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EXPERIMENTAL PROGRAM FOR THE DEVELOPMENT OF PEAT GASIFICATION

Interim Report No. 7

TASK 2. HYDROGASIFICATION
TASK 3. FLUIDIZED-BED TESTS
For the Period October 1, 1978, Through July 31, 1979

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EXECUTIVE SUMMARY

This interim report covers the experimental work conducted from October 1, 1978, through July 31, 1979, on "Experimental Program for the Development of Peat Gasification," a program jointly funded by the U. S. Department of Energy (DOE) and the Minnesota Gas Company under DOE Contract No. EX-76-C-01-2469.

The objectives of the work conducted during the above period were to determine the hydrogasification and char gasification characteristics of peats from Minnesota, North Carolina, and Maine using process development-scale equipment.

Thirty tests were conducted in an entrained-flow hydrogasification process development unit (PDU) with Minnesota, North Carolina, and Maine peats to determine the effects of temperature, hydrogen partial pressure, residence time, and particle size on the product distribution and yields. These tests were conducted at temperatures of about 1000° to 1500°F, hydrogen partial pressures of 0 to 250 psia, residence times of 2 to 30 seconds, and particle sizes of −10+100, −10+20, and −60+120 mesh. The results of the PDU tests show that overall carbon conversion and hydrocarbon gas yield for the Minnesota peat are about 20% and 50% higher than those for North Carolina and Maine peats, respectively. The liquid fuel yields from all three peats are similar.

Seventeen gasification tests were conducted in a 6-inch-diameter fulidized-bed reactor with steam and oxygen. These tests were conducted with raw peat as well as with chars of the peats from Minnesota, North Carolina, and Maine. The objectives of these tests were to determine the effects of temperature, pressure, and steam/feed carbon mole ratios on the gasification characteristics of peats and peat chars. The tests were conducted at pressures, temperatures, steam/feed carbon mole ratios, and fluidization velocities in the ranges of 123 to 544 psia, 1600° to 1850°F, 0.7 to 2.6, and 0.4 to 1.0 ft/s, respectively. In these tests, carbon conversions as high as 96% were achieved. Tests were also conducted to determine the effect of temperature and fluidization velocity on the sintering characteristics of peat chars.

All the data from hydrogasification PDU tests and char gasification PDU tests have been correlated. The unified kinetic description of the three peats is presented.

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INTRODUCTION

The overall objective of the project "Experimental Program for the Development of Peat Gasification," jointly funded by the Department of Energy (DOE) and Minnesota Gas Company, is to develop a process for the conversion of peat to substitute natural gas (SNG) and to evaluate its process economics. Work during the period July 1, 1976, through June 30, 1978, was conducted at the Institute of Gas Technology (IGT) using only Minnesota reed sedge peat. The achievements during the period were as follows:

- Laboratory-scale tests relating to physical properties, hydrogasification, and char gasification were completed.
- Twenty-six tests for hydrogasification and 13 tests for char gasification in the process development units (PDU's) were conducted.
- Kinetic models for hydrogasification and char gasification were developed.
- A preferred reactor configuration (named PEATGAS™) for converting peat to SNG was selected.
- A process design for producing 250 billion Btu's of SNG per day by the PEATGAS Process* with Minnesota peat was completed.

The results of work conducted from July 1, 1976, through June 30, 1978, have been published in the following interim reports:

- Interim Report No. 1 for the Period February 10 to June 30, 1976. ERDA Report No. FE-2469-3, December 1976.
- Interim Report No. 2. Task 2: Thermobalance Studies. ERDA Report No. FE-2469-10, April 1977.
- Interim Report No. 3. Task 3: Coiled Tube Reactor Experiments. DOE Report No. FE-2469-17, January 1978.
- Interim Report No. 4. Task 1: Physical Properties Evaluation. DOE Report No. FE-2469-25, April 1978.
- Interim Report No. 5. Process Design and Cost Estimates for a 250 Billion Btu/Day SNG from Peat Plant by the PEATGAS Process (Minnesota Peat). DOE Report No. FE-2469-34, February 1979.
- Interim Report No. 6. Hydrogasification and Fluidized-Bed Tests as of September 30, 1978. DOE Report No. FE-2469-35. February 1979.

The objectives of the program extension through July 31, 1979, were to obtain additional gasification data on peats, including peats from North Carolina

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

and Maine, and to evaluate the economics of converting peat to SNG. Achievements during the period were as follows:

- A total of 23 laboratory-scale char gasification tests were conducted with North Carolina and Maine peats.
- Thirty-five tests for hydrogasification and 21 tests for char and raw peat gasification in the PDU's were conducted.
- Process designs for plants producing 250 billion Btu's of SNG per day by the PEATGAS Process with predried Minnesota and North Carolina peats were completed.

The program extension is divided into four tasks as shown in Figure 1. The objective of the first task (Thermobalance Studies) is to determine the gasification kinetics of peats from North Carolina and Maine and to develop a kinetic model for these peats similar to those developed for Minnesota peat. This task has been completed, and the results have been presented in Interim Report No. 6. The objectives of Tasks 2 and 3 are to conduct tests with North Carolina and Maine peats in the hydrogasification PDU and with chars from these peats in the steam-oxygen gasification PDU. The objective of Task 4 is to determine the economics of producing SNG from peats from North Carolina and Maine by the PEATGAS Process. The results of the preliminary process design of a plant producing 250 billion Btu/day of SNG from Minnesota and North Carolina peats by the PEATGAS Process are presented in a separate report (Interim Report No. 8. Process Designs and Cost Estimates for the Manufacture of 250 Billion Btu/Day SNG From Peat by the PEATGAS Process. DOE Report No. FE-2469-49, to be published in February 1980).

This interim report presents the results of the work conducted with peats from Minnesota, North Carolina, and Maine in the hydrogasification and fluidized-bed gasification PDU's from October 1, 1978, through July 31, 1979.

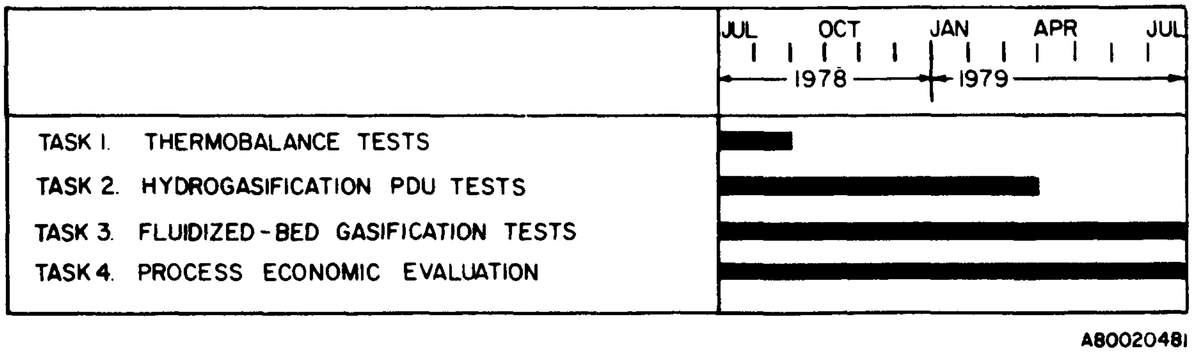

Figure 1. MILESTONE CHART FOR THE PEAT GASIFICATION PROGRAM EXTENSION

HYDROGASIFICATION PDU STUDIES

The objective of this task was to evaluate the hydrogasification characteristics of peats from Minnesota, North Carolina (First Colony Farms), and Maine (Deer Hill Farms). The tests were conducted in a cocurrent, entrained-flow reactor. Detailed descriptions of the experimental apparatus and experimental and data analysis procedures that were used throughout the scope of this work were presented in Interim Report No. 6.

We have conducted a total of 61 hydrogasification tests with the three peats in the hydrogasification PDU. The first 31 PDU tests (Runs LL-1 through LL-26 and HG-1 through HG-5) were conducted with Minnesota peat. The operating conditions, run results, and chemical analyses of the feed peat and residue chars were presented in detail in Interim Report No. 6 and will not be repeated here. Of the remaining 30 tests performed during the program extension, 11 were conducted with Minnesota peat, 11 with North Carolina peat, and 8 with Maine peat. The broad range of operating conditions used in these tests is summarized in Table 1. The operating conditions and run results of Runs HG-5 through HG-35 are presented in Table 2. The proximate, ultimate, and screen analyses of the feed peat and residue char for these runs are presented in Table 3.

Table 1. RANGE OF OPERATING CONDITIONS FOR HYDROGASIFICATION TESTS CONDUCTED IN THE LIFT-LINE PDU WITH MINNESOTA, NORTH CAROLINA, AND MAINE PEATS

Operating Conditions	Range
Peat Feed Rate, lb/hr	8.1-12.7
Feed Gases	H_2, H_2-N_2, N_2, H_2-H_2O, H_2O-H_2-N_2, Synthesis Gas
H_2 Partial Pressure, psia	0-530
Maximum Coil Temperature, °F	1500-1567
Gas Flow Rate, SCF/hr	733-1055
Residence Time, s	2-30

The effect of hydrogen partial pressure on the total carbon conversion and yields of hydrocarbon gases (HG), carbon oxides (CO_x), and heavy hydrocarbons (C_3^+) for Minnesota, Maine, and North Carolina peats is shown in Figures 2 through 5.

Figure 2 shows that the effect of hydrogen partial pressure on the overall carbon conversion is small for both Maine and North Carolina peats when compared

Table 2. OPERATING CONDITIONS AND RESULTS OF PEAT HYDROGASIFICATION TESTS IN THE PDU

Run No.	HG-5	HG-6	HG-7	HG-8	HG-9	HG-10	HG-11	HG-12	HG-13	HG-14	HG-15	HG-16	HG-17	HG-18	HG-19	HG-20	HG-21	HG-22	HG-23	HG-24	HG-25	HG-26	HG-27
Peat Type	Minnesota						North Carolina				Maine					North Carolina			Minn.	N.C.	Maine		
Test Duration, min	77	78	80	35	67	40	64	80	84	63	47	115	63	51	69	59	125	106	248	179	177	205	130
Steady-State Period, min	45	48	50	25	27	--	54	70	74	53	37	105	53	41	59	44	95	91	233	164	162	190	115
Operating Conditions																							
Feed Gas, mol %																							
Hydrogen	44.7	43.0	43.0	24.3	28.9	24.5		23.3	100.0	44.8		100.0	43.3	48.5	22.3	20.8	100.0	100.0	44.1	100.0	100.0	100.0	100.0
Steam	27.8	30.2	26.6	43.4	42.1	45.6									54.4	57.4							
Nitrogen	27.5	26.8	30.4	32.3	29.0	29.9	100.0	76.7		55.2	100.0		56.7	51.5					55.9				
Carbon Monoxide															9.1	8.5							
Carbon Dioxide															13.6	12.7							
Methane															0.6	0.6							
Pressure,[a] psia	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Reactor Temperature, °F																							
Coil Inlet (0-ft)	1066	1160	1295	1256	1177	1075	1430	1372	1370	1320	1399	1347	1357	1333	1374	1367	1023	1081	1349	1163	957	1044	1126
1/4-Point (40-ft)	1093	1192	1355	1316	1209	1116	1542	1518	1549	1502	1522	1567	1493	1490	1493	1486	1101	1211	1482	1317	1048	1162	1260
Mid-Point (80-ft)	1085	1193	1316	1268	1198	1094	1472	1508	1506	1492	1495	1510	1487	1479	1491	1489	1082	1201	1473	1292	1073	1176	1286
3/4-Point (120-ft)	1125	1215	1329	1272	1197	1111	1500	1512	1500	1487	1500	1507	1525	1506	1525	1520	1121	1217	1506	1310	1103	1209	1323
Coil Outlet (160-ft)	1100	1160	1281	1212	1146	1053	1406	1414	1400	1377	1438	1413	1466	1434	1453	1443	1068	1156	1448	1251	1067	1167	1258
Feed Gas Flow Rate, SCF/hr	2399	2223	2121	1997	2321	2461	1055	981	852	733	1048	828	1413	1041	853	864	1173	1128	1123	1006	1358	1101	1002
Peat Feed Rate, lb/hr	10.0	10.3	9.2	9.5	10.9	10.8	10.7	11.8	11.1	12.3	10.7	10.7	11.3	12.4	10.8	9.0	11.3	12.7	10.0	13.2	12.6	11.5	12.6
Operating Results																							
Gas Velocity,[b] ft/s	35.3	32.3	33.6	31.0	35.1	29.8	19.6	18.9	16.2	14.0	20.1	16.5	26.2	19.2	16.2	15.1	17.2	17.8	20.2	16.7	19.1	16.8	16.3
Residence Time,[c] s	4.5	5.0	4.8	5.2	4.6	5.4	8.2	8.5	9.9	11.5	8.0	9.7	6.1	8.3	9.9	10.6	9.3	9.0	7.9	9.6	8.4	9.5	9.8
Product Gas Flow Rate, SCF/hr	1829	1663	1629	1160	1401	1384	1090	1060	868	415	1138	900	1470	551	462	442	1199	1153	1160	1024	1376	1119	1019
Char Residue Rate, lb/hr	3.9	4.3	3.4	3.9	2.9	4.7	4.2	4.3	3.6	4.2	4.5	4.0	4.8	4.2	5.2	3.7	5.1	5.6	3.9	5.0	7.3	5.9	6.4
Liquid Products, lb/hr																							
Oil	0.75	1.92	0.62	0.85	1.37	0.66	0.57	0.60	0.15	0.73	0.15	0.08	0.08	0.29	0.44	0.48	0.86	0.95	0.15	0.74	0.76	0.63	0.49
Water	27.07	24.41	23.47	41.68	46.59	36.85	2.03	1.74	3.75	19.09	1.85	3.04	3.06	27.55	19.73	20.67	2.19	1.71	1.58	2.37	1.75	2.14	2.30
Total	27.82	26.33	24.09	42.53	47.96	37.51	2.60	2.34	3.90	19.82	2.00	3.12	3.14	27.84	20.17	21.15	3.05	2.66	1.73	3.11	2.51	2.77	2.79
Product Gas Composition,[d] mol %																							
Carbon Monoxide	0.68	1.10	1.14	1.15	1.10	1.75	2.86	3.20	3.59	4.58	2.45	2.60	1.62	2.80	16.46	17.19	0.80	1.48	2.47	2.87	0.46	0.90	2.18
Carbon Dioxide	0.55	0.50	0.66	0.93	0.77	0.85	1.64	0.58	0.15	6.73	1.35	0.18	0.24	3.43	32.56	31.81	0.91	1.11	0.20	0.23	0.66	0.76	0.20
Nitrogen	37.38	40.28	40.52	55.53	50.25	55.20	91.64	73.77	0.02	1.14	93.07	0.18	57.42	0.27	0.21	0.06	0.02	0.06	53.91	--	0.10	0.01	--
Hydrogen	60.70	57.09	56.09	40.58	46.58	41.35	2.20	19.01	90.95	77.13	2.03	93.66	39.04	88.18	44.78	42.98	97.00	95.26	40.63	93.85	98.18	97.05	95.37
Methane	0.29	0.53	0.93	1.02	0.65	0.38	1.15	2.63	4.49	8.25	0.74	2.94	1.25	4.04	5.03	6.56	0.58	1.14	2.02	1.93	0.29	0.75	1.47
Ethane	0.13	0.24	0.53	0.54	0.31	0.15	0.08	0.53	0.56	1.60	0.07	0.29	0.30	0.89	0.62	0.98	0.26	0.57	0.58	0.96	0.09	0.30	0.62
Ethylene/Acetylene	0.03/0.02	0.04/0.01	0.02/--	0.06/0.01	0.06/0.01	0.07/0.01	0.33/--	0.14/--	0.01/--	0.14/0.01	0.21/--	0.03/--	0.05/--	0.08/--	0.13/--	0.18/--	0.03/0.01	0.01/0.01	0.06/0.01	0.01/--	0.02/0.01	--/0.01	0.01/--
Propane/Propylene	0.04/0.04	0.09/0.06	0.04/0.01	0.07/0.04	0.08/0.08	0.05/0.08	--/--	--/--	--/--	--/--	--/--	--/--	--/--	--/--	--/--	--/--	0.13/0.07	0.22/0.04	--/--	0.11/0.01	0.05/0.03	0.12/0.03	0.05/0.01
Butanes	0.10	0.04	0.01	0.02	0.07	0.09	--	--	--	--	--	--	--	--	--	--	0.11	0.06	--	--	0.06	0.04	0.01
Pentanes	0.01	--	--	--	0.01	--	--	--	--	--	--	--	--	--	--	--	0.05	--	--	--	0.02	--	--
Benzene	0.01	0.01	0.03	0.03	0.01	0.01	0.09	0.14	0.23	0.42	0.07	0.12	0.08	0.31	0.21	0.24	0.02	0.02	0.12	0.03	0.01	0.01	0.06
Toluene	0.02	0.01	0.02	0.02	0.02	0.01	0.01	--	--	--	0.01	--	--	--	--	--	0.01	0.02	--	--	0.02	0.02	0.02
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	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Material Balances, %																							
Carbon	89.4	116.8	102.7	99.5	90.5	90.0	103.4	103.2	94.3	103.0	100.9	94.2	94.1	88.9	100.7	99.9	94.4	99.6	98.9	91.2	86.3	97.3	94.5
Hydrogen	95.5	89.7	95.1	98.5	97.5	88.6	119.4	98.9	101.5	99.2	105.5	106.0	96.3	73.2	94.4	93.1	100.2	100.2	100.4	99.3	99.6	100.6	100.3
Ash	81.4	97.8	98.5	102.2	55.0	107.2	110.4	102.8	96.6	103.0	96.1	89.1	108.8	78.4	87.0	113.1	96.6	99.2	95.8	95.0	107.7	95.7	100.3
Overall	95.0	97.2	96.4	100.4	99.2	40.6	107.4	102.8	106.0	99.3	99.8	100.7	100.0	98.1	96.0	94.8	100.1	99.4	99.2	94.9	97.1	99.0	98.2
Peat Component Conversions,[e] % of feed (daf)																							
Carbon	62.4	64.7	66.6	63.5	72.7	61.6	46.4	49.1	55.0	54.2	52.0	55.2	52.4	68.7	58.7	57.8	48.9	43.7	62.1	51.3	47.7	45.1	51.7
Hydrogen	82.6	85.7	88.6	87.4	88.9	82.8	86.3	85.4	87.1	86.9	86.8	87.4	85.9	90.5	89.9	89.1	76.8	73.4	89.7	78.8	73.4	73.8	80.7
Oxygen	86.7	88.0	94.4	92.2	93.8	86.2	92.2	95.0	96.1	95.5	92.7	96.5	95.7	95.9	84.4	94.4	85.0	90.0	95.5	93.8	84.6	89.1	95.1
Nitrogen	64.8	75.6	79.9	75.3	83.7	72.9	31.0	71.7	80.5	78.6	75.0	91.6	80.9	89.2	85.3	80.6	57.6	58.6	39.5	74.5	54.2	57.5	75.6
Sulfur	87.4	75.0	89.7	78.6	84.9	69.7	50.0	58.3	59.3	72.7	48.0	53.2	54.6	90.7	94.3	88.2	64.6	65.7	54.7	66.1	61.5	71.4	36.8
Product Yields, % of feed carbon																							
Hydrocarbon Gases																							
Methane	4.0	6.8	12.0	9.2	6.0	3.5	6.6	13.5	19.7	15.4	6.6	19.9	13.1	14.9	14.2	16.8	3.9	5.9	17.4	8.5	2.6	5.9	9.5
Ethane	3.6	6.2	13.7	9.7	5.8	2.8	1.0	5.4	4.9	6.0	1.3	3.9	6.3	6.6	4.5	6.0	3.3	5.9	10.0	8.5	1.6	4.7	8.0
Ethylene	1.3	1.3	0.6	1.3	1.4	1.4	3.9	1.5	0.1	0.6	3.7	0.4	1.1	0.6	3.5	1.1	0.8	0.2	1.3	0.1	0.6	0.2	0.2
Total	8.9	14.3	26.3	20.2	13.2	7.7	11.5	20.4	24.7	22.0	11.6	24.2	20.5	22.1	22.2	23.9	8.0	12.0	28.7	17.1	4.8	10.8	17.7
Carbon Oxides	16.9	20.6	23.2	18.8	17.4	23.8	26.1	19.4	16.4	21.1	33.6	18.8	19.5	23.1	24.7	20.3	11.4	13.3	23.1	13.7	10.1	13.1	15.4
Oils																							
Benzene	0.8	0.8	2.3	1.6	0.6	0.6	3.1	4.3	6.1	4.7	3.8	4.9	5.0	6.9	4.6	4.4	0.4	0.6	6.2	1.0	0.6	0.5	2.3
Others[f]	35.8	29.0	14.8	22.9	41.5	29.5	5.7	5.0	7.8	6.4	3.0	7.3	7.4	16.6	7.2	9.2	29.1	17.8	4.1	19.5	32.2	20.7	16.3
Total	36.6	29.8	17.1	24.5	42.1	30.1	8.8	9.3	13.9	11.1	6.8	12.2	12.4	23.5	11.8	13.6	29.5	18.4	10.3	20.5	32.8	21.2	18.6

Table 2, Cont. OPERATING CONDITIONS AND RESULTS OF PEAT HYDROGASIFICATION TESTS IN THE PDU

Run No.	HG-28	HG-29	HG-30	HG-31	HG-32[g]	HG-33[g]	HG-34	HG-35[h]
Peat Type	N.C.	Minnesota			North Carolina		Minn.	
Test Duration, min	137	120	201	67	265	119	77	70
Steady-State Period, min	122	105	186	—	250	104	62	65
Operating Conditions								
Feed Gas, mol %								
Hydrogen	100.0	25.5	56.4	53.8	100.0	100.0	60.2	41.7
Steam								
Nitrogen		74.5	43.6	46.2			39.8	58.3
Carbon Monoxide								
Carbon Dioxide								
Methane								
Pressure,[a] psia	250	250	250	250	250	250	250	250
Reactor Temperature, °F								
Coil Inlet (0-ft)	1005	1161	1220	1234	1345	1326	1228	1341
1/4-Point (40-ft)	1080	1319	1357	1312	1492	1470	1381	1393
Mid-Point (80-ft)	1094	1358	1352	1318	1484	1473	1362	1379
3/4-Point (120-ft)	1111	1372	1376	1377	1500	1502	1384	1380
Coil Outlet (160-ft)	1060	1298	1325	1324	1433	1441	1281	1292
Feed Gas Flow Rate, SCF/hr	1156	311	877	1591	1167	1215	421	2320
Peat Feed Rate, lb/hr	17.0	8.1	10.3	13.5	12.9	14.0	8.3	9.5
Operating Results								
Gas Velocity,[b] ft/s	17.2	5.3	15.1	26.9	21.1	21.5	21.7	38.5
Residence Time,[c] s	8.3	30.5	10.6	6.0	7.6	7.5	7.4	2.0
Product Gas Flow Rate, SCF/hr	1195	307	910	1642	1200	1231	438	2339
Char Residue Rate, lb/hr	8.3	3.5	3.9	5.3	4.4	5.1	3.4	3.7
Liquid Products, lb/hr								
Oil	1.28	0.27	0.57	0.55	0.02	0.01	0.00	0.0
Water	2.22	1.16	1.60	2.45	2.25	2.08	1.35	1.90
Total	3.50	1.43	2.17	3.00	2.27	2.09	1.35	1.90
Product Gas Composition,[d] mol %								
Carbon Monoxide	1.16	4.38	2.96	2.04	3.25	3.43	4.46	1.28
Carbon Dioxide	1.70	2.48	0.47	0.58	0.21	0.20	0.64	0.22
Nitrogen	--	76.10	43.07	49.13	0.06	0.20	39.04	58.29
Hydrogen	95.42	10.80	49.93	45.74	92.09	92.12	49.74	39.24
Methane	0.77	4.56	2.29	1.56	3.28	3.06	4.24	0.55
Ethane	0.35	1.27	1.09	0.82	0.89	0.83	1.78	0.33
Ethylene/Acetylene	0.05/0.02	0.24/--	0.04/--	0.02/0.01	0.02/--	0.02/--	--/--	0.02/--
Propane/Propylene	0.19/0.13	--/--	--/--	0.04/0.01	--/--	--/--	--/--	0.01/0.01
Butanes	0.14	--	--	--	--	--	--	--
Pentanes	0.04	--	--	--	--	--	--	--
Benzene	0.01	0.15	0.13	0.04	0.20	0.14	0.10	0.04
Toluene	0.02	0.02	0.02	0.01	--	--	--	0.01
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Material Balances, %								
Carbon	97.9	94.4	102.3	101.2	97.6	92.5	98.4	97.7
Hydrogen	99.9	73.7	98.7	86.9	99.9	97.7	95.0	97.7
Ash	94.7	98.4	100.3	98.8	95.1	87.7	97.2	100.1
Overall	98.9	98.5	101.6	100.1	98.5	95.7	99.1	100.7
Peat Component Conversions,[e] % of feed (daf)								
Carbon	38.1	49;8	59.8	58.0	53.4	56.2	51.2	61.1
Hydrogen	69.7	86.3	86.6	85.5	84.9	86.7	85.5	81.1
Oxygen	82.7	96.5	96.8	93.8	96.6	93.4	94.6	79.4
Nitrogen	42.6	70.4	76.0	71.4	76.1	81.1	75.0	71.7
Sulfur	58.0	43.8	58.7	36.4	54.0	32.7	59.1	
Product Yields, % of feed carbon								
Hydrocarbon Gases								
Methane	3.2	11.4	13.4	12.5	17.1	16.1	15.6	10.3
Ethane	2.8	6.3	12.8	13.3	9.3	8.8	13.0	12.6
Ethylene	0.4	1.2	0.4	0.6	0.2	0.2	--	--
Total	6.4	18.9	26.6	26.4	26.6	25.1	28.6	24.6
Carbon Oxides	11.3	17.0	20.1	21.1	18.0	19.1	18.7	28.5
Oils								
Benzene	0.3	2.2	4.6	1.9	6.2	4.4	2.2	5.7
Others[c]	20.1	11.7	8.5	8.6	2.6	7.6	1.7	2.3
Total	20.4	13.9	13.1	10.5	8.8	12.0	3.9	8.0

[a] Measured at reactor outlet.

