



Project Summary

Coal Gasification/Gas Cleanup Test Facility: Volume V. Preliminary Environmental Assessment of the Gasification and Gas Cleaning of North Carolina Peat

J.K. Ferrell, R.M. Felder, R.W. Rousseau, M.J. Purdy, S. Ganesan, and A.A. Bradley

Results are reported for five test runs at a small pilot-scale coal gasification and gas purification facility using North Carolina peat. Results from the peat gasification are compared with results obtained previously with a New Mexico subbituminous coal. The peat gas produced had slightly more CO and CO₂, while the coal gas had slightly more methane. Production of gaseous sulfur species was much less for peat due largely to the lower sulfur content of the peat itself. Wastewater analyses showed higher concentrations of phenols and other acidic compounds and lower concentrations of PNAs in the peat-derived wastewater than in the coal-derived wastewater. Peat char remaining after gasification was depleted of As, Pb, and Hg to a greater extent than was the coal char. The peat itself contained a substantially higher Hg content than did the coal.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

As a part of continuing research on the environmental aspects of solid fuel

conversion, the Department of Chemical Engineering at North Carolina State University tested the steam/oxygen gasification of North Carolina peat and subsequent gas cleaning during the spring and summer of 1981.

The work was sponsored jointly by the North Carolina Energy Institute, the Carolina Power and Light Company, and the U.S. Environmental Protection Agency. The facility, constructed in 1977-78 under the sponsorship of the EPA, is a small coal-gasification/gas-cleaning pilot plant.

The plant, described in detail in Volume I of this report series (1), consists of: a fluidized-bed reactor; a cyclone and venturi scrubber for particulates, condensables, and solubles removal (PCS system); and absorption and stripping columns for acid gas removal and solvent regeneration. The plant has a nominal capacity of 23 kg/hr (50 lb/hr) of feed for steady state operation. A schematic diagram of the gasifier, the PCS system, the acid gas removal system (AGRS), and other major components is shown in Figure 1.

The primary objective of this investigation was to characterize all feed and effluent streams in the integrated gasifier/gas-cleaning facility in order to evaluate the effectiveness of a methanol-based acid gas removal system for peat gasification. Secondary objectives were

difficult due to the different operating conditions used in most cases; however, coal run GO-78 does compare reasonably well with peat run GOP-4B (GO-78 and GOP-4B have significance only as test run identifiers). Gasifier conditions for peat run GOP-4B and New Mexico subbituminous coal run GO-78 are summarized in Table 2. Except for the lower steam rate and corresponding lower steam-to-carbon ratio for the peat run, necessitated by the higher moisture content of the peat, the conditions of the two runs were quite similar and thus form an excellent basis for comparison of results.

Though not evident in Table 2, lower operating temperatures were generally required for peat gasification than for New Mexico coal; however, the product-gas yields obtained from both were of similar magnitude. The higher feed rates

Table 2. Summary of Gasifier Conditions for GOP-4B and GO-78

	GOP-4B (Peat)	GO-78 (Coal)
Pressure, psig	104.7	103.9
Temperature, °F	1607	1606
Coal/Peat Feed, lb/hr	57.9	41.1
Moisture Content of Feed, %	22.3	9.6
Coal/Peat Feed, Dry Basis, lb/hr	45	37
Steam Feed, lb/hr	33	57
Steam/Carbon Ratio	0.83	1.71
Dry Make-Gas Flow, scfm	17.1	15.9

used in the peat runs were probably a major factor in this result, but the similar product rates at lower temperatures may also reflect a greater reactivity of the peat relative to the coal.

Proximate and ultimate analyses of the feed peat, the solid samples collected from the cyclone, and the spent char were as expected. The spent char was found to have a relatively high carbon content as a result of the very low ash content of the peat. Overall carbon conversion was satisfactory for our purposes (56 - 65%), and very little spent char was formed.

The gas analyses for peat are compared with those for New Mexico coal in Table 3. These data indicate no major differences in gas composition, except for the sulfur species. This is undoubtedly due to the difference in the sulfur content of the feed materials, since the ratio of total sulfur in the two product gases is the same as the ratio of sulfur in the feed materials. The peat gas contained slightly more CO and CO₂, while the coal contained slightly more methane. The higher concentration of methane from the New Mexico coal, compared to peat, is consistent with the results of a series of independent devolatilization studies (4,5) of these materials.

