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INSTITUTE OF GAS TECHNOLOGY

MASTER

STATUS OF THE PEATGAS™ PROCESS

by

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STATUS OF THE PEATGAS PROCESS

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Institute of Gas Technology

INTRODUCTION

The United States has the largest peat resources in the world, after Russia. The energy contained in the U.S. peat resources is estimated[1] to be about 1440 quads. In the contigous 48 states the peat deposits are generally located in areas with no significant resources of other fossil fuels. Therefore, for the peat-rich regions in particular, and for the nation as a whole, peat represents a very important energy resource.

Peat has been extensively used in Europe and Russia for years as a source of energy. Russia alone has 76 electricity generation plants fueled by peat. Some of these plants are as large as 730 MW. Therefore, Russia has been harvesting peat commercially on large scales. In the North American continent, even though the techniques of harvesting peat, for horticultural purposes, are the same as those used in Europe and Russia, the scale of operation is much smaller. Experimental efforts are now underway in the U.S. by the First Colony Farms,[2] in North Carolina, with the objective of harvesting peat on a large scale. The U.S. Department of Energy (DOE) is planning to fund[3] efforts in this area.

Peat deposits in the U.S. occur generally at the ground surface, with very little or no overburden. These deposits have an average depth of about 7 feet and a maximum depth of only about 25 feet. Therefore, peat harvesting has no significant problem of overburden, and land reclamation is easy. Currently, most of the peatland (over 52 million acres) is non-productive. After harvesting the peat, the land could be used for crop and tree production, wildlife habitats, and lakes and ponds for fish production. Reclamation efforts in Europe[4] as well as in North America[5] have been very successful. Therefore, on an overall basis, large-scale utilization of peat should have a positive impact on the environment as well as on the socio-economic system.

In July 1976, the Institute of Gas Technology started working on a peat gasification program jointly funded by the U.S. Energy Research and Development Administration (now the U.S. Department of Energy) and the Minnesota Gas Company. The objective of this program is to experimentally obtain gasification data with Minnesota peat in laboratory- and process development unit- (PDU) scale equipment and to evaluate the economics of converting Minnesota peat to SNG. In September 1978, the program was modified to include gasification tests with peats from Maine and North Carolina.

The peat gasification results obtained with Minnesota reed sedge peat in the laboratory-scale equipment have been reported[6,7] previously. The PEATGAS™* Process concept for converting peat to SNG has also been presented previously.[6,7] The PEATGAS reactor concept incorporates single-stage short-residence-time hydrogasification in dilute-phase cocurrent contacting, followed by a fluidized-bed char gasification with steam and oxygen, as shown in Figure 1.

This paper presents some of the results of the PDU-scale hydrogasification and char gasification tests with Minnesota peat, quantitative kinetic descriptions for the gasification of Minnesota peat, and a preliminary process design for converting Minnesota peat to 250 X 10^9 Btu/day of SNG by the PEATGAS Process.

PDU-SCALE HYDROGASIFICATION TESTS

After completing laboratory-scale hydrogasification tests, PDU-scale tests were initiated in August 1977 with Minnesota peat. The tests with this peat are now essentially complete and work has been initiated with North Carolina peat. The primary objective of conducting PDU-scale tests was to determine the effects of initial scale-up from the laboratory-scale equipment. Therefore, the gas-solids contacting in both the laboratory- and PDU-scale reactors was cocurrent and in dilute phase. The hydrogasification PDU represents a scale-up of about 250 times the laboratory-scale hydrogasifier. The tests in the laboratory-scale equipment were conducted with hydrogen and/or helium, whereas the tests in the PDU were conducted with hydrogen, steam-hydrogen, and synthesis gas. The PDU test results are in very good agreement with the results obtained in the laboratory-scale equipment.

Equipment

A block flow diagram of the test equipment constructed for this study is shown in Figure 2. The equipment is designed to operate at temperatures and pressures as high as 1600°F and 1000 psig, respectively. The main component of the equipment is a helically coiled dilute-phase transport reactor made from 160 feet of 1-inch Schedule-160 stainless-steel pipe. The coil is about 15 inches in diameter and has a vertical height of about 10.5 feet. The reactor is heated by a set of two radiative heating elements. Five thermocouples are used for monitoring the temperature profile in the reactor.

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* The Institute of Gas Technology offers PEATGAS research and development, engineering, technical, and educational services relating to the PEATGAS Process.

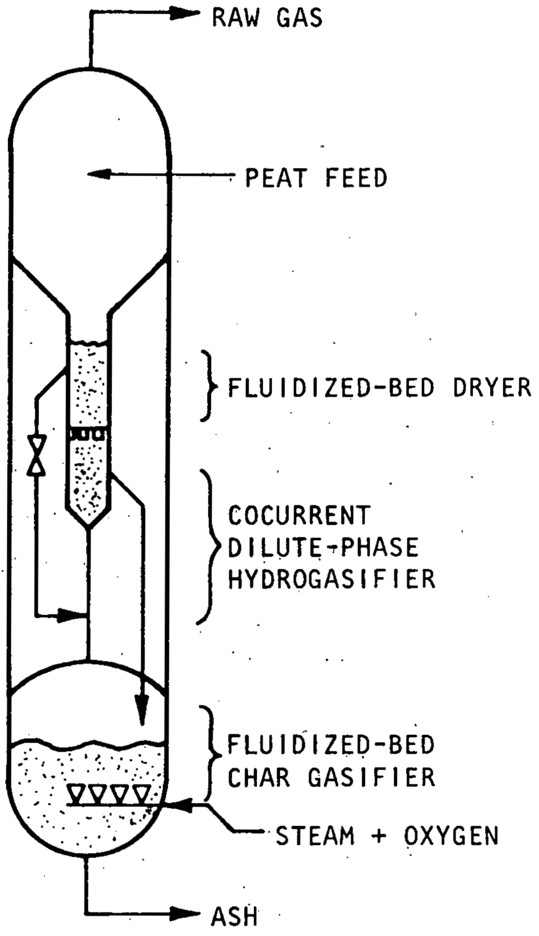

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Figure 1. SCHEMATIC DIAGRAM OF THE PEATGAS REACTOR

