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Program

**Fossil Energy Program
Progress Report for March 1979**

L. E. McNeese

OAK RIDGE NATIONAL LABORATORY
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FOSSIL ENERGY PROGRAM
PROGRESS REPORT FOR MARCH 1979

L. E. McNeese

Date Published - May 1979

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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FOSSIL ENERGY PROGRAM REPORT FOR MARCH 1979

ABSTRACT

This report - the fifty-sixth 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 and other fossil fuel alternatives to oil and gas as sources of clean energy. The projects reported this month include those for coal conversion development, materials engineering, a coal equipment test program, an atmospheric fluid bed combustor for cogeneration, engineering studies and technical support, process and program analysis, environmental assessment studies, magnetic beneficiation of dry pulverized coal, technical support to the TVA fluid bed combustion program, coal cogeneration/district heating plant assessment, and chemical research and development.

1. Summary

L. E. McNeese

Highlights of our progress in March are as follows:

Coal Conversion Development - Operation of the Coal Liquids Flow System with hydrogen and coal slurry mixtures at 700 K (800°F) and 13.9 MPa (2000 psig) are described. Pressure drop measurements in the pipeline viscometer indicate that the slurry passes through the gel stage at 630 K (675°F). The gases which are produced when Wyodak coal reacts with phenol under a H₂ atmosphere have been quantified and identified; these have been found to be largely light paraffins. Final assembly of the electronics package for the prototype in-plant environmental monitor is nearing completion; one complete monitor will be ready for field testing by June 1. Experiments and analyses in support of in situ gasification processes were continued to improve the understanding of physical processes and chemical reactions in underground coal gasification. Summary data on 7 tests of overburden from the Hoe Creek No. 2 site and physical property measurements for Wilcox lignite, Wyodak subbituminous coal, and Pittsburgh bituminous coal are presented.

Materials Engineering - Samples were prepared to obtain additional Charpy and fracture toughness data and to measure the effect of microstructure on hydrogen attack in candidate pressure vessel steels. Metallographic examination of type 320 stainless steel submerged-arc weld clad deposits made with an experimental heat of powder-cored filler wire revealed fissures in the clad in areas where base metal dilution was high. The examination of the heat exchanger tubes from the 4500-h

experiment in the Fluidyne AFBC is continuing. Re-examination of samples exposed for 500 h and 1500 h revealed that nearly all contain small subsurface precipitates identified as manganese sulfide. Analysis of corrosion coupons from the solvent refined coal (SRC) pilot plants at Wilsonville and Fort Lewis continued under the failure analysis task. In addition, ORNL was asked by Catalytic to assume responsibility for the materials testing and surveillance program at the Wilsonville SRC pilot plant. Also under the failure analysis task, the T105 fractionation column and the dissolver at the Wilsonville pilot plant were examined. The former had undergone severe corrosive attack during the past few months during processing of high chloride content coal, but the latter showed only minor pitting since a similar examination in July 1977. The task to study stress-corrosion cracking in coal liquefaction pilot plants was continued. Visual examination of U-bend specimens which had been exposed for 700 to 1200 h in the Fort Lewis SRC pilot plant showed no evidence of cracking. New specimens have been placed in the Fort Lewis pilot plant and others are being placed in the dissolver and fractionation column of the Wilsonville pilot plant. Mechanical property characterization, heat treatment, and weldability studies continued on experimental heats of 9 Cr-1 Mo steels. The effect of tempering temperature, cooling rate from normalizing temperature, and post-weld heat treatment on toughness properties of one heat were completed during the last month. The purchase order for two large heats (14-18 Mg) was sent out. In the ceramic heat exchanger task, a proposal by Hague International for additional testing of silicon carbide heat exchanger tubes was evaluated and a work statement for an ORNL subcontract to Hague was drafted. The design of ceramic heat exchangers for recuperators in the glass, steel, and aluminum industries by Garrett-AiResearch is continuing with completion expected by May 1, 1979.

Coal Equipment Test Program - The feasibility study final report for the Coal Feeding/Handling Facility is being edited prior to publication. Information obtained during the survey of coal handling equipment is being organized and incorporated into the final survey equipment report. Results of the Bechtel National study will also be included in this report. Trips to obtain information concerning the Solvent Refined Coal Project support study were made to Fisher Controls, Inc. (valves) and Argonne National Laboratory (instruments).

AFB Coal Combustor for Cogeneration - A number of vendors have indicated that they intend to submit proposals for the CCC program. A supplementary information package has been sent to all the prospective vendors. The deadline for submission of proposals has been extended to May 14, and all the prospective vendors have been notified.

Engineering Studies and Technical Support - The second issue of the Coal Liquefaction Advanced Research Digest (ORNL/FE-2) was distributed in March. The topics examined included "Liquid Fuels from Coal by the SRC-II Process," "Consol Synthetic Fuel Process," and "Fischer-Tropsch Synthesis."