Table 3. Comparison of Gas Analyses for GOP-4B and GO-78
From Sample Point Following Cyclone (Figure 1)

Species	GOP-4B Peat Run Mole %	GO-78 Coal Run Mole %
H ₂	28.40	27.49
CO	15.56	11.94
CH ₄	5.65	8.46
CO ₂	23.17	21.88
N ₂	25.94	30.21
H ₂ S	0.04	0.24
COS	0.002	0.007
Thiophene	0.001	0.003
CH ₃ SH	0.002	0.005
Ethylene	0.44	0.33
Ethane	0.65	0.46
Propylene	0.53	0.12
Propane	0.14	0.05
Butane	0.07	0.02
Benzene	0.11	0.02
Toluene	0.04	0.04

same. These analyses represent the composition of aqueous condensate collected in a side stream sampling train located immediately after the cyclone shown in Figure 1. The condensate at this point contains no contribution from the recirculating gas quench water. The dissolved carbon content for the peat runs was quite high and was mostly in the form of phenols. This is consistent with other results which indicate that the gasification of peat produces relatively greater amounts of phenols and other acidic compounds than the gasification of coal. An analysis of the peat-derived wastewater by gas chromatography/mass spectrometry (GC/MS) also showed a greater amount of acidic compounds and a smaller amount of base/neutral compounds than did the coal-derived wastewater. Compared to previous results from coal gasification, the wastewater from peat gasification contained a lower concentration of polynuclear aromatic compounds (PNA's), and very few PNAs of high molecular weight (greater than 250).

A GC/MS analysis of the liquid condensed from the gas downstream from the sour gas compressor and heat exchanger is shown in Figure 2 and indicates the presence of only the organic compounds of intermediate volatility:

Peak No.	Compound
1	Hexene or methyl-substituted pentene
2	Benzene
3	Heptene or other C ₇ hydrocarbon
4	Toluene
5	Octene or other C ₈ hydrocarbon
6	Octane
7	Ethylbenzene
8	Xylene
9	Substituted benzene
10	Nonene
11	Nonane
12	Methyl-ethyl-substituted benzene
13	Decene

Gaseous production rates, calculated as grams produced per kilogram of peat or coal fed, are shown in Table 4 and indicate that, in general, hydrocarbons produced are of similar magnitude in both coal and peat gasification, while the sulfur-gas production is much less for peat. The peat gas had a greater benzene production rate than the coal, while the methane production rate was greater for the coal.

As shown in Table 5, except for dissolved carbon (indicated by total carbon, chemical oxygen demand (COD), total organic carbon (TOC), and total volatile carbon (TVC)), the wastewater analyses for coal and peat are nearly the

Table 4. Comparison of Gaseous Production from Gasification of New Mexico Coal and North Carolina Peat
Grams Produced per Kilogram of Feed

Species	N.M. Coal		N.C. Peat	
	Avg for All Runs	GO-78	Avg for All Runs	GOP-4B
H ₂ S	6.4	5.4	0.9	0.7
COS	0.35	0.29	0.07	0.06
CH ₃ SH	0.10	0.17	0.08	0.05
Thiophene	0.17	0.16	0.07	0.05
CH ₄	75	88	52	45
Ethane	15	7.8	10.0	9.3
Ethylene	9.1	6.0	7.6	5.8
Benzene	5.0	0.9	3.5	4.1

Table 5. Sample-Train Cold-Trap Water Analyses for Coal and Peat From Sample Point Following Cyclone (Figure 1) Concentrations mg/l except pH

	Average Value or Range for All Runs		GOP-4B GO-78	
	Peat	Coal	Peat	Coal
Ammonia	6,580	6,000	7,919	6,065
Carbon	13,720	3,200	11,400	3,380
Chloride	115	40	50	38
COD	36,460	6,000-10,000	34,200	9,350
Cyanate	600-1,770	2,000-5,000	870	1,749
Cyanide	55	25-200	64	167
Fluoride	20-120	10	20	10
Nitrogen	4,700-9,800	6,000	9,840	NA ^a
pH	8.5	8.5	8.2	8.5
Phenolics	1,370	600-1,100	1,493	772
Sulfate	14	40-300	20	28
Sulfite	37	40	60	55
Thiocyanate	330	250	NA	233
TOC	11,200	2,600	10,600	2,760
TVC	3,800	1,500	4,450	1,630

^a Not analyzed.

