DEVELOPMENT OF MILD GASIFICATION PROCESS

Quarterly Report
for the period October-December, 1988

By

Charles I. C. Chu
Stephen W. Williams

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U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26505

By
UCC Research Corporation
P.O. Box 1280/Glenway Avenue
Bristol, Virginia 24203

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EXECUTIVE SUMMARY

This report represents the work performed by UCC Research Corporation (UCCRC) from October 1, 1988 to December 31, 1988 under DOE Contract No. DE-AC21-87MC23289, "Development of Mild Gasification Process."

Nine parametric test and twenty-one production runs were conducted on the Mild Gasification Unit (MGU) during this quarterly period. Five parametric tests were conducted to investigate the effects of different coal types, steam sweeping, and lower operating temperature on the quality and quantity of the coal liquids produced. The final four parametric tests were conducted to evaluate the effects of coal feedstock particle size on liquid quality and quantity. After the optimum operating conditions and procedures were established, twenty-one production runs were conducted with the Mild Gasification Unit (MGU) to produce approximately 1300 pounds of char for burning test to be conducted at Tenetec foundry and in a stoker boiler at UCCRC's facility.

The results of the parametric tests show that the higher volatile matter bituminous coals along with the fresh uses of coal (i.e. non-oxidized coal) yield the best quality liquids. The optimum operating temperature was found to be utilizing a 1000 °F furnace with a final coal/char bed temperature of 900 °F. Nitrogen sweep gas was introduced throughout the runs to enhance the yield and quality of the liquids.

The particle size that proved to be most satisfactory for sweep gas effect, ease of char discharge from the reactor tubes and best yield was the smaller 1/8" x 0.

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INTRODUCTION

Oil currently accounts for over 42% of the total U.S. energy consumption and over 40% of the nation's oil is imported from foreign countries. The remaining oil reserve available in this country constitutes less than 6% of the proven total U.S. recoverable fossil energy reserves while coal represents over 90% of the proven total U.S. fossil energy reserves (1)*. Total coal resources in the U.S. are estimated at more than 3.9×10^{12} tons (2). Just the demonstrated coal reserve alone, the coal reserve that is proven and can be economically mined using today's technologies and mining techniques, amounts to 488×10^9 tons. At the current annual U.S. coal production rate of about 900×10^6 tons, the demonstrated coal reserve alone will last more than 500 years. In light of this contrast in available resources, coal vs. oil, it is very desirable to make good use of our abundant coal resource in our ever more difficult pursuit of energy independence.

Most of the high-severity coal conversion processes that have been developed or are being developed are too complicated, too expensive or both, largely because of their reliance on very severe operating conditions and heavy uses of expensive hydrogen.

While conventional coal devolatilization (or "mild gasification") processes are among the oldest methods for obtaining liquid fuels from coal, they are also technically among the least complex. Mild gasification also has the advantages of higher thermal efficiencies than those of other routes to liquid synfuels from coal. Efficiencies of 85-90% can be expected from mild gasification processes, in contrast to only 50 to 70% for high-severity, indirect and direct liquefaction processes (3). Recent papers reporting various coal liquid qualities and hydrotreatment requirements also indicate that mild gasification liquids are generally superior in quality to those produced from high-severity coal liquefaction processes and require a substantially lesser degree of hydrotreating (3-8).

However, in the existing mild gasification processes, the relative quantities and properties of the co-products are not optimized to make the technology economically and environmentally viable. Many times, either the liquid yield is too low or the liquid quality is poor; and the main product, char (representing 65-75 wt.% coal feedstock), often cannot find its proper marketplace.

Under a previous contract with Morgantown Energy Technology Center (METC), Department of Energy (DOE) Contract No. DE-AC21-84MC21108, UCC Research Corporation (UCCRC) built and tested a 1500 lb. day Mild Gasification Process Development Unit (MGU). Testing completed under the previous contract showed that good quality hydrocarbon liquids and good quality char can be produced in the MGU. However, the MGU is not optimized. The primary objectives of the current project are to optimize the MGU and determine the suitability of char for several commercial applications. The program consists of four tasks; Task 1-Test Plan; Task 2-Optimization of Mild Gasification Process; Task 3-Evaluation of Char and Char/Coal Blends as a Boiler/Blast Furnace Fuel; and Task 4-Analysis of Data and Preparation of Final Report. Task 1 has been completed while work continued on Task 2.

*Numbers in parentheses designate references at the end of this report.

Task 1. Test Plan

Objective

The objectives was to develop a test plan for optimizing the mild gasification process.