[b] Gas velocity calculated at the average temperature and outlet pressure.

[c] Residence time calculated at the average gas velocity.

[d] Determined by mass spectrometer analyses of samples taken during the test.

[e] Computed from the ultimate analysis of feed peat and residue char.

[f] Computed as the difference between the total carbon conversion and carbon present in hydrocarbon gases (C_1 and C_2), carbon oxides, and benzene.

[g] HG-32 feed peat size range −10+120 U.S.S.
HG-33 feed peat size range −60+120 U.S.S.

[h] Reactor coil length is 80 feet.

Table 3. CHEMICAL AND SCREEN ANALYSES OF PEAT FEEDS AND RESIDUES FROM HYDROGASIFICATION TESTS IN THE LIFT-LINE PDU

Run No.		HG-5		HG-6		HG-7		HG-8		HG-9		HG-10		HG-11		HG-12	
Sample		Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue
Proximate Analysis, wt %																	
Moisture		3.6	1.3	6.1	1.9	4.8	1.8	4.9	3.4	4.1	2.3	3.2	1.7	5.3	1.2	3.6	1.0
Volatile Matter		53.2	18.3	51.0	15.9	54.5	11.8	54.4	13.5	54.2	14.6	56.5	18.4	56.6	10.2	57.6	9.1
Fixed Carbon		20.4	34.0	18.7	26.8	20.8	33.7	19.8	31.7	20.8	40.0	21.2	33.1	33.2	74.8	33.7	75.6
Ash		22.8	46.4	24.2	55.4	19.9	52.7	20.9	51.4	20.9	43.1	19.1	46.8	4.9	13.8	5.1	14.3
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (Dry), wt %																	
Carbon		43.70	40.64	42.60	34.00	45.50	39.93	45.00	39.30	45.60	46.14	46.20	40.5	58.40	77.0	57.70	78.5
Hydrogen		4.50	1.94	4.40	1.42	4.72	1.41	4.64	1.41	4.73	1.94	4.86	1.9	4.86	1.6	4.93	1.9
Nitrogen		2.02	1.76	2.03	1.22	2.04	1.07	1.91	1.14	2.37	1.43	26.77	8.4	30.62	5.9	30.73	4.1
Oxygen		25.86	8.52	24.95	6.77	26.63	3.91	26.19	4.88	25.27	6.20	2.24	1.4	0.78	1.3	1.22	0.9
Sulfur		0.25	0.14	0.29	0.16	0.25	0.08	0.26	0.12	0.28	0.15	0.25	0.2	0.17	0.2	0.16	0.2
Ash		23.67	47.00	25.73	56.43	20.86	53.60	22.00	53.15	21.75	44.14	19.68	47.6	5.17	14.0	5.26	14.4
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	100.00	100.00
Screen Analysis, U.S.S., wt %																	
+10		0.1	--	0	0.1	0.1	0.0	--	--		--						
−10+20	+12	2.7	1.8	4.3	1.5	14.7	1.7	10.9	1.4	1.2	1.2	0.0	--	0.0	0.2	0.0	--
−20+30	+20	18.2	4.0	20.8	4.7	20.0	4.2	19.3	4.4	11.4	3.7	22.1	2.9	6.4	0.7	10.4	--
−30+40	+30	29.6	7.6	24.0	8.5	20.9	7.6	22.8	9.1	18.2	7.3	19.9	5.2	30.2	11.0	34.7	15.5
−40+50	+40	22.9	9.5	24.8	15.8	17.2	10.4	18.6	13.2	19.4	9.3	20.2	8.2	39.1	25.4	36.6	31.9
−50+70	+60	15.9	10.8	14.4	14.4	13.8	12.2	14.9	15.0	23.5	11.6	22.8	17.0	22.4	39.4	17.2	34.1
−70+100	+80	7.5	12.0	9.0	17.8	8.0	12.6	8.2	14.4	10.0	12.0	10.4	12.4	1.1	5.8	0.5	4.9
−100+140	+100	1.3	8.8	1.5	7.5	2.5	9.6	2.5	8.4	6.5	10.4	2.2	6.4	0.0	2.8	0.0	0.9
−140+170	+200	0.4	4.2	0.4	2.5	0.8	4.5	0.7	3.1	7.6	4.9	1.9	15.5	0.5	4.2	0.3	3.4
−170+270	+325	0.5	6.7	0.6	5.7	1.0	8.0	1.0	5.5	1.0	2.8	0.0	6.3	0.0	1.8	0.0	1.1
−270	Pan	0.9	34.6	0.2	21.5	1.0	29.2	1.1	25.5	1.2	36.8	0.5	26.1	0.3	8.7	0.3	8.2
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	100.0	100.0	100.0	100.0
Average Particle Size, in.		0.0133	0.0036	0.0139	0.0046	0.0136	0.0038	0.0131	0.0042		0.0035	0.0161	0.0036	0.0189	0.0075	0.0204	0.0082
Bulk Density, lb/ft^3		--	--	25.8	36.8	23.8	27.3	25.6	34.5	23.3	29.0	21.6	31.8	25.4	21.6	27.3	21.5

Run No.	HG-13		HG-14		HG-15		HG-16		HG-17		HG-18		HG-19		HG-20	
Sample	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue
Proximate Analysis, wt %																
Moisture	3.5	1.4	3.5	1.7	12.6	1.4	12.7	0.6	13.1	0.4	7.9	1.0	3.2	0.8	1.9	2.3
Volatile Matter	58.0	7.0	57.4	8.8	43.7	9.1	44.9	5.9	45.0	7.2	44.4	8.7	43.4	8.8	57.3	9.8
Fixed Carbon	33.5	76.9	34.1	74.0	21.8	39.9	22.5	45.4	22.4	41.9	21.8	30.7	21.1	31.8	26.3	47.8
Ash	5.0	14.7	5.0	15.5	21.9	49.6	19.9	48.1	19.5	50.5	25.9	59.6	32.3	58.6	14.5	40.1
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	100.0	100.0	100.0	100.0
Ultimate Analysis, wt %																
Carbon	58.2	78.7	57.70	77.44	43.70	43.80	45.10	47.43	45.40	44.76	41.50	35.54	38.70	32.70	51.10	53.00
Hydrogen	5.02	2.0	4.85	1.86	3.85	1.06	3.97	1.18	4.02	1.18	3.72	0.97	3.55	0.73	4.72	1.26
Oxygen	30.33	3.5	30.87	4.10	25.78	3.91	26.55	2.21	26.14	2.35	25.17	2.86	22.66	7.44	27.38	3.71
Nitrogen	1.13	0.7	1.10	0.69	1.15	0.60	1.20	0.24	1.54	0.61	1.06	0.31	1.23	0.38	1.84	0.87
Sulfur	0.18	0.2	0.26	0.21	0.42	0.37	0.44	0.48	0.43	0.41	0.45	0.11	0.44	0.05	0.20	0.05
Ash	5.14	14.9	5.22	15.70	25.10	50.26	22.74	48.46	22.47	50.69	28.10	60.21	33.42	58.70	14.76	41.11
Total	100.00	100.0	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
Screen Analysis, U.S.S., wt %																
+12	0.0	0.0	0.0	0.0	10.5	1.1	14.6	0.7	13.7	1.1	10.0	0.8	--	--	--	--
+20	14.6	1.5	13.6	0.48	32.7	17.2	36.1	20.5	38.1	18.4	30.1	13.6	18.9	1.8	16.0	2.5
+30	37.0	19.9	32.5	14.00	16.5	10.8	15.4	12.5	15.4	11.8	15.5	9.4	23.1	12.7	20.0	10.1
+40	33.0	32.7	32.8	29.62	14.6	13.5	12.6	13.6	12.3	12.5	15.2	12.2	22.2	17.9	20.5	14.5
+60	14.2	33.5	19.3	38.03	15.9	18.1	13.4	17.0	12.5	15.9	17.8	18.3	25.8	25.4	24.5	21.4
+80	0.7	4.6	0.8	5.90	1.0	8.7	4.8	7.6	4.6	7.4	7.1	9.5	9.0	11.4	9.0	10.8
+100	0.0	1.2	0.0	1.29	7.1	6.1	1.5	5.2	1.7	4.9	2.6	6.0	0.5	6.1	3.5	7.3
+200	0.2	1.9	0.5	3.30	1.3	9.1	1.0	7.4	1.0	7.7	1.2	7.8	0.0	6.8	3.5	10.9
+325	0.0	0.6	0.0	0.86	0.2	4.3	0.3	5.5	0.2	6.0	0.2	5.1	0.0	3.1	1.5	4.3
Pan	0.3	4.1	0.5	6.52	0.2	11.1	0.3	10.0	0.5	14.3	0.3	17.3	0.5	14.8	1.5	18.2
Total	100.0	100.0	100.0	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average Particle Size, in.	0.0215	0.0110	0.0197	0.0089	0.0204	0.0062	0.0234	0.0065	0.0231	0.0055	0.0197	0.0050	0.0174	0.0054	0.0126	0.0046
Bulk Density, lb/ft^3	26.8	--	26.0	22.6	26.2	32.2	25.3	29.5	24.8	31.6	27.9	33.0	27.9	33.5	25.5	27.7

Table 3, Cont. CHEMICAL AND SCREEN ANALYSES OF PEAT FEEDS AND RESIDUES FROM HYDROGASIFICATION TESTS IN THE LIFT-LINE PDU

Run No.	HG-21		HG-22		HG-23		HG-24		HG-25		HG-26		HG-27		HG-28	
Sample	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue
Proximate Analysis, wt %																
Moisture	2.1	0.8	1.4	0.5	4.3	0.1	1.4	0.4	3.7	0.1	5.4	0.1	3.1	0.1	1.3	0.2
Volatile Matter	56.8	19.1	56.5	15.2	53.6	8.2	56.5	10.1	44.2	14.6	44.8	12.2	45.6	8.3	57.1	20.7
Fixed Carbon	26.9	50.3	34.0	66.2	21.7	38.4	34.0	69.3	22.0	29.0	22.6	37.2	22.5	34.4	35.0	66.3
Ash	14.2	29.8	8.1	18.1	20.4	53.3	8.1	20.2	30.1	56.3	27.2	50.5	28.8	57.2	6.6	12.8
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	100.0	100.0	100.0	100.0
Ultimate Analysis, wt %																
Carbon	51.20	56.60	56.70	71.16	44.50	41.30	47.20	71.60	39.90	34.50	41.30	41.90	40.80	38.00	57.50	72.20
Hydrogen	4.76	2.39	4.52	2.68	4.50	1.14	4.87	2.49	3.56	1.56	3.73	1.80	3.68	1.37	4.67	2.86
Oxygen	27.38	8.92	28.86	6.44	26.90	2.97	27.68	4.65	23.74	6.07	24.69	4.98	24.02	2.27	29.68	10.47
Nitrogen	1.98	1.82	1.53	1.42	1.18	0.86	2.26	1.01	1.06	0.80	1.12	0.88	1.31	0.61	1.33	1.55
Sulfur	0.21	0.16	0.16	0.12	0.24	0.26	0.19	0.13	0.45	0.28	0.46	0.24	0.47	0.57	0.13	0.11
Ash	14.47	30.11	8.23	18.18	22.68	53.57	17.80	20.12	31.29	56.29	28.70	50.20	29.72	57.18	6.69	12.81
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	100.00	100.00
Screen Analysis, U.S.S., wt %																
+12	--	--	--	--	0.4	--	--	--	--	--	0.2	0.0	0.0	0.0	3.8	0.5
+20	14.7	2.5	16.2	8.1	10.7	1.3	9.2	2.1	12.8	0.5	22.0	2.6	13.4	1.3	27.9	26.8
+30	19.4	10.8	20.0	14.6	19.5	4.1	26.3	10.4	26.7	10.1	24.0	14.1	27.1	11.6	14.3	11.8
+40	19.4	17.8	18.6	21.1	28.6	13.7	35.4	12.9	24.0	14.8	23.7	20.5	24.9	19.1	12.9	11.9
+60	24.6	27.0	29.9	25.5	28.2	31.4	27.1	23.5	29.1	23.2	23.7	24.1	27.9	27.9	23.5	17.1
+80	10.5	14.6	12.1	13.4	8.4	18.2	1.2	17.1	7.4	11.3	4.5	8.2	6.3	10.1	8.2	4.1
+100	4.3	8.7	1.6	5.6	2.3	6.7	0.4	5.6	0.0	2.7	1.3	4.7	0.2	8.5	2.0	7.7
+200	4.3	8.8	0.0	4.4	1.1	3.6	0.0	0.1	0.0	0.9	0.2	7.4	0.0	5.6	4.5	6.3
+325	1.2	3.2	1.6	2.3	0.4	11.0	0.0	11.3	0.0	14.2	0.0	4.8	0.2	7.0	1.3	3.5
pan	1.6	6.3	0.0	5.0	0.4	10.0	0.4	17.0	0.0	22.3	0.4	13.6	0.0	8.9	1.6	10.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Bulk Density, lb/ft^3	25.4	23.3	27.8	21.5	22.8	23.8	18.1	25.2	27.1	38.5	25.2	28.5	25.9	31.9	25.8	23.0
Average Particle Size, in	0.0121	0.0071	0.0151	0.0087	0.0153	0.0054	0.0185	0.0045	0.0182	0.0039	0.0188	0.0056	0.0183	0.0061	0.0134	0.0070

Run No.	HG-29		HG-30		HG-31		HG-32		HG-33		HG-34		HG-35	
	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue	Feed	Char Residue
Proximate Analysis, wt %														
Moisture	1.2	0.5	1.9	0.3	1.9	0.3	2.4	0.1	2.4	0.4	4.6	0.6	11.6	3.7
Volatile Matter	58.5	7.1	58.6	8.3	58.6	8.3	58.5	7.8	53.3	7.4	57.6	9.4	53.3	18.7
Fixed Carbon	24.2	55.7	23.7	48.9	23.7	48.9	33.4	76.3	32.5	63.8	21.9	52.1	18.7	35.0
Ash	16.1	37.2	15.8	42.5	15.8	42.5	5.7	15.8	11.8	28.4	15.9	37.9	16.4	42.6
Total	100.00	100.0	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 %														
Carbon	48.90	57.10	48.90	51.72	48.90	51.72	58.30	78.12	54.20	63.90	48.00	55.10	46.60	43.25
Hydrogen	5.00	1.60	4.98	1.75	4.98	1.75	4.94	2.14	4.43	1.59	5.05	1.72	5.05	2.27
Oxygen	27.31	2.24	27.51	2.30	27.51	2.30	29.63	2.88	27.72	4.95	27.80	3.51	27.53	8.62
Nitrogen	2.32	1.60	2.24	1.41	2.24	1.41	1.16	0.80	1.38	0.70	2.22	1.30	2.08	1.40
Sulfur	0.20	0.36	0.22	0.24	0.22	0.24	0.18	0.24	0.19	0.35	0.22	0.21	0.20	0.22
Ash	16.27	37.18	16.15	42.58	16.15	42.58	5.79	15.82	12.08	28.51	16.71	38.16	18.54	44.24
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
Screen Analyses, U.S.S., wt %														
12	0.0	0.0	0.0	0.0	--	--	0.8	--	--	--	0.3	--	10.0	11.2
20	13.5	1.7	11.7	0.3	11.7	0.3	51.7	7.9	0.0	--	15.6	0.7	34.5	9.2
30	26.7	10.8	25.9	10.0	25.9	10.0	33.6	24.5	1.4	0.2	27.4	12.2	14.8	6.8
40	22.7	19.7	24.6	22.0	24.6	22.0	6.6	34.6	2.6	0.8	22.7	20.2	13.2	7.8
60	28.5	28.1	27.4	27.6	27.4	27.6	2.8	13.6	5.5	2.5	24.9	23.0	18.6	12.8
80	8.2	9.8	8.3	9.6	8.3	9.6	0.8	2.1	24.9	4.5	6.6	10.9	5.8	7.7
100	0.2	11.5	1.5	12.3	1.5	12.3	0.8	2.4	18.9	6.4	1.1	5.8	0.7	3.8
200	0.2	8.3	0.2	2.1	0.2	2.1	1.1	3.9	41.5	38.4	0.8	8.4	1.4	9.9
325	0.0	2.8	0.2	2.5	0.2	2.5	0.6	2.1	4.5	18.6	0.3	5.9	0.5	7.3
pan	0.0	7.4	0.2	7.6	0.2	7.6	1.1	8.9	0.7	28.6	0.3	12.9	0.5	23.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00	100.0	100.00	100.0	100.0	100.0	100.0
Bulk Density, lb/ft^3	19.6	21.8	21.1	19.3	21.1	19.3	26.5	19.2	27.8	24.5	23.0	24.1	18.0	27.3
Average Particle Size, in.	0.0180	0.0069	0.0168	0.0069	0.0168	0.0069	0.0236	0.0083	0.0055	0.0027	0.0173	0.0054	0.0197	0.0041

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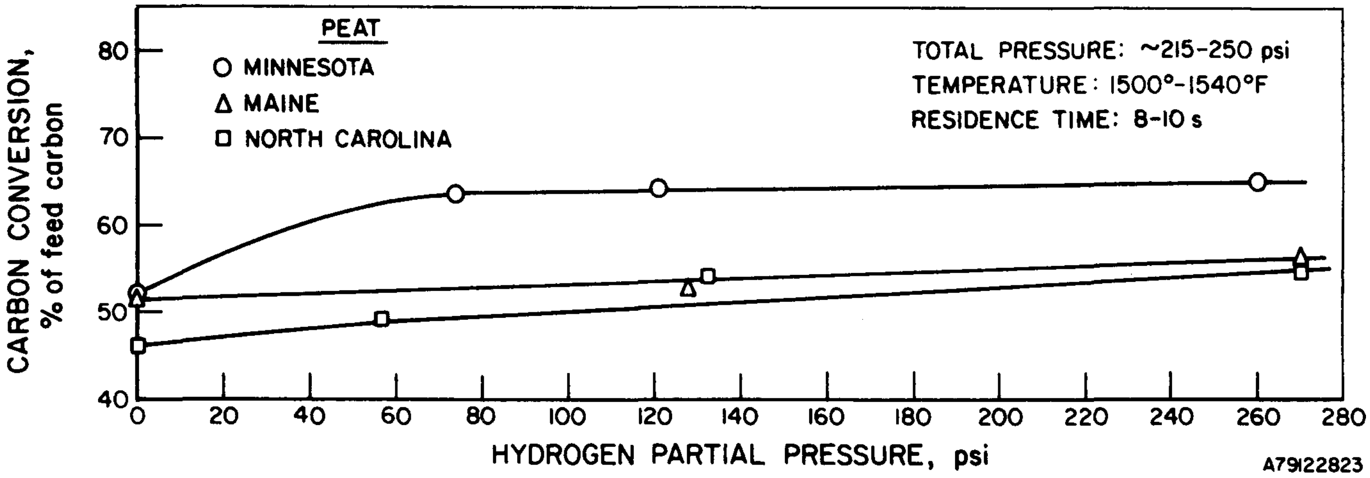