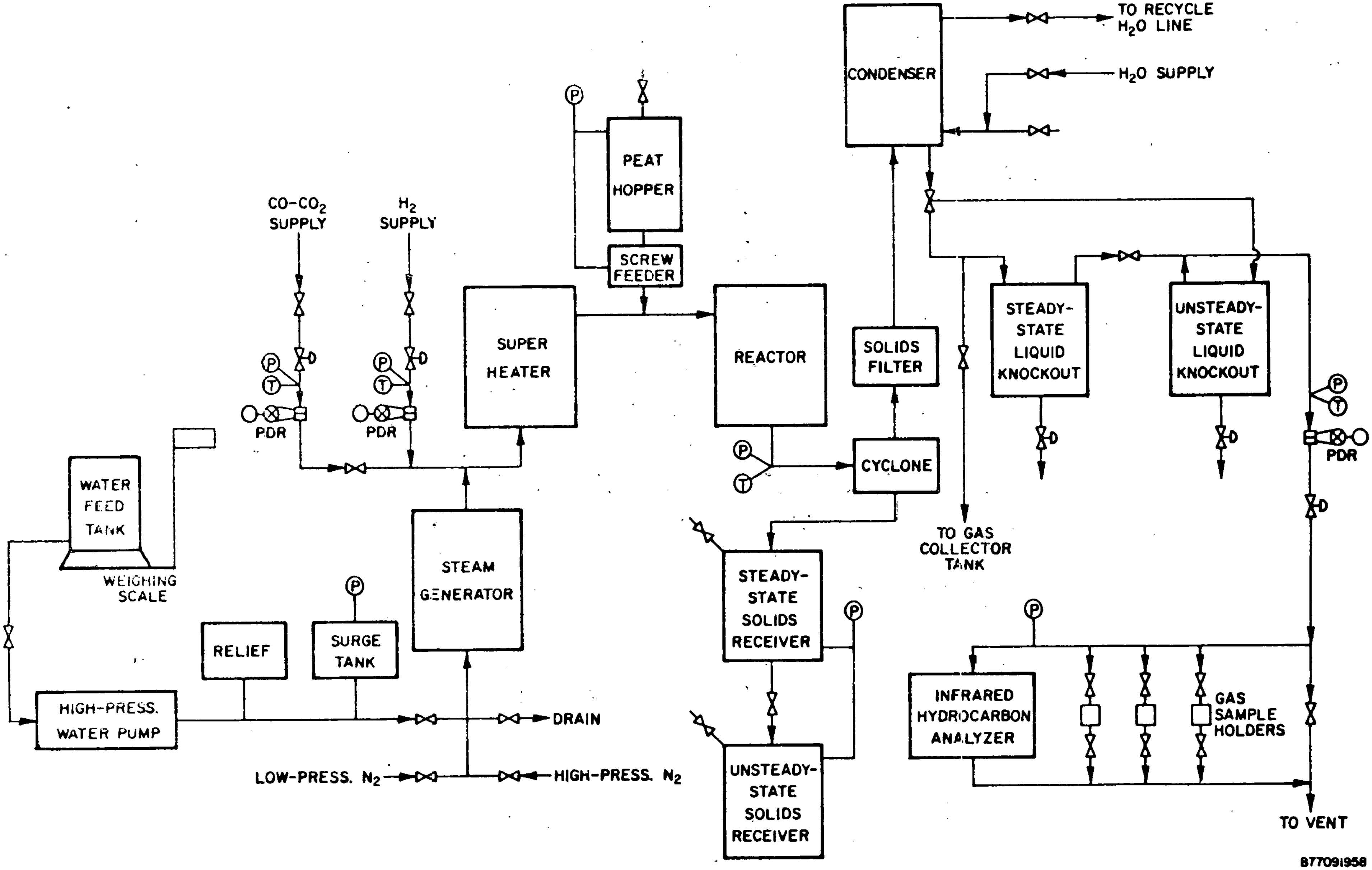

Figure 2. BLOCK FLOW DIAGRAM FOR THE LIFT-LINE REACTOR TEST EQUIPMENT

All the feed gases, after mixing, go through a superheater before entraining the solids and entering the reactor. Peat is fed by a screw feeder into a transfer line, where it is entrained by the superheated feed gases, and the mixture flows through the reactor.

Downstream of the reactor, product gases and peat char flow through a cyclone where most of the char is separated from the gases and flows down to the bottom receiver during the nonsteady-state period and to the top receiver during the steady state. Downstream of the cyclone, the product gas flows through the solids filter, then through the condenser and the knockout pots. An on-line infrared analyzer is used to measure the hydrocarbon content of the product gas and to help identify the steady-state period. Gas is also collected in gas-sample holders to establish average gas composition over a predetermined time period.

Results and Discussion

The typical proximate and ultimate analyses of the Minnesota peat used in the 27 tests conducted with this peat in the current study, and the operating ranges covered in the PDU gasifiers are shown in Tables 1 and 2, respectively.

Figure 3 shows the qualitative model developed for the initial hydrogasification of peat. It shows that the products of primary devolatilization, due to the application of heat alone, consist of light hydrocarbon gases (primarily methane and ethane plus ethylene), carbon oxides (carbon monoxide plus carbon dioxide), hydrocarbon liquids (C_3 and higher), water, and active char, which contains base carbon (the non-volatile carbon). The presence of hydrogen during devolatilization leads to several secondary hydrogenation reactions which increase the yields of light hydrocarbon gases and benzene and decrease the yields of oils and char. By analogy with the behavior of bituminous coals, it is assumed that in the presence of hydrogen, even though the product distribution may differ, the quantity of volatile matter evolved remains the same as in an inert atmosphere. The quantitative details of the hydrogasification model were presented[8] at the recent ACS meeting in Miami. Some of the highlights are presented here.

Table 1. TYPICAL ANALYSES OF THE MINNESOTA PEAT USED IN THE HYDROGASIFICATION STUDIES

Proximate Analysis, wt %	Process Development Unit
Moisture	4.8
Volatile Matter	57.5
Fixed Carbon	22.8
Ash	14.9
Total	100.0
Ultimate Analysis, wt % (dry)	
Carbon	49.20
Hydrogen	4.98
Nitrogen	2.20
Oxygen	27.73
Sulfur	0.21
Ash	15.68
Total	100.00
Average Feed Peat Particle Size, inch	0.011

Table 2. RANGE OF OPERATING CONDITIONS USED FOR PEAT HYDROGASIFICATION TESTS

	Process Development Unit
Peat Feed Rate, lb/hr	5-12.5
Feed Gases	H_2, H_2-H_2O, Synthesis Gas*
Hydrogen Partial Pressure, atm	4.3-36
Maximum Temperature, °F	1000-1500
Gas Flow Rate, SCF/hr	400-1030
Residence Time, sec	3-22

*Component	CO	CO_2	H_2	CH_4	H_2O
Mole %	13.3	19.3	28.2	0.9	38.3

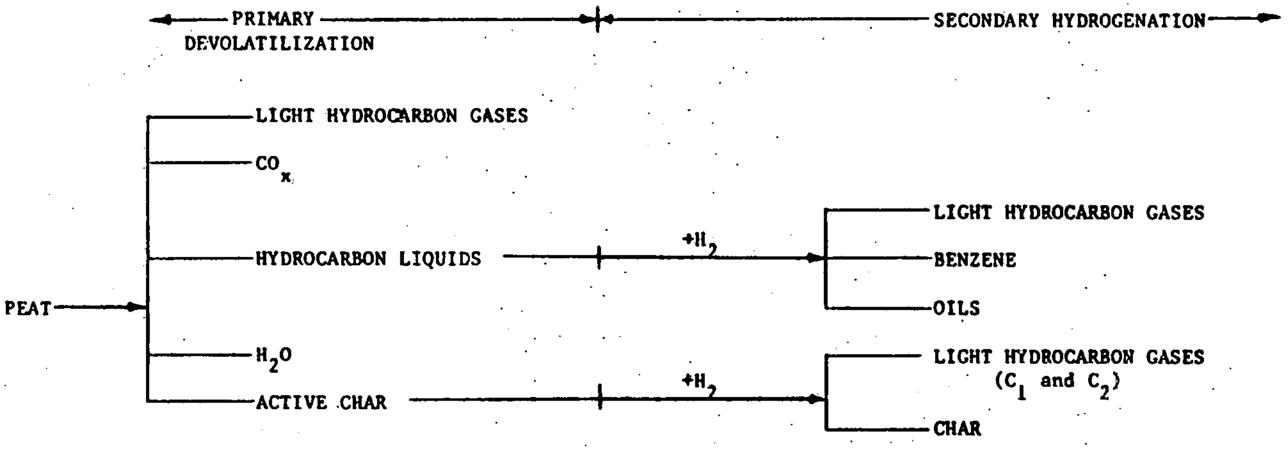

Figure 3. QUALITATIVE MODEL FOR INITIAL PEAT HYDROGASIFICATION

The results show that the yield of light hydrocarbon gases (C_1 and C_2) during primary devolatilization at temperatures above 1000°F is only about 1% to 4% of the feed carbon in peat, which is comparable with the values reported for lignites and higher ranked coals. The ultimate yield of hydrocarbon liquids, including C_3, is achieved at temperatures above 1000°F. Upon completion of primary devolatilization about 35% of the feed carbon is present in these hydrocarbon liquids. The limiting yield of active char, which contains the nonvolatile carbon, is about 48% of the total feed carbon in peat and is achieved at temperatures above 1300°F.

