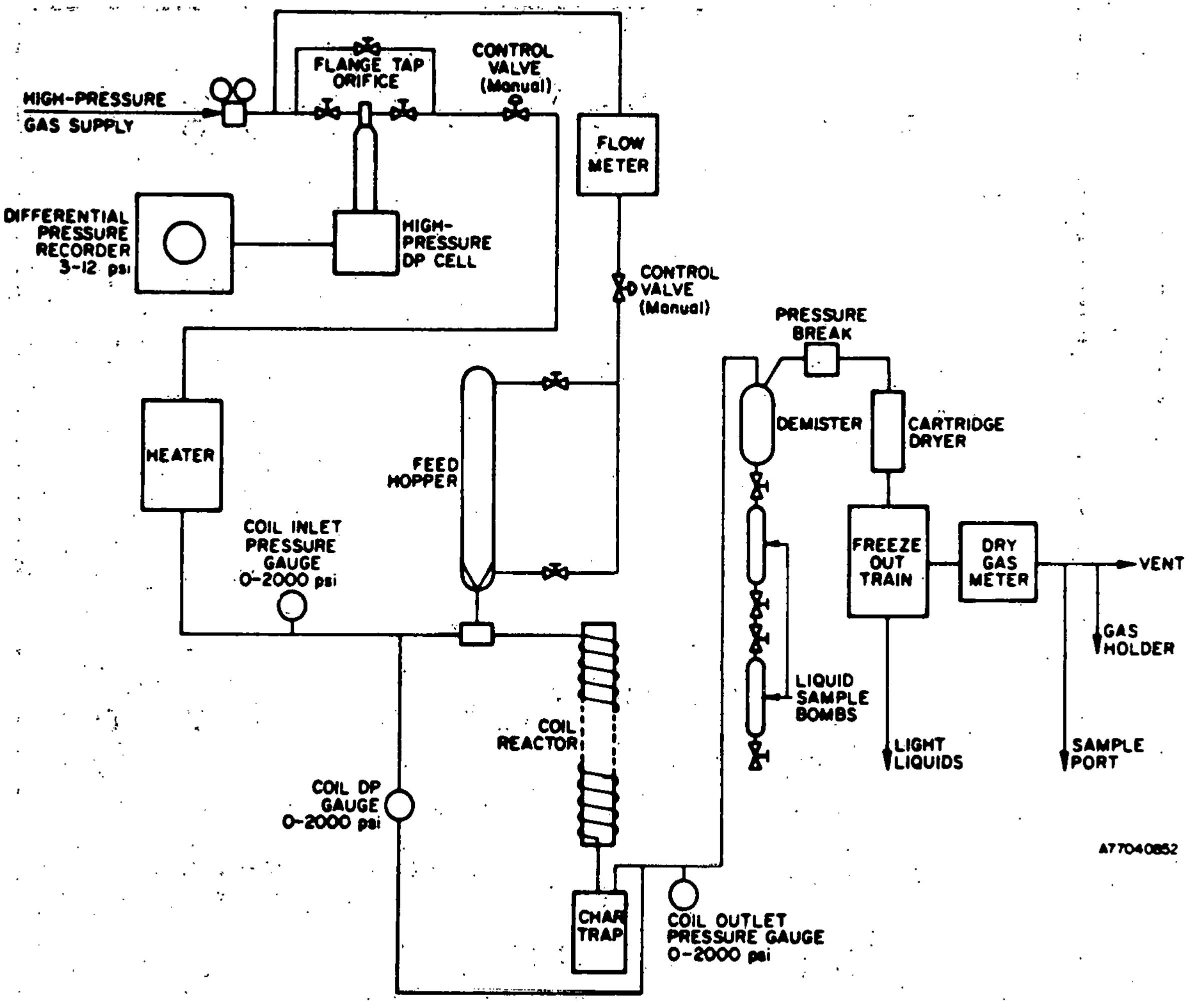

Figure 9. BENCH-SCALE UNIT

Provision was made to preheat gases and generate steam simultaneously using the preheater coil shown in Figure 10. When using this feature, the hot gases entrained the coal in a mixing block located just beneath the feed hopper. The system was introduced into the carrier line at the top of the reactor coil approximately 18-inches downstream from the feed hopper. This was done to prevent steam from wetting the coal and forming a plug.

4. Runs with North Dakota Lignite

a. Preliminary Runs

A summary of runs made in the bench-scale unit program is shown in Table 1. In the initial runs (P-1 though P-7), power plant grind (75% -200 mesh) North Dakota lignite was processed in hydrogen at system operating pressures of 500, 1000, and 1500 psig and coil outlet temperatures of 1000°, 1200°, 1400°, and $1500^{\circ}F$. At 1000° and $1200^{\circ}F$, processing proved to be too mild, and temperatures in the range of 1400° to $1500^{\circ}F$ were found to be necessary to obtain carbon conversions approaching those required for a "balanced plant" operation. Detailed descriptions and the operating data for these runs have been given in earlier reports (Annual reports for 1977 and 1978) and will not be repeated here.

In the remainder of the P-series of runs it was found that in addition to operating pressure and temperature, hydrogen-to-coal ratio has an important influence on feed carbon conversion as shown in Figure 11, in which carbon conversion is shown as it varies with both severity ($K\theta$) and hydrogen-to-MAF coal weight ratio. The severity function ($K\theta$) is an arbitrary measure of the severity of thermal treatment based on the published kinetics of anthracene decomposition in hydrogen.[16] The value of the severity function is the product of the kinetic rate constant k and the time interval the reactants are held at temperature. For a non-isothermal process, the rate constants at the average temperature of suitably small time increments $\Delta\theta$ are used, so that over the whole process —

$$K\theta = \Sigma k\Delta\theta \qquad (1)$$

The details of this numerical method are described in earlier reports, for example, the Third Quarter Report, 1977, page 9.

From Figure 11, it can be seen that at a given operating pressure, significant increase in carbon conversion can be obtained by increasing hydrogen-to-coal ratio for the same runs shown in Figure 11. The effect of hydrogen-to-coal ratio on the yields of methane, ethane and light gases, and hydrocarbon liquids is shown in Figure 12. The effect on hydrocarbon liquids is more pronounced than the effect on methane and ethane and light gas yields. The distribution of benzene, toluene, xylenes and ethyl benzene, and phenols and cresols in the gasoline-boiling-range fraction of hydrocarbon liquids is shown in Figure 13.

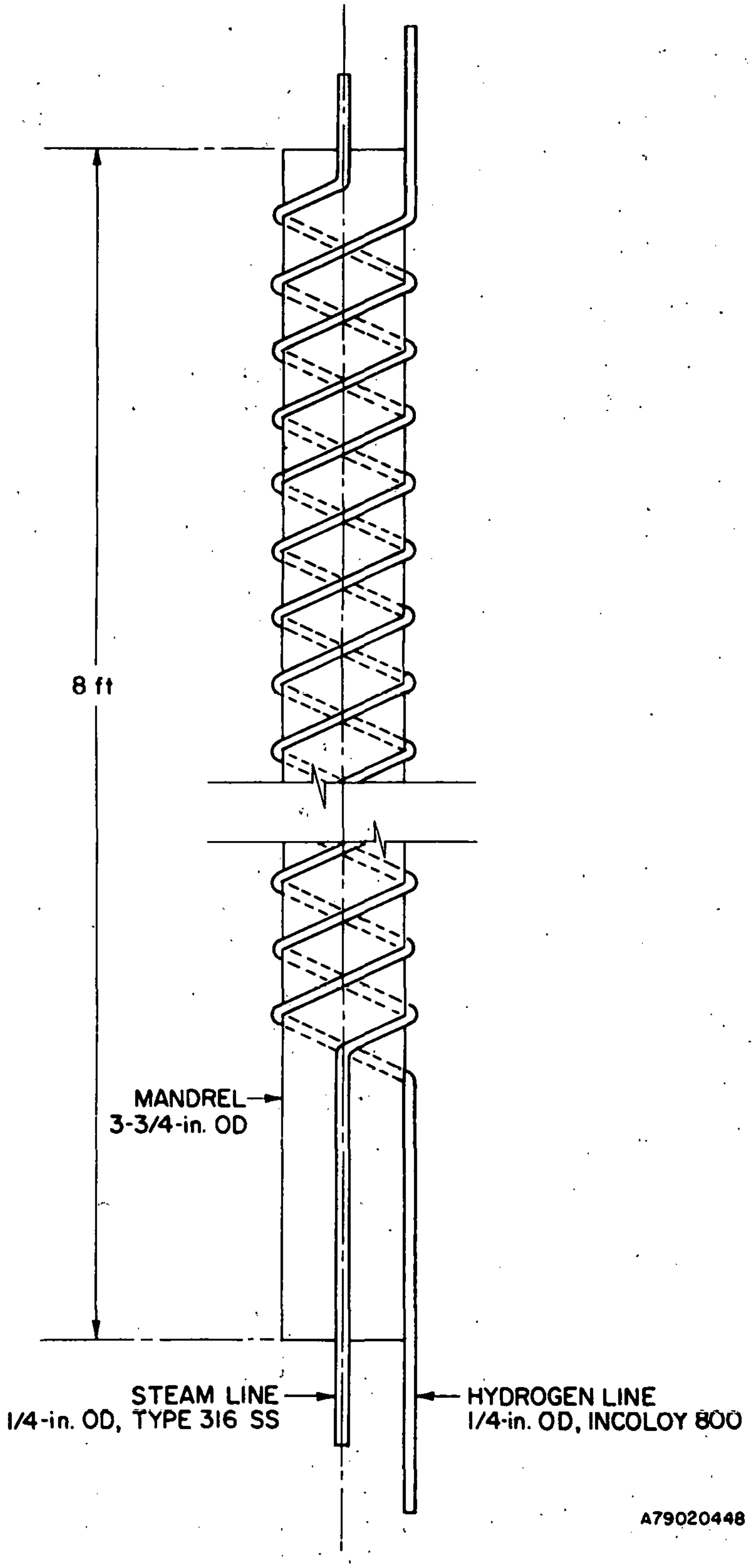

Figure 10. BENCH-SCALE UNIT PREHEATER COIL

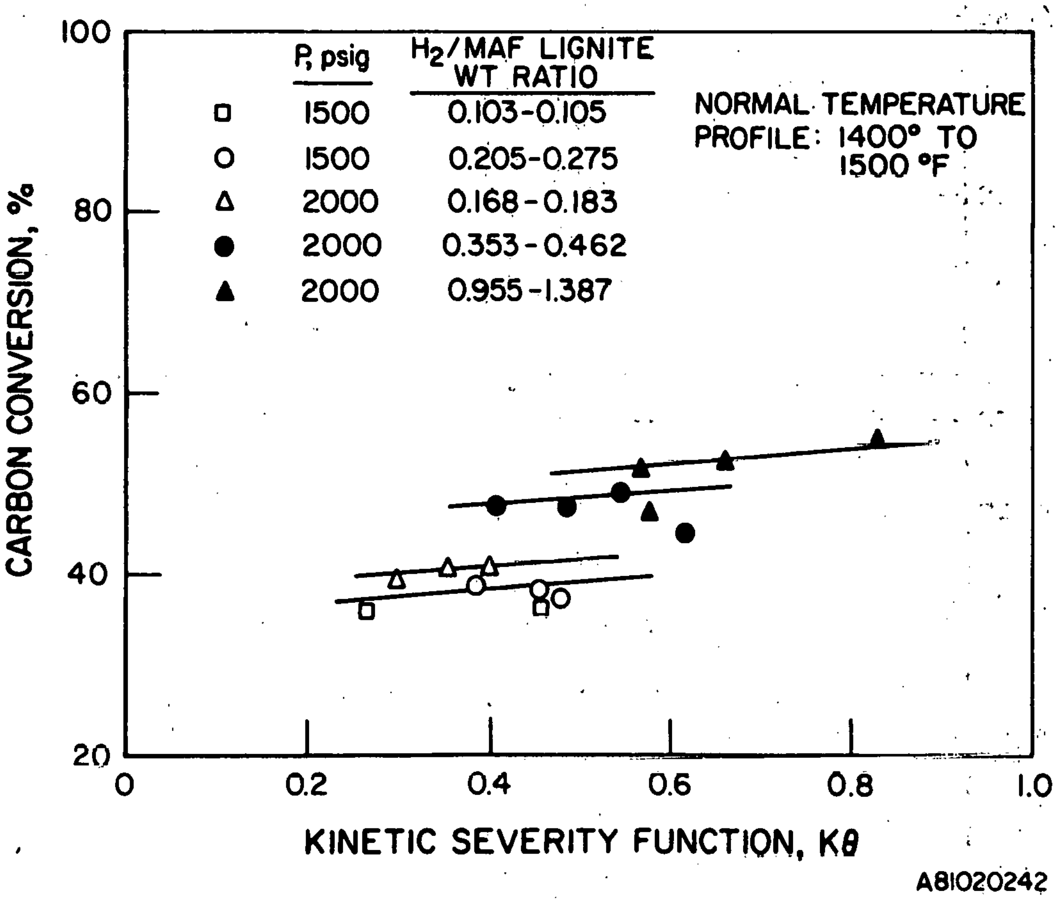

Figure 11. CHANGE IN CARBON CONVERSION WITH THERMAL SEVERITY AND HYDROGEN LEVEL IN FEED

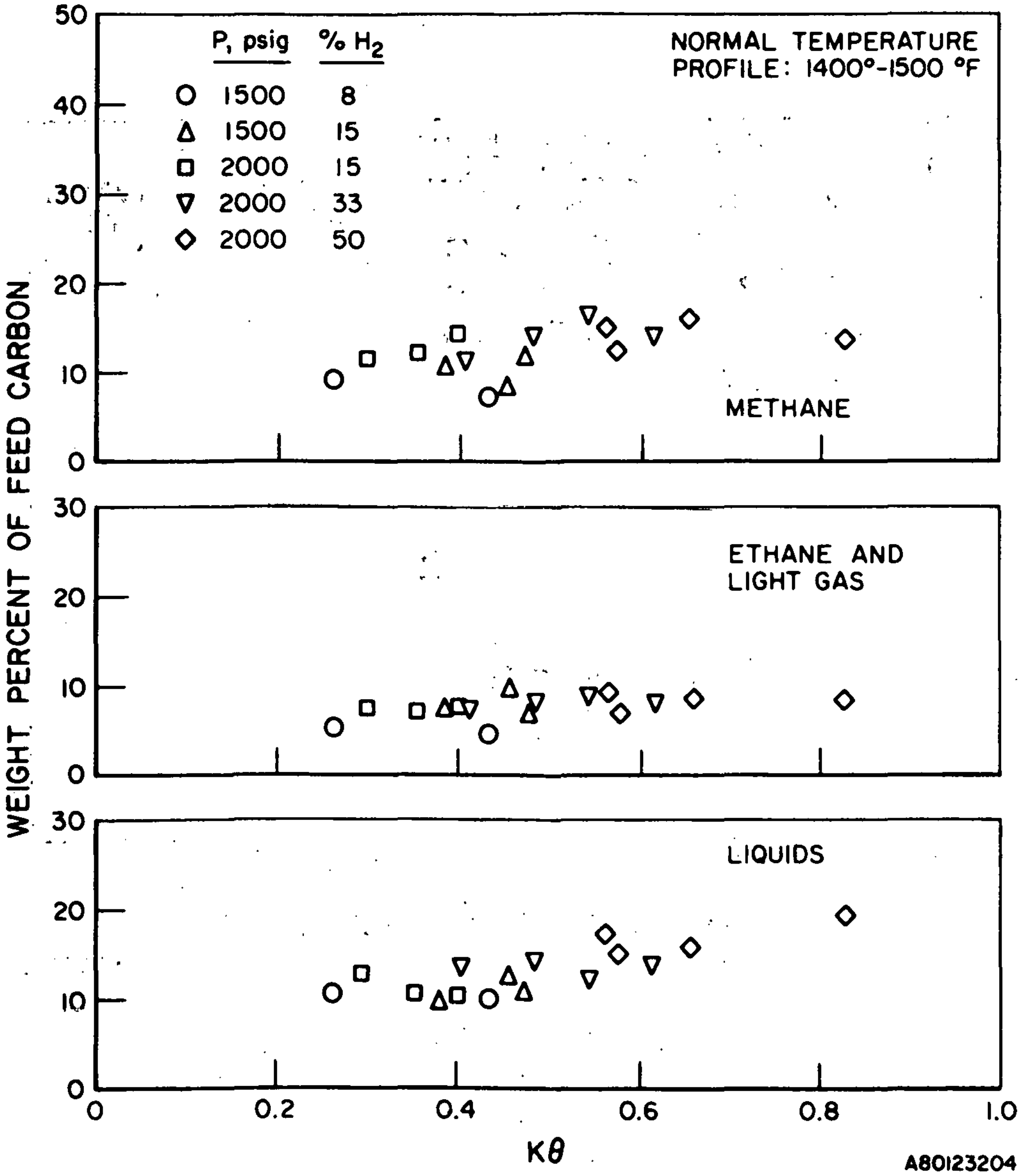

Figure 12. YIELDS OF METHANE, ETHANE AND LIGHT GAS AND HYDROCARBON LIQUIDS IN PRELIMINARY RUNS

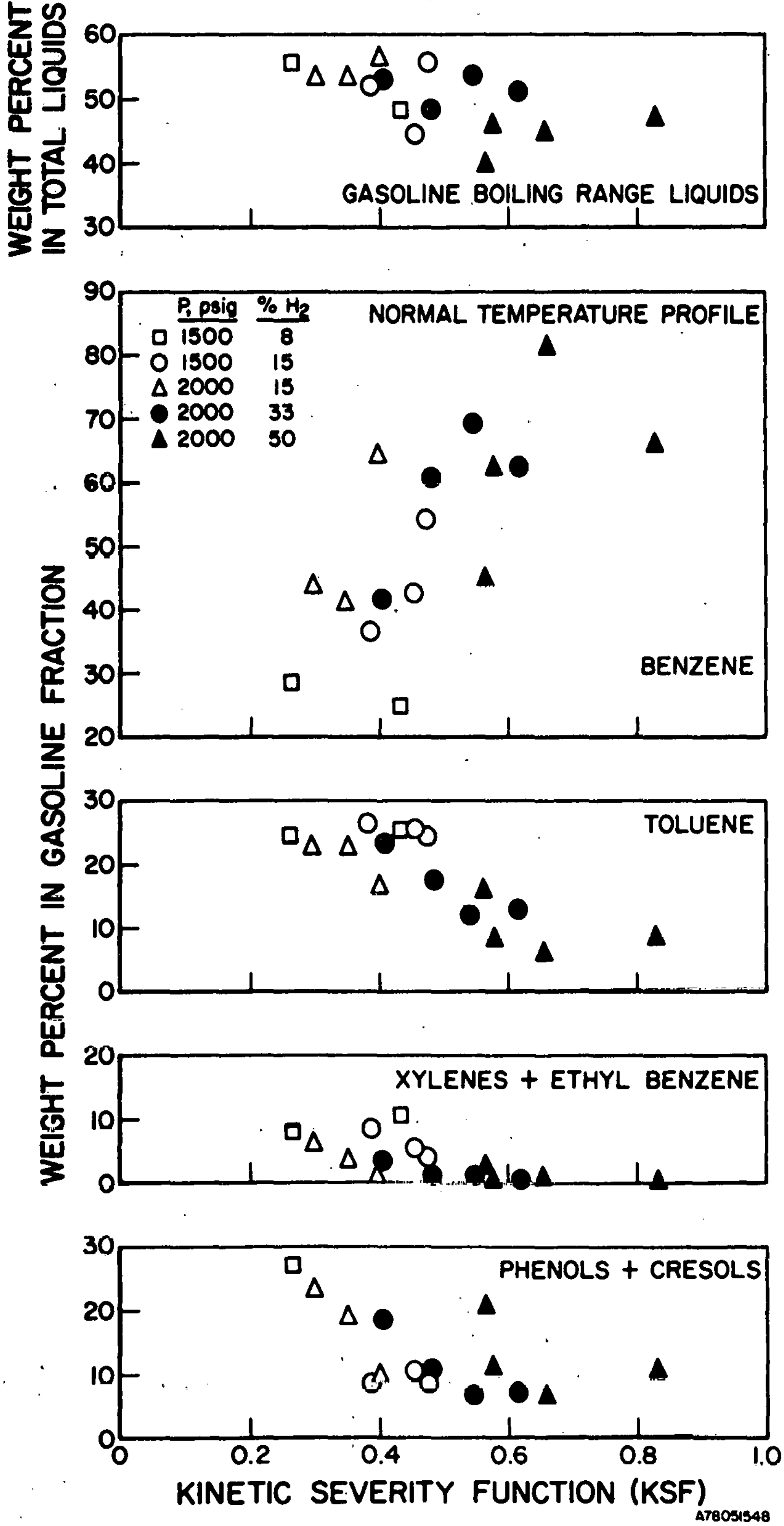

Figure 13. DISTRIBUTION OF BENZENE, TOLUENE, XYLENES, AND PHENOLS IN GASOLINE BOILING RANGE LIQUIDS, P SERIES, 1400° TO 1500°F

Table 1. RISER CRACKING PROJECT BENCH-SCALE UNIT PROGRAM

Run Series	Objectives	Variable Ranges Temp, °F	System Pressure, psig	Residence Time, s	Hydrogen/MAF Coal, lb/lb
P1-7	First runs, essentially isothermal	1000-1500	500-1500	1-3	0.1-0.8
P7-28	"Normal" rising temperature profile; exploration of major variables	1900-1500	1500-2000	1.6-3.5	0.1-1.4
RC1-2	Operation with spent char from prior runs	1475	2000	3.3	0.3
TP1-11	Explore effect of changing temperature profile on product distribution	1450-1500	2000	2.4-3.8	0.3-0.9
RT1-3	Explore effect of increased residence time	1450	1500-2000	3.9-5.2	0.2-0.3
PS1-6	Low temperature soak simulating PDU preheater	1200-1300	1500	3	0.3-0.5
PP1-12	Examine operation of lower pressures	1500	500-1000	3	0.2-0.8
BC1-20	Operate with Illinois No. 6 diluted with sand or dead-burned char	1450-1500	2000	3	0.7-1.3
SF1-5	Explore operation with slurries of lignite and bituminous coal	1400-1500	1500	2-3	0.3-1.5
CT1-14	Explore operation with bituminous coal treated to obtain a non-agglomerating product	1425-1500	2000	3-4	0.3-2.7
HR1-7	Explore the effects of heating rate on product distribution	1500	2000	2.6-4.6	0.26-0.55
HH1-14	Explore the use of hydrogen preheated to pyrolysis temperature	1375-1450	1750	2.8-5.0	0.2-2.8
ES1-6	Explore the substitution of steam for hydrogen	1475	1750	2.0-2.3	0.3-1.6
PSI1	Explore the effect of particle size	1475	1500	3.9	1.0
SYN1-6	Explore the effect of substituting syngas for hydrogen	1475	1200	3	N/A
UL1-2	Evaluate the effect of predrying lignite	1475-1500	2000	3	0.2-0.5

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The fraction of liquids reporting to the gasoline-boiling-range liquids appears to decrease with increase in hydrogen-to-coal ratio; the fraction of benzene increases, while the fractions of toluene, xylenes + ethyl benzene, and phenols + cresols decrease with increase in severity function. This would suggest that at high hydrogen-to-coal ratios, a portion of the gasoline-boiling-range liquids is hydrogasified to methane, ethane, and propane. With increase in severity, the increase in benzene appears to be due to dealkylation of toluene, xylenes, and ethyl benzene and dehydroxylation of the phenols and cresols.

b. Recycle Char Runs

Two runs were made in which char from North Dakota lignite used in the P series of runs was processed at 2000 psig and 1475°F in hydrogen. In both runs approximately 20 percent of the feed carbon was converted to products, with approximately 5 percent of the char carbon being recovered as hydrocarbon liquids. The liquids were heavy, viscous material; the amount recovered was not sufficient for a further analysis. Clearly, however, the char, even after standing several weeks, remained capable of further conversion. Also, hydrocarbon liquids appear to be generated throughout the pyrolysis, rather than in the initial stages only.

c. Temperature Profile Runs

In the preliminary series of runs the imposed temperature profile used is shown in Figure 14. This profile was arbitrary, and was devised as a starting point in the investigation. Other temperature profiles also shown in Figure 14 were investigated to study the effects on carbon distribution among products. In the constant heating rate profile, a temperature rise which was linear with reactor length was used; there was no residence time at the maximum temperature. In the "upsweep" profile the heating rate increased with reactor length. In the "soak and spike" profile, a soaking period of 1200°F was provided with subsequent rapid heating to 1500°F at the coil outlet. For constant feed rates, using different temperature profiles, the order of the values of $K\theta$ would be normal > constant heating rate > "soak and spike" > "upsweep."

The carbon distribution obtained in the TP series is plotted against severity in Figure 15. From the figure, it can be seen that carbon conversion and methane yield both increase with severity, while the ethane + light gas and hydrocarbon liquid yields remain essentially constant. The distribution of benzene, toluene, xylenes + ethyl benzene, and phenols + cresols in the gasoline-boiling-range liquids is shown in Figure 16. From the figure, it can be seen that the fractions of phenols + cresols and xylenes + ethyl benzene decrease with increase in severity, while the fraction of benzene increases. Clearly, the types of products can be altered through the time-temperature history of the reactants by operating on the imposed temperature profile. Temperature profiles characterized by low values of severity function yield phenols, cresols, xylenes, ethyl benzene, and toluene, while temperature profiles characterized by high values of severity function produce benzene.

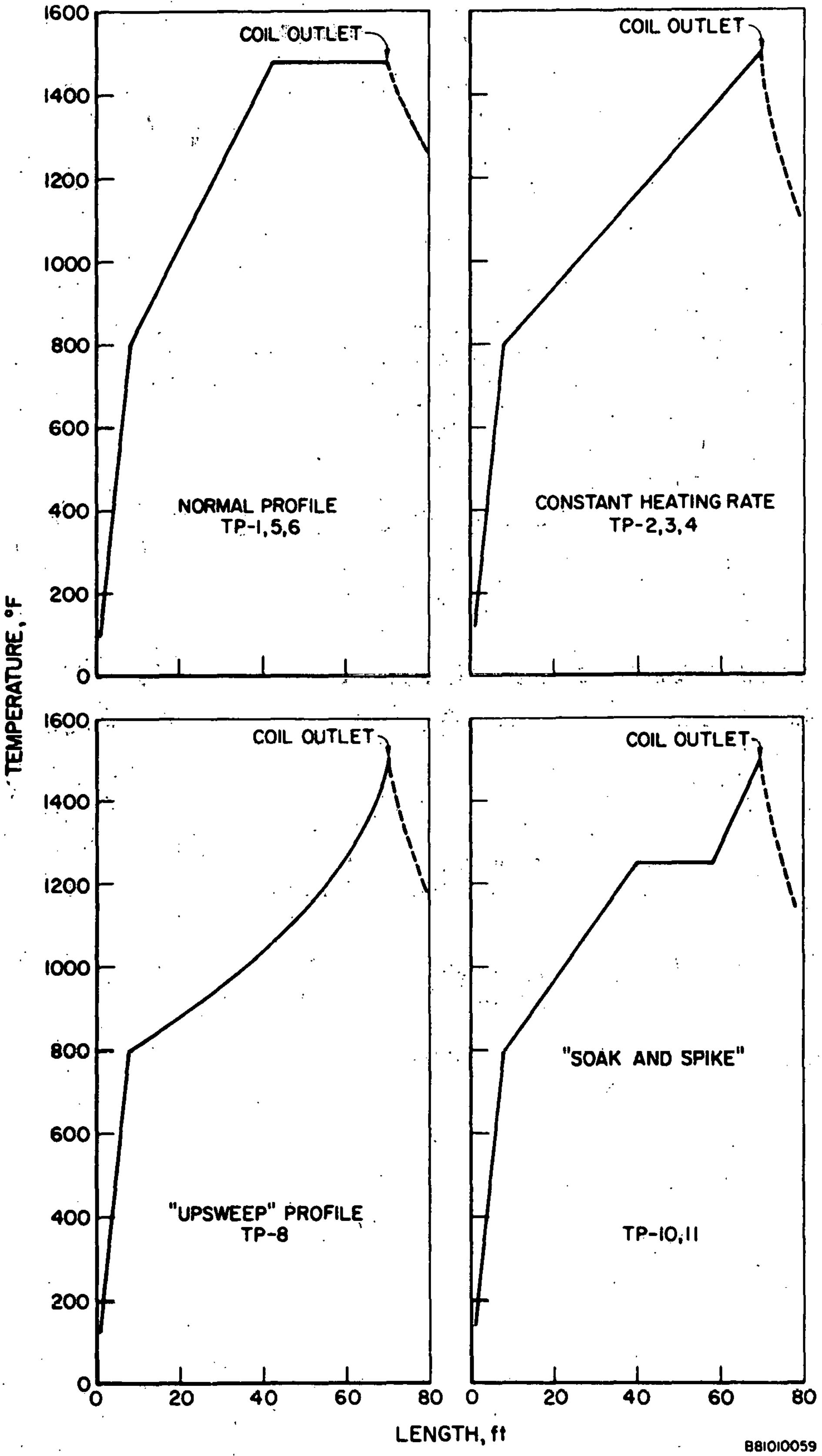

Figure 14. TEMPERATURE PROFILES USED IN BENCH-SCALE UNIT OPERATIONS

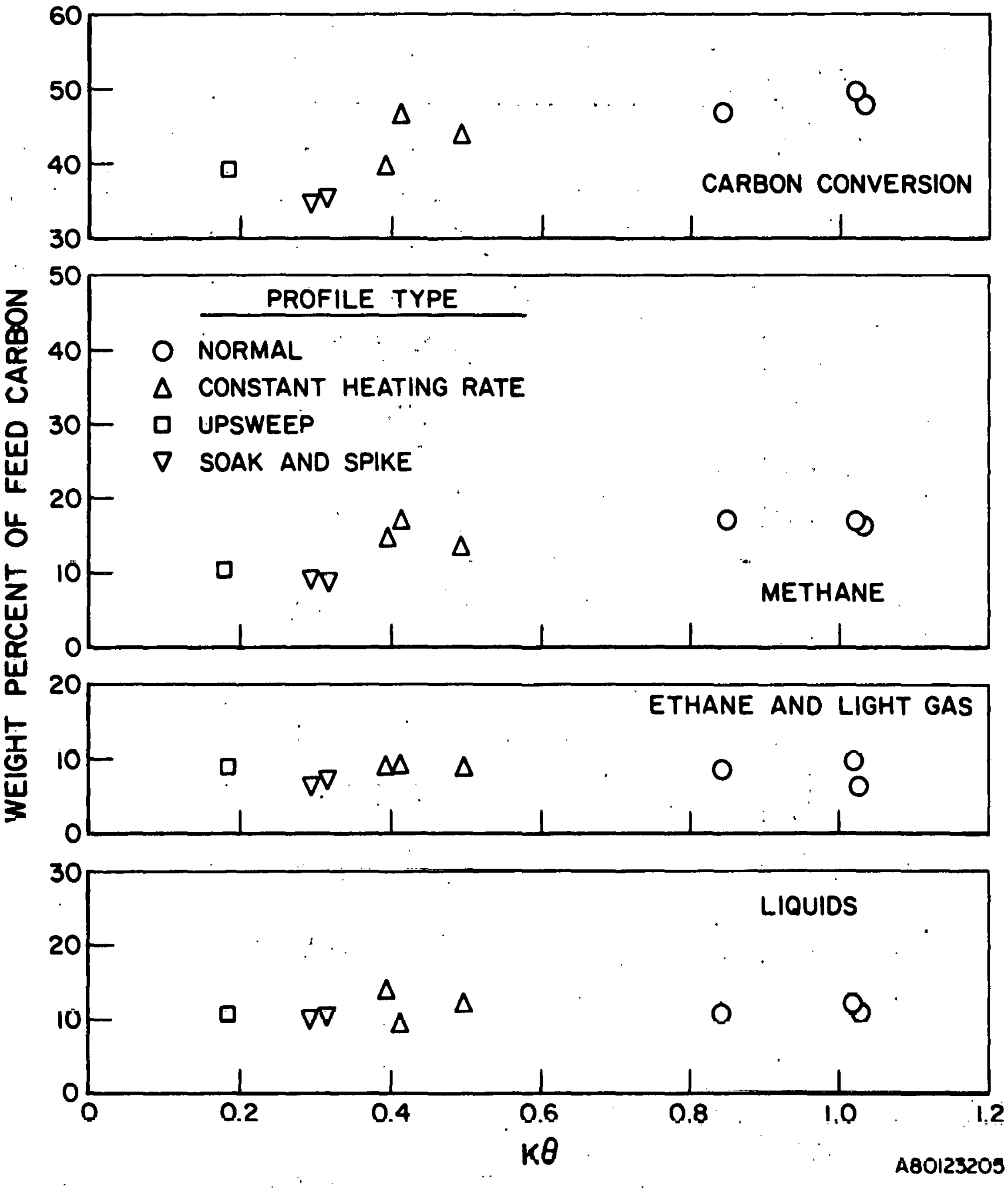

Figure 15. CARBON CONVERSION, METHANE, ETHANE, AND HYDROCARBON LIQUIDS YIELDS FOR TEMPERATURE PROFILE RUNS

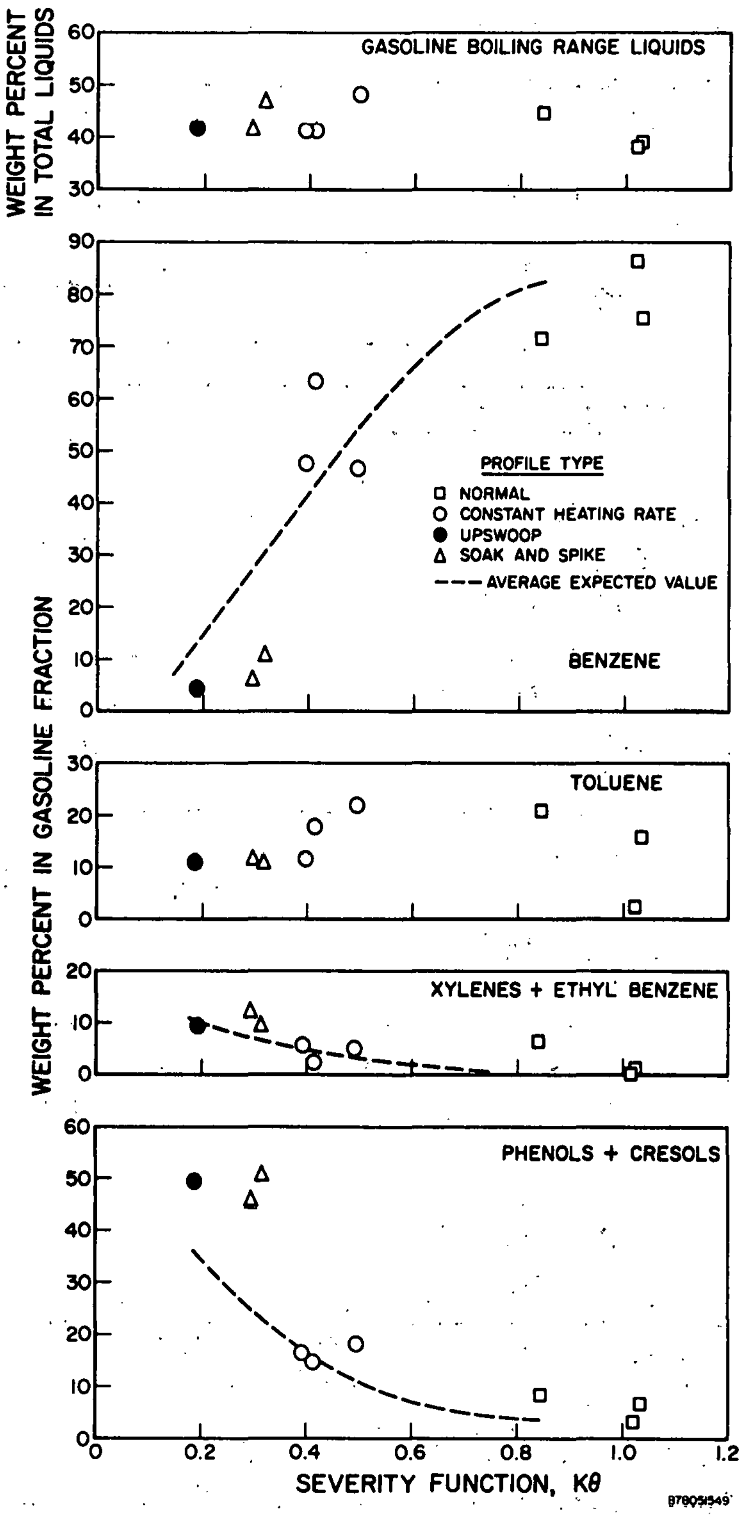

Figure 16. DISTRIBUTION OF BENZENE, TOLUENE, XYLENE + ETHYLBENZENE, AND PHENOLS + CRESOLS IN GASOLINE BOILING RANGE LIQUIDS FOR TEMPERATURE PROFILE RUNS

d. Extended Residence Time Runs

The effects of residence time were investigated at system operating pressures of 1500 and 2000 psig and 1450°F. The operating data and carbon distributions are summarized in Table 2, and the distributions of benzene, toluene, xylenes + ethyl benzene and phenols + cresols in the gasoline boiling-range liquids are shown in Figure 17. The effect of the longer residence times was slight, and the distributions of benzene, toluene, xylenes + benzene, and phenols + cresols appear to be extensions of the distributions shown in Figures 15 and 16.

Table 2. SUMMARY OF EXTENDED RESIDENCE TIME RUNS

Run No.	RT-1	RT-2	RT-3
Coil Outlet Temperature, °F	1450	1450	1450
System Outlet Pressure, psig	2000	2000	1500
Residence Time, s	4.1	5.2	3.9
Carbon Conversion, %	42.9	42.5	35.6
H_2/MAF Coal, lb/lb	0.295	0.194	0.198
Severity Function, Kθ	0.979	1.300	0.978
Carbon Distribution, %			
Hydrocarbon Liquids	9.92	12.83	10.81
Carbon Oxides	6.83	8.12	7.80
Methane	14.57	13.90	11.50
Ethane + Light Gas	8.07	7.44	5.99
Char	55.83	56.90	63.90

e. Preheater Simulation

In the design of the PDU, feed coal and hydrogen were to be preheated to 1200°F in a fired coiled-tube heater. Six runs were made in the bench-scale unit to explore the operation of the PDU preheater at 1500 and 2000 psig operating pressure. With the coil outlet temperature of 1300°F, a trouble free operation was easily obtained, but at 1200°F, some plugging of the make-gas lines with tars was observed, particularly just downstream from the char trap.

f. Pressure Profile Runs

The effects of system operating pressure on the conversion and distribution of carbon among products was investigated in a series of runs in which power plant grind North Dakota lignite was processed with hydrogen at pressures of 500, 1000, 1500, and 2000 psig. The effect of pressure on carbon conversion is shown in Figure 18, which shows carbon conversion increasing with pressure. In Figures 19 and 20, both the methane + ethane yields and hydrocarbon liquids yields can be seen to increase with pressure, in a manner consistent with the Johnson model.[9] The distribution of BTX + ethyl benzene and phenols + cresols in the gasoline-boiling-range liquids was found to be changed with pressure, as shown in Figure 21. Here, an increase in pressure can be seen to have an effect equivalent to an increase in severity (Kθ). Much of the increase in benzene and decrease in phenols and cresols appears to take place by reaction with hydrogen in the vapor phase, with the reaction rates controlled by both temperature and hydrogen partial pressure in a manner analogous to the vapor phase dealkylation of toluene described by Silsby and Sawyer,[13] as shown in Figure 22.

