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Coal Technology Program Progress Report for June 1977

OAK RIDGE NATIONAL LABORATORY

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COAL TECHNOLOGY PROGRAM
PROGRESS REPORT FOR JUNE 1977

Date Published - August 1977

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COAL TECHNOLOGY PROGRAM PROGRESS REPORT FOR JUNE 1977

ABSTRACT

This report — the thirty-fifth of a series — is a compendium of monthly progress reports for the ORNL research and development programs that are in support of the increased utilization of coal as a source of clean energy. The projects reported this month include those for coal conversion process development, materials engineering, alkali metal vapor topping cycles, a coal equipment test facility, engineering and support studies, process and program assistance, environmental assessment studies, and the fluidized bed combustor technology test unit.

1. SUMMARY

J. P. Nichols

Highlights of our progress in June are as follows:

- Three operability tests for hydrocarbonization of Illinois No. 6 coal were conducted during June. The initial observations were quite encouraging in each case, with feed sustained without interruption for more than 4 hr. Subsequent examination, however, indicated that agglomeration had blocked recirculation of the bed during each run. Remedial measures are planned.
- Progress in support of in situ gasification continued on the matrix of experiments planned involving the pyrolysis of large blocks of bituminous coal. Experiment BP2-30 was completed to 1000°C at a heating rate of 0.3°C/min.
- In our coal-solvent-hydrogen mixing project, fluid dynamics data for cocurrent upflow of air and coal slurry through the packed column were measured. Similar data are being accumulated from the contactor containing static mixers.
- Three replicate pressurized carbonization experiments have confirmed earlier indications that pressure has little effect on the extent of degradation of the solvent in the CSF residue.
- Fracture toughness testing has been conducted in specimens from the surface, 1/4 thickness and mid-thickness depth locations, in a 25.4-cm- (10 in.) thick plate of ASTM A543 Class 1 steel. The steel exhibits maximum toughness values at -73°C (-100°F). The toughness decreased with plate depth; the lowest toughness [146 MPa√m (134 ksi√in.)] was observed with RW specimens obtained at the mid-thickness location of the 25.4-cm-thick plate.

- We have completed about 20% of our coating activities in the coal programs. We are still working on automatic offset circuitry to adapt our line-scan thermal camera for testing. We are evaluating commercial eddy-current instruments for ceramic coating thickness measurement. We completed our topical report on arc-discharge testing.

- The effects of variations in current, electrode extension, and travel speed on dilution and penetration of type 320 Cb stainless steel clad deposits has been determined. The addition of 0.5% O₂ to the argon shielding gas doubled the penetration and dilution as compared to that obtained with pure argon.

- Metallurgical analyses of test coupons exposed for 500 hr in the Fluidyne fluidized bed coal combustor have shown only slight to moderate corrosion of the test materials. Specimens for an additional 1000 hr test have been fabricated and Fluidyne is currently installing them in the fluidized bed facility.

- In our gas-fired potassium boiler project, we completed all of the design work and construction of the equipment tower. During the next several months, work will continue on the installation of piping, electrical wiring and heaters, and the instrument and control system.

- In our design studies of a coal-fired alkali metal vapor topping cycle, we have completed the first phase of a cycle analysis and the design and analysis of a metal vapor turbine. We continued the design of an atmospheric pressure fluidized bed furnace, the condenser-steam generator, and the layout work for the overall system.

- In our engineering studies and evaluation project, we continued work on process modeling; preparation of a Synthetic Fuels Research Digest; a survey of industrial coal conversion equipment capabilities; and studies of fluidized bed hydrothermal liquefaction, rapid hydrogenation, hot gas cleanup, large air separation plants, and processes for heat recovery.

- In our process and program analysis project, we continued studies of low-Btu gasification, high-Btu gasification, liquefaction, direct combustion, advanced power conversion, and coal beneficiation.

- The major effort in landfill storage of solid wastes during the past month was devoted to revising the FY 1977 experimental plan and updating the 1978-1979 portion of the overall program plan. Contacts were also made with a number of pilot plants in an attempt to obtain samples of feed coal and representative solid wastes from their processes.

- The construction section (Part III) of the Environmental Monitoring Handbook has been completed and reviewed internally. The operation section (Part IV) is nearing completion. Target date for delivery of the entire draft document is July 29.

- The pipeline gas programmatic assessment has been edited and typed and will be available for internal review during the first week in July. A draft should be ready for ERDA review by mid-July.

- Authorization to continue the coal-burning gas turbine project was received from ERDA-FE this month. The program has been reoriented to the development of technology for fluidized bed coal combustion closed cycle gas turbine systems for potential industrial applications requiring heat and electrical energy.

2. COAL CONVERSION PROCESS DEVELOPMENT

H. D. Cochran, Jr.

Coal conversion process development activities are carried out in the Chemical Technology Division. This section discusses hydrocarbonization studies in a 20-atm bench-scale facility, engineering support studies for in situ gasification, studies for identifying and characterizing alternate reactor concepts for coal hydroliquefaction, and studies of residue carbonization in a pressurized carbonizer.

2.1 Hydrocarbonization Research

E. L. Youngblood, J. B. Gibson, P. R. Westmoreland, C. H. Brown, Jr.
G. E. Oswald, L. S. Dickerson, J. Beams, and J. C. Rose

2.1.1 Experimental Development

Work Accomplished. Cold model testing of the recirculating fluidized-bed during June included solids feeding and withdrawal experiments in support of the bench-scale hydrocarbonization experiment. The bed of char introduced before startup was lost in Runs HC-17 and HC-18 during pressurization/depressurization cycles for air removal. Mock-up tests showed that part of the plume of solids from the draft tube showered against the wall and down into the overflow, causing losses as great as 25% of the bed in 15 min. A combination of gas flowrates was determined which minimized circulation and solids loss during start-up; much of the bed was retained in the start-up for Run HC-19. Prior to Run HC-20, a deflector plate was installed over the overflow. With start-up procedure changes, this minimized loss of the bed during startup.

Gas flowrates for bed circulation during bench-scale hydrocarbonization experiments are scaled from the mock-up studies by maintaining constant the ratio of gas velocities to calculated minimum fluidization velocity. Critical evaluation of this scaling procedure began at the end of the month.

Work Forecast. Evaluation of the dimensionless velocity as a basis for scaling will continue during July.

2.1.2 Bench-Scale Hydrocarbonization

Work Accomplished. During June three operability tests--Runs HC-18, 19, and 20--were completed with caking Illinois No. 6 coal. Reactor bed temperatures up to 1050°F and decreased feed char dilution ratios (3/1 - char/Illinois No. 6 coal) were investigated. Table 2.1 summarizes run conditions for each experiment.

Uninterrupted feed periods of 9 hours for Run HC-18, 4 hours for Run HC-19, and 4.5 hours for Run HC-20 were achieved with 8.5 lb/hr nominal feed rate. A recurrent problem in each run was blockage of the

Table 2.1. Summary of experiment conditions

Experiment	HC-18	HC-19	HC-20
Coal Feed			
Char/Illinois No. 6 coal ratio (wt/wt)	6/1	3/1	3/1
Total weight fed (lb)	84.4	38.3	46.0
Total feed period (hr)	10.0	4.5	5.4
Uninterrupted feed period (hr)	9.0	4.0	4.5
Feed rate (lb/hr)	8.6	8.5	8.5
Reactor			
Total H ₂ input (SCFM)	19.2	20.0	22.0
To coal transport tube (SCFM)	6.5	7.0	11.0
To draft tube nozzle (SCFM)	1.5	1.0	2.0
To downcomer plenum (SCFM)	11.2	12.0	9.0
Temperature of H ₂ entering downcomer plenum (°F)	950	1100	1025
Bed temperature at start of feed (°F)	950	925	1050
Estimated maximum temperature reached by coal in the draft tube during non-recirculation period (°F)	600	550	450

reactor downcomer region by agglomerated solids adhering to the hot reactor wall. This blockage prevented proper bed recirculation which then resulted in incomplete devolatilization of the coal feed. Since much of the reactor heat load is supplied by the electrical heaters on the exterior of the reactor wall, a substantial temperature differential existed between the reactor wall and the reactor bed. To reduce this temperature differential in future runs, a preheater has been designed for the coal transport line. The feed stream will be heated to about 400°F before entering the reactor.

For Run HC-18 coal diluted 6/1 with char which had previously been devolatilized at 1200°F was fed at 8.6 lb/hr to the 950°F, 300 psig reactor bed. Although a bed of char had been loaded into the reactor before startup, most of the char overflowed to the char receiver while purging the system with nitrogen before coal feed was introduced. When coal feed was initiated, the reactor temperature was uniform at 950°F. After feed was introduced the bed temperature dropped to 825°F in 50 minutes. After 10 minutes of steady operation at 825°F there were indications that the downcomer region may have become blocked by agglomerate material adhering to the hot (1100°F) reactor wall. The blockage was indicated by loss of reactor bed differential pressure and scattering of the axially spaced bed temperature measurements. For the remainder of the run (9 hours) there was apparently very little circulation through the downcomer and the main solids flow path was a single pass through the draft tube and out the overflow port. With this flow pattern, the solids residence time in the reactor was less than about 10 seconds while with normal bed recirculation the solids residence time is about 60 minutes. Without the benefit of recirculating char to heat the coal rising through the draft tube and with essentially all of the hydrogen that entered the reactor flowing through the draft tube, the maximum temperature reached by the coal can be calculated to be about 600°F. This temperature is not sufficient for extensive devolatilization of the coal.

Agglomerate material blocking the char overflow line terminated the run after 10 hours of feed. During the run very little light hydrocarbons were detected by the process chromatograph and only small amounts of tar were recovered.

Run HC-19 was the first attempt to operate with a lower feed char/Illinois No. 6 coal dilution ratio--3/1. Hydrogen flow rates into the reactor were about the same as used in Run HC-18. The reactor pressure was 300 psig. To decrease the heat flux through the reactor wall, the temperature of the hydrogen entering the downcomer plenum was increased to 1100°F. When coal feed was initiated, about one quarter of the char starter bed remained and was circulating at 925°F. The behavior of the bed was similar to Run HC-18 with the downcomer apparently becoming blocked 25 minutes after feed was initiated. The bed temperatures decreased rapidly (925 → 825°F), bed differential pressure went to zero and the bed temperature measurements became scattered. Under these

conditions feed was continued at 8.5 lb/hr for 4 hours. The maximum temperature reached by the coal with no char recirculation through the draft tube was calculated to be 550°F.

Run HC-20 was made with the 3/1-char/Illinois No. 6 coal feed mix as in Run HC-19. To minimize loss of the char starter bed, a deflector plate was installed at the reactor char overflow port, and the experimental procedure was modified to allow introduction of the char starter bed after completion of the purge cycles. The hydrogen flow rates into the reactor were chosen to give maximum bed recirculation based on recent ambient mockup work. Reactor pressure was 300 psig. When coal feed was introduced, about 1/2 of the char starter bed remained and was recirculating at 1050°F. As in the previous two runs, the bed temperature dropped when feed was initiated (1050 → 825°F in 20 minutes). The bed temperature measurements stayed closely grouped at 825°F for the next 40 minutes. Then, apparently the downcomer became blocked as before, the bed temperatures spread, and bed differential pressure went to zero. Feed was continuous at 8.5 lb/hr for 4.5 hours. The maximum temperature reached by the coal during the last 3.5 hours of operation was calculated to be 450°F. The run was terminated by a plug at the char overflow port.