Figure 2. THE EFFECT OF HYDROGEN PARTIAL PRESSURE ON THE OVERALL CARBON CONVERSION

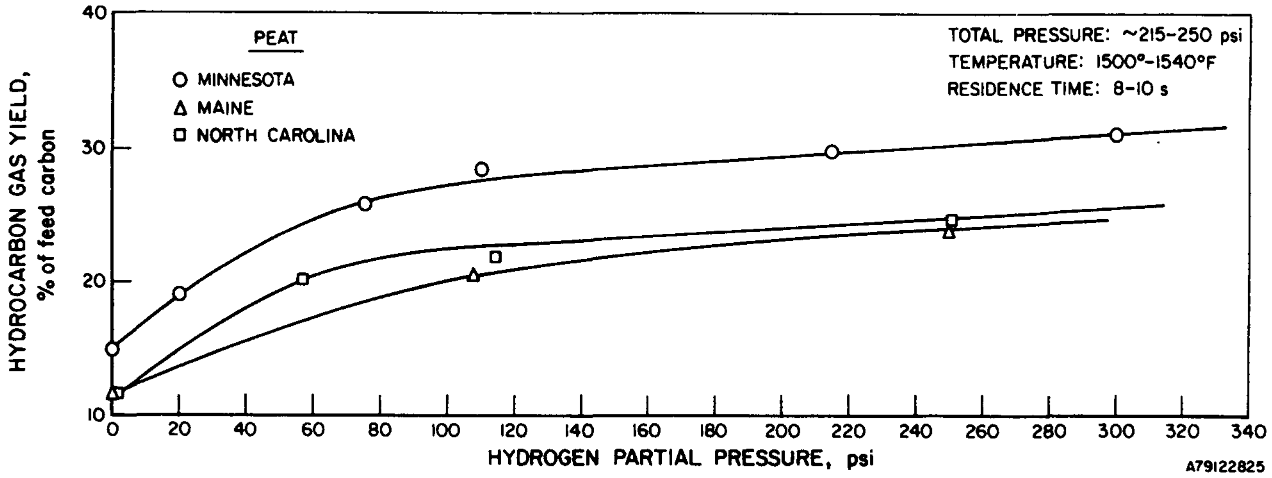

Figure 3. THE EFFECT OF HYDROGEN PARTIAL PRESSURE ON THE YIELD OF HYDROCARBON GASES

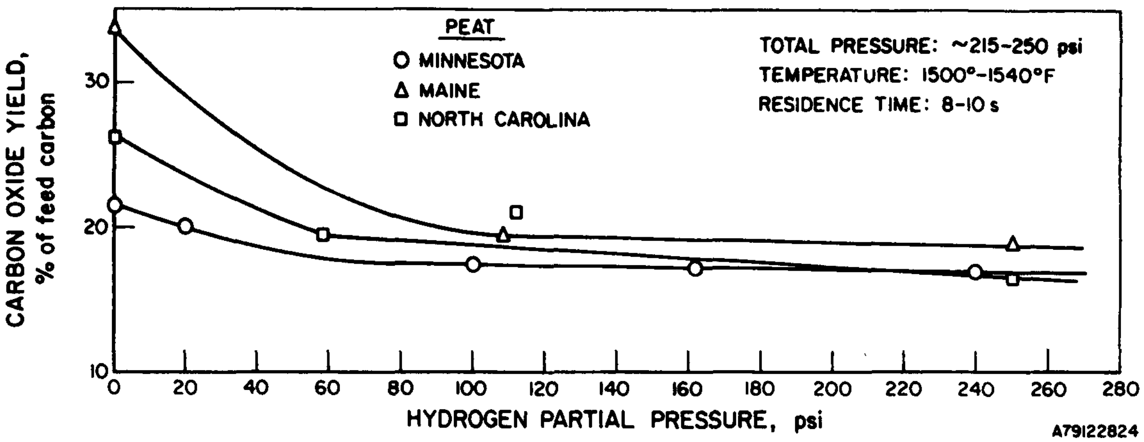

Figure 4. THE EFFECT OF HYDROGEN PARTIAL PRESSURE ON THE YIELD OF CARBON OXIDES

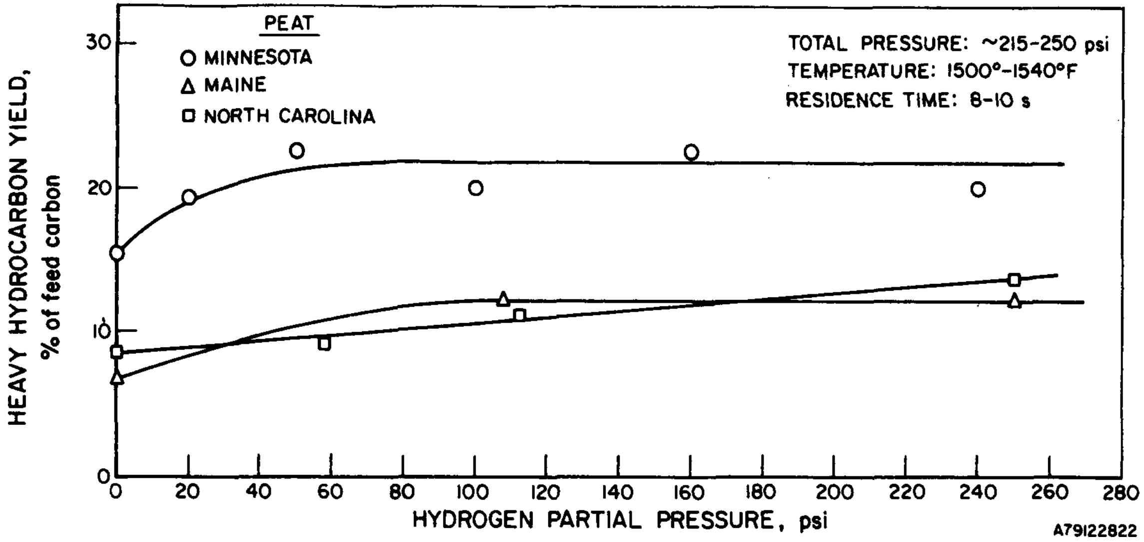

Figure 5. THE EFFECT OF HYDROGEN PARTIAL PRESSURE ON THE YIELDS OF HEAVY HYDROCARBONS

with the effect on the carbon conversion for Minnesota peat tests. For North Carolina peat, overall carbon conversions ranged from 46.4% of the feed carbon at 0 psia hydrogen partial pressure to about 55% at 250 psia, while the overall carbon conversions for the Maine peat increased slightly from 52% at 0 psia hydrogen partial pressure to 55.3% of the feed carbon at 250 psia hydrogen partial pressure. Figure 2 also shows that Minnesota peat exhibits a higher reactivity than that of either the Maine or North Carolina peats. The overall carbon conversion for Minnesota peat was about 66% of the feed carbon compared with approximately 55% for both North Carolina and Maine peats at a hydrogen partial pressure of 240 psia.

The effects of hydrogen partial pressure on the yields of hydrocarbon gases for Maine and North Carolina peats, compared with those of Minnesota peat, are shown in Figure 3. As with the case of total carbon conversion, the effect of hydrogen partial pressure on the yield of hydrocarbon gases in the tests conducted with Maine and North Carolina peats is less pronounced than that of the tests performed with Minnesota peat. However, one similarity shared by all three peats is that the most significant increases in the yields of hydrocarbon gases occur within the first 100 psia of increasing hydrogen partial pressure. Increasing the hydrogen partial pressure beyond about 100 psia leads to only minimal increases in the yields of hydrocarbon gases. For example, hydrocarbon gas yields for the Maine and North Carolina peats increase from 11.5% of the feed carbon for both peats at 0 psia hydrogen partial pressure to approximately 20.5% for the Maine peat and 22% for the North Carolina peat at a hydrogen partial pressure of about 100 psia. Increasing the hydrogen partial pressure to 250 psia increases the yield of hydrocarbon gases for Maine and North Carolina peats slightly to 23.8% and 24.5% of the feed carbon, respectively.

A comparison of the effect of hydrogen partial pressure on the yield of carbon oxides for the three peats is shown in Figure 4. An increase in the hydrogen partial pressure from 0 to 100 psia significantly reduces the carbon oxide yield from 33.7% to 19.5% and from 26.2% to 19.0% of the feed carbon for North Carolina and Maine peats, respectively. The effect of hydrogen partial pressure on the yield of carbon oxides for Minnesota peat is not so marked, declining only from 21.5% to 17.5% of the feed carbon over the same hydrogen pressure range.

At hydrogen partial pressures above about 100 psia (to the maximum pressure tested of 250 psia), the yield of carbon oxides is nearly constant for all three peats.

Figure 5 shows the effect of hydrogen partial pressure on the yields of heavy hydrocarbons for the three types of peat. The yield of heavy hydrocarbons for Maine peat increases from 6.8% at a hydrogen partial pressure of 0 psia to a maximum of about 12% of the feed carbon at hydrogen partial pressures above 100 psia. The heavy hydrocarbon yields for North Carolina peat were 8.9%, 11.1%, and 13.9% at hydrogen partial pressures of 0, 100, and 250 psia, respectively.

The effect of hydrogen partial pressure on the yield of heavy hydrocarbons is similar to that observed for the yield of hydrocarbon gases. The product yield increases rapidly with an increase in hydrogen partial pressure up to about 100 psia, followed by a very gradual increase or nearly stable yield up through 250 psia.

The effects of temperature on the total carbon conversion, hydrocarbon gas, carbon oxide, and heavy hydrocarbon yields are presented in Figures 6 through 9. The operating conditions used throughout this phase of work were total pressures of 215 to 250 psia, residence times of 8 to 12 seconds, hydrogen partial pressures above 100 psia, and maximum temperatures in the reactor of 1100° to 1567°F.

A comparison of the effects of temperature on the overall carbon conversion for Maine, North Carolina, and Minnesota peats is presented in Figure 6. Increasing the maximum coil temperature from 1100° to 1500°F increases the carbon conversion for both Maine and North Carolina peats from about 40% to about 55% of the feed carbon. Over the same temperature range the carbon conversion achieved with Minnesota peat increases only from about 60% to 65% of the feed carbon. The Minnesota peat is significantly more reactive than the other two peats over the temperature range tested.

As indicated in Figure 7, the temperature significantly affects the yield of hydrocarbon gases from Maine, North Carolina, and Minnesota peats. Although the yield of hydrocarbon gases from Minnesota peat is greater than those from Maine and North Carolina peats, the shape of the curves are similar. As in the overall carbon conversion case, the curves for the yields of hydrocarbon

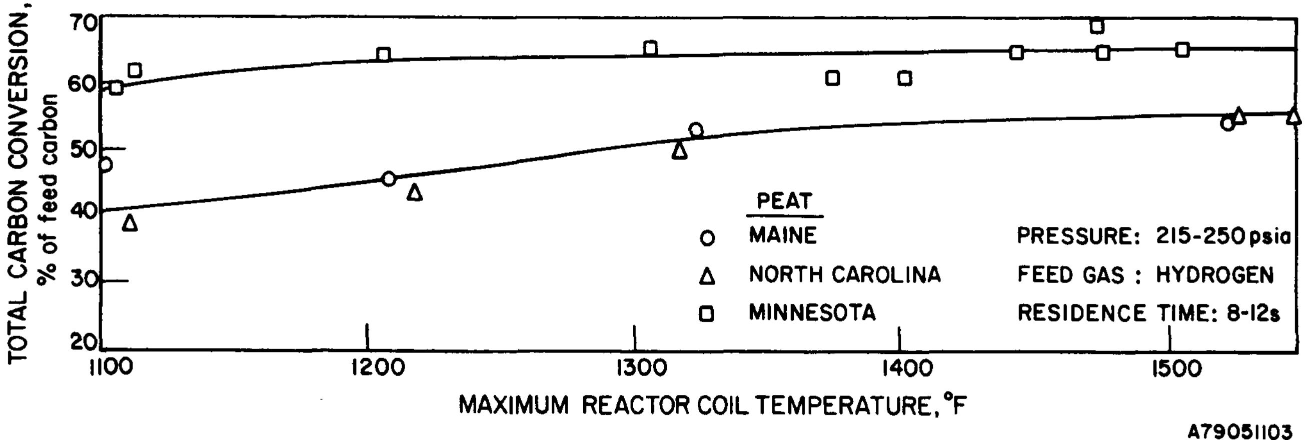

Figure 6. THE EFFECT OF TEMPERATURE ON TOTAL CARBON CONVERSION DURING HYDROGASIFICATION PDU TESTS

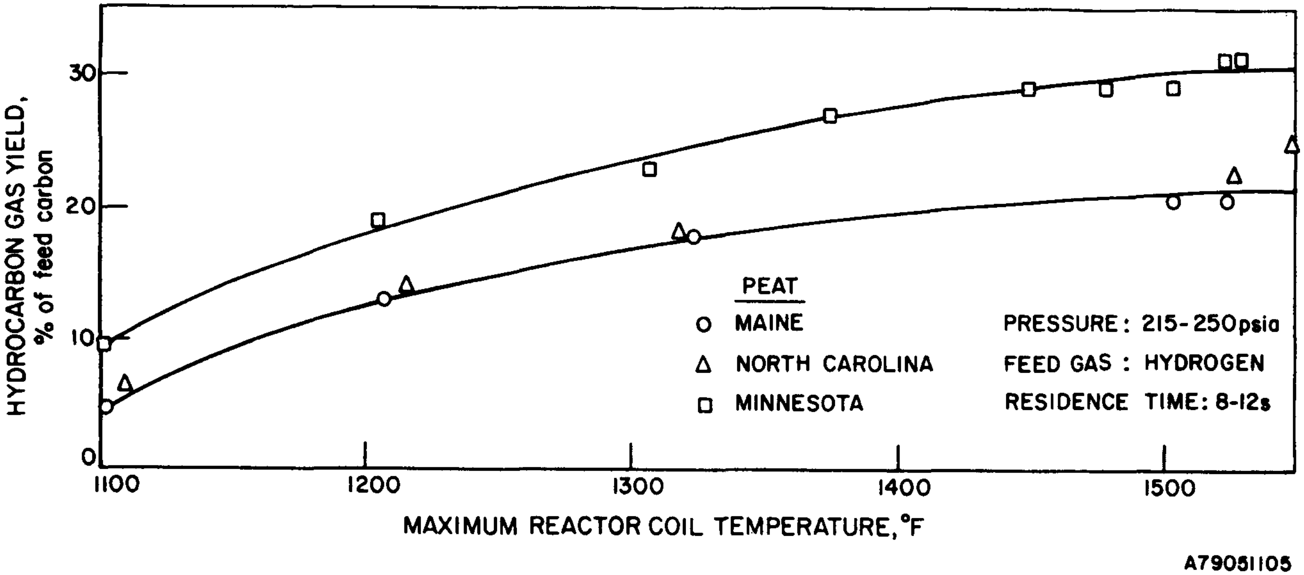

Figure 7. THE EFFECT OF TEMPERATURE ON HYDROCARBON GAS YIELDS DURING HYDROGASIFICATION PDU TESTS

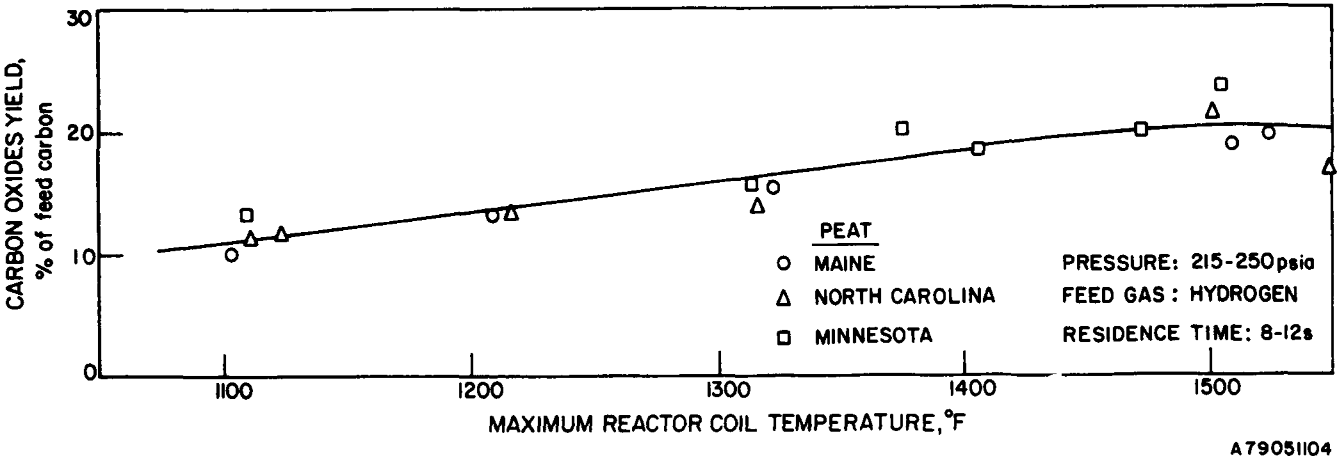

Figure 8. THE EFFECT OF TEMPERATURE ON CARBON OXIDES YIELDS DURING HYDROGASIFICATION PDU TESTS

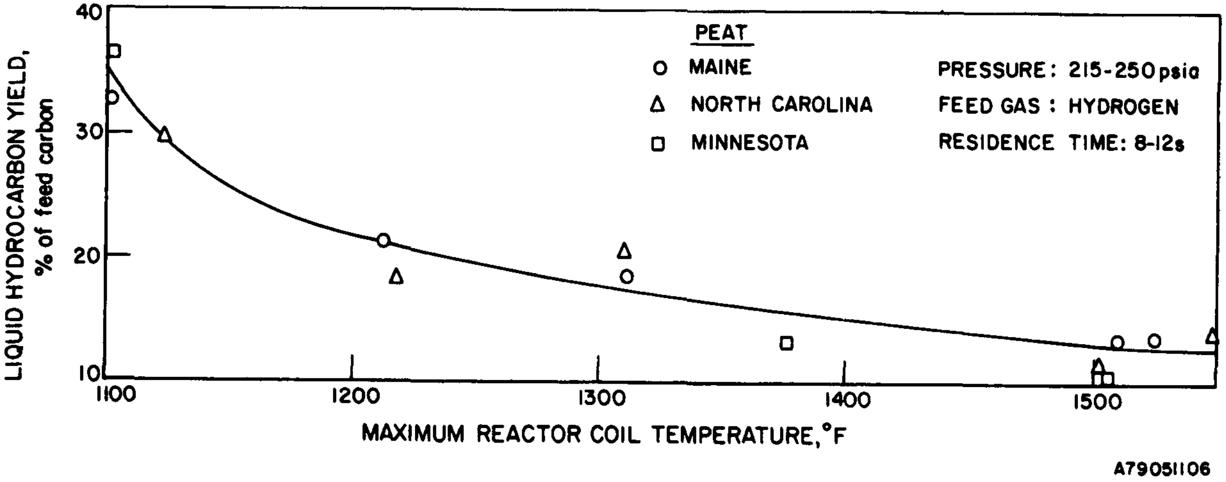

Figure 9. THE EFFECT OF TEMPERATURE ON THE LIQUID HYDROCARBON PRODUCT YIELD DURING HYDROGASIFICATION PDU TESTS

gases from Maine and North Carolina peats coincide. The hydrocarbon gas yields increase from about 4.5% at 1100°F to 21% of the feed carbon at 1500°F. The hydrocarbon gas yield from Minnesota peat is approximately 9.0% at 1100°F, increasing to about 30% of the feed carbon at 1500°F.

The yield of carbon oxides is a roughly linear function of temperature, as shown in Figure 8. At 1100°F the yield of CO_x for all three peats is about 11%, increasing to about 20% of the feed carbon at 1500°F.

The effects of temperature on the yield of heavy hydrocarbons are the same for all three peats, as shown in Figure 9. The yields of heavy hydrocarbons for Maine, North Carolina, and Minnesota peats decrease significantly from about 35% of the feed carbon at 1100°F to about 13% at 1500°F.

Some general conclusions can be drawn from the results of the three hydrogasification tests conducted during the program extension, although the magnitude of the results differ among the three peats tested: 1) hydrogen partial pressure has its greatest impact on the product distribution and total carbon conversion within the first 100 psia, 2) the effects of temperature on the hydrogasification characteristics of the three peats studied were similar, 3) residence times above about 5 seconds and average particle size seemed to have little, if any, effect on the yield and product distribution of hydrogasified Minnesota peat.

Hydrogasification Data Correlation

Interim Report No. 6 presented a kinetic description of the hydrogasification of Minnesota peat based on runs conducted in the 1/16-inch X 200-foot coiled tube and in the 0.8-inch X 160-foot coiled tube. Since then additional runs have been made in the latter apparatus; this section pertains to these runs (the HG series). The major new variable is the peat source. The data have been analyzed with the view of evaluating the appropriateness of applying the previously developed correlations to peats from North Carolina and Maine.

An important set of parameters in the characterization of peat hydrogasification is the limiting conversions with respect to the different products. The overall qualitative scheme used to describe peat hydrogasification is presented in Figure 10. For the residence times, reaction temperatures, and hydrogen pressures studied, there appear to be limiting yields of carbon oxides, light hydrocarbon gases, and benzene. By defining the limiting yields of these products, material balance considerations imply limiting yields of other organic liquids, water, and char carbon. To analyze the current data, it is presumed that these limiting yields are related to the ultimate analysis of the peat. The precision of the data is such that it has not been possible to prove this, but the results with the different peats appear to be consistent.

At the mildest conditions studied (about 1100°F), the carbon dioxide yield appears to be at its limiting value. The previous studies indicate that this is true at 1100°F and possibly at even lower temperatures. To estimate this primary yield of CO_2, tests must be run at temperatures no greater than 1200°F. At higher temperatures the water-gas shift becomes significant, and the CO_2 yield is enhanced in low-hydrogen or high-steam runs and depressed in high-hydrogen runs. For Minnesota peat (Runs HG-2, HG-3, HG-5, HG-6, HG-9, and HG-10) the primary carbon yield as CO_2 is 7.3% of the feed carbon; for North Carolina peat (Runs HG-21, HG-22, and HG-28) it is 6.2%, and for Maine peat (Runs HG-25 and HG-26) it is 6.0%.

The total carbon oxide yield has a significantly larger scatter compared with those of the other gaseous species. Unusually high yields were reported for the runs without hydrogen feeds (HG-11 and HG-15). For the estimate of the limiting yields, only the carbon oxide yields for runs with significant hydrogen feeds and temperatures greater than 1300°F were considered. Data for

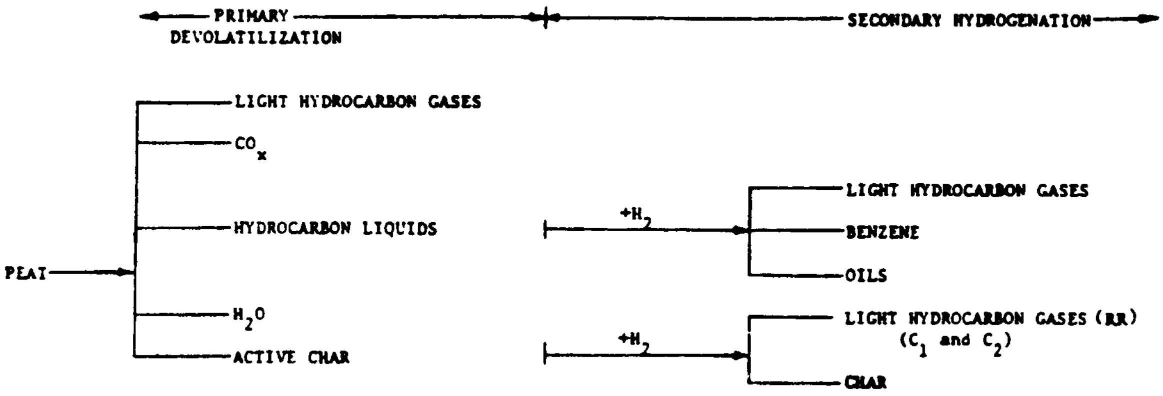

Figure 10. QUALITATIVE MODEL FOR INITIAL PEAT HYDROGASIFICATION

all three peats were included with the assumption that the ultimate carbon oxide yield is proportional to the oxygen content of the raw dry peat. Previous studies had indicated a dependence on hydrogen pressure; this dependence was applied to the current data. Based on a least squares procedure, the limiting carbon oxide yield for hydrogen pressures below 20 atm is estimated to be —

$$\xi_{CO_x}^{o} = (0.477 - 0.0013\ P_{H_2})\ \eta_O \qquad (1)$$

where —

η_O = oxygen/carbon atom ratio in the dry peat feed

P_{H_2} = hydrogen pressure, atm

$\xi_{CO_x}^{o}$ = limiting CO_x yield, fraction of feed carbon.

If we assume that the limiting CO_2 yields are proportional to the peat oxygen content, they would be estimated by —

$$\xi_{CO_2}^{o} = 0.160\ \eta_O \qquad (2)$$

The rate of carbon oxide formation based on these data was estimated assuming that the primary carbon monoxide evolution is of the first order and that the temperature dependence follows an Arrhenius form. It was found, however, that for Eastern peats this CO generation was slower than that of Minnesota peat. The rate expressions developed are —

$$\frac{d\xi_{CO}}{d\theta} = (\xi_{CO}^{o} - \xi_{CO}) \exp (8.95 - 15830\ f/T) \qquad (3)$$

where —

$\xi_{CO}^{o} = \xi_{CO_x}^{o} - \xi_{CO_2}^{o}$ (defined in Equations 1 and 2)

f = 1.0 (for the Minnesota peat) and 1.175 (for the North Carolina and Maine peats).

In Figure 11, a comparison of calculated and reported values of carbon oxides for runs with hydrogen pressures of 3 to 18 atm that had reasonable carbon balances is presented.