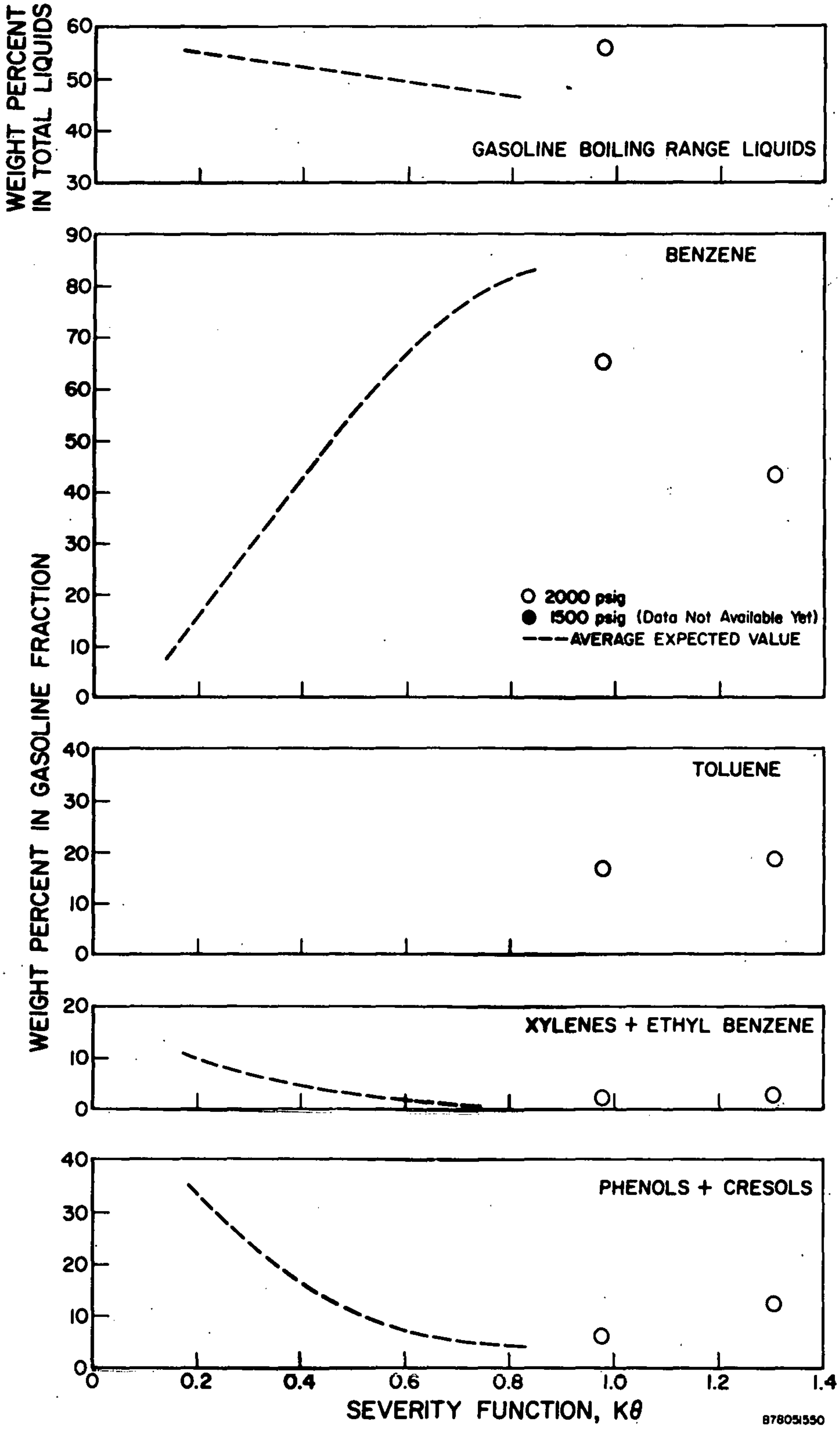

Figure 17. DISTRIBUTION OF BENZENE, TOLUENE, XYLENE + ETHYL BENZENE, AND PHENOLS + CRESOLS IN GASOLINE BOILING RANGE LIQUIDS FOR EXTENDED RESIDENCE TIME RUNS

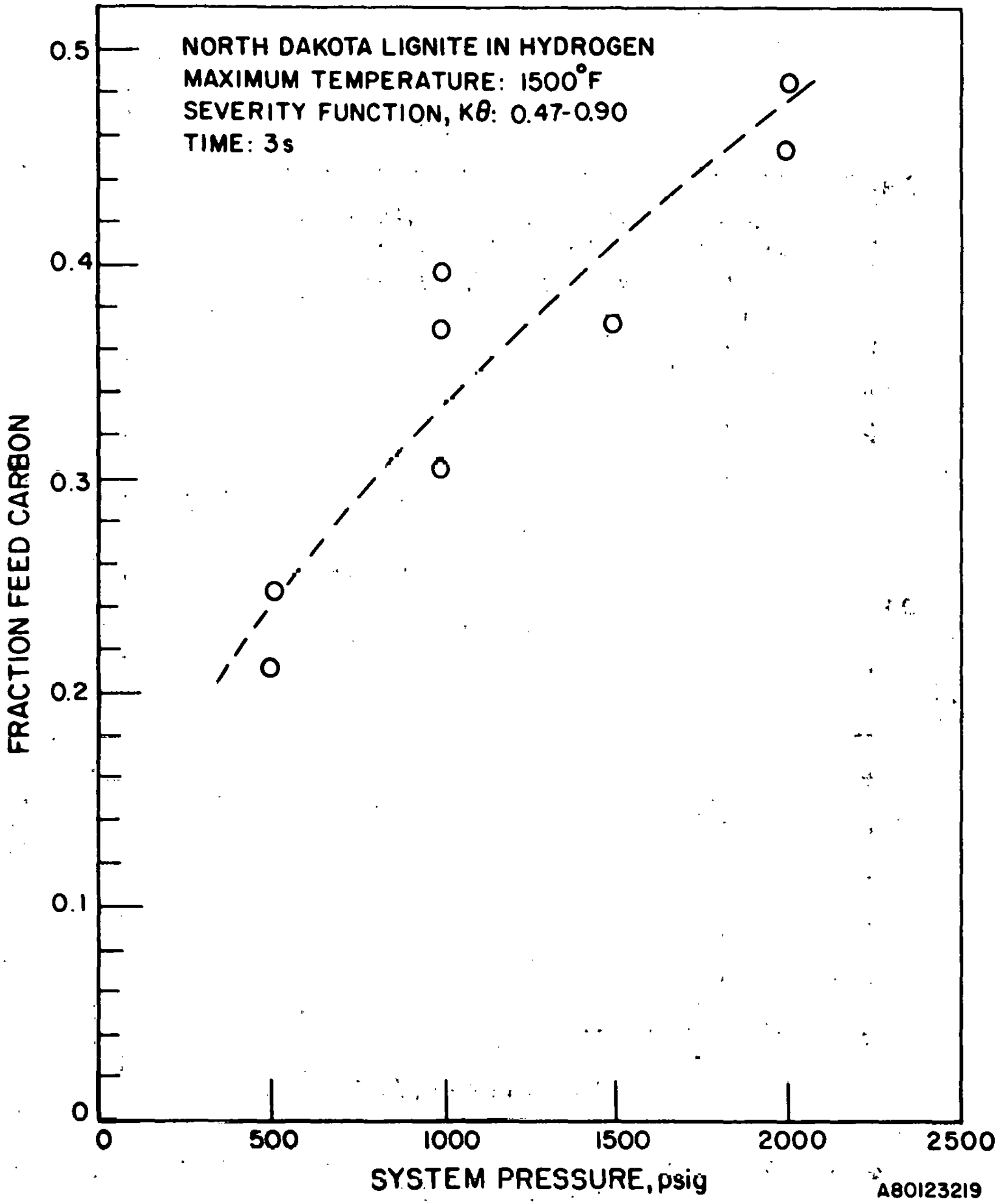

Figure 18. CARBON CONVERSION AS A FUNCTION OF SYSTEM PRESSURE

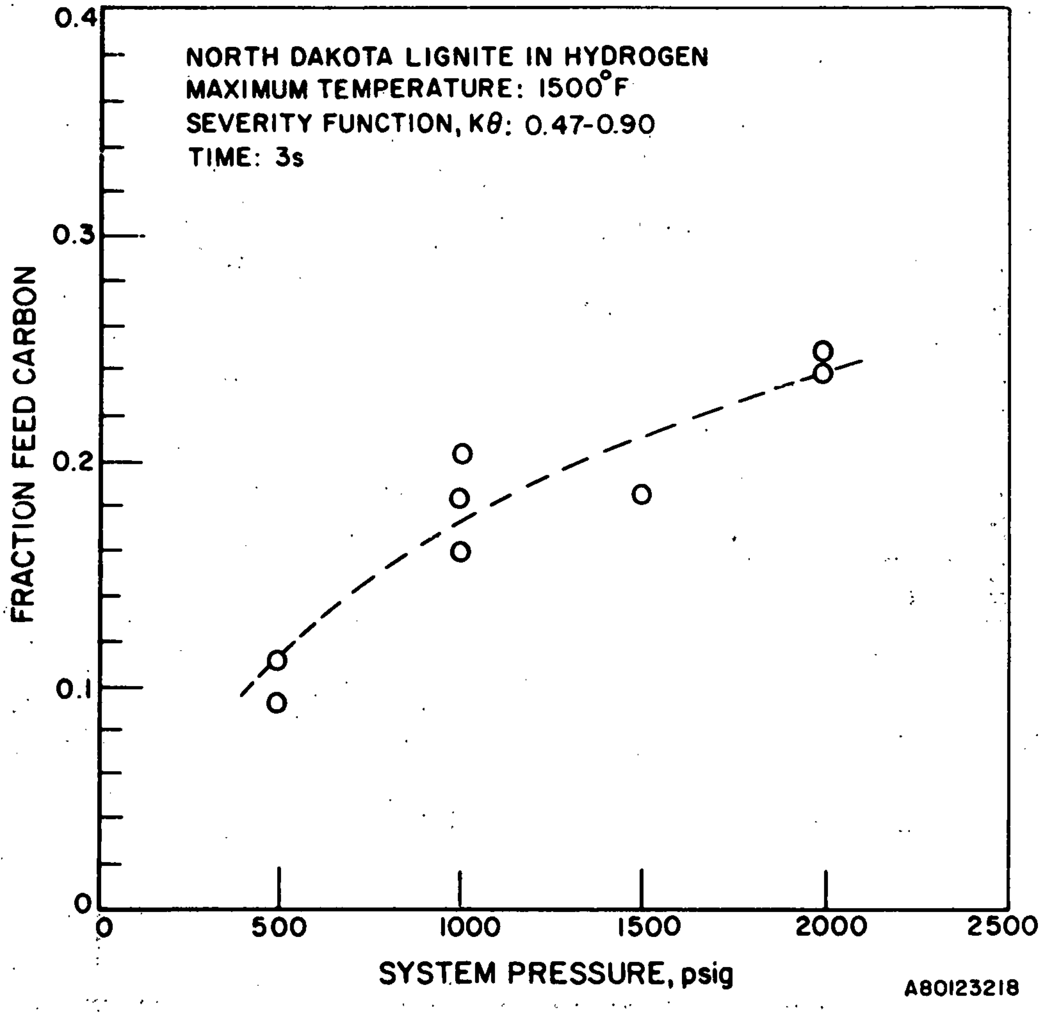

Figure 19. YIELD OF METHANE PLUS ETHANE AS A FUNCTION OF SYSTEM PRESSURE

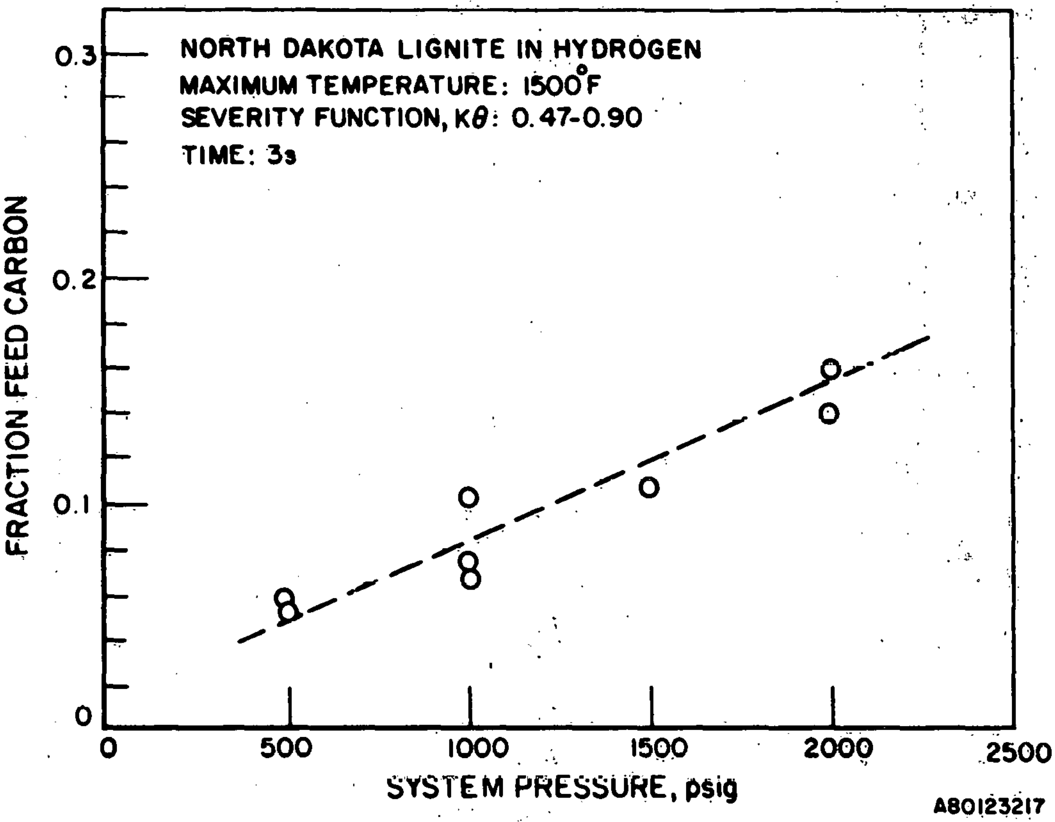

Figure 20. LIQUID YIELD AS A FUNCTION OF SYSTEM PRESSURE

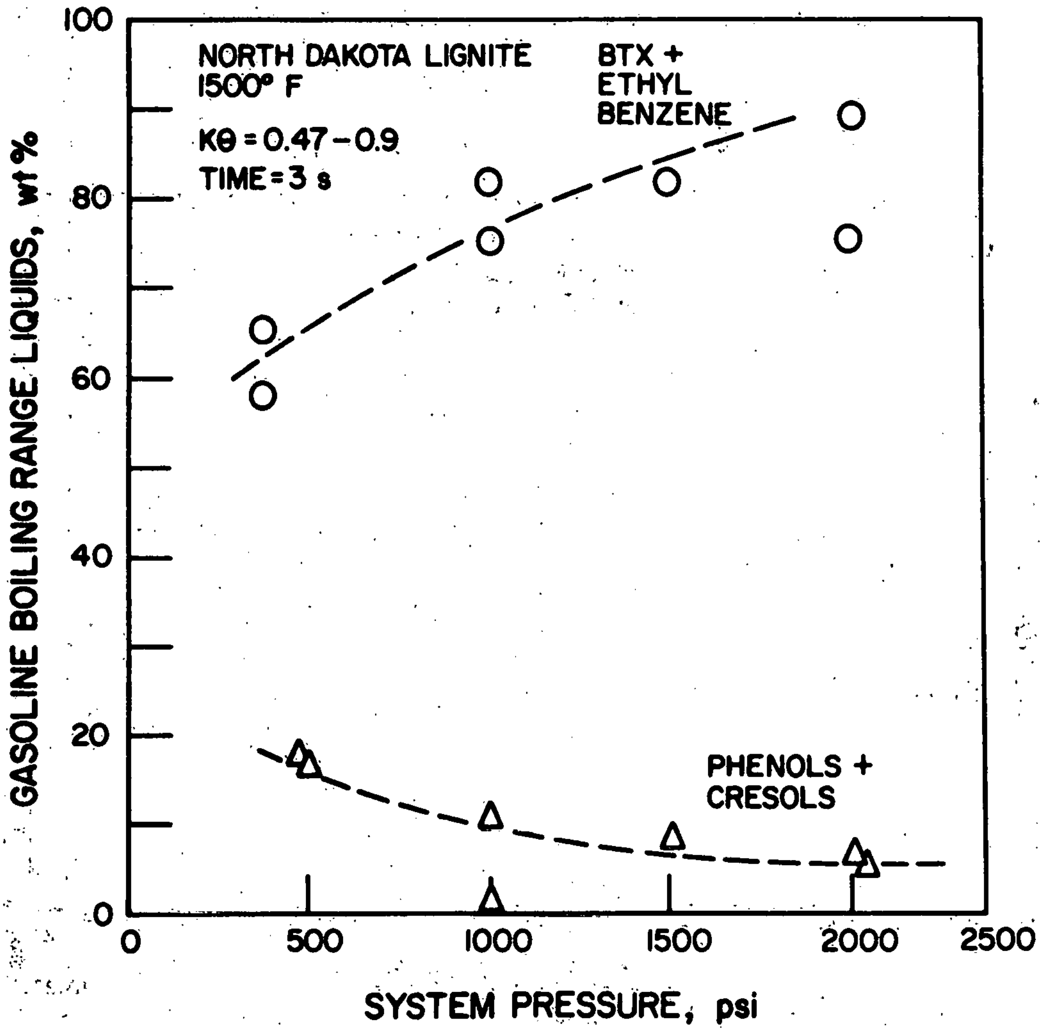

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Figure 21. CHANGE IN GASOLINE BOILING RANGE LIQUIDS COMPOSITION WITH PRESSURE

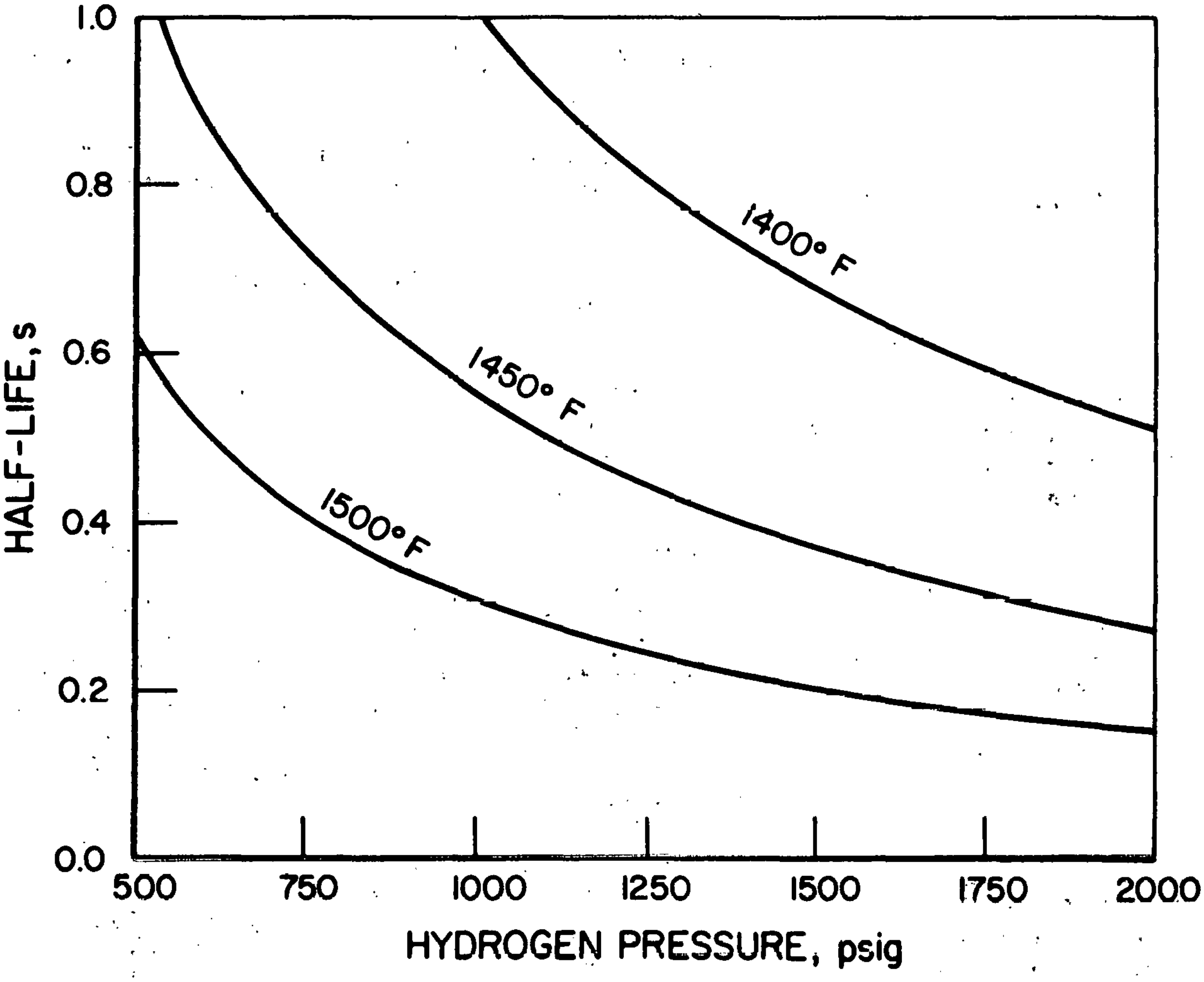

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Figure 22. CHANGE IN THE HALF-LIFE OF TOLUENE WITH TEMPERATURE AND HYDROGEN PARTIAL PRESSURE CALCULATED FROM DATA OF SILSBY AND SAWYER (20)

g. Correlation for Carbon Conversion

A kinetic model for estimating the conversion and distribution of carbon among gases, liquids, and char was developed by Johnson[9]; a typical product distribution calculated from this model is shown in Figure 23. In its present form, this model can be applied only to isothermal or constant heating rate cases; the most important variables are hydrogen pressure, time, and temperature. Because the Johnson model could not be easily applied to the data obtained in this investigation, a correlation was obtained by regression analysis of the data of the form —

$$\frac{1}{1 - x} = A \left(p_{H_2}\right)^{a} (K\theta)^{b} \qquad (2)$$

where x is the fraction carbon converted, p_{H_2} is the effective hydrogen partial pressure in psia, and Kθ is the value of the severity function to obtain —

$$\frac{1}{1 - x} = 0.2741 \left(p_{H_2}\right)^{0.2591} (K\theta)^{0.07229} \qquad (3)$$

The effective hydrogen partial pressure is obtained by adjusting the inlet hydrogen partial pressure, to account for the free moisture in the feed lignite and the steam and carbon oxides released from the feed coal; these were taken to be 54% and 25% of the oxygen in the feed coal.

The expected carbon conversion is compared with observed carbon conversion for the P, TP, RT, PS, PP, and HR series of runs in Figure 24. The coefficient of correlation for the expression given in Equation 3 is 91.5%. The effective hydrogen partial pressure was found to have a strong influence on the depth of carbon conversion; at low hydrogen-to-MAF coal weight ratios, the effective hydrogen partial pressure could be less than the inlet hydrogen partial pressure by several hundred psi.

h. Hydrogen Consumption

Hydrogen consumption for the P, TP, and RT series was calculated from the operating data, obtaining the data shown in Figure 25. Hydrogen consumption appears to vary linearly with carbon conversion, and at 50% carbon conversion was approximately 5.5 grams per 100 grams MAF feed lignite.

5. Runs With Bituminous Coal

a. Runs With Silica Sand and Dead-Burned Char

As a part of the planned experimental program, a series of runs was made using a moderately caking Illinois No. 6 coal having a free swelling index of 4-1/2. In the first runs (BC series), the coal was diluted with −200 mesh silica sand and processed in the bench-scale unit at 2000 psig system operating pressure and coil outlet temperatures ranging from 1400° to 1500°F. Mixtures of 10 weight percent as-received coal and 20 weight percent as-received coal in sand were easily processed, but a mixture of 30 weight

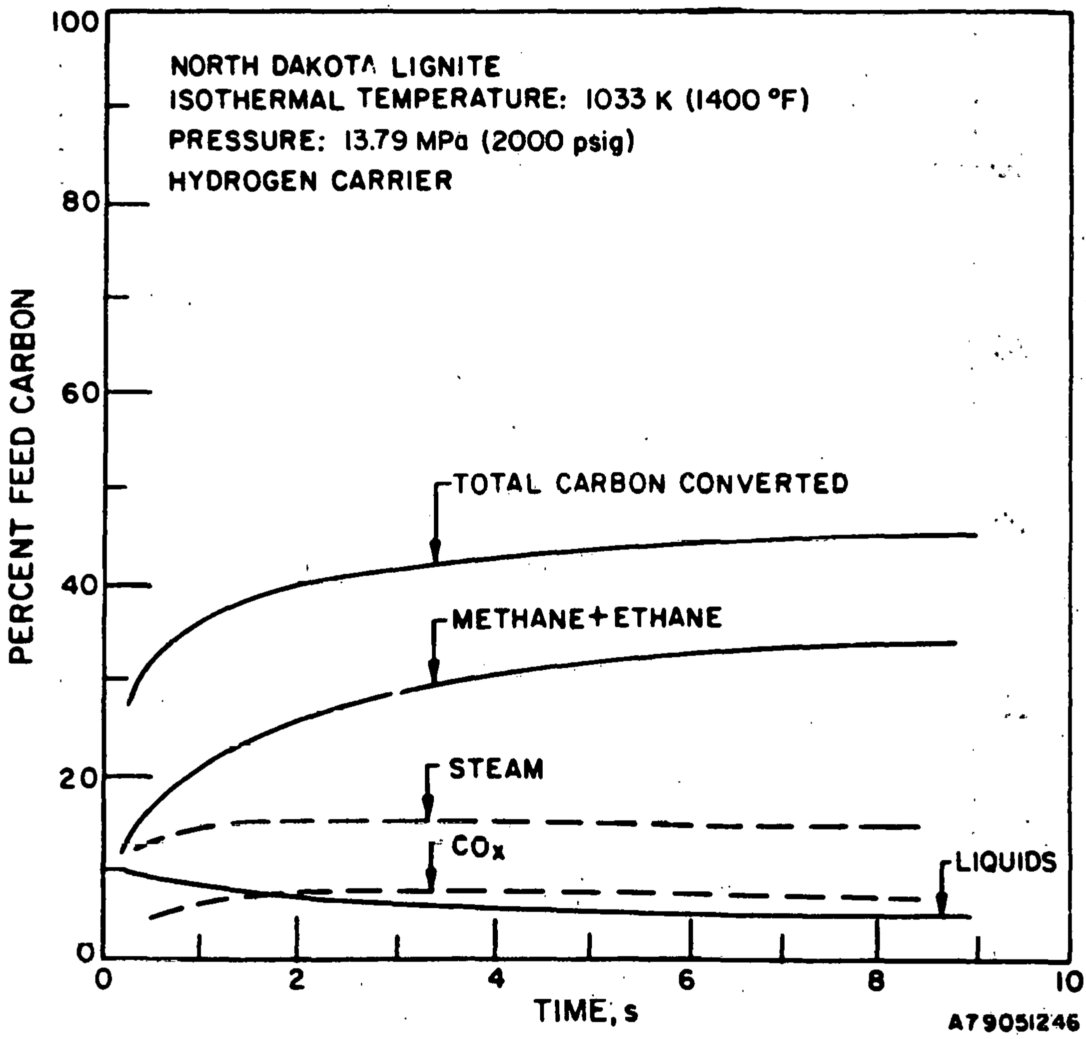

Figure 23. EFFECT OF REACTION TIME ON CARBON CONVERSION AND PRODUCT DISTRIBUTION CALCULATED FROM JOHNSON MODEL (9)

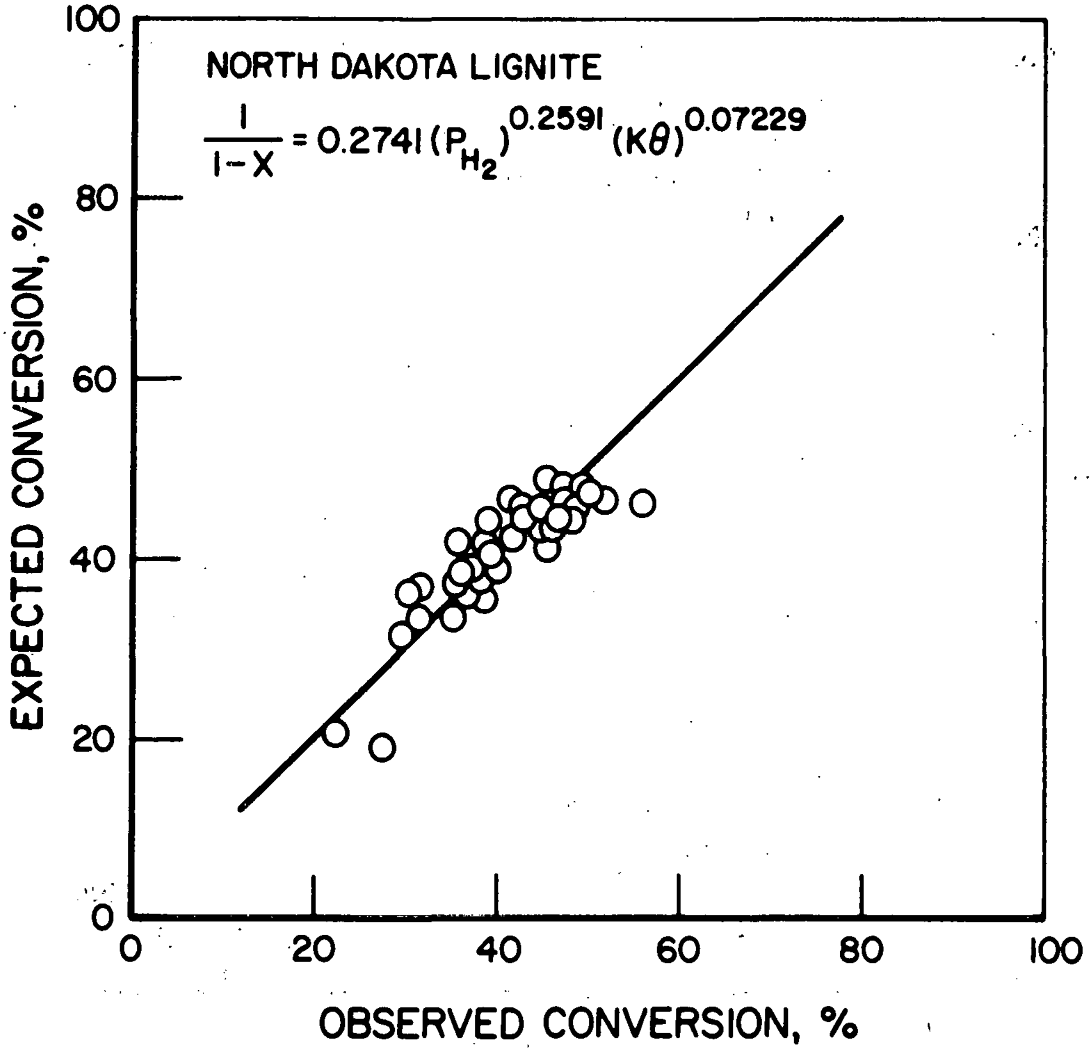

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Figure 24. CORRELATION FOR CARBON CONVERSION FOR NORTH DAKOTA LIGNITE PROCESSED IN HYDROGEN, P, TP, RT, PS, PP, AND HR SERIES

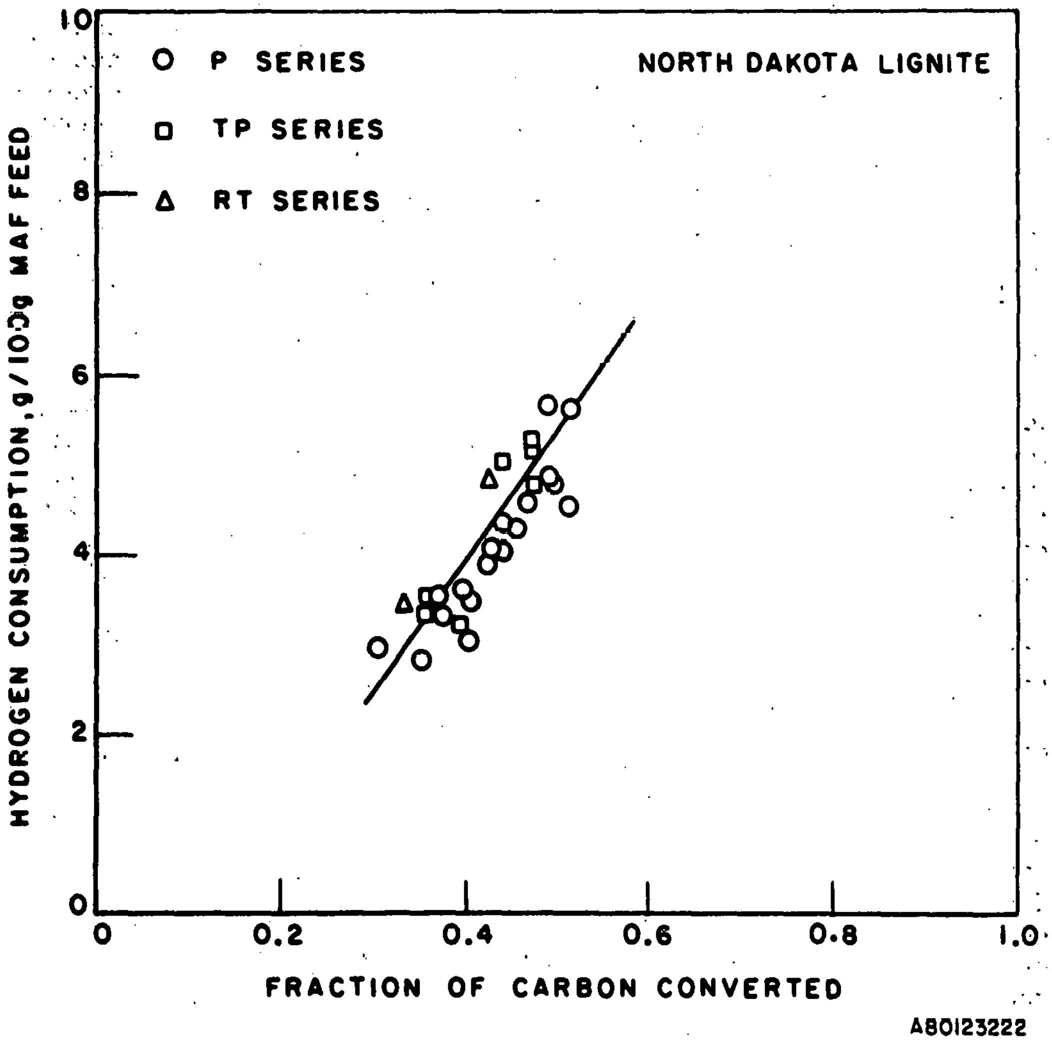


Figure 25. NET HYDROGEN CONSUMPTION, EXPRESSED AS GRAMS OF HYDROGEN PER 100 GRAMS MAF LIGNITE

percent as-received coal in sand plugged the reactor after a short period of operation. Dead-burned char was not as effective a diluent as the silica sand; successful operation of the bench-scale unit was obtained using a mixture of 10 weight percent as-received coal and 90 weight percent char. Higher levels of coal could not be processed, but would quickly plug the reactor. When using char as a diluent, hydrocarbon liquid yields were much reduced and the methane yield greatly increased.

Workers at the U.S. Bureau of Mines reported that by processing caking coal in hydrogen of low heating rates, the agglomerating tendency of the coal could be reduced or destroyed. Some trials were made in which the as-received Illinois No. 6 coal was passed through the reactor three times in sequence at a system operating pressure of 2000 psig and reactor outlet temperatures of 500°, 700°, and 500°F, respectively. In a final run, the coil outlet temperature was raised to 850°F; the reactor quickly plugged, bringing the run to an end. It was then concluded that much longer residence times would be needed to duplicate the processing conditions described by Kawa et al.[10]

b. Runs with Pretreated Coal

Some chemical treatments of coals to reduce their sulfur content have been described in the literature[1,16] which have the important side effect of reducing the caking tendency of the parent coal. Some analogous treatments were devised in which Illinois No. 6 coal was treated with lime, bentonite clay, and iron oxide. The treatment levels were restricted to a maximum of 7.5 weight percent CuO in dry coal, with a maximum of 10 weight percent total additives in coal. The treated coals were successfully processed (CT series) in the bench-scale unit at a system operating pressure of 2000 psig and reactor outlet temperatures ranging from 1400° to 1500°F.

The total carbon conversion, methane + light gas yields, hydrocarbon liquids, and carbon oxide yields for the BC and CT series are shown in Figure 26, the distribution of BTX and phenols + cresols in Figure 27, and the distribution of benzene, toluene, and xylenes + ethyl-benzene in Figure 28. The solid lines in Figure 26 are the expected values for the various quantitites calculated from the Johnson model. The methane + light gas yields are in good agreement with the model for both the BC series and the CT series. Liquid yields were greater than those obtained from North Dakota lignite and those expected from the model. Total conversion was greater than expected, and appears to be accounted for in the high liquids yields.

The distribution of BTX and phenols + cresols shows a change with severity function similar to that observed with liquids obtained from North Dakota lignite, with the phenols + cresols function descreasing with increase in severity function. The distribution of benzene, toluene, and xylene + ethyl-benzene was also similar to that observed with the gasoline-boiling-range liquids obtained from North Dakota lignite; xylenes and ethyl-benzene are found at low severity, and the fraction of benzene increases with increase in severity function. The concentration of benzene in the gasoline-boiling-range liquids obtained from the CT series was less than in the gasoline-boiling-range liquids obtained from North Dakota lignite. Because of the differences in severity, no direct comparison can be made of the BC and CT series of runs.

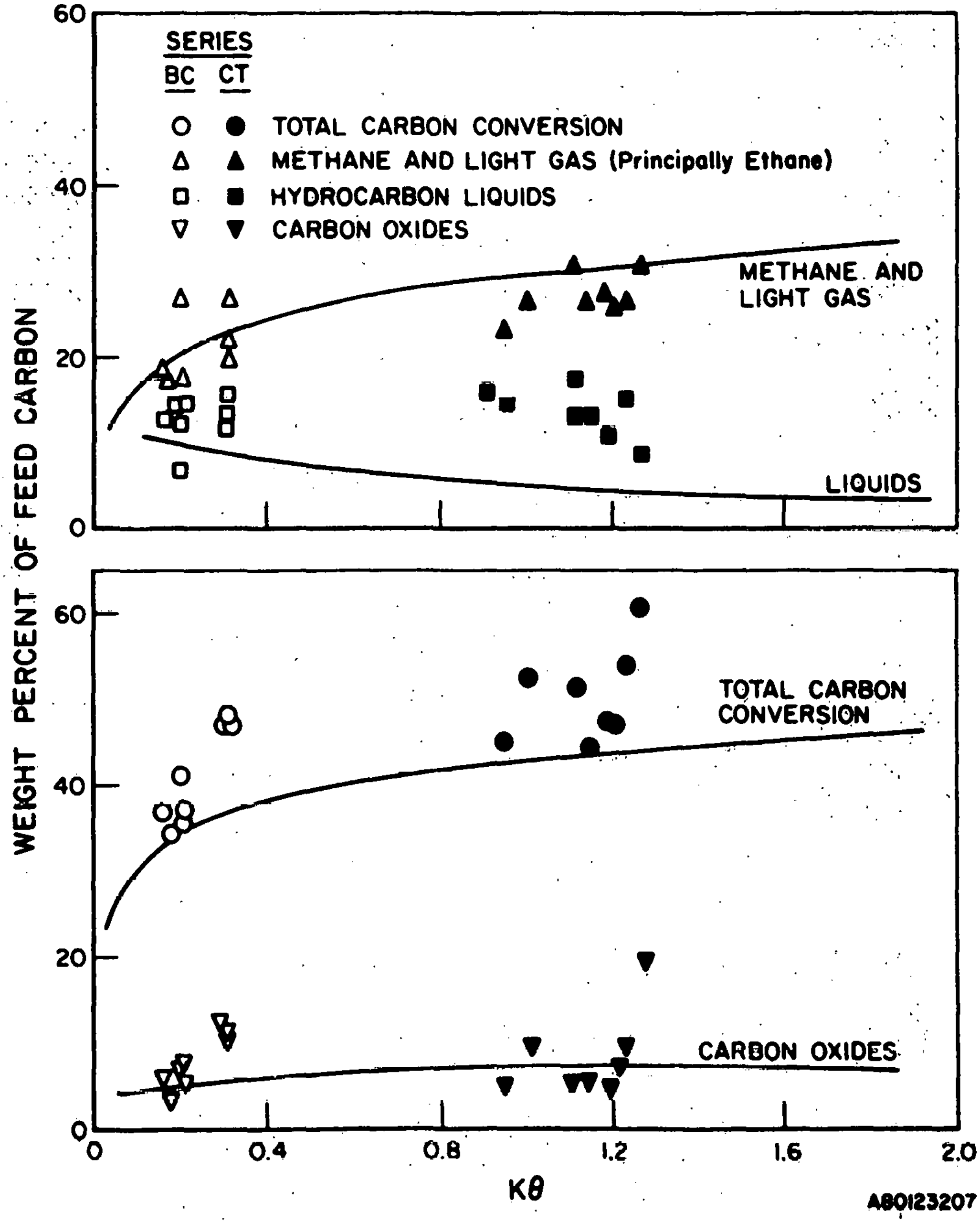


Figure 26. DISTRIBUTION OF FEED CARBON AMONG METHANE + LIGHT GAS, LIQUIDS, AND CARBON OXIDES OBTAINED FROM ILLINOIS NO. 6 COAL

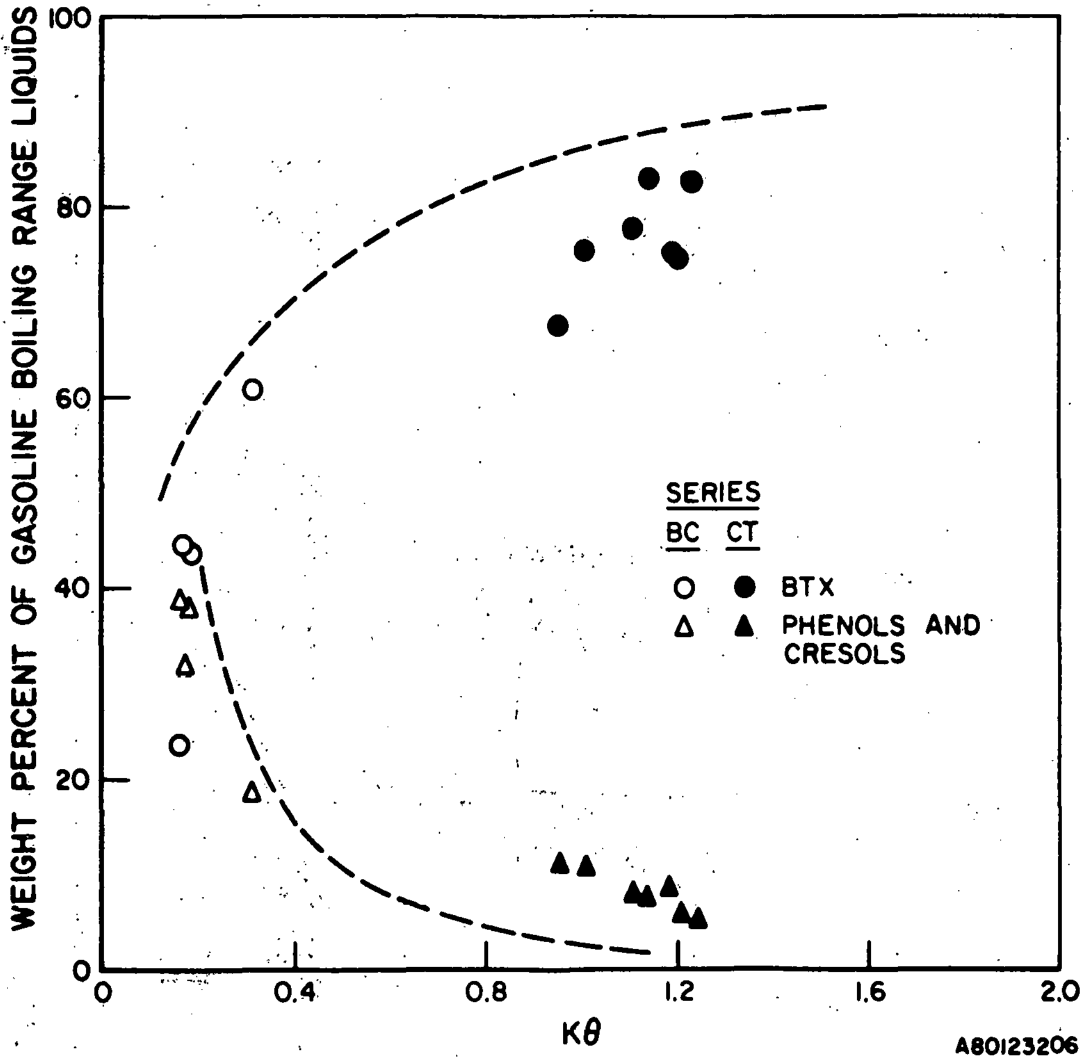


Figure 27. BTX AND PHENOLS + CRESOLS IN GASOLINE-BOILING-RANGE LIQUIDS OBTAINED FROM ILLINOIS NO. 6 COAL

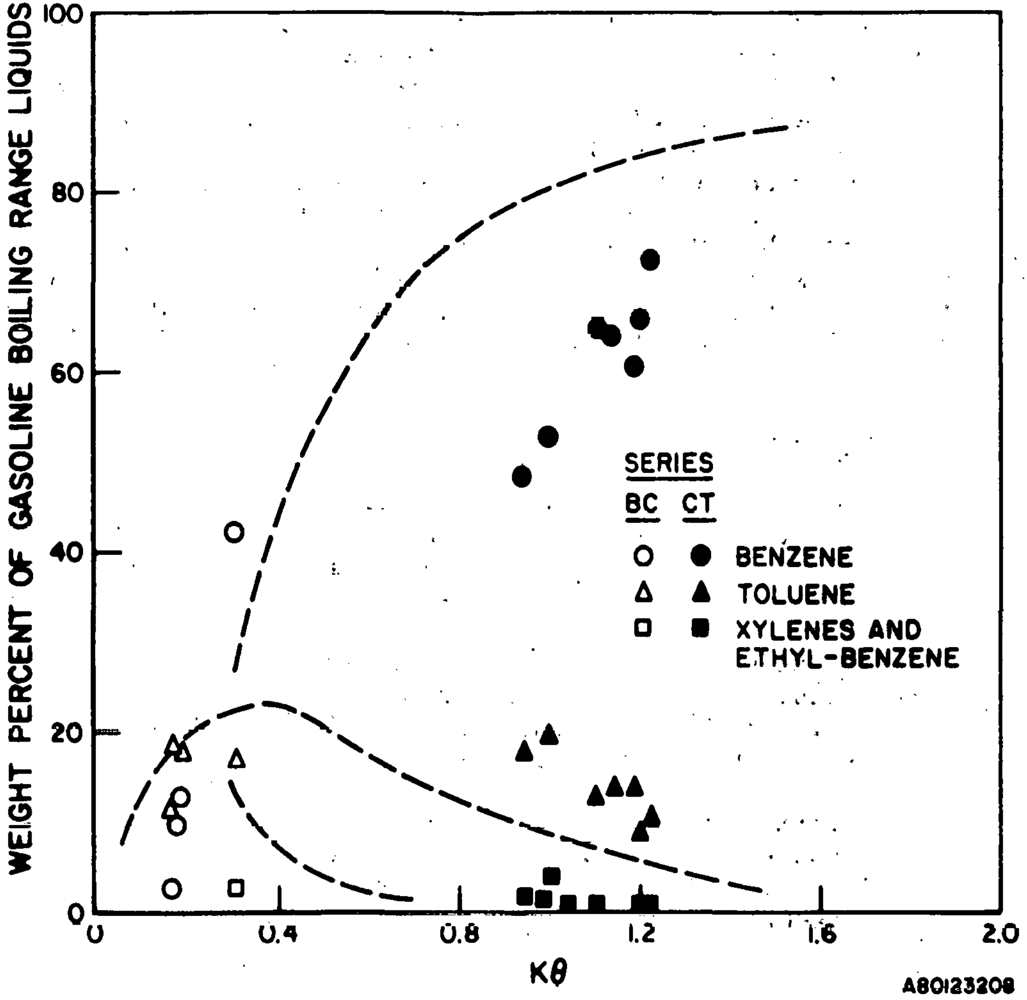


Figure 28. DISTRIBUTION OF BENZENE, TOLUENE, AND XYLENES + ETHYL BENZENE IN GASOLINE BOILING RANGE LIQUIDS OBTAINED

c. Slurry Feeding

A few runs were made in which solvent slurries of lignite and bituminous coals were processed in the bench-scale unit to determine if swelling of bituminous coals could be avoided by processing with phenol, an extractive solvent. Two runs were made in which a slurry of 20 weight percent lignite in toluene was successfully processed to test the equipment. The extractive solvent system consisted of 40 weight percent phenol, 40 weight percent toluene and 20 weight percent naphthalene. This was successfully processed in the bench-scale unit, but a slurry of 20 percent by weight Illinois No. 6 coal in extractive solvent plugged the reactor after 1 minute of operation.

A final trial was made in which a slurry of 20 percent by weight Illinois No. 6 coal in extractive solvent was first autoclaved at 680°F and 2000 psig pressure for 2 hours to partially extract the coal. The slurry was then sieved to break up agglomerates which had formed during the autoclave treatment. The slurry of partially extracted coal and solvent quickly plugged the reactor when a trial was made in the bench-scale unit. No further trials were made.

6. Heating Rate Studies

A series of runs was made to determine the effect of heating rate on carbon conversion and the distribution of carbon among products. In these runs the system operating pressure was 2000 psig and the maximum temperature was 1500°F. Two types of temperature profiles were used as shown in Figure 29. In Type I, the upper half of the reactor furnace was idled at temperatures ranging from 750° to 800°F, with heating to pyrolysis temperatures taking place in the lower half of the reactor furnace. The lowest heater was controlled at 1500°F so that there was no appreciable residence time at 1500°F. Operated in this fashion, maximum heating rates were varied from 127° to 385°F/s.

In the Type II profile, the entire reactor heater furnace was operated at 1500°F. Through choice of feed gas rates, the heating rates were varied from 155° to 1275°F/s. In all runs power plant grind North Dakota lignite was processed in hydrogen. The operating data and results are summarized in Table 3.

Comparing runs HR-1 and HR-5 in which the heating rates were 152° and 155°F respectively, the methane and light gas yields differ considerably, as does the composition of the gasoline-boiling-range liquids. The differences can be accounted for by the values of severity function, which were 0.315 and 1.346 for these runs; i.e., methane yields increase with increase in severity function. The data could not be organized in terms of heating rate only, but could be organized in terms of severity as shown in Figure 30. Here, the changes in carbon conversion, methane plus ethane yield, and hydrocarbon liquids yields change in the same manner as shown in Figures 15 and 23.