Work Forecast. The coal preheater will be fabricated and installed. A run will be made with Wyodak subbituminous coal to provide char for preparation of Illinois No. 6 coal feed mixture. Sustained operation at 1050°F bed temperature with proper bed recirculation is the objective for future runs with Illinois No. 6 coal.

2.2 Experimental Engineering Support of an In Situ Gasification Process

J. B. Gibson, L. S. Dickerson, and T. C. Scott

As described in previous reports, samples of Eastern bituminous coal have been obtained from the Morgantown Energy Research Center (MERC) for use in our large-block pyrolysis studies. The coal is typical of the material which will be burned by MERC in their field test near Pricetown, West Virginia.

During June, a high temperature experiment (1000°C) with a slow heating rate (0.3°C/min) was carried out. As shown in Figure 2.1, maximum gas evolution occurred near the twenty-second hour, between 450 and 550°C. There was a second peak in gas evolution near the twenty-eighth hour, at approximately 685°C. These two peaks correspond to the primary and secondary gasification regimes observed in many earlier runs. Gas evolution during the first peak was slightly erratic due to cycling problems with the temperature controller. This problem was corrected by adjusting the maximum voltage output of the controller.

ORNL DWG 77-1168

Fig. 2.1. Gas evolution and thermal history of bituminous coal block in run BP2-30.

A means of obtaining a permanent record of gas evolution has been devised by connecting a magnetic switch and a recorder to the wet test meter used to measure gas flow. This should improve gas measurement since flow rates will be monitored continuously instead of periodically.

A hydrogen sensor/alarm is being installed near the experimental apparatus. This will be an integral part of the safety system for future runs which utilize hydrogen instead of argon as the carrier gas.

2.3 Coal-Solvent-Hydrogen Mixing

J. M. Begovich, R. C. Lovelace, and J. R. Hightower, Jr.

As described previously¹, a total of 124 pulse test measurements have been completed in the 1-in.-ID x 10-ft-long column packed with 4.6-mm-diam glass beads using air and a 35 wt % coal-water slurry in cocurrent upflow. Flow rates used were in the range of 0-255 cm³/sec and 1.25 - 19.8 cm³/sec for the air and slurry, respectively. Errors in the data digitizing technique were corrected and the preliminary information obtained from the first 72 pulse test measurements is summarized, as corrected, along with information from the remaining coal-water slurry runs in Table 2.2. Correction of the data digitizer errors involved filtering the digitized concentration vs time curves so that a true zero baseline was achieved for both curves. Use of a non-zero baseline for the second curve results in large differences between the calculated spread of the two curves and thus large values for the axial dispersion coefficient, D_L (see Ref. 2 for details of the mathematical model used). On the other hand, use of a non-zero baseline for the first curve results in very small differences between the calculated spread of the two curves and thus small values for D_L . This difference can become so small that it actually goes negative, and causes D_L to be negative, which is physically meaningless.

The pressure drop across the column is shown in Fig. 2.2 as a function of the liquid and gas flow rates. The pressure drop is increased when either the liquid or gas flow rate is increased. Note that the slope of the curves, with the exception of the 169 cm³/sec gas curve, has reached a constant value for gas flow rates of 110 cm³/sec and above. Removing the influence of the liquid static head from the pressure drop, the pressure drop due to flow can be plotted as the energy dissipation per unit volume as shown in Fig. 2.3. This is the same plot as shown in a previous report, with the rest of the data, mainly for low liquid flow rates added; the previous curves extrapolate well through the additional data to the origin. From Fig. 2.3, it is obvious that the liquid flow rate has a greater influence upon the energy dissipation per unit volume than does the gas flow rate. Thus fluid energy input via the slurry is more effective than fluid energy input via the gas in inducing microscale turbulence.

Table 2.2. Results of dispersion and pressure drop experiments in a glass column packed with 4.6-mm-diam glass beads with concurrent upflow of air and coal slurry

Column Diameter = 2.54 cm
 Column Length = 310 cm
 Bed Porosity = 0.42

Run number	Liquid flow cm ³ /sec	Gas flow cm ³ /sec	Liquid holdup, ϵ_L (fraction of total bed volume)	Liquid saturation, R_L (fraction of void volume)	ΔP psi	Peclet number Pe	Dispersion coefficient, D_L cm ² /sec	Energy dissipation per unit volume $\frac{v_L \Delta P_f}{L}$ ft.lbf. ft ⁻³ . sec ⁻¹
140	10.13	0	0.379	0.901	6.1	260.2	6.32	5.6
141	10.41	0	0.377	0.899	6.1	260.4	6.51	5.8
142	10.41	0	0.376	0.894	6.1	226.6	7.42	5.8
143	10.48	0	0.371	0.883	6.1	325.9	5.33	5.8
144	12.75	0	0.384	0.915	7.6	257.4	7.91	8.8
145	12.76	0	0.380	0.904	7.6	277.4	7.44	8.8
146	14.88	0	0.382	0.908	9.1	217.8	11.0	12.3
147	14.88	0	0.379	0.903	9.1	233.7	10.0	12.3
148	14.88	0	0.381	0.914	9.1	242.5	9.81	12.3
149	17.14	0	0.396	0.942	9.8	225.2	11.8	15.3
150	17.00	0	0.397	0.946	9.8	282.4	9.30	15.2
151	17.00	0	0.395	0.939	9.8	303.1	8.73	15.2
152	19.83	0	0.394	0.939	11.5	188.1	16.4	20.8
153	8.15	82.85	0.197	0.470	11.2	688.4	3.68	8.3
154	9.21	83.95	0.211	0.502	11.2	996.4	2.69	9.4
155	9.21	82.85	0.219	0.521	11.2	997.2	2.59	9.4

Table 2.2. (continued)

Run number	Liquid flow cm ³ /sec	Gas flow cm ³ /sec	Liquid holdup, ϵ_L (fraction of total bed volume)	Liquid saturation, R_L (fraction of void volume)	ΔP psi	Peclet number Pe	Dispersion coefficient, D_L cm ² /sec	Energy dissipation per unit volume $\frac{v_L \Delta P_f}{L}$ ft. lb _f . ft ⁻³ . sec ⁻¹
156	6.73	106.03	0.185	0.441	10.4	1080	2.07	6.4
157	6.73	106.03	0.187	0.445	10.4	312.6	7.08	6.4
158	5.95	137.49	0.178	0.423	11.2	402.0	5.12	6.1
159	6.23	137.49	0.186	0.442	12.8	725.9	2.84	7.3
160	6.73	167.19	0.176	0.419	15.2	335.4	7.00	9.3
161	6.66	168.94	0.162	0.385	14.2	383.7	6.58	9.2
162	6.02	200.5	0.156	0.372	16.0	259.5	9.13	8.8
163	6.09	200.5	0.155	0.369	16.0	211.3	11.4	8.9
164	5.74	227.2	0.151	0.359	18.4	248.5	9.40	9.6
165	5.53	224.9	0.147	0.350	18.4	295.8	7.80	9.3
166	11.7	85.1	0.203	0.483	16.0	190.1	18.6	17.1
167	11.7	85.1	0.195	0.464	16.0	913.6	4.03	17.1
168	11.0	116.3	0.178	0.425	18.8	217.6	17.4	18.9
169	11.2	116.3	0.184	0.438	18.8	195.1	19.2	19.2
170	10.6	147.1	0.169	0.402	20.4	162.1	23.8	19.7
171	10.8	147.1	0.175	0.417	20.4	146.0	26.0	20.1
172	10.3	176.6	0.161	0.384	22.4	379.7	10.3	21.1
173	10.3	176.6	0.160	0.382	22.4	262.7	15.0	21.1
174	9.85	204.8	0.156	0.371	24.4	119.2	32.5	22.0
175	9.70	204.8	0.152	0.361	24.4	374.3	10.5	21.6
176	9.21	230.7	0.150	0.358	26.0	155.3	24.2	21.9
177	9.21	230.7	0.146	0.348	26.0	384.9	10.1	21.9
178	15.6	77.9	0.185	0.440	22.0	93.35	55.4	31.3

Table 2.2. (continued)

Run number	Liquid flow cm ³ /sec	Gas flow cm ³ /sec	Liquid holdup, ϵ_L (fraction of total bed volume)	Liquid saturation, R_L (fraction of void volume)	ΔP psi	Peclet number Pe	Dispersion coefficient, D_L cm ² /sec	Energy dissipation per unit volume $\frac{v_L \Delta P_f}{L}$ ft. lb _f . ft ⁻³ . sec ⁻¹
179	15.7	77.9	0.198	0.472	22.0	185.9	26.2	31.5
180	15.1	108.4	0.187	0.445	24.8	187.7	26.4	34.2
181	14.8	108.4	0.187	0.445	24.8	144.2	33.7	33.5
182	14.3	136.1	0.173	0.412	26.4	215.6	23.5	34.5
183	14.2	136.1	0.172	0.408	26.4	323.3	15.8	34.2
184	13.7	163.9	0.164	0.392	28.0	499.4	10.3	35.0
185	13.7	163.9	0.166	0.394	28.0	170.4	29.9	35.0
186	13.7	163.9	0.167	0.397	28.0	125.1	40.5	35.0
187	12.9	150.6	0.154	0.366	29.6	247.2	20.8	34.9
188	13.0	150.6	0.156	0.370	29.6	201.6	25.4	35.1
189	12.1	215.5	0.146	0.349	31.2	397.7	12.8	34.5
190	12.0	215.5	0.150	0.358	31.2	117.7	41.8	34.2
191	5.60	0	0.477	1.136	3.2	521.1	1.4	1.6
192	6.70	0	0.427	1.016	3.2	216.2	4.5	1.9
193	3.61	0	0.420	1.000	3.2	385.5	1.4	1.0
194	6.50	0	0.420	1.000	3.2	271.7	3.5	1.9
196	5.60	0	0.400	0.952	3.2	254.4	3.4	1.6
197	11.20	0	0.438	1.043	3.2	191.2	8.2	3.2
198	3.24	0	0.420	1.000	2.4	218.0	2.2	0.7
199	4.50	0	0.412	0.931	3.2	38.2	1.9	1.3
200	5.70	0	0.403	0.939	3.2	288.5	3.0	1.7
201	5.70	0	0.411	0.978	3.2	231.2	3.7	1.6

Table 2.2. (continued)