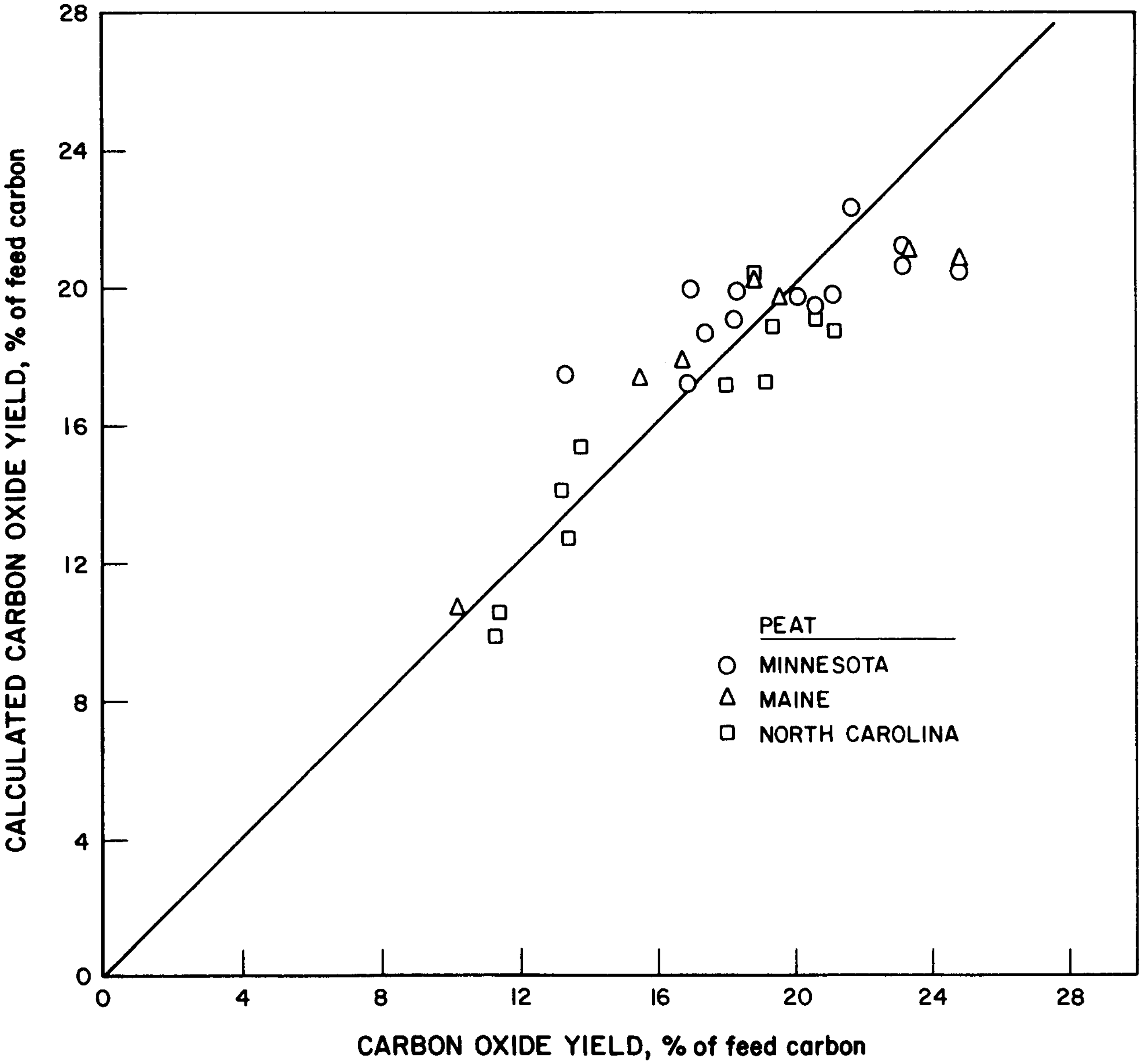

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Figure 11. COMPARISON OF CARBON OXIDE YIELDS WITH CALCULATED YIELDS

The light hydrocarbon gas yield is defined to include methane and the two-carbon (C_2) hydrocarbon gases. In the reaction scheme (Figure 10) these come by three paths: a small amount that is generated in the primary devolatilization, a secondary hydrocarbon derived from the material that is the precursor to heavier products, and another secondary hydrocarbon derived from the material that is the precursor to char carbon. The last is referred to as rapid-rate hydrocarbon gas because its source corresponds to the fixed carbon, which ordinarily reacts slowly but which reacts rapidly in hydrogen atmospheres. By definition, the rapid rate yield is defined as —

$$\xi_{RR} = \xi_C - \xi^o{}_V + \xi^o{}_{CO_x} - \xi_{CO_x} \tag{4}$$

where —

ξ_{RR} = the hydrocarbon gas yield via the rapid-rate char gasification path
ξ_C = the total carbon gasified, fraction of feed carbon
$\xi^o{}_V$ = the volatile carbon in the raw peat, fraction of feed carbon
ξ_{CO_x} = the actual carbon oxide yield, fraction of feed carbon.

In previous studies with Minnesota peat the limiting rapid-rate hydrocarbon yield was estimated to be —

$$\xi^o_{RR} = 0.06 + 0.0032\ P_{H_2} \tag{5}$$

in hydrogen-containing atmospheres with hydrogen pressures less than 20 atm. To test the applicability of this correlation to North Carolina and Maine peats, we assumed that the yield of rapid-rate hydrocarbon gas is proportional to the amount of fixed or base carbon. Runs were conducted at temperatures above 1300°F to avoid kinetically limiting conditions. Figure 12 shows that the char gasified with these peats is consistent with that estimated using the above correlation. On this basis the limiting rapid-rate hydrocarbon gas yield would be estimated by —

$$\xi^o_{RR} = (0.125 + 0.0067\ P_{H_2})(1-\xi^o_V) \tag{6}$$

There is not sufficient precision in the values of total conversion and carbon oxide yield needed for Equation 4 at less severe conditions where both total conversion and carbon oxides yield are kinetically controlled to allow a comparison of the rate of rapid-rate hydrocarbon formation for the three peats. Therefore, in the subsequent discussions, the kinetic expression developed in Interim

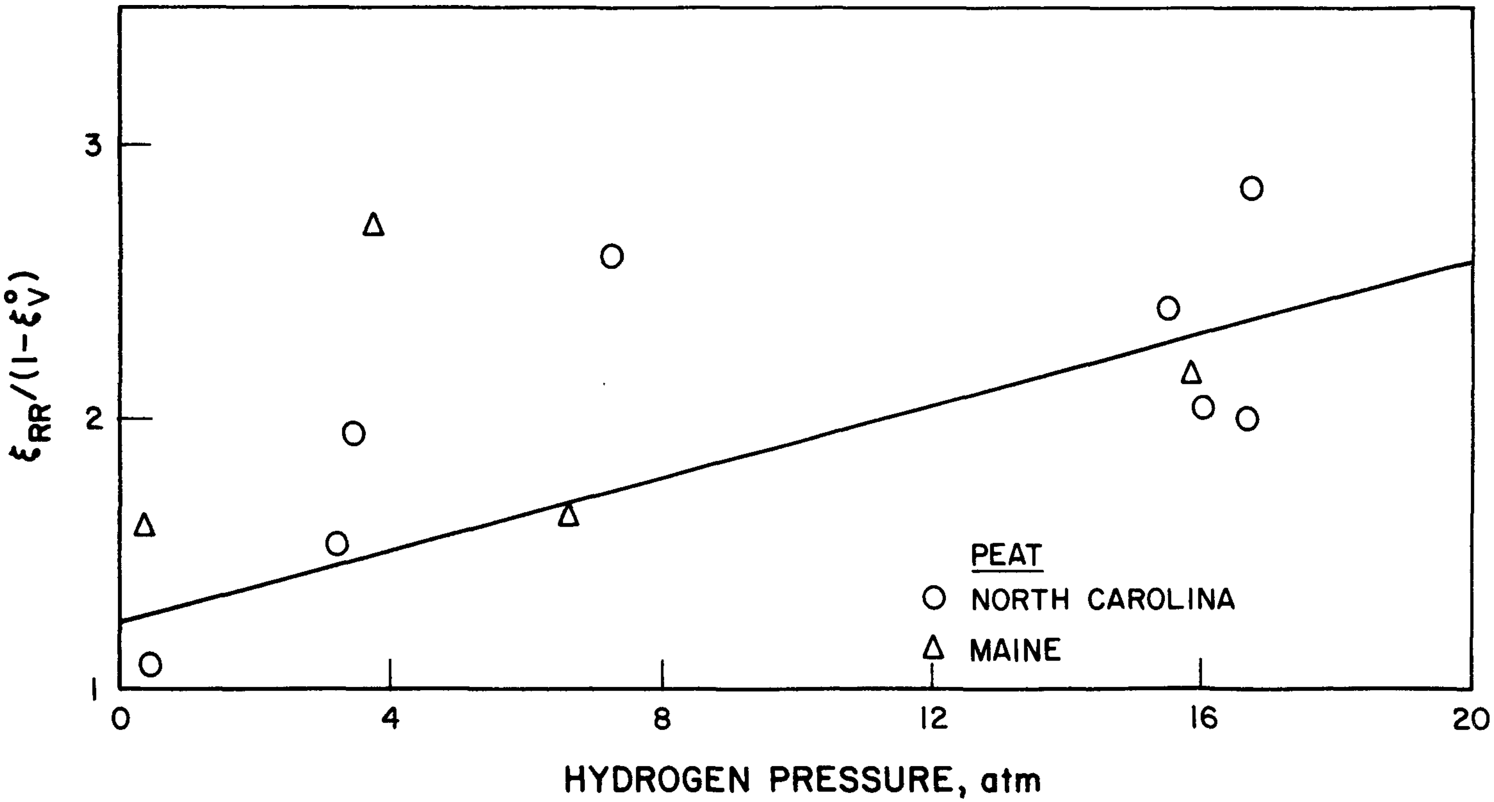

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Figure 12. RAPID-RATE CHAR HYDROCARBON YIELDS FROM NORTH CAROLINA AND MAINE PEATS

Report No. 6 for Minnesota peat are assumed applicable to the other peats. This is —

$$\frac{d\xi_{RR}}{d\theta} = (\xi_{RR}^{o} - \xi_{RR})\, P_{H_2} \exp\,(15.64 - 33208/T) \qquad (7)$$

The remaining source of light hydrocarbons is the heavier molecules that form the liquid product at low temperatures and short residence times. Earlier studies concluded that the limiting value from this source is independent of hydrogen pressure, although hydrogen is necessary. The same is thought to be true of North Carolina and Maine peats for hydrogen pressures greater than 3 atm.

However, at the most severe (>1400°F) conditions, the volatile light hydrocarbon yield for these peats is about 20% (about 2% of the feed carbon) lower than might be expected. Furthermore, at less severe conditions, the yield from the Eastern peats is even lower than might be expected, based on the low ultimate values. This may indicate that the Eastern peats have slower rates of formation of volatile light hydrocarbons and that, even at the most severe conditions studied, the yield is kinetically limited. The ultimate yield of volatile light hydrocarbons for the three peats is estimated to be —

$$\xi_{VHC}^{o} = 0.65\,(\xi_{V}^{o} - \xi_{CO_x}^{o}) + 0.0013\, P_{H_2} \cdot \eta_{O} \qquad (8)$$

Minnesota peat was studied extensively and yielded the best data for evaluating the kinetics of volatile light hydrocarbon formation. Of the runs with reasonable material balances, the rate constants based on the rate equation —

$$\frac{d\xi_{VHC}}{d\theta} = k_{VHC}\,(\xi_{VHC}^{o} - \xi_{VHC}) \qquad (9)$$

were calculated and plotted on an Arrhenius basis shown in Figure 13. Some runs for which the reported conversions were too close to the limiting conversion to allow valid estimates of the rate constant could not be included. Of the runs that have rate constants different from those predicted by an Arrhenius dependence, Runs HG-29 and HG-34 had total carbon conversions less than that expected by devolatilization alone (the carbon conversion was less than the percent of volatile carbon in the feed). These two runs had the longest residence times:

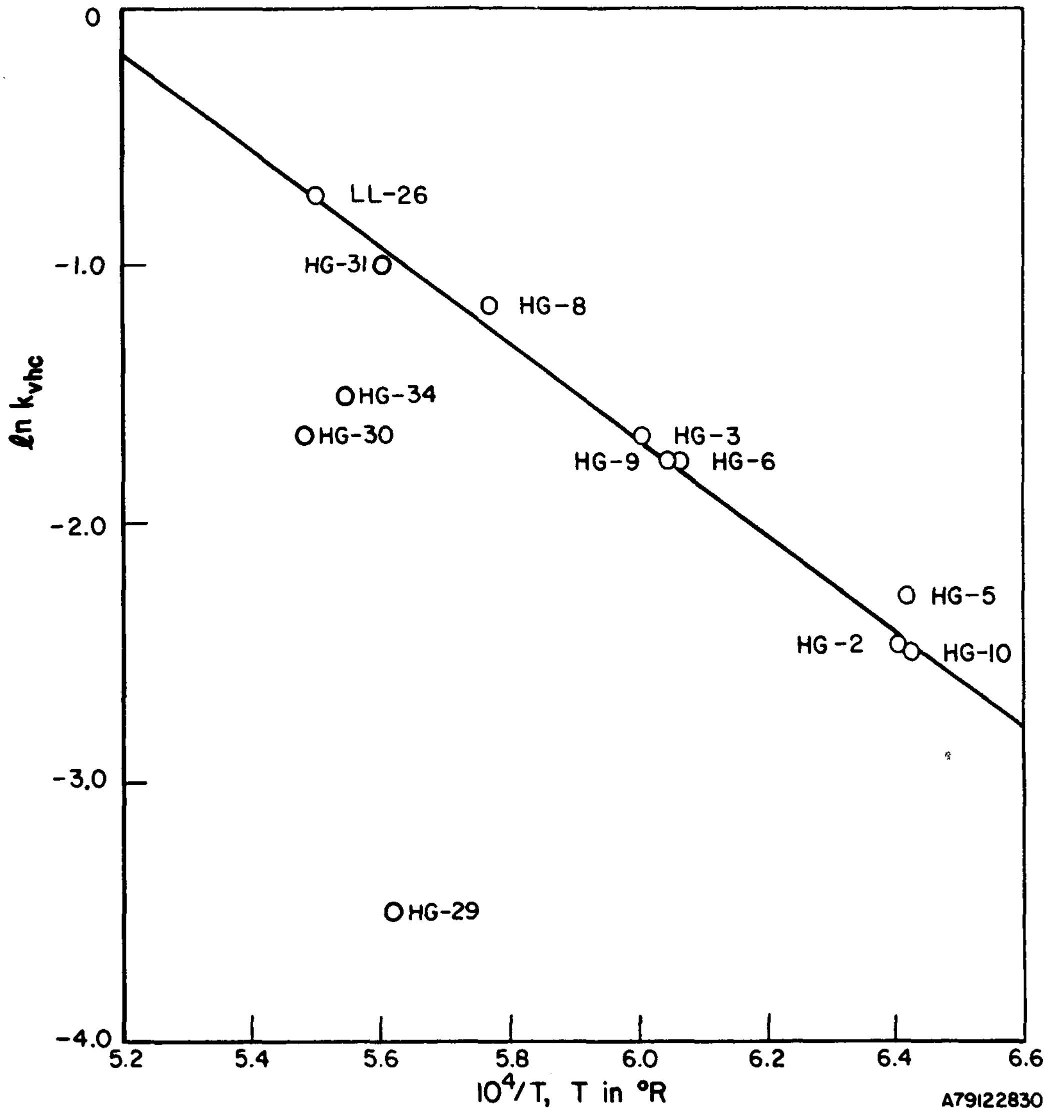

Figure 13. CORRELATION OF VOLATILE LIGHT HYDROCARBON RATE CONSTANT WITH TEMPERATURE

30 and 20 seconds, respectively. The methane concentration in Run HG-29 is about twice the equilibrium value; we should consider the possibility that at these long residence times, some reversal of the methane-forming reaction may be significant. Although the methane concentration in Run HG-34 is not in excess of the equilibrium value, the ethane, which is about half of the volatile hydrocarbon yield, is orders of magnitude greater than the equilibrium amount. In most runs, some of the hydrocarbons have the thermodynamic potential for forming carbon; enough time may be available in Runs HG-24 and HG-35 for that to actually occur.

An equation for the line drawn in Figure 13 is —

$$k_{VHC} = \exp\ (9.512 - 18600/T) \tag{10}$$

The data include runs with hydrogen partial pressures from 3.8 to 14 atm, and yet the line implies no significant dependence on hydrogen pressure. A different conclusion, discussed in Interim Report No. 3,[1] was based on low hydrogen pressure runs and long residence times; these may be further indications of reaction reversal under certain conditions.

The volatile light hydrocarbon yields from North Carolina and Maine peats were analyzed assuming Equations 8 and 9 applied; this required modifying the constants in Equation 10. If we assume that the difference is in the temperature parameter only, a least squares procedure gives, for the two Eastern peats —

$$k_{VHC} = \exp\ (9.512 - 21670/T) \tag{11}$$

The calculated and experimental total light hydrocarbon yields are compared in Figures 14, 15, and 16 for each of the peats studied.

The third product for which kinetic expressions had been reported in Interim Report No. 6 was the benzene-plus-toluene yield. The ultimate yield of benzene was found to be dependent upon the hydrogen pressure. To analyze the more recent data with the Eastern peats, we assumed that this yield could be related with the proximate and ultimate analyses and that the pressure dependence was that found for the Minnesota peat. The data available for the Eastern peats did not indicate any significant difference in the kinetics of benzene-toluene formation. The limiting yields and the rates can be estimated by the following equations:

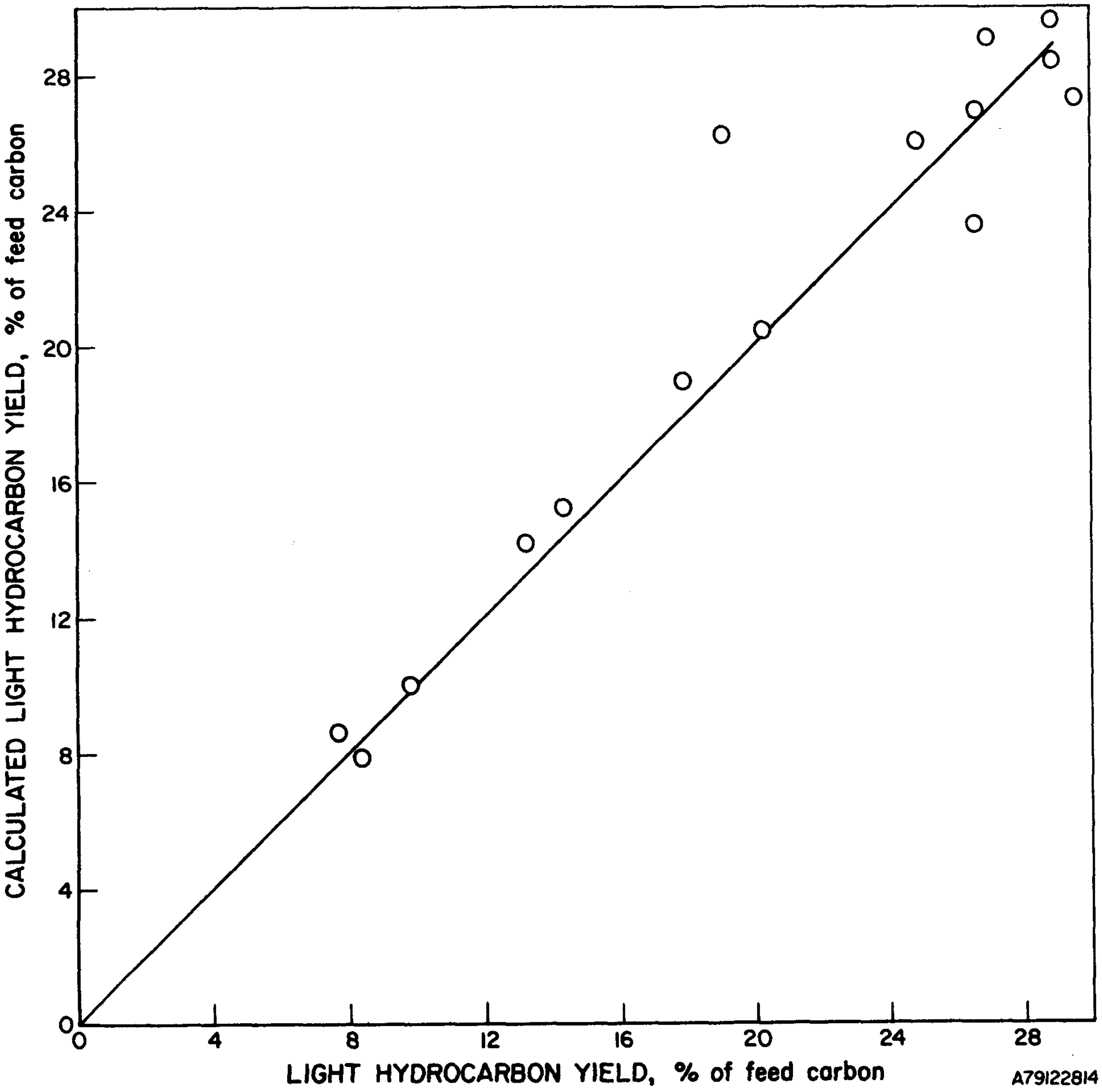

Figure 14. COMPARISON OF LIGHT HYDROCARBON YIELDS WITH CALCULATED YIELDS FOR MINNESOTA PEAT

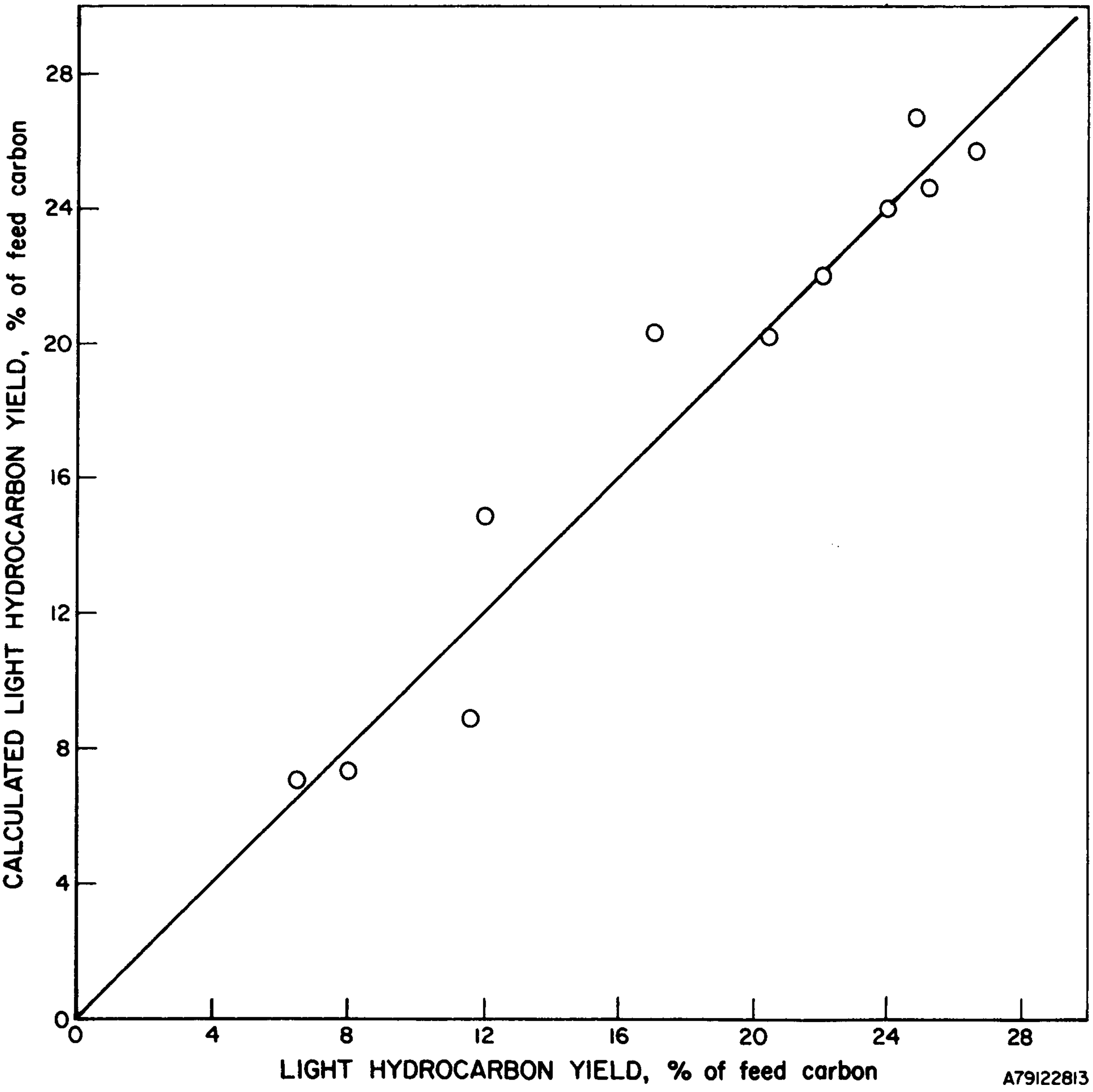

Figure 15. COMPARISON OF LIGHT HYDROCARBON YIELDS WITH CALCULATED YIELDS FOR NORTH CAROLINA PEAT

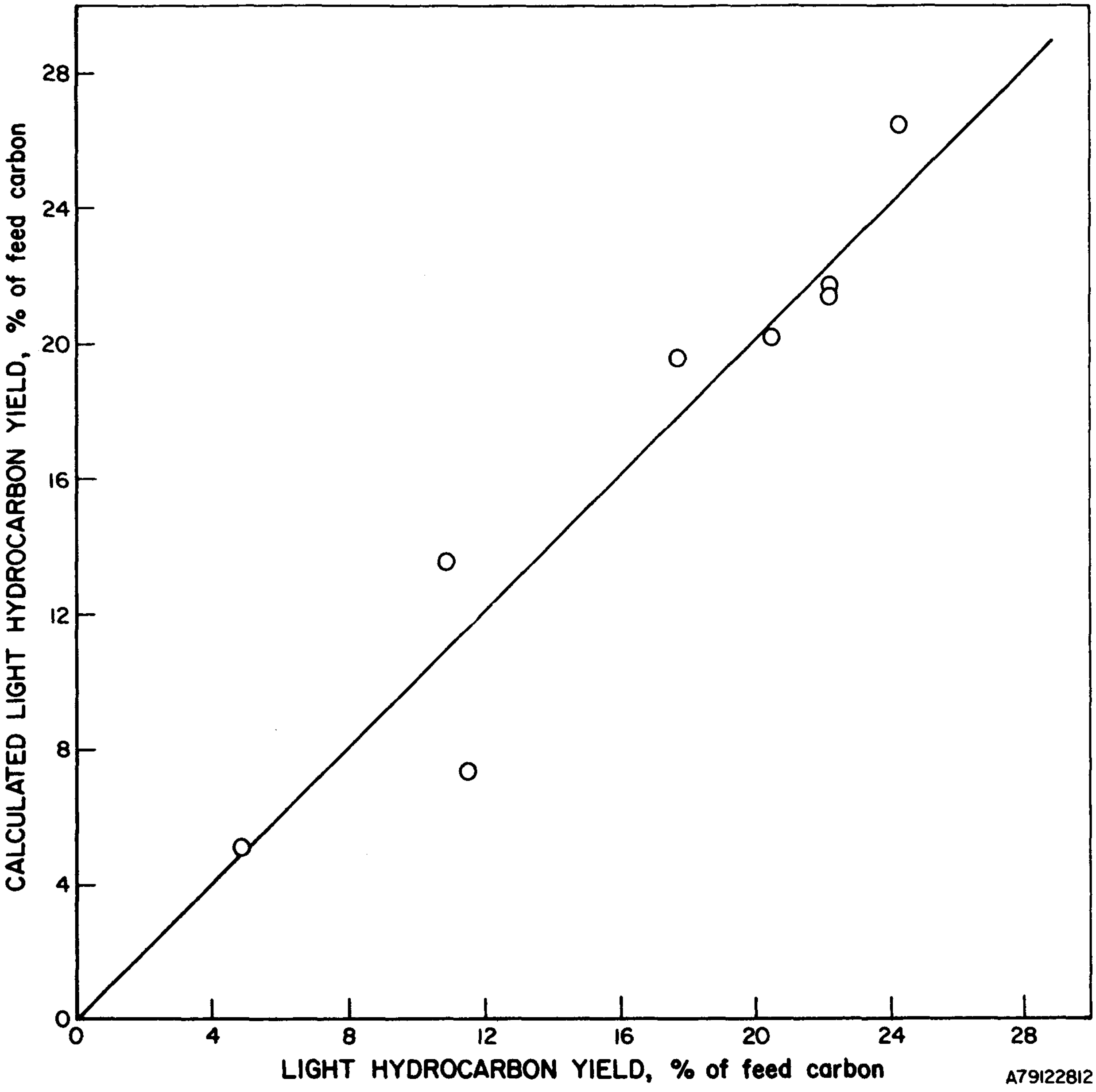

Figure 16. COMPARISON OF LIGHT HYDROCARBON YIELDS WITH CALCULATED YIELDS FOR MAINE PEAT

$$\xi_{\Phi H}^{o} = (0.0132 \ln P_{H_2} + 0.044) \times 3.33 \times (\xi_V^o - \xi_{CO_x}^{o}) \tag{12}$$

$$d\xi_{\Phi H}/d\Theta = k_{\Phi H} (\xi_{\Phi H}^{o} - \xi_{\Phi H}) \tag{13}$$

$$k_{\Phi H} = \exp (8.32 - 18500/T) \tag{14}$$

The computed and experimental values of benzene yield for the three peats are compared in Figure 17. The runs conducted with the lowest pressure (no hydrogen feed) were not included.

The remaining products of the volatilization process appear in different places: condensible hydrocarbons other than benzene and toluene exist in the exit gas stream. Those present in quantities large enough to be detected by mass spectrophotometric analysis range from propane to pentane. Accurate values for carbon yield in the gaseous form cannot be expected because the analysis reports molar quantities that are in the lowest regime of accuracy. The reported carbon yield in the C_3-C_5 range is plotted against temperature in Figure 18 for the Minnesota peat runs. A residence time dependence and possibly a hydrogen pressure dependence should be apparent, but the inaccuracy overshadows them. The curve shown represents the calculated uncompleted secondary or volatile light hydrocarbon yield for Minnesota peat at the average residence time, in accordance with Equation 9. There is reasonable agreement with the upper bound of the C_3-C_5 fraction, inferring that this fraction is the major, if not complete, source of volatile light hydrocarbon gases. (More precisely, we should think of the precursors of the C_3-C_5 fraction as the source of the lighter hydrocarbons, because the C_3-C_5 fraction exists, as far as we know, only upon quenching of the reactant gas stream.)

The remaining volatilization products are recovered in the quench system. These products divide themselves into the oil layer and water soluble materials. This recovery is often incomplete, requiring indirect means of estimating this oil make. As estimation procedure used in the previous studies is based on the assumption that the oils come only from the volatile matter and that the rapid-rate hydrocarbon is the only product from the char carbon. With these, the estimate is —

$$\xi_{oil} = \xi_V^o - \xi_{VHC} - \xi_{CO_2}^{o} - \xi_{C_3\text{-}C_5} - \xi_{\Phi H} \tag{15}$$

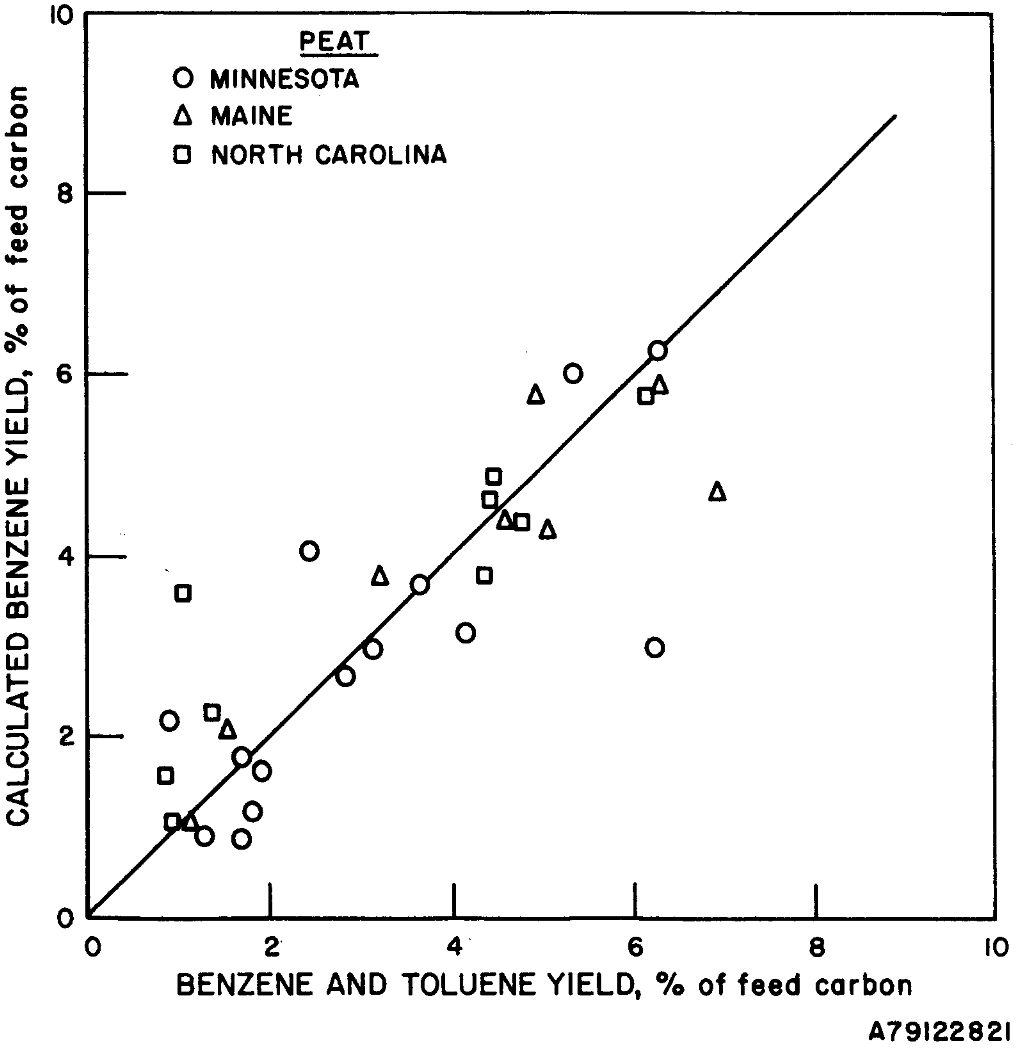

Figure 17. COMPARISON OF EXPERIMENTAL AND CALCULATED YIELDS OF BENZENE

where —

ξ_{oil} is the carbon yield in the condensed liquid product

$\xi_{C_3-C_5}$ is the carbon yield in the C_3-C_5 range.

To test the validity of this estimation method, the recovered oil yield was plotted against the estimated yield for the Minnesota peat. In Figure 19, the upper values include the organic carbon in the water phase when significant. The upper bound of the total recovered oil carbon is in very good agreement with this estimation procedure.

In these hydrogasification tests, the recovered liquid yields were large enough to allow a detailed composition analysis. As indicated, the organic liquid product was recovered as an oil and as a solute in the condensed water

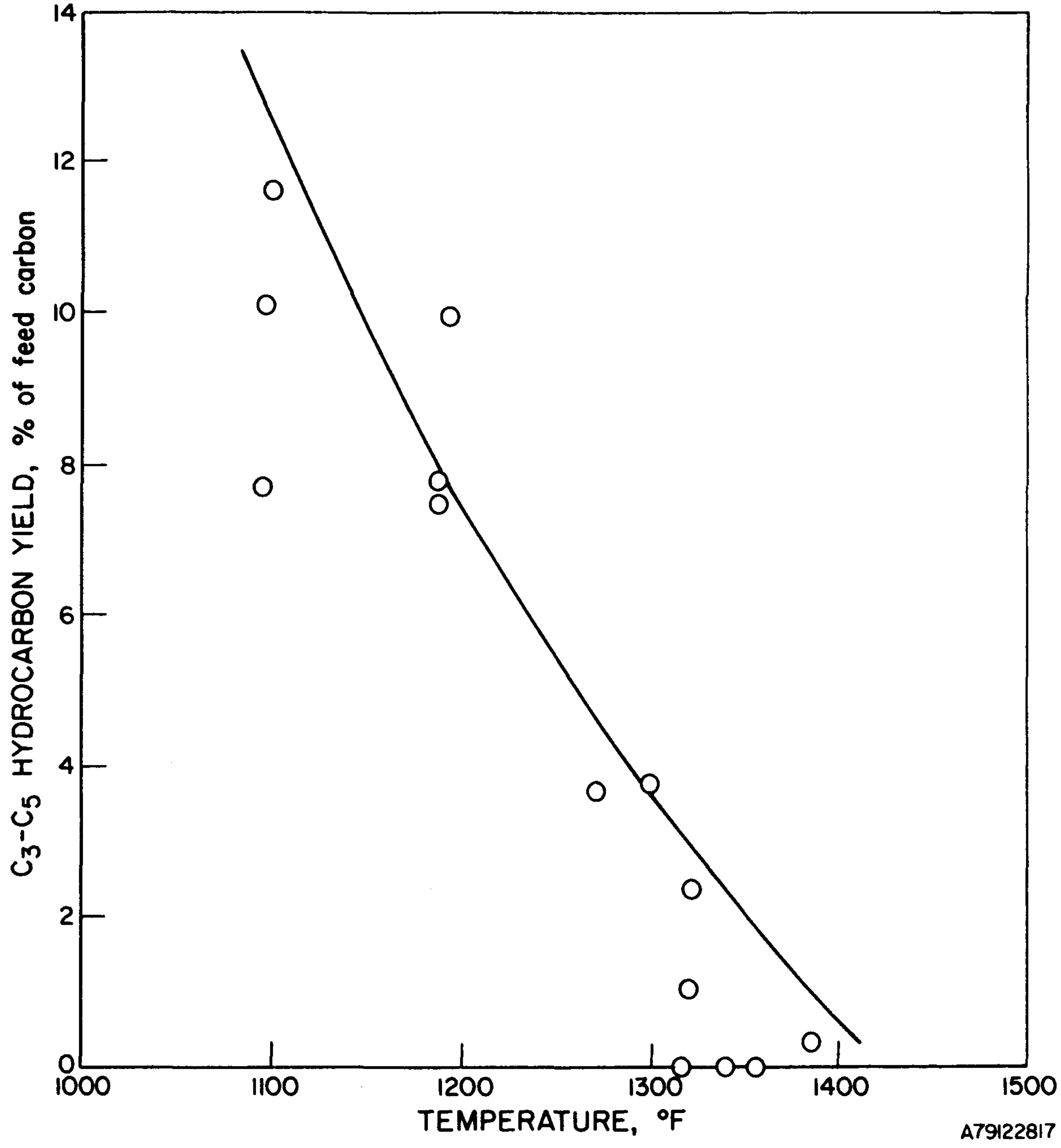

Figure 18. COMPARISON OF C_3 –C_5 HYDROCARBON YIELD WITH SECONDARY LIGHT HYDROCARBON FORMATION FOR MINNESOTA PEAT

phase. The relatively large volume of the water phase meant that very small fractions (a few tenths of a percent) of dissolved organic species were a significant portion of the organic liquid yield. Particularly, from 30% to 90% of the recovered quantities of the phenols and pyridines appeared in the water phase. In the following discussion, these were included in the recovered oil yields, assuming equal efficiencies of recovery and equal accuracies in analysis.

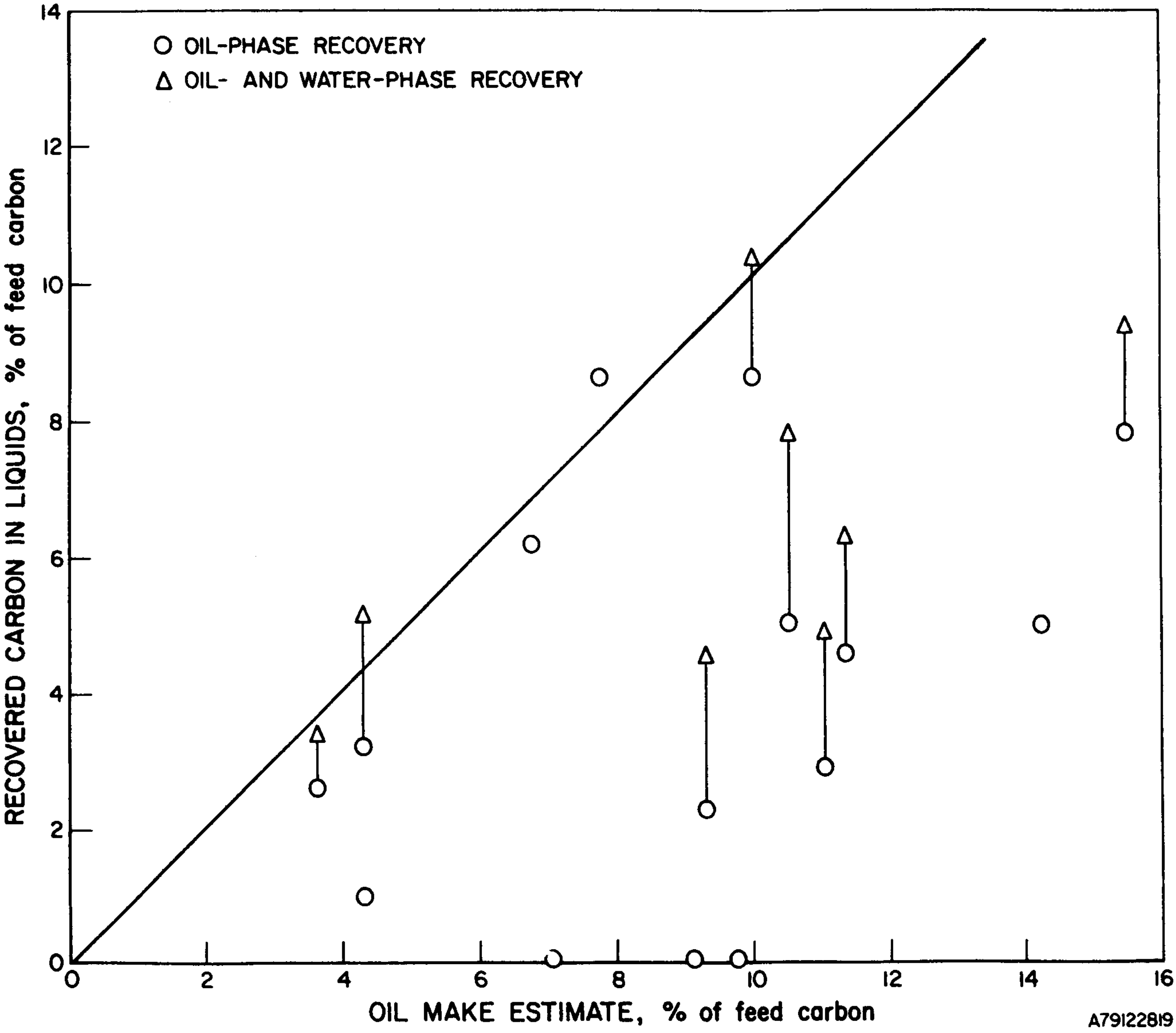

Figure 19. COMPARISON OF CARBON RECOVERED IN LIQUIDS WITH ESTIMATED OIL MAKE

The liquid analyses by GCMS gives a very detailed composition of the collected liquids but, because of the fluctuation in total liquid recovery efficiency and in probable fractionation during the recovery process, significant variations in the liquid composition were observed. An estimate of the standard deviation of yields of the major oil components is about 25% of the observed values based on runs at similar temperatures. For most of the fractions, this uncertainty is a small portion of the total product (gas and liquid) and may amount to 2% of the feed carbon under conditions of high oil yield where some fractions dominate the liquid product.

In these analyses the oil phase of the liquid yield is distilled into a below-400°F fraction, a 400° to 600°F fraction, and the residue. For these discussions, the distillable fractions are combined with the water phase material. Because their appearance below 600°F was caused by incomplete fractionation, the four-ring aromatics were added to the residue fraction. It should be kept in mind that the lighter hydrocarbons are not collected in the liquid phase and that the BTX yield therefore is determined from the product gas composition.

Because the liquid collection is not complete, the total liquid yield must be estimated by difference. To be consistent with the results of the earlier studies, the total oil yield was estimated using Equation 15. This estimate of the oil yield is shown in Figure 20 for Minnesota peat runs within the current series.

The curve drawn emphasizes the runs that had consistent yields of the measured components. The points, derived by difference, reflect the discrepancies of all the other species. Also plotted is the sum of the reported benzene fraction and the estimated oil yield. The line drawn reflects a possible downward trend, implying that a portion of the oil reduction (∿30%) goes to light hydrocarbons and the remainder to benzene. A horizontal line would imply the oil reduction corresponds to benzene formation.

The components of the recovered liquid were combined into characteristic groups:

- Indan and Indene
- Naphthalenes
- Other two-ring aromatics (e.g., biphenyl and acenaphthene)
- Three-ring aromatics (e.g., anthracenes, phenanthrenes, and fluorenes)
- Phenols
- Other oxygenated aromatics (e.g., benzofuran and dibenzofuran)
- Nitrogenated compounds
- Residue (boiling range above 600°F and unidentified)
- Non-aromatics (e.g., alkanes, alkenes, ketones, and alcohols).