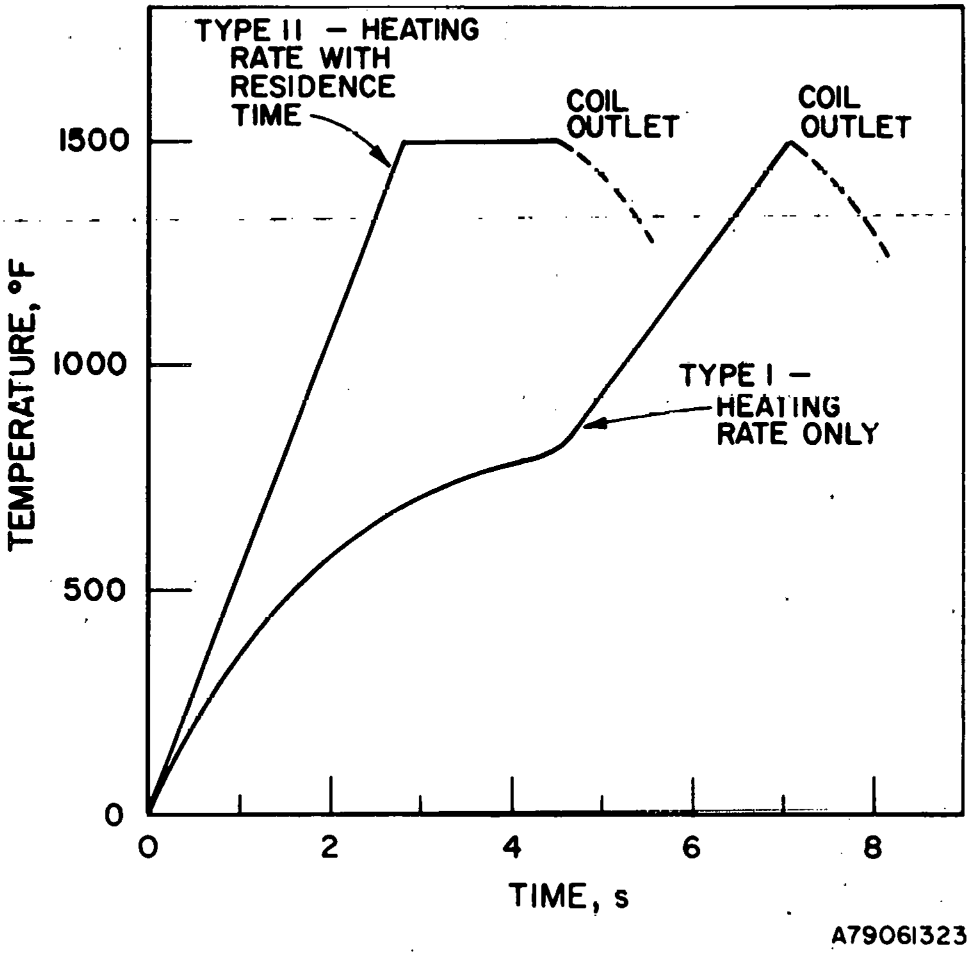


Figure 29. TEMPERATURE PROFILES USED IN HEATING RATE STUDIES

Table 3. CARBON DISTRIBUTIONS OBTAINED FROM NORTH DAKOTA LIGNITE PROCESSED AT VARIOUS HEATING RATES

Run No.	HR-2	HR-1	HR-3	HR-4	HR-5	HR-6	HR-7
System Outlet Pressure, psig	2000	2000	2000	2000	2000	2000	2000
Coil Outlet Temperature, °F	1500	1500	1500	1500	1500	1500	1500
Severity Function	0.3833	0.315	0.148	0.767	1.346	1.954	1.434
H_2/MAF Lignite Weight Ratio	0.44	0.26	0.48	0.43	0.30	0.45	0.55
Residence Time, s	4.6	4.0	2.6	3.0	4.9	4.5	4.4
Heating Rate, °F/s	125	152	385	412	155	780	1275
	No Appreciable Residence Time at 1500°F			Variable Residence Times at 1500°F			
Carbon Distribution, %							
Liquids	12.25	11.03	11.71	13.19	12.44	7.30	8.59
Carbon Oxides	9.47	9.05	8.18	11.27	9.72	8.47	10.35
Methane	12.40	10.90	10.59	16.34	17.35	19.69	19.47
Light Gases	7.37	11.36	6.26	8.43	8.33	8.61	8.63
Char	52.20	51.23	58.87	52.51	52.52	52.69	54.55
Analysis of C_5-400 Liquids							
Benzene	37.2	38.8	27.6	72.0	85.7	90.0	80.8
Toluene	18.4	23.4	16.6	10.7	6.0	1.5	2.2
Xylenes	3.7	2.5	4.8	0.8	Tr	Tr	0.1
Ethyl-benzene + Indans	4.3	4.4	5.9	1.6	Tr	0.5	0.8
Phenols + Cresols	22.7	18.0	31.2	7.1	1.6	Tr	0.2
Naphthalenes	12.6	12.2	10.6	6.7	5.3	7.8	15.2
Not Identified	1.1	0.7	3.3	1.1	1.4	0.2	0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

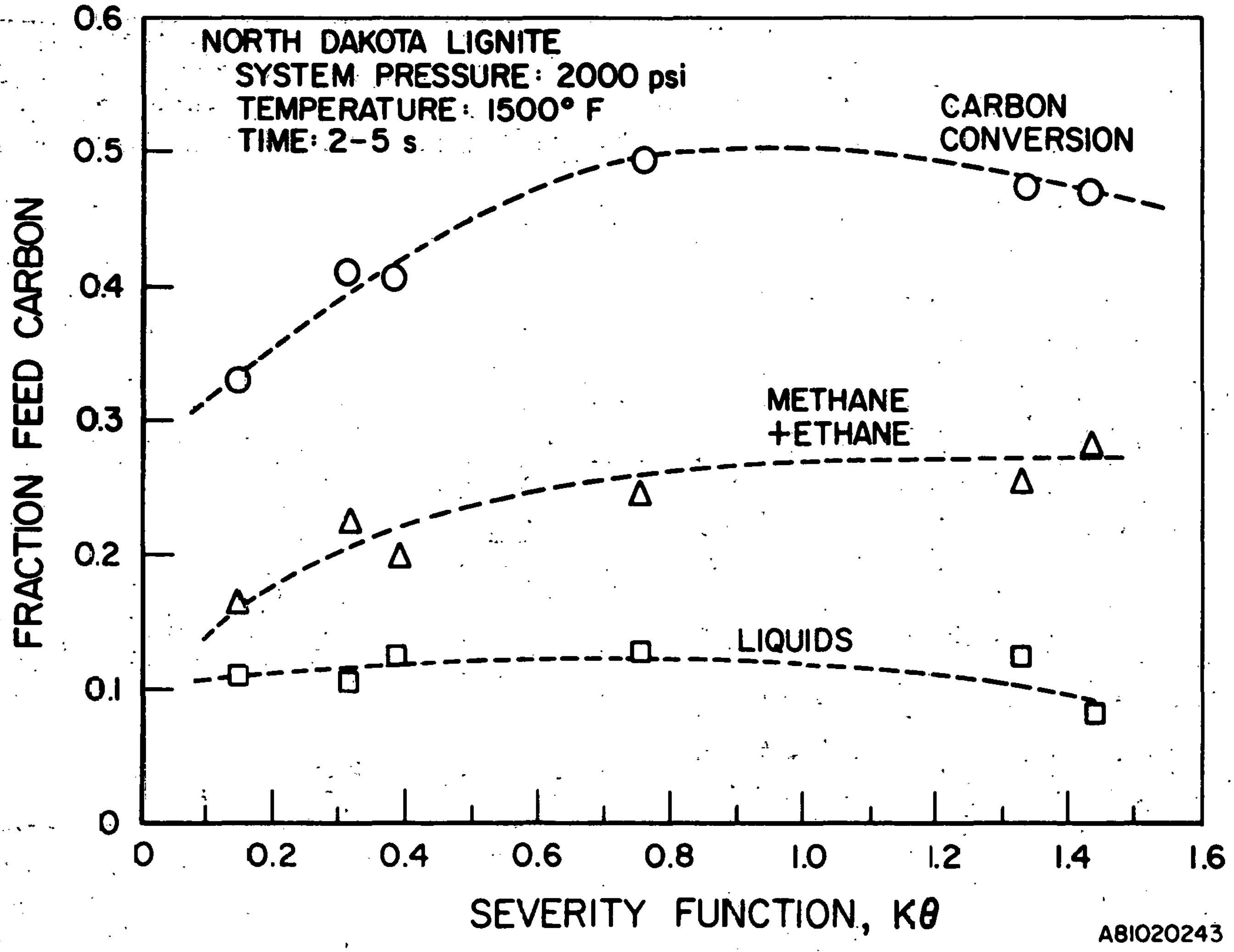


Figure 30. EFFECT OF SEVERITY ON YIELDS AND CONVERSION IN HEATING RATE RUNS

7. Runs with Preheated Hydrogen

In the runs with preheated hydrogen, power plant grind North Dakota lignite was processed in hydrogen preheated to temperatures from 1100° to 1350°F at the point of contact with the coal. The system operating pressure was 1750 psig. The final mix temperature, just downstream from the tee in which the coal was mixed with hydrogen, ranged from 710° to 1250°F, depending upon the hydrogen-to-coal ratio. The carbon conversion and distribution of feed carbon between methane + ethane, hydrocarbon liquids, and carbon oxides are shown in Figure 31. The solid lines represent the expected values for these quantities calculated from the Johnson model. The distributions of BTX and phenols + cresols in the gasoline-boiling-range liquids are plotted with severity function in Figure 32, and the distributions of benzene, toluene, and xylenes + ethyly-benzene are plotted with severity function in Figure 33. From Figure 31, with the exception of two runs (HH-11 and 12) which were made using a hydrogen-to-MAF coal ratio of 2.78 and 5.90, the conversions and distributions of carbon among products are in reasonable agreement with the expected conversions.

Both the distributions of BTX and phenols + cresols and benzene, toluene, and xylenes + EB show change with severity function similar to that found when the feed lignite and hydrogen were heated cocurrently (Figures 13, 16). Over the range of operating conditions used, there does not seem to be any sharply defined advantage to preheating the hydrogen, and if anything, the conversions and distributions of carbon among products would seem typical rather than different.

8. Runs with Steam and Hydrogen

In this series of runs, power plant grind North Dakota lignite was processed with a mixture of 50 mole percent steam in hydrogen. The system operating pressure was 1750 psig and the reactor outlet temperature was 1475°F. The operating data and carbon distributions for these runs are summarized in Table 4.

Table 4. OPERATING CONDITIONS AND CARBON DISTRIBUTIONS FOR RUNS WITH NORTH DAKOTA LIGNITE AND 50% STEAM IN HYDROGEN

Run No.	HS-2	HS-3	HS-4	HS-5	HS-6
System Pressure, psig	1750	1750	1750	1750	1750
Maximum Temp, °F	1475	1475	1475	1475	1475
Feed Gas Preheat Temp, °F	1250	1245	1250	1300	1300
Adiabatic Mix Temp, °F	850	920	1130	790	1050
Residence Time, s	2.3	2.2	2.2	2.3	2.0
Feed Rate, lb/hr	2.1	0.65	0.75	2.0	0.55
H_2/MAF Feed Wt Ratio	0.34	1.16	1.04	0.41	1.63
Severity Function, $K\theta$	0.744	0.944	1.003	0.869	0.854
Carbon Distribution, %					
Liquids	2.54	3.86	5.96	4.18	5.75
Carbon Oxides	14.18	12.91	12.02	12.30	10.57
Methane	15.77	18.00	18.88	15.16	15.27
Light Gases	7.82	6.97	7.20	7.04	6.50
Char	59.22	56.76	55.94	61.32	61.03

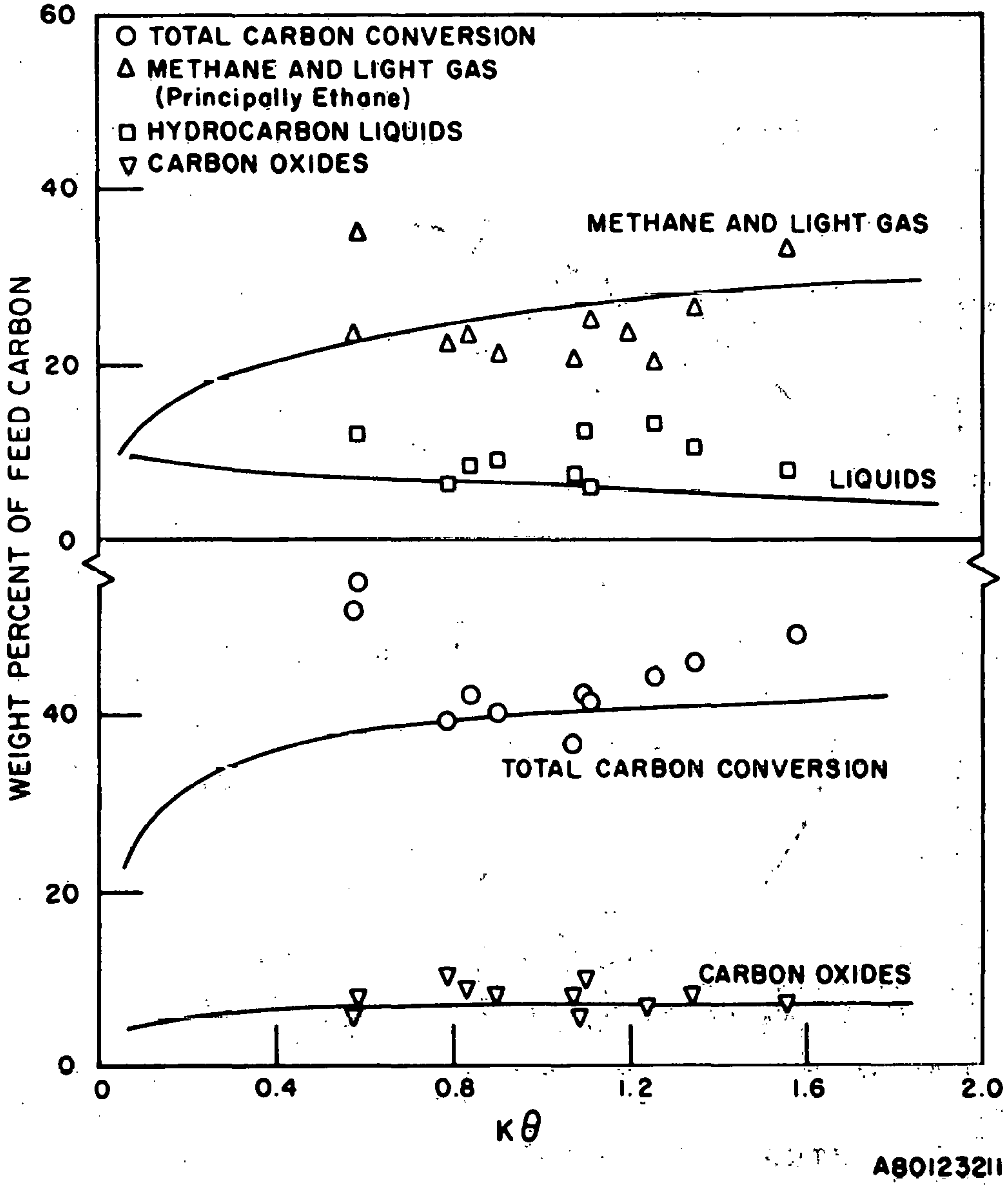


Figure 31. CARBON CONVERSION AND DISTRIBUTION OF FEED CARBON BETWEEN METHANE + ETHANE, HYDROCARBON LIQUIDS, AND CARBON OXIDES FOR RUNS WITH PREHEATED HYDROGEN

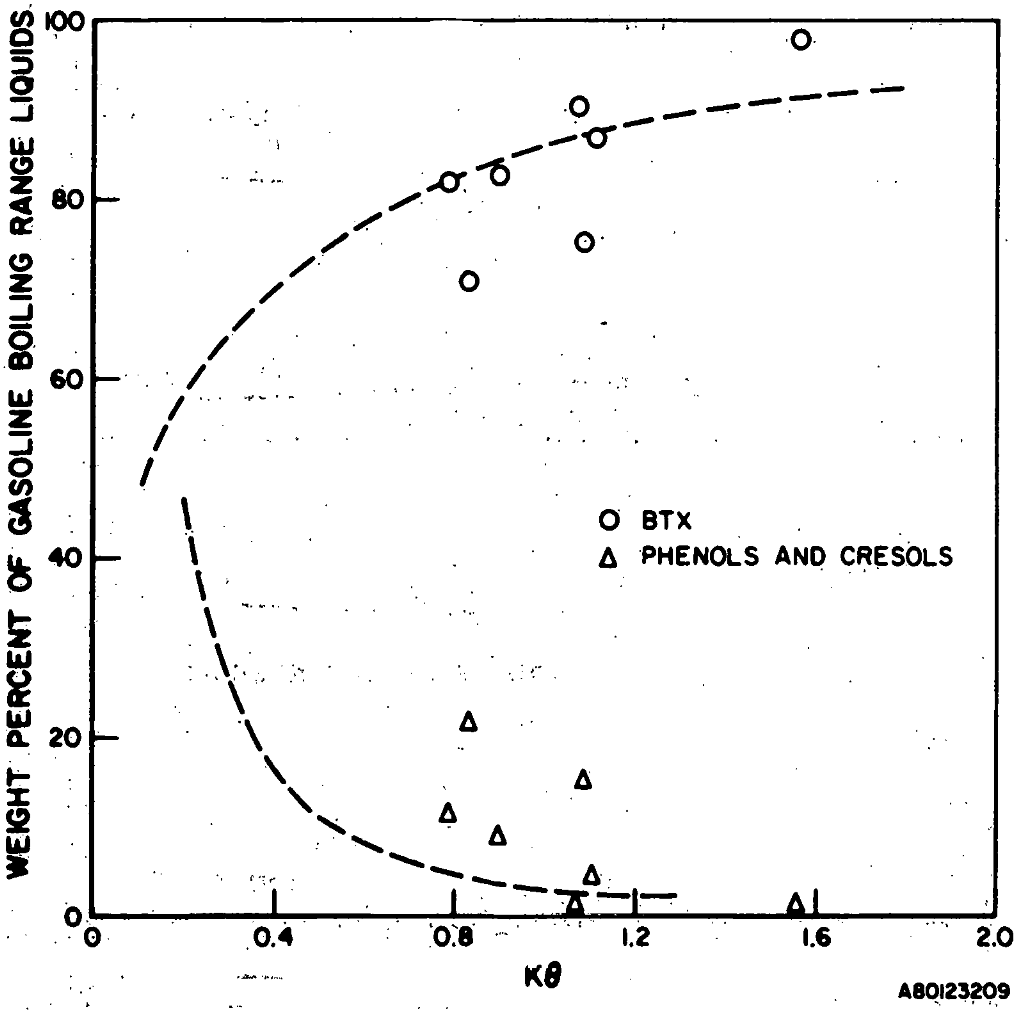


Figure 32. DISTRIBUTION OF BTX AND PHENOLS + CRESOLS IN GASOLINE BOILING RANGE LIQUIDS FROM HH SERIES

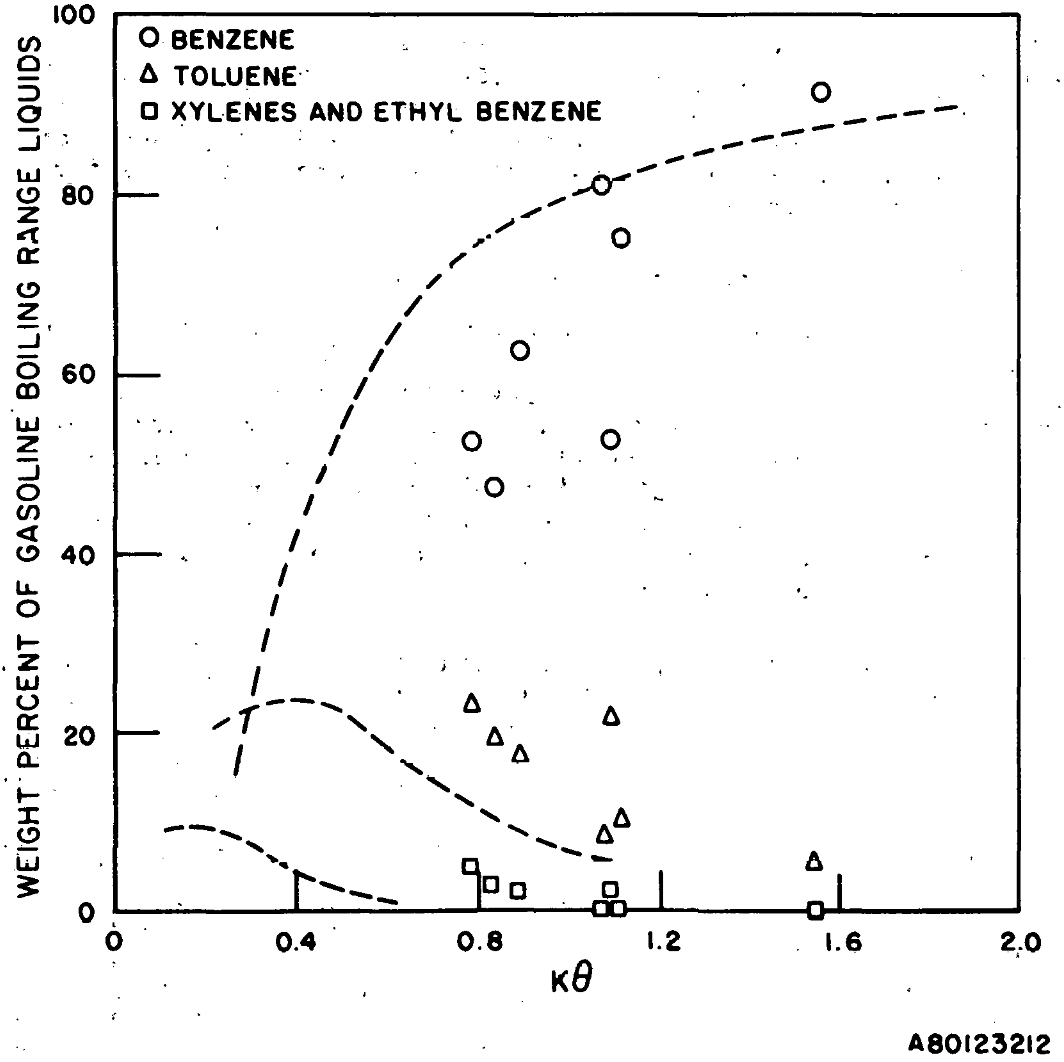


Figure 33. DISTRIBUTION OF BENZENE, TOLUENE, AND XYLENE + ETHYL BENZENE IN GASOLINE BOILING RANGE LIQUIDS FROM HH SERIES

The carbon conversions ranged from 39 to 45 percent, reflecting the reduction in hydrogen partial pressure caused by the presence of the steam. The hydrocarbon liquid yields were low, generally less than 6 percent of the feed carbon; the carbon oxides yields and methane + ethane were high. This would suggest that a portion of the hydrocarbons are converted to carbon oxides by steam-reforming. From the pressure profile runs, the expected carbon conversion at 800 psig would be approximately 38 percent, the methane plus light gas yield approximately 16-18 percent, and the hydrocarbon liquids yields 6-8 percent of the feed carbon.

The depth of conversion was generally greater than 38 percent, and the hydrocarbon liquid yields less than 6 percent of the feed carbon. The methane + ethane yields were generally greater than 21 percent, suggesting that the steam does not act as an inert diluent, and the products are different than those expected at 800 psig, the approximate effective value of hydrogen partial pressure.

9. Effect of Particle Size

The effect of particle size was investigated by operating the bench-scale unit with a 60 x 100 mesh size fraction of North Dakota lignite at a system pressure of 1750 psig and a reactor outlet temperature of 1475°F. The hydrogen was preheated to 1200°F prior to being mixed with the coal. The results are compared with data obtained using power plant grind (75% -200 mesh) in Table 5. The main effect of increasing particle size appears to be a reduction in hydrocarbon liquids and an increase in methane yield. This is thought to be caused by coking in the longer diffusional paths associated with larger particles.

Table 5. COMPARISON OF CARBON DISTRIBUTIONS OBTAINED FROM 60 x 100 MESH NORTH DAKOTA LIGNITE (PSI-1) WITH POWER PLANT GRIND NORTH DAKOTA LIGNITE

Run No.	PSI-1	TP-1	HH-8
System Pressure, psig	1750	2000	1750
Maximum Temp, °F	1475	1475	1450
Feed Gas Preheat, °F	1200	N/A	1270
Adiabatic Mix Temp, °F	780	N/A	1100
Residence Time, s	3.9	2.5	3.3
Feed Rate, lb/hr	1.22	1.6	0.68
H_2/MAF Feed Weight Ratio	1.00	0.878	1.33
Carbon Distribution, %			
Liquids	5.46	12.06	13.63
Carbon Oxides	7.23	9.43	7.00
Methane	20.17	17.66	17.71
Light Gases	7.14	9.82	2.38
Char	52.52	50.02	50.52

10. Runs with Syngas

A considerable simplification of equipment would result if the pyrolysis of the feed coal were carried out in syngas (mixtures of hydrogen, carbon monoxide, and steam) by the elimination of water gas shift equipment from a grass-roots plant. In such a plant, the syngas would be generated by steam-oxygen gasification of the spent char from the primary converter. Some trials were made in which the bench-scale unit was operated with syngas and North Dakota lignite at 1250 psi and 1450°F, but were aborted when the reactor plugged with amorphous carbon formed from the reaction —

$$2CO \rightarrow CO_2 + C \qquad (4)$$

Comparison of gas analyses showed that when syngas alone was passed through the reactor, some methanation took place, apparently catalyzed by the nickel in the Incoloy tubing walls.

The system was not operable for any length of time because of plugging. A trouble free operation might be obtained at lower temperatures, but residence times would be on the order of minutes, outside the capabilities of an entrained flow reactor.

11. Disposable Catalyst Systems

In the planned technical program, provision was made to investigate the use of catalytic materials. Because of recovery problems, sodium and potassium compounds, cobalt, molybdenum, and zinc chloride were avoided. Bentonite clay, iron oxide and lime were chosen as being inexpensive and capable of being formulated into disposable catalyst systems. Both Illinois No. 6 coal and North Dakota lignite were treated with the amounts of bentonite clay, iron oxide, lime, and potassium dichromate shown in Table 6. The results obtained from processing bentonite clay/lime treated coals with hydrogen are summarized in Table 7, and the results obtained from iron oxide treated coals processed in hydrogen are summarized in Table 8.

Table 6. COMPOSITIONS OF NORTH DAKOTA LIGNITE AND ILLINOIS NO. 6 COAL TREATED WITH CATALYTIC MATERIALS

Run No.	**CT-12**	**CT-13**	**CT-15**	**CT-16**	**CT-17**	**CT-18**
North Dakota Lignite	--	--	89.84	89.84	89.84	90.00
Illinois No. 6	89.84	89.84	--	--	--	--
Bentonite Clay	--	9.00	--	9.00	9.00	9.00
Iron Oxide	9.00	--	9.00	--	--	--
$Ca(OH)_2$	1.16	1.16	1.16	1.16	1.16	--
$K_2Cr_2O_7$	--	--	--	--	--	1.00
	100.00	100.00	100.00	100.00	100.00	100.00

Table 7. COMPARISON OF CARBON DISTRIBUTIONS AND GASOLINE COMPOSITIONS OBTAINED FROM NORTH DAKOTA LIGNITE TREATED WITH BENTONITE CLAY AND UNTREATED NORTH DAKOTA LIGNITE

Run No.	CT-16	CT-18	CT-13*	P-14	P-16
System Pressure, psig	2000	2000	2000	2000	2000
Maximum Temperature, °F	1475	1475	1475	1475	1500
Residence Time, s	3.2	3.3	3.5	1.8	2.9
Feed Rate, lb/hr	4.6	4.9	1.5	9.0	2.5
H_2/MAF Feed Weight Ratio	0.225	0.242	0.622	0.163	0.445
MAF Feed Composition					
Carbon	66.90	67.31	74.73	68.80	68.95
Hydrogen	4.37	4.43	4.99	4.54	4.60
Sulfur	0.82	1.15	5.35	1.03	1.02
Nitrogen	0.96	1.07	1.31	0.96	0.84
Oxygen	26.95	26.04	13.63	24.67	24.59
Carbon Distribution, %					
Liquids	10.91	11.12	13.51	10.44	14.06
Carbon Oxides	8.66	9.23	7.86	7.84	7.64
Methane	16.88	17.88	17.29	12.09	14.88
Light Gases	7.49	8.90	8.45	7.38	8.92
Char	55.87	56.20	52.89	59.57	55.06
Liquids Inspections					
Specific Gravity	0.963	0.959	1.011	1.013	1.021
C_5-400°F, wt %	61.5	65.5	56.3	53.2	51.0
400°F+	38.5	34.5	43.7	46.8	49.0
Gasoline Composition, wt %					
BTX	92.53	91.70	74.80	65.62	75.77
Ethyl Benzene	Tr	0.36	0.36	0.78	0.11
C_9 Aromatics	Tr	Tr	0.11	0.44	Tr
Indene + Indans	0.47	0.53	0,79	1.52	0.56
Naphthalene	4.76	4.01	17.12	7.49	12.38
Phenol	1.21	2.15	5.63	16.87	6.62
Cresol	Tr	Tr	0.02	1.94	0.36
C_8 Phenols	Tr	Tr	Tr	0.13	0.10
Unidentified	1.03	1.25	1.17	5.21	4.10
Total	100.00	100.00	100.00	100.00	100.00

* Illinois No. 6 coal.

Table 8. COMPARISON OF CARBON DISTRIBUTION OBTAINED FROM NORTH DAKOTA LIGNITE TREATED WITH IRON OXIDE AND UNTREATED NORTH DAKOTA LIGNITE

Run No.	CT-15	CT-17	P-17	P-19	CT-12**
System Pressure, psig	2000	1000	2000	2000	2000
Maximum Temperature, °F	1475	1475	1475	1450	1475
Residence Time, s	2.7	3.0	2.8	3.0	3.2
Feed Rate, lb/hr	2.76	1.30	2.55	2.79	3.45
H_2/MAF Feed Weight Ratio	0.521	0.504	0.462	0.402	0.295
MAF Feed Composition, wt %					
Carbon	68.20	68.20	68.81	68.24	75.90
Hydrogen	4.40	4.40	4.62	4.50	5.38
Sulfur	1.08	1.08	1.03	1.04	5.66
Nitrogen	1.42	1.42	0.99	1.26	1.38
Oxygen	24.90	24.90	24.55	24.96	11.68
Carbon Distribution, %					
Liquids	12.10	3.84	12.67	14.60	17.46
Carbon Oxides	8.73	8.53	8.16	7.67	6.00
Methane	20.49	15.05	16.98	14.01	19.90
Light Gases	10.08	6.29	9.02	8.97	11.08
Char	48.60	64.03	50.80	52.24	51.99
Liquids Composition, %					
Carbon	92.00	90.81	91.62	90.66	82.24
Hydrogen	6.91	6.99	6.72	6.58	5.86
Sulfur	0.20	1.24	0.22	0.26	0.75
Nitrogen	0.29	0.39	0.72	0.86	1.15
Oxygen	0.60	0.57	0.72	1.59	10.00
Gasoline Content, wt %	60.7	*	53.3	48.5	50.2

* Insufficient sample.
** Illinois No. 6 coal.

By inspection of Table 7, it can be seen that the treatment of North Dakota lignite with bentonite clay and lime resulted in an oxygen uptake of approximately 2 percentage points. In the carbon distribution, it can be seen that methane yields increased, compared to untreated lignite (Runs P-14 and P-16) and, on average, the hydrocarbon liquids yields were less. For the treated lignite, the function of gasoline-boiling-range constituents in the hydrocarbon liquids was larger than for the untreated lignite. The fraction of BTX in the gasoline boiling range liquids obtained from the treated lignite was higher than 90% while the fractions of naphthalene and phenols were low, approximately 4.5 and 1.8 percent by weight respectively. This would suggest that the bentonite clay catalyzed hydrocracking reactions and also suppressed naphthalene formation.

From Table 8, it can be seen that the elemental composition of the MAF treated coal was not greatly different from that of the untreated coal. In runs at 2000 psig operating pressure, the conversion of the treated lignite (CT-15) was somewhat deeper than for the untreated lignite. Both the methane and light gas yields were higher for the treated lignite. A single run (CT-17) was made at 1000 psig system operating pressure to determine if conversions of interest could be obtained at the lower pressure. The observed carbon conversion was approximately 36%, probably too low to allow operation in a balanced plant mode. Treated Illinois No. 6 consistently produced higher hydrocarbon liquid yields (CT-12 and CT-13) than North Dakota lignite but the liquids were heavier, and contained larger fractions of naphthalene and oxygenated compounds.

Although only "single point" observations are available, both bentonite clay and iron oxide appear to have beneficial effects in terms of improved gasoline compositions and yields. In addition, methane and ethane yields are also somewhat enhanced. In view of the low cost of bentonite clay and iron oxide, further investigation would seem justified.

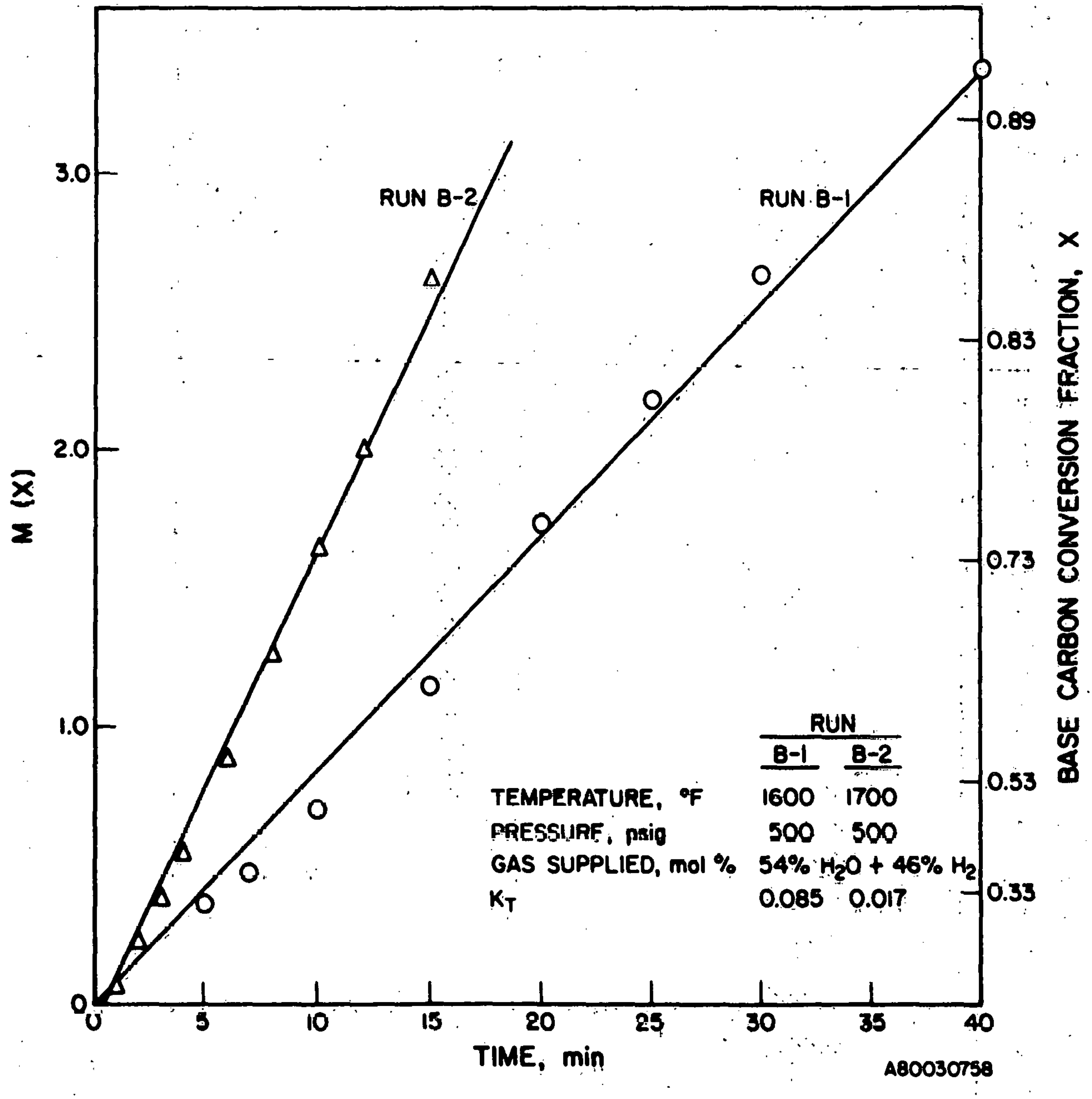
12. Char Reactivity

Char from Run P-16 was tested in a thermobalance for reactivity by gasification under isothermal conditions in an atmosphere of 50 mole percent steam in hydrogen. The data obtained are shown in Figure 34 and were used to calculate the overall rate constants shown in Table 9. The observed rate constants are compared with rate constants for a reference North Dakota lignite char and a reference bituminous coal char. Clearly, the char from Run P-16 is very similar in reactivity to the reference lignite char.

Table 9. THERMOBALANCE TEST OF CHAR REACTIVITY (Isothermal Gasification With 50 Mole Percent Steam in Hydrogen)

	Overall Rate Constants		
Temperature, °F	P-16 Residue	Ref. Lignite Char *	Ref. Bituminous Coal Char
1600	0.085	0.097	0.0097
1700	0.172	0.168	0.0407

* North Dakota lignite.



	RUN	
	B-1	B-2
TEMPERATURE, °F	1600	1700
PRESSURE, psig	500	500
GAS SUPPLIED, mol %	54% H_2O + 46% H_2	
K_T	0.085	0.017

Figure 34. GASIFICATION OF CHAR FROM RUN P-16

B. Tasks 4 and 5. Build and Operate a PDU

1. PDU Program

As a part of the planned technical program (Task 3) a process development unit was designed based on the operating experience and results obtained in the bench-scale unit. After D.O.E. approval for the design was obtained, the construction site was prepared, and the principal equipment ordered. During the construction phase, a combustor development program was carried out in available equipment to determine the design and construction method for the combustors to be installed in the PDU.

After the construction phase was completed, the operating phase was started. A number of equipment deficiencies and oversights surfaced which required either equipment modifications or development of operating techniques to overcome. A total of 16 runs were made at system operating pressures of 1000, 1500, and 2000 psig and temperatures ranging from 1200° to 1475°F.

2. Combustor Simulator

During the construction phase of the PDU several combustor designs were piloted in a simulator (Figure 35) operated at ambient pressure. In operation, dead-burned bituminous coal char was metered from the feed hopper into a stream of hydrogen which transported the char through the simulator to a char trap. The stream of hydrogen and char was heated to 1100°F prior to entering the combustor section where either air or oxygen was injected. The gases were above the autoignition temperature so that an igniter was not needed. The stream of char and hydrogen was heated to temperatures as high as 1700°F by combustion with oxygen.

Early in the study it was observed that the thin metal walls overheated very quickly during lapses in solids feeding, and were frequently damaged by melting. Heavy walled tubing (0.37-in. ID Incoloy 800 with 0.128-in. walls) was found to be capable of surviving minor upsets without damage. For aerodynamic reasons, it was desirable to introduce oxygen through a small-diameter tube inserted coaxially into the combustor section. This presented formidable fabrication problems. Meanwhile, an alternate design, shown in Figure 36, was found to perform well in the simulator, and was chosen for incorporation into the PDU. In this design, the oxygen was injected through a part drilled in heavy-walled tubing. The tubing was inserted through holes drilled in the combustor section walls and welded in position. This construction was dimensionally stable even at red heat, and was easily incorporated into the PDU.

There was some concern that metal in the vicinity of the oxygen inlet port would burn, eventually destroying the assembly. Throughout the PDU program, there were no metal failures in the oxygen port, although there were numerous failures due to melting damage to the walls of the combustor sections.

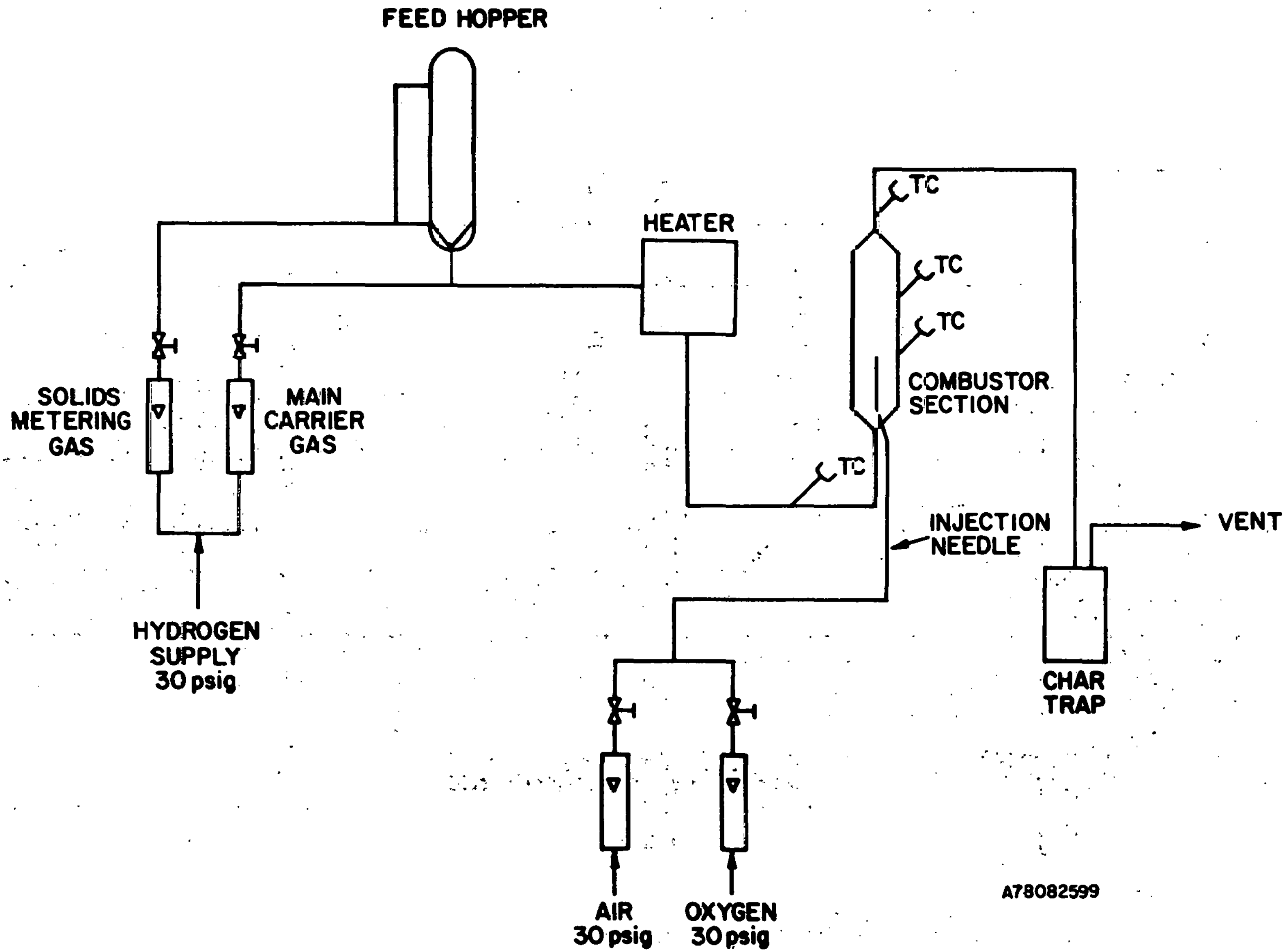


Figure 35. FLOW DIAGRAM OF PDU COMBUSTOR SIMULATOR

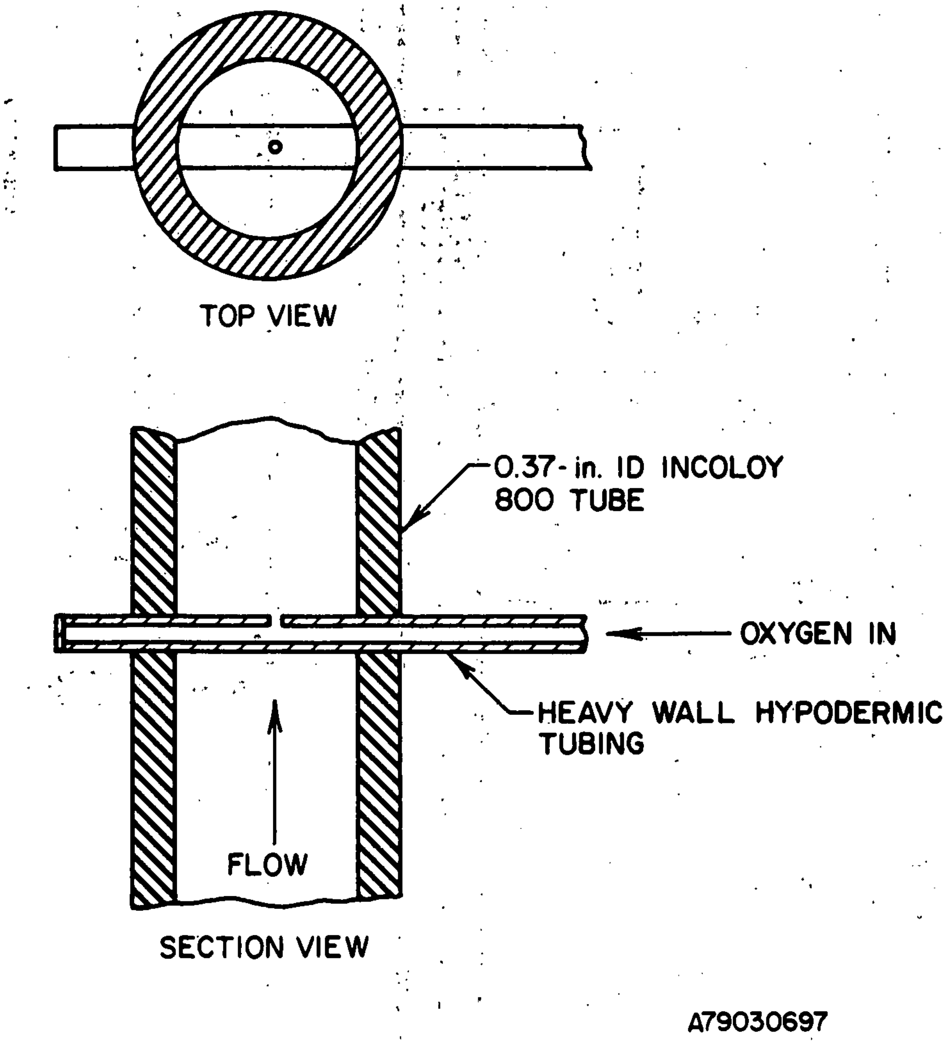


Figure 36. OXYGEN INLET SECTION OF PDU COMBUSTOR

3. Description of Equipment

A simplified flow diagram of the PDU is shown in Figure 37. In operation, coal was metered from the feed hopper into a stream of carrier gas in a manner analogous to that used in the bench-scale unit. The feed coal and carrier hydrogen passed through a gas-fired preheater coil where they were heated to temperatures ranging from 1200° to 1300°F. The effluent from the preheater coil then entered the riser which was contained in a pressure shell.

Oxygen was injected at two points in the riser, the first located near the bottom of the pressure shell and the second approximately 16 feet above the bottom of the pressure shell. Combustion of the oxygen occurred through autoignition, raising the temperature of the process stream to pyrolysis temperatures. The temperature of the process stream was monitored by two thermocouples inserted directly into the riser at points located 18 inches above each combustor.

Temperatures along the length of the riser were monitored by thermocouples located at positions shown in Figure 38. Effluent from the top of the riser passed through the char trap where spent solids were disentrained and collected. The solids-free hot gases and vapors were cooled in a heat exchanger to condense out liquids which were subsequently collected in the liquids receiver. The make gases then passed through a backpressure regulator in which pressure was reduced to essentially atmospheric pressure. After passing through a meter the gases were sampled and vented.