Run number	Liquid flow cm ³ /sec	Gas flow cm ³ /sec	Liquid holdup, ϵ_L (fraction of total bed volume)	Liquid saturation, R_L (fraction of void volume)	ΔP psi	Peclet number Pe	Dispersion coefficient, D_L cm ² /sec	Energy dissipation per unit volume $\frac{v_L \Delta P_f}{L}$ ft. lb _f · ft ⁻³ · sec ⁻¹
202	10.40	84.1	0.223	0.533	16.8	10711	0.27	15.9
203	10.00	84.1	0.217	0.517	16.8	-1690	-1.7	15.3
204	3.36	102.0	0.204	0.487	4.4	2043	0.49	1.3
205	8.10	90.3	0.234	0.486	12.8	1621	1.5	9.5
206	5.00	94.8	0.200	0.475	10.0	683.7	2.3	4.6
207	5.80	94.8	0.214	0.509	9.6	1553	1.1	5.1
208	5.20	98.2	0.214	0.509	6.8	4219	0.35	3.2
209	3.77	100.0	0.207	0.492	6.0	2057	0.54	2.1
210	3.15	103.0	0.209	0.497	4.4	1905	0.49	1.3
211	2.50	105.2	0.197	0.469	4.0	2943	0.25	0.9
212	2.50	105.2	0.200	0.477	4.0	4259	0.18	0.9
213	2.95	142.4	0.196	0.467	6.4	385.4	2.40	1.7
214	5.47	130.5	0.193	0.459	8.0	6445.0	0.27	4.0
215	6.46	126.5	0.203	0.482	13.2	1824.7	1.07	7.8
216	7.42	124.6	0.209	0.498	14.8	729.4	2.99	10.0
217	4.56	130.5	0.172	0.410	10.8	21078	0.08	4.5
218	8.21	126.5	0.206	0.490	13.2	776.5	3.16	9.9
219	3.80	139.7	0.191	0.454	7.6	471.1	2.60	2.6
220	6.70	128.4	0.188	0.447	14.0	1131.7	1.93	8.6
221	2.58	145.1	0.180	0.427	6.4	601.8	1.47	1.5
222	8.00	154.9	0.184	0.439	16.0	173.5	15.37	11.7

Table 2.2. (continued)

Run number	Liquid flow cm ³ /sec	Gas flow cm ³ /sec	Liquid holdup, ϵ_L (fraction of total bed volume)	Liquid saturation, R_L (fraction of void volume)	ΔP psi	Peclet number Pe	Dispersion coefficient, D_L cm ² /sec	Energy dissipation per unit volume $\frac{v_L \Delta P_f}{L}$ ft. lb _f . ft ⁻³ . sec ⁻¹
223	6.46	169.0	0.187	0.444	12.0	1504.6	1.41	7.1
224	2.03	177.6	0.181	0.430	9.2	2507.1	0.28	1.7
225	2.25	177.6	0.189	0.449	9.6	834.5	0.88	2.0
226	1.87	177.6	0.187	0.444	9.2	539.4	1.14	1.6
227	2.43	174.6	0.184	0.438	9.2	4823	0.17	2.0
228	12.00	0	0.422	1.005	12.0	908.3	1.92	13.1
229	4.15	168.8	0.189	0.451	12.8	1185.3	1.14	4.8
230	4.86	164.9	0.186	0.442	14.0	1460.5	1.10	6.2
231	4.15	168.8	0.181	0.431	13.2	1099.4	1.28	5.0
232	5.42	161.3	0.200	0.475	14.0	13120	0.13	6.9
233	4.46	150.1	0.168	0.400	17.2	724.1	2.25	7.0
234	4.76	192.7	0.177	0.422	15.6	852.5	1.93	6.8
235	4.31	187.6	0.177	0.421	17.6	633.8	2.36	6.9
236	6.00	185.2	0.182	0.432	19.2	730.4	2.78	10.5
237	7.98	179.6	0.172	0.409	20.2	511.8	5.57	14.7
238	7.60	185.2	0.235	0.556	19.2	217.5	9.19	13.3
239	4.31	193.2	0.176	0.419	14.4	607.7	2.48	5.7
240	3.80	206.0	0.183	0.435	12.2	18657	0.07	4.2
241	4.37	159.8	0.178	0.424	13.2	1109.3	1.36	5.3
242	4.05	198.4	0.185	0.441	14.0	817.3	1.64	5.2
243	1.90	218.3	0.176	0.418	8.4	7121	0.09	1.6
244	4.03	198.4	0.188	0.449	11.8	1225.8	1.07	4.3

Table 2.2. (continued)

Run number	Liquid flow cm ³ /sec	Gas flow cm ³ /sec	Liquid holdup, ϵ_L (fraction of total bed volume)	Liquid saturation, R_L (fraction of void volume)	ΔP psi	Peclet number Pe	Dispersion coefficient, D_L cm ² /sec	Energy dissipation per unit volume $\frac{v_L \Delta P f}{L}$ ft. lb _f . ft ⁻³ . sec ⁻¹
245	1.33	240.9	0.189	0.450	12.4	224.0	1.93	1.5
246	4.68	220.1	0.171	0.408	18.0	1080.8	1.55	1.7
247	4.99	220.1	0.171	0.406	18.0	479.2	3.75	8.2
248	4.92	220.1	0.174	0.415	18.4	1277.4	1.36	8.3
249	6.46	210.9	0.187	0.446	21.6	665.7	3.18	12.7
250	6.46	210.9	0.176	0.419	22.4	721.2	3.13	13.2
251	1.25	246.6	0.177	0.421	10.6	883.8	0.49	1.2
252	3.72	229.0	0.179	0.426	16.0	664.7	1.92	5.4
253	2.47	235.6	0.173	0.411	13.8	921.1	0.95	3.1
254	3.15	235.6	0.164	0.389	14.2	601.0	1.97	4.1
255	1.82	240.9	0.169	0.403	12.4	983.3	0.67	2.1
256	3.71	230.6	0.184	0.439	14.8	4551.7	0.27	5.0
257	2.58	254.5	0.164	0.391	18.0	441.0	2.19	4.2
258	6.08	229.6	0.187	0.446	24.0	2512	0.79	13.3
259	7.30	229.6	0.168	0.401	24.0	1501.2	1.77	16.0
260	3.75	254.5	0.172	0.410	20.4	1098.6	1.22	7.0
261	5.70	239.7	0.169	0.401	23.2	798.3	2.60	12.1
262	5.47	237.1	0.168	0.400	23.4	546.1	3.67	11.7
263	1.98	272.4	0.171	0.408	13.2	1210.6	0.59	2.4
264	1.52	272.4	0.173	0.411	13.2	6738	0.08	1.8

Fig. 2.2. Effect of fluid flow rates on the pressure drop for air and coal slurry in cocurrent upflow through a packed column.

Fig. 2.3. Effect of fluid flow rates on the energy dissipation per unit volume for air and coal slurry in cocurrent upflow through a packed column.

The effect of liquid and gas flow rates upon the liquid saturation in the column is shown in Fig. 2.4. As the gas flow rate is increased, liquid is displaced and hence the liquid saturation is decreased. The effect of liquid flow rate is not immediately obvious, but careful inspection indicates that the liquid saturation is slightly decreased as the liquid flow rate increases.

The liquid phase axial dispersion coefficient, D_L , plotted as averages of the repeated runs shown in Table 2.2, is presented in Fig. 2.5 as a function of the fluid flow rates. Increasing the liquid flow rate, in general, causes D_L to increase. Similarly, the addition of gas flow to a liquid-only system causes D_L to increase. Once established, however, the gas flow rate does not appear to have a large effect upon the axial dispersion coefficient. This result is in agreement with work done by Stiegel and Shah³ on a similar system using 1/8-in.-diam polyethylene extrudates in a 2-in.-ID x 7-ft-long packed column.

Pulse test measurements are currently under way in the 1-in.-ID x 5-ft-long Kenics contactor. Visual observations made while operating the column with air and water in cocurrent upflow indicate that the inline static mixers may be ineffective for use as turbulent contactors. For low gas flow rates, gas bubbles swirl around the helical path of the mixer elements, without being split by the elements' leading edges. For slightly higher gas flow rates, the flow regime in the contactor shifts from bubble flow to gas continuous flow. The pressure drop across the column is much lower than that found in the packed column and is due almost entirely to the liquid static head. Thus the energy dissipation per unit of liquid volume is quite low, and microscale turbulence is probably not being induced. Further experiments and subsequent analysis will give quantitative information on these important parameters.

2.4 Pressurized Carbonization of Consol Synthetic Fuel Residues

R. E. Barker, S. M. Gibson, and G. D. Smith

This project is intended to determine experimentally the degree of coking and liquid degradation to be expected when Consol Synthetic Fuel (CSF) liquefaction residue is fed to a pressurized, fluidized-bed carbonizer. The experimental system and early experiments are described in earlier reports in this series. Preliminary results have shown that increased pressure does not seriously affect degradation of the valuable light liquids contained in the residue.

Since the last report, three runs have been made using CSF residue and solvent. These runs, replications of earlier runs, were completed without operational difficulties, and appear to be the most successful runs attempted to date. Complete analytical results, needed for material balance calculations, are not yet available. Material balance calculations for the runs previously reported are nearly complete, showing total material balance closures of 70-98%. It is thought that most

Fig. 2.4. Effect of fluid flow rates on the liquid saturation for air and coal slurry in cocurrent upflow through a packed column.

Fig. 2.5. Effect of fluid flow rates on the liquid phase axial dispersion coefficient for air and coal slurry in cocurrent upflow through a packed column.

of the deficiency in the balances is caused by incomplete liquid recovery. Since less than complete recovery of liquids or gases would make characterization of products difficult, an effort for better liquid recovery is being made.

During the next month several experimental runs are planned. One run is planned using char from the hydrocarbonization of Wyodak coal as the fluidized solid to determine if the nature of the solid has any effect on cracking. The solid used in studies to date is a high-fired, low surface area alumina, which should have little catalytic activity. Later tests will be made using a reducing gas, probably a mixture of hydrogen and argon, to test the effect of gas composition on cracking.

2.5 References for Section 2

1. J. P. Nichols (ed.), Coal Technology Program Progress Report for May, 1977, ORNL/TM-5980.
2. J. R. Hightower, Jr. et al., in Coal Technology Program Quarterly Progress Report for the Period Ending December 31, 1976, ORNL-5252.
3. G. J. Stiegel and Y. T. Shah, "Backmixing and Liquid Holdup in a Gas-Liquid Cocurrent Packed Column," Ind. Eng. Chem., Proc. Des. Dev. 16 (1), 37 (1977).

3. MATERIALS ENGINEERING

R. T. King

The materials engineering and associated technology reported here are in support of activities directed by the Materials and Power Generation Branch of the Division of Materials and Exploratory Research. Other related work not funded directly by this division of ERDA/FE is included also.

Summary

Fracture toughness testing has been conducted in specimens from the surface, 1/4 thickness and mid-thickness depth locations, in a 25.4 cm (10 in.) thick plate of ASTM A543 Class 1 steel. The steel exhibits maximum toughness values at -73°C (-100°F). The toughness decreases with plate depth; the lowest toughness [$146 \text{ MPa } \sqrt{\text{m}}$ ($134 \text{ ksi } \sqrt{\text{in.}}$)] was observed with RW specimens obtained at the mid-thickness location of the 25.4-cm-thick plate.

We have completed about 20% of our coating survey in the Coal Programs. We are still working on automatic offset circuitry to adapt our line-scan thermal camera for testing. We are evaluating commercial eddy-current instruments for ceramic coating thickness measurement. We completed our topical report on arc-discharge testing.