Minnesota peat product distribution in these categories is presented in Table 4 for runs in which analysis was reasonably complete. In this table, the total liquid recovery was adjusted according to Figure 20 and its distribution among the several groups taken from the GCMS analyses. Certain qualitative conclusions are apparent. Even for the lowest temperatures studied (1100°F), which include hydrogen pressures as low as 4 atm, the identifiable oil product

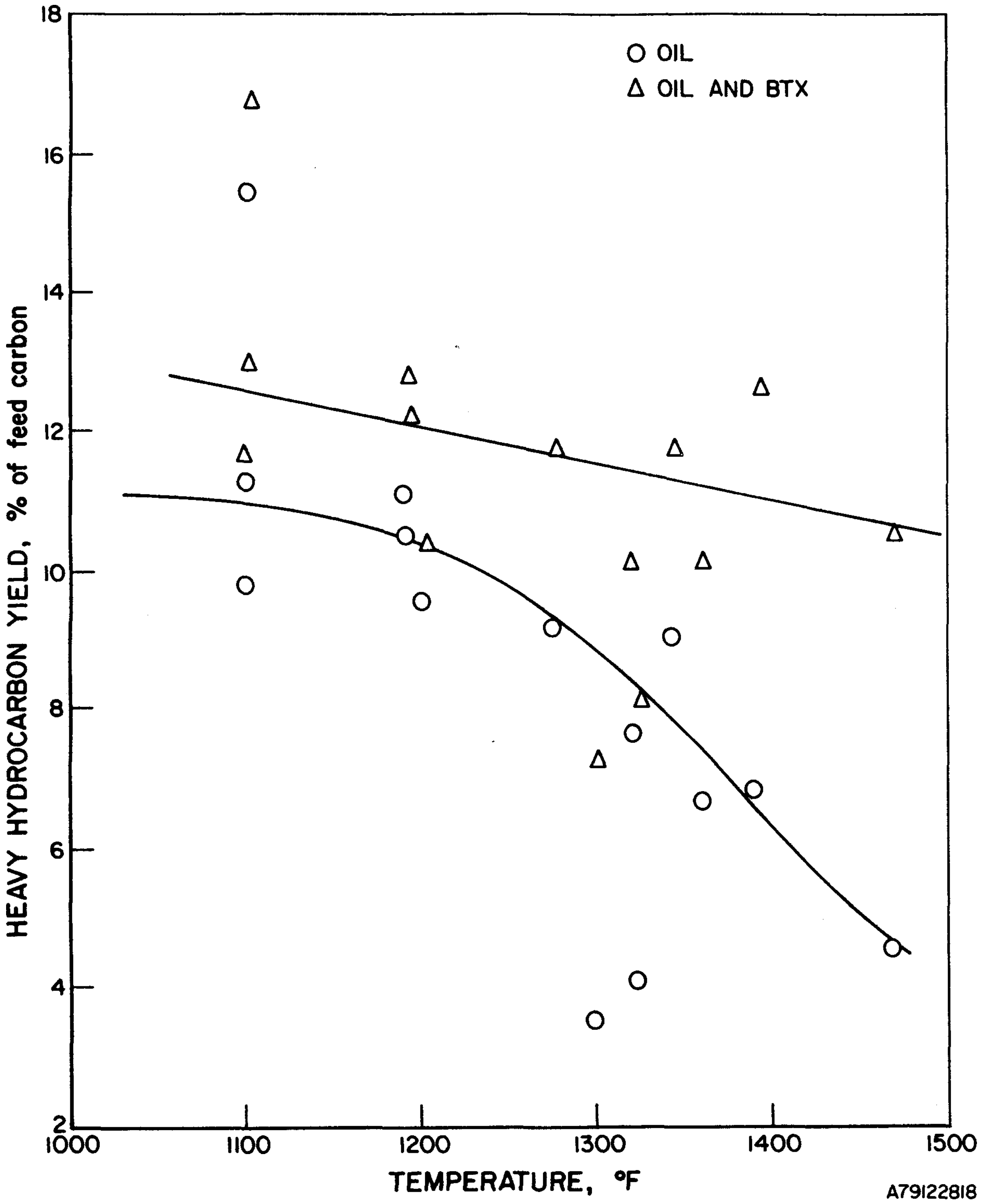

Figure 20. THE EFFECT OF TEMPERATURE ON THE HEAVY HYDROCARBON YIELD

is essentially aromatic. With increasing temperature, the production of all of these species is reduced but becomes most significant above 1300°F. The scatter is too great to define the effect of hydrogen pressure. However, as discussed earlier, hydrogen enhances the rate and amount of benzene production as well as the rate of methane production at the expense of these liquids.

The reported kinetics of decomposition of the larger aromatic materials[1] are much slower than implied by these data. The actual process should not be viewed as a sequential reaction of the stable species from large to small molecules but of some reactive transient species that exist in the reactor that form the stable species observed only on cooling.

Table 4. CONDENSED-PHASE RECOVERIES FROM MINNESOTA PEAT

Run No.	HG-2	HG-5	HG-10	HG-6	HG-9	HG-4	HG-7	HG-23
Temperature, °F	1100	1100	1100	1190	1190	1300	1325	1470
Component, % of feed carbon								
Indans	0.22	0.18	0.20	0.24	0.13	0.09	0.06	0.04
Naphthalene	0.86	0.46	0.71	0.63	0.55	0.66	0.63	0.95
Other 2-Ring Compounds	0.37	0.26	0.39	0.36	0.26	0.34	0.34	0.11
3-Ring Compounds	0.44	0.54	0.45	0.46	0.43	0.67	0.37	0.21
Phenols	3.61	4.24	2.29	4.33	3.22	2.87	3.10	0.55
Other 'O' Compounds	0.78	0.73	0.85	0.56	0.90	0.24	0.50	0.18
'N' Compounds	0.77	0.66	0.67	0.73	1.00	0.69	1.13	0.36
Residue	3.23	3.27	4.64	2.73	3.31	3.22	2.07	1.91
Non-aromatic Compounds	0.76	0.69	0.79	0.38	0.60	0.07	0.10	0.05

FLUIDIZED-BED GASIFICATION TESTS

In the second reaction stage of the conceptual PEATGAS reactor, char from the hydrogasifier is gasified in a fluidized-bed reactor with steam and oxygen to produce synthesis gas. The primary objective of this task was to investigate the gasification characteristics of chars produced from Minnesota, North Carolina, and Maine peats in a PDU-scale fluidized-bed reactor. Additional objectives of this task were to determine the gasification characteristics of the raw peats with steam and oxygen when fed to the top of a single-stage fluidized-bed gasifier and when injected into the bottom high-temperature zone of a single-stage fluidized-bed gasifier.

We conducted a total of 17 tests in a 6-inch-diameter fluidized-bed gasifier. All of these tests were conducted with peat fed to the top of the reactor simulating the flow in the PEATGAS reactor. Three of the tests (Runs CG-5 through CG-7) were performed with Minnesota peat char; five tests (Runs CG-9, CG-10, CG-12, CG-14, and CG-15) were performed with North Carolina peat char; four tests (Runs CG-8, CG-11, CG-13, and CG-16) were performed with dried North Carolina peat; two tests (Runs CG-19 and CG-21) were performed with Maine peat char; and three tests (Runs CG-17, CG-18, and CG-20) were performed with dried Maine peat.

The effect of fluidization velocity on the sintering characteristics of peat was also studied. Operating ranges investigated in these tests are summarized in Table 5 for the tests with Minnesota peat and peat char, in Table 6 for the test with North Carolina peat and peat char, and in Table 7 for the tests with Maine peat and peat char.

All of the tests were conducted with a 34-inch-high fluidized bed in a 6.4-inch inside diameter reactor tube. Three different fluidizing-gas distributors were used for introducing the feed gases to the bottom of the reactor. In Runs CG-5 through CG-9, a 6-port manifold feeder with 1-inch-high cones at each 5/32-inch-diameter port was used. In Runs CG-10 through CG-21, a single, square-edged feed port with a 1/2-inch inside diameter was used.

All chars were produced by limited devolatilization of the partially dried peats in a 10-inch-diameter fluidized-bed reactor at temperatures of 800° to 850°F using air and nitrogen for fluidization. Drying of the as-received peats for char preparation and direct gasification was done in a natural gas-fired rotary dryer at temperatures of 275° to 350°F.

Table 5. OPERATING RANGES TESTED WITH MINNESOTA PEAT CHAR

Dried Peat Moisture Content, wt%	1.6-2.1
Peat Particle Size, U.S.S.	-10+100
Temperature, °F	
Bottom Bed	1680-1705
Average	1630-1660
Pressure, psia	388-541
Fluidization Velocity, ft/s	0.56-0.67
Feed Rate (Dry), lb/hr	51-62
Solids Residence Time, min	27-35
Oxygen/Carbon, mole ratio	0.23-0.44
Steam/Carbon, mole ratio	1.28-2.39
Conversion to Gaseous Products, %	
Carbon	77.3-89.0
Steam	27.1-31.2

Table 6. OPERATING RANGES TESTED WITH NORTH CAROLINA PEAT CHAR AND DRIED PEAT

	Dried Peat	Peat Char
Dried Peat Moisture Content, wt %	3.4-24	0.4-1.0
Peat Particle Size, U.S.S.	-6+60, -10+100	-10+100
Temperature, °F		
Bottom of Bed	1675-1895	1680-1850
Average	1640-1850	1605-1830
Pressure, psia	123-517	365-544
Fluidization Velocity, ft/s	0.45-1.02	0.39-0.78
Feed Rate (Dry), lb/hr	56-76	54-74
Solids Residence Time, min	34-48	22-36
Oxygen/Carbon, mole ratio	0.20-0.30	0.22-0.35
Steam/Carbon, mole ratio	0.74-0.96	1.22-2.04
Conversion to Gaseous Products, %		
Carbon	83.8-94.7	73.3-96.0
Steam	17.6-27.6	32.8-48.8

Table 7. OPERATING RANGES TESTED WITH MAINE PEAT CHAR AND DRIED PEAT

	Dried Peat	Peat Char
Dried Peat Moisture Content, wt %	5.8-20.0	0.7-0.8
Peat Particle Size, U.S.S.	-10+100	-10+100
Temperature, °F		
Bottom of Bed	1680-1820	1730-1910
Average	1610-1720	1675-1840
Pressure, psia	469-530	524-526
Fluidization Velocity, ft/s	0.49-0.78	0.63-0.76
Feed Rate (Dry), lb/hr	51-62	47-60
Solids Residence Time, min	24-35	31-33
Oxygen/Carbon, mole ratio	0.35-0.44	0.39-0.53
Steam/Carbon, mole ratio	1.39-1.71	2.14-2.58
Conversion to Gaseous Products, %		
Carbon	86.2-95.3	91.8-95.2
Steam	3.6-12.6	21.7-28.0

Ash fusion temperatures for the Minnesota, North Carolina, and Maine peats used in the fluidized-bed gasification tests in reducing and in oxidizing atmospheres are given in Table 8. These temperatures are also applicable to the chars of the respective peats.

Equipment used for the raw peat and char gasification tests and the experimental and data analysis procedures are the same as those described in detail in Interim Report No. 6. and will not be repeated here.

Discussion of Experimental Results

The results of the 10 fluidized-bed tests conducted with the three different types of peat chars in the PDU indicate the same high degree of reactivity for the carbon in the chars to steam-oxygen gasification as that found in earlier tests of the peat gasification program performed with Minnesota peat char. Chars prepared from the Minnesota, North Carolina, and Maine peats exhibit similar levels of carbon conversion at similar operating conditions. Conversions of carbon to gaseous products above 89% were obtained with chars

Table 8. ASH FUSION TEMPERATURES OF PEATS FROM MINNESOTA, NORTH CAROLINA, AND MAINE

Sample	Minnesota		North Carolina		Maine	
	Red.*	Ox.**	Red.	Ox.	Red.	Ox.
Initial Deformation, IT	2070	2120	2110	2170	2050	2180
Softening, ST	2190	2240	2540	2580	2270	2360
Softening, HT	2230	2280	2580	2620	2320	2440
Fluid, FT	2650	2700	2700	2700	2700	2700

* Reducing atmosphere.

** Oxidizing atmosphere.

from all three peats at temperatures below 1750°F. In most of the tests the residue chars generally consisted of very fine grayish particles with ash contents above 90%. Only negligible amounts of heavy hydrocarbon liquids were produced in the tests with the peat chars. Except for three tests specifically designed to produce ash sintering, no ash sintering related to operating conditions was experienced in the tests with the different peat chars.

Carbon conversions to gaseous products as high as 95% were obtained with North Carolina and Maine peats at temperatures in the range of 1680° to 1835°F. The amount of heavy hydrocarbon liquids formed depended on the degree of total carbon conversion attained. Carbon appearing in the hydrocarbon liquids was in the range of 2.5% to 4.9% of the carbon in the peat. Residue chars from the tests with both raw peats were similar in appearance and in ash content to the residues from the peat char gasification tests.

We were able to successfully gasify dried North Carolina and Maine peats, following the operational techniques used in earlier tests with dried Minnesota peat. Control of the moisture content and particle size range of the raw peat was required to obtain uniform screw feeding of the peat from the pressurized hopper, to keep the feeder from plugging, and to prevent peat accretion in the reactor freeboard as it was preheated. At high moisture contents, the small particle size range peat would tend to plug the flights of the screw feeder and stop the flow.

Operating conditions and results of the tests performed with the three different dried raw peats and the peat chars are presented in Table 9. Chemical and screen analyses of the feeds for and the residues from these tests are given in Table 10.

Minnesota Peat and Peat Char Tests

The highest carbon gasification achieved in the Minnesota peat char gasification tests was 89.0% of the feed carbon. This level of gasification was obtained in Run CG-7, performed at a pressure of 388 psia, a maximum bed temperature of 1705°F, an oxygen/feed carbon mole ratio of 0.23, a steam/feed carbon mole ratio of 2.4, and a char residence time of 39 minutes. Steam conversion in this test was 29.9% of the steam plus moisture in the char feed. Reducing gas component yields amounted to 6.74 SCF of carbon monoxide and 20.1 SCF of hydrogen per pound of carbon fed. The yield of hydrocarbon gases, mostly methane, was 12% of the carbon fed. The ash content of the residue peat leaving the reactor was 89.2%.

North Carolina Peat and Peat Char Tests

The highest carbon gasification achieved in the tests with North Carolina peat char was 96.0% of the carbon fed in Run CG-12. This test was conducted at a pressure of 492 psia, a maximum bed temperature of 1850°F, and oxygen/feed carbon mole ratio of 0.34, a steam/feed carbon mole ratio of 1.4, and a char residence time of 36 minutes. Steam conversion of the above conditions was 44.2% of the steam plus the char moisture fed. Yields of reducing gases (carbon monoxide and hydrogen) and of hydrocarbon gases per pound of carbon fed were 14.1 SCF of carbon monoxide, 18.2 SCF of hydrogen, and 2.63 SCF of hydrocarbons. Ash content of the gasified peat char leaving the reactor was 89.4%.

Two tests, Runs CG-10 and CG-14, were conducted with North Carolina peat char to determine the fluidization velocity at which the ash sintering in the char would begin when the char was gasified at nominal temperatures of 1800° and 1700°F. In Run CG-10, performed at 1800°F and a nominal pressure of 520 psia,

Table 9. OPERATING CONDITIONS AND RESULTS OF MINNESOTA PEAT CHAR STEAM-OXYGEN GASIFICATION TESTS PERFORMED IN A 6-INCH REACTOR

Run No.	CG-5	CG-6	CG-7	CG-8	CG-9	CG-10			CG-11	CG-12
Feed Material	Minnesota Peat Char (Reducing Atmosphere)		Minnesota Peat Char (Nitrogen Atmosphere)	North Carolina Peat (Dried)	North Carolina Peat Char	North Carolina Peat Char			North Carolina Peat (Dried)	North Carolina Peat Char
Feed Source	IGT Pretreater, Runs PC-29, PC-30, PC-34, PC-37, and PC-40	IGT Pretreater, Runs PC-36, PC-37, PC-39, and PC-43	IGT Pretreater, Runs PC-52 and PC-53	IGT Gas Fired Rotary Dryer	IGT Pretreater, Runs PC-54 and PC-55	IGT Pretreater Runs NC-1, NC-2, & NC-3			IGT Gas-Fired Rotary Dryer	IGT Pretreater Runs NC-4 through NC-7
Feed Sieve Size, U.S.S.	−10+100	−10+100	−10+100	-6+60	-10+100	-10+100			−10+100	−10+100
Duration of Test, hr	4-1/2	5	5-1/4	3	4-3/4	4-1/2			5	5
Steady-State Operating Period, min	100	110	115	25	105	60			70	90
						1	2	3[j]	--	--
Operating Conditions										
Peat (Char) Bed Height, in.	34	34	34	34	34	34	34	34	34	34
Reactor Pressure, psia	541	532	388	514	544	519	519	526	504	507
Reactor Temperature, °F										
Tube Wall, in. from tube bottom[a]										
8	740	510	570	--	975	485	485	485	408	490
12	1505	1480	1455	--	1010	--	--	--	--	--
16	1540	1515	1340	--	995	--	--	--	--	--
78	1190	1175	1220	765	1525	--	--	--	--	--
Internal, in. from tube bottom										
12	1560	1670	1705	1650	1680					
16	1680	1685	1675	1675	1605					
25	1640	1630	1640	1630	1575					
40	1630	1625	1620	1595	1555					
84	1460	1505	1345							
92	1300	1375	1215							
55				1475	1550					
73				1395	1510					
9						1610	1700	1695	1735	1850
11						1710	1730	1725	1790	1830
14						1725	1760	1770	1855	--
18						1725	1775	1790	1855	1825
22						1730	1785	1805	1875	1835
26						1730	1800	1830	1885	1830
34						1725	1810	1850[k]	1880	1820
44						1700	1755	1820	1815	1750
Feed Gas Distributor										
Number of Feed Ports[b]	6	6	6	6	6	1	1	1	1	1
Diameter of Feed Ports, in.	5/32	5/32	5/32	5/32	5/32	0.5	0.5	0.5	1/2	1/2
Char Feed Rate,[c] lb/hr	62.2	50.6	59.7	57.1	65.2	74.1	78.5	83.3	75.5	62.8
Nitrogen Rate, SCF/hr	3393	337	440	2000	2156	3020	2200	1870	3721	2904
Oxygen Rate, SCF/hr	306	336	207	206	253	422	401	389	332	361
Oxygen Concentration in Feed Gas, mol %	8.26	9.1	32.0	9.3	10.5	12.3	--	--	8.2	11.1
Oxygen/Char Ratio, SCF/lb	4.9	6.65	3.5	3.6	3.9	5.7	--	--	4.4	5.8
Oxygen/Carbon Ratio, mol/mol	0.3	0.44	0.23	0.21	0.23	0.35	--	--	0.26	0.31
Steam Rate, lb/hr	59.8	79.8	108.0	44.6	79.0	70.2	71.1	71.1	44.4	79.4
Steam/Char Ratio, lb/lb	0.96	1.6	1.81	0.8	1.2	0.95	--	--	0.6	1.3
Steam/Carbon Ratio, mol/mol	1.3	2.2	2.4	1.0	1.5	1.2	--	--	0.7	1.3
Purge Nitrogen (Shell), SCF/hr	218	280	308	270	232	253	--	--	258	250
Purge Nitrogen (Feed Screw), SCF/hr	96	125	125	138	99	134	--	--	225	168
Char Space Velocity, lb/ft³-hr	97.39	80.3	93.4	89.4	102.0	116	--	--	118.0	98.3
Fluidized Bed Density, lb/ft³	23.1	20.3	22.4	15.6	21.4	23.7	--	--	24.8	26.5
Steam Residence Time,[d] min	0.0707	0.0632	.0848	0.105	0.087	0.637	--	--	0.059	0.061
Superficial Feed Gas Velocity,[e] ft/s	0.673	0.75	0.56	0.45	0.54	0.72	0.62	0.56	0.80	0.79
Operating Results										
Product Gas Rate (Purge Nitrogen-Free),[f] SCF/hr	4596	4685	1878	3240	3509.0	4738	--	--	5200	4710
Product Gas Yield (Nitrogen-Free), SCF/lb	19.24	27.1	24.1	21.1	20.7	23.2	--	--	19.6	28.7
Hydrogen Yield, SCF/lb	7.22	10.1	10.1	6.7	8.3	7.7	--	--	5.0	10.9
Carbon Monoxide Yield, SCF/lb	4.13	6.1	3.4	4.9	3.9	8.9	--	--	5.2	8.4
Carbon Dioxide Yield, SCF/lb	6.71	9.2	8.8	7.4	7.0	5.3	--	--	7.2	8.3
Hydrocarbon Yield, SCF/lb	1.120	1.1	0.12	0.19	0.06	0.085	--	--	0.18	0.07
Residue Char,[g] lb/hr	23.2	15.3	18.0	11.2	29.1	28.6	--	--	10.1	16.7
Bayonet Filter Fines, lb/hr	9.2	9.2	9.0	3.2	6.1	6.2	--	--	6.6	5.1
Sintered Ash (Total), lb	--	--	--	--	--	--	--	3.5	--	--
Sintered Ash Rate, lb/hr	--	--	--	--	--	--	--	--	--	--
Condensed Liquid, Water,[h] lb/hr	41.4	58.9	76.6	32.8	45.3	36.3	--	--	45.0	44.5
Condensed Liquid, Oils and Tars, lb/hr	--	--	--	0.9	--	--	--	--	1.6	--
Net MAF Peat (Char) Gasified, %	76.4	80.3	86.5	91.9	72.3	92.7	--	--	93.8	93.7
Carbon Gasified, wt %	77.3	81.1	89.0	92.6	73.3	95.4	--	--	94.7	96.0
Steam Reacted, lb/hr	19.3	21.9	32.6	12.9	26.0	34.5	--	--	9.64	35.19
Steam Reacted, % of steam fed	31.2	27.1	29.9	27.6	32.8	48.8	--	--	17.6	44.2
Steam Concentration in Product Gas, mol %	15.92	20.9	46.1	18.4	24.2	13.9	--	--	15.4	16.6
Overall Material Balance, %	100.0	101.4	101.0	100.9	101.0	98.4	--	--	102.5	100.4
Carbon Balance, %	101.7	--	106.7	108.2	103.0	112.2	--	--	108.7	107.3
Hydrogen Balance, %	98.6	--	96.2	98.8	98.9	87.9	--	--	99.5	90.7
Oxygen Balance, %	98.9	--	101.1	106.2	102.1	89.4	--	--	107.3	99.1
Product Gas Properties										
Gas Composition (Purge Nitrogen-Free), mol										
Nitrogen	73.93	70.7	23.5	61.7	61.5	63.9	--	--	71.5	61.7
Carbon Monoxide	5.61	6.6	10.8	8.8	7.3	13.9	--	--	7.6	11.2
Carbon Dioxide	9.10	9.9	28.1	13.3	13.1	8.2	--	--	10.4	11.0
Hydrogen	9.80	11.6	32.2	12.2	15.4	12.1	--	--	7.2	14.5
Argon	0.02									
Methane	1.40	1.2	4.9	2.9	2.6	1.8	--	--	2.4	1.5
Ethane	0.10		0.3/	0.6	0.1	0.1	--	--	0.4	0.1
Propane	--			0.1	0.0				0.1	--
Iso-Butane	--									
Ethylene	0.02		0.1	0.1	0.0				0.2	Trace
Propylene	--			0.1	0.0				0.1	--
Butane	--			0.1	0.0				Trace	--
Butadiene	--									
Acetylene	--								Trace	--
Benzene	0.02		0.1	0.1	trace	Trace	--	--	0.1	Trace
Toluene			Trace	Trace	0.0	0.0	--	--	Trace	--
Total	100.00	100.0	100.0	100.0	100.0	100.0	--	--	100.0	100.0
Heating Value,[i] Btu/SCF	65.0	--	195	117	100	89.4	--	--	94.8	98.0
Specific Gravity (Air = 1.00)	0.928	0.925	0.818	0.928	0.895	0.900	--	--	0.958	0.896

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Table 9, Cont. OPERATING CONDITIONS AND RESULTS OF MINNESOTA PEAT CHAR STEAM-OXYGEN GASIFICATION TESTS PERFORMED IN A 6-INCH REACTOR