From the bench-scale investigations, the concentrations of benzene and toluene in the make gases were seldom higher than 0.02 mole percent. Both of these materials were adsorbed by the columns of the on-line gas chromatograph, and thus were not detectable. To provide an estimate of the fraction of condensable liquids in the make gas, a portion of the make gases could be passed through a refrigerated freeze-out train capable of being operated at -80°F. A metered quantity of gases would be passed through the freeze-out train, and from the weight of liquids recovered and a knowledge of the volume of gas, the amount of condensables in the make gas could be estimated.

4. Operating Problems

a. Coal Feeding

As constructed, the feed hopper was fitted with a hydraulically-driven rotary spindle to break bridges and promote discharge from the hopper into the feeder plenum. This did not perform to expectations; the pin connecting the hydraulic motor to the rotating spindle failed by shearing several times, and because of the small size of the hydraulic motor, could not be enlarged. A set of flat vanes (Figure 39) were then suspended from a vibrator motor which was substituted for the hydraulic motor. In tests at atmospheric pressure, the power-plant grind North Dakota lignite discharged freely, and flow rates into the plenum chamber in excess of 100 lb/hr were easily attained.

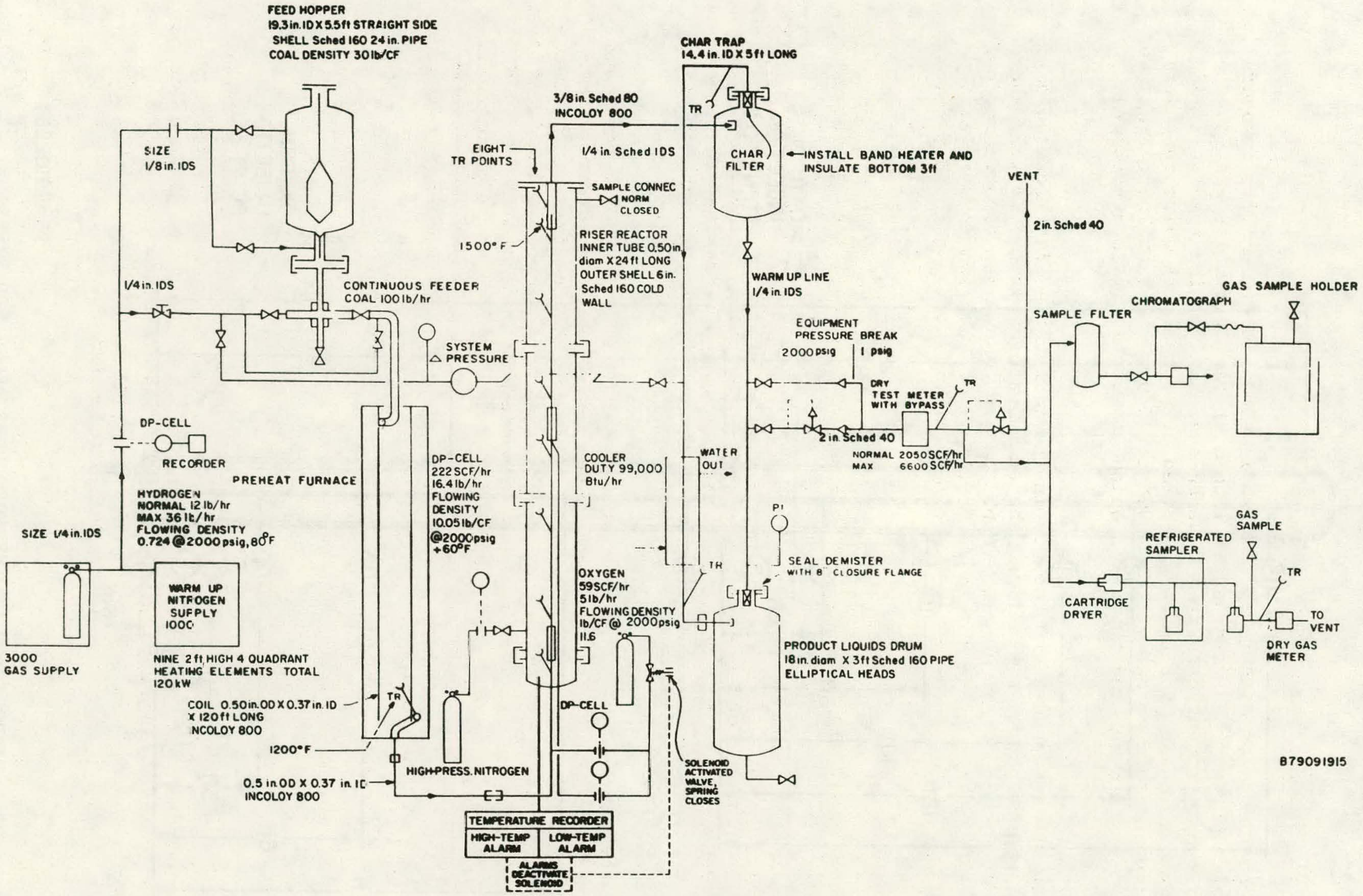


Figure 37. PDU EQUIPMENT

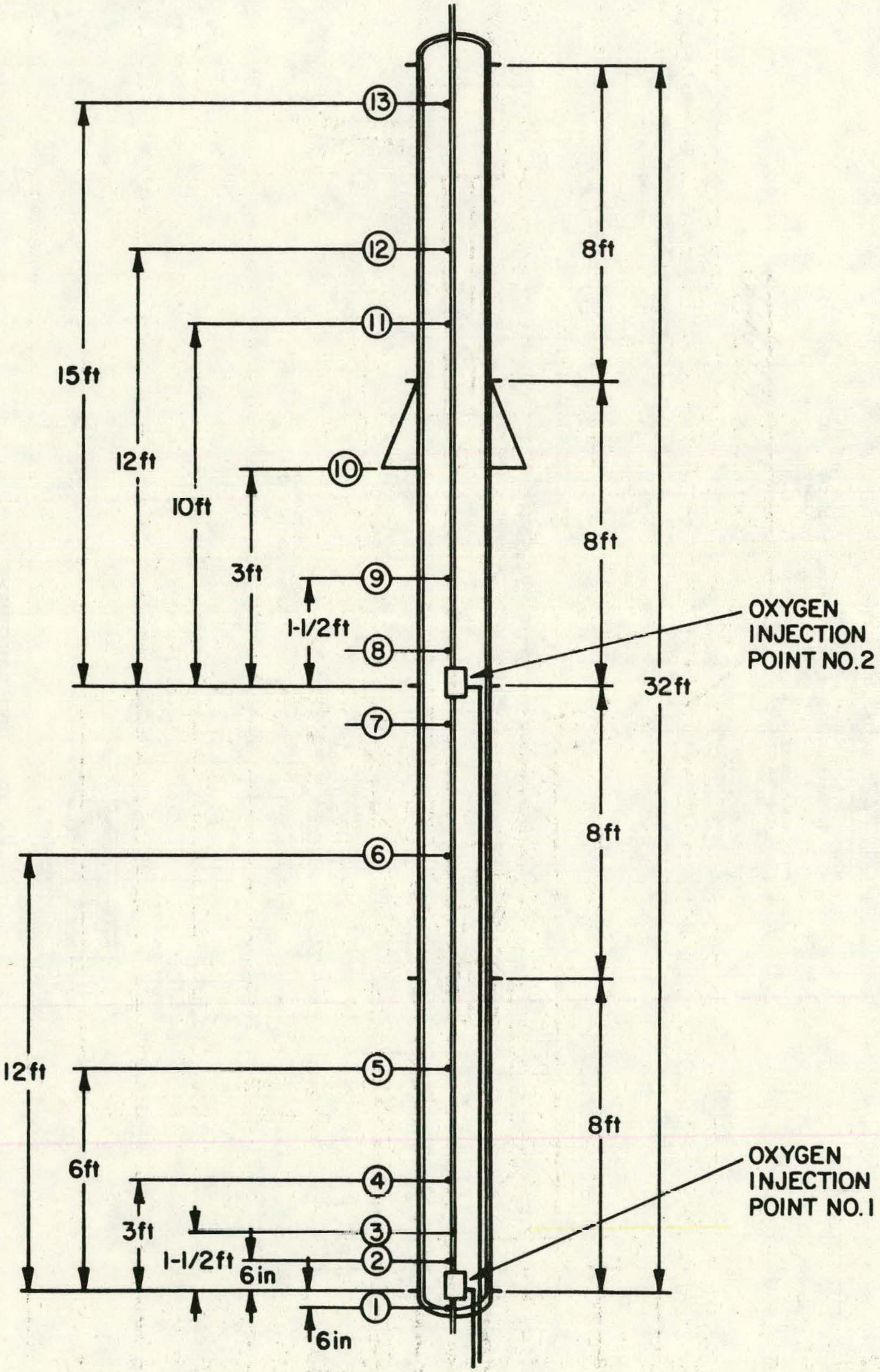


Figure 38. DISPOSITION OF THERMOCOUPLES ALONG PDU RISER

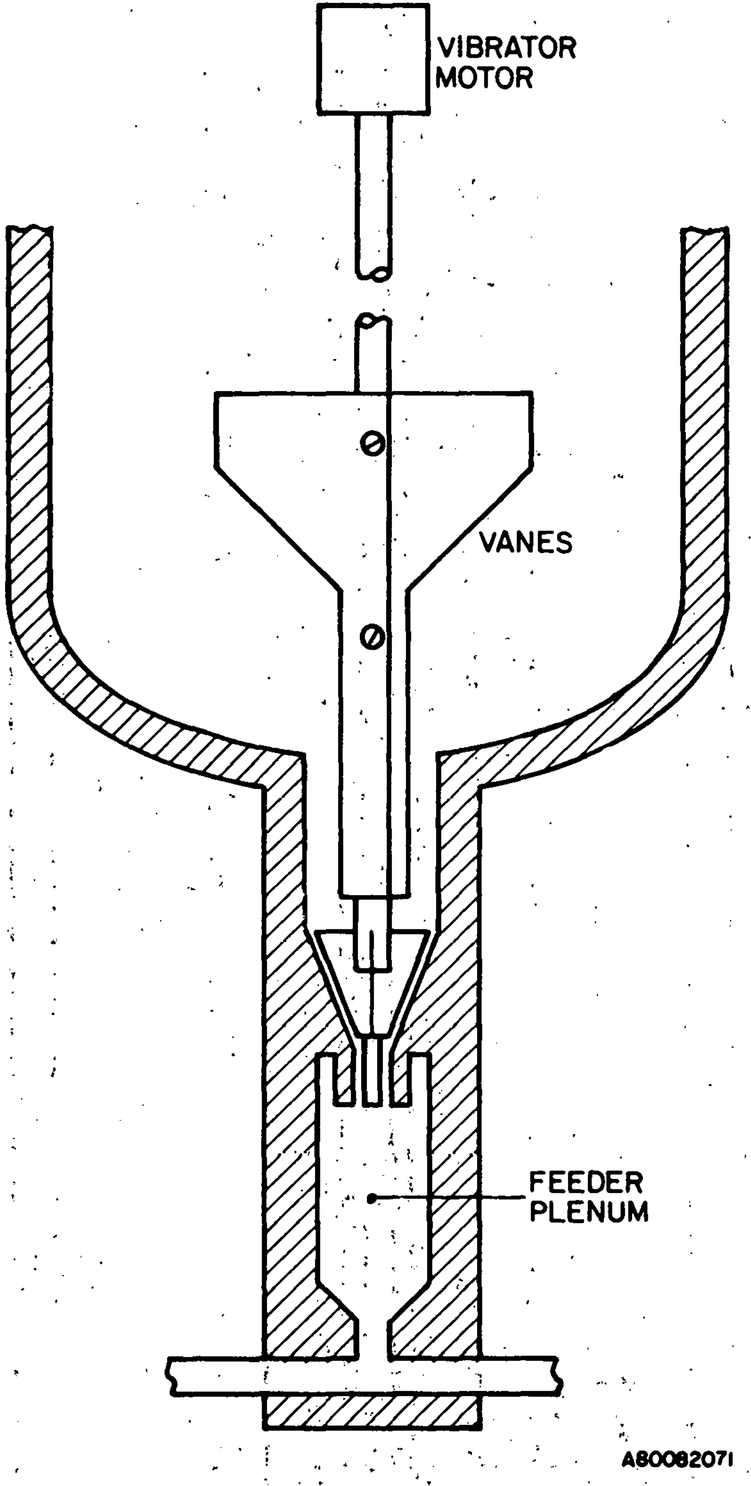


Figure 39. VIBRATING FLAT VANES INSTALLED TO PROMOTE SOLIDS DISCHARGE FROM FEED HOPPER

b. Solids Transport

In operating the equipment, some difficulty was encountered in maintaining solids transport between the feed hopper and the entrance to the preheater coil. Momentary disturbances in gas flow allowed the flowing solids to "slump," plugging the carrier line. To correct this, sections of 1/4-inc. OD copper tubing were sealed and inserted into the carrier line to reduce the cross-sectional area and increase gas velocity, making it easier to maintain solids flow by increasing the superficial gas velocity from approximately 4 ft/s to 8 ft/s.

At the start of solids feeding a pressure surge at times would cause solids to back up through the equalizer line connecting the feeder plenum with the free space at the top of the feed hopper. At times, coal was found to have backed through instrument lines into the main carrier gas line upstream of the feed hopper. This was corrected by placing a valve as shown in Figure 40 which prevented feed solids from blowing back into the carrier gas line.

In operation, the valve was kept closed until the equipment had been placed in feed mode, and all flow disturbances had died away. The valve was then opened, and hopper gas introduced at a predetermined rate to regulate the solids feed rate. In shutdown, the valve was closed first before shifting the equipment to bypass mode.

Plugs formed when moisture and/or tar condensed in the line connecting the top of the riser to the char trap. To prevent this, it is necessary to preheat these lines to at least 400°F prior to feeding coal. In turnaround processing, the lines connecting the char trap exit with the liquids receiver were flushed with toluene to remove accumulations of tars that would occasionally form plugs.

c. Oxygen Line Purge System

In a number of runs, combustors were found to have holes melted in their walls; in these runs, there was no evidence of a malfunction during the operating period. In a normal shutdown, the oxygen valves were closed prior to stopping solids feeding. After solids feeding was stopped, the pressure in the riser would drop slightly, allowing residual oxygen in the combustor supply runs to bleed into the riser and continue burning. To prevent this, a purge system (Figure 41) was installed in which nitrogen was bled continuously through the combustors. In operation, the combustion oxygen was mixed with nitrogen; in shutdown, the nitrogen purged the oxygen from the supply lines. Solids feeding was continued until the temperature of both combustors began to drop, signalling that solids feeding could be terminated without danger of damage to the combustors.

d. Combustor Designs

To obtain a combustor which was less susceptible to melting damage, a quartz sleeve was incorporated into the combustors as shown in Figure 42. Fused quartz was believed to be capable of withstanding thermal shock and

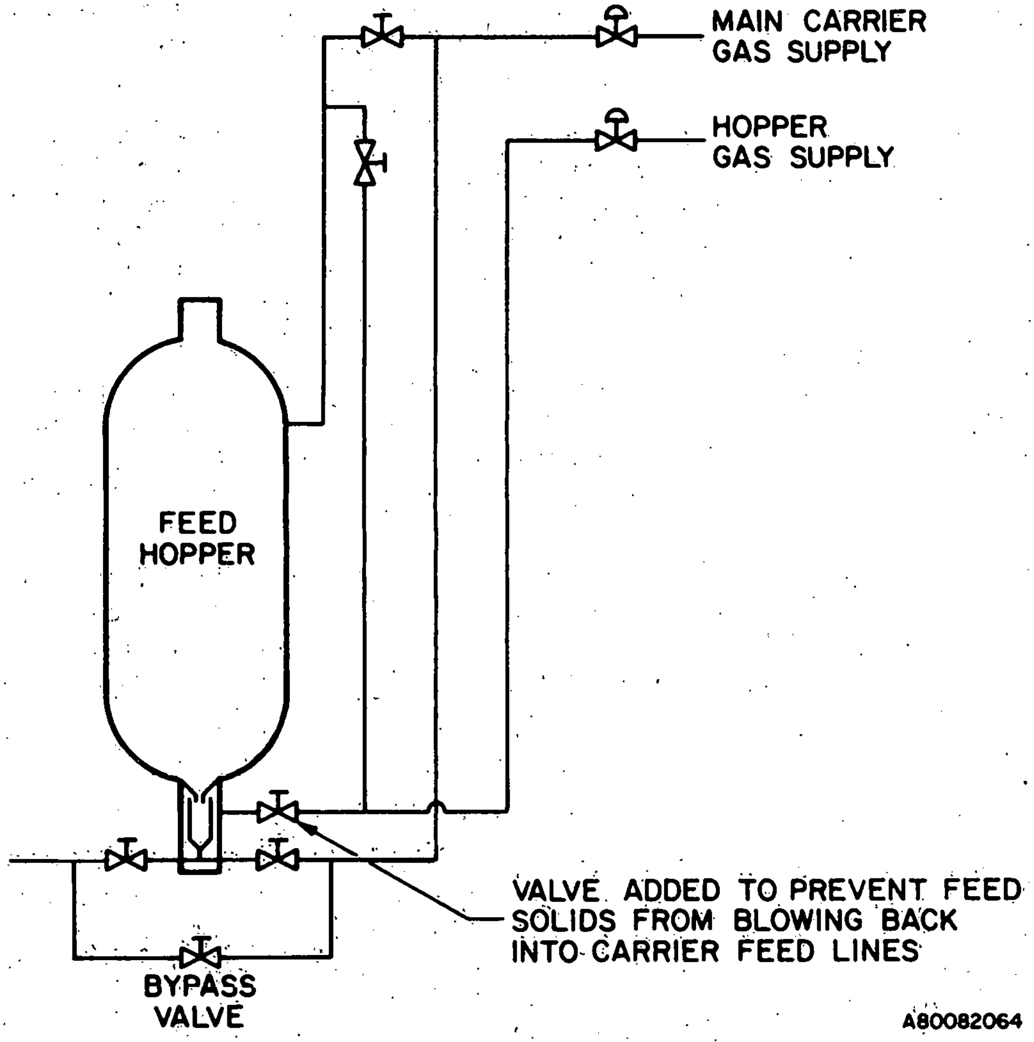


Figure 40. VALVING REVISION IN HOPPER GAS LINE

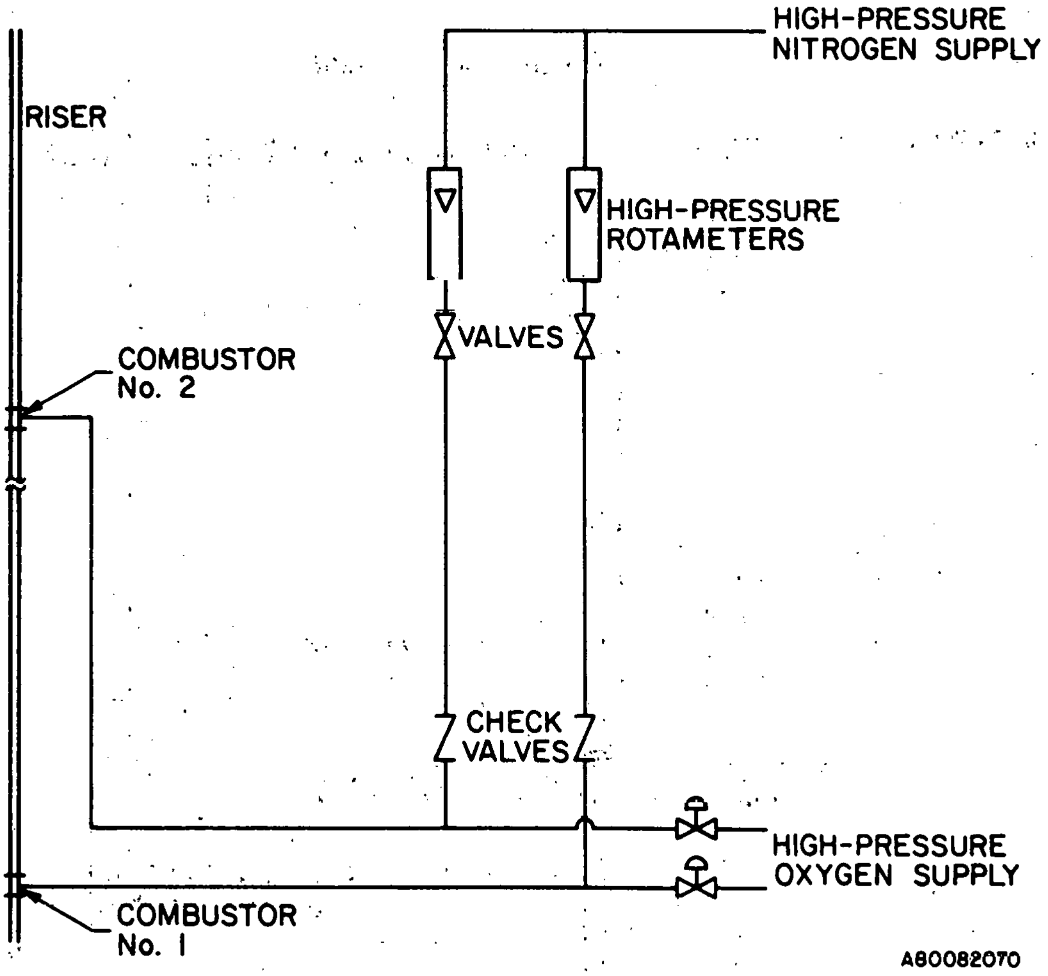


Figure 41. NITROGEN PURGE SYSTEM FOR COMBUSTORS

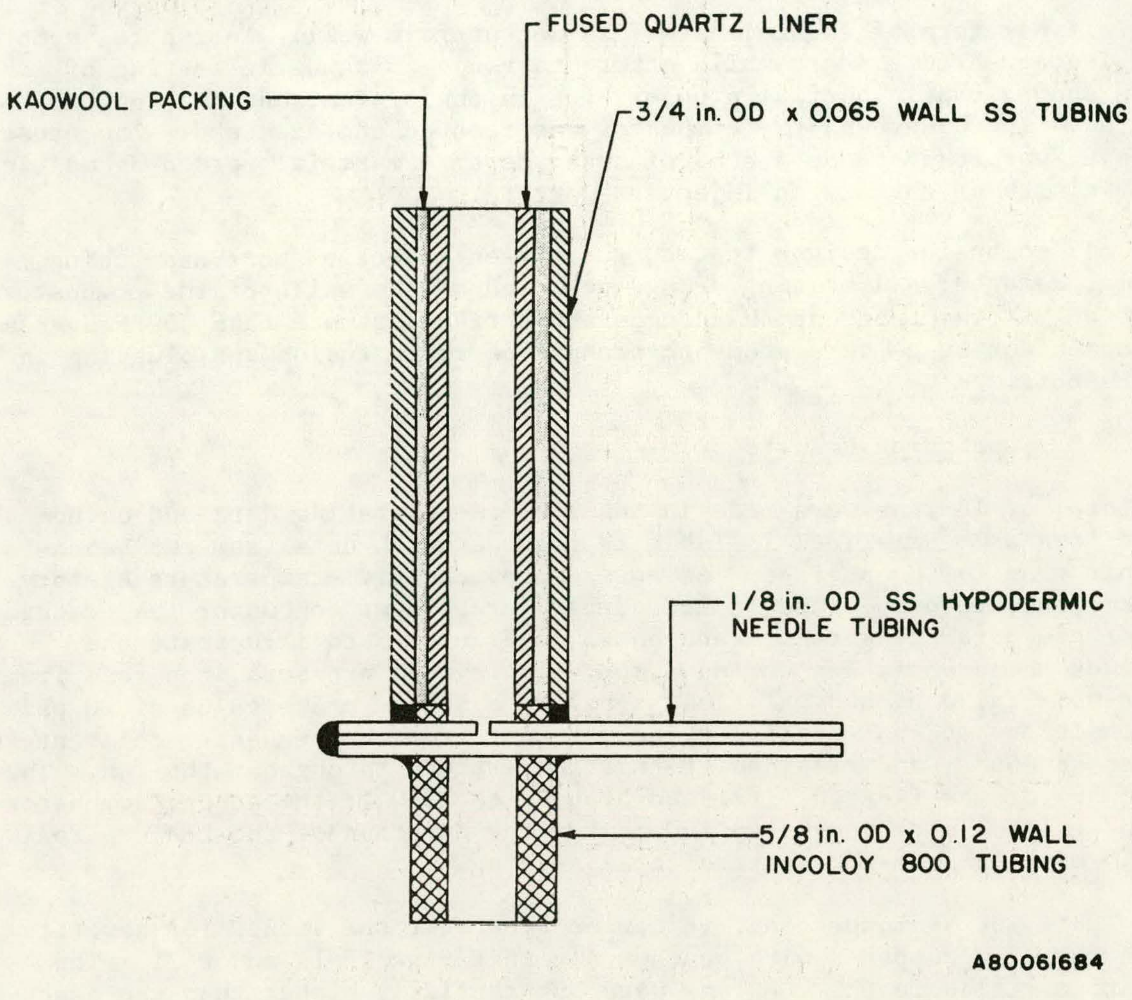


Figure 42. MODIFIED COMBUSTOR ASSEMBLY WITH QUARTZ LINER

temperature extremes. When tested in the PDU, however, the quartz shields shattered, leading to failures caused by shards of quartz deflecting the oxygen/hydrogen flame towards the walls.

In a cold flow model simulator, the transverse tube containing the oxygen port was found to generate eddies in the vicinity of the flame. To eliminate these, the oxygen was introduced through a coaxial tube into a cermaic-lined combustor section shown in Figure 43. The riser tube was modified to incorporate the new design, and the thermocouples repositioned as shown in Figure 44.

This final form of the combustor did not perform well. In run 16, symptoms of plugging appeared a short while after start-up. Diagnostic testing of pressure showed that a partial plug existed in the system, and the run was terminated. In turnaround the combustor was removed and examined. The cause of the plug was found to be a bead of fused ceramic material formed by melting in the vicinity of the oxygen injection port.

In all combustor designs tested, the oxygen injection port and tubing were never damaged; all melting damage occurred on the walls of the combustors. In addition, it was apparent that temperature rises of more than 450°F over a single combustor stage were prone to produce particle fusion and plugging in the combustors.

5. Operating Results

A total of 16 runs were made in the PDU; the operating data and carbon distributions are summarized in Table 10 together with data from two bench-scale unit runs for comparison. As an example, the time-temperature history of system pressure drop, riser inlet temperature, lower combustor temperature and upper combustor temperature are shown in Figure 45 to illustrate the behavior of these variables during a run. The system pressure drop rose from a bypass-mode value of approximately 2 psi to a steady-state value of 10 psi under conditions of coal feeding. The effluent from the preheater coil entered the riser at 850°F, and remained at this temperature throughout the run. The lower combustor was ignited first and brought to 1250°F; the second combustor was then ignited, and brought to 1400°F for the duration of the run, approximately 40 minutes from the start of coal feeding.

In Table 10, by inspection, it can be seen that the values for severity function were low compared with bench-scale unit runs TP-11 and P-21. The carbon oxide yields in the PDU runs were substantially higher than the bench-scale unit runs, probably through combustion of the feed coal and volatile products released in the pyrolysis. Because of losses between the preheater and the riser reactor, riser inlet temperatures were lower than planned, requiring more heat input by oxygen combustion in the riser, and increasing the tendency to combust coal volatiles. At low to intermediate values of severity function, methane + ethane yields are low, and the hydrogen liquids contain large fractions of oxygenated aromatics such as phenols and cresol. The compositions of the gasoline-boiling-range liquids obtained in the PDU runs exhibit these traits. Although the fraction of feed carbon recovered as hydrocarbon liquids was low, the methane plus ethane yields were only slightly less than those which would have been expected at comparable hydrogen pressures and thermal severity in bench-scale unit runs.

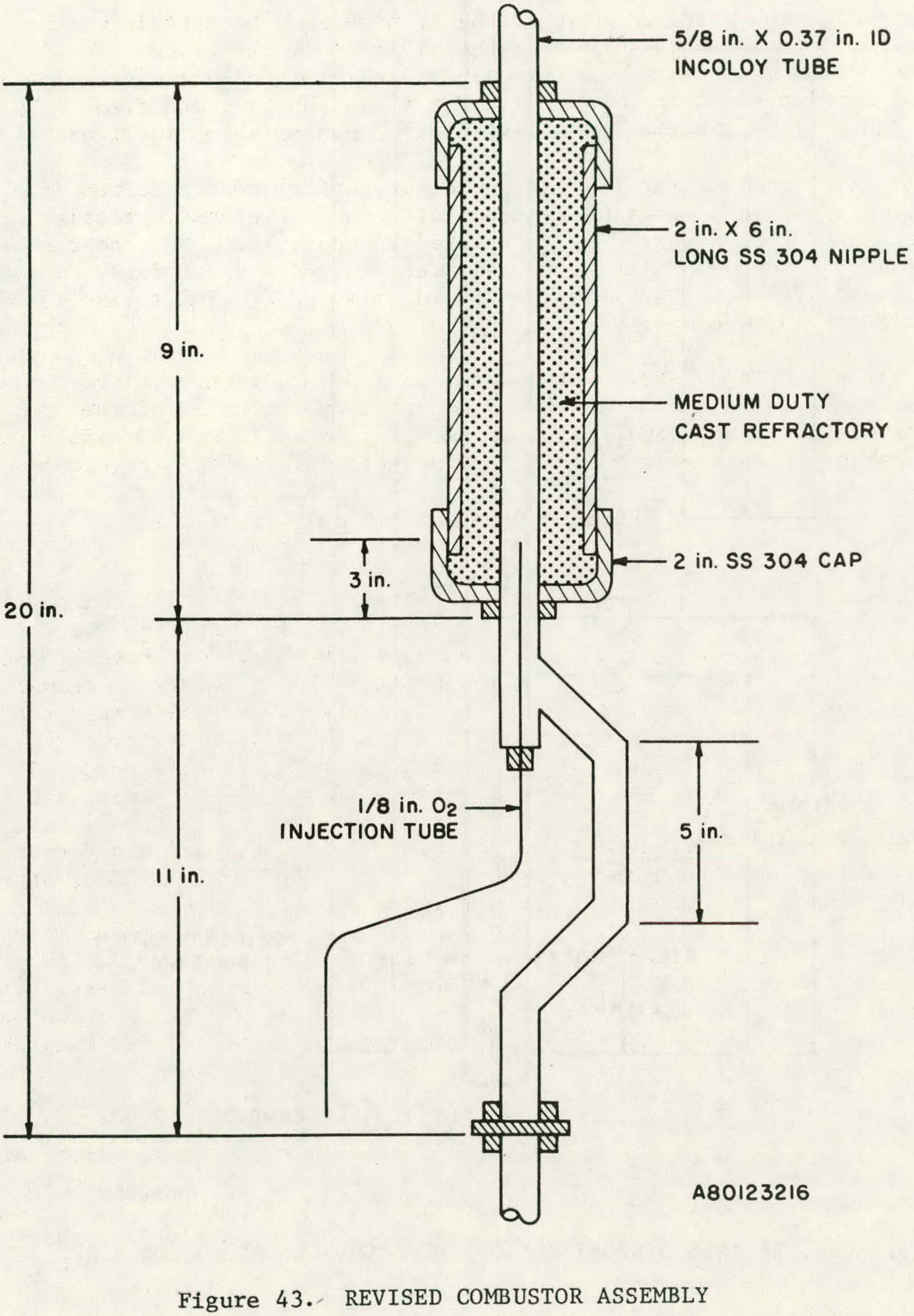


Figure 43. REVISED COMBUSTOR ASSEMBLY

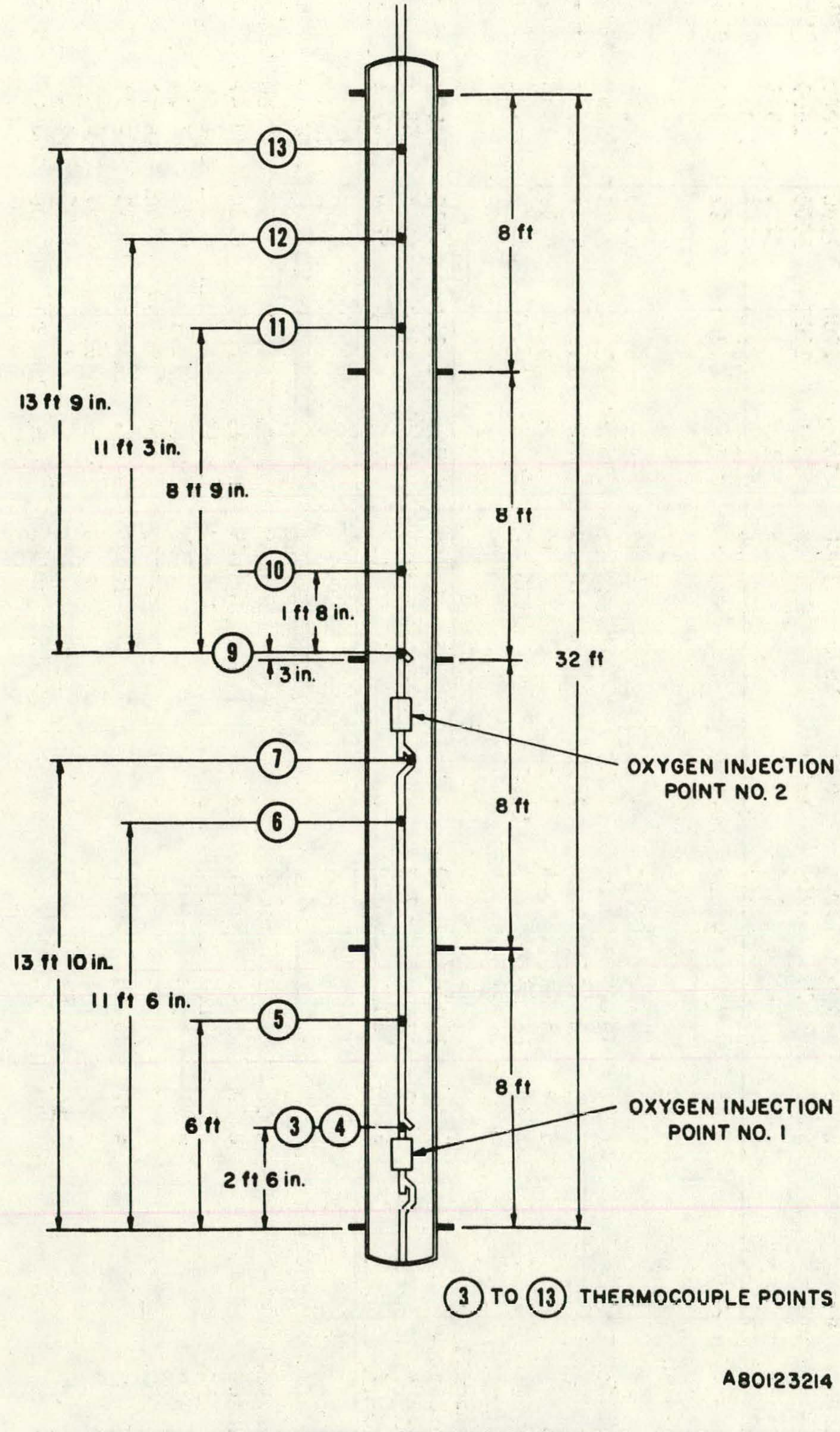


Figure 44. REVISED DISPOSITION OF THERMOCOUPLES ALONG PDU RISER

Table 10. COMPARISON OF PDU OPERATING DATA AND BENCH-SCALE UNIT DATA

Run No.	PDU-5	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-12	PDU-13	TP-11	P-21	PDU-16
System Pressure, psig	1000	1000	1000	1000	1000	1500	1500	2000	1500	2000	2000
Maximum Temperature, °F	1300	1400	1200	1220	1380	1320	1360	1400	1500	1400	1475
Residence Time, s	1.3	1.5	1.5	1.6	1.7	1.9	1.7	1.6	2.4	3.1	1.9
H_2/MAF Coal Weight Ratio	0.137	0.130	0.111	0.102	0.187	0.205	0.209	0.250	0.295	0.372	0.291
Severity Function (Kθ)	0.085	0.215	0.053	0.051	0.221	0.155	0.204	0.265	0.292	0.405	0.634
Carbon Distribution, wt %											
Liquids	4.89	5.24	2.72	1.37	3.25	4.00	3.98	6.11	10.40	13.39	7.72
Carbon Oxides	12.72	12.46	10.05	7.16	15.18	19.69	17.47	12.92	8.28	6.81	27.15
Methane	7.70	8.19	6.62	2.52	9.50	10.29	10.08	11.15	9.25	11.23	18.21
Light Gases	6.09	5.34	5.44	2.52	5.00	11.48	5.26	5.09	6.99	7.46	7.79
Char	68.60	66.99	75.17	86.04	63.59	58.28	60.95	64.39	62.60	52.29	39.12
Liquids Inspections											
Specific Gravity	1.016	1.006	1.032	1.027	1.036	1.040	1.044	1.037	1.070	1.026	--
C_5-400, wt %	57.9	56.3	27.7	39.9	49.5	38.3	42.3	47.0	41.1	52.7	--
400°F+, wt %	42.1	43.1	72.3	60.1	50.5	61.7	57.7	53.0	58.9	47.3	--
Gasoline Composition, wt %											
BTX	16.20	30.12	11.49	7.82	17.80	13.46	20.07	36.91	26.53	68.08	--
Ethyl Benzene	1.96	2.42	1.60	1.19	1.08	1.19	1.88	1.59	2.70	0.80	--
C_9 Aromatics	8.23	5.45	7.24	6.88	4.18	5.09	4.93	2.59	4.26	0.47	--
Indans + Indenes	9.32	7.87	8.85	7.01	8.44	8.13	6.15	5.25	9.07	1.52	--
Naphthalenes	6.45	7.48	4.61	3.90	12.21	7.89	9.56	14.12	9.97	7.56	--
Phenol	23.30	19.90	24.60	22.50	23.40	25.40	24.00	19.50	29.20	14.94	--
Cresols	24.32	18.63	26.77	31.90	20.09	26.45	21.87	11.45	14.93	2.91	--
C_8 Phenols	5.12	3.48	8.08	10.90	8.44	6.21	4.55	5.39	0.39	0.04	--
Unidentified	5.10	4.65	6.76	7.90	4.36	6.18	6.99	3.20	2.95	3.68	
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

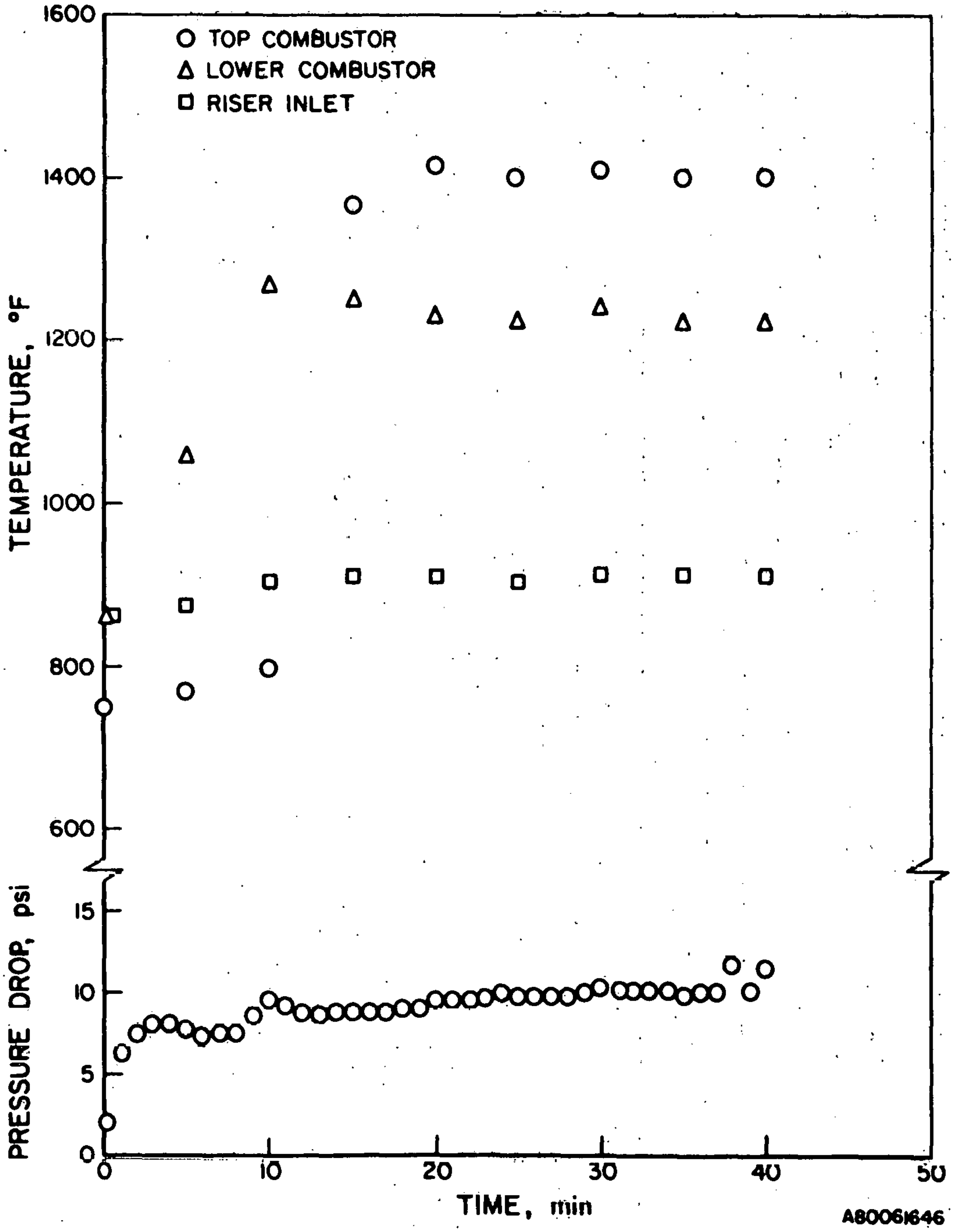


Figure 45. OPERATING DATA FROM RUN PDU-13

The carbon conversions for each PDU run were estimated from the correlation given in Equation 3 and are compared with the observed conversions in Figure 46. On the whole, the observed conversions exceeded the observed conversions by an amount roughly equal to the increase in carbon oxide yields. The distribution of BTX and ethyl-benzene and phenols plus cresols in the gasoline-boiling-range liquids obtained in the PDU runs are plotted with severity function in Figure 47. The decrease in phenols plus cresols with increase in severity, with an attendant increase in BTX + ethyl-benzene, is very similar to the change in gasoline-boiling-range liquids with increase in severity observed in bench-scale unit data.

C. Task 6. Process Assessment

In early comparisons[3,11] of flash hydropyrolysis with other coal conversion technologies, such as Fischer-Tropsch, donor solvent hydrogenation, and gasification via the Lurgi process, flash hydropyrolysis was identified as having a potential cost advantage over other processes. In a later cost study, Steinberg et al.[14] considered three coal hydropyrolysis processing scenarios in which all fuel gases were produced, a mix of gaseous and liquid fuels was produced, and all liquid fuels were produced, and they concluded that a mixture of gaseous and liquid fuels could be produced for less cost than liquid fuels only, or fuel gases only.

The process assessment based on work here was based on a further refinement of a fuel gas and hydrocarbon liquids scenario in which the option were selling the hydrocarbon liquids as gasoline blending stock and fuel oil, or as chemicals (phenol, cresol, benzene, naphthalene, and ethane) and fuel oil.

The analyses were based on a grass roots plant processing 16,000 tons per day of North Dakota lignite or Illinois No. 6 coal (treated to render it non-agglomerating) to obtain the following products:

	FOE, Bbl/day
Methane	20,617
Ethane + Propane	5,915
Carbon Monoxide	956
Blending Gasoline Stock	4,475
No. 6 Fuel Oil	3,870

Approximately 200 tons/day of ash would also be produced.

A flow sheet showing the principal equipment of the conceptual process plant is shown in Figure 48. Such a plant would operate essentially in a "balanced" mode, with steam-oxygen gasification of the char and an additional 2320 tons per day lignite to produce operating hydrogen. The essential features of the plant design are summarized in Table 11.