In the presence of hydrogen, the major secondary hydrogenation reactions involve the conversion of hydrocarbon liquids and nonvolatile carbon in the active char to light hydrocarbon gases. In the PDU tests, the yield of light hydrocarbon gases from hydrogenation of hydrocarbon liquids at temperatures above 1350°F averaged about 20% of the feed carbon (about 57% of the total carbon in the hydrocarbon liquids) with no evidence of a hydrogen pressure effect over the 4 to 70-atmosphere range. The effect of temperature on the hydrogenation of hydrocarbon liquids is shown in Figure 4. The apparently rapid change between 1200° and 1400°F indicates a very high energy of activation and implies this reaction is complete within a couple of seconds at 1400°F. It is the unique feature of peat that the amount of light hydrocarbon gases produced from the secondary hydrogenation liquids is from 5 to 10 times as much as that produced during primary devolatilization. In the case of other coals,[9] the ratio is about 1.

During secondary hydrogenation, light hydrocarbon gases are also formed by the additional conversion of nonvolatile carbon (referred to as base carbon) which would, in an inert atmosphere, completely go to char; in hydrogen, however, by competing paths, this base carbon can go to light hydrocarbon gases or to char. The product of this char-hydrogen reaction has been referred to as the rapid-rate methane.[10]

The ultimate yield of hydrocarbon gases by the rapid-rate reaction, as with the bituminous and lignite coals, is also hydrogen-pressure-dependent. The rate of its formation also appears to be dependent on hydrogen pressure. The limiting rapid-rate hydrocarbon yield, based on runs at sufficiently high temperatures, is shown in Figure 5.

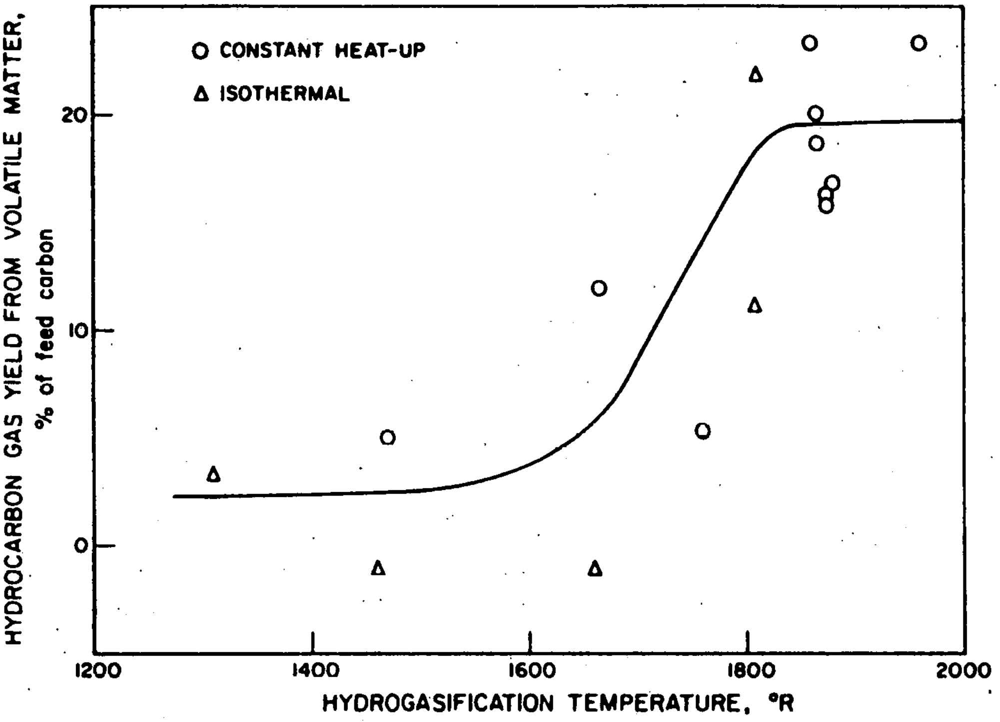

Figure 4. HYDROCARBON PRODUCTION IN HYDROGEN

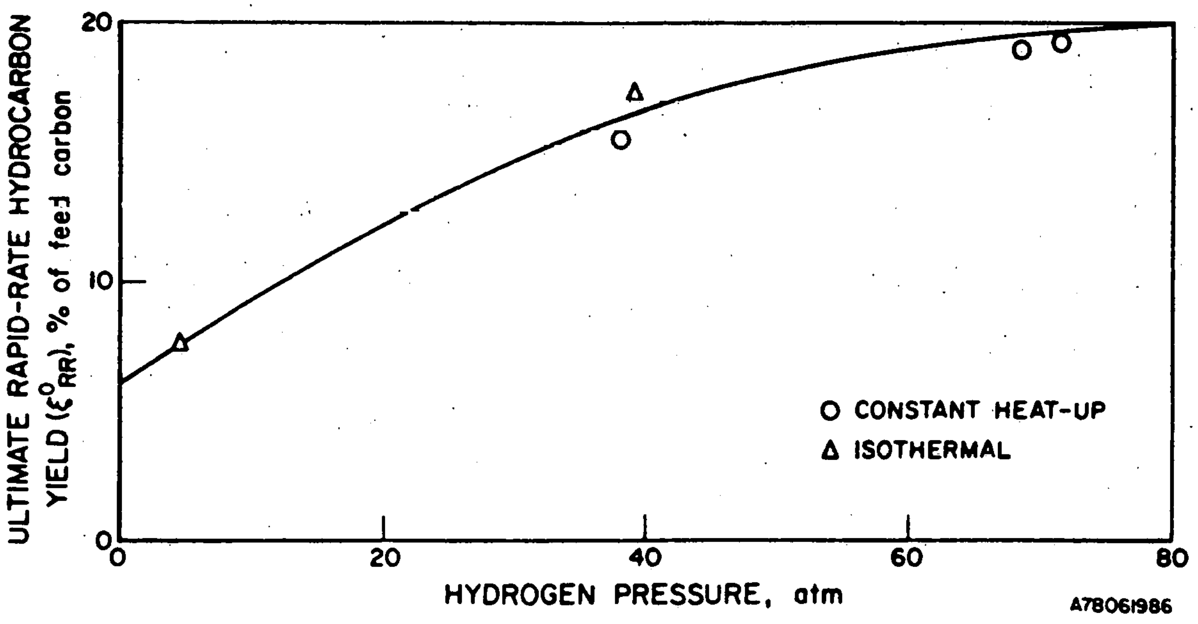

Figure 5. EFFECT OF HYDROGEN PRESSURE ON THE ULTIMATE RAPID-RATE HYDROCARBON GAS YIELDS ABOVE 1300°F

A mathematical kinetic model has been established for the laboratory and PDU data to predict product distribution for peat gasification. A comparison of the calculated yields with the measured values of light hydrocarbons is shown in Figure 6. Except for the lowest point, the temperatures are sufficiently high that the range of yields is primarily due to variation in hydrogen partial pressure and its effect on ultimate rapid-rate hydrocarbon gas yield.

An additional reaction that can be followed in the PDU is the formation of benzene from the primary liquid products. The ultimate benzene production as a function of the hydrogen partial pressure is shown in Figure 7. It is based on the assumption that above 1400°F this reaction is complete. Where the temperature is nonuniform, an effective kinetic temperature based on an activation energy of 60,000 Btu/mole and a first-order rate law was used. An estimate of the effect of temperature on benzene yield is presented in Figure 8.

PDU-SCALE CHAR GASIFICATION TESTS

The results of laboratory-scale gasification tests conducted in a thermobalance with char from Minnesota peat have been reported previously.[7,11] The thermobalance tests were conducted with samples of a few grams. Similar tests have been successfully used[12] for developing differential kinetic equations for coal chars.