Process and Program Analysis - An examination of coal beneficiation techniques, including the entire spectrum of operations ranging from relatively simple physical separations to elaborate chemical treatment processes has been completed. The project efforts culminated in the issue of a final report (Survey and Evaluation of Current and Potential Coal Beneficiation Processes, ORNL/TM-5953) which summarizes technical and economic evaluations of currently used and several novel coal beneficiation systems.

In the Fossil Energy Environmental Project, physical/chemical characterization as well as batch and column leaching of U-Gas solid waste have been completed. Four drums of Grace-Ebasco solid waste were received and physical/chemical characterization was initiated. Column leaching runs have been completed on British Gas/Lurgi waste. Technical assistance was provided to DOE on all six demonstration plants: Grace, MLGW, CONOCO, ICGG, SRC-I, and SRC-II. Considerable effort was expended on the GTF project to implement the new CEQ regulations and initiate monitoring programs.

Magnetic Beneficiation of Dry Pulverized Coal - Quantitative separation of dry, crushed coal free-falling through an open-magnetic gradient has now been accomplished.

The contract for demonstration of continuous high-gradient magnetic separation at 1 ton/hr is being negotiated.

A TVA engineer on guest assignment will conduct an experimental program in our laboratory.

A motion picture of magnetic coal preparation is being filmed.

FBC Industrial Applications Project Survey - The review team has had briefing sessions in Morgantown on most of the projects and in March made two trips to Curtiss-Wright to review their PFB and anthracite culm AFB projects.

TVA FBC Demonstration Plant Program - The shop fabrication of new air piping components for the cold flow model was completed this month. In the AFBC Modeling and Simulation task, an effort is being made to obtain two major AFBC models: MIT's model and Wen's model (West Virginia State University). In-house development of the combustion efficiency model continued. Heat transfer tests with 1900 μ m limestone were completed during the first part of this month in the AFBC Bench Scale model. Regarding the PFBC Assessment task, Combustion Power Company in Menlo Park, California, was visited to review their granular bed filter development program. As a result of several meetings with TVA personnel concerning the Materials Support task, ORNL is formulating a program to investigate the corrosion potential on boiler materials of the AFBC environment that obtains during bed slumping.

Coal Cogeneration/District Heating Plant Assessment - Northern States Power Company has completed the task of investigating the siting of new units at existing facilities and has started the task of investigating new sites near the twin cities. The cogeneration power plant model is now complete.

Chemical Research and Development - The initial product distribution from pyrolysis of bibenzyl depends on the concentration (pressure) of bibenzyl because benzyl radicals formed by C-C cleavage are partially converted to 1,2-diphenylethyl radicals formed by hydrogen transfer from the substrate. In the neat liquid phase, most closely analogous to decomposing coal, essentially all the benzyl radicals are captured by the substrate to effect the analog of internal hydrogen redistribution.

2. COAL CONVERSION DEVELOPMENT

J. R. Hightower, Jr.

Coal conversion development activities are carried out in the Chemical Technology Division. This section discusses four projects conducted for the Division of Fossil Fuel Processing -- Physical Properties of Coal Liquids, Coal Slurry Preheaters, New Liquefaction Techniques, and In-Plant Environmental Monitors -- and one project conducted for the Division of Fossil Fuel Extraction -- Experimental Engineering Support for In-Situ Gasification Processes.

2.1 Physical Properties of Coal Liquids

G. E. Oswald, M. R. Gibson, and E. L. Youngblood

Physical properties (viscosity, density, thermal conductivity, and heat capacity) of both coal-solvent slurries and solids-free, coal-derived liquids will be measured at typical processing conditions, up to 31 MPa (4500 psig) hydrogen pressure and 810 K (1000°F) in a bench-scale, continuous flow system. The system includes a slurry preheater section and a hydrogenation reactor to simulate processing conditions prior to physical property measurement. Immediately after physical property measurement, the test fluids will be quenched and sampled for chemical characterization. Physical properties will be correlated with chemical characteristics of the test liquid.

Work accomplished. Two one-week-long operation periods were completed. The objective of the first operation period was to demonstrate operation of the system in combined phase slurry/hydrogen mix preheating mode. The system was operated for 1.5 hr at the following conditions; preheater discharge temperature 700-710 K, reactor temperature 700 K, system pressure 13.9 MPa, slurry rate 3.6 kg/hr [35 wt % Illinois No. 6 coal (-170 mesh)/Wilsonville recycle solvent], hydrogen rate 0.91 scmh. Operations were terminated when solids build-up on the interior walls of the high pressure/high temperature vapor liquid separator prevented operation of the liquid level detector. The build-up resulted from operating the separator at a temperature too low (560 K) to prevent solids agglomeration. This problem has been overcome in subsequent operations by maintaining the separator at 670 K.

As reported last month, differential pressure measurements across the pipeline viscometer located immediately downstream from the preheater indicate a sharp rise in slurry viscosity as the slurry passes through the gel stage during the preheating operation. Viscosity appears to peak at 630 K. Subsequent measurements at 700-710 K preheater discharge infer a significant viscosity decrease as temperature increases beyond the gel stage; at 700-710 K differential pressure was less than half that observed at 630 K even though the slurry rate was 3.7 times greater for the higher temperature measurement. These results are

presented in Fig. 2.1. Since these differential pressure measurements were made on combined phase flow, they should not be interpreted as absolute viscosity measurements on the liquid phase but as a qualitative indication of overall changes during the preheating operation.