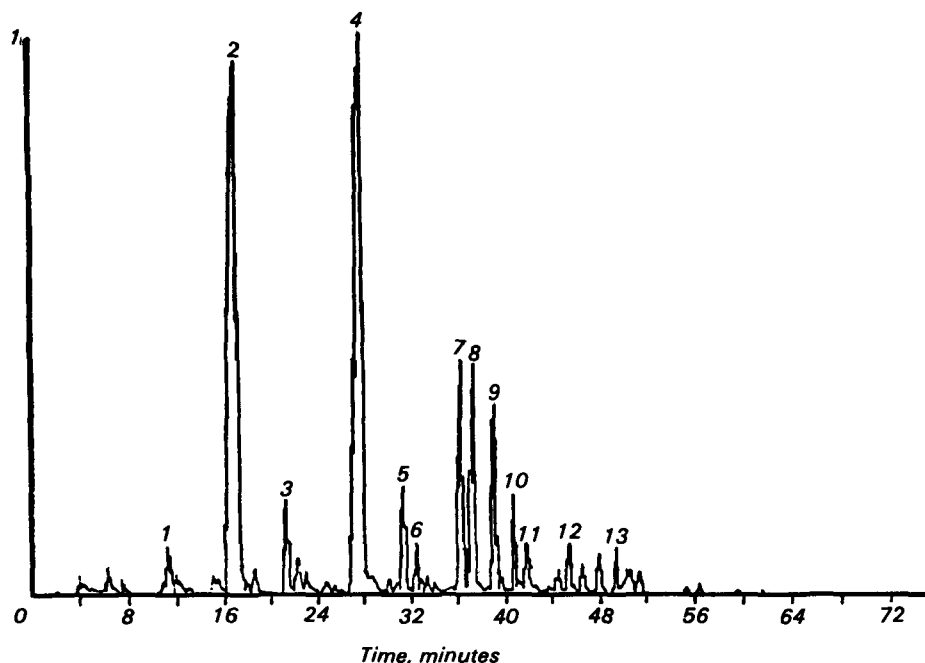


Figure 2. GC/MS analysis of compressor knockout liquid (from combined peat runs GPO-1 through -6).

primarily benzene, toluene, xylene, and other substituted benzenes. While substantial amounts of these compounds had persisted in the gas stream up to this point in the process, only traces of compounds heavier than C₁₀-compounds were found, indicating that most of the PNAs and other heavy hydrocarbons were effectively removed by the scrubbing, cooling, and filtering operations of the PCS system.

Samples of tar collected from the sample-train cold trap, located at the sampling point following the cyclone,

were partitioned into acid, base, and neutral fractions. The neutral fraction was further partitioned into nonpolar neutrals, polar neutrals, PNAs, and compounds insoluble in cyclohexane. Tar partition results are given in Table 6.

Generally, the tar from the peat gasification contained more acidic compounds and fewer of the higher molecular weight PNA compounds, although the differences were not great. The peat-derived tar contained very few organic sulfur compounds in contrast to the coal-derived tar. Concentrations of most sulfur

compounds in the peat tar were below detection limits. Results of the tar analyses are shown in Table 7.

Detailed trace element analyses for As, Pb, and Hg were performed on samples of peat feed, gasifier char, cyclone dust, and the tar, particulates, and condensate collected in the side stream sample train for run GOP-4B. Mass balance closures for Pb and Hg were well below 100%, indicating that substantial amounts of these volatile metals remained in the gas stream at this point in the system. The gasifier char from peat gasification was depleted of these elements to a greater extent than the coal char. One possible explanation is that these elements are not as strongly bound to the organic matrix in peat as they are in coal, and hence are more easily devolatilized. A somewhat surprising result was the relatively high concentration of Hg in the peat feed material; about 10 times that in the New Mexico coal.

A major purpose of this study was to evaluate the potential environmental consequences of the use of methanol as an acid-gas removal solvent for gases generated by peat gasification. In this study, the AGRS operated well and, for both AGRS runs, the overall mass balances and the balances for the major compounds were excellent (overall mass balance closures were 101.7 and 102.2%). Under the absorber conditions used, the principal acid gases, CO₂ and H₂S, were removed to very low levels in the sweet gas (see Table 8), with a combination of lower solvent inlet temperature, higher solvent flow rate, and higher absorber pressure giving somewhat higher removal efficiencies. Table 8 shows a complete set of gas analyses for one AGRS run.