These kinetic equations are useful in developing kinetic models for char gasification in integral reactors. The model for the integral reactors would vary depending upon the reactor system. Since the PEATGAS reactor incorporates a fluidized-bed char gasifier, the PDU-scale tests were conducted in a fluidized-bed using steam and oxygen. The tests with Minnesota peat char have been completed, and tests have been initiated with char from North Carolina peat. Subsequently, tests will be conducted with char from Maine peat. In addition to obtaining kinetic data, the PDU tests were also used to obtain sintering related information.

Equipment

The equipment used for the char gasification tests was the same used previously[13] for gasification tests with coal chars. A cross-sectional view of the reactor used in the test program is shown in Figure 9. The upper section of the reactor was expanded to a diameter of 16 inches to minimize

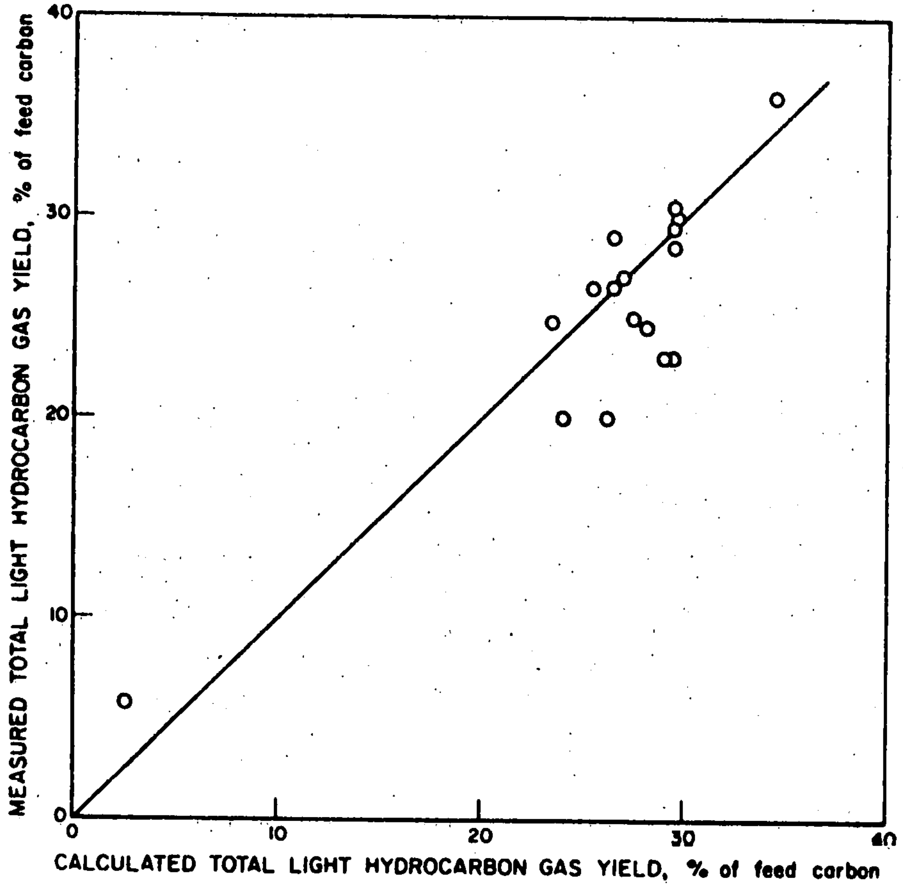

Figure 6. COMPARISON OF EXPERIMENTAL AND CALCULATED LIGHT HYDROCARBON GAS YIELDS FROM THE 0.8-INCH COILED-TUBE REACTOR STUDIES