Run No.	CG-13				CG-14					CG-15	CG-16	CG-17	CG-18	CG-19	CG-20	CG-21
Feed Material	North Carolina Peat (Dried)				North Carolina Peat Char					North Carolina Peat Char	North Carolina Peat (Dried)	Maine Peat (Dried)	Maine Peat (Dried)	Maine Peat Char	Maine Peat (Dried)	Maine Peat Char
Feed Source	IGT Gas-Fired Rotary Dryer				IGT Pretreater, Runs NC-8 and NC-9					IGT Pretreater, Runs NC-10 and NC-11	IGT Gas-Fired Rotary Dryer	IGT Gas-Fired Rotary Dryer	IGT Gas-Fired Rotary Dryer	IGT Pretreater, Runs MAC-1 and MAC-2	IGT Gas-Fired Rotary Dryer	IGT Pretreater, Runs MAC-2, MAC-3a, MAC-4
Sieve Size, U.S.S.	-10+100				-10+100					-10+100	-10+100	-10+100	-10+100	-10+100	-10+100	-10+100
Duration of Test, hr	5				4-3/4					5	3-3/4	3-3/4	4-1/2	4-1/4	5-3/4	4
Steady State Operating Period, min	98				135					120	60	40	90	110	60	30
Run Part No.	1	2	3	4[j]	1	2	3	4	5[j]	--						
Operating Conditions																
Char Bed Height, in.	34				34					34	34	34[m]	34	34	34	34
Reactor Pressure, psia	517	505	507	509	526	528	519	516	517	365	123	530	525	526	469	524
Reactor Temperature, °F																
Tube Wall, in. from tube bottom[a]																
8	500	485	480	480	495	500	495	495	495	485	--	--	470	485	480	480
12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
22	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
30	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
38	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
78	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Internal, in. from tube bottom																
9	1800	1735	1650	1820	1700	1750	1745	1750	1750[k]	--	295	555	1020	1340	665	
11	1805	1790	1740	1785	1705	1740	1730	1725	1735	1670	1730	615	1540	1580	1390	
14	1810	1810	1825	1770	1685	1750	1725	1730	1700	1740	1865	630	1600	1635	1470	
18	1815	1820	1835	1820	1695	1745	1730	1725	1700	--	1865	640	1765	1730	1655	
22	1835	1835	1845	1830	--	--	--	--	--	1670	1895	645	1800	1715	1655	
26	1835	1835	1850	1835	1695	1745	1730	1720	1690	--	1815	650	1815	1705	1685	
34	1815	1820	1860	1845[k]	1695	1740	1720	1705	1670	1605	1600	1570	1805	1690	1820	
44	1705	1710	1755	1745	1695	1735	1715	1690	1670	1565	1385	1680	1605	1580	1720	
Feed Gas Distributor																
Number of Feed Ports[b]	1				1					1	1	1	1	1	1	1
Diameter of Feed Port, in.	1/2				1/2					1/2	1/2	1/2	1/2	1/2	1/2	1/2
Char (Peat) Feed Rate,[c] lb/hr	68.1	69.4	67.9	68.1	54.3	65.4	65.7	66.4	65.5	62.8	55.7	53.3	62.5	59.5	51.4	46.7
Nitrogen Rate, SCF/lb	3525	2971	2268	1591	2836	2204	1476	1098	550	423	436	2350	3017	2470	3606	2917
Oxygen Rate, SCF/hr	352	295	253	272	367	343	330	320	317	250	198	242	274	302	285	335
Oxygen Concentration in Feed Gas, mol %	9.1	--	--	--	11.4	--	--	--	--	37.1	31.2	9.3	8.3	10.9	7.3	10.3
Oxygen/Char Ratio, SCF/lb	5.2	--	--	--	6.8	--	--	--	--	4.0	3.6	4.6	4.4	5.0	5.6	7.19
Oxygen/Carbon Ratio, mol/mol	0.30	--	--	--	0.34	--	--	--	--	.22	0.20	0.37	0.35	0.39	0.44	0.53
Steam Rate, lb/hr	51.1	51.7	52.1	52.8	79.7	80.5	81.9	82.7	83.3	112.0	44.0	45.6	51.9	79.4	52.5	77.9
Steam/Char Ratio, lb/lb	0.8	--	--	--	1.5	--	--	--	--	1.8	0.8	0.9	0.830	1.33	1.02	1.67
Steam/Carbon Ratio, mol/mol	0.9	--	--	--	1.6	--	--	--	--	2.0	0.9	1.4	1.4	2.1	1.7	2.6
Purge Nitrogen (Shell), SCF/hr	253	--	--	--	278	--	--	--	--	194	188	190	223	304	276	255
Purge Nitrogen (Feed Screw), SCF/hr	162	--	--	--	157	--	--	--	--	127	136	150	147	146	274	124
Char (Peat) Space Velocity, lb/ft^3-hr	107.0	--	--	--	85	--	--	--	--	98.2			97.8	93.06	80.48	73.0
Fluidized-Bed Density, lb/ft^3	22.9	--	--	--	22.9	--	--	--	--	25.1	13.0	14.6	17.4	30.2	19.6	22.5
Steam Residence Time,[d] min	0.062	--	--	--	0.066	--	--	--	--	0.077	0.047	0.097	0.077	0.075	0.061	0.063
Superficial Feed Gas Velocity,[e] ft/s	0.77	0.69	0.57	0.47[k]	0.70	0.62	0.54	0.47	0.39[k]	0.62	1.03	0.49	0.64	0.63	0.776	0.76
Operating Results																
Product Gas Rate[f] (Purge Nitrogen-Free), SCF/hr	4899	--	--	--	4471	3837	3133	2646	2174	2254	1651	3197	3946	3618	4261	3854
Product Gas Yield, (Nitrogen Free), SCF/lb	20.2	--	--	--	30.1	--	--	--	--	29.2	21.8	15.9	14.9	19.3	12.71	20.1
Hydrogen Yield, SCF/lb	4.9	--	--	--	11.6	--	--	--	--	12.4	7.6	4.6	3.6	7.3	2.40	7.2
Carbon Monoxide Yield, SCF/lb	5.2	--	--	--	7.4	--	--	--	--	3.9	5.8	3.3	3.2	3.8	1.66	3.8
Carbon Dioxide Yield, SCF/lb	8.0	--	--	--	9.38	--	--	--	--	10.45	6.7	6.4	6.4	7.3	7.71	8.3
Carbon in Hydrocarbon Gas, mol/mol feed carbon	0.18	--	--	--	0.086	--	--	--	--	0.13	0.149	0.177	0.13	0.076	0.21	0.061
Residue Char,[g] lb/hr	7.0	--	--	--	13.0	--	--	--	--	19.0	4.9	16.0	16.3	25.4	12.38	17.2
Bayout Filter Fines, lb/hr	5.8	--	--	--	5.2	--	--	--	--	6.2	8.0	2.9	5.0	6.8	6.89	7.1
Sintered Ash (Total), lb	--	--	--	2.10	--	--	--	--	4.50	--	--	--	--	--	--	5.4
Sintered Ash Rate, lb/hr	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.17
Condensed Liquids,[h] Water, lb/hr	50.1	--	--	--	47.9	--	--	--	--	71.8	49.2	42.7	51.7	57.5	62.98	61.3
Condensed Liquids, Oils and Tars, lb/hr	1.2	--	--	--	--	--	--	--	--	--	1.2	1.1	1.46	--	1.20	--
Net MAF Char (Peat) Gasified, %	93.7	--	--	--	92.7	--	--	--	--	89.2	86.4	93.3	93.8	89.9	87.0	93.4
Carbon Gasified, %	94.2	--	--	--	94.5	--	--	--	--	91.4	83.8	95.3	95.2	91.8	86.2	95.2
Steam Reacted, lb/hr	10.73	--	--	--	32.3	--	--	--	--	40.8	12.0	6.2	5.08	22.39	2.35	17.0
Steam Reacted, % of steam feed	17.6	--	--	--	40.3	--	--	--	--	36.3	19.7	12.6	8.9	28.0	3.60	21.7
Steam Concentration in Producted Gas, mol %	17.7	--	--	--	18.4	--	--	--	--	58.1	38.5	21.9	21.6	25.0	23.7	25.0
Overall Material Balance, %	101.7	--	--	--	99.7	--	--	--	--	102.8	103.3	99.9	100.6	99.5	100.0	98.7
Carbon Balance, %	108.9	--	--	--	107.8	--	--	--	--	105.7	106.2	104.9	105.0	104.4	101.8	108.5
Hydrogen Balance, %	95.5	--	--	--	94.3	--	--	--	--	89.6	90.1	98.4	97.0	94.9	93.5	95.9
Oxygen Balance, %	102.4	--	--	--	96.1	--	--	--	--	103.3	103.7	98.2	100.6	96.8	99.5	93.1
Product Gas Properties																
Gas Composition (Purge Nitrogen-Free), mol %																
Nitrogen	72.0	71.2	64.8	55.5	63.5	57.5	47.2	41.6	25.3	18.9	26.5	73.6	76.5	68.4	84.6	75.80
Carbon Monoxide	7.2	6.8	9.3	12.8	9.1	11.6	14.5	15.5	17.8	10.9	19.4	5.5	5.1	6.2	2.0	4.60
Carbon Dioxide	11.1	11.1	12.6	14.4	11.4	12.0	14.1	16.0	21.2	29.1	22.7	10.6	10.2	12.0	9.3	10.10
Hydrogen	6.8	7.7	9.6	11.9	14.1	16.6	21.1	22.8	28.1	34.5	25.6	7.6	5.7	12.0	2.9	8.70
Methane	2.1	2.5	2.9	4.3	1.8	2.2	3.2	4.0	7.3	6.5	4.3	2.2	2.0	1.3	0.9	0.73
Ethane	0.4	0.4	0.5	0.6	0.1	0.1	0.1	0.1	0.2	0.1	0.5	0.3	0.3	0.1	0.1	0.04
Ethylene/Acetylene	0.2/Trace	0.1/Trace	0.1/--	0.1/Trace							0.4/trace	0.1/trace	0.11/--	trace/--	0.2/--	0.04
Propane/Propylene	Trace/0.1	Trace/0.1	Trace/0.1	0.1/0.1	0.0	0.0	0.0	0.0	0.0	0/tr	0.1/0.1	trace/trace	trace/trace	--/--	--/trace	
Butanes	Trace	Trace	Trace	0.1	0.0	0.0	0.0	0.0	0.0	0/tr	0.1	0.0	trace	--	trace	
Pentanes	--	--	--	--	0.0	0.0	0.0	0.0	0.0	0/tr	trace	0.0	trace	--	trace	
Benzene	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0/tr	0.2	0.1	0.1	trace	trace	Trace
Toluene	Trace	Trace	Trace	Trace	0.0	0.0	0.0	0.0	0.0	0.0	0.1	trace	trace	--	--	--
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	100.0	100.0	100.00	100.00
Heating Value[i], Btu/SCF	82.8	89.2	108.6	142.1	93.7	114	147	164	224	210.8	221	75	65	73	31	51.3
Specific Gravity (Air = 1.00)	0.966	0.969	0.947	0.930	0.901	0.880	0.847	0.838	0.807	0.795	0.857	0.955	0.971	0.925	0.995	0.946

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[a] Bottom of char bed at 8 inches.

[b] Eight inches above the bottom of the reactor tube.

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

[d] (Char-bed volume)/(CF/min feed gas at reactor pressure and temperature).

[e] Based on feed gases: steam + oxygen + nitrogen. (CF/s feed gas at reactor pressure and temperature)/(cross-sectional area of reactor).

[f] Dry-gas volume in SCF at 60°F and 30-in. Hg pressure.

[g] By ash balance.

[h] Based on weight of liquid recovered.

[i] Gross: gas saturated at 60°F, 30-in. Hg pressure.

[j] Ash sintering occurred during this part of the run.

[k] Average maximum temperatures and fluidization velocities at the onset of ash sintering:

Run CG-10 1850°F, 0.56 ft/s
Run CG-13 1845°F, 0.47 ft/s
Run CG-14 1750°F, 0.39 ft/s

[m] The bottom of the fluidized bed was lifted above the gas feed port during the data-reporting period. The bed height varied from 34 to 40 inches during the test.

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Table 10. CHEMICAL AND SCREEN ANALYSES OF FEED AND RESIDUES OF PEAT CHAR STEAM-OXYGEN GASIFICATION TESTS PERFORMED IN A 6-INCH REACTOR

Run No.	CG-5			CG-6			CG-7			CG-8			CG-9		
Sample	Feed	Residue	Filter Fines	Feed	Residue	Filter Fines	Feed	Residue	Filter Fines	Feed*	Residue	Filter Fines	Feed**	Residue	Filter Fines
Proximate Analysis, wt %															
Moisture	1.6	0.2	2.2	1.7	0.0	1.4	2.1	0.1	7.6	3.4	1.0	1.7	0.4	0.2	4.9
Volatile Matter	16.3	2.4	12.6	20.2	2.3	8.6	20.2	1.6	9.4	47.2	8.1	11.1	13.7	3.3	9.4
Fixed Carbon	44.1	13.9	36.1	40.5	6.6	32.0	42.9	8.8	31.1	33.4	14.6	60.9	50.1	20.2	66.8
Ash	38.0	83.5	49.1	37.6	91.1	58.0	34.8	89.5	51.9	16.0	76.3	26.3	35.8	76.3	18.9
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	100.0	100.0	100.0
Ultimate Analysis (Dry), wt %															
Carbon	49.90	15.60	43.40	48.30	8.48	36.10	50.40	10.71	37.40	54.0	17.7	65.3	54.3	20.9	72.3
Hydrogen	2.08	0.16	1.36	2.30	0.15	1.18	2.24	0.08	1.81	4.05	0.76	1.92	2.00	0.36	1.55
Nitrogen	1.83	0.00	1.18	1.97	0.04	1.10	2.11	0.00	1.11	1.22	0.23	1.22	1.25	0.16	1.01
Oxygen	7.36	0.51	3.67	8.93	0.20	2.68	9.46	0.00	3.28	23.95	4.17	4.64	6.20	2.05	5.14
Sulfur	0.25	0.09	0.21	0.22	0.01	0.16	0.26	0.06	0.21	0.20	0.06	0.18	0.29	0.05	0.13
Ash	38.58	83.64	50.18	38.28	91.12	58.78	35.53	89.15	56.19	16.58	77.08	26.74	35.96	76.48	19.87
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	100.00
Screen Analysis, U.S.S., wt %															
+12	2.4	1.0	5.2	1.6	0.9	1.6	6.3	1.1	1.7	0.5	0.1	0.5	8.5	1.7	0.0
+20	16.4	9.0	2.3	13.6	6.4	1.6	36.7	7.4	0.4	20.2	5.7	0.7	25.2	4.7	0.0
+30	9.5	6.4	0.7	9.3	4.3	0.7	12.3	6.5	0.4	13.9	6.1	0.5	14.0	4.0	0.0
+40	13.3	8.6	0.9	14.6	6.6	0.7	11.8	9.6	0.4	14.2	7.3	0.2	12.4	5.0	0.0
+60	19.3	16.3	0.9	21.4	14.6	1.0	15.5	18.9	0.2	23.5	19.9	0.7	15.9	13.1	0.0
+80	11.1	13.7	0.5	11.3	12.7	0.7	6.8	13.0	0.6	14.2	24.9	1.2	11.6	22.8	0.0
+100	8.1	9.8	0.5	7.3	9.9	0.7	3.1	9.7	0.9	3.9	9.1	1.5	7.0	20.1	3.4
+200	13.3	9.5	7.5	12.8	16.0	4.9	4.4	13.5	9.0	2.9	8.3	7.4	5.4	24.3	35.6
+325	3.8	6.6	22.9	4.5	7.3	12.5	1.8	7.8	14.3	2.2	9.8	13.9	0.0	2.0	26.9
−325	2.8	19.1	58.6	3.6	21.3	75.6	1.3	12.5	72.1	4.5	8.8	73.4	0.0	2.3	34.1
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	100.0	100.0	100.0
Bulk Density, lb/ft^3	28.5	46.6	31.6	28.5	49.5	28.9	27.3	37.3	26.7	30.0	42.1	21.6	35.6	38.1	22.7
Gross Heating Value, Btu/lb	7987	2332	6880	7768	1311	5781	7998	1617	6316	8,517	2,725	10,336	8,669	3,106	11,083

Run No.	CG-10			CG-11			CG-12			CG-13			CG-14		
Sample	Feed	Residue	Filter Fines	Feed*	Residue	Filter Fines	Feed**	Residue	Filter Fines	Feed*	Residue	Filter Fines	Feed	Residue	Filter Fines
Proximate Analysis, wt %															
Moisture	0.8	0.1	2.0	11.9	0.0	5.5	0.4	0.1	6.2	12.5	0.2	1.2	1.0	0.1	3.2
Volatile Matter	15.6	1.3	9.3	46.6	2.5	11.9	18.7	3.1	8.0	48.5	2.4	17.3	18.6	1.7	8.0
Fixed Carbon	46.8	8.8	31.1	27.8	5.0	47.7	53.6	7.5	44.4	29.1	14.7	48.7	56.1	11.6	50.2
Ash	36.8	89.8	57.6	13.7	92.5	34.9	27.3	89.3	41.4	9.9	82.7	32.8	24.3	86.6	38.6
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	100.0	100.0	100.0
Ultimate Analysis (Dry), wt %															
Carbon	51.60	9.30	60.90	53.30	6.50	55.30	59.60	10.00	49.90	54.00	15.80	56.90	62.30	12.80	54.40
Hydrogen	2.00	0.18	1.29	4.19	0.20	1.61	2.49	0.15	0.99	4.43	0.23	2.13	2.46	0.16	1.24
Nitrogen	1.20	0.06	0.86	1.28	0.14	1.04	1.51	0.17	0.70	1.27	0.19	1.06	1.41	0.12	0.84
Oxygen	7.93	0.56	4.87	25.39	0.58	4.65	8.85	0.21	4.12	28.76	0.88	6.45	9.22	0.23	3.57
Sulfur	0.21	0.02	0.36	0.29	0.07	0.40	0.15	0.03	0.14	0.20	0.06	0.25	0.09	0.00	0.08
Ash	37.06	89.88	31.72	15.55	92.51	37.00	27.40	89.44	44.15	11.34	82.84	33.21	24.52	86.69	39.87
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	100,00
Screen Analysis, USS, wt %															
+12	10.5	2.6	0.0	11.5	11.6	0.0	9.3	4.2	0.4	22.5	5.3	1.1	11.8	2.6	0.0
+20	25.1	4.3	0.0	21.4	10.2	0.0	23.3	8.9	0.4	26.1	9.4	1.8	28.1	6.1	0.5
+30	11.2	2.3	0.0	9.4	2.8	0.0	11.1	4.6	0.4	10.1	4.4	1.4	11.3	3.6	0.0
+40	11.6	2.3	0.0	15.4	2.7	0.0	10.1	4.7	0.4	9.4	3.8	1.4	9.4	3.6	0.3
+60	16.1	9.2	0.7	21.4	13.6	2.3	16.1	22.1	3.1	12.1	11.7	2.3	14.3	13.9	0.8
+80	3.3	33.4	1.5	6.5	23.9	0.9	12.6	36.5	9.3	1.0	24.3	3.4	11.3	33.3	0.5
+100	13.6	22.5	2.5	9.5	23.8	2.1	5.4	7.1	8.0	9.2	13.9	3.7	4.9	16.6	4.3
+200	6.8	21.5	36.1	3.6	9.8	26.7	9.7	7.1	23.0	5.9	17.8	24.4	6,8	14.6	26,6
+325	0.7	1.0	25.8	0.9	0.4	12.3	1.2	0.6	9.1	2.0	3.8	17.2	0.8	1.7	20.7
-325	1.1	0.9	33.4	0.4	1.2	55.7	1.2	4.2	45.9	1.7	5.6	43.3	1.3	4.0	46.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100,0	100.0
Bulk Density, lb/ft^3	28.5	66.1	19.8	28.8	46.0	18.6	28.4	63.4	21.6	31.1	41.3	25.3	25.2	51.5	22.7
Gross Heating Value, Btu/lb	8139	1422	9[illegible]	8394	1027	8697	9533	1532	7558	8380	2375	9107	9876	1943	8408

* North Carolina peat (dried).
** North Carolina peat char.

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Table 10, Cont. CHEMICAL AND SCREEN ANALYSES OF FEED AND RESIDUES OF PEAT CHAR STEAM-OXYGEN GASIFICATION TESTS PERFORMED IN A 6-INCH REACTOR

Run No.	CG-15			CG-16			CG-17			CG-18		
Sample	Feed	Residue	Filter Fines	Feed*	Residue	Filter Fines	Feed**	Residue	Filter Fines	Feed**	Residue	Filter Fines
Proximate Analysis, wt %												
Moisture	0.9	0.0	9.6	23.6	1.4	1.1	5.8	0.2	8.8	7.3	0.2	1.7
Volatile Matter	15.3	3.1	8.7	42.9	17.4	20.7	42.5	1.5	14.8	42.7	1.5	5.7
Fixed Carbon	53.7	6.0	55.4	26.6	19.5	53.5	20.8	0.5	20.2	20.7	2.0	12.5
Ash	30.1	90.0	26.3	6.9	61.7	24.7	30.9	97.8	56.2	29.3	96.3	80.1
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 (dry), wt %												
Carbon	58.30	6.60	63.80	56.60	27.80	62.10	39.50	1.20	30.70	39.70	2.70	15.70
Hydrogen	2.08	0.18	1.06	4.54	1.68	2.30	3.60	0.07	1.37	3.64	0.08	0.61
Nitrogen	1.21	0.12	1.96	1.41	0.65	1.28	1.60	0.03	0.99	1.23	0.10	0.42
Oxygen	7.89	2.09	3.88	28.06	6.92	8.99	21.95	0.63	4.69	23.30	0.59	1.64
Sulfur	0.15	0.03	0.17	0.37	0.39	0.37	0.53	0.10	0.64	0.53	0.04	0.17
Ash	30.37	90.98	29.13	9.02	62.56	24.96	32.82	97.97	61.61	31.60	96.49	81.46
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
Screen Analysis, U.S.S., wt %												
+12	7.7	3.7	0.5	29.2	3.1	1.5	59.4	19.2	7.6	43.7	4.2	0.6
+20	22.6	2.3	1.7	20.7	5.6	2.2	34.2	29.1	4.2	29.7	11.4	0.6
+30	10.2	1.1	1.0	9.3	5.6	1.0	4.1	9.1	1.8	9.3	7.3	0.4
+40	9.3	1.6	3.2	8.6	7.3	1.0	1.2	7.4	1.6	6.4	10.0	0.4
+60	16.0	8.7	6.7	11.7	16.5	1.5	0.5	9.0	3.1	5.4	20.5	0.4
+80	15.1	30.5	3.2	7.1	25.1	3.9	0.2	4.4	7.3	0.5	12.3	0.8
+100	7.5	21.5	10.1	3.3	14.4	3.9	0.0	1.8	38.8	2.1	5.7	1.2
+200	10.7	29.4	36.8	6.1	18.5	29.7	0.2	4.9	23.6	1.2	15.0	17.9
+325	0.7	1.1	14.3	2.2	2.4	20.1	0.0	7.2	8.7	1.2	4.4	15.9
-325	0.2	0.1	22.5	1.8	1.5	35.2	0.2	7.9	3.3	0.5	9.2	61.8
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
Bulk Density, lb/ft^3	26.9	82.3	20.6	31.1	47.0	22.3	27.8	37.6	27.5	33.3	46.3	35.9
Gross Heating Value, Btu/lb	9164	961	9643	8880	4565	9776	6297	179	4977	6247	398	2542

Run No.	CG-19			CG-20			CG-21		
Sample	Feed†	Residue	Filter Fines	Feed*	Residue	Filter Fines	Feed	Residue	Filter Fines
Proximate Analysis, wt %									
Moisture	0.8	0.0	2.0	20.0	0.1	1.7	0.7	0.1	2.0
Volatile Matter	15.7	3.1	6.8	37.3	10.6	7.3	18.5	3.0	8.2
Fixed Carbon	35.6	3.3	20.0	17.5	3.4	11.8	35.6	0.9	25.5
Ash	47.9	93.6	71.2	25.2	85.9	79.2	45.2	96.0	64.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %									
Carbon	41.70	5.90	24.20	39.90	9.00	15.90	43.10	3.26	29.80
Hydrogen	1.62	0.13	0.87	3.45	0.37	0.57	1.53	0.15	0.91
Nitrogen	0.85	0.10	0.47	1.18	0.22	0.35	0.73	0.09	0.51
Oxygen	7.04	0.09	1.54	23.43	4.12	2.29	9.28	0.38	2.93
Sulfur	0.53	0.12	0.23	0.52	0.23	0.31	0.06	0.06	0.26
Ash	48.26	93.66	72.69	31.52	86.06	80.58	45.30	96.06	65.59
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Screen Analysis, U.S.S., wt %									
+12	2.7	0.0	0.0	31.4	9.8	0.7	14.1	3.6	0.0
+20	13.9	6.1	0.0	25.2	11.4	0.7	15.4	6.0	0.0
+30	7.7	6.1	0.0	10.5	8.8	0.5	9.5	3.7	0.0
+40	13.0	12.3	0.0	11.6	11.4	0.5	9.8	7.0	0.2
+60	37.8	41.6	0.0	12.4	17.6	0.9	16.2	18.1	0.2
+80	21.9	26.7	1.6	1.9	10.3	1.6	10.4	13.2	0.5
+100	1.2	2.6	0.3	3.1	4.8	1.6	4.8	12.0	0.8
+200	1.1	3.4	10.5	2.3	6.8	8.2	9.2	24.3	10.3
+325	0.0	0.3	9.4	0.4	8.8	26.5	8.1	6.2	35.3
-325	0.7	0.9	78.2	1.2	10.3	58.8	2.5	5.9	52.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Bulk Density, lb/ft^3	34.1	64.4	25.1	27.5	54.7	34.0	40.1	54.6	33.4
Gross Heating Value, Btu/lb	6545	937	3949	6147	1318	2501	6500	540	4682

* North Carolina peat.