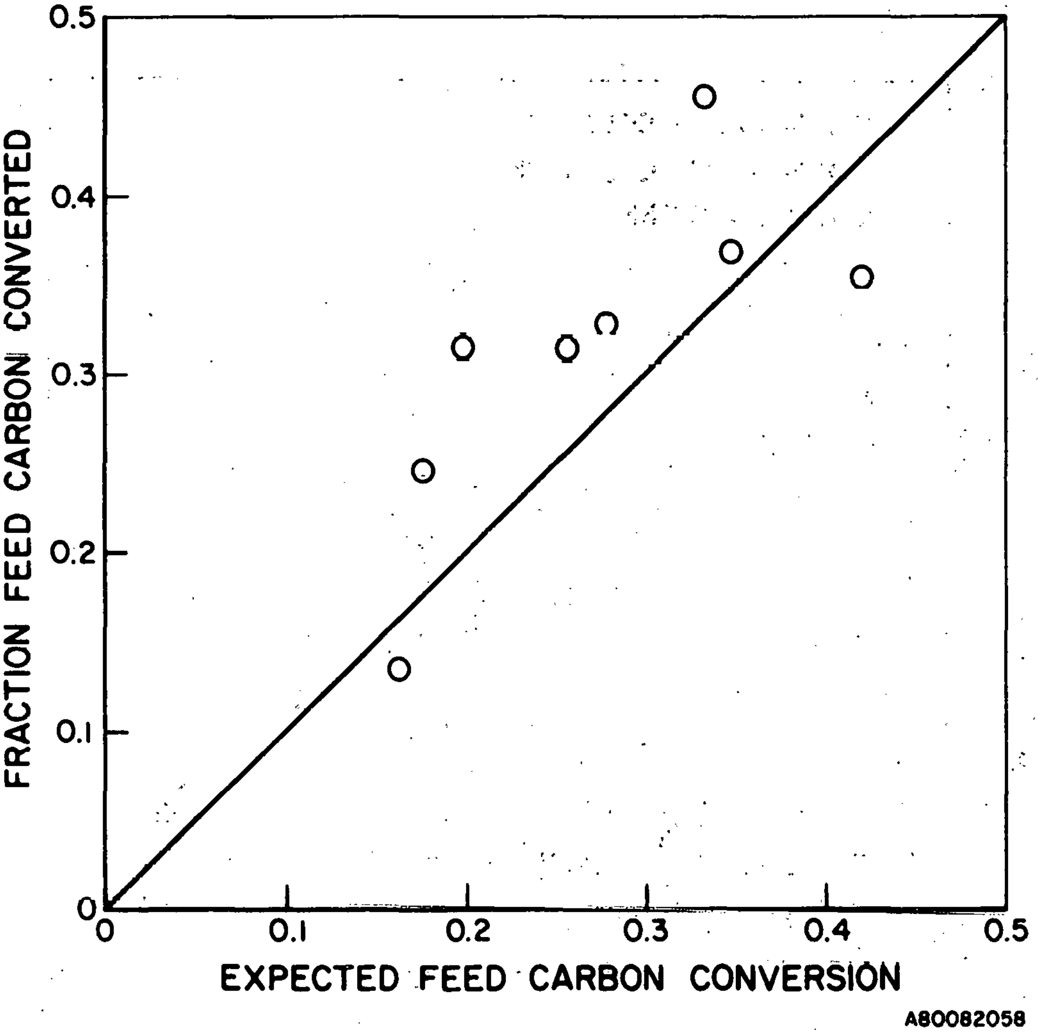


Figure 46. COMPARISON OF OBSERVED CARBON CONVERSION WITH BENCH-SCALE-UNIT CARBON CONVERSION

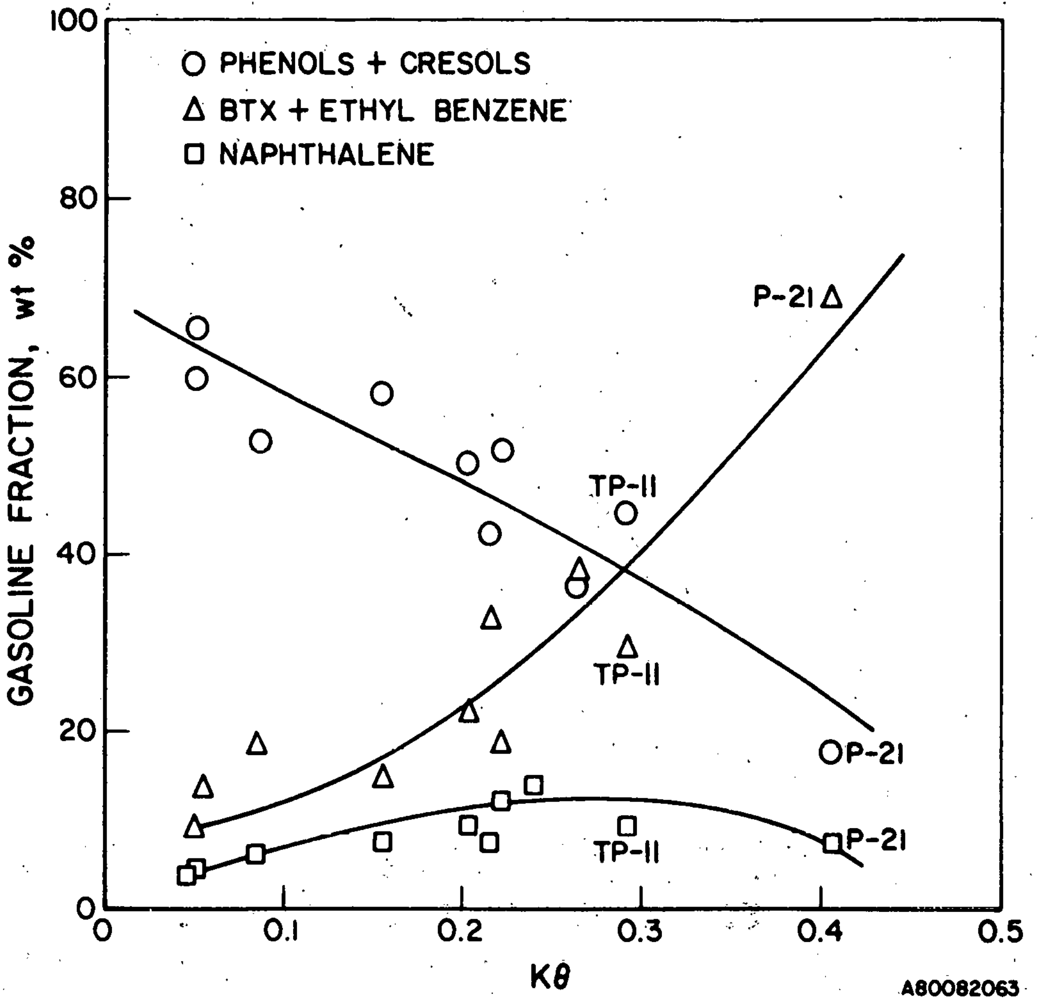


Figure 47. CHANGE IN GASOLINE-BOILING-RANGE LIQUIDS COMPOSITION WITH SEVERITY FUNCTION

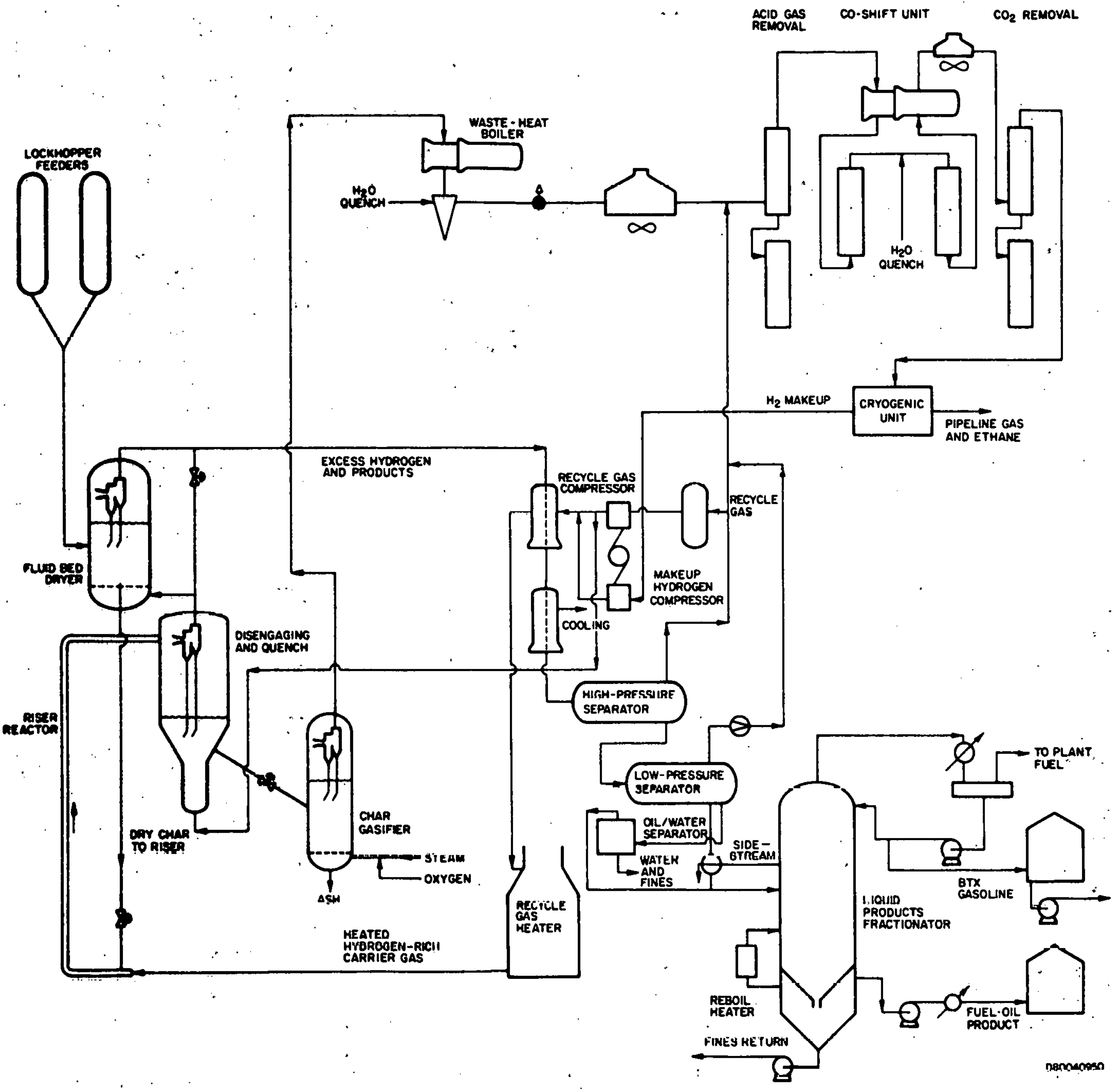


Figure 48. FLOW DIAGRAM RISER CRACKING OF COAL PROCESS — COMMERCIAL CONCEPT

Table 11. BASIS FOR COMMERCIAL PLANT DESIGN

Parameter	Value
Feed Coal	North Dakota Lignite
Feeding Method	40 wt % coal in slurry oil
Coal Feed Rate	16,000 tons/day (1,333,533 lb/hr)
Slurry Oil Rate	148,150 bbl/day (2,000,000 lb/hr)
Hydrogen/Coal Weight Ratio	0.33 lb hydrogen/lb coal
Riser Inlet Temperature	1200°F
Maximum Riser Temperature	1500°F
System Operating Pressure	2000 psig
Riser Superficial Gas Velocity	25 ft/s
Riser Height	94 ft
Residence Time in Riser	6 s
Oxygen Injection Burners	2 each, 600 million Btu/hr
Quench	Recycle gas
Product Recover	By cryogenics
Recycle Gas to Cryogenics	22%
Hydrogen Make-Up Rate	4.9 wt % MAF coal
Make-Up Hydrogen Source	Steam-oxygen gasification of spent char + 2230 ton/day coal

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In operating, feed coal will be slurried with oil, pumped to pressure, and discharged into a fluidized-bed dryer, where the slurry will be flashed from the coal. The dry coal will then be discharged from the dryer, entrained in hydrogen-rich carrier gas, and transported through the riser.

In the riser, the coal will pass two points at which oxygen is injected into the stream. The temperature will be above autoignition. The combustion of the oxygen and hydrogen will heat the process stream to pyrolysis temperatures in two steps. Effluent from the riser will then pass through a quench and disengaging vessel. Spent char will be transported to the char gasifier and the make gases will be admixed with the fluidized-bed dryer effluent and passed through two heat exchangers to cool and condense water and hydrocarbon liquids.

Condensed liquids are separated from the gases in the high-pressure separator, and the bulk of these gases are recycled to process. A slipstream (22%) is added to the make gases from the char gasifier, and the whole passes through a shift-and-scrub module to convert CO to hydrogen and remove acid gases. The hydrogen make up stream is obtained after stripping methane and ethane from the effluent from the shift-and-scrub module by cryogenics.

Liquids from the high-pressure separator pass into a low-pressure separator, where absorbed gases are flashed and recovered. The hydrogen liquids are recovered by phase separation and fractionated into gasoline blending stock and fuel oil. Additional modules could be employed to separate benzene, toluene, xylene, phenols, cresols, and naphthalene for sale as chemical products. Two parallel process trains would be needed to process the 16,000 tons of coal per day. The discharge from the slurry feed pump would be split into the two streams, which would recombine at the feed inlet of the liquids fractionator.

Two processing scenarios were considered, one in which the products would be pipeline gas, BTX gasoline blending stock, and fuel oil (fuels option), and one in which ethane and other chemicals would be recovered for sale separately (chemicals option). The product slate for these two options is summarized in Table 12. In the fuels option, the research octane number of the gasoline liquids would be 110; after hydrotreating to correct for the high nitrogen content (0.41%), this would be reduced to a research octane number of 108. The fuel oil would also require hydrotreating to reduce the nitrogen content from 0.44 to 0.24% to meet the Federal guideline requirements.

Table 12. PRODUCT SLATES FOR FUELS AND CHEMICALS OPTIONS

	MAF Coal Components	
	Fuels Option	Chemicals Option
	wt %	
Fuel Gases	32.15	25.27
Ethane	--	6.63
Propane	--	0.25
400° F EP Gasoline	5.97	0.24
Chemicals	--	6.97
Fuel Oil	5.68	4.44
Total MAF Coal	43.80	43.80

The feed lignite and spent char analyses for the conceptual plant are shown in Table 13 and the detailed yields are summarized in Table 14. The elemental composition of the fuel oil fraction is shown in Table 15, together with the composition and octane number of the blending gasoline.

For a 16,000 ton per day plant, a capital investment summary is shown in Table 16, and the operating energy summary for the plant is shown in Table 17. The estimated annual operating cost (Table 18) was used with the capital investment summary to prepare the estimate of the total investment requirements summarized in Table 19. The total estimated investment cost for the plant is $1,141 million, based in part on a 1976 estimate for a commercial scale HYGAS® SNG plant adjusted to 1979 dollars. From Table 19, the selling prices for the products were projected to be —

Gasoline	$0.86/gal
Fuel Oil	$0.59/gal
Fuel Gas	$3.76/10^6 Btu

Table 13. FEED AND CHAR ANALYSES

	Feed Lignite	Char Product
Proximate Analysis, wt %		
Moisture	13.6	0.1
Volatile Matter	35.2	12.4
Ash	10.5	27.8
Fixed Carbon	40.7	59.7
Total	100.0	100.0
Ultimate Analysis (dry basis), wt %		
Ash	12.11	27.81
Carbon	60.60	65.60
Hydrogen	4.04	2.27
Sulfur, Observed/Federal Guideline Maximum	0.90/0.58	0.80/0.69
Nitrogen, Observed/Federal Guideline Maximum	0.74/0.31	0.46/0.37
Oxygen	21.61	3.06
Total	100.00	100.00

Sieve Analysis of Feed Lignite

U. S. Mesh Size	Opening, Microns	Observed, wt %	Accumulated, wt % larger than	Accumulated, wt % less than
+ 60	250	0	0	100.0
+ 80	177	1.2	1.2	98.8
+ 100	149	1.9	3.1	96.9
+ 200	74	13.6	16.7	83.3
+ 325	44	34.4	51.1	48.9
− 325 (pan)	<44	48.9	100.0	--
Total		100.0		

Table 14. YIELDS FROM NORTH DAKOTA LIGNITE

Run Conditions	
System Pressure, psig	2000
Coil Outlet Temp., °F	1500
Residence Time, s	2.9
H_2, wt % of solids	58
H_2 Partial Pressure, psi	1626

	Yields from Riser, wt % MAF Coal	
	As Chemicals	As Gasoline and Fuels
Methane	13.85	13.85
Ethane	6.63	6.63
CO	11.42	11.42
Ethylene-Propylene	0.04	0.04
Propane	0.21	0.21
Subtotal Fuel Gas	32.15	32.15
400 EP Gasoline	0.24	5.97
Above 400 EP Liquid	4.44	5.68
Char	38.50**	38.50**
CO_2	1.19	1.19
Water	21.43	21.43
Chemicals		
Benzene	3.75	--
Toluene	0.78	--
Xylenes	0.03	--
Ethylbenzene through Indenes	0.05	--
Phenol	0.40	--
Cresols	0.03	--
Naphthalene	1.93	--
Subtotal Chemicals	6.97	--
Total	104.92	104.92
Hydrogen Consumed	4.92	4.92
Total MAF Lignite*	100.00	100.00

* MAF = 75.9% lignite

** Char and 2320 tons/day lignite gasified for hydrogen balance.

Table 15. PRODUCT ANALYSIS

Fuel Oil Product Elemental Analysis	Weight %	Federal Guideline Maximum, wt %
Carbon	93.5	--
Hydrogen	6.02	--
Carbon/Hydrogen	15.53	--
Sulfur	0.09	0.69
Nitrogen	0.99	0.24
Conradson Carbon Residue	5.6	--

Gasoline Composition, wt %	
Benzene	55.0
Toluene	15.3
Ethyl-benzene + Xylenes	0.6
Naphthalenes	14.9
Phenol	8.0
Cresol	0.4
Unidentified	5.0
Unlisted	0.8
Total	100.0
Clear Research Octane*	110
Clear Research Octane After Hydrotreating*	108
Sulfur*	0.10
Nitrogen*	0.41

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* Before hydrotreating.

Table 16. CAPITAL INVESTMENT SUMMARY

	$ Million (1979)
Coal Storage and Reclaiming	**12.8**
Coal Preparation	**16.7**
Coal Feed	**31.3**
Riser Cracking and Products Recovery	**167.4**
Gasifier Quench	**24.3**
Shift Conversion	**143.5**
Acid-Gas Removal	**252.8**
Cryogenics Unit	**29.4**
Sour Water Stripping, NH_3 Removal, and Bio-Oxidation	**70.0**
Sulfur Recovery	**70.0**
Solids Disposal	**10.7**
Steam and Utility System	**113.6**
Plant Water System	**23.5**
Oxygen Plant	**61.0**
General Facilities	**114.0**
Contractor's Fee and Contingency	**Included in Above**
Total Plant/Investment	**1,141.0**

Basis for Investment Estimate:

The above estimate is based on a factored estimate for the IGT HYGAS process prepared by C. F. Braun Company.* This factored estimate cost was adjusted for inflation to show 1979 dollars. Contractor's fee and contingency costs were distributed to the individual cost areas when making the adjustments for inflation. The gasification and recovery system costs for the HYGAS process were backed out of the listing and replaced with our own factored cost estimate for the total Riser Cracking system as depicted on the attached flow diagram, Figure 2.

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* Report FE-2240-S, "Factored Estimates for Western Gas Commercial Concepts," dated 3/1/76.

Table 17. ENERGY SUMMARY

(Case 6, 16,000 tons/day Riser Cracker for Coal)

		1000 Btu/hr		Percent	Tons/Day
Process Charge and Yields					
Coal to Process Direct		11,152			16,000
Coal to Gasifier		1,612			2,313
Total Exclusive Fuel			12,764	100.0	18,313
Product Yield					
Gas Produced		7,436.3		58.2	
Gasoline		1,094		8.6	
Fuel Oil		1,016		8.0	
Total Fuels			9,546.3	74.8*	
Process Energy Consumption	bhp				
Oxygen Supply	88,820				
Recycle Gas Compressor	10,096				
Cryogenic Compressor	19,790				
Slurry Oil and Fract. Pumps	15,260				
Total Demand	133,966				
Steam Plant Fuel for Demand		1,567			2,248
Less Char Ash Burned		387			556
Net Coal Demand - Steam Plant			1,180	7.1	1,692
Recycle Gas Heater		1,947.7		11.7	3,828
Oxygen Combustion		1,200		7.2	--
Total Fuel, Net Demand			4,327.7	26.0	5,520
Total Coal (Process, Gasifier, and Fuel)			16,610	100.0	23,833

---

* 57.5% of total coal.

Table 18. ANNUAL OPERATING COSTS (Commercial Riser Cracker)

	$ Million
Total Plant Investment, TPI	1141
	$ Million/yr
Coal 23,833 tons/day @ 6.77/ton 16,000 tons/day Process 2,313 tons/day Gasification 5,520 tons/day Fuel	53.00
Catalyst	2.72
Chemicals	1.78
Labor, Operating	3.22
Maintenance Labor @ 60% Total Maintenance	20.02
Supervision, 20% Direct Labor	4.65
Administration and General Overhead (60% Labor and Supervision)	16.73
Supplies, Operating, 30% of Operating Labor	0.97
Supplies, Maintenance, 40% of Total Maintenance	13.34
Local Taxes and Insurance, 2.7% TPI	30.81
Total Gross Annual Operating Cost	147.24
By-Product Credits	4.83
Net Annual Operating Cost	142.41

Table 19. CAPITAL REQUIREMENT AND CAPITAL CHARGES
(Commercial Riser Cracker)

	$ Million, 1979		$ Million
Total Plant Investment (TPI) (From Table A-6)	1,141.00		
Initial Charge of Catalyst and Chemicals			
Catalyst	4.86		
Chemicals	4.05		
Paid Up Royalties	1.59		
Allowance for Construction Funds	179.71		
Start-Up Cost (20% Total Annual Gross Operating Cost)	27.44		
			Annual Depreciation Charge
Subtotal, Depreciable Capital	1,358.65	X 0.05 =	67.932
Working Capital	24.46		
			Annual Charge For R.O.I.
Total Capital for Return on Investment (R.O.I.) Calculation*	1,383.11		98.258
Net Annual Operating Cost (From Table C-7)			142.41
Total Annual Cost Applied to Gas, Gasoline, and No. 6 Fuel Oil Products			308.60

DEVELOPMENT OF PRODUCT PRICES

	Product, 10^{12} Btu/yr	Normal Expected Price Per Btu Ratio	Btu/gal
Gasoline	8.36	1.00	132,700
No. 6 Fuel Oil	8.01	0.62	146,830
Gas	58.6	0.58	--

		$/10^6 Btu		10^6 Btu/gal	Price/gal
Price, Gas =	$\frac{0.58 \times 308.60}{0.58(58.6)+1(8.63)+0.62(8.01)} =$	3.76			
Price, Gasoline =	$\frac{1 \times 308.60}{0.58(58.6)+1(8.63)+0.62(8.01)} =$	6.49	X	0.132700	= 0.86
Price, No. 6 F. O. =	$\frac{0.62 \times 308.60}{0.58(58.6)+1(8.63)+0.62(8.01)} =$	4.02	X	0.146830	= 0.59

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* Modified A.G.A. Utility Financing method used by Synthetic Gas-Coal Task Force.

A similar analysis was made for a process plant in which hydrogen was recovered by oil absorption, and for a plant processing Illinois No. 6 coal chemically treated to render it nonagglomerating by a process developed in the experimental program. The projected gasoline prices for these cases were estimated to be 88 and 91 cents per gallon, and the prices for the fuel oil were 61 and 69 cents per gallon, respectively. The prices for fuel gas were \$3.86 and \$3.90/10^6 Btu. These prices are economically attractive in current markets, so that economic viability appears possible for a hydropyrolysis plant.

IV. CONCLUSIONS

Over the course of the experimental program, 143 runs were carried out in the bench-scale unit, investigating variables such as temperature, hydrogen pressure and operating pressure, residence time, particle size, temperature profile, heating rate, and entraining gas composition (hydrogen, hydrogen/steam, and syngas). The principal findings are summarized as follows:

1. With North Dakota lignite and Illinois No. 6 coal, the depth of conversion increases with increase in processing temperature over the range 1200° to 1500°F; conversion is minimal at temperatures below 1200°F.

2. With North Dakota lignite and Illinois No. 6 coal, depth of conversion increases with hydrogen partial pressure. At low hydrogen-to-coal feed ratios, the hydrogen partial pressure can be substantially reduced by the diluting effect of volatile matter released from the coal.

3. The pyrolysis can be characterized by a severity function based on anthracene hydrogasification kinetics which is useful in comparing run-to-run data and results.

4. The character and amounts of products are functions of severity; at low severity, the amounts of methane, ethane, and propane were less than the amounts produced at high severity. The amounts of liquids did not vary as much, but the composition varied considerably. At low severity, the condensed liquids contained sizable fractions of phenols and cresols, while at high severity, the liquids contained sizable fractions of benzene and toluene, apparently formed by vapor-phase hydrogenation of the phenols and cresols. The rate of the vapor-phase hydrogenation appears to be dependent upon both temperature and hydrogen partial pressure.

5. Over the range investigated, heating rate had little or no effect on the distribution of carbon among products.

6. Over the range of tempeatures used, preheating hydrogen to pyrolysis temperatures prior to contact with the feed coal had little or no effect on the distribution of carbon among products, and the amounts and character of the products did not differ appreciably from those obtained by heating the coal and hydrogen concurrently.

7. When steam was substituted for hydrogen, a portion of hydrocarbon liquid products was lost, apparently through steam-reforming reaction.

8. It was not possible to operate the bench-scale unit with syngas at 1250 psig and 1475°F because of plugs formed by carbon deposition.

9. Both bentonite clay and iron oxide appear to have catalytic effects, and should be investigated further.

10. The gasoline-boiling-range liquids obtained from coal contain sizable fractions of high octane (>100) materials such as benzene, toluene, ethyl-benze, and phenol which would suggest that the process be used as a source for blending stock rather than bulk gasoline.

The main findings and conclusions from PDU operations can be summarized as follows:

1. The operation of an in-line oxygen/hydrogen combustion system was technically successful, with ignition being obtained at bulk-gas stream temperatures as low as 750°F.

2. The distribution of carbon among products in the PDU runs, relative to the bench-scale runs, showed a shift towards higher carbon oxide yields, slightly reduced methane and ethane yields, and approximately a 50% reduction in hydrocarbon liquids when operated at 2000 psig and 1450°F.

3. To avoid damage to the in-line combustors, the rise in bulk-gas temperature across the combustion zone should be limited to 300°F.

4. Heat loss between the preheater and the riser reactor should be greatly reduced so as to unload the riser combustors and decrease the tendency to convert coal volatiles to CO.

5. The composition of the hydrocarbon liquids produced in the PDU runs did not differ greatly from those produced in the bench-scale unit runs.

In the economic analysis performed in Task 6, the projected selling prices for the products were found to be attractive in the current market. In addition, phenol commands a better price than benzene, so there is some incentive for operating to produce phenol. Overall, because of the favorable economics, Riser Cracking of Coal appears to merit further work in spite of the immediate technical shortcomings of the equipment used in the program just concluded.

V. PUBLICATIONS

The following publications were a result of the work performed during the experimental program:

1. Duncan, D. A., Beeson, J. L. and Oberle, R. D., "Riser Cracking of Coal to Oil and Gas." Paper presented at the 1977 Annual Meeting of the American Chemical Soceity, August 28 - September 2, 1977. Chicago, Illinois.

2. Dunca, D. A., Beeson, J. L. and Oberle, R. D., "Coal Hydropyrolysis Permits Product Yield Variation." Paper presented at the 85th National Meeting of AIChE, Philadelphia, June 4-8, 1978.

3. Dunca, D. A., Beeson, J. L. and Oberle, R. D., "Riser Cracking of Coal to Gasoline, Fuel Oil and Gas." Paper presented at the 87th National Meeting of AIChE, Boston, Aug. 19-22, 1979.

4. Duncan, D. A., Beeson, J. L. and Oberle, R. D., "Flash Hydrogenation of Lignite in an Entrained Flwo Reactor." Paper presented before the Division of Fuel Chemistry, American Chemical Society, Washington, D. C., September 9-14, 1979.

5. Duncan, D. A., "Process for Hydrocracking Carbonaceous Material to Provide Fuels or Chemical Feedstock," U. S. Patent 4,225,414. September 30, 1980.

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4. Fallon, P. and Steinberg, M., "Design and Preliminary Results of the BNL 1 lb/hr Coal Flash Hydropyrolysis Experiment." Paper presented at the 173rd National Meeting of the American Chemical Society, New Orleans, March 20-25, 1977.

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7. Hill, G. R. and Wood, R. E., "Rapid Conversion of Hydrogen-Coal Slurries to Liquid Fuels in Small Diameter Tubes." Paper presented at the 164th National Meeting of the Amercian Chemical Soceity, New York, August 27 - September 1, 1972.

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11. Ladelfa, C. J. and Greene, M. I., "Comparative Economics of SNG Production by the Cities Service SC-SRT Process and the Lurgi Process." Paper presented at the 174th National Meeting of the American Chemical Society, Chicago, September 1977.

12. Oberg, C. L. et al., "Coal Liquefaction Under High-Mass Flux and Short Residence Time Conditions." ACS Div. Fuel Chem. Prepr. 22, No. 2, 185-96 (1977).

13. Silsby, R. J. and Sawyer, E. W., "The Dealkylation of Alkyl Aromatic Hydrocarbons I. The Kinetics and Mechanism of Toluene Decomposition in the Presence of Hydrogen," J. Appl. Chem. 6, No. 8, 347-55 (1956).

14. Steinberg, M., et al., "Reaction, Process, and Cost Engineering for the Flash Hydropyrolysis (FHP) of Coal." Paper presented at the 71st Annual Meeting of the American Institute of Chemical Engineers, Miami Beach, November 12-16, 1978.

15. Suuberg, E. H., Peters, W. A. and Howard, J. B., "Product Composition and Kinetics of Lignite Pyrolysis." Paper presented at the 173rd National Meeting of American Chemical Society, New Orleans, March, 1977.

16. Virk, P. S., Chambers, L. E. and Woebcke, H. N., "Thermal Hydrogasification of Aromatic Compounds." Paper presented at the 165th National Meeting of the American Chemical Society, Dallas, April 1973.

17. Wiser, W. H., "Hydrogenation of Western Coal in Dilute Phase Under Medium Pressures for Production of Liquids and Gases," Final Report, ERDA Contract FE (49-18) - 1200. (1975).

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APPENDIX A. Bench-Scale Unit Data

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Table A-1, Part 1. SUMMARY OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run/Date	Objective	Results
P-7/4-4-77	Operate coil isothermally at 1500°F, 1500 psig.	Partially successful; coil plugged after 23 minutes of operation.
P-8/4-21-77	Operate with modified temperature profile at 1500 psig and 1450°F coil outlet temperature.	Successful; operated 60 minutes with voluntary shutdown.
P-9/4-27-77	Operate with modified temperature profile at 1500 psig and 1450°F coil outlet temperature.	Partially successful; operated 50 minutes with voluntary shutdown. Solids feed rate higher than planned.
P-10/5-6-77	Operate with modified temperature profile at 1500 psig and 1475°F coil outlet temperature.	Partially successful; operated 39 minutes. Run terminated when feed hopper vibrator failed, causing irregularity in feed rate.
P-11/5-11-77	Operate with modified temperature profile at 1500 psig and 1500°F coil outlet temperature.	Successful; operated 60 minutes with voluntary shutdown.
P-12/5-20-77	Operate with modified temperature profile at 2000 psig and 1400°F coil outlet temperature.	Successful; operated 40 minutes with voluntary shutdown.
P-13/5-26-77	Operate with modified temperature profile at 2000 psig and 1450°F coil outlet temperature.	Successful; operated 40 minutes with voluntary shutdown.
P-14/6-3-77	Operate with modified temperature profile at 2000 psig and 1475°F coil outlet temperature with 88% solids in the feed gas.	Successful; operated 40 minutes with voluntary shutdown.
P-15/6-9-77	Operate with modified temperature profile at 2000 psig and 1500°F coil outlet temperature with 88% solids in the feed gas.	Successful; operated 40 minutes with voluntary shutdown.

Table A-1, Part 2. SUMMARY OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run/Date	Objective	Results
P-16/6-15-77	Operate with modified temperature profile at 2000 psig and 1500°F coil outlet temperature with 67% solids in the feed gas.	Successful; operated 120 minutes with voluntary shutdown.
P-17/6-17-77	Operate with modified temperature profile at 2000 psig and 1475°F coil outlet temperature with 67% solids in the feed gas.	Successful; operated 120 minutes with voluntary shutdown.
P-18/6-22-77	Operate with modified temperature profile at 2000 psig and 1450°F coil outlet temperature with 67% solids in the feed gas.	Unsuccessful; discharge from feeder hopper blocked by insulation fiber.
P-19/6-26-77	Replication of Run P-18.	Successful; operated 120 minutes with voluntary shutdown.
P-20/6-30-77	Operate with modified temperature profile at 2000 psig and 1400°F coil outlet temperature with 67% solids in the feed gas.	Unsuccessful; run terminated by power outage during a thunderstorm.
P-21/7-5-77	Replication of Run P-20.	Successful; operated 2 hours with voluntary shutdown.
P-22/7-19-77	Operate with modified temperature profile at 2000 psig and 1450°F coil outlet temperature with 50% solids in the feed gas.	Successful; operated 3 hours with voluntary shutdown.
P-23/7-22-77	Operate with modified temperature profile at 2000 psig and 1475°F coil outlet temperature with 50% solids in the feed gas.	Partially successful; solids feed rate was not as high as expected. Operated 3 hours with voluntary shutdown.
P-24/7-27-77	Replication of Run P-23.	Unsuccessful; run stopped by a fire in the unit.
P-25/8-16-77	Replication of Run P-23.	Partially successful; off-gas line in the demister plugged with tar after 2-1/2 hours of operation.

Table A-1, Part 3. SUMMARY OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run/Date	Objective	Results
P-26/9-22-77	Replication of Run P-23.	Successful; operated 180 minutes with voluntary shutdown.
P-27/9-30-77	Operate with modified temperature profile at 2000 psig and 1475°F coil outlet temperature with 1:1 solids-to-gas feed ratio.	Successful; operated 180 minutes with voluntary shutdown.
P-28/10-12-77	Operate with modified temperature profile at 2000 psig and 1500°F coil outlet temperature with 1:1 solids-to-gas feed ratio.	Successful; operated 180 minutes with voluntary shutdown.
RC-1/10-17-77	Operate with spent char feed with modified temperature profile at 2000 psig and 1475°F coil outlet temperature.	Successful; operated 60 minutes with voluntary shutdown.
RC-2/10-20-77	Replication of Run RC-1.	Successful; operated 60 minutes with voluntary shutdown.
TP-1/10-26-77	Operate with severe temperature profile at 2000 psig and 1475°F coil outlet temperature with 67% solids in feed gas.	Successful; operated 120 minutes with voluntary shutdown.
TP-2/11-1-77	Operate with constant heating rate profile at 2000 psig and 1500°F coil outlet temperature with 83% solids in feed gas.	Successful; operated 75 minutes with voluntary shutdown.
TP-3/11-9-77	Replication of Run TP-2.	Successful; operated 90 minutes with voluntary shutdown.
TP-4/11-16-77	Replication of Run TP-3.	Successful; operated 90 minutes with voluntary shutdown.
TP-5/11-21/77	Operate with "soaking" temperature profile at 2000 psig and 1475°F coil outlet temperature with 83% solids in feed gas.	Successful; operated 90 minutes with voluntary shutdown.
TP-6/11-23-77	Operate with "soaking" temperature profile at 2000 psig and 1450°F coil outlet temperature with 83% solids in feed gas.	Successful; operated 90 minutes with voluntary shutdown.

Table A-1, Part 4. SUMMARY OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run/Date	Objective	Results
TP-7/11-30-77	Operate with "upsweep" temperature profile at 2000 psig and 1500°F coil outlet temperature.	Unsuccessful; run aborted due to malfunction in feeder.
TP-8/12-7-77	Replication of Run TP-7.	Partially successful; coil plugged after 50 minutes of operation.
TP-9/12-9-77	Operate with "unsweep" temperature profile with soak at 1250°F at 2000 psig and 1500°F coil outlet temperature.	Unsuccessful due to solids feeder malfunction.
TP-10/12-13-77	Replication of Run TP-9.	Technically successful, but material balance incomplete due to missing data.
TP-11/12-22-77	Replication of Run TP-9 at 1500 psig.	Successful; operated 1-1/2 hours with voluntary shutdown.
RT-1/1-5-78	Operate with increased residence time and soaking temperature profile at 1450°F and 2000 psig system outlet pressure.	Successful; operated 1-1/2 hours with voluntary shutdown.
RT-2/1-10-78	Operate with increased residence time and soaking temperature profile at 1450°F and 2000 psig system outlet pressure.	Successful; operated 1-1/2 hours with voluntary shutdown.
RT-3/1-24-78	Operate with increased residence time and soaking temperature profile at 1450°F and outlet pressure at 1500 psig.	Successful; operated 1-1/2 hours with voluntary shutdown.
PS-1/2-10-78	Operate with soaking temperature profile at 1200°F and 2000 psig to simulate operation of PDU preheater.	Unsuccessful; aborted because of plug in char trap entrance after 15 minutes of operation.
PS-2/2-14-78	Replication of Run PS-1.	Unsuccessful; aborted because of plug in char trap entrance after 5 minutes of operation.

Table A-1, Part 5. SUMMARY OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run/Date	Objective	Results
PS-3/2-16-78	Operate with soaking temperature profile at 1300°F and 1500 psig to simulate operation of PDU preheater.	Successful; operated 60 minutes with voluntary shutdown.
PS-4/2-21-78	Replication of Run PS-1.	Unsuccessful; aborted because of tubing rupture after 15 minutes of operation.
PS-5/2-24-78	Replication of Run PS-1.	Unsuccessful; aborted because of plug forming during pressurization.
PS-6/3-1-78	Replication of Run PS-1 with coil outlet heater set at 1200°F.	Successful; operated 60 minutes with voluntary shutdown.
PP-2/3-7-78	Operate at system outlet pressure of 1000 psig, hydrogen-to-feed ratio of 0.18 and normal temperature profile with 1500°F coil outlet temperature.	Partially successful; operated 90 minutes with shutdown forced by partial plug in coil outlet.
PP-3/3-10-78	Replication of PP-2.	Unsuccessful; tramp scale from hopper walls plugged feeder after 5 minutes of operation.
PP-4/3-14-78	Replication of PP-2.	Partially successful; plug formed in outlet after 90 minutes.
PP-5/3-20-78	Operate at system outlet pressure of 500 psig, hydrogen-to-feed ratio of 0.18 and normal temperature profile with 1500°F coil outlet temperature.	Partially successful; tar plug formed in make-gas line making system inoperable after 73 minutes.
PP-6/3-23-78	Operate at system outlet pressure of 1000 psig, hydrogen-to-feed ratio of 0.5 and normal temperature profile with 1500°F coil outlet temperature.	Unsuccessful; tramp scale from hopper walls plugged feeder after 10 minutes of operation.

Table A-1, Part 6. SUMMARY OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run/Date	Objective	Results
PP-7/4-4-78	Operate at reduced system pressure of 1000 psig and normal temperature profile to evaluate yields at reduced pressure.	Unsuccessful; aborted because of tar plug in make-gas line after 30 minutes of operation.
PP-8/4-7-78	Operate at reduced system pressure of 500 psig and normal temperature profile to evaluate yields at reduced pressure.	Unsuccessful; aborted because of plug in make-gas line after 15 minutes of operation.
PP-9/4-12-78	Repeat of PP-7.	Successful; operated for 120 minutes with voluntary shutdown.
PP-10/4-15-78	Replication of PP-7.	Unsuccessful; aborted because of plug in carrier gas line after 6 minutes of operation.
PP-11/4-25-78	Repeat of PP-8.	Successful; operated for 180 minutes with voluntary shutdown.
PP-12/4-27-78	Replication of PP-7.	Successful; operated for 180 minutes with voluntary shutdown.
BC-1/5-2-78	Operate with 10% mixture (by weight) of caking coal and sand at coil outlet temperature of 1450°F and pressure of 2000 psig to determine yields from bituminous coal.	Successful; operated for 60 minutes with voluntary shutdown.
BC-2/5-4-78	Operate with 20% mixture (by weight) of caking coal and sand at coil outlet temperature of 1450°F and pressure of 2000 psig to determine yields from bituminous coal.	Unsuccessful; aborted after 30 minutes of operation because of plug in carrier gas line.
BC-3/5-9-78	Repeat of Run BC-2.	Successful; operated for 60 minutes with voluntary shutdown.
BC-4/5-12-78	Operate with 30% mixture (by weight) of caking coal and sand at coil outlet temperature of 1450°F and pressure of 2000 psig to determine yields from bituminous coal.	Unsuccessful; aborted because of plug in coil after 23 minutes of operation.

Table A-1, Part 7. SUMMARY OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run/Date	Objective	Results
BC-5/5-16-78	Repeat of Run BC-4.	Unsuccessful; aborted after 10 minutes of operation because of plug in coil.
BC-6/5-18-78	Repeat of Run BC-2.	Unsuccessful; aborted after 19 minutes of operation because of plug in feed hopper.
BC-7/5-25-78	Repeat of Run BC-2.	Successful; operated for 90 minutes with voluntary shutdown.
BC-8/5-31-78	Replication of Run BC-2.	Unsuccessful; aborted after 25 minutes of operation because of plug in coil.
BC-9/6-2-78	Replication of Run BC-2.	Successful; operated for 90 minutes with voluntary shutdown.
BC-10/6-6-78	Operate with mixture of 20% (by weight) caking coal and 80% silica sand at pressure of 2000 psig and coil outlet temperature of 1500°F.	Unsuccessful; aborted after 30 minutes of operation because of plug in coil.
BC-11/6-13-78	Repeat of Run BC-10.	Successful; operated for 90 minutes with voluntary shutdown.
BC-12/6-15-78	Replication of Run BC-10.	Successful; operated for 120 minutes with voluntary shutdown.
BC-13/6-20-78	Replication of Run BC-10.	Successful; operated for 90 minutes with voluntary shutdown.
BC-14/6-22-78	Operate with mixture of 30% (by weight) caking coal and 70% devolatilized char at 2000 psig and coil outlet temperature of 1450°F.	Unsuccessful; coil plugged after 1 minute of operation.

Table A-1, Part 8. SUMMARY OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run/Date	Objective	Results
BC-15/6-29-78	Operate with 20 wt % of caking coal and dead-burned char at coil outlet temperature of 1450°F and 2000 psig to determine yields from bituminous coal.	Unsuccessful; aborted after 1 minute of operation because of plug in coil.
BC-16/7-14-78	Operate with 10 wt % of caking coal and dead-burned char at coil outlet temperature of 1450°F and 2000 psig to determine yields from bituminous coal.	Successful; run terminated after 53 minutes of operation due to plug in coil.
BC-17/7-20-78	To perform a hydrogen pretreatment of a caking coal at coil outlet temperature of 800°F and 2000 psig.	Partially successful; aborted after 26 minutes of operation because of plug in coil.
BC-18/7-25-78	To perform a hydrogen pretreatment of a caking coal at coil outlet temperature of 700°F and 2000 psig.	Technically successful; however, material balance incomplete due to incomplete data.
BC-19/7-27-78	To perform an additional hydrogen pretreatment of the caking coal previously treated in Run BC-18 at coil outlet temperature of 800°F and 2000 psig.	Successful; operated for 75 minutes with voluntary shutdown.
BC-20/8-8-78	To perform an additional hydrogen pretreatment of the caking coal previously treated in Run BC-19 at a coil outlet temperature of 850°F and pressure of 2000 psig.	Unsuccessful; run terminated when the coil plugged after a few minutes of operation.
SF-1/8-21-78	To feed a slurry of 20% lignite in toluene using a coil outlet temperature of 1450°F and pressure of 1500 psi.	Successful.
SF-2/8-24-78	To repeat Run SF-1 for a longer operating period.	Partially successful; run terminated when check valve in feed pump malfunctioned.

Table A-1, Part 9. SUMMARY OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run/Date	Objective	Results
SF-3/8-31-78	To test the feeding of solvent system of naphthalene, toluene, and phenol at 1500 psig and coil outlet temperature of 1400°F.	Successful; run ended when sample bombs were filled.
SF-4/9-7-78	Operate with slurry of 20% by weight bituminous coal at 1500 psig and coil outlet temperature of 1450°F. Slurry solvent consisted of 40% by weight phenol, 40% by weight toluene, and 20% by weight naphthalene.	Unsuccessful; plug formed in coil after 1 minute of operation.
SF-5/9-15-78	Repeat of SF-4. Prior to run slurry was autoclaved at 680°F and 2000 psig for 2 hours.	Unsuccessful; plug formed in coil after 1 minute of operation.
CT-1/9-21-78	Operate with bituminous coal pretreated with calcium hydroxide at 1800 psig and soaking temperature profile at 1475°F.	Unsuccessful; plug formed in coil after 1 minute of operation.
CT-2/9-28-78	Operate with Illinois No. 6 coal pretreated with calcium hydroxide sized to -100 mesh at 2000 psig and coil outlet temperature of 1475°F.	Unsuccessful; plug formed in feed end of coil after 1 minute of operation.
CT-3/9-28-78	Replication of CT-2.	Unsuccessful; plug formed in feed end of coil within 1 minute of startup, due to residues from solvent runs.

Table A-1, Part 10. SUMMARY OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run/Date	Objective	Results
CT-4/10-3-78	Operate with bituminous coal pretreated with 10% by weight calcium hydroxide at 2000 psig and soaking temperature profile of 1475°F.	Successful; operated for 56 minutes with voluntary shutdown.
CT-5/10-10-78	Replication of CT-4.	Partially successful; plug formed in heat exhanger after 22 minutes of operation.
CT-6/10-12-78	Replication of CT-4.	Successful; operated for 90 minutes with voluntary shutdown.
CT-7/10-18-78	Operate with bituminous coal pretreated with 10% by weight bentonite clay at 2000 psig and soaking temperature profile of 1475°F.	Unsuccessful; plug formed in coil after 1.5 minutes of operation.
CT-8/10-24-78	Operate with bituminous coal pretreated with 10% by weight calcium hydroxide at 2000 psig and soaking temperature profile of 1425°F.	Successful; operated for 90 minutes with voluntary shutdown.
CT-9/10-31-78	Replication of CT-8.	Successful; operated for 3 hours with voluntary shutdown.
CT-10/11-2-78	Operate with bituminous coal pretreated with 10% by weight calcium hydroxide at 2000 psig and soaking temperature profile of 1475°F.	Successful; operated for 180 minutes with voluntary shutdown.
CT-11/11-7-78	Replication of CT-10.	Successful; operated for 180 minutes with voluntary shutdown.
CT-12/11-9-78	Operate with bituminous coal pretreated with 8% by weight ferric oxide and 1-1/2% CaO at 2000 psig and soaking temperature profile of 1475°F.	Successful; operated for 60 minutes with voluntary shutdown.

Table A-1, Part 11. SUMMARY OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run/Date	Objective	Results
CT-13/11-14-78	Operate with bituminous coal pretreated with 2% by weight calcium hydroxide and 8% by weight bentonite clay at 2000 psig and soaking temperature profile of 1475°F.	Successful; operated for 120 minutes with voluntary shutdown.
CT-14/11-17-78	Operate with bituminous coal pretreated at moderate temperature in air with coil outlet temperature of 1500°F at 2000 psig.	Unsuccessful; plug formed in coil after 0.5 minute of operation.
HR-1/11-21-78	Operate with lignite coal and linear heating rate from 1000°F to outlet temperature of 1500°F at 2000 psig.	Successful; operated for 130 minutes with voluntary shutdown.
HR-2/11-28-78	Replication of HR-1.	Successful; operated for 175 minutes with voluntary shutdown.
HR-3/11-30-78	Operate with lignite coal and high linear heating rate from 600°F to outlet temperature of 1500°F at 2000 psig.	Successful; operated for 120 minutes with voluntary shutdown.
HR-4/12-2-78	Investigate the effects of high heating rate (458°F per second) on product yield at 2000 psig and 1500°F.	Successful; operated for 120 minutes with voluntary shutdown.
HR-5/12-12-78	Investigate the effects of low heating rate on product yield at 2000 psig and 1500°F.	Successful; operated for 180 minutes with voluntary shutdown.
HR-6/12-14-78	Investigate the effects of high heating rate (1000°F per second) on product yield at 2000 psig and 1500°F.	Successful; operated for 120 minutes with voluntary shutdown.
HR-7/12-20-78	Investigate the effects of high heating rate (1200°F per second) followed with descending profile to determine presence of exothermic hydrogenation.	Successful; operated for 120 minutes with voluntary shutdown.