The effects of variations in current, electrode extension, and travel speed on dilution and penetration of type 320 Cb stainless steel clad deposits has been determined. The addition of 0.5% O_2 to the argon shielding gas doubled the penetration and dilution as compared to that obtained with pure argon.

Metallurgical analyses of test coupons exposed for 500 hr in the Fluidyne fluidized bed coal combustor have shown only slight to moderate corrosion of the test materials. Specimens for an additional 1000 hr test have been fabricated and Fluidyne is currently installing them in the fluidized bed facility.

3.1 Pressure Vessel and Piping Materials

D. A. Canonico and W. J. Stelzman

We have employed the equivalent energy procedures with precracked charpy V-notch specimens to determine the fracture toughness of 25.4 cm (10 in.) thick ASTM A543 Class 1 steel plate. The static fracture toughness was determined at the surface, 1/4 thickness and mid-thickness locations in the plate. Both RW and WR oriented specimens were tested.

(R signifies rolling direction, W is transverse to the rolling direction. The first-letter designates the direction of the principal axis of the specimen; the second letter identifies the direction of crack propagation.) The specimens all reached their maximum toughness value at -73°C (-100°F). The toughness values obtained for the RW and WR oriented specimens were quite similar. The table below summarizes the results.

Fracture Toughness of 25.4 cm (10 in.)
Thick ASTM A543 Class 1 Plate

Plate Depth	Test Temperature		MPa $\sqrt{\text{m}}$ (ksi $\sqrt{\text{in.}}$)	
	$^{\circ}\text{C}$	($^{\circ}\text{F}$)	RW	WR
Surface	-18	(0)	229 (208)	229 (208)
	38	(100)	-	225 (205)
	260	(500)	203 (185)	192 (175)
1/4 Thickness	-18	(0)	223 (203)	225 (205)
	38	(100)	-	198 (180)
	260	(500)	196 (178)	170 (155)
Mid-Thickness	-18	(0)	214 (195)	192 (175)
	38	(100)	-	185 (168)
	260	(500)	147 (134)	176 (160)

The lower bound toughness values decrease with increasing temperature. This behavior is similar to that exhibited by other structural steels such as SA 533, Grade B, Class 1. Also the maximum toughness decreases with increasing plate depth. For example, the mid-thickness fracture toughness (K_{Icd}) of RW oriented specimens at 260°C (500°F) is 147 MPa $\sqrt{\text{m}}$ (134 ksi $\sqrt{\text{in.}}$) whereas the toughness for the same orientation at the 1/4 thickness depth is 196 MPa $\sqrt{\text{m}}$ (178 ksi $\sqrt{\text{in.}}$). This lower toughness at the mid-thickness location was also exhibited in the charpy V-notch tests.

3.2 Inspection Techniques for Wear- and Process-Resistant Coatings

R. W. McClung and G. W. Scott

3.2.1 Review and Evaluation (G. W. Scott)

We have completed about 20% of our survey of coating-related activities. The general consensus thus far is that a nondestructive inspection capability will be useful and probably necessary. There were some indications that experimenters had difficulty verifying the initial conditions of

test specimens going into experiments and would like to have had more information about the specimens before testing them. We also found out about a few groups of used specimens that might be available to us.

3.2.2 Specimens and Standards Fabrication (J. D. Hudson and D. P. Edmonds)

During this reporting period several test specimens have been prepared by the Welding and Brazing Laboratory for NDE. These specimens include the following:

(a) Electrochemical Specimens:

Base metal - Incoloy 800 [3.18 mm (.13 in.)] thick

Coating - Cermet, 50% ZrO₂/50% NiCrAl (.254 mm (.010 in.)) thick

(b) Tensile specimens - Incoloy 800 [3.18 mm (.13 in.)] thick
Base Metal:

ZrO₂ coating - .254 mm thick

50% ZrO₂/50% NiCrAl Coating .254 mm thick

NiCr Al Coating - .076 mm thick plus 50% ZrO₂/50% NiCrAl
.254 mm thick

(c) Thermal specimens with known defects - we are investigating techniques for successfully making these specimens.

3.2.3 Thermal Testing (W. A. Simpson)

We have been experiencing difficulty in adapting an automatic offset circuit, previously described, to use with the line-scanning camera which we are using to examine our coating nonbond standards. The circuit is being redesigned to make it compatible with the camera unit. In the interim we will begin looking at the new version of the HEATING Code which is available for modeling the heat flow in coated materials. The new version is considerably more versatile than that with which we performed the initial mockup of heat conduction in ZrO₂ coatings.

3.2.4 Eddy Current Testing (G. W. Scott and M. R. Cohen¹)

We have begun the evaluation of commercial eddy current instruments for lift-off sensitivity and use in measuring the thickness of nonconductive coatings, such as ceramics, on paramagnetic metal substrates. We are now looking at a Dermatron,² which is an AC-bridge instrument; our model is a vacuum-tube type, but has performance characteristics similar to newer ones with solid-state electronics.

¹Summer Research Participant, sponsored by Oak Ridge Associated Universities

²Unit Process Assemblies, Inc., Syosset, N.Y.

3.2.5 High Voltage Testing (G. W. Scott)

We completed the draft of our topical report on the design and demonstration of our arc-discharge testing system. It is now undergoing technical review.

3.3 Welding and Cladding

J. D. Hudson, W. C. Oliver, J. J. Woodhouse, and D. P. Edmonds

We are investigating the effects of welding conditions on the structure and properties of gas metal-arc (GMA) and submerged-arc (SA) type 320 Cb stainless steel clad deposits. During this reporting period we have made several experimental deposits with both processes. For the GMA deposits we have investigated the effects of varying currents, electrode extension, and travel speed using pure argon shield gas and 1.59 mm (0.063 in.) diam wire. Using stringer bead techniques and varying the above parameters from the minimum to the maximum values producing stable welding conditions, dilution varied from 9 to 31% and penetration varied from 1/25 mm to 4.25 mm. The deeper penetrations and higher dilutions occurred at the higher currents, shorter electrode extensions and lower travel speeds. Also, we found that the addition of 0.5% O₂ to pure argon shield gas doubles the penetration and dilution obtained from the pure argon deposits. We are presently evaluating the effects of torch oscillation width and frequency. For the SA cladding we have made deposits with varying travel speeds, welding currents, oscillation width, and oscillation frequency. The structure of these deposits is presently being evaluated. All of the above clad deposits have been made on plain carbon steel base plates using no preheater. Later, we will investigate the effects of different types of base metals, using preheat requirements of Section VIII of the ASME Boiler and Pressure Vessel Code.

In addition we have consulted with ERDA on a fabrication problem at Synthane. We have reviewed procedures for replacing several nozzles in the vessel and have reported the results of this review to ERDA-FE.

3.4 Fireside Corrosion

R. H. Cooper and J. H. DeVan

Metallurgical analysis of test coupons exposed for 500 hr in the Fluidyne fluidized bed coal combustor is continuing. Results to date have shown only slight to moderate corrosion of the high temperature test materials. Corrosion products are those associated with oxidation rather than sulfidation.

The original test specimens from the 500 hr test and some additional test specimens to replace those destructively examined have been fabricated and shipped to Fluidyne for an additional 1000 hr exposure. Fluidyne is currently installing these test materials in the fluidized bed facility and anticipates starting the 1000 hr test run in the next few weeks. Test materials from this exposure should be available for metallurgical evaluation in mid-September.

During this reporting period, the preliminary results from the first 500 hr testing at Fluidyne were reported to the conference on Coal Ash Deposits and Corrosion held at Henniker, New Hampshire. In general, those attending this conference felt that the results from this test and other ongoing corrosion tests in fluidized beds indicated the need for additional work in relating the effect of changes in operating parameters on the corrosion response of inbed materials.

4. ALKALI METAL VAPOR TOPPING CYCLES

R. S. Holcomb and G. Samuels

4.1 Gas-Fired Potassium Boiler

R. S. Holcomb, D. B. Lloyd, and R. H. Guymon

4.1.1 Contract Objective

Design, construction, and testing of a full-scale potassium boiler tube bundle and burner module on water and then potassium to determine the performance and operating characteristics.

4.1.2 Status Summary

1. The design necessary for construction of the instrument and control system has been completed. A total of 22 instrument and control drawings were issued this month. These include 5 new drawings for field wiring and instrument piping, and 17 revised drawings for wiring of the instrument cabinets. This completes the design work for the installation of the potassium system. Additional instrument and control drawings will be made for operation and maintenance and drawings will be revised to incorporate as-built changes and design modifications.

2. Fabrication work completed includes installation of heaters and thermocouples on the argon separator vent line, the vapor separator was installed in the boiler and the upper head was welded onto the boiler, the sample box was insulated, and the fabrication and checkout of control cabinets 6 and 7 was completed.

3. The bids were received for the electric air preheater and the purchase order has been placed. Delivery is expected in early August.

4. Construction work on the equipment tower by the CPFF contractor was completed on June 10 with the completion of the installation of the aluminum siding, louvers, and the roof ventilator. Installation of the piping was begun and welding of the vapor line between the boiler and condenser and the fill-and-drain line is in progress.

5. Plans for Next Month. Work will continue on the installation of piping, electrical wiring and heaters, and instrument and control wiring, piping, and components.

4.2 Coal-Fired Alkali Metal Power System

G. Samuels

4.2.1 Contract Objective

The objective of the Coal-Fired Alkali Metal Power System Design Study is to establish a reference design for a 200-MW(e) alkali metal vapor/steam Rankine cycle system employing a coal-fired atmospheric fluidized bed furnace and to prepare a preliminary design of a fluidized bed furnace. This will be accomplished by studying the relative merits of both potassium and cesium vapor cycle systems and making a comparison of these systems. The results will be analyzed and potassium or cesium will be chosen as the cycle fluid and one of the systems will be selected as the reference. The reference system will be used for the preparation of a preliminary design of a fluidized bed furnace-boiler.

4.2.2 Status Summary

1. The first phase of the cycle analysis has been completed. This was a parametric analysis of the three basic systems of the plant, i.e., atmospheric, intermediate, and high pressure fluidized bed combustion systems. The results of this analysis were reported in the January 1977 monthly report. Several variations of the cycle arrangement for the atmospheric pressure system were analyzed during the month.

2. The first phase of the metal vapor turbine design and analysis has been completed. This effort was restricted to a determination of the number of stages, hub diameter, blade height, and stress and turbine efficiency.

3. The work on the fluidized bed furnace during the first six months of the project was concentrated on a vertical tube boiler arrangement for a pressurized furnace and is thus invalidated by the change in direction of the program. The atmospheric furnace concept now being studied is a horizontal forced-circulation unit.

4. Work on the alkali metal condenser-steam generator was continued. A computer code has been prepared to analyze a reentry tube type unit for this application.

4.2.3 Future Work

Work for the next two months will be concerned with selecting the design operating points for the reference design, designing the coal feed and ash handling system, completing the design of the alkali metal condenser-steam generator, analyzing the furnace startup procedure, estimating the system alkali metal inventory, estimating the plant parasitic power losses, and deriving a general arrangement of the major plant equipment.