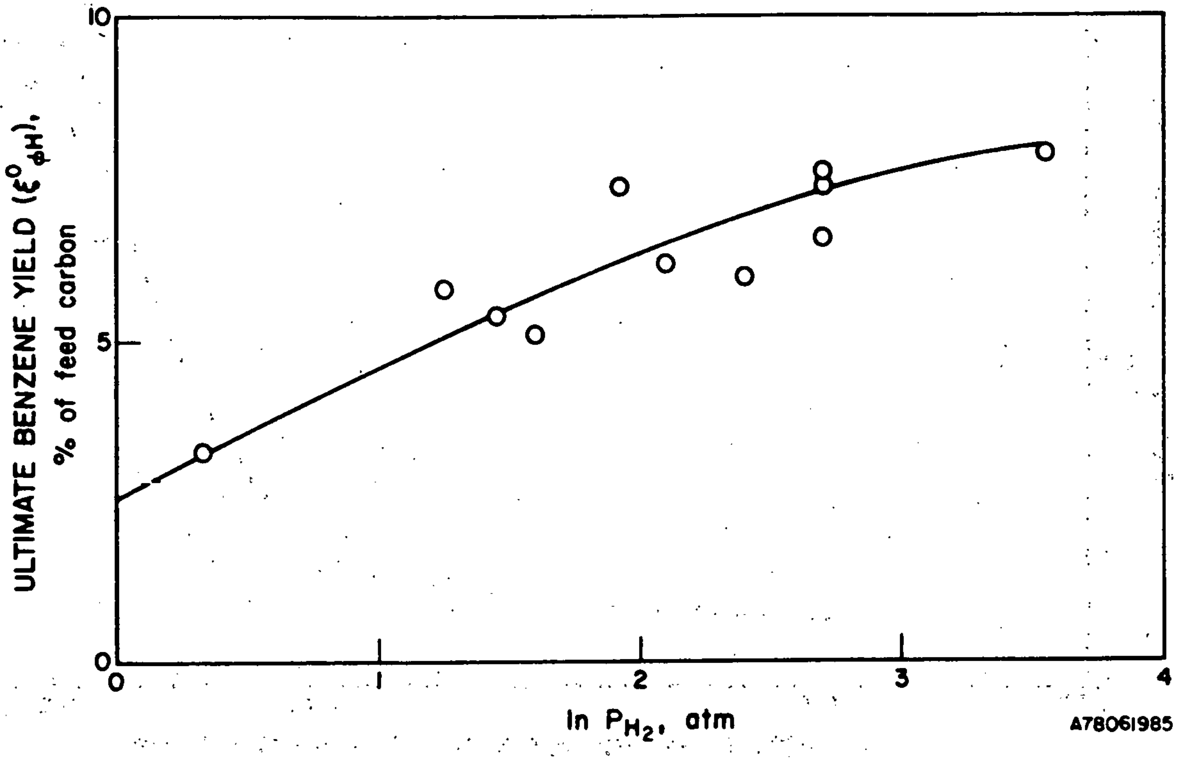

Figure 7. EFFECT OF HYDROGEN PARTIAL PRESSURE ON THE ULTIMATE BENZENE YIELD ABOVE 1300°F

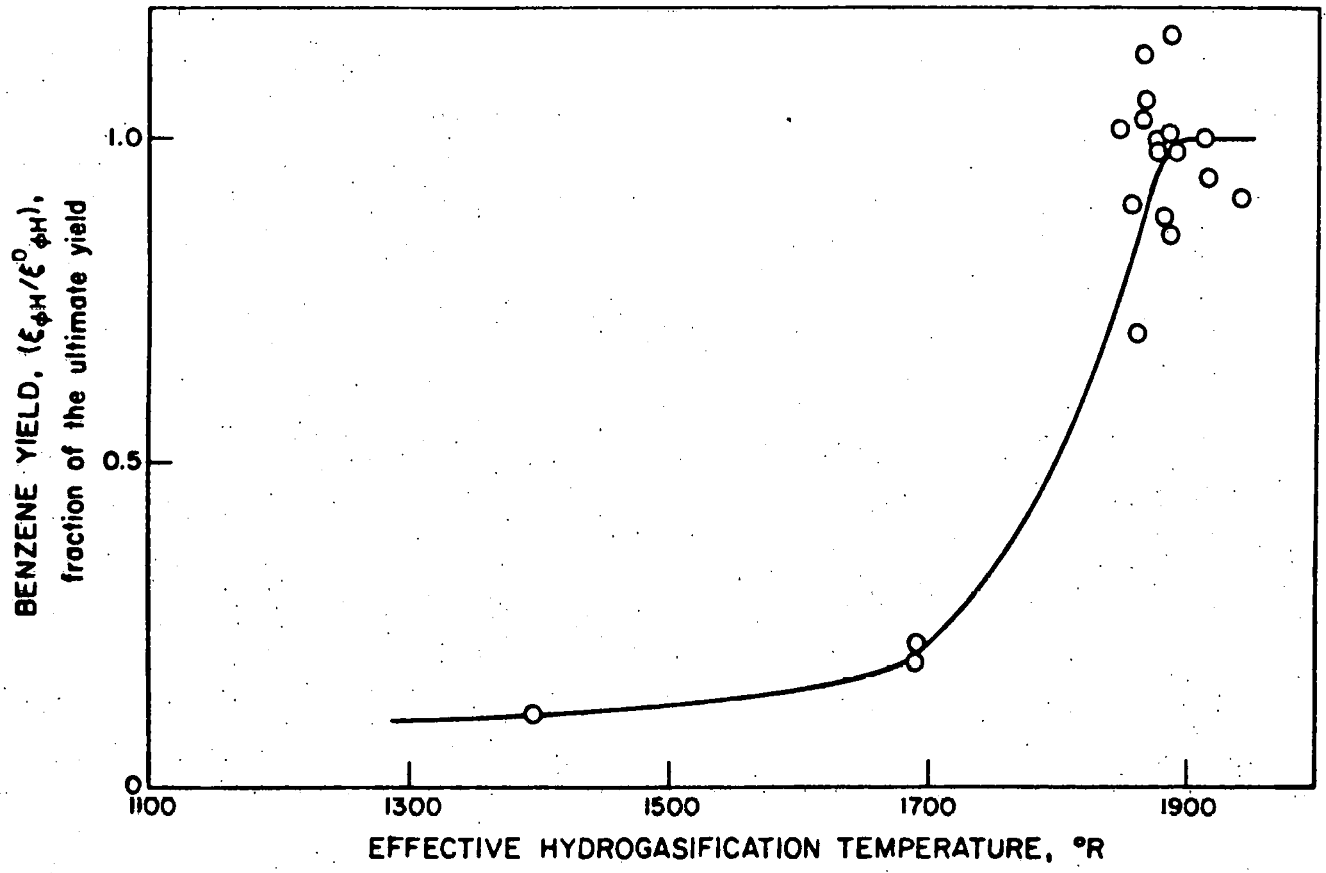

Figure 8. EFFECT OF HYDROGASIFICATION TEMPERATURE ON BENZENE YIELD

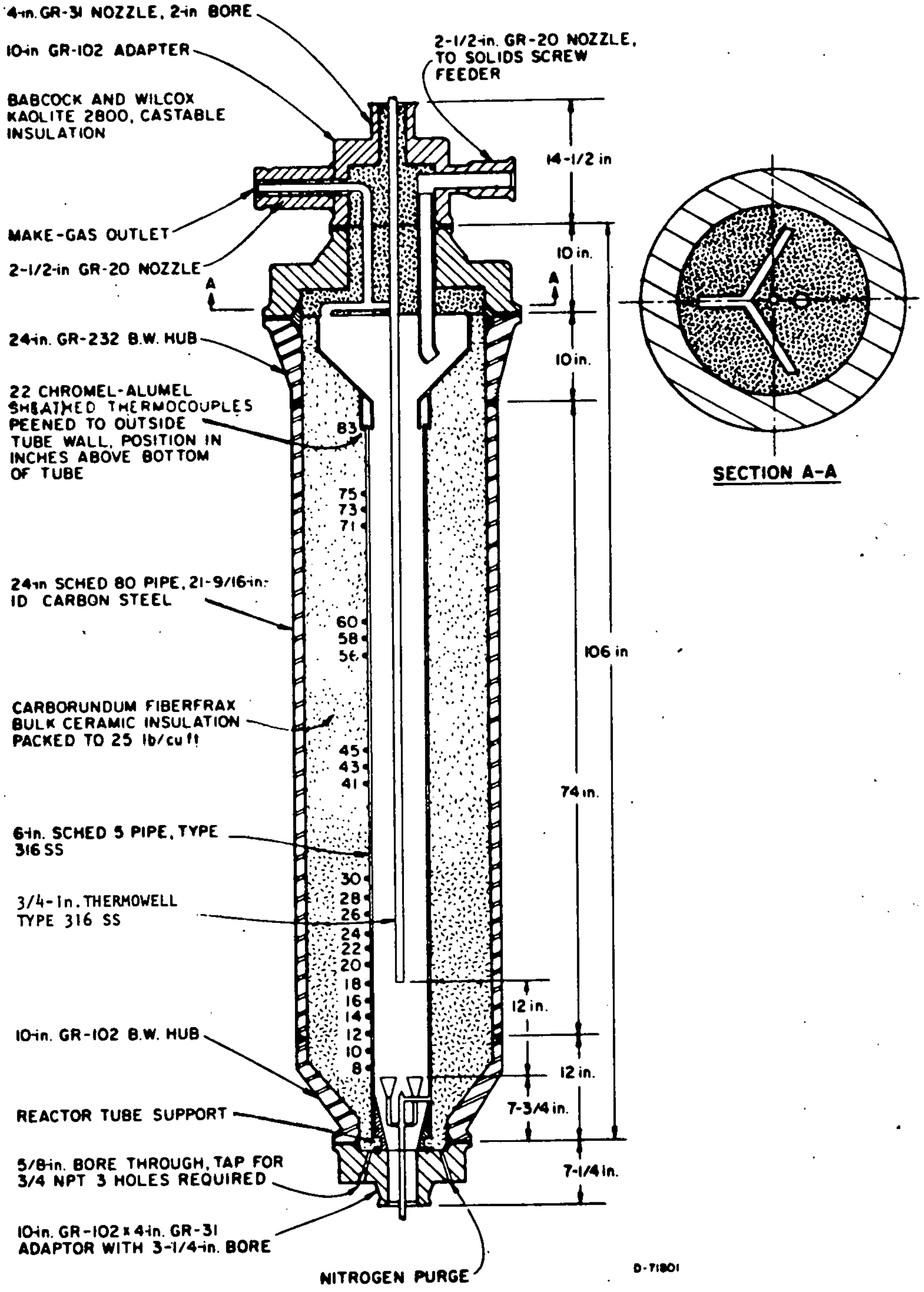

Figure 9. CHAR GASIFICATION PDU-SCALE REACTOR

fines carry-over. Twenty-two thermocouples were located along the tube wall and six inside the thermowell to obtain temperature profiles in the fluidized bed.

The char required for the gasification tests was prepared by devolatilizing peat in a 10-inch-diameter fluidized-bed reactor by using nitrogen at about 1000°F. The char was fed to the reactor in a free-board above the bed and its feed rate was maintained at a steady rate by a screw feeder located at the bottom of an unheated, pressurized hopper which contained enough char for an 8-hour test. Bed height was controlled by manual adjustment of another screw feeder, which delivered the reactor char to a pressurized solids receiver. This feeder was manually controlled to maintain the bed at the desired level, as indicated by a radiation gage.

In many runs, oxygen flow was purposely increased until sintering occurred in the fluidized bed. Sintering was noted by sharp temperature increases in the bed. This type of operation pinpointed the initiation of sintering at the particular fluidization velocity and temperature used. After shutdown, solids samples were obtained from the top of the residue receiver and the reactor bed, since these represented steady-state samples.