Discussion

The test plan has been completed and was submitted to the Department of Energy March, 1987.

Task 2. Optimization of the Mild Gasification Process

Objective

The objective of this task are to (A) modify the MGU to optimize the unit operation; (B) conduct parametric tests to determine the effect of process parameters on product (gas, condensable, and char) quantity and quality; and (C) produce enough char and hydrocarbons in order to evaluate these products in various commercial applications.

Discussion

Nine parametric tests and twenty-one production runs were conducted during this quarterly period. Five of the nine parametric tests (#24/P13 - #28/P17) were conducted to investigate the effects of different coal types, steam sweeping, and lower temperature on the quantity and quality of the coal liquids produced. The types of coal used for these tests were Mississippi Lignite, Wellmore #8 Refuse, Wellmore #8 Clean coal, and a strip mine coal, the H&K #2 Williamson seam. In addition, steam was used for sweeping in one test with the H&K bituminous coal. A lower temperature of pyrolysis (850 °F) was also used in one of these five tests. The four remaining parametric tests were conducted to evaluate the effects of coal feedstock particle size and the insulation wrap in the top of the reactor tubes on liquid yield.

Test #24/P13 was conducted using Mississippi Lignite Coal. This test was a repeat of Test #23/P12 in which some irregularities were encountered with the center coal bed thermocouple. It is believed that in the previous test as the lignite coal charge shrank in volume (as the moisture and volatile materials were driven off) the top of the coal/char bed was lowered to approximately the same location as the center thermocouple, thus exposing the thermocouple to the much lower temperature of the evolving gases. In order to insure that the thermocouples would remain covered in the coal/char bed throughout the run, the gravel charge was increased from 40 lbs per reactor tube to 60 lbs in Test #24/P13. It should also be noted that a new thermocouple was installed in the center coal/char bed location prior to the initiation of Test #24/P13. A summary of the results from Tests (#24/P13 - #28/P17) are given in Table 1.

The liquids collected from Test #24/P13 were very similar to those collected in the previous test (23/P12). The "coal oil" was lighter than water and brown in color. This oil contained a substantial amount of waxy material, which dissolved in the oil when the temperature was raised to approximately 100°F. The results of the analytical tests conducted on these liquids are shown in Table 2.

A substantial quantity (14.2 lbs) of liquids condensed in the char hopper during this test. The majority of this liquid was water and had a stronger odor than those condensed in the slip-stream condenser. The oil portion of these liquids appeared to contain a high concentration of a waxy tar material. It was also apparent that this "oil" fraction had dripped from the bottom of the reactor tubes as it formed "stalagmites" in a circular pattern on the char hopper lid. It was not possible to effectively decant this oil fraction as it was very thick and contained a large concentration of fine char.

Test #25/P14 was conducted using coal preparation plant refuse with a particle size of 1/16" x 0. Due to the greater density of this material the charge was increased to 140 pounds, which would roughly be equivalent (by volume) to that of 110 pounds of bituminous coal. The duration of this test was approximately 75 to 100 minutes less than that needed to complete a test under the same conditions using bituminous coal as a feedstock. Due to the higher ash content of this feedstock (56.5%), some variations of conditions experienced during this run with the coal refuse were that there was little gas pressure build-up inside the reactor tubes, the condensing system remained under a vacuum condition throughout the entire test period, and the char chute area was under little or no positive pressure during the latter half of the run.

The char product did agglomerate to form some rather large sized lumps, however it was very friable and easily reduced to "powder".

The coal liquid produced in this test was lighter than water and dark brown/black in color. An ammonia odor was readily apparent particularly associated with the water portion of the liquids. Although there was a noticeable odor, it was milder than the ammonia odor associated with the liquids derived from previous bituminous coal tests. As shown in Table 1, the total liquid yield for this test was 9.28 pounds (6.63% by weight). This lower yield was due to the lower volatile matter content of the refuse feedstock (see Table 3). However the quality of the coal liquids is quite good - in fact, very similar to that of the liquids produced in other MGU tests with raw bituminous coals (see Table 2).

Test #26/P15 was conducted using Wellmore #8 Bituminous Coal. The purpose of this test was to examine the effect of the slightly lower volatile content of the Wellmore #8 coal (32.7% volatile) on the MGU product yields and qualities.

The liquid product obtained from this test was very similar in appearance to those obtained using the H&K #2 bituminous coal. The decanted oil and water yields were 8.16% and 4.83% respectively which are close to the yields from previous MGU tests utilizing H&K #2.