5. COAL EQUIPMENT TEST FACILITY

R. E. MacPherson

Work by TRW Energy Systems on a subcontract for the purpose of planning for the evaluation of potentially critical equipment and components of coal conversion/utilization demonstration/commercial plant is expected to be underway early in July.

The ERDA sponsored conference on Coal Feeding Systems held June 21-23, 1977, at the California Institute of Technology was attended by several staff members. The items covered by this conference included Process Operation Experience; the ERDA Coal Feed Program; Advanced Concepts, Experiments; and Advanced Concepts and Analysis.

6. ENGINEERING STUDIES AND TECHNICAL SUPPORT

J. R. McWherter

6.1 Process Modeling

R. Salmon and D. M. Lister

6.1.1 Contract Objective

The objective is to assist the Fossil Energy Major Facility Project Management Division of ERDA in its plan for computer analysis and computer support for coal conversion studies. This includes assistance to Purdue and Lehigh Universities in the development of computer programs for this plan.

6.1.2 Status Summary

1. A meeting of Lehigh, Purdue, ERDA, DARCOM, and Oak Ridge National Laboratory representatives was held in Washington, D.C., on May 25 and 26. Progress on the project was reviewed, and plans for proceeding with the ICGG COGAS flowsheet simulation were discussed. On May 26, a briefing session was held for representatives of the ERDA/FE Mathematical Modeling Committee.

2. A report on the installation of the Lehigh differential equation solving program DSS/2 on the IBM 360-195 computer at ORNL has been completed. A preliminary draft was distributed at the meeting referred to above, and the final report will be issued shortly.

As a result of discussions with Lehigh, it was agreed that ORNL would convert five numerical differentiation routines to double precision for use on the IBM system. Three of these have now been rewritten and are in the process of being tested. Results of these tests should be available for the next monthly report.

3. Several literature searches and bibliographies have been completed for Purdue University. Items sent to Purdue include a set of U.S. Steel monthly reports on the development of the Clean Coke process, a literature search on the hydrotreating of coal-derived liquids, and a bibliography on cyclone combustors. Bibliographies have been compiled on the Bigas and UCC-Battelle Ash Agglomerating gasification processes. These will be sent to Purdue shortly.

4. Discussions with Corps of Engineers personnel were held at the Corps' Construction Engineering Research Laboratory (CERL) at Champaign, Illinois, on June 7. The purpose was to discuss the work being done at CERL on computer-aided design and cost estimating. Parts of the CERL studies appear to be adaptable for use in the design and costing of coal conversion facilities, particularly in regard to the civil engineering portions of such facilities. They have done a great deal of work on the costs of grading, excavation, site preparation, foundations, steel structures, buildings, water systems, and sewers, and are willing to make this information available for our studies.

5. Computerized design and cost estimating techniques were discussed with representatives of Fluor Engineers and Constructors at a meeting at the Fluor offices on June 17. Fluor is developing an overall system using a number of self-standing programs. Of particular interest to our project is their approach to process plant cost estimating. They are working toward a rapid system for producing estimates of greater detail and accuracy than those of the "factored" variety, using the information normally developed in a conceptual process design. Although they cannot release proprietary cost data, several of their techniques appear to be adaptable for our use.

6.1.3 Problem Areas

Acquisition of process data on the ICGG gasification system remains a problem. The data are needed by Purdue and Lehigh in connection with the development of their simulation models, which are to be used on the ICGG flowsheet.

6.2 Synthetic Fuels Process Research Digest

R. W. Glass

6.2.1 Contract Objective

The objective is to provide continuing technical assistance to the Assistant Director for Processes of the Division of Materials and Exploratory Research (DMER) by preparing digest reviews of current or potential subjects relating to coal conversion technology.

6.2.2 Status Summary

Significant achievements were made during this reporting period. Efforts on the first issue articles this month are summarized as follows:

"Conversion of Methanol to High-Octane Gasoline" - Evaluation of review comments and final camera-ready copy were completed. Final draft review copies were completed.

"Flash Hydropyrolysis of Coal" - Draft review comments were evaluated and incorporated into the article. A major revision was requested by ERDA/FE/DMER to include information made available since the preparation of the first draft. The revision, which reflects the current research and development work of Brookhaven National Laboratory concerning flash hydropyrolysis of coal, has been completed and reviews are underway.

"Zinc Chloride Hydrocracking of Coal and Coal Extracts" - Drafts of this article have been completed and reviews are in progress.

"Coal Gasification Using Chemically Incorporated Catalysts" - Draft editing and type setting have been completed this month. The article has been released for review.

Collection of information for use in two articles slated for the second digest issue are well along. Outlining of one second issue article has begun. Efforts on remaining second issue articles are pending direction of ERDA/FE/DMER.

6.3 Survey of Industrial Coal Conversion Equipment Capabilities

R. W. Glass and J. M. Holmes

6.3.1 Contract Objective

The general objective of this project is to conduct surveys of industrial equipment capabilities that will identify the present capability of industry to supply the equipment needed. The project will also determine research and development needs, including lead time requirements, for producing equipment of advanced design for the various unit operations of critical importance to the Major Facility Project Management Division's (MFPM) programs.

6.3.2 Rotating Components (J. R. Horton, M. Siman-Tov, and W. R. Williams)

The compilation of responses to the questionnaires is continuing. Data from all manufacturers on equipment recommended for a given application are being tabulated on an individual sheet. Data sheets for each category have been developed. Compilation and analysis of data are still being delayed by late responses expected from certain manufacturers. A check is now being made to determine whether or not these manufacturers will supply information. Analysis will continue without these responses with conclusions being modified as necessary on receipt of further information.

During the week of June 6, W. R. Williams attended a 4-day short course on Applied Process Pump Technology sponsored by the Center for Professional Advancement. The operating and mechanical characteristics of the various types of pumps were discussed with emphasis being given to centrifugal pumps and system hydraulics. On June 10, a visit was made to Worthington Canada, Ltd., located in Brantford, Ontario, to discuss slurry pumps. The need for as complete a characterization of the operating environment of the pump as possible was stressed in both the short course and the visit with Worthington personnel.

T. K. Lau of MFPM of ERDA/FE met with ORNL personnel on June 15 to discuss the status of this and several related studies being conducted at ORNL. Several tentative conclusions based on responses received and visits made to AE's, users, and manufacturers to date were presented.

A literature search for information on problem areas of rotating equipment such as corrosion, erosion, cavitation, bearings, and seals is being made; RECON, a computer search program, has been used to obtain reference citations. Only a few reports have been reviewed to date with little significant information being found so far.

A draft outline of the final report has been made. First drafts of several sections of the report should be completed during the first week of July. A "complete" first draft of the final report should be ready by the first of August.

A summary of travel plans for this project was developed. One meeting with a steam turbine manufacturer is planned for Oak Ridge. Other meetings with manufacturers, if required, will probably be scheduled for Oak Ridge. These meetings and trips will be for the purpose of discussing problems revealed by the analysis of data received from industry in the last several months. Potential solutions to these problems including research and development requirements will be discussed.

Mike Culver, a co-op student from the Georgia Institute of Technology, is working on this project during the summer quarter. He is providing assistance in the compilation of data and in analysis of that data under the direction of those principally involved in the project.

6.3.3 Valves and Other Letdown Devices (W. A. Bush and E. C. Slade)

Survey questionnaires were mailed in June to valve manufacturers to enlist their aid in determining capacity and research and development needs of the critical valves for coal conversion plants. One questionnaire was sent to approximately 180 manufacturers who have capability to manufacture ball valves. A second questionnaire was sent to approximately 70 manufacturers who specialize or have major capability to manufacture blast type valves.

We have received several follow-up phone calls and also some completed questionnaires have been returned.

The trip to the WKM Valve Company was made to enlist the aid of the Valve Manufacturers' Association (VMA). Mr. A. M. Williamson, Director of Engineering for WKM is also the Chairman of the VMA's Technical Coordinating Committee. He reviewed our survey form and suggested several changes that we adopted.

On June 15 and 16, 1977, meetings were held at ORNL with T. K. Lau of ERDA/FE/MFPM. He expressed his desire that the extent of the valve study portion of this project would include, in the FY 1977 Final Report, both a section on valve actuators and valve research and development.

Valve actuator parameters have been determined and a questionnaire has been prepared to be mailed in early July. Time will not permit a meaningful section on valve research and development this fiscal year.

6.3.4 Hot Gas Cleanup Devices (J. P. Meyer and M. S. Edwards)

During the reporting interval, the following work has been completed:

1. Much of the analysis associated with an evaluation of the performance of particulate removal equipment has been completed this month. Tables 6.1 through 6.6 provide the germane data. As evidenced by Table 6.6, the conditions to be met in hot gas cleaning are formidable. Very few of the suggested devices have the capacity to meet these tolerances either alone (Table 6.1) or in parallel with other units. Since projected turbine specifications require the removal of all particulate material greater than 6 microns from the gas stream, this means that one of the first six devices listed in Table 6.3 must be present in the purification train. When estimates are made using process configurations compatible with the 6-micron requirement (Table 6.6), it is evident that if particulate carryover is largely composed of fines, monumental difficulties in collection still persist.

Although the information presented in Tables 6.1 through 6.6 is based on estimates using extrapolated data and approximations regarding particle size distributions, Table 6.5 confirms that many of the projected results are consistent with those observed in actual operation of known devices. Hence the conclusions reached using these techniques has validity.

2. Work has begun on writing up a number of sections of the forthcoming report.

6.3.5 Heat Recovery Equipment Survey (W. R. Gambill)

Meetings were held with ERDA/FE/MFPM project management on June 15 and 16.

A tentative outline of the final report was prepared.

Telephone discussions were held with representatives of the following companies: The Garrett Corporation, Thermo Electron Corporation, Struthers-Wells, The American-Schack Company, Thermal Transfer Corporation, Nooter Corporation, Industrial Fabricating Company, Hughes-Anderson Engineering Corporation, Hughes Aircraft Company (Electron Dynamics Division), and Q-dot Corporation. Requested literature has been received from most of the subject vendors.

For shell-and-tube exchangers, the collective vendor experience extends to shell diameters of 16 ft, tube lengths of 80 ft, tube-sheet thicknesses of 12 in., number of tube passes to 28, area per shell of $\sim 40,000 \text{ ft}^2$, and approach temperature differences as small as 1°F .

Additional heat recovery information is given in Sect. 6.8.