Results and Discussion

Nineteen tests have been conducted covering a wide range of operating conditions as shown in Table 3. Carbon conversions up to 97 percent of the feed carbon in the char have been achieved.

Since the gasification characteristics of the char depend upon the temperature and on the type of gases present during devolatilization, tests were conducted in a thermobalance to evaluate the gasification characteristics of the char produced by devolatilizing peat in nitrogen at 1000°F. It was determined that this char behaves very similarly to the char devolatilized in hydrogen at 1500°F and then cooled down to ambient conditions. However, the reactivity of both of these chars is lower than the char devolatilized in hydrogen at 1500°F and then gasified, without cooling to the ambient conditions, as will be the case in an integrated PEATGAS reactor. A comparison of the results obtained in thermobalance tests with the three chars is shown in Figure 10. Therefore, as long as proper reactivities are used in analyzing the fluidized-bed char gasification data, it is not essential to supply hydrogasified char for char gasification tests in the PDU.

Table 3. OPERATING RANGES (MINNESOTA PEAT) FLUIDIZED-BED GASIFICATION TESTS IN PDU

TYPES OF FEED: RAW AND CHAR	
Peat/Char Feed Rate, lb/hr	35-80
FEED GASES: STEAM AND OXYGEN	
Total Pressure, psia	365-535
Steam/Carbon Feed Ratio, mol/mol	0.7-3.9
Oxygen/Steam Ratio, mol/mol	0.09-0.32
Fluidization Velocity, ft/s	0.44-1.03
Maximum Bed Temperature, °F	1170-1910
Carbon Conversions, % of total feed	58-97
Bed Ash Content, wt %	65-96

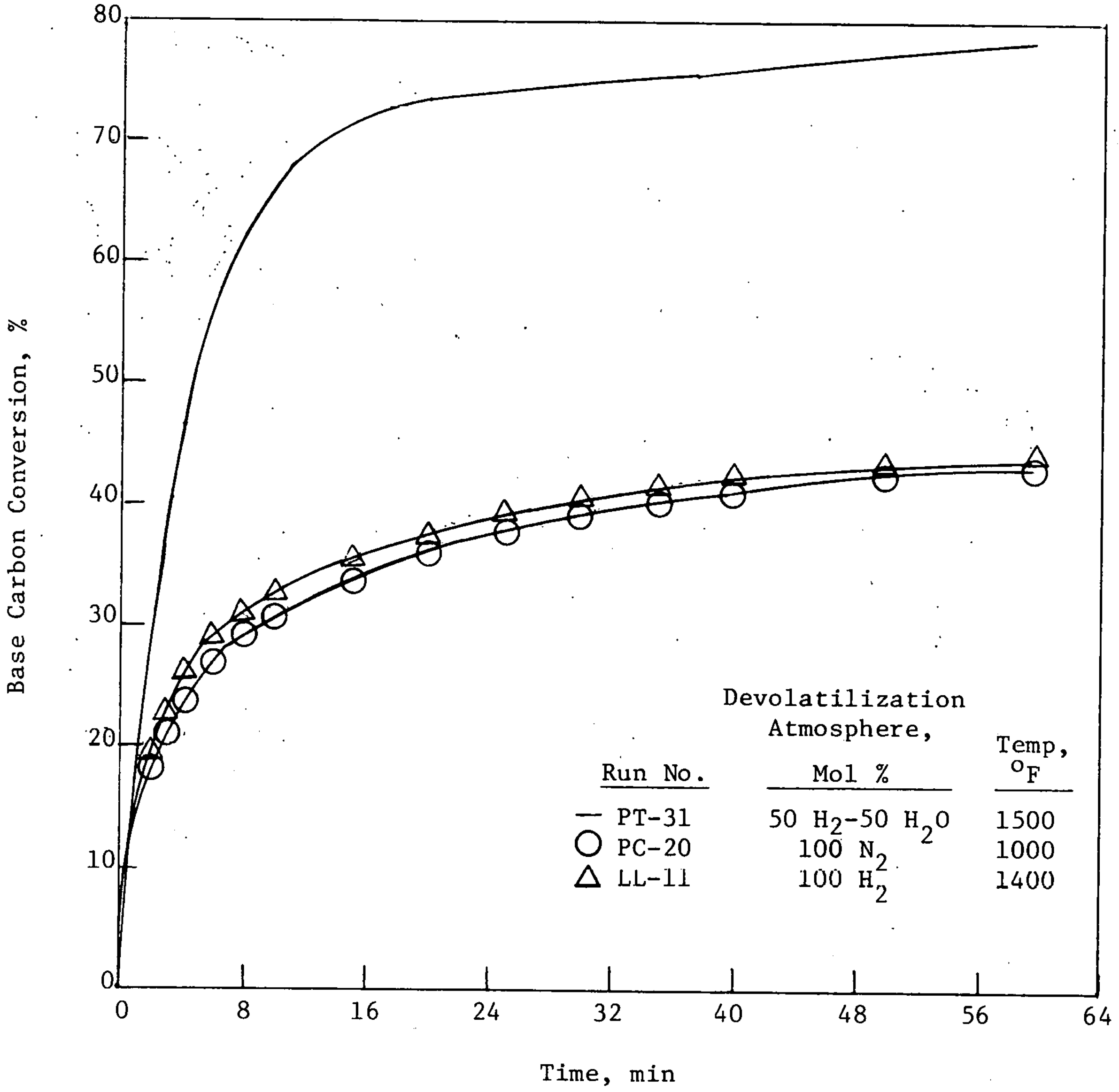

Figure 10. A COMPARISON OF THE GASIFICATION RATES OF PEAT AND PEAT CHARS AT 1500°F IN A STEAM AND HYDROGEN MIXTURE ($H_2O/H_2 = 1$) AND A TOTAL PRESSURE OF 515 PSIA

In order to apply the kinetic equations developed earlier, on the basis of the thermobalance tests, to the fluidized-bed PDU tests, some assumptions have to be made about the gas-solid mixing modes. In IGT's previous studies[14] with gasification of coal chars in a fluidized bed, satisfactory results were obtained by assuming complete backmixing of the gas and solids in the reactor. A typical comparison of the calculated and the experimental yields achieved in some of the PDU tests is shown in Table 4. It shows that the kinetic model developed for the fluidized-bed gasification of peat char predicts the experimental yields of methane and carbon oxides very well. However, the calculated yields of hydrogen are lower than those obtained experimentally.

The effects of temperature and fluidization velocity on sintering characteristics of peat char are shown in Figure 11. The regions above and below the shaded band represent the regions of sintering and sinter-free operations, respectively. Figure 11 shows that in order to achieve sinter-free operation at a particular temperature in a fluidized bed with steam and oxygen, a certain minimum fluidization velocity must be maintained. This minimum design velocity can be obtained from Figure 11 corresponding to any temperature in the range of 1700° to 1950°F. Similar design curves have been developed[13] for gasification of coal char in fluidized beds with steam and oxygen.

PROCESS DESIGN

A process design has been completed for production of 250 billion Btu per day of SNG from Minnesota peat. The reason for selecting this plant size is that it has been used[16] in the past for evaluating various coal gasification processes. The basic flow scheme is very similar to a coal gasification plant. Details of the process design have been reported earlier.[15]

The reactor operating conditions, selected for completing the preliminary process design for converting peat to SNG by the PEATGAS Process, consist of 500 psig pressure, 1700°F char gasifier temperature, and 440°F peat dryer temperature. Material and energy balance calculations as well as reaction kinetic and thermodynamic considerations yield a hydrogasifier temperature of 1475°F.