Table 1.
COMPARISON OF RESULTS FROM PARAMETRIC TESTS P13 - P17

TEST #	<u>#24/P13</u>	<u>#25/P14</u>	<u>#26/P15</u>	<u>#27/P16</u>	<u>#28/P17</u>
OVEN TEMP (°F)	1000	1000	1000	950	1000
COAL TYPE	LIGNITE	REFUSE	WELLMORE #8	H&K	H&K
PARTICLE SIZE	3/4" x 0	1/16"x 0	1 x 0	1-1/2" x 0	1-1/2" x 0
MAX CENTER COAL TEMP	901°F	901°F	901°F	851°F	902°F
SWEEP GAS	none	none	none	none	steam
NON-CONDENSIBLE GAS YIELD (%) *	21.0%	2.8%	10.4%	4.2%	11.6%
CHAR YIELD (%)	45.2%	90.5%	76.6%	82.5%	76.4%
TOTAL LIQUID YIELD (%)	33.8%	6.6%	13.0%	13.3%	12.1%
OIL YIELD (%)	5.8%	2.5%	8.2%	8.6%	10.0%
WATER YIELD (%)	28.0%	4.1%	4.8%	4.7%	2.1%

*NOTE: The non-condensable gas yield is calculated by difference.

TABLE 2.
RESULTS OF ANALYTICAL DATA CONDUCTED ON MGU COAL LIQUIDS SAMPLES

TEST #	<u>24/P13</u>	<u>25/P14</u>	<u>26/P15</u>	<u>27/P16</u>	<u>28/P17</u>
% MOISTURE *	0.89	0.45	0.71	0.78	0.65
% CARBON	85.08	85.83	84.74	84.32	85.31
% HYDROGEN	10.78	8.87	8.45	9.32	8.94
% NITROGEN	0.57	0.48	0.91	0.71	0.82
% SULFUR	0.36	0.68	0.63	0.51	0.42
% OXYGEN	4.09	4.31	5.47	4.26	5.25
MOLECULAR WEIGHT *	252	235	229	229	251
BTU/LB.	17,881	17,055	16,837	17,042	16,967
H/C RATIO	1.50	1.23	1.19	1.32	1.21

* NOTE: All values except molecular weight and percent moisture are reported on dry basis.

TABLE 3.
PROXIMATE ANALYSIS OF COAL FEED STOCKS*
 (As Received, Wt %)

	<u>Moisture</u>	<u>Volatile Matter</u>	<u>Fixed Carbon</u>	<u>Ash</u>	<u>Sulfur Wt %</u>	<u>BTU/lb.</u>
Mississippi Lignite	33.20	38.36	19.84	8.60	1.00	7,293
Wellmore #8 Refuse	1.18	17.33	25.00	56.49	2.74	5,788
Wellmore #8	1.32	32.73	57.24	8.71	1.54	14,048
H&K	1.88	33.80	59.40	5.00	0.98	13,843

* Analysis performed by Galbraith Laboratory.

MGU Test #27/P16 was conducted to investigate the effect of reduced temperature on the quantity and quality of the MGU coal liquids. For this test the oven temperature was reduced from 1000°F to 950°F and the maximum desired coal/char bed center temperature was reduced from 900°F to 850°F.

The quantity and quality of the coal liquid produced in this test appear to be nearly identical to those of liquids produced with a 1000°F furnace temperature.

The char product did have a somewhat higher volatile content than the chars from previous tests conducted at the higher 1000°F furnace temperature. The results of the analytical tests conducted on the char are given in Table 4.

Test #28/P17 utilized steam as a sweep gas. The steam for this test was produced by a 17 kw electric steam generator. The steam was introduced into the tops of the two 8" gas heater tubes, where it was heated to super heated steam, and then entered the coal bed through the 1" crossover pipes located at the bottoms of the reactor tubes. Due to the low injection rate (3.2 lbs/hr) and long distance that the steam had to travel before entering the gas heater tubes, the steam cooled and entered the gas heater tubes primarily in the form of hot water. The pressure surges produced as the "steam" was injected into the gas heater tubes during the test substantiate this theory.

Approximately 11 lbs of the 19.2 lbs of steam (water) utilized in this test condensed in the char hopper. The coal liquid generated in the test is lighter than water and appears to be quite similar in overall quality of that of the liquids produced in previous tests using a 1000°F oven temperature.

The non-condensable gas analysis data for all of these test runs are shown in Table 5.