A feature of gases produced from coal or peat is the relatively high levels of COS produced with the H₂S. The conversion of COS to H₂S before it enters the acid-gas removal system is necessary in many processes proposed for treating these gases because of the difficulty of removing COS to levels required for downstream catalytic processes. From the data collected, both in this study and from previous studies on coal, refrigerated methanol appears to remove COS effectively, and no unusual solubility characteristics are evident.

Conclusions

The fluidized-bed steam/oxygen gasification of North Carolina peat produces a gas similar in composition to that produced from New Mexico subbituminous coal, except for lower concentrations

Table 6. Tar Partition Results
Tar Sample from Sample-Train Cold Trap

	GO-78 Wt %	GOP-4B Wt %
Acids	17.29	22.5
Bases	6.05	4.4
TOTAL NEUTRALS	76.66	^a
Nonpolar	11.53	16.6
Polynuclear Aromatics	26.85	15.8
Polar Neutrals	16.45	20.8
Cyclohexane Insolubles	21.83	2.6

^aAnalytical difficulties with the cyclohexane insoluble species precluded a material balance for the neutral fraction of the peat derived tar.

Table 7. Capillary GC Tar Analyses
Tar Samples from Sample-Train Cold Trap

Compound	GO-78 Wt %	GOP-4B Wt %
Phenol	NA ^a	4.93
Cresols	NA	6.14
Xylenols	NA	4.40
Naphthalene	2.10	6.06
Benzo(b)thiophene	0.08	0.02
Quinoline	0.13	0.20
2-Methylnaphthalene	0.97	3.17
1-Methylnaphthalene	0.81	1.22
Biphenyl	0.28	0.74
Acenaphthylene	0.60	0.80
Acenaphthene	0.26	1.83
Dibenzofuran	0.53	2.58
Fluorene	0.43	1.74
Dibenzothiophene	0.09	ND ^b
Phenanthrene	0.47	1.70
Anthracene	0.49	0.56
Fluoranthene	0.23	0.53
Pyrene	0.17	0.14
Benzo(a)anthracene	0.05	0.07
Chrysene	0.04	0.04
Triphenylene	0.02	0.02
Benzo(b)fluoranthene	0.013	0.50 Total of 5 Ring Compounds
Benzo(k)fluoranthene	0.007	
Benzo(e)pyrene	0.007	
Benzo(a)pyrene	0.015	
Perylene	0.01	
Total Wt %	7.802	37.39

^a Not analyzed

^b Not detected

of sulfur compounds and higher concentrations of acidic organic species (such as phenols) in the peat-derived gas.

The raw gas cleaning (PCS) system, consisting of a cyclone separator, a venturi scrubber, filters, coolers, and demisters, removed nearly all of the relatively nonvolatile compounds from the gas stream. For all practical purposes, no hydrocarbons with boiling points greater than that of decane entered the acid gas removal system (AGRS). Over the range of conditions studied, an important point to be made about the distribution of aliphatic (C₁ to C₄) hydrocarbons through the AGRS is their presence in significant quantities in the flash- and acid-gas streams. Since the

gasification of peat tends to produce more of these compounds than coal, the point may be of some importance for the design of gas cleaning systems for peat gasification.

Substantial amounts of aromatic hydrocarbons are also produced during peat gasification. In this study, these species were observed to accumulate in the recirculating methanol. A sample of the methanol leaving the stripper was analyzed by high performance liquid chromatography (HPLC). The only compounds identified were benzene, toluene, xylenes, and other substituted benzenes; no multi-ring aromatic compounds were found. Those compounds which did accumulate in the chilled methanol

solvent appear to be easily removed by distillation.

The fluidized-bed gasification of peat can also be expected to produce relatively large quantities of heavy organic compounds (which will condense as tars) and significant quantities of water soluble organic compounds such as phenols (which will appear in the wastewater). Both the tars and wastewater, while presenting potential environmental problems, are also potential sources of valuable chemical byproducts or fuels.