Table 6.1. Estimated Overall Collection Efficiencies for
Various Hot Gas Cleanup Devices as a Function of
Different Inlet Loading Distributions

Device	Mean	Particle	Diameter
	132	66	33
High efficiency ESP ^a	100.0	100.0	100.0
Metal/ceramic/fabric filter	100.0	99.9	99.8
Venturi scrubber	99.7	99.3	98.6
Medium efficiency ESP ^a	99.3	98.7	97.9
High efficiency scrubber	99.3	98.6	97.1
Tornado cyclone	98.9	97.8	95.8
Low efficiency ESP ^a	98.4	97.0	95.0
Granular bed filter	98.1	96.2	93.1
Low efficiency scrubber	97.9	96.0	92.9
Multiclone	96.8	94.3	90.3
High efficiency cyclone	94.5	90.6	85.0
Medium efficiency cyclone	92.3	87.2	80.1

^aElectrostatic precipitator

Based on:

- (i) The assumption that the particle mass distribution is log-normally distributed with respect to particle size.

$$F(\ln(x)) = \frac{1}{\sqrt{2\pi} \sigma} \exp \left[- \left\{ \frac{\ln(x) - \ln(d_p)}{\sqrt{2} \sigma} \right\}^2 \right]$$

where:

$F(\ln(x))$ = particle mass distribution

x = particle diameter (μ)

μ = mean particle diameter (μ)

σ^2 = variance (in this case, taken as 5.2)

- (ii) The collection efficiencies of various devices can be represented by the error function

$$\eta = \text{ERF} \left(\frac{\ln(x) - \ln(\gamma)}{\theta} \right)$$

where:

η = collection efficiency

ERF = error function

x = particle diameter (μ)

γ = device mean particle diameter

θ^2 = device variance

as presented by Shannon [1]. Values of γ and θ are presented in Table 6.2 and device efficiencies are shown graphically in Figure 6.1.¹

- (iii) Limits of integration for the particle size distribution are from 0.01μ to $10^6\mu$.

¹L. J. Shannon, Particulate Pollutant Study, Vol. II, Fine Particulate Emissions, Midwest Research Institute, Kansas City, MO, NTIS PB-203-521 (August 1971).

Fig. 6.1. Extrapolated fractional efficiency of particulate removal devices.

Table 6.2. Parameters Used in Predicting Device Efficiencies

Device	Parameters	
	γ	θ
High efficiency ESP ^a	8.30×10^{-6}	5.71
Metal/ceramic/fabric filter ^b	0.152	0.92
Venturi scrubber	0.185	0.92
Medium efficiency ESP	0.032	3.59
High efficiency scrubber	0.335	1.15
Tornado cyclone $\left\{ \begin{array}{l} (d > 1.5\mu) \\ (d \leq 1.5\mu) \end{array} \right.$	0.830	0.77
	0.439	1.95
Low efficiency ESP ^a	0.335	2.30
Granular bed filter $\left\{ \begin{array}{l} (d > 2.3\mu) \\ (d \leq 2.3\mu) \end{array} \right.$	0.100	2.48
	1.00	0.69
Low efficiency scrubber	0.950	1.15
Multiclone	1.34	1.35
High efficiency cyclone	2.51	1.40
Medium efficiency cyclone	4.38	1.04

^aElectrostatic precipitator

^bBelow 0.6μ filter efficiency assumed to be 0.95.

Table 6.3. Estimated Overall Collection Efficiencies of Various Hot Gas Cleanup Devices in the Range 6 Microns to Infinity as a Function of Different Inlet Loading Distributions

Device	Mean	Particle	Diameter
	132	66	33
High efficiency ESP ^a	100.0	100.0	100.0
Metal/ceramic/fabric filter	100.0	100.0	100.0
Venturi scrubber	100.0	100.0	100.0
High efficiency scrubber	100.0	100.0	100.0
Low efficiency scrubber	100.0	100.0	100.0
Tornado cyclone	100.0	100.0	100.0
Granular bed filter	99.9	99.9	99.9
Medium efficiency ESP ^a	99.8	99.7	99.6
Multiclone	99.8	99.7	99.6
Low efficiency ESP ^a	99.7	99.6	99.5
High efficiency cyclone	99.0	98.5	98.0
Medium efficiency cyclone	98.4	97.7	96.9

^aElectrostatic precipitator.

Table 6.4. Estimated overall collection of efficiencies of various hot gas cleanup systems in the range 0.01 microns to infinity as a function of different inlet loading distributions

System	Mean	Particle	Diameter
	132	66	33
MEC ^a - High efficiency ESP ^b	100.0	100.0	100.0
MEC ^a - Metal/ceramic/fabric filter	100.0	99.9	99.8
MEC ^a - Venturi scrubber	99.7	99.4	98.6
MEC ^a - High efficiency scrubber	99.3	98.6	97.2
MEC ^a - Tornado cyclone	98.9	97.8	95.9
MEC ^a - Granular bed filter	98.2	96.4	94.3
MEC ^a - Low efficiency scrubber	98.1	96.3	93.2

^aMedium efficiency cyclone.

^bElectrostatic precipitator.

Table 6.5. Comparison of predicted vs observed overall collection efficiencies of various hot gas cleanup devices as a function of different inlet loading distributions

Device	Mean		Particle		Diameter		Comments
	132		66		33		
	P ^a	O ^b	P	O	P	O	
Electrostatic precipitator (1400°F, 7 atm)							91 to 96% efficient using negative corona.
Novel Devices							
Battelle Venturi scrubber	99.7		99.3		98.6		Designed to collect 99% of all particles greater than 4 μ.
Electrofluidized bed							Estimated to collect 90% of all particles between 0 and 3 μ.
Metal/Ceramic/Fabric Filter							
3M fabric filter (ambient)	100.0		99.9		99.8		99.5% efficient.
Acurex ceramic filtration system	100.0		99.9		99.8		Estimated to be 100% efficient for all particles greater than 1 μ.
Brunswick filter	100.0		99.9		99.8		Predicted to be 99.5% efficient.
Pall Trinity micro porous metal filter	100.0		99.9		99.8		Estimated to be 100% efficient for all particles greater than 1 μ.
Mott metallurgical filter	100.0		99.9		99.8		Estimated to be 100% efficient for all particles greater than 1 μ.
Bed Filters							
Ducon granular filter (900°F, 2 atm)	98.1		96.2		93.1		85 to 98% efficient.
Combustion Power Company (800°F, 1 atm)	98.1		96.2		93.1		85 to 97% efficient.
Squires Panel Bed filter (1000°F, 1 atm)	98.1		96.2		93.1		95 to 96% efficient.
Rexnord Gravel Bed filter (400°F, 1 atm)	98.1		96.2		93.1		97.5% efficient for all particles greater than 5 μ.
Westinghouse Granular filter (ambient)	98.1	99.8	96.2	99.6	93.1	99.4	98.1% efficient in the range 0-10 μ; 100% efficient otherwise.
Cyclones (high efficiency)							
Van Tongeren	94.5	96.0	90.6	93.5	85.0	89.6	
Environmental Elements Corp. (Koppers)	94.5	96.5	90.6	93.7	85.0	89.6	
Fisher-Klosterman	94.5		90.6		85.0		Estimated to be 95% efficient at 5 μ.
Multiclones							
Peerless Mfg. Co.	96.8	97.6	94.3	95.8	90.3	93.0	
Joy Mfg. Co.	96.8	93.7	94.3	88.2	90.3	83.6	
Environmental Element Corp. (Koppers)	96.8	95.9	94.3	93.0	90.3	88.2	
Tornado Cyclones							
Aerodyne--Tornado (1600°F, 1 atm)	98.9	97.1	97.8	94.8	95.8	91.1	
Donaldson--Tanjet (1600°F, 1 atm)	98.9	97.2	97.8	95.0	95.8	91.3	

^aPredicted from theoretical work of Shannon.

^bEither observed or computed from manufacturers' data.

Table 6.6. Overall process clean-up efficiencies (%)
needed for acceptable turbine life as a function of
gasifier effluent loading and inlet turbine specifications

Effluent loading (g/scf)	Turbine tolerance (g/scf)		
	0.05	0.002	0.0001
35	99.86	99.99	99.99
15	99.67	99.99	99.99
5	99.00	99.98	99.99

6.4 Engineering Assistance

J. M. Holmes

6.4.1 Contract Objective

The objective is to provide engineering assistance to the Fossil Energy Major Facility Project Management Division of ERDA.

6.4.2 Status Summary

Preparation of a conceptual flowsheet for the Fluid Bed Hydrothermal Liquefaction Process has been initiated. Of particular importance is the development of a hydrogen balance in order to provide sufficient hydrogen for both the hydrothermal liquefaction step and the subsequent coal liquid hydrotreating step. Since the source of hydrogen will be the gasification of the char product from hydrothermal liquefaction, a balance between the char and coal liquids produced must be developed. A computer program is being developed to establish a material balance for the process as a function of the coal composition, hydrothermal hydrogen requirements. Coal liquid characterization information for the computer program is being developed using regression analysis to correlate the molecular weights with the hydrogen, oxygen, nitrogen, and sulfur contents of the coal liquids. A correlation of molecular weight with average normal boiling point for coal liquid fractions has also been developed. Investigation of equipment for feeding coal to high-pressure systems has also been started.

Since a decision has been made by ERDA/MFPM to discontinue this study, the program is being terminated and a report summarizing the progress to date is under preparation.

6.5 Flash Hydropyrolysis

S. P. N. Singh

6.5.1 Contract Objective

The objectives are to perform a scoping study on two conceptual flash hydropyrolysis processes and to determine if a more detailed engineering evaluation of one of these processes is justified.

6.5.2 Status Summary

Preliminary economic analyses are currently being performed on the two conceptual processes under evaluation. Also, information is being gathered from available published studies of other coal liquefaction and gasification processes to form a basis for comparison with the two flash hydropyrolysis processes. Work accomplished to date is estimated to be about 50% of the project effort.

We are having difficulty obtaining process information regarding the Schroeder version of the Spencer Chemical Company process because some process information is considered to be of a proprietary nature. We plan to circumvent the difficulty by estimating process information from the information available in open literature and patent disclosures.

6.6 Hot Gas Purification Processes

M. S. Edwards and J. P. Meyer

6.6.1 Contract Objective

The objective of this project is to investigate the present state-of-the-art hot gas cleanup processes. The application of most interest is the removal of contaminants (i.e., particulates, sulfurous gases, alkali metals, etc.) from coal-derived fuel gas prior to firing combined cycle turbines.

6.6.2 Status Summary

1. University of Kentucky responded to our requests for information by providing open literature publications on the use of ash for removing sulfur compounds from fuel gases.

2. Similarly, the City College of the City University of New York responded with a recent report on the cyclic use of half-calcined dolomite for H_2S removal, performed under contract with Empire State Electric Energy Research Corporation.

3. The Institute of Gas Technology responded to requests for information on the IGT/Meissner Process with the statement that this process is proprietary and currently undergoing IGT in-house development.

4. Air Products and Chemicals feels it has the capability of putting together a complete package, from project design to commercial operation, for hot gas desulfurization using iron oxide sorption. However, any requirement for removal of ammonia, alkali metals, or particulates is outside the present scope of Air Products' expertise. A preliminary technical and economic evaluation of the iron oxide desulfurization process is currently underway and the results are promised as soon as available.

5. The Hanna Mining Company has provided copies of two patents on the use of iron oxide in sulfurous gas removal. The patents, however, are for the removal of the oxidized form SO_2 rather than H_2S .

6. UOP Process Division provided several reports on the Shell Flue Gas Desulfurization process for removal of SO_x and NO_x at high temperature using a copper based sorbent. These are being reviewed to assess the possibility of operating the Shell process on reducing gases.

7. Much of the analysis associated with an evaluation of the performance of particulate removal equipment has been completed this month.

This information was discussed in Tables 6.1 through 6.6 in Sect. 6.3.5.