TABLE 4.
RESULTS OF ANALYTICAL TESTS CONDUCTED ON MGU CHAR SAMPLES

TEST#	<u>24/P13</u>	<u>25/P14</u>	<u>26/P15</u>	<u>27/P16</u>	<u>28/P17</u>
PROXIMATE, %					
MOISTURE	0.77	0.38	1.46	0.67	1.18
ASH	20.07	63.65	9.88	6.43	5.12
VOLATILE	24.68	9.05	10.69	11.28	10.30
FIXED CARBON	55.25	27.60	79.43	82.29	84.58
ULTIMATE, %					
CARBON	67.16	31.13	82.66	84.73	86.81
HYDROGEN	2.93	1.71	3.03	2.86	3.15
NITROGEN	1.19	0.70	2.60	1.83	0.82
SULFUR	1.66	2.86	0.72	0.82	0.85
CHLORINE	0.020	0.022	0.066	0.11	0.074
OXYGEN	6.97	0.23	2.70	3.90	3.18
(by difference)					
BTU/LB.	11,362	7681	13,452	13,879	14,345

NOTE : The ULTIMATE and PROXIMATE (except moisture) are reported on DRY BASIS.

Table 5.
Gas Analysis - MGU Parametric Tests

SAMPLE#	ELAPSED TIME	INNER REACTOR TEMP °F	OUTER REACTOR TEMP °F	VOLUME PERCENTAGE						
				H ₂	CO*	CO ₂	CH ₄	C ₂ H ₆	C ₂ H ₄ + C ₂ H ₂	H ₂ S
TEST #24/P13										
1	57 min	289°	920°	8.2	8.1	69.1	9.5	2.9	1.5	0.7
2	117	325	948	19.7	4.8	55.4	14.0	4.0	1.5	0.6
3	177	421	959	25.1	3.3	49.8	15.6	4.4	1.4	0.4
4	237	657	963	25.4	3.9	44.8	17.9	5.3	2.4	0.5
5	297	817	967	27.4	3.6	36.1	21.9	7.2	3.4	0.4
TEST #25/P14										
2A	133 min	568°	947°	16.8	5.2	12.7	41.0	13.4	3.7	7.1
2B	133	568	947	16.2	5.7	12.7	40.7	13.4	3.7	7.6
3	193	737	956	16.9	5.0	10.6	41.2	13.1	3.2	10.0
TEST #26/P15										
4	138 min	565°	962°	16.8	6.1	5.3	47.6	16.3	3.4	4.4
5A	168	634	964	19.1	1.5	4.2	50.6	16.9	3.7	4.1
5	168	634	964	16.6	4.9	4.5	44.9	21.7	3.3	4.1
6	228	736	958	19.8	5.1	3.0	50.1	15.5	3.3	3.2
7	288	785	962	19.7	3.5	3.4	50.4	16.4	3.1	3.6
8A	348	839	965	22.0	1.6	2.8	52.5	14.9	2.9	3.3
8B	348	839	965	22.0	3.7	3.0	51.1	14.4	2.8	3.0
9	408	883	971	24.3	3.8	2.8	51.4	12.4	2.4	2.9
10	448	900	825	22.5	6.4	3.0	50.6	12.1	0.9	4.5
TEST #27/P16										
1	68 min	330°	878°	10.8	4.1	15.1	48.1	18.4	2.2	1.4
2	115	481	894	12.0	5.8	9.4	50.4	18.1	2.0	2.4
3	175	617	897	15.6	8.1	7.1	48.8	16.7	1.6	2.0
4	237	714	901	18.2	5.7	5.0	50.6	16.8	1.6	2.0
5	295	779	905	18.0	5.6	4.0	51.9	16.9	1.5	2.1
TEST #28/P17										
1	64 min	372°	938°	0.0	5.2	13.6	57.3	20.1	2.4	1.4
2	108	453	946	16.7	3.5	8.0	50.6	16.7	2.5	2.0
3	168	587	949	18.9	3.2	6.1	50.6	16.3	2.8	2.2
4	228	716	953	19.8	4.8	4.1	50.9	15.5	2.5	2.5
5	288	763	956	21.5	3.2	3.2	52.5	15.1	2.2	2.4
6	348	828	959	24.1	4.4	3.0	51.6	13.2	2.1	1.6
7	408	879	960	27.8	4.4	2.7	47.8	14.4	1.6	1.3

* NOTE: Value shown for CO concentration also includes N₂.