Table A-1, Part 12. SUMMARY OF RUNS MADE FROM APRIL 1, 1978 THROUGH MAY 31, 1979

Run/Date	Objective	Results
HH-1/3-8-79	Operate with preheated hydrogen to test operation of revised bench-scale unit at 1500 psig.	Unsuccessful; feeder "dumped" at start; leaks in instrument ines.
HH-2/3-13-79	Operate with preheated hydrogen to test operation of revised bench-scale unit at 1500 psig and 1400°F coil temperature.	Successful; operated 90 minutes with voluntary shutdown.
HH-3/3-15-79	Operate with preheated hydrogen to test operation of revised bench-scale unit at 1750 psig and 1400°F coil temperature.	Partially successful; coke plug formed in mixing block where lignite is mixed with preheated hydrogen.
HH-4/3-29-79	Operate with preheated hydrogen to test operation of revised bench-scale unit at 1750 psig and 1375°F coil temperature.	In process.
HH-5/4-4-79	Operate the bench-scale unit with isothermal coil at 1375°F and hydrogen preheated to 1200°F with system pressure of 1750 psig and feed rate of 2.25 lb/hr.	Partially successful; feed hopper became overpressured and damped, giving an average solids rate of 5.24 lb/hr.
HH-6/4-10-79	Replication of HH-5	Partially successful; coil pressure drop varied erratically due to difficulties in controlling gas rate.
HH-7/4-12-79	Replication of HH-5	Successful; operated 120 minutes at an average solids feed of 1.35 lb/hr lignite and on hydrogen-to-coal ratio of 0.8.
HH-8/5-2-79	Explore operating the bench-scale unit with preheated hydrogen with the coil maintained at 1450°F.	Successful; 150 minutes of operation with voluntary shutdown and steady adiabatic mixing temperature of 1100°F.

Table A-1, Part 13. SUMMARY OF RUNS MADE FROM MAY 1, 1979 THROUGH MARCH 31, 1980

Run/Date	Objective	Results
HH-9/5-10-79	Explore operating the bench-scale unit with preheated hydrogen at a higher feed rate than in HH-8. Coil maintained at 1450°F.	Partially successful; feeding terminated by a tar plug in the char trap outlet.
HH-10/5-24-79	Replication of HH-9	Partially successful; feeding terminated by a tar plug in the char trap outlet (as in HH-9)
HH-11/6-8-79	Explore operating with adiabatic mixing temperature of 1250°F and coil temperature of 1350°F.	Successful; operated 180 minutes with voluntary shutdown.
HH-12/6-14-79	Replication of HH-11	Successful; operated 180 minutes
HS-1/7-20-79	Explore operating with 50 mole percent steam in hydrogen at a hydrogen-to-MAF coal feed ratio of 0.3 at 1475°F and 1750 psig	Unsuccessful due to failure in solids feeding.
HS-2/7-26-79	Repeat of HS-1	Unsuccessful; heater section burned out and plug formed after 30 minutes.
HS-3/8-2-79	Repeat of HS-1	Partially successful; operated 55 minutes with voluntary shutdown. Solids feed rate unaccountably low.
HS-4/8-16-79	Repeat of HS-1	Partially successful; operated 60 minutes with voluntary shutdown. Solids feeding uneven.

Table A-1, Part 14. SUMMARY OF RUNS MADE FROM AUGUST 1, 1979 THROUGH MARCH 31, 1980

Run/Date	Objective	Results
HS-5/8-21-79	Repeat of HS-1 using a 100 x 200 mesh North Dakota lignite instead of power plant grind to improve solids feeder operation	Partial plug developed after 50 minutes of operation; pressure drop through coil unaccountably high.
HS-6/8-31-79	Repeat of HS-5	Partially successful; operated 80 minutes with voluntary shutdown. Some unevenness in solids feeding, and pressure drop through coil unaccountably high.
HH-13/9-11-79	Operate with preheated hydrogen and 100 x 200 mesh North Dakota lignite using an adiabatic mixing temperature of 1250°F.	Successful; operated 120 minutes with voluntary shutdown.
HH-14/9-28-79	Repeat of HH-13 to obtain additional liquids for analysis.	Tubing in steam feed system ruptured, bringing the run to an end.
PSI-1/11-6-79	Operate the bench-scale unit at 1750 psig system outlet pressure and with 60 x 100 mesh North Dakota lignite in hydrogen.	Successful; operated 90 minutes with voluntary shutdown.
SYN-1/11-14-79	Operate the bench-scale unit with syngas at 1250 psig system outlet pressure and 1475°F with North Dakota lignite.	Unsuccessful; reactor plugged with carbon before the start of solids feeding.
SYN-2/12-4-79	Repeat of SYN-1	Unsuccessful, coil plugged.
SYN-3/12-11-79	Repeat of SYN-1	Unsuccessful, coil plugged.
SYN-4/12-14-79	Repeat of SYN-1	Unsuccessful, coil plugged.

Table A-1, Part 15. SUMMARY OF RUNS MADE FROM AUGUST 1, 1979 THROUGH MARCH 31, 1980

Run/Date	Objective	Results
SYN-5/2-26-80	Operate the bench-scale unit with 25% CO and 75% H_2 admixed with steam at 1250 psig system outlet pressure and 1475°F.	Considerable methane formation due to catalytic wall effects.
SYN-6/3-6-80	Operate the bench-scale unit with 25% CO and 75% H_2 admixed with steam at 1250 psig system outlet pressure and 1475°F.	Coil plugged upon start of solids feeding.
DL-1/3-11-80	Operate the bench-scale unit with dry lignite in hydrogen at 2000 psig to explore the effect of moisture derived steam on the product distribution.	Successful; operated 45 minutes with voluntary shutdown.
DL-2/3-27-80	Operate the bench-scale unit with dry lignite in hydrogen at 1000 psig to obtain product distribution at lower operating pressure.	Successful; operated 60 minutes with voluntary shutdown.
CT-15/3-13-80	Operate the bench-scale unit at 2000 psig with Fe_2O_3 catalyzed North Dakota lignite to compare with catalyzed bituminous coal data.	Successful; operated 35 minutes with voluntary shutdown.
CT-16/3-19-80	Operate the bench-scale unit at 2000 psig with bentonite clay-catalyzed North Dakota lignite to compare with catalyzed bituminous coal data.	Successful; operated 60 minutes with voluntary shutdown.
CT-17/3-21-80	Operate the bench-scale unit with Fe_2O_3 catalyzed North Dakota lignite at 1000 psig to explore conversion and product distribution.	Successful; operated 60 minutes with voluntary shutdown.

Table A-2. SCREEN ANALYSIS OF MATERIALS USED FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Size, U.S. Mesh	North Dakota Lignite	Illinois No. 6 Coal	Coal* and Silica Sand	Coal** and Devolatilized Char
> 60	0	0	2.8	3.4
60 x 80	1.2	24.1	11.6	13.3
80 x 100	1.9	12.0	18.0	18.4
100 x 200	13.6	40.5	35.7	33.3
200 x 325	34.4	21.4	15.7	17.3
pan	48.9	1.5	16.2	14.3
	100.0	100.0	100.0	100.0

*20% (by weight) Illinois No. 6 coal with 80% silica sand.

**20%(by weight) Illinois No. 6 coal with 80% devolatized char.

Table A-3, Part 1. OPERATING CONDITIONS AND RESULTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16
System Outlet Pressure, psig	1500	1500	1500	1500	1500	1500	2000	2000	2000	2000
Coil Outlet Temperature, °F	1500	1450	1450	1475	1500	1400	1450	1475	1500	1500
Residence Time, s	1.7	2.3	3.0	1.6	2.5	2.2	2.0	1.8	1.9	2.9
Lignite Feed Rate, lb/hr	2.28	4.94	8.94	5.61	6.31	12.4	9.20	9.03	8.20	2.49
Run Length, min	20	60	50	39	60	40	40	40	40	120
Solids in Feed Gas, wt %	63.9	85.5	92.6	83.1	87.0	89.5	83.8	82.0	81.6	63.3
H_2/Lignite (MAF), wt ratio	0.767	0.229	0.106	0.275	0.205	0.105	0.158	0.163	0.166	0.445
Balances, wt %										
Ash	84.2	102.1	106.5	99.4	101.4	94.5	100.4	98.9	98.3	116.5
Carbon	92.9	90.8	91.6	96.2	99.4	98.7	100.7	97.3	100.0	100.6
Hydrogen	91.3	97.3	104.0	105.1	100.1	102.7	100.4	99.2	100.3	100.1
Oxygen	--	103.9	99.3	107.9	98.1	108.7	102.5	101.7	103.9	100.0
Carbon Distribution, wt %										
Liquids	7.12	12.68	10.08	9.73	10.87	10.69	12.51	10.44	10.61	14.06
Carbon Oxides	7.45	5.71	5.63	7.72	7.99	8.21	8.32	7.84	8.62	7.64
Methane	22.16	8.54	7.43	10.81	11.75	9.27	11.44	12.09	14.51	14.88
Ethane	6.58	4.90	3.71	5.74	6.09	4.73	6.18	6.55	7.55	8.61
Propane	0	0.79	0.86	0.85	0.40	1.33	1.00	0.67	0.24	0.27
Light Gases	1.46	4.08	0.31	0.46	0.24	0.50	0.35	0.16	0.08	0.04
Char	48.15	54.85	63.97	60.89	61.99	63.95	60.86	59.57	58.41	55.06

Table A-3, Part 2. OPERATING CONDITIONS AND RESULTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-17	P-19	P-21	P-22	P-26	P-27	P-28	RC-1	RC-2	TP-1
System Outlet Pressure, psig	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Coil Outlet Temperature, °F	1475	1450	1400	1450	1475	1475	1500	1475	1475	1475
Residence Time, s	2.8	3.0	3.1	3.4	2.5	3.5	3.0	3.3	3.4	2.5
Lignite Feed Rate, lb/hr	2.55	2.79	3.00	1.01	0.996	0.915	0.83	3.4	3.0	1.6
Run Length, min	120	120	120	180	180	180	180	60	60	120
Solids in Feed Gas, wt %	63.3	65.3	69.2	45.1	34.4	41.3	34.8	69.9	66.7	48.4
H_2/Lignite (MAF), wt ratio	0.462	0.402	0.372	1.02	1.38	0.94	1.30	**	**	0.8779
Balances, wt %										
Ash	97.1	96.3	90.9	103.9	97.6	94.3	96.2	91.0	95.2	104.1
Carbon	97.5	96.5	90.2	95.6	*	89.7	93.8	**	94.7	*
Hydrogen	99.4	98.9	99.8	102.8	*	104.9	102.5	**	98.8	*
Oxygen	104.8	102.8	97.6	93.01	106.9	110.5	101.9	--	151.6	122.6
Carbon Distribution, wt %										
Liquids	12.67	14.60	13.39	15.35	*	14.1	16.27	†	4.5	*
Carbon Oxides	8.16	7.67	6.81	6.82	9.89	3.61	7.83	5.12	1.30	9.43
Methane	16.98	14.01	11.23	12.50	15.35	13.94	15.99	3.54	4.86	17.66
Ethane	8.5	8.43	5.95	6.62	9.62	3.62	8.75	1.53	2.16	9,62
Propane	0.26	0.47	1.13	0	0	0	0	0	0	0
Light Gases	0.26	0.07	0.38	10.19	0.10	0.18	0.16	0.11	0.01	0.20
Char	50.80	52.24	52.29	53.64	44.02	45.01	45.37	80.56	81.9	50.02

* Chemical analyses incomplete.
** Char used as feed.
† Insufficient sample.

Table A-3, Part 3. OPERATING CONDITIONS AND RESULTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	TP-2	TP-3	TP-4	TP-5	TP-6	TP-8	TP-10	TP-11	RT-1	RT-2
System Outlet Pressure, psig	2000	2000	2000	2000	2000	2000	2000	1500	2000	2000
Coil Outlet Temperature, °F	1500	1500	1500	1475	1450	1500	1500	1500	1450	1450
Residence Time, s	3.8	3.5	3.3	3.1	3.3	3.4	2.9	2.4	4.07	5.19
Lignite Feed Rate, lb/hr	2.0	1.3	2.1	3.4	2.4	3.0	4.1	3.0	2.97	3.36
Run Length, min	90	90	90	90	90	50	50	90	80	90
Solids in Feed Gas, wt %	61.9	45.8	59.6	67.2	58.1	66.4	72.8	68.7	69.0	77.8
H_2/Lignite (MAF), wt ratio	0.4047	0.6543	0.4363	0.2976	0.411	0.318	0.232	0.291	0.295	0.192
Balances, wt %										
Ash	106.7	115.8	95.5	94.6	100.4	95.9	100.0	100.6	97.9	100.0
Carbon	96.5	*	95.47	*	100.27	96.5	93.7	97.5	95.0	99.5
Hydrogen	96.09	*	95.76	*	92.9	89.9	108.3	104.6	98.6	107.8
Oxygen	101.4	--	102.1	*	108.9	102.8	99.4	100.1	107.1	105.08
Carbon Distribution, wt %										
Liquids	11.55	*	9.01	*	10.5	10.4	10.87	10.4	9.92	12.83
Carbon Oxides	8.67	7.86	8.93	10.14	10.69	9.2	6.68	8.28	6.83	8.12
Methane	13.10	14.52	16.81	17.26	17.04	10.06	8.97	9.25	14.57	13.9
Ethane	7.31	8.55	8.75	16.6	8.56	4.73	4.34	4.34	7.59	7.15
Propane	0.89	0	0.17	0	0	1.98	1.85	1.8	0.22	0.23
Light Gases	0.08	0.26	0	0.01	0.19	2.07	1.04	0.85	0.26	0.06
Char	53.56	60.21	50.77	51.89	52.96	59.62	60.50	62.6	55.83	56.9

* Chemical analyses incomplete.

Table A-3, Part 4. OPERATING CONDITIONS AND RESULTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	RT-3	PS-3	PS-5	PP-2	PP-4
System Outlet Pressure, psig	1500	1500	1500	1000	1000
Coil Outlet Temperature, °F	1450	1200	1200	1500	1500
Residence Time, s	3.91	2.86	2.96	2.98	2.71
Lignite Feed Rate, lb/hr	3.29	3.1	1.75	1.18	2.2
Run Length, min	90	60	60	90	80
Solids in Feed Gas, wt %	77.2	68.3	54.8	58.7	74.2
H_2/Lignite (MAF), wt ratio	0.199	0.309	0.534	0.455	0.234
Balances, wt %					
Ash	103.5	*	100.0	*	102.4
Carbon	*	*	*	*	*
Hydrogen	*	*	*	*	*
Oxygen	*	*	*	*	*
Carbon Distribution, wt %					
Liquids	*	*	*	*	*
Carbon Oxides	7.8	9.46	9.23	11.07	8.2
Methane	11.5	9.62	5.88	12.71	10.9
Ethane	5.69	4.03	1.95	4.99	4.73
Propane	0.3	2.2	1.03	0.225	0.22
Light Gases	0	0	2.09	0.313	0.03
Char	63.9	*	68.33	*	72.2

* Chemical analyses incomplete.

Table A-3, Part 5. OPERATING CONDITIONS AND RESULTS OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run No.	PP-5	PP-9	PP-11	PP-12	BC-1	BC-3	BC-7	BC-9	BC-11	BC-12	BC-13
System Outlet Pressure, psig	500	1000	500	1000	2000	2000	2000	2000	2000	2000	2000
Coil Outlet Temperature, °F	1500	1500	1500	1500	1450	1450	1450	1450	1500	1500	1500
Residence Time, s	2.6	2.7	2.9	0	3.2	3.1	3.5	3.4	3.5	3.2	3.4
Solids Feed Rate, lb/hr	1.9	2.4	1.4	0.74	6.0	6.7	6.0	4.0	3.1	2.5	2.5
Run Length, min	70	120	180	180	55	60	90	90	90	120	90
Solids in Feed Gas, wt %	76.9	75.8	85.0	49.7	81.1	80.8	81.1	72.4	67.7	60.0	61.3
H_2/MAF Coal Weight Ratio	0.19	0.23	0.23	0.76	1.34	0.77	0.71	1.18	1.50	2.04	1.96
Balances, wt %											
Ash	88.2	98.6	96.9	93.0	98.5	97.9	100.2	93.5	98.7	98.8	96.5
Carbon	90.9	98.7	95.3	97.2	100.3	101.4	100.4	98.6	100.7	97.3	90.4
Hydrogen	85.4	96.8	97.2	99.2	109.0	95.8	96.7	95.8	96.4	98.4	94.7
Overall	90.5	99.2	95.0	95.8	100.8	98.0	100.4	98.2	98.9	99.0	97.3
Carbon Distribution, wt %											
Liquids	5.44	8.44	5.81	7.44	12.94	14.35	14.62	12.04	15.29	13.37	11.72
Carbon Oxides	8.06	7.51	6.12	9.34	6.00	3.71	5.50	6.53	12.84	10.46	11.30
Methane	7.75	9.57	5.86	13.95	10.80	9.92	9.66	10.19	13.98	14.53	12.81
Light Gases	3.56	4.45	3.27	6.25	7.33	7.26	7.73	6.89	6.38	7.49	6.67
Char	66.00	68.71	74.25	60.23	63.25	66.18	62.88	64.36	52.19	51.42	47.89

Table A-3, Part 6. OPERATING CONDITIONS AND RESULTS OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run No.	BC-16	BC-18	BC-19	SF-2	SF-3
System Outlet Pressure, psig	2000	2000	2000	1500	1500
Coil Outlet Temperature, °F	1450	700	800	1400	1400
Residence Time, s	2.9	4.0	3.8	2.2	2.2
Solids Feed Rate, lb/hr	8.3	3.6	3.8	2.9	0
Run Length, min	53	75	70	25	19
Solids in Feed Gas, wt %	82.6	76.7	76.2	25.0	0
H_2/MAF Coal Weight Ratio	1.1*	0.304	0.313	1.459	0
Balances, wt %					
Ash	85.6	100.0	100.0	76.0	--
Carbon	95.6	100.0	100.0	--	--
Hydrogen	111.5	100.0	100.0	--	--
Overall	99.6	100.0	100.0	84.6	92.3
Carbon Distribution, wt %					
Liquids	6.96*	0	0	--	--
Carbon Oxides	7.61*	0	0	10.80*	--
Methane	21.44*	0	0	--	--
Light Gases	5.25*	0	0	--	--
Char	--	100.0	100.0	73.86*	--

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* Based on feed coal fraction.

Table A-3, Part 7. OPERATING CONDITIONS AND RESULTS OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run No.	CT-4	CT-6	CT-8	CT-9	CT-10
System Outlet Pressure, psig	2000	2000	2000	2000	2000
Coil Outlet Temperature, °F	1475	1475	1425	1425	1475
Residence Time, s	3.6	3.6	3.7	3.7	3.7
Solids Feed Rate, lb/hr	2.74	3.30	2.40	0.873	0.328
Run Length, min	56	90	90	180	180
Solids in Feed Gas, wt %	63.4	68.0	59.6	35.7	17.8
H_2/MAF Coal Weight Ratio	0.3259	0.2830	0.3863	1.0422	2.688
Balances, wt %					
Ash	95.30	100.97	98.89	98.66	100.00
Carbon	96.76	98.70	92.07	98.95	97.95
Hydrogen	100.85	90.51	103.66	101.45	97.50
Overall	100.11	104.63	101.64	104.33	99.84
Carbon Distribution, wt %					
Liquids	10.89	13.72	14.68	16.28	8.97
Carbon Oxides	5.50	5.78	5.15	9.79	20.04
Methane	17.14	17.06	14.29	16.20	21.87
Light Gases	9.89	9.50	8.80	10.21	8.94
Char	53.34	52.64	50.43	46.47	38.12

Table A-3, Part 8. OPERATING CONDITIONS AND RESULTS OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run No.	CT-11	CT-12	CT-13	HR-1	HR-2
System Outlet Pressure, psig	2000	2000	2000	2000	2000
Coil Outlet Temperature, °F	1475	1475	1475	1500	1500
Residence Time, s	3.6	3.2	3.5	4.0	4.6
Solids Feed Rate, lb/hr	0.957	3.452	1.519	3.203	1.560
Run Length, min	180	60	120	130	175
Solids in Feed Gas, wt %	37.6	67.4	50.0	69.5	55.9
H_2/MAF Coal Weight Ratio	1.0090	0.2949	0.6224	0.2578	0.4375
Balances, wt %					
Ash	86.5	94.4	96.3	86.6	101.1
Carbon	95.8	106.4	102.6	93.6	93.7
Hydrogen	94.1	93.1	91.4	100.4	102.0
Overall	100.0	104.5	101.3	102.2	100.5
Carbon Distribution, wt %					
Liquids	15.24	17.46	13.51	11.03	12.25
Carbon Oxides	9.77	6.00	7.86	9.05	9.47
Methane	17.66	19.90	17.29	10.90	12.40
Light Gases	9.07	11.08	8.45	11.36	7.37
Char	44.04	51.99	52.89	51.23	52.20

Table A-3, Part 9. OPERATING CONDITIONS AND RESULTS OF RUNS MADE FROM APRIL 1, 1978 THROUGH MARCH 31, 1979

Run No.	HR-3	HR-4	HR-5	HR-6	HR-7
System Outlet Pressure, psig	2000	2000	2000	2000	2000
Coil Outlet Temperature, °F	1500	1500	1500	1500	1500
Residence Time, s	2.6	3.0	4.9	4.5	4.4
Solids Feed Rate, lb/hr	2.506	2.544	2.172	2.063	1.738
Run Length, min	120	120	180	120	120
Solids in Feed Gas, wt %	54.3	57.5	65.3	57.1	52.3
H_2/MAF Coal Weight Ratio	0.4823	0.4282	0.2967	0.4465	0.5488
Balances, wt %					
Ash	95.7	77.0	100.6	100.0	92.9
Carbon	95.2	100.0	100.4	98.8	101.6
Hydrogen	99.7	100.0	99.8	100.3	93.7
Overall	100.7	102.0	101.2	97.3	99.5
Carbon Distribution, wt %					
Liquids	11.71	13.19	12.44	7.30	8.59
Carbon Oxides	8.18	11.27	9.72	8.47	10.35
Methane	10.59	16.34	17.35	19.69	19.47
Light Gases	6.26	8.43	8.33	8.61	8.63
Char	58.87	52.51	52.52	52.69	54.55

Table A-3, Part 10. OPERATING CONDITIONS, COMPONENT BALANCES, AND CARBON DISTRIBUTIONS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HS-2	HS-3	HS-4	HS-5	HS-6	PSI-1	DL-1	DL-2	CT-15	CT-16	CT-17
System Outlet Pressure, psig	1750	1750	1750	1750	1750	1500	2000	1000	2000	2000	1000
Maximum Temperature, °F	1475	1475	1475	1475	1475	1475	1500	1475	1475	1475	1475
Residence Time, s	2.3	2.2	2.2	2.3	2.0	3.9	2.7	3.0	2.7	3.2	3.0
Solids Feed Rate, lb/hr	2.1	0.65	0.75	2.0	0.55	1.22	2.72	2.76	2.76	4.62	1.30
Run Length, min	30	60	60	50	80	90	45	55	30	53	60
Solids in Feed Gas, wt %	27.4	10.5	13.4	25.9	8.7	42.1	71.5	76.9	62.7	76.8	62.3
H_2/MAF Coal Weight Ratio	0.34	1.16	1.04	0.41	1.63	1.00	0.460	0.206	0.521	0.225	0.504
Feed Gas Preheat Temp., °F	1250	1245	1250	1300	1300	N/A	N/A	N/A	N/A	N/A	N/A
Adiabatic Mix Temp., °F	850	920	1130	790	1050	N/A	N/A	N/A	N/A	N/A	N/A
Balances, wt %											
Ash	100.0	100.0	94.3	105.5	96.8	100.0	95.9	86.2	--	100.0	82.9
Carbon	99.5	98.5	100.0	100.0	100.0	92.5	101.1	97.3	--	99.8	97.7
Hydrogen	--	--	--	--	--	--	93.2	105.9	--	105.0	102.6
Overall	98.9	97.0	94.7	98.7	97.5	100.7	99.0	99.1	97.4	100.8	100.7
Carbon Distribution, wt %											
Liquids	2.54	3.86	5.96	4.18	5.75	5.46	11.65	3.69	12.10	10.91	3.84
Carbon Oxides	14.18	12.91	12.02	12.30	10.57	7.23	7.66	8.05	8.73	8.66	8.53
Methane	15.77	18.00	18.88	15.16	15.27	20.17	20.21	12.01	20.49	16.88	15.05
Light Gases	7.82	6.97	7.20	7.04	6.50	7.14	6.53	4.05	10.08	7.49	6.29
Char	59.22	56.76	55.94	61.32	61.03	52.52	54.55	69.50	--	55.87	64.03

Table A-3, Part 11. OPERATING CONDITIONS, COMPONENT BALANCES, AND CARBON DISTRIBUTIONS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HH-2	HH-3	HH-4	HH-5	HH-6	HH-7	HH-8	HH-9	HH-10	HH-11	HH-12
System Outlet Pressure, psig	1500	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750
Maximum Temperature, °F	1400	1400	1375	1375	1375	1375	1450	1450	1450	1350	1350
Residence Time, s	3.4	4.8	5.0	3.5	3.8	3.8	3.3	3.2	3.2	2.8	2.8
Solids Feed Rate, lb/hr	0.44	0.87	1.53	5.63	2.93	1.35	0.68	2.70	4.1	0.39	0.18
Run Length, min	90	108	120	50	90	120	150	85	90	180	180
Solids in Feed Gas, wt %	17.4	37.8	51.1	78.7	67.4	48.7	29.7	64.0	74.5	20.3	10.3
H_2/MAF Coal Weight Ratio	2.78	0.992	0.546	0.161	0.278	0.597	1.33	0.308	0.21	2.45	5.40
Feed Gas Preheat Temp., °F	1180	1300	1110	1160	1160	1270	1270	1270	1270	1350	1350
Adiabatic Mix Temp, °F	1150	1150	840	710	850	1050	1100	870	800	1250	1255
Balances, wt %											
Ash	115.7	104.8	100.0	96.2	94.1	100.0	98.9	97.8	95.6	99.5	104.4
Carbon	100.0	100.0	100.4	100.0	96.3	97.6	91.3	100.0	91.2	97.6	98.1
Hydrogen	--	--	--	--	--	--	--	--	--	--	--
Overall	101.0	101.8	100.2	103.2	99.4	100.1	99.3	102.2	97.9	101.1	100.2
Carbon Distribution, wt %											
Liquids	8.19	10.98	12.88	6.94	9.25	8.88	13.63	6.27	7.80	21.09	12.38
Carbon Oxides	7.41	8.29	5.82	10.39	8.47	9.01	7.00	10.01	8.26	6.10	8.06
Methane	25.17	17.88	15.70	14.39	13.50	14.80	17.71	16.93	13.95	15.33	24.22
Light Gases	8.43	8.40	8.24	7.93	7.77	8.82	2.38	8.19	6.88	8.32	10.98
Char	50.80	53.47	57.71	60.34	57.33	56.04	50.52	58.59	63.09	46.79	42.47

Table A-4, Part 1. ANALYSIS OF FEED LIGNITE FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17
Proximate Analysis, wt %											
Moisture	14.6	13.3	13.3	15.7	16.0	15.1	13.2	12.4	12.2	13.6	14.1
Volatile Matter	34.3	34.7	34.7	34.0	33.5	34.5	35.2	35.4	36.6	35.2	34.9
Ash	11.8	11.6	11.6	10.4	11.2	11.4	10.4	10.6	10.6	10.5	10.1
Fixed Carbon	39.3	40.4	40.4	39.9	39.3	39.0	41.2	41.6	40.6	40.7	40.9
Ultimate Analysis (Dry Basis), wt %											
Ash	13.85	13.32	13.32	12.39	13.39	13.41	11.97	12.07	12.09	12.11	11.78
Carbon	59.2	60.2	60.2	60.2	59.8	60.0	60.5	60.5	60.3	60.6	60.7
Hydrogen	3.87	3.94	3.94	3.94	3.95	3.89	4.15	3.99	4.07	4.04	4.08
Sulfur	1.12	1.03	1.03	0.99	0.96	0.98	0.98	0.91	0.9	0.9	0.91
Nitrogen	0.8	0.84	0.84	0.78	0.85	0.79	0.79	0.84	0.79	0.74	0.87
Oxygen (Diff)	21.16	20.67	20.67	21.7	21.05	20.93	21.61	21.7	21.85	21.61	21.6

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Table A-4, Part 2. ANALYSIS OF FEED LIGNITE FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run	P-19	P-21	P-22	P-26	P-27	P-28	RC-1	RC-2	TP-1	TP-2	TP-3	TP-4
Proximate Analysis, wt %												
Moisture	13.7	13.4	13.1	15.5	14.7	13.9	0.7	0.8	14.2	13.6	1.4	11.2
Volatile Matter	35.2	35.0	36.2	34.9	35.5	36.1	12.5	13.0	35.5	35.7	39.0	37.0
Ash	10.2	10.2	9.9	9.8	10.0	10.2	25.1	23.7	10.1	9.9	9.4	7.8
Fixed Carbon	40.9	41.4	40.8	39.8	39.8	39.2	61.5	62.5	40.2	40.8	52.2	44.0
Ultimate Analysis (Dry Basis), wt %												
Ash	11.78	11.72	11.42	11.55	11.77	11.81	25.32	23.86	11.83	11.49	9.5	8.79
Carbon	60.2	60.7	60.2	60.3	60.2	60.3	68.5	68.2	60.3	60.6	62.8	62.8
Hydrogen	3.97	4.08	4.12	4.03	4.09	4.05	2.4	2.42	3.99	3.95	3.71	4.11
Sulfur	0.92	0.93	0.90	0.93	0.91	0.67	0.91	0.88	0.9	0.89	0.96	1.04
Nitrogen	1.11	1.16	0.83	0.79	0.8	0.85	0.54	0.63	0.8	0.91	0.93	0.89
Oxygen (Diff)	22.02	21.41	22.53	22.4	22.23	22.23	2.33	4.01	22.18	22.16	22.1	22.37

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Table A-4, Part 3. ANALYSIS OF FEED LIGNITE FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run	TP-5	TP-6	TP-8	TP-10	TP-11	RT-1	RT-2	RT-3	PS-3	PS-5	PP-2	PP-4
Proximate Analysis, wt %												
Moisture	12.1	5.5	12.2	11.7	12.0	12.3	14.2	11.8	11.8	12.2	11.7	10.8
Volatile Matter	36.3	38.3	36.1	36.5	36.1	36.1	35.4	36.0	36.2	35.9	36.2	36.6
Ash	8.7	9.3	8.5	8.5	8.8	9.4	8.1	8.6	9.8	10.1	10.1	10.1
Fixed Carbon	42.9	46.9	43.2	43.3	43.1	42.2	42.3	43.6	42.2	41.8	42.0	42.5
Ultimate Analysis (Dry Basis), wt %												
Ash	9.89	9.87	9.71	9.62	10.03	10.67	9.42	5.80	11.11	11.56	11.49	11.37
Carbon	62.7	62.2	62.4	62.7	62.3	61.40	63.2	62.0	60.9	61.0	60.6	60.8
Hydrogen	4.02	3.80	3.98	4.00	4.03	4.02	3.97	3.94	4.09	3.98	4.02	3.97
Sulfur	0.99	0.99	0.97	0.93	1.02	0.93	0.96	0.96	0.91	0.99	0.90	0.78
Nitrogen	0.87	0.95	0.95	0.91	0.82	0.86	0.82	0.80	0.79	0.75	0.79	0.80
Oxygen (Diff)	21.53	22.19	21.99	21.84	21.80	22.12	21.63	22.50	22.20	21.72	22.20	22.28

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Table A-4, Part 4. ANALYSIS OF FEED SOLIDS

Run No.	PP-5*	PP-9*	PP-11*	PP-12*	BC-1**	BC-3†	BC-7†	Illinois No. 6 Coal	Devolatilized Char
				wt %					
Proximate Analysis									
Moisture	10.1	12.9	15.9	15.7	0.3	1.0	1.1	5.3	0.7
Volatile Matter	37.1	36.0	35.2	34.8	3.9	7.5	8.3	37.6	1.7
Ash	10.1	8.9	8.8	8.8	90.7	81.6	80.5	10.2	27.5
Fixed Carbon	42.7	42.2	40.1	40.7	5.1	9.9	10.1	46.9	70.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ulimate Analysis (Dry Basis)									
Ash	11.24	10.27	10.43	10.40	90.99	82.40	81.39	10.76	27.72
Carbon	60.5	61.3	61.1	61.9	7.00	13.7	14.4	68.8	69.40
Hydrogen	4.02	4.13	4.13	4.15	0.53	1.02	1.01	5.03	0.34
Sulfur	0.88	0.79	0.80	0.78	0.37	0.74	0.77	4.16	1.91
Nitrogen	0.78	0.81	0.82	0.79	0.12	0.10	0.24	1.16	0.72
Oxygen (by difference)	22.58	22.70	22.72	21.98	0.99	2.04	2.19	10.09	0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.0	100.0

*North Dakota lignite.

**10% (by weight) Illinois No. 6 coal with 90% silica sand.

†20% (by weight) Illinois No. 6 coal with 80% silica sand.

Table A-4, Part 5. ANALYSIS OF FEED SOLIDS

Run No.	BC-9	BC-11	BC-12	BC-13	BC-16
	wt %				
Proximate Analysis					
Moisture	1.1	1.1	1.2	1.1	2.6
Volatile Matter	8.0	7.6	7.3	7.5	6.4
Ash	81.3	81.6	82.0	81.8	18.5
Fixed Carbon	9.6	9.7	9.5	9.6	72.5
Total	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (Dry Basis)					
Ash	82.22	82.54	82.99	82.78	18.99
Carbon	13.50	13.20	13.10	13.20	74.60
Hydrogen	0.97	0.95	0.95	0.96	1.04
Sulfur	0.71	0.72	0.71	0.72	2.38
Nitrogen	0.09	0.16	0.12	0.17	0.74
Oxygen (by difference)	2.51	2.43	2.13	2.17	2.25
Total	100.00	100.00	100.00	100.00	100.00

Table A-4, Part 6. ANALYSIS OF FEED SOLIDS

Run No.	CT-4	CT-6	CT-8	CT-9	CT-10	CT-11
	wt %					
Proximate Analysis						
Moisture	4.5	8.4	5.6	4.1	6.9	5.2
Volatile Matter	37.5	36.5	36.6	35.9	36.1	37.3
Ash	15.1	13.3	16.2	17.8	18.2	19.5
Fixed Carbon	42.9	41.8	41.6	42.2	38.8	38.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (Dry Basis)						
Ash	15.85	14.49	17.16	18.54	19.59	20.61
Carbon	60.20	62.30	60.80	59.10	58.00	59.10
Hydrogen	4.28	4.38	4.42	4.29	4.15	4.22
Sulfur	3.87	3.96	4.35	4.35	4.50	4.58
Nitrogen	1.12	0.99	1.22	1.23	0.91	1.06
Oxygen (by difference)	14.68	13.88	12.05	12.49	12.85	10.43
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table A-4, Part 7. ANALYSIS OF FEED SOLIDS

Run No.	CT-12	CT-13	HR-1	HR-2	HR-3	HR-4
	wt %					
Proximate Analysis						
Moisture	0.9	1.0	12.7	9.6	9.6	9.9
Volatile Matter	34.2	32.2	--	38.5	38.3	38.3
Ash	21.4	20.2	9.7	8.8	9.3	10.4
Fixed Carbon	43.5	46.6	--	43.1	42.8	41.4
Total	100.0	100.0		100.0	100.0	100.0
Ultimate Analysis (Dry Basis)						
Ash	21.61	20.38	11.08	9.73	10.31	11.50
Carbon	59.50	59.50	61.00	61.00	60.90	61.00
Hydrogen	4.22	3.97	3.97	4.11	3.97	4.04
Sulfur	4.44	4.26	0.87	0.80	0.81	0.77
Nitrogen	1.08	1.04	1.01	1.01	0.98	0.85
Oxygen (by difference)	9.15	10.85	22.07	23.35	23.03	21.84
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table A-4, Part 8. ANALYSIS OF FEED SOLIDS

Run No.	HR-5	HR-6	HR-7
Proximate Analysis		wt %	
Moisture	10.5	10.7	10.7
Volatile Matter	37.5	37.8	37.2
Ash	9.0	9.0	8.9
Fixed Carbon	43.0	42.5	43.2
Total	100.0	100.0	100.0
Ultimate Analysis (Dry Basis)			
Ash	10.07	10.11	9.95
Carbon	61.40	61.10	61.50
Hydrogen	4.03	3.96	3.93
Sulfur	0.81	0.82	0.82
Nitrogen	0.75	0.93	0.72
Oxygen (by difference)	22.94	23.08	23.08
Total	100.00	100.00	100.00

Table A-4, Part 9. PROXIMATE AND ULTIMATE ANALYSES OF FEED SOLIDS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HH-2	HH-3	HH-4	HH-5	HH-6	HH-7	HH-8	HH-9	HH-10	HH-11	HH-12	HS-2
Proximate Analysis, wt %												
Moisture	8.8	11.0	10.0	11.1	8.3	7.8	8.0	9.0	12.8	17.7	17.0	15.5
Volatile Matter	38.7	38.1	38.7	38.2	39.3	39.8	39.8	39.6	39.9	35.7	36.8	35.8
Ash	9.3	9.0	8.9	9.0	9.3	8.9	8.9	8.9	8.6	8.2	8.3	8.7
Fixed Carbon	43.2	41.9	42.4	41.7	43.1	43.5	43.3	42.5	38.7	35.4	37.9	40.0
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, wt % (Dry Basis)												
Ash	10.18	10.15	9.88	10.09	10.16	9.62	9.70	9.80	9.82	9.95	9.97	10.27
Carbon	61.20	61.00	61.00	60.90	60.80	60.10	60.10	60.10	60.60	60.70	60.60	61.00
Hydrogen	4.11	4.05	4.05	4.04	4.15	4.17	4.21	4.18	4.23	4.13	4.13	4.08
Sulfur	0.75	0.73	0.74	0.75	0.77	0.72	0.70	0.72	0.73	0.73	0.73	0.74
Nitrogen	0.95	0.95	0.97	0.99	0.86	0.96	0.85	0.95	0.97	0.92	0.93	0.92
Oyxgen (Diff)	22.81	23.12	23.36	23.23	23.26	24.43	24.44	24.25	23.65	23.57	23.64	22.99
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Run No.	HS-3	HS-4	HS-5	HS-6	PSI-1	DL-1	DL-2	CT-15	CT-16	CT-17
Proximate Analysis, wt %										
Moisture	15.5	17.0	18.2	17.8	22.8	0.7	1.2	8.8	6.37	8.8
Volatile Matter	35.8	33.9	36.8	38.3	35.1	40.5	40.3	37.6	36.04	37.6
Ash	8.7	9.2	4.9	4.9	4.0	12.7	14.5	22.2	17.23	22.2
Fixed Carbon	40.0	39.9	40.1	39.0	38.1	46.1	44.0	31.4	40.35	31.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00	100.0
Ultimate Analysis, wt % (Dry Basis)										
Ash	10.27	11.05	6.00	6.00	5.13	12.84	14.63	24.34	18.38	24.34
Carbon	61.00	61.40	64.80	64.30	65.00	59.10	57.30	51.60	54.60	51.60
Hydrogen	4.08	4.07	4.25	4.30	4.25	3.72	3.88	3.33	3.57	3.33
Sulfur	0.74	0.88	0.73	0.78	0.65	0.92	0.95	0.82	0.67	0.82
Nitrogen	0.92	0.98	0.93	0.91	0.93	0.90	0.98	1.08	0.78	1.08
Oxygen (Diff)	22.99	21.62	23.29	23.71	24.04	22.52	22.26	18.83	22.00	18.83
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-5, Part 1. ANALYSIS OF SPENT CHAR FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17
Proximate Analysis, wt %											
Moisture	0.7	0.4	0.2	0.1	0.3	0.2	0.2	0.2	0.1	0.1	1.0
Volatile Matter	10.6	10.2	12.0	13.2	11.7	13.0	12.8	13.7	12.7	12.4	12.7
Ash	27.0	27.2	25.2	23.2	25.1	22.8	22.7	23.0	23.3	27.8	24.9
Fixed Carbon	61.7	62.2	62.6	63.5	62.9	64.0	64.3	63.1	63.9	59.7	61.4
Ultimate Analysis (Dry Basis), wt %											
Ash	27.2	27.3	25.23	23.18	25.21	22.81	22.73	23.07	23.36	27.8	24.9
Carbon	66.6	66.3	68.2	69.0	69.0	69.1	69.6	69.4	69.3	65.6	67.9
Hydrogen	1.96	2.25	2.39	2.37	2.36	2.51	2.54	2.38	2.31	2.27	2.24
Sulfur	1.32	0.99	0.91	0.87	0.88	0.89	0.87	0.82	0.84	0.8	0.8
Nitrogen	0.42	0.56	0.68	0.59	0.62	0.73	0.59	0.65	0.6	0.46	0.52
Oxygen (Diff)	2.5	2.6	2.59	3.99	1.93	3.96	3.67	3.68	3.59	3.06	3.64

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Table A-5, Part 2. ANALYSIS OF SPENT CHAR FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run	P-19	P-21	P-22	P-26	P-27	P-28	RC-1	RC-2	TP-1	TP-2	TP-3	TP-4
Proximate Analysis, wt %												
Moisture	0.6	0.5	0.5	0.3	0.4	0.5	0.3	0.3	0.4	0.5	0.3	0.5
Volatile Matter	13.1	13.6	11.9	10.6	10.0	9.9	8.8	9.1	13.4	15.3	14.0	15.7
Ash	24.4	22.9	25.0	26.0	27.1	26.4	27.8	27.0	25.3	25.3	20.1	18.8
Fixed Carbon	61.9	63.0	62.5	63.1	62.5	63.2	63.1	63.6	60.9	58.9	65.6	65.0
Ultimate Analysis (Dry Basis), wt %												
Ash	24.57	23.05	25.13	26.04	27.21	26.53	27.84	27.12	25.39	25.39	20.15	18.90
Carbon	67.6	68.6	68.4	67.5	66.7	67.3	67.5	67.4	67.4	68.4	71.9	73.3
Hydrogen	2.24	2.54	2.5	2.36	2.24	2.19	2.19	2.17	2.27	2.42	2.57	2.62
Sulfur	0.77	0.78	1.06	1.09	1.25	1.22	1.02	0.98	0.92	0.78	1.23	1.00
Nitrogen	0.95	0.82	0.54	0.59	0.59	0.54	0.53	0.54	0.56	0.67	0.6	0.59
Oxygen (Diff)	3.87	4.21	2.37	2.42	2.01	2.22	0.92	1.79	3.46	2.34	3.55	3.59

A78061831

Table A-5, Part 3. ANALYSIS OF SPENT CHAR FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run	TP-5	TP-6	TP-8	TP-10	TP-11	RT-1	RT-2	RT-3	PS-3	PS-5	PP-2	PP-4
Proximate Analysis, wt %												
Moisture	0.4	0.6	0.4	0.4	0.3	0.2	0.5	0.4	0.5	0.5	0.7	0.7
Volatile Matter	12.3	13.9	16.1	17.8	15.6	13.3	14.4	13.1	15.3	19.1	12.7	13.1
Ash	20.0	20.1	17.8	18.1	18.4	21.4	18.9	18.4	20.0	18.2	20.2	20.0
Fixed Carbon	67.3	65.4	65.7	63.7	65.7	65.1	66.2	68.1	64.2	62.2	66.4	66.2
Ultimate Analysis (Dry Basis), wt %												
Ash	20.14	20.18	17.86	18.17	18.50	21.46	19.05	18.50	20.10	18.29	20.33	20.13
Carbon	72.3	72.6	73.3	73.2	73.3	71.6	73.5	73.40	70.9	70.2	71.5	72.0
Hydrogen	2.49	2.54	2.94	2.87	2.91	2.45	2.57	2.50	2.79	3.28	2.42	2.32
Sulfur	0.9	0.95	0.89	0.92	0.91	0.88	0.91	0.85	0.79	0.89	0.88	0.79
Nitrogen	0.65	0.77	0.85	0.78	0.74	0.63	0.56	0.58	0.65	0.80	0.61	0.60
Oxygen (Diff)	3.52	2.96	4.16	4.06	3.64	2.98	3.41	4.17	4.77	6.54	4.26	4.16

A78061831

Table A-5, Part 4. ANALYSIS OF SPENT SOLIDS

Run No.	PP-5	PP-9	PP-11	PP-12	BC-1	BC-3	BC-7
	wt %						
Proximate Analysis							
Moisture	0.5	0.9	0.9	0.90	0.10	0.10	0.1
Volatile Matter	11.3	12.1	12.1	11.7	0.9	1.7	1.9
Ash	13.3	17.6	16.5	18.9	95.0	88.9	88.9
Fixed Carbon	69.9	69.4	70.5	68.5	4.0	9.3	9.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (Dry Basis)							
Ash	18.41	17.8	16.67	19.06	95.12	89.01	89.01
Carbon	74.2	74.0	74.8	73.5	4.70	10.0	9.9
Hydrogen	2.36	2.43	2.43	2.34	0.19	0.41	0.42
Sulfur	0.79	0.64	0.68	0.76	0.13	0.27	0.25
Nitrogen	0.60	0.67	0.65	0.57	0.08	0.03	0.13
Oxygen (by diff)	3.64	4.46	4.77	3.77	0	0.28	0.29
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-5, Part 5. ANALYSIS OF SPENT SOLIDS