8. Work has begun on writing up a number of sections of the forthcoming report.

6.7 Large Air Separation Plant Study

W. R. Reed and W. R. Gambill

6.7.1 Contract Objective

The objective of this study is to determine if significant economies of scale would be provided by building single-train cryogenic air separation plants with capacities in the range of 2000 to 20,000 TPD oxygen production. The oxygen purity is to be 95 vol. % or higher; and the delivery pressure, within the range 1 to 70 atm abs., is to be determined by economics.

6.7.2 Status Summary

A report, Results of Task I Survey, is now being prepared to describe the reactions of various American oxygen producers to a suggested study of scale-up economics of oxygen plants beyond the 2100 TPD plant size (currently the largest American plant).

Meetings were held with representatives of UCC-ND Engineering, procurement, and Chemical Technology and USERDA procurement to select the proper procurement approach. A list of criteria for vendor selection and a detailed scope of work were routed to interested parties for constructive comment.

6.7.3 Open Items

Unit costs for utilities and permissible financing charges are included in the proposed scope of work in order to simplify the study and allow the effort to be concentrated on technical problems. Similarly the interface between oxygen plant and coal conversion plant will be left as the subject of later work that will be attempted if the economies of scale predicted by this study are attractive.

6.8 Review of State-of-the-Art of Processes for Heat Recovery

W. R. Gambill

6.8.1 Contract Objective

The objective of this review is to survey, appraise, and catalog the processes for heat recovery which industry offers or plans to offer or may logically be expected to offer. These processes will be applicable to the recovery of heat in process streams from primary exothermic coal conversion and combustion process steps. Simple unaugmented application of conventional heat transfer equipment will not be included. The review will distinguish between presently installable technology, near term developable technology, and future prospects. Consideration will be given to possible transfer of technology from other industries.

6.8.2 Status Summary

A copy of Waste Heat Management Guidebook (NBS, February 1977) was ordered; this reference, which deals with industrial-process waste heat, includes an overview of off-the-shelf technology presently available. Additional information regarding IGT's improved industrial stack-type recuperator is being sought. The review to date indicates that heat-pipe heat exchangers are presently commercially available only for applications up to ~450°F although R&D is active in the area of extending the commercial temperature limit to 1300-1400°F.

6.9 Assessment of a Moving Bed System for Heat Recovery and Contaminant Removal from Raw Gasifier Gas

6.9.1 Contract Objective

The objective is to evaluate the feasibility of a proposed moving bed system for recovery of heat and removal of sulfur and particulates from raw gasifier gas.

6.9.2 Status Summary

R. H. Lamb (consultant) has been commissioned to assist the ORNL staff in the assessment of the task subject. Selection of feed stream variables (T, P, composition) have been made and preliminary flowsheets are in preparation.

6.10 Technical/Economic Assessment of Hydrogen Production by the Steam/Molten Iron Process

6.10.1 Contract Objective

The objective is to determine if there is sufficient incentive to develop the subject process for production of hydrogen from coal.

6.10.2 Status Summary

A work statement was prepared and an effort initiated to obtain the assistance of a consultant for this study.

7. PROCESS AND PROGRAM ANALYSIS

J. R. McWherter and R. Salmon

Process and program analysis studies are being conducted for the ERDA Fossil Energy Office of Program Planning and Analysis. This effort includes research studies on most of the coal conversion and utilization processes. The program objective is to provide, on a consistent basis, technical and economic evaluations of competing processes and systems for coal conversion and utilization.

7.1 Low Btu Coal Gasification

H. F. Hartman, D. E. Reagan, and J. P. Belk

7.1.1 Summary

Activities in June 1977 involved work on the process screening and selection section and in obtaining and summarizing process data. Problems associated with increased coal usage were listed in a memo describing the May 1977 West Virginia University/ERDA conference. The status of the work was reviewed with L. M. Joseph, ERDA/FE/OPPA, at a June 3, 1977, ORNL meeting.

Activities forecast for July 1977 include issuing a draft of the process screening and selection section for comment and preparing initial drafts of process data subsections. Work is also planned on the process comparison section.

7.1.2 Process Screening

Work was completed on a draft of the screening and selection section (3) of the Low Btu Coal Gasification Study report. This section provides qualitative reasons used in screening (selecting or rejecting) processes. The following screening factors were used to determine which processes of those (85) originally considered should be included in the process summary section (54). Selection of the (22) processes for more detailed evaluation/comparison was done using the screening factors and other process information.

<u>Category</u>	<u>Reasons for Selection</u>	<u>Reasons for Rejection</u>
Status	Commercial or advanced	Small scale or conceptual
Technical complexity	Moderate	High
Feed coal	All or many types	Few or specific types
Operating conditions	Moderate	Severe
Process concept	Representative or unique	Similar to others
Conversion efficiency	Higher	Lower
Gasifier capacity	High or moderate	Low
Data availability	Adequate	Little
Funding	ERDA and/or others	(not used)

7.1.3 Process Data

Work continued on collecting, reviewing, and summarizing data for some of the 22 processes that are being described and evaluated. Initial drafts are being prepared for a number of the processes.

7.1.4 Coal Conversion Problems

Problems associated with increased coal usage were listed in a memo that briefly described the May 23-25, 1977, West Virginia University/ERDA conference, "Institute on Scientific Problems Relevant to Coal Utilization." Some of these problems pertaining to low Btu coal gasification follow:

Coal properties - correlating coal properties and characteristics with processing requirements.

Gasification - demonstrating feasibility on a small scale; integrating with combined cycle power generation systems.

Instrumentation - measuring and controlling solids flow and gasifier temperature.

Environmental - demonstrating that acceptable reductions can be made in discharges; understanding the movement and effects of trace elements and hazardous materials.

Materials - acquiring data on corrosion and erosion/abrasion at gasifier operating conditions; developing satisfactory refractories and other materials.

7.1.5 Work Review

The status of work on this study was reviewed at a June 3, 1977, ORNL meeting with Dr. L. M. Joseph of ERDA-Fossil Energy/Office of Program Planning and Analysis. Comments were provided on the process summary section and suggestions were made on an approach for obtaining the latest process information. The process comparisons and evaluations are of particular interest. Gasifiers will be identified that could be used to produce hydrogen or synthesis gas as well as fuel gas.

7.1.6 Work Forecast

The process screening and selection section draft will be published in July for review and comment. Additional work will be done on the process data section. Work will begin to prepare process comparisons: (1) generically by gasifier type (fixed, fluidized, entrained, molten), and (2) specifically for the 22 processes of greatest interest.

7.2 Direct Combustion

E. C. Fox, T. D. Anderson, and J. R. Tallackson

7.2.1 Objectives

The purpose of this study program is to assist ERDA/FE in their effort to develop a national strategy to increase the near-term use of coal through direct combustion; the applications of interest in this study are the small-to-moderate industrial user and the large residential/commercial user. The following objectives will be accomplished:

1. Identify and quantify the important factors restricting the use of coal in the sectors of interest.
2. Evaluate potential technological and institutional solutions to the problems identified in (1) above.
3. Make recommendations to ERDA/FE relative to the most promising approaches to increasing the near-term use of coal.

7.2.2 Results

Much of this past month has been spent contacting potential industrial users of coal as a boiler fuel. T. D. Anderson and E. C. Fox traveled to the Houston, Texas, area June 6-9, 1977, to meet with J. T. Cockburn, Manager of Celanese's Fuel Conversion Program; R. L. Wright, Union Carbide Corporation, who is coordinator of the proposed joint project between Monsanto, Amoco, and Union Carbide at Texas City, Texas; Phyllis Proctor, Manager of Research and Planning, Texas Industrial Commission; representatives from Power Systems Engineering Inc.; Dave White of the Texas Governor's Energy Advisory Council and representatives from the Texas Air Control Board. Many important factors restricting the conversion to coal were discussed in this series of meetings and following are a few of them:

Financial Restrictions. Availability of capital for industrial projects is restricted by internal and external forces. Covenants and companies' policies restrict the maximum allowable debt-to-equity ratio. This fixed ratio of debt to equity establishes an internal competition for capital between a nonprocess project such as coal conversion and the capital needs for process and product development. The risks associated with large capital expenditures for steam supply systems are amplified by the risk of deferring capital expenditure for process development with the possible consequences in the loss of market share.

Additionally, it was learned that a cooperative or joint facility has certain financial advantages over single user installations. For example, a cooperative energy supply system may, under certain circumstances, allow the individual users to treat the expense as direct operating costs rather than straight indebtedness. However, a hard take-or-pay contract, one in which the customer is obligated to an annual payment regardless of whether he takes the service or whether the service is available, is viewed by company auditors as a direct capital investment.

Coal Conversion Economics. Celanese is one chemical company in Texas which announced conversion to coal. Their Pampa, Texas, chemical plant, which presently uses natural gas, will be converted with two 550,000 lb/hr pulverized coal units. The key factors governing their decision to convert to coal were:

1. Estimated escalation of fuel prices.
2. Viability of the site as a potential site for future chemical processes.
3. Early decision for conversion to coal places them in a favorable position in regard to both equipment and coal supply purchases.

Without exception, the industrialists contacted felt the coal terminal and central steam generation concepts had merit. The following points were made:

1. The cost scaling effect with coal fired boilers makes installations under $\sim 10^6$ lb of steam per hour (with unit sizes less than 500,000 lb/hr) uneconomical. Thus, a shared large facility is desirable. The opportunity to use cogeneration is also enhanced because small turbine generators are expensive.

2. Another reason for "bigness" is that it is necessary to assure a long-term supply of coal and to get a long term (20-yr) contract the coal demand needs to be on the order of 10^6 tons/yr (equivalent to boiler capacity of $\sim 2 \times 10^6$ lb/hr). The million ton per year figure is a typical output of one mine. The mining company uses the long term contract to justify the financing for mine development.

Land Utilization. The space necessary for coal unloading and storage facilities can be a problem. At Texas City, the coal yard will be about 200 acres; this includes the rail unloading loop and the storage area for 60 to 90 days supply. They have tentatively selected a site for the yard 8-9 miles away from the boilers. The enclosed conveyor belt will add another $\$12 \times 10^6$ to the project.

The rail unloading loop, which must be 2 miles long to provide enough room to unload a 100-car unit train, is the key factor in sizing the coal unloading facility.

Environmental Constraints and Public Acceptance. The Texas Air Control Board indicated that they were not as concerned about SO₂ emissions as they were about particulates, hydrocarbons, and other oxidants. For instance, along the Houston ship channel, they have a nonattainment of particulates primarily from local construction and area roads. Although EPA's position is to require an offset for any additional emission sources, the Texas Air Control Board feels that a new coal fired plant should be required to incorporate the best available control technology without requiring offset.

With EPA's "tradeoff" policy on emissions, it is necessary to offset the increased emissions from a new facility with decreases from another. A single plant may not have the "pollution rights" to trade off. But with several companies involved there are more tradeoff opportunities. For instance, at Texas City one of the biggest polluters in the area, a metal fabricator, is not a participant in the proposed coal project. One possible option for the participants is to buy the operation and shut it down.

The consensus was that Texans would accept conversion to coal readily if such things as the traffic inconveniences were minimized. It was felt that a local truck distribution system for coal would be unacceptable to the populace, considering the present traffic loads in Texas' industrial centers.