If the product gas from gasification of North Carolina peat is to be used in a catalytic process such as the production of substitute natural gas (SNG) or methanol, an acid gas removal system of some type will be necessary to prevent sulfur species from poisoning the catalysts. Alternatively, the product gas could be burned as an industrial fuel gas on-site. Either the incineration of the acid gas from an AGRS or the direct combustion of the raw product gas in an industrial boiler would result in a maximum emission of about 0.4 lb SO₂/10⁶ Btu (173 ng/J) of heat input to the gasifier, assuming that all the sulfur originally present in the peat is converted ultimately to SO₂, a worst case possibility.

References

1. Ferrell, J.K., R.M. Felder, R.W. Rousseau, J.C. McCue, R.M. Kelly, and W.E. Willis, Coal Gasification/Gas Cleanup Test Facility: Volume 1. Description and Operation, EPA-600/7-80-046a, March 1980 (NTIS PB80-188378).
2. Ferrell, J.K., R.M. Felder, R.W. Rousseau, S. Ganesan, R.M. Kelly, J.C. McCue, and M.J. Purdy, Coal Gasification/Gas Cleanup Test Facility: Volume II. Environmental Assessment of Operation with Devolatilized Bituminous Coal and Chilled Methanol, EPA-600/7-82-023, April 1982 (NTIS PB82-222936).
3. Ferrell, J. K., R. M. Felder, R. W. Rousseau, R. M. Kelly, M. J. Purdy, and S. Ganesan, Coal Gasification/Gas Cleanup Test Facility: Volume III. Environmental Assessment of Operation with New Mexico Sub-bituminous Coal and Chilled Methanol, EPA-600/7-82-054, August 1982 (NTIS PB83-107417).
4. Agreda, V.H., R.M. Felder, and J.K. Ferrell, Devolatilization Kinetics and Elemental Release in the Pyrolysis of Pulverized Coal, EPA-600/7-79-241, November 1979 (NTIS PB80-130222).

Table 8. Gas Analysis Summary for GOP-4B, AMIP-2
Concentrations in Mole %

Species	Cyclone Exit	PCS Exit ^a	AGRS Feed	Sweet Gas	Flash Gas	Acid Gas
H ₂	28.40	28.61	28.61	38.47	16.45	0.8882
CO	15.57	15.60	15.60	20.42	18.94	1.3970
CH ₄	5.65	5.55	5.55	6.31	9.82	2.52
CO ₂	23.17	23.26	23.26	0.32	23.68	67.15
N ₂	25.95	25.75	25.75	34.37	28.65	24.71
H ₂ S	0.0436	0.0480	0.0480	0.0047	0.0196	0.0771
COS	0.0021	0.0021	0.0021	0.0019	0.0019	0.0031
Thiophene	0.0011	0.0023	0.0023	0.0000	0.0000	0.0000
CH ₃ SH	0.0020	0.0014	0.0014	0.0000	0.0000	0.0014
C ₂ H ₅ SH	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CS ₂	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001
Ethylene	0.4359	0.2863	0.2863	0.0920	0.6889	0.9867
Ethane	0.6512	0.4518	0.4518	0.0833	1.2203	1.5965
Propylene	0.5319	0.2994	0.2994	0.0249	0.2248	1.1883
Propane	0.1351	0.1051	0.1051	0.0728	0.1038	0.2703
Butane	0.0706	0.0389	0.0389	0.0057	0.0256	0.0960
Benzene	0.1072	0.1074	0.1074	0.0000	0.0855	0.0217
Toluene	0.0374	0.0421	0.0421	0.0000	0.0000	0.0000
Methanol	0.0000	0.4532	0.0000	0.4385	3.5977	7.5832

^aDue to sampling difficulty, sour gas sample was taken to be the same as PCS exit sample.

5. Felder, R.M., C.C. Kau, J.K. Ferrell, and S. Ganesan, Rates and Equilibria of Devolatilization and Trace Element Evolution in Coal Pyrolysis, EPA-600/7-82-027, September 1982 (NTIS PB82-260944).

J. K. Ferrell, R. M. Felder, R. W. Rousseau, M. J. Purdy, S. Ganesan, and A. A. Bradley are with North Carolina State University, Raleigh, NC 27650.

N. Dean Smith is the EPA Project Officer (see below).

The complete report, entitled "Coal Gasification/Gas Cleanup Test Facility: Volume V. Preliminary Environmental Assessment of the Gasification and Gas Cleaning of North Carolina Peat," Order No. PB 84-113 091; Cost: \$13.00 subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use \$300

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBURN STREET
CHICAGO IL 60604