Run No.	BC-9	BC-11	BC-12	BC-13	BC-16
	wt %				
Proximate Analysis					
Moisture	0.2	0.2	0.2	0.0	0.3
Volatile Matter	2.0	1.6	1.5	1.8	3.0
Ash	88.5	90.5	90.9	90.9	18.3
Fixed Carbon	9.3	7.7	7.4	7.3	78.4
Total	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (Dry Basis)					
Ash	88.68	90.68	91.04	90.94	18.39
Carbon	10.00	8.50	8.30	8.20	77.60
Hydrogen	0.48	0.32	0.32	0.33	0.92
Sulfur	0.27	0.20	0.18	0.20	2.04
Nitrogen	0.08	0.07	0.00	0.06	0.62
Oxygen (by diff)	0.49	0.23	0.16	0.27	0.43
Total	100.00	100.00	100.00	100.00	100.00

Table A-5, Part 6. ANALYSIS OF SPENT SOLIDS

Run No.	CT-4	CT-6	CT-8	CT-9	CT-10	CT-11
	wt %					
Proximate Analysis						
Moisture	0.2	0.3	0.4	0.3	0.3	0.2
Volatile Matter	14.6	15.0	14.4	13.4	10.8	12.6
Ash	28.5	27.1	31.4	34.0	38.0	34.3
Fixed Carbon	56.7	57.6	53.8	52.3	50.9	52.9
Total	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (Dry Basis)						
Ash	28.59	27.15	31.55	34.10	38.16	34.35
Carbon	61.40	62.30	59.20	56.80	54.00	56.20
Hydrogen	2.21	2.22	2.15	2.18	1.93	2.05
Sulfur	4.95	4.14	4.64	5.61	6.19	5.36
Nitrogen	0.87	0.79	1.08	1.01	0.75	0.78
Oxygen (by diff)	1.98	3.40	1.38	0.30	0.00	1.26
Total	100.00	100.00	100.00	100.00	101.03	100.00

Table A-5, Part 7. ANALYSIS OF SPENT SOLIDS

Run No.	CT-12	CT-13	HR-1	HR-2	HR-3	HR-4
	wt %					
Proximate Analysis						
Moisture	0.2	0.2	0.3	0.3	0.2	0.2
Volatile Matter	8.3	8.2	13.5	14.0	13.9	12.2
Ash	37.0	34.5	21.1	21.1	19.2	18.9
Fixed Carbon	54.5	57.1	65.1	64.6	66.7	68.7
Total	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (Dry Basis)						
Ash	37.07	34.58	21.19	21.12	19.22	18.98
Carbon	58.00	59.30	71.00	71.40	72.60	71.20
Hydrogen	2.07	2.13	2.52	2.62	2.61	2.32
Sulfur	6.57	2.55	0.74	0.65	0.67	0.62
Nitrogen	0.78	0.83	0.81	0.77	0.71	0.56
Oxygen (by diff)	0.00	0.61	3.74	3.44	4.19	6.32
Total	104.49	100.00	100.00	100.00	100.00	100.00

Table A-5, Part 8. ANALYSIS OF SPENT SOLIDS

Run No.	HR-5	HR-6	HR-7
	wt %		
Proximate Analysis			
Moisture	0.3	0.4	0.5
Volatile Matter	13.4	11.5	12.0
Ash	22.2	22.3	19.9
Fixed Carbon	64.1	65.8	67.6
Total	100.0	100.0	100.0
Ultimate Analysis (Dry Basis)			
Ash	22.26	22.39	20.00
Carbon	70.90	71.30	72.60
Hydrogen	2.29	2.10	2.18
Sulfur	0.64	0.58	0.66
Nitrogen	0.54	0.44	0.49
Oxygen (by diff)	3.37	3.19	4.07
Total	100.00	100.00	100.00

Table A-5, Part 9. PROXIMATE AND ULTIMATE ANALYSES OF SPENT SOLIDS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No	HH-2	HH-3	HH-4	HH-5	HH-6	HH-7	HH-8	HH-9	HH-10	HH-11	HH-12	HS-2
Proximate Analysis, wt %												
Moisture	0.4	0.3	0.5	0.5	0.2	0.7	0.5	0.4	0.4	0.7	0.5	2.1
Volatile Matter	11.4	13.9	14.0	13.2	14.0	14.0	12.7	12.7	13.1	10.8	13.6	12.8
Ash	23.0	22.0	19.5	18.6	19.5	19.8	21.7	19.7	19.4	22.0	24.6	20.0
Fixed Carbon	65.2	63.8	65.9	67.7	66.2	65.5	65.1	67.2	67.1	66.5	61.3	65.1
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, wt % (Dry Basis)												
Ash	23.05	22.12	19.72	18.72	19.69	19.91	21.84	19.75	19.49	22.20	24.72	20.47
Carbon	70.40	70.90	72.20	73.70	72.60	72.00	70.70	73.10	72.80	64.90	68.30	72.00
Hydrogen	2.32	2.40	2.50	2.53	2.55	2.57	2.30	2.41	2.39	2.66	2.66	2.30
Sulfur	1.12	0.70	0.68	0.70	0.63	0.60	0.80	0.62	0.60	0.73	1.32	0.43
Nitrogen	0.62	0.63	0.71	0.75	0.56	0.73	0.63	0.69	0.70	0.54	0.68	0.68
Oxygen (Diff)	2.49	3.25	4.19	3.60	3.97	4.19	3.73	3.43	4.02	8.97	2.32	4.12
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Run No.	HS-3	HS-4	HS-5	HS-6	PSI-1	DL-1	DL-2	CT-15	CT-16	CT-17
Proximate Analysis, wt %										
Moisture	1.6	5.2	1.4	1.3	0.3		0		0.1	0
Volatile Matter	13.6	12.5	13.2	12.4	11.3		11.3		13.2	11.7
Ash	20.7	20.1	11.4	11.3	12.2		23.0		34.7	36.7
Fixed Carbon	64.1	62.2	74.0	75.0	76.2		65.7		52.0	51.6
Total	100.0	100.0	100.0	100.0	100.0		100.0		100.0	100.0
Ultimate Analysis, wt % (Dry Basis)										
Ash	21.03	21.15	11.54	11.48	12.19		23.04		34.70	36.69
Carbon	70.90	71.20	80.60	80.50	80.90		69.50		57.60	60.10
Hydrogen	2.27	2.21	2.60	2.57	2.44		2.20		2.00	1.95
Sulfur	0.83	0.54	0.27	0.15	0.48		0.97		0.62	1.33
Nitrogen	0.72	0.71	0.79	0.75	0.66		0.06		0.35	0.49
Oxygen (Diff)	4.25	4.19	4.20	4.55	3.33		4.23		4.73	0
Total	100.00	100.00	100.00	100.00	100.00		100.00		100.00	100.00

Table A-6, Part 1. MASS BALANCES AND PRODUCT DISTRIBUTIONS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17
Component, g											
Feed Lignite	345	2263	3380	1653	2861	3743	2771	2733	2483	2262	2312
Feed Hydrogen	195	385	261	336	426	288	356	371	350	787	810
Feed Methane	0	0	0	0	0	0	0	0	0	0	0
Feed Carbon Monoxide	0	0	0	0	0	0	0	0	0	0	0
Feed Nitrogen	0	0	0	0	0	0	0	0	0	0	0
Feed Argon	0	0	8	0	0	151	131	228	207	524	529
Total Mass In	540	2648	3649	1989	3287	4182	3308	3333	3040	3573	3651
Spent Char	127	981	1658	741	1295	1768	1275	1246	1110	995	911
Liquids	108	830	1117	586	990	1243	928	891	815	834	839
Light Liquids	50	2	4	6	11	6	7	9	8	11	19
Gases	262	736	791	680	1004	1219	1156	1210	1178	1824	1911
Total Mass Out	547	2525	3570	2013	3300	4236	3366	3356	3111	3664	3685
Distribution of Products, g											
Hydrogen	163	338	245	316	351	226	289	307	282	702	720
Nitrogen	0	0	0	0	0	0	0	0	0	0	0
Argon	0	0	2	0	0	145	181	228	207	524	529
Methane	52	135	166	121	225	236	222	234	255	235	273
Light Gases (C_2-C_4)	14	84	107	73	123	155	136	133	129	132	133
Carbon Oxides	30	176	271	167	305	455	323	304	301	223	243
Hydrocarbon Liquids											
Main Liquid Product (MLP)	14	172	206	89	170	231	209	174	160	199	167
Freeze-Out	1	3	4	6	11	6	7	9	8	11	19
Make Gas	3	4	2	3	3	2	5	4	4	8	12
Gases (MLP Work-Up)	0	20	27	10	17	17	20	16	19	15	17
Char	127	981	1638	741	1295	1768	1275	1246	1110	995	911
Water (by Diff)	143	612	902	487	800	995	699	701	636	620	661
Total Mass Out	547	2525	3570	2013	3300	4236	3366	3356	3111	3664	3685

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Table A-6, Part 2. MASS BALANCES AND PRODUCT DISTRIBUTIONS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No	P-19	P-21	P-22	P-26	P-27	P-28	RC-1	RC-2	TP-1	TP-2	TP-3
Component, g											
Feed Lignite	2533	2726	1380	1355	1245	1133	1554	1373	1067	1376	896
Feed Hydrogen	775	735	1014	1404	962	1122	354	362	715	427	523
Feed Methane	0	0	0	8	3	33	10	11	22	11	20
Feed Carbon Monoxide	0	0	0	0	0	16	5	5	10	13	15
Feed Nitrogen	0	0	0	0	0	65	21	21	31	31	31
Feed Argon	573	481	664	1172	805	887	280	286	580	366	471
Total Mass In	3881	3942	3058	3939	3015	3257	2224	2057	2425	2223	1956
Spent Char	1023	1097	569	497	435	420	1281	1153	427	577	484
Liquids	936	952	478	531	440	443	77	111	429	501	288
Light Liquids	20	15	6	23	20	34	11	10	24	13	18
Gases	1898	1760	2003	2817	2101	2383	862	754	1607	1137	1218
Total Mass Out	3883	3835	3065	3868	2996	3280	2231	2028	2487	2228	2008
Distribution of Products, g											
Hydrogen	677	668	1004	1377	972	1117	352	337	665	400	456
Nitrogen	0	0	0	0	0	61	61	23	33	25	70
Argon	568	487	674	1059	805	887	280	278	573	351	418
Methane	246	218	121	143	120	132	51	61	135	128	112
Light Gases (C_2-C_4)	147	137	65	77	64	65	21	26	73	76	57
Carbon Oxides	251	251	111	161	129	113	127	29	128	156	106
Hydrocarbon Liquids											
Main Liquid Product (MLP)	198	213	100	110	75	73	*	43	48	100	75
Freeze-Out	20	11	6	21	16	31	7	7	21	11	15
Make Gas	7	1	23	0	12	8	10	0	5	0	0
Gases (MLP Work-Up)	16	17	12	6	7	8	2	0	12	13	8
Char	1023	1097	569	497	435	420	1281	1153	427	577	484
Water (by Diff)	730	735	380	417	361	365	*	71	367	391	207
Total Mass Out	3883	3835	3065	3868	2996	3280	2231	2028	2487	2228	2008

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* In process.

Table A-6, Part 3. MASS BALANCES AND PRODUCT DISTRIBUTIONS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run No.	TP-4	TP-5	TP-6	TP-8	TP-10	TP-11	RT-1	RT-2	RT-3	PS-3	PS-5	PP-2	PP-4
Component, g													
Feed Lignite	1423	2287	1637	1144	1547	2095	2028	2296	2246	1411	793	805	1484
Feed Hydrogen	503	539	574	289	288	484	469	346	356	342	330	286	276
Feed Methane	22	40	37	11	12	33	13	12	16	26	26	17	2
Feed Carbon Monoxide	0	24	34	21	21	7	38	10	5	5	15	13	8
Feed Nitrogen	22	48	42	21	17	35	27	15	21	15	19	17	12
Feed Argon	419	465	494	236	241	395	361	273	266	264	263	234	218
Total Mass In	2389	3403	2818	1723	2128	3049	2936	2952	2905	2063	1446	1372	2000
Spent Char	564	937	696	526	726	1008	872	979	1086	693	441	416	760
Liquids	511	803	487	386	524	714	734	813	710	524	250	257	403
Light Liquids	16	0	18	2	5	5	20	8	14	2	1	3	12
Gases	1346	1742	1527	774	905	1375	1388	1257	1120	907	750	725	808
Total Mass Out	2436	3482	2728	1688	2160	3102	3014	3057	2930	2126	1442	1401	1983
Distribution of Products, g													
Hydrogen	437	448	465	240	280	453	394	311	290	321	302	253	233
Nitrogen	31	43	35	14	35	28	55	36	34	19	23	15	26
Argon	419	456	455	212	250	400	361	385	260	267	246	233	214
Methane	182	300	220	87	105	145	217	234	191	82	35	76	118
Light Gases (C_2-C_4)	91	141	106	71	78	101	110	118	93	62	28	31	50
Carbon Oxides	178	337	247	151	154	247	248	273	252	155	116	128	164
Hydrocarbon Liquids													
Main Liquid Product (MLP)	85	139	96	77	107	141	112	179	86	122	54	47	45
Freeze-Out	15	0	17	2	5	4	19	8	13	1	1	3	11
Make Gas	3	18	0	0	2	0	2	1	0	1	0	0	1
Gases (MLP Work-Up)	18	46	21	7	10	12	14	16	19	6	4	6	12
Char	564	937	696	526	726	1008	872	979	1086	693	441	416	760
Water (by Diff)	413	617	370	301	408	562	610	617	606	397	192	203	349
Total Mass Out	2436	3482	2728	1688	2160	3102	3014	3057	2930	2126	1442	1401	1983

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Table A-6, Part 4. MASS BALANCES AND PRODUCT DISTRIBUTIONS

Run No.	PP-5	PP-9	PP-11	PP-12	BC-1	BC-3	BC-7	BC-9	BC-11	BC-12	BC-13
Component					g						
Feed Solids	981	2207	1968	1008	2474	3025	4071	2729	2076	2227	1692
Feed Hydrogen	150	400	333	582	310	407	534	564	538	765	564
Feed Methane	8	16	1	35	9	15	19	23	26	36	10
Feed CO	7	17	0	0	9	6	23	16	23	11	66
Feed Nitrogen	11	17	9	35	23	24	31	25	23	34	8
Feed Argon	119	256	4	370	226	269	343	410	380	638	422
Total Mass In	1276	2913	2315	2030	3051	3746	5021	3767	3066	3711	2762
Spent Char/Solids	477	1104	1013	435	2326	2718	3686	2469	1848	1986	1470
Liquids	244	701	521	330	59	144	211	127	106	111	88
Light Liquids	5	21	13	22	4	8	9	4	30	12	13
Gases	429	1065	652	1158	685	800	1136	1099	1055	1565	1117
Total Mass Out	1155	2891	2199	1945	3074	3670	5042	3699	3039	3674	2688
Distribution of Products											
Hydrogen	115	346	313	518	336	380	501	528	510	745	524
Nitrogen	26	24	13	35	56	34	55	23	13	22	21
Argon	98	253	7	346	227	256	363	381	368	628	442
Methane	55	151	79	98	25	54	75	52	56	62	43
Ethane	21	62	41	41	8	26	38	23	24	29	19
Propane	1	0	0	0	6	10	13	7	0	0	0
Light Gases (C_2-C_4)	1	4	0	0	1	1	4	3	0	1	2
Carbon Oxides	111	225	174	119	24	39	80	61	95	78	66
Hydrocarbon Liquids											
Main Liquid Product (MLP)	29	96	52	22	26	68	99	53	45	40	26
Freeze-Out	5	19	13	21	1	5	6	4	10	11	9
Make Gas	0	0	0	0	0	0	0	0	0	0	0
Gases (MLP work-up)	8	14	11	7	0	0	0	1	3	1	3
Char	477	1104	1013	435	2326	2718	3686	2469	1848	1986	1470
Water (by difference)	207	593	483	303	37	79	122	94	67	71	63
Total Mass Out	1155	2891	2199	1945	3073	3670	5042	3699	3039	3674	2688

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Table A-6, Part 5. MASS BALANCE AND PRODUCT DISTRIBUTIONS

Run No.	BC-16
Component	
Feed Solids	3345
Feed Hydrogen	319
Feed Methane	30
Feed CO	19
Feed Nitrogen	19
Feed Argon	318
Total Mass In	4050
Spent Char/Solids	2890
Liquids	196
Light Liquids	4
Gases	944
Total Mass Out	4034
Distribution of Products	
Hydrogen	334
Nitrogen	28
Argon	350
Methane	73
Ethane	29
Propane	3
Light Gases (C_2-C_4)	1
Carbon Oxides	77
Hydrocarbon Liquids	
Main Liquid Product (MLP)	15
Freeze-Out	2
Make Gas	4
Gases (MLP work-up)	3
Char	2890
Water (by difference)	225
Total Mass Out	4034

Table A-6, Part 6. MASS BALANCE AND PRODUCT DISTRIBUTIONS

Run No.	CT-4	CT-6	CT-8	CT-9	CT-10	CT-11
			g			
Component						
Feed Solids	1161	2246	1632	1188	446	1302
Feed Hydrogen	304	498	493	965	965	988
Feed Methane	9	36	37	82	65	118
Feed CO	0	7	7	29	29	0
Feed Nitrogen	4	22	51	43	43	44
Feed Argon	352	493	512	1022	956	1006
Total Mass In	1830	3302	2732	3329	2504	3458
Spent Char/Solids	587	1112	811	613	214	642
Liquids	274	673	477	300	93	369
Light Liquids	20	23	20	22	14	34
Gases	951	1647	1474	2535	2179	2396
Total Mass Out	1832	3455	2782	3470	2500	3441
Distribution of Products						
Hydrogen	299	461	496	967	938	918
Nitrogen	9	28	16	44	28	52
Argon	314	519	544	1072	938	946
Methane	154	299	186	162	88	193
Ethane	89	153	102	88	29	86
Propane	2	3	6	7	0	0
Light Gases (C_2-C_4)	1	0	0	0	0	0
Carbon Oxides	88	181	121	182	142	186
Hydrocarbon Liquids						
Main Liquid Product (MLP)	74	177	147	109	5	104
Freeze-Out	11	23	20	22	14	34
Make Gas	2	3	4	11	11	4
Gases (MLP work-up)	9	20	13	5	3	12
Char	587	1112	811	613	214	642
Water (by difference)	193	476	316	188	90	264
Total Mass Out	1832	3455	2782	3470	2500	2441

Table A-6, Part 7. MASS BALANCE AND PRODUCT DISTRIBUTIONS

Run No.	CT-12	CT-13	HR-1	HR-2	HR-3	HR-4	HR-5
				g			
Component							
Feed Solids	1566	1378	3148	2064	2273	2308	2956
Feed Hydrogen	359	676	630	737	889	788	706
Feed Methane	30	80	59	52	51	36	37
Feed CO	16	0	9	22	26	47	42
Feed Nitrogen	27	40	28	22	26	23	21
Feed Argon	326	584	654	793	918	814	763
Total Mass In	2324	2758	4528	3690	4183	4016	4525
Spent Char/Solids	856	776	1248	873	1057	972	1207
Liquids	383	283	1212	703	750	765	1001
Light Liquids	16	22	27	18	18	34	36
Gases	1173	1714	2143	2113	2387	2327	2335
Total Mass Out	2428	2795	4630	3707	4212	4098	4579
Distribution of Products							
Hydrogen	290	580	546	699	833	705	612
Nitrogen	22	43	38	27	84	22	33
Argon	335	672	643	787	906	799	735
Methane	253	201	251	197	184	287	376
Ethane	129	92	120	97	83	114	168
Propane	3	0	123	12	18	4	2
Light Gases (C_2-C_4)	0	0	0	1	0	0	0
Carbon Oxides	137	172	190	279	268	366	405
Hydrocarbon Liquids							
Main Liquid Product (MLP)	153	112	188	137	146	142	180
Freeze-Out	16	22	25	17	17	33	36
Make Gas	4	4	3	8	9	8	5
Gases (MLP work-up)	13	15	35	16	13	8	14
Char	856	776	1248	873	1057	972	1207
Water (by difference)	217	106	900	557	594	638	806
Total Mass Out	2428	2795	4530	3707	4212	4098	4579

Table A-6, Part 8. MASS BALANCES AND PRODUCT DISTRIBUTIONS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HS-2	HS-3	HS-4	HS-5	HS-6	PSI-1	DL-1	DL-2	CT-15	CT-16	CT-17
						g					
Component,											
Feed Solids	473	296	338	802	333	813	925	1147	626	1923	591
Feed Hydrogen	124	260	259	239	419	489	368	199	225	330	206
Feed Methane	2	7	3	3	5	16	0	5	5	8	6
Feed CO	2	1	4	6	12	0	0	0	0	0	0
Feed Nitrogen	0	0	0	0	0	0	0	3	0	5	3
Feed Argon	119	245	237	229	356	410	0	136	143	238	144
Feed Steam	1007	2014	2014	1678	2685	0	0	0	0	0	0
Total Mass In	1727	2823	2855	2957	3810	1728	1293	1490	999	2504	950
Spent Char/Solids	205	124	146	328	135	265	440	620	305	995	320
Liquids	1080	2060	2071	1824	2747	366	221	211	149	415	129
Light Liquids	Tr	3	6	12	8	10	18	13	10	34	0
Gases	428	552	622	755	824	1100	601	633	505	1073	503
Total Mass Out	1713	2739	2845	2919	3714	1741	1280	1477	969	2517	952
Distribution of Products,											
Hydrogen	119	260	249	229	354	442	324	187	187	286	197
Nitrogen	2	8	9	8	2	0	20	33	0	17	5
Argon	117	245	240	229	358	404	0	141	136	220	142
Methane	51	37	43	86	36	110	112	104	81	231	60
Light Gases (C_2-C_4)	24	13	17	37	14	36	44	41	37	96	24
Carbon Oxides	106	61	64	162	56	72	97	127	62	218	61
Hydrocarbon Liquids											
Main Liquid Product (MLP)	Tr	3	Tr	3	2	15	66	26	37	116	12
Freeze-Out	Tr	3	6	12	8	10	18	13	0	0	0
Make Gas	3	2	8	4	3	0	3	0	2	5	1
Gases (MLP Work-Up)	3	3	3	Tr	3	0	0	0	0	0	0
Char/Spent Solids	205	124	146	328	135	265	440	620	305	995	320
Water (By Diff)	1083	1980	2060	1821	2743	387	156	185	126	333	130
Total Mass Out	1713	2739	2845	2419	3714	1741	1280	1477	973	2517	952

Table A-6, Part 9. MASS BALANCES AND PRODUCT DISTRIBUTIONS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HR-7	HH-2	HH-3	HH-4	HH-5	HH-6	HH-7	HH-8	HH-9	HH-10	HH-11	HH-12
						g						
Component,												
Feed Solids	1577	174	678	1392	2128	1996	1223	769	1736	2792	536	242
Feed Hydrogen	696	384	562	617	273	457	609	853	439	467	975	977
Feed Methane	10	15	22	23	8	14	20	19	10	11	7	19
Feed CO	10	0	0	9	4	0	0	0	0	0	0	0
Feed Nitrogen	20	11	17	36	4	13	9	13	13	7	0	14
Feed Argon	702	386	565	648	287	480	652	931	460	520	1128	1087
Feed Steam	0	0	0	0	0	0	0	0	0	0	0	0
Total Mass In	3015	970	1844	2725	2704	2960	2513	2585	2658	3797	2646	2339
Spent Char/Solids	656	81	291	631	986	889	543	316	770	1177	198	85
Liquids	512	52	244	472	610	577	352	240	480	902	206	99
Light Liquids	27	7	17	29	13	24	13	25	28	25	22	2
Gases	1816	840	1325	1599	1181	1452	1608	1987	1439	1614	2250	2158
Total Mass Out	3011	980	1877	2731	2790	2942	2516	2568	2717	3718	2676	2344
Distribution of Products,												
Hydrogen	586	373	531	571	233	393	570	840	392	409	986	961
Nitrogen	41	11	20	20	22	17	11	15	11	12	7	14
Argon	645	386	566	648	290	480	650	931	463	520	1128	1087
Methane	225	38	92	164	208	202	137	104	216	252	56	44
Light Gases (C_2-C_4)	94	12	41	81	107	112	76	14	98	117	28	19
Carbon Oxides	222	19	76	114	319	244	162	72	254	296	40	26
Hydrocarbon Liquids												
Main Liquid Product (MLP)	51	1	27	86	69	89	53	31	36	84	60	9
Freeze-Out	27	7	16	22	13	24	13	24	26	25	22	2
Make Gas	3	2	4	4	2	3	3	12	4	9	5	8
Gases (MLP Work-Up)	26	0	5	16	25	18	12	5	19	2	3	0
Char/Spent Solids	656	81	291	630	986	889	543	316	770	1177	198	85
Water (By Diff)	435	50	208	375	516	471	286	204	428	815	143	89
Total Mass Out	3011	980	1877	2731	2790	2942	2516	2568	2717	3718	2676	2344

Table A-7, Part 1. AVERAGE MAKE-GAS COMPOSITIONS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run No.	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17
Component	mol % (wet basis)										
CO	0.80	1.76	2.78	1.93	2.60	2.97	2.93	2.72	2.73	1.47	1.46
CO_2	0.00	0.41	0.75	0.34	0.77	2.09	0.93	0.82	0.86	0.15	0.18
Hydrogen	87.63	78.32	64.19	79.35	71.48	57.45	67.77	68.88	68.54	81.31	81.01
Methane	2.28	3.20	4.62	3.25	4.98	5.70	5.23	5.35	6.10	3.08	3.20
Ethane	0.35	0.88	1.20	0.86	1.29	1.44	1.38	1.44	1.57	0.89	0.88
Propane	0.00	0.08	0.19	0.09	0.06	0.27	0.15	0.10	0.03	0.18	0.02
Butane	0.00	0.00	0.02	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00
Ethylene	0.00	0.03	0.05	0.03	0.06	0.06	0.06	0.01	0.01	Tr	0.01
Propylene	0.00	0.00	0.01	0.02	0.05	0.03	0.01	0.02	0.00	0.00	0.00
Acetylene	0.00	0.00	Tr	Tr	0.00	0.00	0.00	0.01	Tr	0.00	0.00
Benzene	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Argon	0.00	0.00	0.00	0.00	0.00	1.87	2.14	2.60	2.50	3.06	3.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Steam	8.91	15.23	25.79	14.03	18.67	78.10	19.37	18.05	17.61	9.99	10.03
Total	99.97	99.96	99.81	99.91	99.97	100.01	97.98	100.02	99.97	100.15	99.81

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12/80

Table A-7, Part 2. AVERAGE MAKE-GAS COMPOSITIONS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run No.	P-19	P-21	P-22	P-26	P-27	P-28	RC-1	RC-2	TP-1	TP-2	TP-3	TP-4
Component						mol % (wet basis)						
CO	1.57	1.55	0.67	0.71	0.67	0.61	1.48	0.44	0.99	1.62	1.34	1.63
CO_2	0.20	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.18	0.07	0.19
Hydrogen	80.95	81.44	90.93	88.34	90.22	90.50	91.64	91.13	87.20	81.78	86.78	82.74
Methane	3.36	2.82	1.25	1.12	1.25	1.26	1.28	1.69	1.89	2.71	2.51	3.35
Ethane	1.00	0.78	0.34	0.30	0.36	0.33	0.26	0.38	0.50	0.76	0.65	0.87
Propane	0.04	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.01
Butane	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	0.01	0.02	0.03	0.03	0.00	Tr	0.02	0.01	0.01	Tr	0.02	0.00
Propylene	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acetylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzene	0.02	0.00	0.05	0.00	0.01	0.01	0.06	0.00	0.01	0.00	0.00	0.01
Argon	3.43	3.00	3.08	3.42	3.76	3.63	3.68	3.80	3.79	3.62	3.95	3.76
Nitrogen	0.00	0.00	0.00	2.94	0.00	0.37	0.39	0.45	0.31	0.36	0.36	0.39
Steam	9.31	9.98	3.68	3.09	3.72	3.28	1.17	2.06	5.30	8.88	4.33	7.07
Total	99.99	99.97	100.03	99.95	99.99	99.99	99.98	99.76	100.03	99.97	100.02	100.02

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Table A-7, Part 3. AVERAGE MAKE-GAS COMPOSITIONS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977 THROUGH MARCH 31, 1978

Run No.	TP-5	TP-6	TP-8	TP-10	TP-11	RT-1	RT-2	RT-3	PS-3	PS-5	PP-2	PP-4
Component	mol % (wet basis)											
CO	2.88	2.32	2.02	1.84	2.09	2.11	2.36	2.67	1.73	1.06	2.01	2.77
CO_2	0.57	0.21	0.42	0.44	0.40	0.48	0.82	0.67	0.42	0.54	0.49	0.35
Hydrogen	74.68	80.84	79.16	77.37	79.00	74.78	70.56	70.31	80.11	86.69	82.56	75.44
Methane	5.84	4.01	2.58	2.62	2.74	4.29	5.47	4.85	2.15	1.15	2.84	4.11
Ethane	1.46	1.00	0.62	0.63	0.65	1.11	1.33	1.21	0.45	0.18	0.57	0.89
Propane	0.00	0.00	0.17	0.18	0.18	0.03	0.03	0.05	0.16	0.06	0.02	0.03
Butane	0.00	0.00	0.15	0.04	0.03	0.00	0.00	0.00	0.01	0.03	0.00	0.00
Ethylene	0.01	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.04	0.01	0.02	0.01
Propylene	0.00	0.00	0.01	0.03	0.02	0.00	0.01	0.00	0.05	0.05	0.00	0.00
Acetylene	0.00	0.00	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Benzene	0.07	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01
Argon	3.84	3.99	3.53	3.50	3.52	3.46	3.26	3.17	3.35	3.57	3.67	3.50
Nitrogen	0.51	0.44	0.33	0.70	0.36	0.76	0.32	0.58	0.33	0.47	0.34	0.61
Steam	10.13	7.19	11.16	12.58	10.97	12.97	15.83	16.45	11.16	6.18	7.47	12.55
Total	99.99	100.00	100.02	99.96	100.00	100.00	100.00	99.96	99.96	99.99	100.00	100.27

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Table A-7, Part 4. AVERAGE MAKE-GAS COMPOSITIONS

Run No.	PP-5	PP-9	PE-11	PP-12	BC-1	BC-3	BC-7	BC-9	BC-11	BC-12	BC-13
Component	mol-% (wet basis)										
CO	3.56	2.45	1.88	1.13	0.34	0.37	0.65	0.56	0.86	0.65	0.72
CO_2	0.31	0.45	0.62	0.09	0	0.07	0.10	0.07	0.10	0	0
Hydrogen	72.22	75.03	79.81	87.74	93.39	92.11	90.72	92.95	93.05	93.08	92.78
Methane	4.10	3.66	2.43	1.73	0.62	1.19	1.43	0.97	1.04	0.87	0.82
Ethane	1.84	0.80	0.52	0.31	0.12	0.30	0.40	0.24	0.26	0.22	0.21
Propane	0.03	0	0.02	0	0.06	0.08	0.09	0.05	0	0	0
Butane	0	0	0	0	0	0	0	0.03	0	0	0
Ethylene	0.04	0.05	0.06	0.03	0.01	0.01	0.01	0.0	0.02	0.01	0.02
Propylene	0	0	0.01	0	0	0	0.02	0	0	0	0
Acetylene	0	0	0	0	0.01	0	0.01	0	0	0	0
Benzene	0.01	0	0	0	0	0	0	0	0	0	0
Argon	3.16	2.77	0.02	3.04	3.18	3.13	3.32	3.38	3.39	3.99	3.95
Nitrogen	0.57	0.38	0.13	0.24	1.13	0.59	0.72	0.30	0.17	0.20	0.27
Steam	14.63	14.39	14.46	5.69	1.13	2.14	2.45	1.43	1.12	0.98	1.23
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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Table A-7, Part 5. AVERAGE MAKE-GAS COMPOSITIONS

Run No.	BC-16	BC-18	BC-19	SF-3
	mol % (wet basis)			
Component				
CO	1.1	0.7	0.7	0.5
CO_2	0.2	0	0	0
Hydrogen	85.9	93.9	93.9	93.3
Methane	1.9	0.5	0.5	0.4
Ethane	0.4	0	0	0
Propane	Tr	0	0	0
Butane	0	0	0	0
Ethylene	0	0	0	0
Propylene	0	0	0	0
Acetylene	0	0	0	0
Benzene	Tr	0	0	0
Argon	4.6	4.4	4.5	4.7
Nitrogen	0.5	0.5	0.4	1.1
Steam	5.4	Tr	Tr	0
Total	100.0	100.0	100.0	100.0

Table A-7, Part 6. AVERAGE MAKE-GAS COMPOSITIONS

Run No.	CT-4	CT-6	CT-8	CT-9
Component	mol % (wet basis)			
CO	1.37	1.98	1.19	0.95
CO_2	0.01	0.10	0.10	0.13
Hydrogen	86.73	81.81	87.24	90.68
Methane	4.16	5.76	3.45	1.78
Ethane	1.18	1.56	1.04	0.52
Propane	0.02	0.02	0.04	0.03
Butane	0.00	0.00	0.00	0.00
Ethylene	0.00	0.00	0.00	0.00
Propylene	0.00	0.00	0.00	0.00
Acetylene	0.01	0.00	0.00	0.00
Benzene	0.01	0.01	0.01	0.02
Argon	4.61	4.64	4.84	5.07
Nitrogen	0.20	0.36	0.20	0.30
Steam	1.70	3.76	1.91	0.52
Total	100.00	100.00	100.00	100.00

Table A-7, Part 7. AVERAGE MAKE-GAS COMPOSITION

Run No.	CT-10	CT-11	CT-12	CT-13
Component	mol % (wet basis)			
CO	0.76	1.19	2.05	1.37
CO_2	0.00	0.00	0.10	0.20
Hydrogen	92.42	90.27	82.96	88.59
Methane	0.91	2.15	7.17	3.47
Ethane	0.19	0.57	1.94	0.85
Propane	0.00	0.00	0.03	0.00
Butane	0.00	0.00	0.00	0.00
Ethylene	0.00	0.00	0.00	0.00
Propylene	0.00	0.00	0.00	0.00
Acetylene	0.00	0.00	0.00	0.00
Benzene	0.02	0.01	0.02	0.01
Argon	4.66	4.69	4.83	4.80
Nitrogen	0.20	0.37	0.45	0.47
Steam	0.84	0.75	0.45	0.24
Total	100.00	100.00	100.00	100.00

Table A-7, Part 8. AVERAGE MAKE-GAS COMPOSITIONS

Run No.	HR-1	HR-2	HR-3	HR-4
Component	mol % (wet basis)			
CO	2.63	1.91	1.44	2.18
CO_2	0.67	0.22	0.24	0.24
Hydrogen	79.22	86.36	87.49	84.77
Methane	4.02	2.77	2.19	3.73
Ethane	1.01	0.72	0.54	0.92
Propane	0.80	0.06	0.08	0.02
Butane	0.00	0.00	0.00	0.00
Ethylene	0.00	0.00	0.00	0.00
Propylene	0.00	0.00	0.00	0.00
Acetylene	0.00	0.01	0.00	0.00
Benzene	0.01	0.03	0.02	0.02
Argon	4.70	4.94	4.80	4.85
Nitrogen	0.40	0.24	0.63	0.19
Steam	6.54	2.74	2.57	3.08
Total	100.00	100.00	100.00	100.00

Table A-7, Part 9. AVERAGE MAKE-GAS COMPOSITIONS

Run No.	HR-5	HR-6	HR-7
Component	mol % (wet basis)		
CO	2.67	1.66	1.73
CO_2	0.46	0.15	0.22
Hydrogen	80.22	84.89	85.79
Methane	5.56	4.10	3.63
Ethane	1.32	0.91	0.79
Propane	0.01	0	0.01
Butane	0	0	0
Ethylene	0	0	0
Propylene	0	0	0
Acetylene	0	0	0
Benzene	0	0	0
Argon	4.87	4.72	4.76
Nitrogen	0.31	0.43	0.29
Steam	4.57	3.14	2.77
Total	100.00	100.00	100.00

Table A-7, Part 10. AVERAGE MAKE-GAS COMPOSITIONS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HH-2	HH-3	HH-4	HH-5	HH-6	HH-7	HH-8	HH-9	HH-10	HH-11	HH-12
Component, mol % (wet basis)											
CO	0.35	0.70	1.31	2.91	2.30	1.12	0.49	1.93	2.25	0.23	0.17
CO_2	Tr	0.02	0.12	1.29	0.51	Tr	Tr	0.61	0.67	Tr	Tr
Hydrogen	92.14	88.54	83.97	66.97	76.40	86.17	90.33	77.78	70.60	92.17	92.88
Methane	0.94	1.56	2.72	5.87	4.37	2.19	1.23	4.28	4.86	0.61	0.48
Ethane	0.17	0.35	0.66	1.46	1.17	0.56	0.30	1.02	1.17	0.13	0.08
Propane	Tr	0.01	0.04	0.10	0.08	0.06	Tr	0.01	0.02	0.02	0.02
Butane	0	0	0	0	0	0	0	0	0	0	0
Ethylene	0	0	0	0	0	0	0	0	0	0	0
Propylene	0	0	0	0	0	0	0	0	0	0	0
Acetylene	0	0	0	0	0	0	0	0	0	0	0
Benzene	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.03	0.01	0.01
Argon	4.81	4.76	4.81	4.21	4.70	4.95	5.05	4.64	4.53	5.32	5.30
Nitrogen	0.20	0.24	0.21	0.46	0.24	0.12	0.12	0.15	0.14	0.15	0.10
Steam	1.38	3.81	6.15	16.72	10.22	4.82	2.45	9.56	15.73	1.45	0.96
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-7, Part 11. AVERAGE MAKE-GAS COMPOSITIONS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HS-2	HS-3	HS-4	HS-5	HS-6	PSI-1	PL-1	PL-2	CT-15	CT-16	CT-17
Component, mol % (wet basis)											
CO	0.65	0.33	0.33	0.64	0.19	0.07	1.45	2.82	1.06	2.98	1.56
CO_2	0.82	0.14	0.38	0.80	0.19	0.06	Tr	0.18	0.07	0.27	0.05
Hydrogen	48.39	51.48	50.15	47.28	52.27	86.82	89.32	79.12	86.16	76.04	86.27
Methane	1.63	0.69	1.10	1.75	0.55	2.12	3.10	4.52	2.66	6.27	2.71
Ethane	0.40	0.13	0.24	0.40	0.12	0.41	0.79	0.91	0.63	1.36	0.57
Propane	0.01	0	0	0.01	0	0	0.01	0.01	0.01	0.01	Tr
Butane	0	0	0	0	0	0	0	0	0	0	Tr
Ethylene	0	0	0	0	0	0	0.01	0.01	0.01	0.01	Tr
Propylene	0	0	0	0	0	0	0	0	0	0	0
Acetylene	0	0	0	0	0	0	0	0	0	0	0
Benzene	0.03	0	0.02	0.02	0.01	0	0.01	0	0.01	0.02	Tr
Argon	2.39	2.45	2.44	2.39	2.27	3.97	0	3.00	3.16	2.96	3.14
Nitrogen	0.05	0.12	0.14	0.12	0.02	0.50	0	0.32	Tr	0.32	Tr
Steam	45.63	44.66	45.20	46.59	44.38	6.05	5.31	9.12	6.23	9.77	5.70
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-8, Part 1. ANALYSES OF MAIN LIQUIDS PRODUCTS FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17	P-19	P-21
Specific Gravity	1.059	1.043	1.037	1.006	1.019	1.020	1.022	1.002	1.021	1.013	1.039	1.026
IBP, °F	166	200	176	175	104	147	129	153	153	154	154	156
Ultimate Analysis, wt %												
Carbon	89.85	87.01	88.67	--	87.04	88.84	89.20	90.53	91.51	91.62	90.66	88.76
Hydrogen	6.65	6.99	6.86	--	7.11	7.04	6.84	6.85	6.76	6.72	6.58	6.94
Sulfur	—	—	--	--	0.47	0.31	0.37	0.32	0.24	0.22	0.26	0.32
Nitrogen	—	—	--	--	0.85	0.76	0.78	0.64	0.71	0.72	0.86	0.81
Oxygen (by Diff)	—	—	--	--	4.53	3.04	2.79	1.65	0.78	0.72	1.59	3.12
Ash	—	—	--	--	0.00	0.01	0.02	0.01	0.00	0.00	0.05	0.05
C/H Weight Ratio	13.52	12.46	12.93	--	12.25	12.61	13.03	13.21	13.54	13.69	13.78	12.80
Fraction	vol %				wt %							
C_5-400°F	42.0	46.5	46.5	52.0	54.0	50.5	49.7	54.3	46.3	44.6	41.5	50.0
>400°F	58.0	53.5	53.5	48.0	46.0	49.5	50.3	45.7	53.7	55.4	58.5	50.0

Table A-8, Part 2. ANALYSES OF MAIN LIQUIDS PRODUCTS FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-22	P-26	P-27	P-28	RC-1	RC-2	TP-1	TP-2	TP-3	TP-4	TP-5	TP-6
Specific Gravity	1.084	--	1.079	--	1.097	1.088	1.282	--	1.119	1.074	1.050	1.044
IBP, °F	156	--	113	156	156	155	--	156	160	151	152	138
Ultimate Analysis, wt %												
Carbon	89.04	--	86.43	89.47	*	84.61	--	84.66	*	85.84	84.62	86.62
Hydrogen	6.50	--	5.88	5.92	*	6.26	--	6.23	*	5.91	5.82	6.08
Sulfur	0.39	--	0.22	1.02	*	0.18	0.38	0.23	*	0.65	1.22	0.62
Nitrogen	0.76	--	0.54	0.71	*	0.80	0.60	0.52	0.91	0.44	0.63	0.65
Oxygen (by Diff)	3.31	--	6.93	2.88	*	8.95	--	8.36	*	7.16	7.71	6.03
Ash	0.00	--	0.00	0.00	*	0.00	--	0.00	*	0.00	0.00	0.00
C/H Weight Ratio	13.70	--	14.70	15.11	*	13.52	--	13.59	*	14.54	14.54	14.25
Fraction	wt %											
C_5-400°F	29.8	28.1	26.9	13.9	18.6	13.9	5.9	42.3	29.6	28.8	30.3	34.6
>400°F	70.2	71.9	73.1	86.1	81.4	86.1	94.1	57.7	70.4	71.2	69.7	65.4

* Insufficient sample.

Table A-8, Part 3. ANALYSES OF MAIN LIQUIDS PRODUCTS FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	TP-8	TP-10	TP-11	RT-1	RT-2
Specific Gravity	1.070	1.052	1.070	1.004	1.058
IBP, °F	172	162	140	174	160
Ultimate Analysis, wt %					
Carbon	84.09	84.36	83.95	81.14	86.38
Hydrogen	6.84	6.99	6.57	5.70	6.05
Sulfur	0.47	0.28	0.64	0.76	0.90
Nitrogen	0.77	0.71	0.58	0.49	0.51
Oxygen (by Diff)	7.83	7.66	8.26		
Ash	0.00	0.00	0.00	0.00	0.00
C/H Weight Ratio	12.29	12.07	12.78	14.24	14.28
Fraction					
C_5-400°F	40.4	43.1	39.4	47.5	25.5
>400°F	59.6	56.9	60.6	52.5	74.5

12/80

Table A-8, Part 4. ANALYSES OF MAIN LIQUIDS PRODUCTS FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	RT-3	PS-1	PP-2	PP-4	PP-9	P-26	TP-1
Specific Gravity	1.028	1.058	1.061	0.999	1.010	1.110	1.282
IBT, °F	160	145	154	154	153	157	--
Ultimate Analysis, wt %							
Carbon	88.63	82.65	80.65	80.68	85.36	91.41	92.35
Hydrogen	6.68	7.15	6.53	6.17	6.54	5.32	6.08
Sulfur	0.79	0.30	2.01	0.72	0.79	--	0.38
Nitrogen	0.46	0.59	0.61	0.37	0.69	--	0.60
Oxygen (by difference)	2.84	7.81	10.20	12.06	6.62	--	--
Ash	0.6	1.5	0	0	0	--	--
C/H Weight Ratio	13.27	11.56	12.35	13.08	13.05	17.2	15.19
Fraction, wt %							
C_5-400°F	40.7	38.3	38.3	53.8	49.7	28.1	5.9
400°F+	56.0	58.0	57.5	46.2	44.9	71.9	94.1

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Table A-8, Part 5. ANALYSES OF MAIN LIQUIDS PRODUCTS FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	PP-11	PP-12	BC-1	BC-3	BC-7,9	BC-11, 12,13	BC-16
Specific Gravity	1.051	1.051	1.093	1.065	1.079	1.080	1.074
IBP, °F	120	115	179	156	149	152	*
Ultimate Analysis, wt %							
Carbon	80.61	81.23	82.80	79.79	80.00	81.56	80.71
Hydrogen	7.53	6.11	6.47	6.56	6.62	6.05	6.37
Sulfur	2.21	1.38	2.72	3.26	2.57	2.71	3.24
Nitrogen	0.45	0.52	0.68	0.85	0.83	0.84	0.70
Oxygen (by difference)	9.20	10.76	7.33	9.54	9.98	8.64	8.98
Ash	0.0	0.0	0.0	0.0	0.0	0.20	0.0
C/H Weight Ratio	10.70	13.29	12.80	12.16	12.08	13.48	12.67
Fraction, wt %							
C_5-400°F	46.1	37.3	43.1	43.9	44.8	29.9	*
400°F+	53.9	62.7	56.9	56.1	55.2	70.1	*

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* Insufficient sample.