Fifty percent moisture content peat is received into the plant. After grinding and screening, peat is transferred to lockhoppers used for feeding the peat into the high pressure PEATGAS reactor at 500 psig. With 50% moisture content peat, the lockhopper feed system at 500 psig is preferred to a slurry feed system because the lockhopper feed system eliminates the need for external

Table 4. COMPARISON OF EXPERIMENTAL AND CALCULATED CHAR GASIFICATION RESULTS

Run No.	PSO-6		PSO-7		PSO-8	
Operating Conditions						
Temperature, °F	1710		1725		1830	
Pressure, psia	380		525		373	
Fluidization Velocity, ft/s	0.78		0.55		0.78	
Steam/Carbon Ratio, mol/mol	3.32		3.92		3.45	
	Experimental	Calculated	Measured	Calculated	Measured	Calculated
Product Yields, % of feed carbon						
Methane	5.7	7.2	6.9	6.7	5.3	6.8
Carbon Dioxide	59.0	57.2	60.6	60.6	63.8	63.2
Carbon Monoxide	23.2	23.2	20.0	20.2	27.5	27.5
Hydrogen, SCF/mol carbon	257.9	215.0	307.9	222.6	344.8	237.1

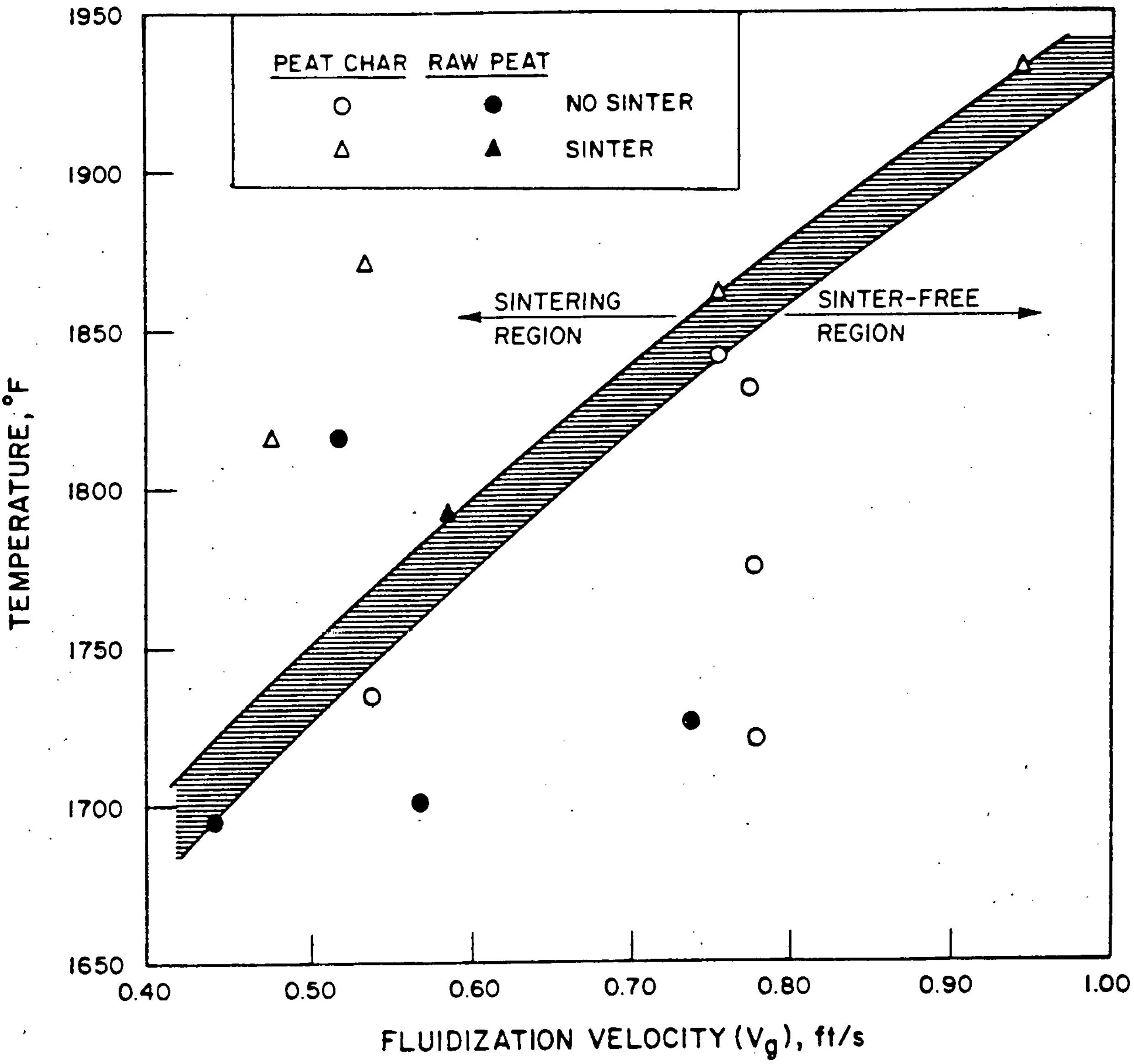

Figure 11. EFFECTS OF TEMPERATURE AND GAS VELOCITY ON SINTERING WITH MINNESOTA PEAT

dryers. Also, the raw gas from the PEATGAS reactor can go directly into the CO-shift reactor — eliminating the need for the shift-steam. In a slurry feed system, peat would have to be dried to about 10% moisture and then slurried with about 67% oil. Downstream of the PEATGAS reactor oil would have to be condensed out, and mixed with additional steam before entering the shift reactor. Our preliminary evaluation indicates that the advantages of the lock-hopper system overweigh its disadvantages of higher equipment cost and higher compression energy requirements.

A comparison of feed requirements and by-products for the PEATGAS Process with some of the coal gasification processes for western coal is shown in Table 5. The information about the coal gasification processes was obtained from published reports.[16,17] The PEATGAS plant requires a total of about 56,300 tons per day of "as received" peat containing 50% moisture. Of that peat, 78% is gasified and 22% is used as boiler fuel. The plant requires 1,506,140 lb/hr of process steam and 3914 tons of oxygen (commercial grade, 98% purity) on a daily basis. These steam requirements are within the range of 1,016,000 and 1,670,000 lb/hr steam requirements for an equivalent size western subbituminous coal gasification plant for SNG production as shown in Table 5. The oxygen requirements of the PEATGAS Process are lower than those of the coal gasification processes, except the HYGAS® Process. The daily yield of useful by-products from the peat-to-SNG plant are about 136,000 gallons of benzene, 6680 barrels of fuel oil, 565 tons of anhydrous ammonia, and 52 long tons of sulfur. Compared to gasification plants based on a western subbituminous coal, peat gasification by the PEATGAS Process produces larger amounts of anhydrous ammonia and lower yields of sulfur. This is because of the high nitrogen and low sulfur contents of peat. The energy content of the by-products in the PEATGAS plant is 70 billion Btu. The total fuel (SNG, benzene and fuel oil) output of the plant is about 309 billion Btu per day.

An overall energy distribution around the entire peat gasification complex is summarized in Figure 12. It shows that the overall thermal efficiency of the process is 67% and that, of the total energy input to the peat gasification complex, 52.4% is converted to SNG and 12.2% is converted to liquid hydrocarbons (benzene and fuel oil).