The final four parametric tests were conducted on the Mild Gasification Unit (MGU) during the month of November. As was the case in each of the 28 previous parametric tests, the slip-stream condensing system was utilized in each of these tests to condense the entire gas stream from the coal reactor tubes.

The purpose of the first of these four parametric tests (MGU Test #29/P18) was to investigate the consequences of removing the insulation wrapped around the upper 15 inches of the reactor tubes inside the oven. This insulation was originally placed around the reactor tubes in an attempt to reduce the degree of coal gas cracking by reducing the impact of the oven burner flame on the temperature of the upper part of the tubes. Test #29/P18 was conducted using 110 pounds of 1-1/2 inch x 0 H&K (Williamson #2 Seam) bituminous coal. The MGU was operated in vacuum mode with no sweep or recycle gas through the bed.

As can be seen in Table 6, the total liquid yield obtained in MGU Test #29/P18 was 14.3% (9.0% oil + 5.3% water). The quantity and quality of the coal liquid produced appear to be similar to those of liquids produced in MGU tests which did have insulation wrapped around the upper part of the reactor tubes (also see Table 7). This indicates that the insulation has little to no effect on reducing the degree of coal gas cracking when operating the MGU with a 1000°F oven temperature. However, the insulation may indeed reduce the degree of coal gas cracking when the MGU is operated at higher oven temperatures - such as the 1200°F temperature utilized during the MGU shakedown testing period.

The remaining three parametric tests (MGU Tests 30/P19, 31/P20, & 32/P21) were conducted to investigate the effects of using different feed coal particle sizes in combination with nitrogen sweep gas on the performance of the MGU. For MGU Test 30/P19, the 1-1/2" x 0 H&K bituminous feed coal was crushed to 1/8" x 0. A very low nitrogen flow rate was utilized (0.5 to 1.0 cfm) in this test, however, the low rate allowed the nitrogen to be utilized throughout the test without excessive pressure build-up in the gas heater pipes.

Table 6.
COMPARISON OF RESULTS FROM PARAMETRIC TESTS P18-P21

TEST #	<u>29/P18</u>	<u>30/P19</u>	<u>31/P20</u>	<u>32/P21</u>
OVEN TEMP (°F)	1000	1000	1000	1000
COAL TYPE & SIZE	H&K 1-1/2"x 0	H&K 1/8"x 0	H&K 1/4"x 0	H&K 1/2"x 0
MAX CENTER COAL TEMP (°F)	903	900	907	896
SWEEP GAS	None	N ₂	N ₂	N ₂
CHAR YIELD (%)	77.3	78.9	76.6	76.1
NON-CONDENSIBLE GAS YIELD (%)	N/A	N/A	N/A	11.3
TOTAL LIQUID YIELD (%)	14.3	13.8	15.7	15.4
OIL YIELD (%)	9.0	8.5	10.3	10.0
WATER YIELD (%)	5.3	5.3	5.4	5.4
MATERIAL BALANCE CLOSURE (%)	N/A	N/A	N/A	102.8

* NOTE: Non-condensable gas yields were calculated by measuring the gas flowrate and composition at set intervals during each test run. Gas yields for Tests 29-31 are not given due to inaccuracy of gas flow meter readings during those tests.

Table 7.
RESULTS OF ANALYTICAL TESTS CONDUCTED ON MGU COAL LIQUID SAMPLES

	<u>29/P18</u>	<u>30/P19</u>	<u>31/P20</u>	<u>32/P21</u>
MOLECULAR WEIGHT *	251	240	251	243
% MOISTURE	1.14	0.87	0.49	0.84
% CARBON	85.60	84.60	85.16	85.45
% HYDROGEN	8.93	9.49	9.13	9.10
% NITROGEN	0.85	0.54	0.82	0.82
% SULFUR	0.43	0.41	0.57	0.65
% OXYGEN	5.73	5.98	4.75	4.77
BTU/lb	17,060	17,742	17,209	17,208
H/C ATOMIC RATIO	1.24	1.34	1.28	1.27

* NOTE: All values except molecular weight and % moisture are reported on a dry (moisture free) basis.
All analyses were conducted by Galbraith Laboratories, Inc. of Knoxville, Tennessee.