** Maine peat.

† Maine peat char.

the fluidization velocity was reduced in two increments from an initial value of 0.72 ft/s, to 0.62 ft/s, and finally to 0.56 ft/s. Ash sintering began 10 minutes after the fluidization velocity was reduced to 0.56 ft/s. The average maximum temperature in the fluidized bed during the ash sintering portion of the test was 1850°F.

To study ash sintering at a lower temperature, Run CG-14 was conducted at a nominal temperature of 1700°F and a nominal pressure of 520 psia. The test was started at a fluidization velocity of 0.70 ft/s after which the fluidization velocity was reduced in four stages to 0.39 ft/s. Ash sintering occurred shortly after the last fluidization velocity was reached. The temperature at the bottom of the reactor was 1750°F at the time ash sintering started.

In the gasification tests performed with dried North Carolina peat, the highest carbon conversion achieved was 94.7% of the carbon in the peat. To obtain this carbon conversion, the peat was gasified at a pressure of 504 psia, a maximum bed temperature of 1885°F, an oxygen/carbon mole ratio of 0.26, a steam/carbon mole ratio of 0.74, and a peat residence time of 46 minutes. Steam conversion was 17.6% of the steam plus the moisture in the peat fed. The residue peat leaving the reactor had an ash content of 92.5%. Oils, condensed from the wet product gas leaving the top of the reactor, contained carbon representing 3.3% of the carbon in the feed peat. Yields of reducing gases and hydrocarbons per pound of carbon fed were 9.82 SCF of carbon monoxide, 9.30 SCF of hydrogen, and 3.94 SCF of hydrocarbons.

The objective of Run CG-13 was to determine the fluidization velocity at which the ash in the dried North Carolina peat would sinter. The test was conducted at a nominal temperature of 1850°F and a nominal pressure of 510 psia. This test, Run CG-13, was started at a fluidization velocity of 0.77 ft/s. The fluidization velocity was then lowered in three stages to 0.47 ft/s by reducing the fluidizing nitrogen rate. Shortly after the last reduction in the fluidization velocity was made, ash sintering began.

Maine Peat and Peat Char Tests

The tests with Maine peat char indicated a high degree of reactivity for the carbon in the char to steam-oxygen gasification as carbon conversions of 91.8% and 95.2% were achieved at a pressure of 525 psia and at temperatures of 1730° and 1910°F, respectively. To obtain the higher carbon conversion, an oxygen/feed carbon mole ratio of 0.53, a steam/feed carbon mole ratio of 2.6, and a char residence time of 31 minutes were required. At these conditions, 21.7% of the steam plus the moisture in the char fed was converted, and a residue char with an ash content of 96.1% was produced. Gaseous yields per pound of carbon fed were 8.82 SCF of carbon monoxide, 16.68 SCF of hydrogen, and 1.57 SCF of hydrocarbons.

The highest level of carbon gasification achieved with raw Maine peat was 95.3% in a test using Maine peat dried to a 5.8% moisture content. The peat was gasified at a nominal pressure of 530 psia, a temperature of 1680°F, and a residence time of 24 minutes in the reactor. An oxygen/feed carbon mole ratio of 0.36 and a steam/feed carbon mole ratio of 1.44 were required for the gasification of the peat in this test. Conversion of the feed steam plus the moisture in the peat was 12.6%. Reducing gas yields per pound of carbon fed were 8.36 SCF of carbon monoxide and 11.55 SCF of hydrogen; gaseous hydrocarbon yield was 4.10 SCF per pound of carbon fed.

The reported carbon gasification percentages for both the peat char and the peat tests are based on the carbon in the feed leaving the feed hopper. If corrected for the carbon in the char fines carried out with the product gases and collected in the bayonet filter, which is not available for gasification in the char bed, the carbon gasification percentage would be higher. Carbon remaining in the bayonet filter fines, for all tests, was in the range of 3.1% to 15.6% of the carbon in the peat and peat char fed. Carbon converted to heavy hydrocarbon liquids, also limited the total carbon conversion to gaseous products. Typically, with dried North Carolina peat 2.5% to 3.3% of the feed carbon appeared in the hydrocarbon liquids, and with dried Maine peat, 4.4% to 4.9% of the feed carbon appeared in the hydrocarbon liquids. In the tests performed with the peat chars, the production of hydrocarbon liquids was substantially less. For the three different peats and peat chars tested, the concentrations and yields of the different gas species in the product gases were influenced by the gasification temperature, pressure, oxygen/feed carbon ratio, and the steam/feed carbon ratio. Generally, the carbon oxide yields (particularly the carbon dioxide yield) per pound of carbon feed increased with in increase in the oxygen/feed carbon ratio. Hydrogen yields from the peat char gasifications tended to increase with an increase in the steam/feed carbon ratio. In the raw peat gasification tests, the hydrogen yields were significantly affected by the steam/feed carbon ratio. The high oxygen and moisture contents of the raw peats, relative to that of the chars, limited the steam decomposition in the raw peat tests. There was a significant difference in the concentrations and yields of the gaseous species between gases produced in the peat char and peat tests. The most prominent difference was that the hydrocarbon yield in peat gasification tests was 2 to 3 times larger than that from the peat char gasification tests. Hydrocarbon gases produced in tests with peat char consisted of methane and ethane. In tests with raw peat, hydrocarbon gases (in addition to methane and ethane) included ethylene, propane, propylene, butanes, and pentanes. The predominant hydrocarbon in the product gases from both feeds was methane. However, carbon monoxide and hydrogen yields in the peat char gasification tests tended to be nearly twice as large as those in the raw peat gasification tests.

With all three peats, the steam conversions were substantially higher in the tests with peat char than in the tests with raw peat. Part of the reason for this difference is the higher oxygen content of the raw peat compared with that in the peat char. In addition to temperature and pressure, steam conversions were basically determined by the steam/feed carbon ratio and by the total steam feed. Steam conversions, on a mole/mole feed carbon basis, generally increased with an increase in the steam/feed carbon ratio. However, the fraction of steam reacting generally decreased with an increase in the steam feed rate. In the tests with North Carolina peat char steam conversions were in the range of 0.49 to 0.74 mole/mole feed carbon, whereas with the raw peat, steam conversions were in the range of 0.16 to 0.28 mole/mole feed carbon. Gasification tests with Maine peat char yielded steam conversions in the range of 0.56 to 0.60 mole/mole feed carbon, and those with raw peat produced steam conversion in the range of 0.076 to 0.20 mole/mole feed carbon.

The influence of the maximum gasification temperature and the fluidization velocity on the ash sintering characteristics of North Carolina peat and peat char is shown in Figure 21. Data from nine tests are plotted in this figure. Although not definitive, the curve delineates operating regions of ash sintering and non-sintering up to 1900°F.

Most of the tests were conducted with a 34-inch fluidized bed as solids were screw fed to the top of the reactor for free-fall to the top of the

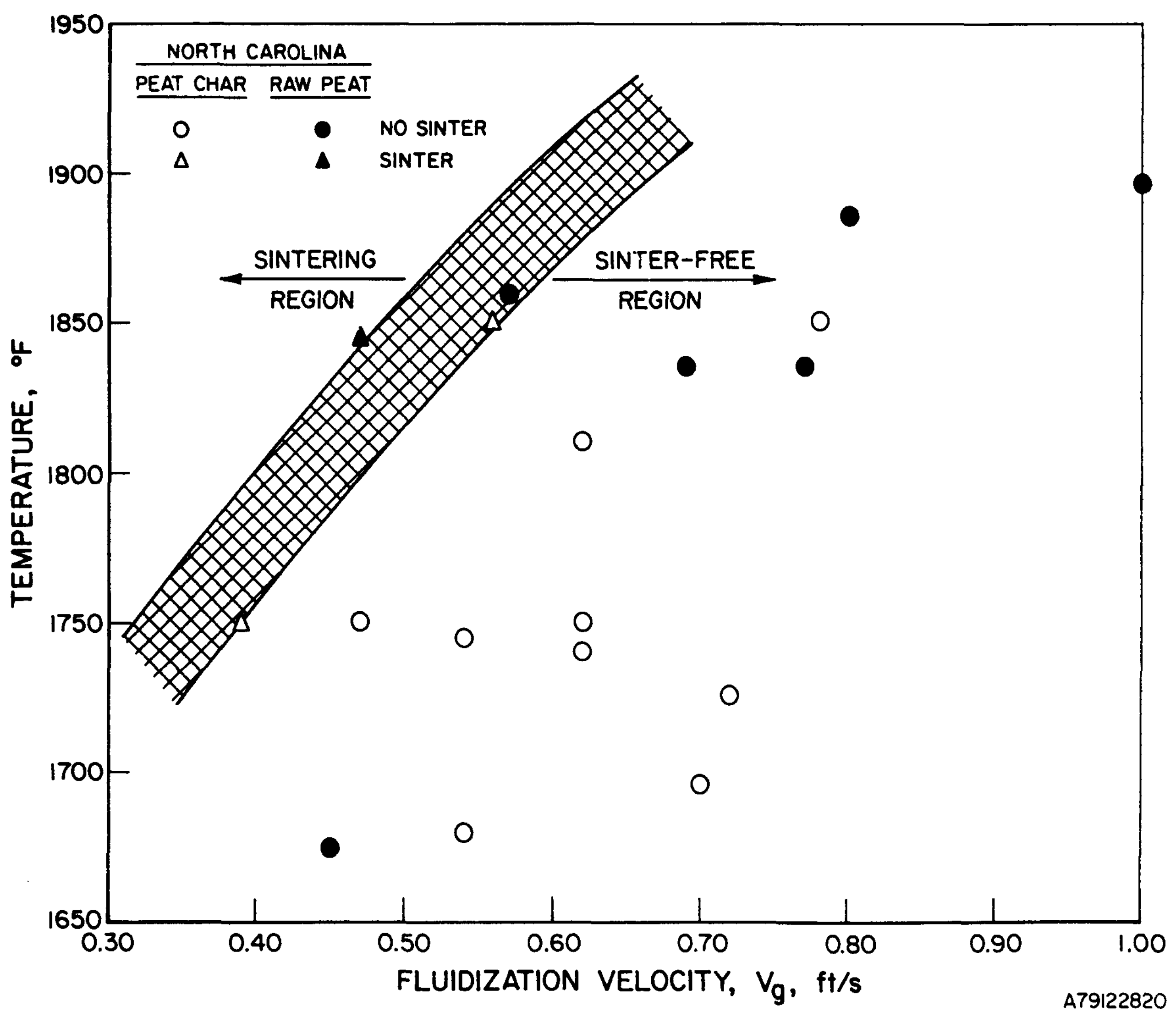

Figure 21. THE EFFECTS OF TEMPERATURE AND FLUIDIZATION VELOCITY ON THE ASH SINTERING CHARACTERISTICS OF NORTH CAROLINA PEAT

fluidized bed. Feed gases were introduced to the bottom of the reactor through either a 6-port or a single-port feeder. For tests scheduled to be conducted with direct peat injection into the bottom of the fluidized bed, we modified the solids feeding system of the unit, as well as the internals of the 6-inch reactor tube.

The modifications to the unit include connecting the existing feed hopper bottom with a 6-inch-diameter pipe (as shown in Figure 22) to a level approximately 15 inches below the bottom of the reactor pressure shell. At this level, the extension is joined to a specially fabricated feed screw housing. The discharge end of the housing is joined to a tee section at the reactor shell bottom. Peat flows by gravity from the feed hopper through the 6-inch line to the screw conveyor housing. From there it is screw fed to the tee section, where it is fluidized with nitrogen in the annulus between the tee section walls and the standpipe (1.5-inch OD and 1.4-inch ID) for discharging solids to the residue receiver. Internal modifications to the reactor include a lower gas distributing ring for feeding nitrogen to fluidize and lift the peat into the reactor annulus, and an upper feed gas distributing ring for feeding steam and oxygen. The peat is fed into the standpipe by overflowing from the bed around the standpipe. Therefore, in addition to discharging residue from the bed, this standpipe controls the bed height automatically. Gasification of the peat takes place in the annulus formed by the standpipe and the inside wall of the reactor (6.4-inch ID).

The feed screw and the feed screw drive used for feeding peat to the top of the reactor was removed; and the two feed screw housing connections at the bottom of the feed hopper, the feed screw drive connection, and the connection to the top of the reactor were blanked off.

Because of project fund limitations, however, no tests were conducted with raw peat as a part of the program extension.

Char Gasification Kinetics Model

In Interim Report No. 6, a model was proposed to describe the steam-oxygen char gasification in fluidized beds. (Two errors, in the reported constants for Equations 22 and 25 of that report, were detected in the course of preparing the following discussion.) The same model was applied to the more recent results by reassigning values to the appropriate kinetic parameters;

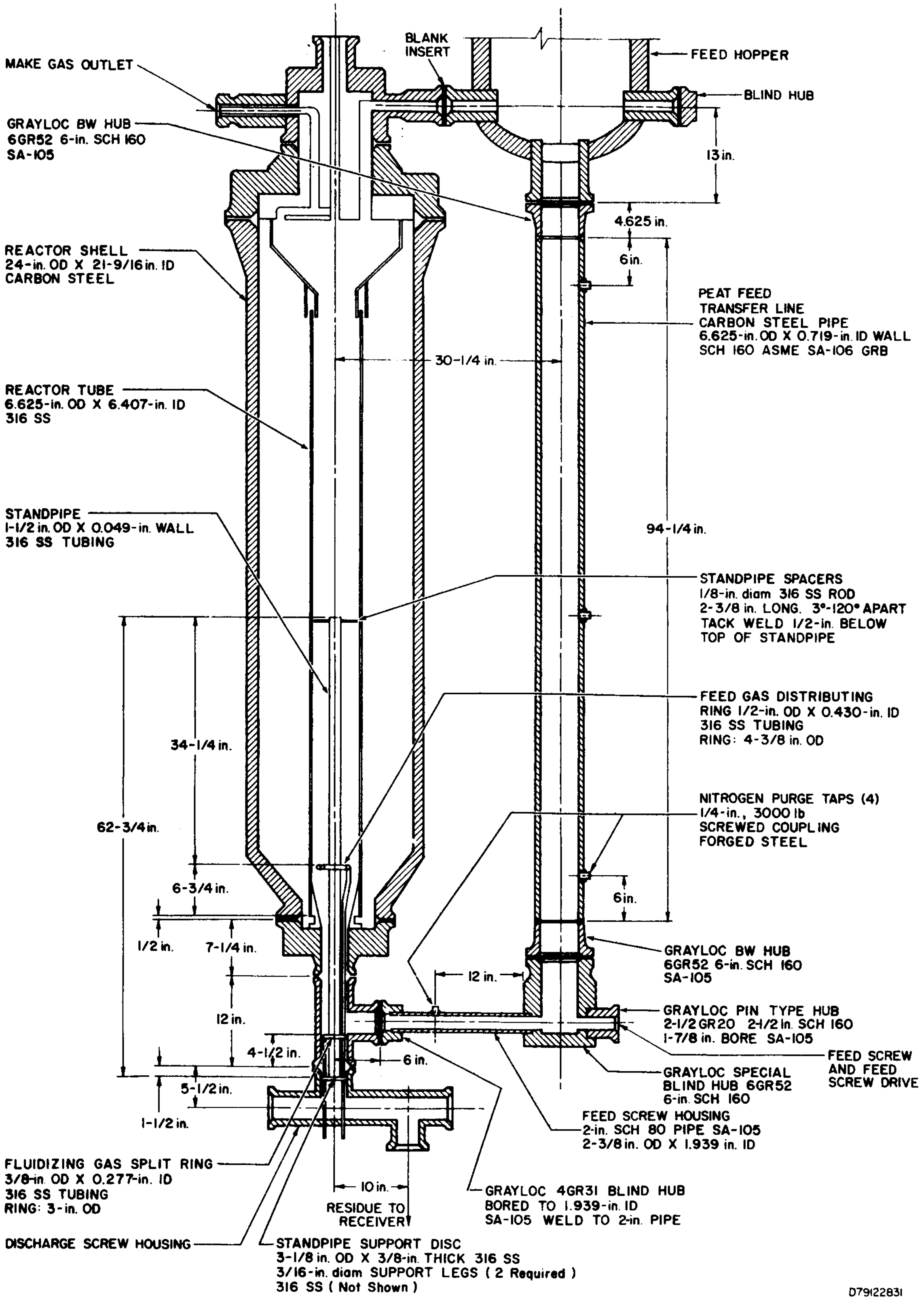

Figure 22. BOTTOM SOLIDS FEED TO 6-INCH-DIAMETER STEAM-OXYGEN GASIFIER

therefore, the model is based on the full set of runs, which is three times that available previously.

The base or nonvolatile carbon conversion is assumed to occur by four paths. (See Figure 10.) At the temperatures of interest, the rapid-rate methane comes off rapidly from a nondevolatilized peat as discussed earlier in the hydrogasification section. The remaining char carbon is gasified according to the kinetics described by the following equation:

$$dX/d\theta = r_{tc} + r_{sg} + r_{O_2} \qquad (16)$$

The relatively fast transient catalytic path has the rate —

$$r_{tc} = \beta K_p K_n e^{-K_n \theta'} (1-X) \qquad (17)$$

The slow gasification path has the rate —

$$r_{sg} = f_L K_t (1-X)^{2/3} e^{-\alpha X^2} \qquad (18)$$

The rate of reaction with oxygen is —

$$r_{O_2} = K_{O_2} Q_{O_2} (1-X)/V_b \qquad (19)$$

where —

X is the fraction of char carbon gasified

θ is the time, min

Q_{O_2} is the oxygen feed rate, SCF/min

V_b is the reactor fluidized-bed volume, CF

K_p and K_n are temperature- and composition-dependent rate constants characteristic of the raw peat char

β is a reactivity factor to account for any pretreatment

K_t and α are the temperature- and composition-dependent parameters developed for bituminous chars

f_L is a reactivity factor to account for the particular char

K_{O_2} is the temperature-independent rate constant used to characterize the carbon oxygen reaction.

For each of the peats studied in the char gasification tests, the following estimates were developed in Interim Report No. 6:

Minnesota Peat

$f_L = 2$

$$K_n = \exp(12.1127 - 28260/T) \tag{20}$$

$$K_p = \frac{\exp(3.1474 - 5106/T)}{(1 + 0.0062\ P_{H_2} + 0.02\ P_{CO})^2} \tag{21}$$

North Carolina Peat

$f_L = 1$

$$K_n = \exp(4.05 - 12450/T) \tag{22}$$

$$K_p = \frac{\exp(3.1481 - 5480/T)}{(1 + 0.011\ P_{H_2} + 0.02\ P_{CO})^2} \tag{23}$$

Maine Peat (Deer Hill Farm)

$f_L = 1$

$$K_n = \exp(9.8590 - 24044/T) \tag{24}$$

$$K_p = \frac{\exp(4.3498 - 7648/T)}{(1 + 0.0095\ P_{H_2} + 0.03\ P_{CO})^2} \tag{25}$$

where T is the absolute temperature (^oR).

As noted in the earlier report, in the particular peat feed arrangement used in these studies, the char developed from raw peat feed appears to have a reactivity characteristic of a peat devolatilized in an inert gas. The peat is presumably devolatilized while falling through the gas space above the fluidized bed. It is not known whether this phase of the reaction occurs in a dilute or relatively dense region. But the assumption that the char kinetics deduced from the thermobalance runs can be extrapolated to very high conversions leads to the low reactivity estimate. The carbon-oxygen rate constant was assumed to be the same for all of the peats, but the transient reactivity factor, β, was peculiar to each peat. The slow gasification reactivity factors, f_L, could not be estimated from these data because only a few percent of the conversion occurred by this path, and any reasonable values did not significantly affect the other estimates. Therefore, while the other parameters were estimated by a least squares technique, the value of f_L was assigned 0.35, the value determined in thermobalance studies for inert gas devolatilized Minnesota peat char.

The estimates of the remaining parameters are, for these runs —

β (Minnesota) = 0.25
β (North Carolina) = 0.30
β (Maine) = 0.63
$K_{O_2} = 0.019$

The fixed-carbon conversion levels calculated with the above parameters showed a standard deviation of 3% from the actual values.

The reactor bed was assumed to be a completely mixed system with the exit solid characteristic of the bed. Suitable accounting was made of the effect of residence time distribution, as discussed in Interim Report No. 6. The average residence time was estimated from the rate of solids removed and the weight of solids in the bed. The latter was estimated from the bed density and volume.

Of the product distribution, the carbon-oxygen reaction presumably yields CO_2 and CO. The slow gasification products had been defined from the coal char studies. The transient catalytic gasification products must be estimated from these runs. On the basis of the runs with char feeds, to avoid the difficulty of differentiating between volatile, rapid rate, and char methane, the following estimates were made of the methane yield in the transient gasification step:

Minnesota Peat

$$\left(\frac{CH_4}{CH_4 + CO_x}\right)_{tc} = 0.063\ P_{H_2} \tag{26}$$

North Carolina Peat

$$\left(\frac{CH_4}{CH_4 + CO_x}\right)_{tc} = 0.16\ P_{H_2} \tag{27}$$

The assumption of proportionality to hydrogen pressure is arbitrary. The data for these estimates cover the range of 3 to 6 atmospheres of hydrogen. The number of Maine char fed runs is too small to allow a corresponding estimate for that peat. On the basis of the two runs available, Maine peat has a value of about 0.1 for the coefficient in the CH_4 yield ratio.

CONCLUSIONS

The results of tests conducted in the lift-line hydrogasification PDU with North Carolina and Maine peats show that the characteristics of these peats are similar to those of Minnesota peat. In general, however, the reactivities and yields of hydrocarbon gases are somewhat higher for Minnesota peat gasification than for North Carolina and Maine peat gasification.

The particle size of peat does not materially affect the carbon conversion or product yields during hydrogasification.

Sinter-free operation of the fluidized-bed steam-oxygen gasifier has been attained with Minnesota, North Carolina, and Maine raw peats and peat chars at high temperatures and pressures.

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