Table A-8, Part 6. ANALYSES OF MAIN LIQUIDS PRODUCTS FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	SF-2	SF-3	CT-4	CT-6	CT-8	CT-9	CT-10	CT-11	CT-12	CT-13
Specific Gravity	0.871	0.969	1.029	1.014	1.054	--	*	1.051	1.025	1.034
IBP, °F	220	< 220	150	156	148	--	*	148	148	150
Ultimate Analysis, wt %										
Carbon	91.17	82.54	83.02	88.16	82.10	83.64	81.19	86.15	82.24	83.33
Hydrogen	8.68	7.66	6.35	6.49	5.86	5.97	5.63	5.97	5.86	5.84
Sulfur	0.11	0.10	1.34	1.06	1.29	1.22	3.36	1.10	0.75	0.77
Nitrogen	0.00	0.06	0.79	0.79	0.97	1.11	1.33	0.84	1.15	0.85
Oxygen (by difference)	0.00	9.44	8.50	3.50	8.98	8.06	8.29	5.84	10.00	9.01
Ash	0.00	0.20	0.00	0.00	0.80	0.00	0.20	0.10	0.00	0.20
C/H Weight Ratio	10.50	10.78	13.07	13.58	14.01	14.01	14.42	14.43	14.03	14.27
Fraction, wt %										
C_5-400°F	100.00	91.50	46.70	47.40	41.90	39.50	*	35.90	43.70	46.10
400°F+	0.00	8.50	53.30	52.60	58.10	60.50	*	64.10	56.30	53.90

Table A-8, Part 7. ANALYSES OF MAIN LIQUIDS PRODUCTS FROM RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7
Specific Gravity	1.065	1.058	1.044	1.023	1.008	0.975	0.963
IBP, °F	156	146	155	150	--	172	168
Ultimate Analysis, wt %							
Carbon	84.59	84.90	83.92	91.19	91.25	92.11	92.43
Hydrogen	6.21	6.09	6.39	6.61	6.23	6.78	6.81
Sulfur	0.71	0.46	0.32	0.37	0	0.86	0.55
Nitrogen	0.74	0.75	0.71	0.71	0.54	0.25	0.19
Oxygen (by difference)	7.75	7.50	8.66	1.12	1.98	0	0.02
Ash	0	0.30	0	0	0	0	0
C/H Weight Ratio	13.62	13.94	13.13	13.80	14.65	13.59	13.57
Fraction, wt %							
C_5-400°F	40.3	43.0	40.5	40.8	44.1	56.9	67.5
400°F+	59.7	57.0	59.5	59.2	55.9	43.1	32.5

Table A-8, Part 8. ANALYSES OF MAIN LIQUID PRODUCTS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HH-3	HH-4†	HH-5	HH-6	HH-7	HH-8	HH-9	HH-10†	HH-11,12†	DL-1†	DL-2†	CT-15†	CT-16†	CT-17†
Specific Gravity	1.090	1.001	1.023	0.991	1.016	1.079	1.048	0.971		0.981	0.974	0.981	0.963	0.965
IBP, °F	*	152	150	154	151	*	164	146	152	152	*	150	152	*
Ultimate Analysis, wt %														
C	88.05	89.67	88.75	89.76	*	87.03	89.60	90.05	88.92	91.82	92.05	92.00	92.00	90.81
H	6.19	6.88	7.01	7.48	*	6.38	6.41	6.98	6.37	6.99	7.05	6.91	6.92	6.99
S	2.62	0.36	1.25	0.69	0.62	1.42	2.54	1.23	3.51	0.13	0.25	0.20	0.09	1.24
N	0.54	0.49	0.54	0.73	0.61	0.64	0.88	0.54	0.57	0.68	0.31	0.29	0.44	0.39
O (Diff)	2.60	2.60	2.45	1.34	*	4.53	0.47	0.75	0.81	0.38	0.34	0.60	0.55	0.57
Ash	0	0	0	0	*	0	0.10	0	0.32	0	0	0	0	0
C/H Weight Ratio	14.22	13.03	12.66	12.00	*	13.64	13.98	12.90	13.90	13.13	13.05	13.31	13.29	12.99
Fraction, wt %														
C_5-400°F	*	49.5	39.0	54.4	54.2	*	33.5	60.5	60.5	58.0	*	58.6	59.8	*
400°F	*	50.5	61.0	45.6	45.8	*	66.5	39.5	39.5	42.0	*	41.4	40.2	*

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* Insufficient sample.

† Main liquids combined with Cold Trap Liquids.

Table A-9, Part 1. ANALYSES OF GASOLINE FRACTIONS OF THE MAIN LIQUID PRODUCTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17	P-19
Component	wt %										
Benzene	34.9	21.7	26.3	48.5	25.9	32.0	32.5	58.0	55.0	58.5	49.5
Toluene	25.2	26.4	29.7	25.9	25.3	22.5	24.9	18.4	15.3	15.8	21.2
Ethyl benzene	3.6	4.1	2.51	1.09	1.94	1.26	0.9	0.2	0.13	0.34	0.28
Xylenes	4.2	7.5	8.12	3.67	6.80	4.83	3.05	0.60	0.47	0.94	0.95
C_9 Aromatics	1.5	3.1	1.67	0.62	1.87	1.07	0.51	0.89	--	--	0.07
Indan	--	--	5.57	--	1.86	1.92	1.28	0.67	0.56	0.39	0.95
Indene	0.3	0.5	0.08	0.44	0.46	0.49	0.47	0.04	0.12	0.13	0.19
Naphthalenes	8.9	7.2	11.15	7.83	4.33	8.09	8.61	9.24	14.93	11.75	10.18
Phenol	--	--	9.16	8.7	21.8	18.8	19.4	10.0	7.99	9.13	12.9
Cresols	--	--	1.47	0.60	7.19	4.24	2.23	0.73	0.43	0.45	1.03
C_8 Phenols	--	--	--	--	--	0.12	0.15	0.14	0.12	--	--
Unidentified	21.4	29.5	4.27	2.65	2.55	4.68	6.00	1.09	4.95	2.57	2.75
Total	100.0	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-9, Part 2. ANALYSES OF GASOLINE FRACTIONS OF THE MAIN LIQUID PRODUCTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-21	P-22	P-26	P-27	P-28	RC-1	RC-2	TP-1	TP-2	TP-3	TP-4
Component						wt %					
Benzene	37.5	27.6	20.40	24.00	30.40	1.19	49.5	0.04	31.70	7.96	23.1
Toluene	23.9	14.2	16.10	14.80	17.50	0.08	23.9	0.03	26.70	17.3	20.4
Ethyl benzene	0.89	0.36	1.07	0.56	0.91	0.01	1.15	0.01	1.23	1.40	0.75
Xylenes	2.99	0.96	1.97	1.21	1.30	0.06	2.10	0.05	4.54	6.12	2.30
C_9 Aromatics	0.53	0.21	0.41	0.26	0.54	0.03	0.48	0.10	0.71	0.54	0.41
Indan	1.43	1.31	0.78	0.54	0.11	1.13	0.59	1.50	0.10	3.40	3.00
Indene	0.26	0.27	0.17	0.19	0.08	0.82	0.27	0.36	0.08	0.12	0.07
Naphthalenes	8.54	30.37	23.42	32.63	17.77	95.55	14.19	56.74	11.34	34.35	22.30
Phenol	16.6	20.0	32.60	24.20	29.60	--	5.33	37.10	18.80	19.5	19.5
Cresols	3.23	1.47	1.30	0.25	0.07	--	0.04	0.24	1.69	3.10	1.88
C_8 Phenols	0.04	0.02	--	--	--	--	--	--	--	0.21	0.18
Unidentified	4.09	3.23	1.78	1.36	1.72	1.13	2.45	3.83	3.11	6.00	6.03
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-9, Part 3. ANALYSES OF GASOLINE FRACTIONS OF THE MAIN LIQUID PRODUCTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	TP-5	TP-6	TP-8	TP-10	TP-11	RT-1	RT-2	RT-3	PS-3	PS-5	PP-2
Component	wt %										
Benzene	52.30	45.20	1.53	1.03	1.82	56.00	34.70				
Toluene	19.80	23.20	9.61	8.24	10.00	20.40	21.60				
Ethyl benzene	0.54	0.66	2.35	2.35	2.89	0.91	1.25				
Xylenes	1.28	1.71	3.26	8.10	9.42	2.14	2.40				
C_9 Aromatics	0.33	0.37	3.77	4.19	4.58	0.49	0.50				
Indan	1.38	1.62	5.45	6.23	9.54	1.52	2.75				
Indene	0.04	0.19	0.35	0.78	0.18	0.11	0.19				
Naphthalenes	12.62	13.61	12.41	11.58	10.69	9.02	18.96				
Phenol	8.62	11.20	33.60	31.50	31.30	8.10	14.80				
Cresols	0.10	0.16	13.50	20.80	16.00	0.32	0.12				
C_8 Phenols	--	--	0.90	2.03	0.42	---	--				
Unidentified	2.99	2.08	2.27	3.17	3.16	0.99	2.73				
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00				

Table A-9, Part 4. ANALYSES OF GASOLINE FRACTIONS OF THE MAIN LIQUID PRODUCTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	RT-3	PS-1	PP-2	PP-4	BC-3	BC-7, 9
	wt %					
Component						
Benzene	36.1	3.19	10.4	33.4	4.77	4.36
Toluene	25.4	9.28	17.0	23.9	15.5	15.6
Ethyl benzene	1.24	2.56	1.13	0.59	3.99	3.51
Xylenes	3.23	7.82	5.06	2.63	7.22	9.32
C_9 Aromatics	0.40	5.40	2.32	0.55	3.35	4.80
Indans	2.25	4.62	3.88	2.42	5.47	6.94
Indene	0.28	0.53	0.24	0.07	0.13	0.08
Naphthalenes	13.9	5.41	21.15	17.48	10.56	12.78
Phenols	14.5	31.0	28.4	17.0	30.90	21.6
Cresols	0.44	20.0	7.98	0.73	13.12	14.21
C_8 Phenols	0	1.33	0.47	0	0.41	0.63
Unidentified	2.26	8.86	1.87	1.23	4.58*	6.17*
Total	100.00	100.00	100.00	100.00	100.00	100.00

* 75% or more thiophene and thiophene derivatives.

Table A-9, Part 5. ANALYSES OF GASOLINE FRACTIONS OF THE MAIN LIQUID PRODUCTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	BC-11,12,13
	— wt % —
Component	
Benzene	12.10
Toluene	15.40
Ethyl benzene	1.30
Xylenes	3.25
C_9 Aromatics	1.07
Indans	3.48
Indene	0.05
Naphthalenes	20.31
Phenols	35.20
Cresols	2.99
C_8 Phenols	0.11
Unidentified	4.74
Total	100.00

Table A-9, Part 6. ANALYSES OF GASOLINE FRACTIONS OF THE MAIN LIQUID PRODUCTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	SF-2	SF-3	CT-4	CT-6	CT-8	CT-9	CT-11	CT-12	CT-13
Component	wt %								
Benzene	7.55	2.35	48.20	54.80	32.40	30.60	50.10	55.50	52.00
Toluene	92.00	56.40	17.20	15.40	21.00	21.70	16.00	15.00	10.70
Ethyl benzene	0.11	0.03	0.76	0.68	1.01	1.54	0.79	0.64	0.54
Xylenes	0.15	0.05	0.87	0.76	2.00	1.19	0.73	0.64	0.46
C_9 Aromatics	0.06	--	0.19	0.14	0.33	0.56	0.19	0.12	0.16
Indans	--	--	1.05	0.91	1.63	1.94	1.16	0.98	1.01
Indene	--	--	0.34	0.15	0.08	0.32	0.08	0.21	0.15
Naphthalenes	--	12.40	15.35	13.81	23.27	18.14	20.14	14.40	25.03
Phenols	--	28.70	10.72	9.40	14.67	18.59	9.45	10.09	8.22
Cresols	--	--	0.38	0.38	0.23	0.36	0.02	0.03	0.04
Pyridines	--	--	1.23	1.37	Tr	Tr	Tr	0.99	Tr
Thiophenes	--	--	1.27	0.82	2.44	2.55	1.00	0.67	0.79
Unidentified	0.13	0.07	2.44	1.38	0.94	2.51	0.34	0.73	0.90
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-9, Part 7. ANALYSES OF GASOLINE FRACTIONS OF THE MAIN LIQUID PRODUCTS OF RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7
Component	wt %						
Benzene	24.10	17.20	7.64	54.80	79.50	89.30	79.70
Toluene	24.80	20.30	14.30	16.10	7.92	1.57	2.34
Ethyl benzene	1.05	1.10	1.77	0.53	0.33	0.14	0.17
Xylenes	3.09	4.99	5.66	1.32	0.18	0.04	0.05
C_9 Aromatics	0.87	0.91	2.05	0.61	0.05	0.05	0.07
Indans	3.92	3.33	4.17	1.28	0.57	0.35	0.47
Indene	0.06	0.68	0.06	0.22	0.05	0.02	0.09
Naphthalenes	16.77	17.89	15.53	11.43	7.99	8.28	16.10
Phenols	21.21	29.11	33.04	11.70	2.40	Tr	0.20
Cresols	3.39	3.18	11.81	0.36	Tr	Tr	0.02
Pyridines	Tr	0.38	Tr	0.96	0.60	Tr	Tr
Thiophenes	0.24	0.17	0.15	0.13	0.05	0.04	0.06
Unidentified	0.50	0.76	3.82	0.56	0.35	0.21	0.73
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-9, Part 8. ANALYSES OF GASOLINE FRACTIONS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	**HH-4**	**HH-5**	**HH-6**	**HH-7**	**HH-9**	**HH-10**	**PL-1**	**CT-16**
Component, wt %								
Benzene	48.8	31.6	47.4	42.7	36.3	79.9	79.0	87.3
Toluene	21.7	31.5	22.0	21.2	15.3	8.8	8.8	4.4
Ethyl benzene	0.7	2.0	1.1	1.1	0.5	0.2	0.2	Tr
Xylenes	1.8	5.2	2.8	2.6	1.0	0.2	0.3	0.3
C_9 Aromatics	0.2	0.9	0.6	0.4	0.1	Tr	0.2	Tr
Indan	1.2	2.9	1.5	0.8	0.7	0.1	0.5	0.4
Indene	0.1	0.2	0.1	0.1	Tr	Tr	0.3	0.1
Naphthalenes	9.3	7.7	9.7	7.9	27.7	6.9	6.1	5.1
Phenol	15.3	17.0	12.8	20.3	16.3	3.4	3.8	1.3
Cresols	0.5	0.9	1.2	2.7	0.3	Tr	0.2	Tr
C_8 Phenols	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Unidentified	0.4	0.1	0.8	0.2	1.8	0.5	0.6	1.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A-10, Part 1. ANALYSES OF COLD TRAP LIQUIDS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17	P-19
Benzene	66.4	68.0	79.1	87.5	67.4	--	--	92.8	95.4	94.2	90.1
Toluene	27.1	20.1	16.7	9.4	25.5	--	--	6.6	4.3	5.5	9.3
Xylene	1.7	1.6	0.9	0.4	2.8	--	--	0.19	0.09	0.13	0.32
Indan + Indene	0.0	0.1	0.0	0.0	0.0	--	--	0.25	0.05	0.03	0.04
Ethyl benzene	1.5	1.2	0.1	0.1	0.0	--	--	0.07	0.04	0.07	0.14
Naphthalenes	1.8	1.1	1.4	0.3	0.6	--	--	--	--	--	--
Unidentified	1.5	7.9	1.8	2.3	3.7	--	--	0.09	0.12	0.07	0.10
Total	100.0	100.0	100.0	100.0	100.0	--	--	100.00	100.00	100.00	100.00

Table A-10, Part 2. ANALYSES OF COLD TRAP LIQUIDS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-21	P-26	P-27	P-28	RC-1	RC-2	TP-1	TP-2	TP-3	TP-4	TP-6
Benzene	79.4	81.30	93.50	95.90	92.40	88.00	94.90	83.20	86.8	90.4	92.3
Toluene	18.9	15.90	6.10	3.89	6.98	9.74	3.79	15.10	12.0	8.74	7.41
Xylene	1.11	1.04	0.12	0.04	0.06	0.18	0.05	0.17	0.37	0.24	0.11
Indan + Indene		0.14	0.03	0.01	0.06	0.13	0.03	0.06	0.08	0.08	0.0
Ethyl benzene	0.52	0.40	0.09	0.05	0.06	0.18	0.05	0.17	0.11	0.10	0.08
Naphthalenes	--	--	--	--	--	--	--	--	0.46	0.28	0.10
Unidentified	0.07	1.22	0.03	0.10	0.44	1.28	0.79	1.17	0.18	0.16	0.0
Total	100.00	100.00	99.87	99.99	100.00	99.51	99.61	99.87	100.00	100.00	100.00

Table A-10, Part 3. ANALYSES OF COLD TRAP LIQUIDS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	TP-8	TP-10	TP-11	RT-1	RT-2	RT-3	PS-3	PS-5	PP-2	PP-4
Benzene	50.0	53.5	58.7	88.9	96.8	90.5	20.0	3.91	79.3	93.6
Toluene	36.4	32.1	33.4	8.14	2.53	6.1	55.5	14.04	15.4	4.98
Xylene	2.48	4.64	3.92	1.22	0.10	0.2	7.7	--	1.66	0.15
Indan + Indene	0.73	0.43	0.22	0.14	0.08	0.3	0.64	--	0.24	0.15
Ethyl benzene	1.34	2.03	1.23	--	0.03	0.08	3.81	--	0.39	0.04
Naphthalenes	0.37	1.17	0.60	0.24	0.08	2.19	6.59	82.46	0.52	0.20
Unidentified	8.68	6.13	1.93	1.36	0.38	0.63	5.76	--	2.49	0.88
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.41	100.00	100.00

Table A-10, Part 4. ANALYSES OF COLD TRAP LIQUIDS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	PP-5	PP-9	PP-11	PP-12	BC-1	BC-3	BC-7	BC-9	BC-11	BC-12	BC-13
Component						wt %					
Benzene	84.0	89.1	82.4	90.4	7.70	56.6	49.2	41.8	80.5	85.3	64.8
Toluene	13.4	9.56	15.0	7.77	60.50	30.5	34.7	39.5	13.8	10.5	27.6
Xylene	0.63	0.24	0.68	0.50	12.48	3.48	4.74	5.47	0.67	0.82	2.10
Indene & Indan	0.60	0.12	0.41	0.14	2.97	0.72	1.08	1.68	0.38	0.21	0.40
Ethyl benzene	0.14	0.05	0.16	0.11	7.19	2.52	3.25	3.84	0.59	0.41	1.14
Naphthalenes	0.11	0.06	0.54	0.10	3.21	1.26	1.03	1.37	0.75	0.26	0.94
Unidentified	1.12	0.87	0.81	0.98	5.95*	4.42	5.28	6.34	3.31	2.50	3.02
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Unidentified fraction 90% thiophene and derivatives of thiophene.

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Table A-10, Part 5. ANALYSES OF COLD TRAP LIQUIDS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	BC-16
Component	—wt%—
Benzene	21.60
Toluene	49.20
Xylene	6.17
Indene & Indan	1.90
Ethyl benzene	4.16
Naphthalene	13.09
Unidentified	3.88*
Total	100.00

---

* Unidentified fraction 90% thiophene and derivatives of thiophene.

Table A-10, Part 6. ANALYSES OF COLD TRAP LIQUIDS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	CT-4	CT-6	CT-8	CT-9	CT-10	CT-11
Component	wt %					
Benzene	93.60	92.90	88.00	81.20	96.90	94.40
Toluene	5.29	6.04	10.10	15.80	1.46	4.24
Xylenes	0.05	0.06	0.18	0.58	0.04	0.03
Indan + Indene	0.00	0.00	0.02	0.06	0.11	0.05
Ethyl benzene	0.04	0.07	0.13	0.39	0.11	0.11
Thiophenes	0.95	0.91	1.15	1.69	0.55	0.81
Unidentified	0.07	0.02	0.42	0.28	0.83	0.36
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table A-10, Part 7. ANALYSES OF COLD TRAP LIQUIDS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	**CT-12**	**CT-13**	**HR-1**	**HR-2**	**HR-3**	**HR-4**	**HR-5**
Component				wt %			
Benzene	96.20	93.50	76.00	76.90	58.80	95.30	97.40
Toluene	3.14	3.31	22.10	20.50	33.60	3.86	1.74
Xylenes	0.02	0.06	0.84	0.90	4.11	0.12	0.02
Indan + Indene	0.02	0.05	0.09	0.20	0.39	0.15	0.16
Ethyl benzene	0.06	0.07	0.22	0.20	1.15	0.03	0.01
Thiophenes	0.37	2.71	0.14	0.18	0.41	0.05	0.02
Unidentified	0.19	0.30	0.61	1.12	1.54	0.49	0.65
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-10, Part 8. ANALYSES OF COLD TRAP LIQUIDS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HH-2	HH-3	HH-5	HH-8	HH-9	HS-4	HS-5	HS-6	PSI-1
Component, wt %									
Benzene	91.5	90.7	89.5	90.5	90.3	50.0	92.8	91.7	96.8
Toluene	6.0	8.1	10.0	6.5	8.0	18.6	5.6	4.3	0.6
Xylene	0.5	0.1	0.2	0.4	0.1	1.3	0.1	0.1	Tr
Indene & Indan	0.5	0.2	Tr	0.2	0.1	3.1	0.1	0.3	0.1
Ethyl benzene	0.2	0.1	0.1	1.1	0.7	0.7	0.1	0.1	0.6
Naphthalenes	1.3	0.7	0.1	1.1	0.7	25.2	1.2	3.1	1.7
Unidentified	0	0.1	0.1	0.2	0.1	1.1	0.1	0.4	0.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A-11, Part 1. ANALYSES OF FUEL OIL FRACTION OF MAIN LIQUID PRODUCTS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	P-12	P-13	P-14	P-15	P-16	P-17	P-19	P-21	P-22	P-26	P-27	P-28
Ultimate Analysis, wt %												
Carbon	89.87	91.80	--	93.15	93.50	92.52	93.14	91.27	92.02	91.41	86.43	92.20
Hydrogen	6.13	6.15	--	5.99	6.02	5.89	5.97	6.07	5.81	5.32	5.57	5.73
Sulfur	0.17	0.14	0.13	0.11	0.10	0.12	0.11	0.14	0.14	0.03	0.06	0.12
Nitrogen	0.55	0.49	0.59	0.45	0.41	0.44	0.62	0.55	0.66	0.14	0.10	0.30
C/H Weight Ratio	14.65	14.92	--	15.56	15.53	15.70	15.61	15.04	15.84	17.20	15.52	16.09
CC Residue, wt %	4.20	4.30	5.00	3.50	5.60	5.60	6.90	8.80	11.70	10.30	3.60	10.30

Table A-11, Part 2. ANALYSES OF FUEL OIL FRACTION OF MAIN LIQUID PRODUCTS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	RC-1	RC-2	TP-1	TP-2	TP-3	TP-4	TP-5	TP-6	TP-8	TP-10	TP-11	RT-1	RT-2
Ultimate Analysis, wt %													
Carbon	85.00	93.38	92.35	91.16	91.23	91.86	87.14	91.21	**	85.21	91.44	**	92.70
Hydrogen	5.30	5.75	6.08	5.89	5.74	5.73	6.25	5.48	**	5.63	5.47	**	6.28
Sulfur	0.08	0.87	0.03	0.11	0.08	0.12	0.20	0.02	0.10	0.09	0.10	0.13	0.31
Nitrogen	0.03	0.79	0.20	0.31	0.18	0.10	0.56	0.63	0.15	0.18	0.15	0.38	0.63
C/H Weight Ratio	16.00	16.20	15.19	15.48	15.89	16.03	13.94	16.64	**	15.13	16.72	**	14.76
CC Residue, wt %	*	5.90	6.70	11.60	14.70	13.30	9.70	8.80	16.40	32.00	16.70	6.70	4.40

* Insufficient sample.
** In process.

Table A-11, Part 3. ANALYSES OF FUEL OIL FRACTION OF MAIN LIQUID PRODUCTS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	RT-3	PS-1	PS-5	PP-2	PP-4	PP-5	PP-9
Ultimate Analysis, wt %							
Carbon	88.27	87.09	83.58	85.78	--	90.31	91.99
Hydrogen	5.85	6.80	6.79	6.14	--	5.82	5.97
Sulfur	0.12	0.13	--	0.23	0.15	--	0.11
Nitrogen	0.43	0.16	--	0.15	0.09	--	0.66
Oxygen (by difference)	4.26	3.23	--	7.70	--	--	1.77
Ash	1.07	2.59	--	0	--	--	0
C/H Weight Ratio	15.09	12.81	12.31	13.97	--	15.52	15.32
CC Residue, wt %	3.8	13.5	18.1	20.9	8.3	13.2	6.19

Table A-11, Part 4. ANALYSES OF FUEL OIL FRACTION OF MAIN LIQUID PRODUCTS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	PP-11	PP-12	BC-1	BC-3	BC-7,9	BC-11, 12,13	SF-3
Ultimate Analysis, wt %							
Carbon	89.46	91.44	84.90	84.64	83.43	87.40	91.79
Hydrogen	5.77	6.04	5.48	5.98	5.80	5.63	6.32
Sulfur	--	--	--	--	--	--	0.01
Nitrogen	--	--	--	--	--	--	0.71
Oxygen (by difference)	--	--	--	--	--	--	0.07
Ash	--	--	--	--	--	1.1	1.10
C/H Weight Ratio	15.53	15.14	15.49	14.15	14.38	15.39	14.52
CC Residue, wt %	--	*	*	19.1	18.8	13.8	5.20

* Insufficient sample.

Table A-11, Part 5. ANALYSES OF FUEL OIL FRACTION OF MAIN LIQUID PRODUCTS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	CT-4	CT-6	CT-8	CT-9	CT-11	CT-12	CT-13
Ultimate Analysis, wt %							
Carbon	90.24	92.15	90.44	89.75	91.30	91.77	91.40
Hydrogen	5.98	5.93	5.68	5.72	5.77	5.83	5.68
Sulfur	0.82	0.75	1.02	0.93	0.77	0.56	0.66
Nitrogen	1.11	0.97	1.58	1.66	1.25	1.62	1.46
Oxygen (by difference)	1.85	0.00	0.58	1.94	0.71	0.22	0.40
Ash	0.40	0.20	0.70	0.00	0.20	0.00	0.40
C/H Weight Ratio	15.09	15.54	15.92	15.69	15.82	15.74	16.09
CC Residue, wt %	7.70	5.20	9.30	9.80	4.20	3.00	4.80

Table A-11, Part 6. ANALYSES OF FUEL OIL FRACTION OF MAIN LIQUID PRODUCTS FOR RUNS MADE DURING THE PERIOD APRIL 1, 1977, THROUGH MARCH 31, 1978

Run No.	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7
Ultimate Analysis, wt %							
Carbon	89.61	91.09	88.41	92.88	93.49	92.83	92.18
Hydrogen	5.81	5.84	6.03	6.00	5.98	5.64	5.66
Sulfur	0.17	0.12	0.10	0.13	0.19	0.52	0.34
Nitrogen	--	--	--	--	--	--	--
Oxygen (by difference)	--	--	--	--	--	--	--
Ash	0.50	0.50	--	0	0	0.10	0
C/H Weight Ratio	15.42	15.60	14.66	15.48	15.63	16.46	16.46
CC Residue, wt %	14.6	13.5	12.4	3.7	5.7	5.4	--

Table A-11, Part 7. ANALYSES OF FUEL OIL FRACTIONS FOR BENCH-SCALE UNIT RUNS MADE FROM APRIL 1, 1979, THROUGH MARCH 31, 1980

Run No.	HH-4	HH-5	HH-6	HH-7	HH-9	HH-10	HH-11,12	PL-1	CT-16
Ultimate Analysis, wt %									
Carbon	90.76	91.31	91.60	89.46	92.07	91.25	90.53	92.73	92.23
Hydrogen	5.80	6.06	6.05	5.77	5.77	5.88	6.00	5.81	5.96
Sulfur	0.10	0.42	0.26	0.17	0.17	1.43	0.23	0.10	0.08
Nitrogen	0.74	0.89	1.05	1.14	--	0.83	1.00	0.88	0.02
Oxygen (by difference)	2.00	0.92	0.74	1.86	--	0.51	0.51	0.48	1.71
Ash	0.60	0.40	0.30	1.60	0.20	0.10	1.73	0	0
C/H Weight Ratio	15.65	15.07	15.14	15.50	15.96	15.52	15.08	15.97	15.66
CC Residue, wt %	10.00	7.90	6.30	15.30	12.00	8.80	13.50	5.30	3.60

Table A-12. COMPOSITION OF 400° to 500°F BOILING RANGE LIQUID

Run No.	P-11	P-12	P-13	P-14	P-15	P-16	P-17	P-19	P-21	P-26	TP-5	TP-6	TP-8	TP-10
400° to 500° Fraction, wt % of Main Product Liquid	17.30	11.90	11.90	12.90	14.00	16.30	16.60	15.10	11.70	21.00	22.70	20.80	14.90	16.00
Composition, wt %														
Benzene	0.10	--	--	--	--	--	--	--	--	--	--	--	0.02	0.03
Toluene	0.22	--	--	--	--	--	--	--	--	--	--	--	0.05	0.07
Xylenes	0.63	--	--	--	--	--	--	--	--	--	--	--	0.26	0.20
Ethyl benzene Indene	2.19	1.88	0.85	0.56	0.50	0.71	0.70	1.03	0.89	1.21	0.93	0.17	2.57	5.03
Oxygenated Compounds														
Phenol	10.10	1.33	1.75	1.99	0.97	0.30	1.27	0.88	2.72	1.34	0.79	0.33	0.58	0.20
Cresols	4.27	6.39	5.34	3.29	0.67	0.08	0.10	0.50	4.49	1.04	0.42	0.37	5.70	2.84
Other	1.83	7.89	2.82	2.00	2.34	2.08	1.73	1.81	1.96	2.39	0.35	0.31	11.52	9.58
Benzothiophene	0.52	0.43	0.44	0.32	0.25	1.11	0.23	--	0.25	0.19	--	0.10	--	0.10
Nitrogen Compounds														
Pyridine & Substituted	0.93	--	--	--	--	--	--	--	--	--	--	--	1.50	1.52
Quinolines & Indols	4.29	4.25	6.04	4.98	5.50	5.38	4.98	9.78	4.60	2.96	2.44	1.98	2.40	2.82
Other	0.55	0.17	0.25	0.15	0.25	1.33	0.15	2.23	0.14	0.22	1.81	1.42	0.00	0.00
Naphthalenes & Tetralin	64.91	60.56	64.15	72.77	70.65	69.23	76.08	68.42	70.42	69.41	81.77	84.06	53.80	55.47
Biphenyls	6.12	7.24	8.77	8.85	9.98	10.58	7.83	9.68	9.15	9.04	8.50	6.30	14.60	9.39
Unidentified	0.30	5.15	6.36	1.07	0.43	0.61	0.39	0.07	0.84	1.56	0.15	3.00	4.50	7.80
Not Listed Above	3.04	4.71	3.23	4.02	8.46	8.59	6.54	5.60	4.94	10.64	2.84	1.96	2.50	4.95
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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APPENDIX B. PDU Data

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Table B-1. OPERATING CONDITIONS, COMPONENT BALANCES, AND CARBON DISTRIBUTIONS FOR PDU RUNS MADE BETWEEN APRIL 1, 1979 AND MARCH 31, 1980

Run No.	PDU-4	PDU-5	PDU-6	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-12	PDU-13
System Pressure, psig	1000	1000	1000	1000	1000	1000	1000	1500	1500	2000
Maximum Preheater Temp, °F	1225	1200	1120	1130	1190	1020	1000	1000	1010	960
Riser Inlet Temp, °F	1050	1105	1070	1050	1050	950	950	960	970	950
Lower Combustor Inlet Temp, °F	1000	960	870	960	820	820	850	730	900	900
Lower Combustor Outlet Temp, °F	1250	1300	1300	1400	1200	1150	1250	1210	1250	1210
Upper Combustor Outlet Temp, °F	1260	1180	1230	1275	1200	1220	1380	1320	1360	1400
Residence time, s	--	1.3	1.7	1.5	1.5	1.6	1.7	1.9	1.7	1.6
Solids Feed Rate	43.7	67.3	84.2	49.8	62.2	70.5	35.0	45.0	46.1	45.4
Run Length, min	25	24	30	60	26	50	45	25	30	40
Solids in Feed Gas, wt %	--	77.8	93.3	91.1	91.0	97.5	72.2	75.2	73.4	70.6
H_2/MAF Coal Wt Ratio	--	0.137	0.080	0.130	0.111	0.102	0.187	0.205	0.209	0.250
Balances, wt %										
Ash	96.9	115.0	100.0	89.4	94.4	108.1	85.5	79.8	92.2	95.3
Carbon	--	115.4	--	98.4	100.0	100.0	97.4	100.0	101.4	99.7
Hydrogen	--	85.1	--	97.7	93.9	90.9	107.0	108.5	94.3	107.3
Overall	--	101.2	--	98.1	93.7	94.5	100.7	99.2	99.3	100.8
Carbon Distribution, wt %										
Liquids	0.84	4.89	--	5.24	2.72	1.37	3.25	4.00	3.98	6.11
Carbon Oxides	--	12.72	--	12.46	10.05	7.16	15.18	19.69	14.47	12.92
Methane	--	7.70	--	8.19	6.62	2.52	9.50	10.29	10.08	11.15
Light Gases	--	6.09	--	5.34	5.44	2.52	5.00	11.48	5.26	5.09
Char	62.50	68.60	--	66.99	75.17	86.04	63.59	58.28	60.95	64.39

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Table B-2. PROXIMATE AND ULTIMATE ANALYSES OF FEED SOLIDS FOR PDU RUNS

Run No.	PDU-2	PDU-4	PDU-5	PDU-6	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-12	PDU-13
Proximate Analysis, wt %											
Moisture	12.2	12.7	15.4	15.3	15.4	10.8	12.2	8.8	13.3	12.7	0.6
Volatile Matter	36.8	36.0	35.0	35.2	34.8	33.9	34.7	39.2	35.1	35.2	40.6
Ash	10.5	9.2	9.3	9.3	9.3	10.3	9.8	9.6	9.4	8.4	11.6
Fixed Carbon	40.5	42.1	40.3	40.2	40.5	45.0	43.3	42.4	42.2	43.7	47.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis, wt % (dry basis)											
Ash	11.92	10.56	10.98	11.02	10.95	11.59	11.18	10.55	10.86	9.67	11.70
Carbon	59.70	61.10	61.30	71.30	71.30	63.00	63.20	61.30	62.10	63.10	59.90
Hydrogen	4.03	4.00	4.07	4.09	4.04	3.75	3.83	4.10	3.96	3.98	3.75
Sulfur	0.88	0.89	0.92	0.92	0.92	0.85	0.86	0.78	0.80	0.77	0.84
Nitrogen	0.96	0.96	0.96	1.00	0.92	0.99	0.97	0.90	1.02	0.91	0.80
Oxygen (diff)	22.51	22.54	21.77	21.67	21.87	19.82	19.96	22.37	21.26	21.57	23.01
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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Table B-3. PROXIMATE AND ULTIMATE ANALYSES OF SPENT SOLIDS FOR PDU RUNS

Run No.	PDU-2	PDU-4	PDU-5	PDU-6	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-12	PDU-13
Proximate Analysis, wt %											
Moisture	2.7	1.1	0.5	5.4	1.0	0.5	1.9	1.8	4.1	1.1	0.9
Volatile Matter	20.3	16.9	18.1	19.6	15.5	18.1	21.8	15.5	19.1	17.1	13.6
Ash	18.4	18.5	18.0	15.7	16.5	15.8	15.0	15.5	14.4	15.7	19.2
Fixed Carbon	58.6	63.5	63.4	61.3	67.0	65.6	61.3	67.2	62.4	66.1	66.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis, wt % (dry basis)											
Ash	18.90	18.71	18.10	16.60	16.64	15.92	15.33	15.83	15.00	15.89	19.33
Carbon	68.90	69.80	70.50	71.30	72.70	71.90	69.90	73.60	71.10	72.70	71.80
Hydrogen	3.15	2.79	2.91	2.90	2.88	3.07	3.18	2.88	3.05	2.91	2.70
Sulfur	0.81	0.79	1.17	0.77	0.73	0.69	0.75	0.62	0.56	0.50	0.71
Nitrogen	1.08	0.90	0.98	0.94	0.99	1.03	1.04	0.86	1.07	0.91	0.80
Oxygen (diff)	7.16	7.01	6.34	7.49	6.06	7.39	9.80	6.21	9.22	7.09	4.66
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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Table B-4. AVERAGE MAKE GAS COMPOSITIONS FOR PDU RUNS

Run No.	PDU-5	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-12	PDU-13
Component, mol % (wet basis)								
CO	5.60	3.40	5.27	3.40	4.08	4.89	5.22	3.37
CO_2	4.43	3.02	2.20	2.66	1.86	1.81	2.34	0.90
Hydrogen	62.79	62.54	64.67	68.84	70.25	75.87	69.45	78.93
Methane	6.10	4.21	4.92	2.13	3.72	3.50	4.36	3.68
Ethane	1.14	0.81	0.90	0.47	0.76	0.90	0.84	0.67
Propane	0.32	0.17	0.33	0.13	0.10	0.14	0.16	0.07
Butane	0.15	0.04	0.07	0.03	0.01	0.04	0.02	Tr
Ethylene	0.01	0.05	0.17	0.11	0.01	0.05	0.04	0.02
Propylene	0.20	0.07	0.11	0.07	0.02	0.04	0.01	0.02
Acetylene	0.02	0.02	0.07	Tr	Tr	0.00	0.00	Tr
Benzene	0.08	0.08	0.02	0.03	0.04	0.10	0.11	0.02
Argon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	8.12	7.19	6.46	8.01	5.10	3.52	4.09	2.55
Steam	11.04	18.40	14.81	14.12	14.05	9.14	13.36	9.77
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table B-5. MASS BALANCES AND PRODUCT DISTRIBUTIONS FOR PDU RUNS

Run No.	PDU-4	PDU-5	PDU-6	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-12	PDU-13
Component, lb										
Feed Solids	18.2	24.93	52.00	49.75	30.50	58.73	25.50	18.75	23.05	30.25
Feed Hydrogen	--	2.57	2.45	5.65	2.66	4.66	3.89	2.97	3.80	6.65
Feed Nitrogen	--	3.58	3.80	7.69	3.02	6.61	3.76	1.98	2.53	2.80
Feed Oxygen	--	0.96	1.31	2.48	1.26	2.29	2.18	1.25	2.04	3.13
Total Mass In	--	32.04	55.76	65.57	32.44	72.29	35.33	24.95	31.42	42.85
Spent Char/Solids	8.79	14.79	25.20	25.00	18.78	41.43	13.50	9.79	11.41	17.50
Liquids	1.57	3.77	9.42	13.72	4.69	7.96	7.02	3.50	6.12	7.97
Light Liquids	0.00	0.00	--	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gases	--	13.87	--	25.62	11.62	18.92	15.06	11.45	13.60	17.69
Total Mass Out	--	32.43	--	64.34	35.09	68.31	35.58	24.74	31.21	43.16
Distribution of Products, g										
Hydrogen	--	1.99	--	4.82	2.18	4.08	3.72	3.07	3.10	6.26
Nitrogen	--	3.58	--	7.69	3.02	6.61	3.76	1.98	2.53	2.80
Methane	--	1.54	--	2.58	1.32	1.01	1.57	1.13	1.55	2.32
Light Gases (C_2-C_4)	--	1.11	--	1.56	0.99	0.90	0.76	0.62	0.79	0.99
Carbon Oxides	--	5.54	--	8.72	4.08	6.25	5.16	4.35	5.52	5.27
Hydrocarbon Liquid										
Main Liquid Product (MLP)	0.12	0.68	0.92	1.18	0.40	0.42	0.33	0.17	0.34	1.04
Freeze-Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Make Gas	--	0.11	--	0.23	0.03	0.07	0.09	0.20	0.19	0.13
Gases (MLP Work-Up)										
Char/Spent Solids	8.79	14.79	25.20	25.00	18.78	41.43	13.50	9.79	11.41	17.50
Water (by diff)	--	3.09	--	12.56	4.28	7.54	6.69	3.43	5.78	6.85
Total Mass Out	--	32.43	--	64.34	35.09	68.31	35.58	24.74	31.21	43.16

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Table B-6. ANALYSES OF MAIN LIQUID PRODUCTS FROM PDU RUNS

Run No.	PDU-2	PDU-4	PDU-5	PDU-6	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-12	PDU-13
Specific Gravity	1.047	1.042	1.016	1.009	1.006	1.032	1.027	1.036	1.040	1.044	1.037
IBP, °F	146	*	148	140	139	148	136	141	172	150	149
Ultimate Analysis, wt %											
C	78.87	83.32	82.25	81.79	82.97	78.30	81.32	83.39	83.04	83.13	87.42
H	7.66	7.46	7.72	7.57	7.25	7.12	7.96	7.49	7.15	7.26	7.03
S	0.55	0.82	1.06	0.62	0.48	1.17	1.69	1.69	1.83	0.10	0.89
N	0.68	1.00	0.99	0.87	0.92	0.99	0.05	0.58	0.77	0.17	0.55
O (diff)	12.24	7.40	7.88	9.15	8.38	9.02	8.98	6.85	7.21	9.34	4.11
Ash	0.00	0.00	0.10	0.00	0.00	3.40	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
C/H wt Ratio	10.29	11.03	10.65	10.80	11.44	11.00	10.22	11.13	11.61	11.45	12.44
Fraction, wt %											
C_5-400°F	57.5	*	57.9	56.2	56.9	27.7	39.9	49.5	38.3	42.3	47.0
400°F	42.5	*	42.1	43.8	43.1	72.3	60.1	50.5	61.7	57.7	53.0

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* Insufficient sample.

Table B-7. ANALYSES OF GASOLINE FRACTIONS OF MAIN LIQUID PRODUCTS FROM PDU RUNS

Run No.	PDU-2	PDU-5	PDU-6	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-12	PDU-13
Component, wt %										
Benzene	0.23	1.53	2.80	8.33	1.10	0.61	3.10	1.98	6.52	15.20
Toluene	0.89	5.90	7.57	13.00	4.41	2.91	8.38	5.55	7.45	16.30
Ethyl Benzene	0.41	1.96	1.88	2.42	1.60	1.19	1.08	1.19	1.88	1.59
Xylenes	2.39	8.77	8.02	8.79	5.98	4.30	6.32	5.93	6.14	5.41
C_4 Aromatics	4.20	8.23	7.13	5.45	7.24	6.88	4.18	5.09	4.93	2.59
Indan	4.74	6.32	4.71	4.98	6.33	5.06	5.53	5.07	4.83	4.53
Indene	1.04	3.00	2.92	2.89	2.52	1.95	2.91	3.06	1.32	0.72
Naphthalenes	9.74	6.45	5.25	7.48	4.61	3.90	12.21	7.89	9.56	14.12
Phenol	27.40	23.30	23.20	19.90	24.60	22.50	23.40	25.40	24.00	19.50
Cresols	34.82	24.32	24.73	18.63	26.77	31.90	20.09	26.45	21.87	11.45
C_8 Phenols	10.53	5.12	5.57	3.48	8.08	10.90	8.44	6.21	4.55	5.39
Unidentified	3.61	5.10	6.22	4.65	6.76	7.90	4.36	6.18	6.99	3.20
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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Table B-8. ANALYSES OF FUEL OIL FRACTIONS OF MAIN LIQUID PRODUCTS FROM PDU RUNS

Run No.	PDU-2	PDU-5	PDU-6	PDU-7	PDU-8	PDU-9	PDU-10	PDU-11	PDU-13
Ultimate Analysis, wt %									
C	83.33	86.04	86.08	87.51	83.52	83.78	85.85	85.17	89.74
H	7.06	6.67	7.27	7.21	6.96	7.83	6.99	7.14	6.37
S	0.37	0.70	0.55	0.46	0.55	0.96	1.14	0.76	0.48
N	1.20	1.27	1.23	1.22	0.20	0.82	0.00	0.75	0.42
O	7.44	5.32	4.87	3.60	7.57	6.61	6.02	6.18	2.99
Ash	0.60	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.00
C/H Wt Ratio	11.81	12.90	11.85	12.13	12.01	10.71	12.27	11.92	14.09
CC Residue, wt %	16.0	13.0	7.5	4.9	11.0	9.0	11.0	9.1	9.4

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Table B-9. SUMMARY OF RUNS MADE FROM AUGUST 1, 1979, TRHOUGH APRIL 30, 1980

Run/Date	Objective	Results
PDU-1/8-10-79	Test operation of PDU at 1000 psig system pressure; general shakedown	Successful ignition of combustor obtained. Partial plug formed after 10 min. which caused system pressure drop to become erratic.
PDU-2/8-151-79	Repeat of PDU-1	Numerous mechanical problems; warm-up nitrogen contaminated with compressor oil, pressure regulators malfunctioned due to presence of compressor oil.
PDU-3/9-5-79	Repeat of PDU-1	Run aborted because of numerous mechnical problems.
PDU-4/9-27-79	Repeat of PDU-1	Successful ignition of combustor obtained, temperature control poor due to fluctuations in solids feed rate.
PDU-5/10-12-79	Operate the PDU at 1000 psig system outlet pressure and 1400°F to test modification of feeder.	Achieved solids feed rate of 50 lb/hr; feed exhausted at shutdown.
PDU-6/11-1-79	Operate the PDU at 1000 psig system outlet pressure and 1500°F.	Achieved solids feed rate of 88 lb/hr with maximum temperature of 1350°F. Voluntary shutdown after 60 min. of operation.
PDU-7/11-12-79	Operate at 1000 psig system outlet pressure and 1400°F with North Dakota lignite.	Operated successfully for 60 min; temperature 18 inches above lower combustor maintained at 1400°F, shutdown voluntary.

Table B-9, Part 2. SUMMARY OF RUNS MADE FROM AUGUST 1, 1979, THROUGH APRIL 30, 1980

Run/Date	Objective	Results
PDU-8/12-10/79	Operate at 1000 psig system outlet pressure using both combustors and a mixture of 50 mole percent oxygen in nitrogen to reduce the risk of damage to the combustors.	Both combustors operated for 30 minutes operation was shut down when system showed signs of plugging.
PDU-9/2-15-80	Operate the PDU at 1000 psig with North Dakota lignite and hydrogen-to-MAF coal ratio of 0.3 and a maximum temperature of 1400°F.	Operated 50 min. using both combustors; voluntary shutdown.
PDU-10/2-22-80	Replication of PDU-9 at higher temperature.	Operated 45 minutes using both combustors; maximum temperature of 1400°F; voluntary shutdown.
PDU-11/3-5-80	Operate the PDU at 1500 psig system outlet pressure and a hydrogen-to-MAF coal ratio of 0.3 and a maximum temperature of 1400°F.	Partially successful; operation unstable due to partial plugs formed from tars.
PDU-12/3-20-80	Replication of PDU-11	Operated with both combustors for 30 min. Run terminated when symptoms of partial plugs surfaced.
PDU-13/4-11-80	Operate the PDU at 2000 psig system outlet pressure and a hydrogen-to-MAF coal ratio of 0.3 and a maximum temperature of 1400°F.	Operated 40 minutes using both combustors; shutdown voluntary.

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