Table 8.
RESULTS OF ANALYTICAL TESTS CONDUCTED ON MGU CHAR SAMPLES

	<u>29/P18</u>	<u>30/P19</u>	<u>31/P20</u>	<u>32/P21</u>
% MOISTURE	0.46	1.14	0.69	0.58
% ASH	5.02	4.40	5.84	6.91
% VOLATILE	10.69	11.41	10.22	10.48
% FIXED CARBON	84.29	84.19	83.94	82.61
% CARBON	85.72	86.75	86.47	84.74
% HYDROGEN	3.38	3.67	3.16	3.23
% NITROGEN	1.84	1.44	1.95	1.64
% SULFUR	0.76	0.74	0.94	1.44
% CHLORINE	0.072	0.067	<0.05	0.048
% OXYGEN *	3.21	2.93	1.59	1.99
BTU/lb	14,436	14,403	14,230	13,973

* NOTE: Oxygen values are calculated "by difference".

No liquids collected in the char chamber during Test 30/P19 - as has been true in every test that utilized N₂ sweep. The char produced in the lower part of the reactor tubes appeared to contain a high concentration of volatile material (i.e., some of the char appeared to be almost "wet").

The liquid yield in Test 30/P19 was 13.8% (8.5% oil and 5.3% water). Although the coal oil yield was slightly lower than "normal", the coal liquid collected appeared to be very light and "thin" (low in viscosity). The oils did not display the greenish tint that the lightest MGU liquids have - these coal liquids were more of an amber (reddish brown) color. The results of the analytical testing conducted on the oil fraction (see Table 7) indicate that the liquid is indeed of good quality as evidenced by the relatively low molecular weight (240) and hydrogen/carbon ratio of 1.34.

MGU Test 31/P20 utilized a 1/4" x 0 raw H&K bituminous coal feed size. As in the preceding MGU test, a very low nitrogen flow rate was utilized (0 to 1.2 cfm - 0.64 avg), however in this test, the nitrogen had to be shut off at certain periods during the run to prevent an excessive pressure build-up in the gas heater pipes and char hopper area. As in Test #30/P29, no liquids collected in the char chamber during this run.

The total liquid yield obtained in Test 31/P20 was 15.7% (10.3% oil and 5.4% water). The coal liquid collected appeared to be very light and "thin" (low in viscosity) and was very similar in appearance to the oil fraction from MGU Test #30/P29. However, the increase in oil quantity appears to have been accomplished at the expense of the oil quality as indicated by the higher molecular weight (251 vs. 240) and lower H/C atomic ratio (1.28 vs. 1.34).

MGU Test 32/P21 utilized a 1/2" x 0 raw H&K bituminous coal feed size. A low nitrogen flow rate was again utilized in this test (0 to 1.35 cfm - 0.54 avg). As was true in Test #31/P20, the nitrogen had to be shut off at certain periods during the run to prevent an excessive pressure build-up in the gas heater pipes.

As in the two previous tests, no liquids collected in the char chamber during this run. The coal liquid collected appeared to be very light and "thin" (low in viscosity) and was very similar in appearance to the oils from MGU Tests #30/P29 and #31/P20. This liquid did appear to contain a somewhat greater amount of fine char than that from the preceding MGU tests. As can be seen in Table 7, the molecular weight of the coal liquid was nearly the same as that from Test 30/P19 (243 vs. 240), but the lower H/C ratio more closely resembled the coal liquid from Test 31/P20 (1.27 vs. 1.28).

Based on the results obtained during the parametric testing program, the "optimum" MGU operating conditions were determined. These are as follows:

Temperature: The best quality coal liquids have been produced when utilizing a 1000° F furnace temperature with a final center coal bed temperature of 900° F. Although somewhat greater liquid yields are obtained at higher temperatures, the additional yield is composed primarily of heavy tar which mars the combustion characteristics of the liquid. The chars produced under higher temperatures also were of poorer quality (in terms of volatile matter content). It seems apparent that the small gain in liquid yield under higher operating temperatures is more than offset by the loss in liquid and char quality as well as thermal efficiency.

Sweep Gas: A relatively low nitrogen sweep gas rate appears to improve the quality as well as the quantity of the coal liquid collected. The sweep gas helps to reduce the residence time of the coal gases inside the reactor tubes and prevents them from entering and condensing in the char hopper area. It should be noted that the use of sweep gas does increase, to a small degree, the entrainment of fine coal/char particles in the coal gas stream. However, as long as the sweep gas flow rate is small, this problem is not serious.