7.2.3 Subcontract Status

United Engineers and Constructors have transmitted their cost summaries for conventional coal fired facilities. They are completing their estimates of costs of fluidized bed combustors and for residential/commercial systems. In turn, these are being reviewed and integrated into the overall economic analysis of coal fired systems and the possible alternatives to determine the best application for each.

7.3 Advanced Power Conversion Systems

A. P. Fraas,* G. Samuels, M. E. Lackey,
W. M. Wells, S. Thompson, and Fred J. Young*

Four additional reports summarizing the research and development effort on advanced power systems were transmitted in draft form to OPPA-FE during June. These reports covered gas turbine-steam combined cycles, closed cycle gas turbines, open cycle MHD systems, and air- and water-cooled gas turbines. These bring the total number of reports issued on the project to eight.

The report on fuel cells was completed during June but is being revised to include additional information which was presented at a meeting on fuel cells held in Boston the latter part of June. This report will be completed during the first week of July.

* Consultant.

There are three other reports still to be completed. An overall summary report based on the topical reports is in preparation and should be completed during the first half of July. It is anticipated that the final two topical reports on conventional steam and on supercritical CO₂ systems will be completed by early August.

7.4 Liquefaction

This work is being done under subcontract by the Ralph M. Parsons Company (J. B. O'Hara, Project Manager).

7.4.1 Survey Liquefaction Processes

Work was initiated on the preparation of a report to summarize the characteristics of the 32 liquefaction processes which were surveyed; these processes are considered representative of the generic processes available for conversion of coal into liquid fuels. This report will serve as background material for subsequent project work.

Parsons continued to compare the strengths and weaknesses of the candidate liquefaction processes.

7.4.2 Establish Uniform Economic Comparison Basis

The objective of this task is to provide techniques and methods for economic comparison of the most viable processes on a uniform basis for the detailed process and analyses.

The preliminary procedure for economic comparison of the processes is being revised to incorporate potential improvements defined during the course of our screening survey. A recommended procedure will be transmitted to ORNL for review following completion of the revision.

7.4.3 Detailed Review of High Potential Liquefaction

The objective is to perform detailed process, technological, and economic analyses of high potential liquefaction processes. ORNL and Parsons will agree on processes to be reviewed.

Parsons essentially completed a preliminary design to serve as a basis for review of the potential for the Mobil M. Process to produce gasoline from coal. As a part of this effort, Parsons requested some additional process information on the methanol-to-gasoline step from ERDA.

Information contained in the report prepared by DuPont under ERDA contract titled Economic Feasibility Study - Fuel Grade Methanol from Coal has been used as the basis for the assessment of the economics of methanol production from coal. Information contained in the report prepared by Mobil and titled Development Studies on Conversion of Methanol and Related Oxygenates to Gasoline has been used to develop the design of the gasoline-from-methanol production unit; this report was published in November 1976 under ERDA Contract No. E(49-18)-1773.

A block flow diagram and heat and material balances for the overall process from feed coal to gasoline product were prepared. The design capacity was production of 50,000 bbl of gasoline per day.

A process flow diagram, heat and material balance, and equipment data sheets were prepared for the Mobil M - Gasoline process unit for conversion of methanol to gasoline, and for the gas-liquid separation plant.

Fixed capital investments are being prepared for the coal-methanol-gasoline complex.

7.5 High Btu Gas

This subprogram is being analyzed under subcontract by the Scientific Design Company, Incorporated (A. S. West, Project Manager).

7.5.1 Contract Objective

The objective of the work is to provide technical and economic evaluations of competing processes, concepts, and systems for the production of high Btu gas from coal.

7.5.2 Summary Status

During the month of June work was directed in the following areas:

1. A meeting was held with Battelle to review their comments on our Evaluation of the Agglomerating Ash Burner Process. ERDA was represented by Larry M. Joseph of OPPA and Louis Jablansky and Leonard Naphtali of CCU.
2. A process flowsheet, heat and material balance, and equipment specifications have been prepared for our hydrogen from char production study.
3. Work is continuing on developing a "Generalized Approach to High Btu Coal Gasification." The major processes parameters affecting capital, operating and gas costs for methanation, shift, and sulfur recovery have been established.

7.6 In Situ Coal Gasification

W. C. Ulrich and M. S. Edwards

7.6.1 Contract Objective

The objective of this program is to provide technical and economic evaluations of candidate processes for the conversion of coal in situ to fluid products presently of interest.

7.6.2 Status Summary

The process flowsheet for a nominal 1000 MW(e) combined-cycle generating plant operating on low-Btu gas from a linked vertical well process was finalized. Material and heat balance calculations were essentially completed, and major equipment items were sized. Generalized plot plans showing equipment and piping arrangements were also prepared. Work was initiated on determining a cost estimate for this plant.

A member of the evaluation group visited the Morgantown Energy Research Center on June 14, 1977, to discuss gas and water treating problems associated with the process.

7.7 Coal Beneficiation

G. R. Peterson and S. P. N. Singh

7.7.1 Contract Objective

The objective of this project is to provide technical and economic evaluations of current beneficiation processes.

7.7.2 Status Summary

Work is in progress to make the changes requested by Larry Joseph of ERDA/OPPA at a meeting held at ORNL on June 3, 1977, to review the preliminary draft of the coal beneficiation report.

7.8 Gas Cleanup Studies

M. S. Edwards

7.8.1 Contract Objective

The objective of the gas cleanup study is to collect information on the technology and economics of processes for the removal of impurities (principally hydrogen sulfide) from fuel gas streams. High and low temperature cleanup processes will be reviewed.

7.8.2 Status Summary

1. Peabody Engineered Systems has promised various cost estimates for the Stretford process by the beginning of July.

2. Seven detailed process descriptions will be provided; these are listed in Table 6.1. The write-up on molecular sieves is planned for information purposes only because open literature sources were inconclusive for bulk H₂S removal.

3. A trip to the Morgantown Energy Research Center was made to obtain an update on the iron oxide process for H₂S removal at high temperature.

4. The first process description, on the Benfield process, is complete. A typed draft will be furnished to the process vendor, the Benfield Corporation. Corrections will be incorporated and suggestions noted in the final draft of the process description.

5. The second process selected for detailed description is the Selexol process of Allied Chemical Corporation. Process writeup is underway.

6. Several additional responses have been received from high temperature gas cleanup process developers, but these have caused no change in the selection of a high temperature gas cleanup candidate.

7.9 Coal Prices and Volumes

O. L. Culberson*

The report describing the correlation of coal price to distance shipped, heating value, and sulfur and ash content was completed as a preliminary draft.

7.10 The Potential of the Synthesis of Chemicals from Coal as an ERDA Research Program

This work is being done under subcontract by the Radian Corporation (D. N. Garner, Project Director).

7.10.1 Status Summary

A meeting was held with Larry Joseph of ERDA/FE/OPPA on June 8. The purpose of the meeting was to discuss current progress on the contract and to map out future directions. Larry Joseph made several suggestions for the final report based on his observations of the mid-project report. In addition, Joseph suggested that we drop the scenario approach for a more direct analysis of demand for petrochemical feedstocks and a summary of the chemicals that can be supplied from coal through existing technologies.

Joseph suggested that the final report emphasize the following points:

1. The history of petrochemical feedstocks, in particular, the fact that BTX fractions were once supplied by coal but they were replaced by petroleum.

2. The chemical nature of coal, such as the fact that coal is highly aromatic and therefore BTX fractions are in abundance.

3. Processing techniques for coal liquids, in particular, the work being done by UOP, Air Products, and Chevron.

4. Old and existing routes from coal to chemicals, in particular, syngas to ammonia and methanol.

5. The chemical nature of shale.

6. Point out areas of potential work (things that can be done to change the picture), emphasize technical feasibility as opposed to economic.

7. Emphasize that report is a scoping document, not a technical assessment.

The final report needs to contain the theme that all the points made are recommendations to ERDA.

8. FOSSIL ENERGY ENVIRONMENTAL PROJECT

C. R. Boston

8.1 Landfill Storage of Coal Conversion
Solid Wastes/Information Assessment

H. M. Braunstein

A written report is still due from one external referee. Finalization of the document is proceeding.

8. Landfill Storage of Coal Conversion
Solid Wastes/Experimental Phase

W. J. Boegly

The major effort during the past month was devoted to revising the FY 1977 program plan and updating the 1978-1979 portion of the overall program plan. Contacts were also made with a number of pilot plants in an attempt to obtain samples of feed coal and representative solid wastes from their processes. To date, two of the pilot plants have expressed an interest in supplying us with samples. As soon as these samples arrive at ORNL we will initiate the laboratory leaching studies.

8.3 Environmental Monitoring Handbook

L. H. Stinton

The construction section (Part III) of the Environmental Monitoring Handbook has been completed and reviewed internally. The operation section (Part IV) is nearing completion. Target date for delivery of the entire draft document is July 29.

8.4 Programmatic Assessment/Pipeline Gas

L. H. Stinton

The pipeline gas programmatic assessment has been edited and typed and will be available for internal review during the first week in July. A draft should be ready for ERDA review by mid-July.

8.5 Programmatic Assessment/Fuel Gas

L. H. Stinton

Preliminary work continued on the fuel gas programmatic assessment.

9. FLUIDIZED BED COMBUSTOR TECHNOLOGY TEST UNIT

R. S. Holcomb and W. R. Nixon

This project for analysis, design, and demonstration of a concept utilizing a fluidized-bed coal combustion system as a heat source for a gas turbine generator suitable for applications in Modular Integrated Utility Systems (MIUS) is carried out under the ORNL-HUD-MIUS Program within the Energy Division. Work is supported by the U. S. Department of Housing and Urban Development under HUD Interagency Agreement No. IAA-H-40-72 and by the Energy Research and Development Administration, Office of Fossil Energy (formerly Office of Coal Research, Department of the Interior), under ERDA Contract No. E(49-18)-1742. The project consists of four phases: I - Conceptual Preliminary Evaluation; II - Conceptual Design; III - Detailed Design and Construction; and IV - Shakedown, Performance, and Endurance Tests.

9.1 Program Planning

Authorization to continue the program with direct funding from ERDA/Fossil Energy was received this month. The program has been reoriented to the development of technology for fluidized-bed coal combustion coupled to closed-cycle gas turbine systems for potential industrial applications requiring heat and electrical energy. The program plan calls for a market survey and application assessment study, preparation of combustor designs by furnace manufacturers, procurement and installation of combustor systems, combustor tests on plant air, and testing with a gas turbine. The program schedule and cost estimates are undergoing final review.

9.2 Supplemental Studies

The four chrome-moly steel tubes were shipped to Fluidyne this month and thermocouples have now been installed in all of the 20 corrosion specimen tubes.

Shakedown operation of the Fluidyne fluidized bed furnace has required additional time for complete sulfation of the fresh limestone bed. The heat transfer test is now scheduled to begin on July 5.

During shakedown, it was found that the bed temperature could not be held at a uniform temperature of 1650°F with four tubes cooled to a wall temperature of 1000°F. It was concluded that only two of the chrome-moly steel tubes could be included in the 1000 hr corrosion test.

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