Table 5. RAW MATERIALS AND PRODUCTS FOR NOMINAL 250 X 10^9 BTU/DAY SNG PLANT

PROCESS:	PEATGAS	HYGAS	BI-GAS	SYNTHANE		LURGI
Raw Material	Peat	Montana Subbituminous Coal[1]				
Moisture Content of Raw Material, wt%	50	22				
Feed Requirements (dry), tons/day				A[2,3]	B[2,4]	
Process	21,951.3	13,629.6	13,870.8	21,733.2	19,031	15,163.2
Fuel	6,202.0	2,337.6	3,813.6	--	--	3,673.2
Total	28,153.3	15,967.2	17,684.4	21,733.2	19,031	18,836.4
Oxygen (98%), tons/day	3,914.0	2,954.4	5,892.0	6,127.2	8,229	4,860.0
Steam, lb/hr	1,506,140	1,098,100	1,479,340	1,016,000	1,554,000	1,670,000
Process Makeup Water, gpm	2,060	1,906	2,156	2,009	12,800	2,434
BY-PRODUCTS						
Liquid Fuels, bbl/day	9,919[5]	4,594	--	4,286	--	9,411
Ammonia, tons/day	565	88.8	92.4	86.4	180	140.4
Sulfur, long tons/day	52	88.9	96.4	112.5	155	85.7
Export Power, kW	--	--	--	128,190	--	--
Export Char, tons/day	--	--	--	--	1,277	--

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1) Coal gasification data for various processes taken from "Factored Estimates for Western Coal: Commercial Concepts Interim Report," prepared by C. F. Braun for ERDA, October 1976.

2) Weiss, A. J., "The Synthane Process: A Technical and Economic Assessment," paper presented at the Miami International Conference on Alternative Energy Scurces, Miami, December 1977.

3) Coal feed injection in freeboard.

4) Coal feed injection in deep bed.

5) Includes benzene.

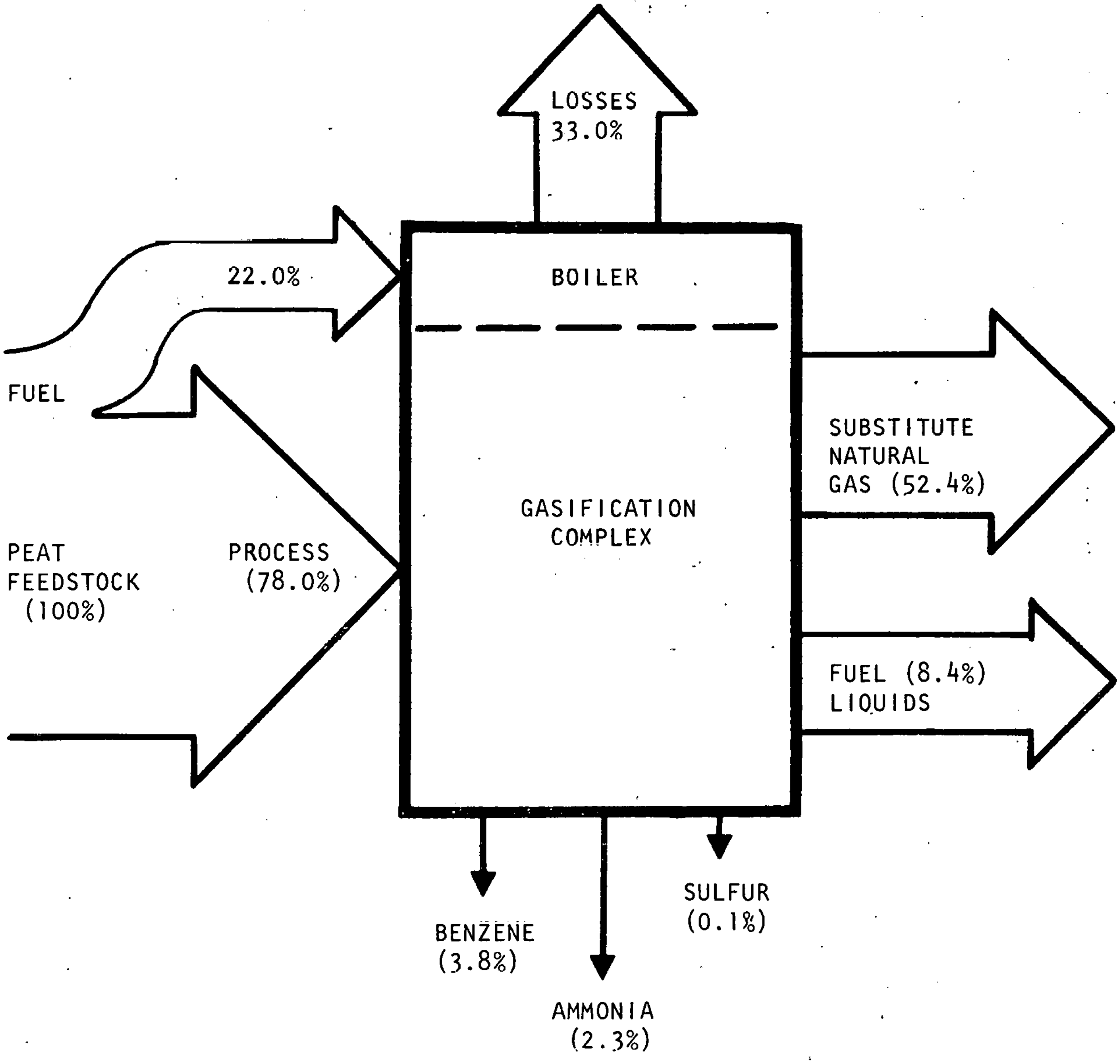

Figure 12. ENERGY DISTRIBUTION FOR THE PEATGAS REACTOR

A comparison of the sources of methane and overall plant thermal efficiency for the PEATGAS Process with those for some of the coal gasification processes is shown in Table 6. In the PEATGAS Process, 78% of the total methane produced in the plant is made in the gasifier and only 22% of the methane has to be made by catalytic methanation of carbon monoxide and hydrogen. In comparison, coal gasification processes require higher percentages, 31-74%, of the methane to be made by catalytic methanation. High methane formation in the PEATGAS reactor favors higher overall thermal efficiency of the process.

SUMMARY

Gasification tests with a Minnesota reed sedge peat have been completed in laboratory-scale as well as in PDU-scale equipment. The tests in the PDU-scale equipment, which represent a scale-up of 250 times the laboratory-scale equipment, confirm the results obtained in the laboratory-scale equipment. The PEATGAS Process for converting peat to SNG is thus ready for the next logical step in its development — large-scale pilot-plant testing.

A mathematical model that describes the kinetics of the Minnesota peat has been developed for the PEATGAS Process. A complete process design has been prepared for a preliminary base case for producing 250 X 10^9 Btu/day of SNG from the Minnesota peat (containing 50 percent moisture content). The plant thermal efficiency of this process is estimated to be 67 percent.

Process economics for the completed base-case process design as well as several modified designs will be evaluated. The laboratory-scale as well as the PDU-scale tests with the peats from North Carolina and Maine will be completed.

ACKNOWLEDGEMENT

The work described in this paper was jointly funded by the Department of Energy and the Minnesota Gas Company.

Table 6. COMPARISON OF METHANE SOURCE AND OVERALL EFFICIENCIES FOR THE PEATGAS PROCESS WITH THOSE FOR COAL GASIFICATION PROCESSES

RAW MATERIAL:	PEAT	MONTANA SUBBITUMINOUS[1]				
PROCESS:	PEATGAS	HYGAS	BI-GAS	SYNTHANE		LURGI[4]
				A[2]	B[3]	
Gasifier Conditions						
Pressure, psig	510	1200	1260	1000	600	400
No. of Stages	2	3	2	2	1	1
Temp. Range, °F	1475-1700	1360-1850	1600-2800	1690-1800	1500-1800	700-2000+
Source of Methane In Product Gas, % of total						
Gasifier[5]	78	61	26	69	48	48
Methanator	22	39	74	31	52	52
Overall Efficiency, Products as % of Coal H.H.V.	67	77	64	59	65	72

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1) Derived from "Factored Estimates for Western Coal Commercial Concepts," by C. F. Braun for ERDA, October 1976.

2) Coal feed injection in freeboard.

3) Coal feed injection in deep bed.

4) Single feed.

5) Includes methane equivalent of C_2H_6 and C_2H_4, as well as CH_4, formed in the gasifier.

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