Coal Feed & Particle Size: By far the best quality and quantity of coal liquids have been obtained from bituminous coals. Freshly mined bituminous coal feedstocks produced liquids of better quality and greater yield than those which have been in storage for an extended period of time (i.e., oxidized coals). It appears that using freshly mined and smaller size (1/8" x 0) feed coal, in combination with nitrogen sweep gas and a low operating temperature, produces the best quality liquids. Also, surprisingly, it appears that the sweep gas has less difficulty continuously penetrating a coal bed of minus 1/8-inch particles than it does beds with larger coal sizes. Furthermore, char produced from coal feeds with a smaller particle size seemed to be easier to discharge from the reactor tubes. Table 9 shows the analytical data for fresh H&K coal feedstock.

TABLE 9
Analysis of H&K Fresh coal feedstock

CARBON	79.14%	ASH	6.85%
HYDROGEN	4.91%	FIXED CARBON	59.51%
NITROGEN	1.26%	VOLATILE MATTER	33.64%
CHLORINE	0.15%	BTU/POUND	14,723
SULFUR	0.98%	MOISTURE	1.91%
OXYGEN	6.71%		

NOTE: All values except moisture are reported on dry basis.

With the parametric testing complete and the "optimum" conditions at which to conduct the production runs established, we then embarked on a schedule to produce approximately 1300 lbs of char for combustion tests at Tenetek foundry and stoker boiler tests at UCCRC's facility. This entailed a total of 21 runs to produce sufficient quantities of char for the char combustion tests. The liquids that are produced during these "production runs" will be sent to DOE/METC for use in other programs.

The production runs were conducted using two eight hour shifts. By running in shifts we were able to complete two runs per 24 hour period. This was accomplished due to the less extensive sampling and cleaning procedures as was needed in the previous parametric testing. For example char was used instead of gravel to raise the coal bed above the crossover pipes to prevent plugging, thus the time involved in the separation of the gravel from the char was eliminated. Other examples are the slip-stream condenser which did not need to be disassembled and reassembled to clean residual liquids from the previous test to lessen the contamination from test condition to condition. Also the liquids collected did not need to be decanted and shipped for analysis after every test. These lesser procedures significantly reduced the turn around time between each MGU production run.

The liquids from the production runs appear to be of good quality. The analysis shown in Table 10 indicate that the molecular weight varies about 14% (201 for Test #33/PRO-1 vs. 228 for Test #46/PRO-14). However after discussion with Galbraith personnel this falls within their estimated variance in molecular weight measurement of the coal liquids that they have encountered in the past. There is a small quantity of "waxy" material evident in the liquids, but when heated to 100°F this material dissolves in with the oil. When the oil sample was allowed to settle, very small particles of this "waxy" material seemed to precipitate on to the sides of the glass bottle. The total yield for the liquids throughout the production runs were generally from 15% to 16%. In Table 11 the liquid yield is somewhat less for Test #33/PRO-1 than shown for Test #46/PRO-14. We attribute this in part to the limited penetration of the nitrogen sweep gas through the coal/char bed during the test. An additional complication was that due to delivery mix up we were unable to utilize nitrogen for the complete duration on the test run.

Table 10.

Analytical Results For Two Production Run Liquids

	<u>TEST #33/PRO-1</u>	<u>TEST #46/PRO-14</u>
MOLECULAR		
WEIGHT	201	228
CARBON (%)	84.88	85.87
HYDROGEN (%)	9.18	8.82
NITROGEN (%)	0.59	0.73
SULFUR (%)	0.71	0.55
OXYGEN (%)	3.84	4.64
MOISTURE (%)	0.87	1.18
BTU/POUND	17,331	17,093
H/C ATOMIC RATIO	1.29	1.23

NOTE: All values except molecular weight and % moisture are reported on dry basis.

Table 11.

Comparison Of Operating Conditions & Yields For Two Production Runs

	<u>TEST #33/PRO-1</u>	<u>TEST #46/PRO-14</u>
OVEN TEMP. (°F)	1000	1000
COAL TYPE & SIZE	FRESH H&K 1/8" x 0	FRESH H&K 1/8" x 0
MAX CENTER COAL TEMP (°F)	893	904
SWEEP GAS	N ₂	N ₂
CHAR YIELD (%)	77.3	76.4
NON-CONDENSIBLE BY DIFFERENCE (%)	7.3	7.8
TOTAL LIQUID YIELD (%)	13.9	15.8
OIL (%)	7.8	10.0
WATER (%)	6.1	5.8

The characteristics of the char collected from the 21 production runs was very consistent throughout the testing. The char was discharged hot and cooled by quenching it with water to enable the second run to be initiated quickly. As shown in Table 12, this procedure did not have any adverse effects on the quality of the char. The char is friable and appears to be well cooked. The 3" x 0 particle size of the char will be used to conduct Stoker boiler burning tests at UCCRC, and the +3" lumps will be used for burning test at the Tenetek foundry.

Table 12.

Analytical Results For Two Production Run Char

	<u>Test #33/PRO-1</u>	<u>Test #46/PRO-14</u>
Moisture, %	0.29	0.58
Carbon	85.60	86.40
Hydrogen	2.71	2.82
Nitrogen	1.85	1.83
Chlorine	0.097	0.09
Sulfur	0.97	1.08
Ash	7.90	8.16
Volatile Matter	10.22	10.27
Fixed Carbon	81.88	81.57
Btu/lb	13,714	13,932

Note: All values except % moisture are reported on dry basis.

Table 13. contains the results of the gas chromatograph (GC) analyses conducted on the non-condensable gas samples taken during Test #33/PRO-1 and Test 46/PRO-14 of the production runs.

Table 13.

Non-Condensable Gas Analysis For Two Production Runs

MGU PRODUCTION RUN #1 11-30-88

VOLUME % - N₂ SUBTRACTED

Sample #	TIME	H ₂	CO	CO ₂	H ₂ S	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₃ H ₈	C ₃ H ₆	n-C ₄ H ₁₀	i-C ₄ H ₈	ISO BUTANE	C ₄ &C ₅	TOTAL
1	60	17.05	0.00	8.57	1.74	45.34	14.53	1.97	4.79	2.32	1.22	0.10	0.22	2.14	100.00
2	120	19.92	5.49	6.17	2.19	33.39	17.36	2.13	5.95	2.59	1.47	0.20	0.27	2.86	100.00
3	180	22.96	0.00	4.54	2.52	36.95	18.02	2.02	5.95	2.52	1.45	0.18	0.28	2.62	100.00
4	255	24.16	0.59	3.55	2.52	34.95	18.13	2.20	6.31	2.71	1.54	1.00	0.30	2.05	100.00
5	300	25.60	0.61	3.53	2.63	35.61	17.41	1.91	5.77	2.39	1.46	0.68	0.26	2.15	100.00
6	360	30.30	0.63	3.88	2.14	39.88	13.19	1.28	4.00	1.53	1.00	0.60	0.19	1.37	100.00
7	420	23.22	0.00	5.58	0.00	45.63	15.87	1.01	4.66	1.47	0.97	0.50	0.21	0.88	100.00

MGU PRODUCTION RUN #14 12-16-88

VOLUME % - N₂ SUBTRACTED

Sample #	TIME	H ₂	CO	CO ₂	H ₂ S	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₃ H ₈	C ₃ H ₆	n-C ₄ H ₁₀	i-C ₄ H ₈	ISO BUTANE	C ₄ &C ₅	TOTAL
1	83	20.44	0.00	5.59	2.46	40.28	16.28	2.65	5.29	2.83	1.27	0.00	0.24	2.67	100.00
2	138	23.01	0.67	5.07	2.50	39.17	15.21	2.57	4.92	2.70	1.18	0.90	0.21	1.90	100.00
3	195	24.27	0.47	4.44	2.47	39.02	15.00	2.67	4.83	2.79	1.12	0.92	0.20	1.79	100.00
4	255	26.12	0.00	3.29	2.50	41.77	13.71	2.30	4.35	2.39	1.04	0.79	0.20	1.54	100.00
5	318	27.03	0.35	2.90	2.68	43.30	12.54	1.95	3.96	2.01	0.96	0.70	0.19	1.44	100.00
6	375	30.57	0.45	2.50	2.30	44.53	11.08	1.57	3.30	1.63	0.77	0.00	0.16	1.15	100.00
7	416	31.71	0.00	3.24	2.23	47.53	8.63	0.79	2.54	0.96	0.66	0.00	0.96	0.74	100.00

Task 3. Evaluation of Char and Char/Coal Blends as an Industrial
Boiler/Blast Furnace Fuel

Objective

The objective of this task is to evaluate the MGU char product in three commercial applications. Tests will be conducted to determine the suitability of char in industrial/utility pulverized coal boilers, stoker coal boilers, and as a replacement for coke in foundry/blast furnaces.

Discussion

A test for the char as a foundry coke application has been scheduled for January at Tenetec Foundry in Johnson City, Tennessee. The stoker boiler tests will be conducted at United Coal Research Corporation (UCCRC) facility.

Task 4. Preparation of Final Report

Summary

No work scheduled during this reporting period.

Charles I.C. Chu
Project Manager
UCC Research Corporation

CICC:llv
Enclosures

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