During the second week of operation rheological characterizations were performed on 35 wt % slurry at 500 K and 550 K with 13.9 MPa overpressure. For these tests, slurry exiting the preheater (liquid phase flow only) was passed through the pipeline viscometer. The slurry was then combined with hydrogen in the reactor to allow sufficient reaction to supply the vapor-liquid separator with an easily handled stream. Reactor temperature was 700 K and residence time was nominally 0.17 hr. The results of these characterizations will be presented in the quarterly progress report for the period ending March 31, 1979. Some data were obtained at 700 K preheater discharge and 13.9 MPa overpressure; although the amount of data was not sufficient for complete rheological characterization, it did indicate highly pseudoplastic behavior and the apparent viscosity at 300/sec shear rate was 2 mPa·s (2 cp). Sufficient data for complete rheological characterization could not be obtained at 700 K because of instability in pipeline viscometer temperature control and differential pressure apparently caused by unpredictable changes in the reacting slurry.

Prior to March operations the length of the preheater was increased from 4.3 M to 11.9 M and heating capacity was increased by 150%.

Work forecast. Slurry rheological characterization operations will continue. A modified ring with increased internal diameter has been received from the falling ring viscometer manufacturer; it will be evaluated for viscosity measurements on slurries. The gamma ray absorption liquid density instrument will be calibrated and piped into the flow system; this instrument will be operated in conjunction with slurry rheological characterization tests.

2.2 Coal Slurry Preheaters

J. R. Thurgood, R. L. Andrews, J. Beams, and E. L. Youngblood

In coal liquefaction processes using slurries, such as the SRC process, preheaters are used to heat the slurry or slurry-hydrogen mixture to about 700 K (800°F) at pressures from 10 to 14 MPa (1500-2000 psig). During preheating, coal dissolution and chemical reactions occur which change the properties and flow characteristics of the slurry. These changes are not well understood and result in difficulties in the design and operation of preheaters. The objective of this work is to improve understanding of the preheating process; it focuses specifically on the thermal and rheological characteristics of the slurry at preheater conditions. Measurements can be made at temperatures up to 811 K (1000°F) and at pressures up to 31 MPa (4500 psig). The work compliments that of

Fig. 2.1. Pipeline viscometer differential pressure vs preheater discharge temperature.

a companion project, "Physical Properties of Coal Liquids," which is also being conducted in the same experimental facility at Oak Ridge National Laboratory.

Several experimental tests were conducted with the slurry preheater during the reporting period. The first set of tests was run with 35 wt % coal slurry and helium overpressure. The second set of tests was also run with 35 wt % coal slurry but with combined mixed phase hydrogen/slurry flow. An additional test was run with slurry flow (no gas present) through the preheater and with hydrogen flow through the reactor section of the system.

2.2.1 Experimental work

Three tests with 35 wt % coal/Wilsonville recycle solvent slurry and with helium overpressure were conducted to further characterize the rheological behavior of the slurry at various temperatures and at a pressure of 13.9 MPa (2000 psig). These tests consisted of two tests at a temperature of 500 K (440°F) and a pressure of 13.9 MPa and a test at 550 K (530°F) and at a pressure of 13.9 MPa.

During the first test, the weigh cell indicator (which monitors the slurry flow rate) began to malfunction and give erratic readings. Data from the test were, therefore, inaccurate and not conclusive. The weigh cell indicator has since been replaced and sent out for repair. The second and third tests were run late in the period and full data reduction and analysis are not yet complete. Analysis results on these two tests will be given in subsequent reports.

Two tests were run with hydrogen/slurry combined phase flow through the preheater. Both tests were conducted at approximately 700 K (800°F) and 13.9 MPa. The first test was run with the slurry leaving the preheater and entering directly into the vapor-liquid separator. Difficulties were encountered with this configuration. Gelation of the slurry occurred in the separator which caused plugging and blockage of the discharge lines. To overcome this problem, the preheater effluent stream was directed first to the reactor, and then to the vapor-liquid separator. This provided a slurry residence time of about 10 min in the reactor where it could go through the gelation phase and then enter the separator in a less viscous condition. The second test was conducted to check out this mode of operation. The test proved successful and some preliminary pressure drop data were obtained with the pipeline viscometer (these data will be reported in the "Physical Properties of Coal Liquids" quarterly progress report for January-March of 1979).

The last test conducted was made by flowing a 35 wt % coal slurry through the preheater with no admixed gas. The slurry exited the preheater and entered the reactor along with a separate stream of hydrogen which bubbled up through the slurry in the reactor. The hydrogen was maintained at an overpressure of 13.9 MPa. This mode of operation was used to permit testing of the slurry through the preheater without

hydrogen at 700 K. The operational procedure worked as planned. Little data was collected, however, because the temperature control of the pipeline viscometer became unstable. This may have been caused by reaction exotherms at the 700 K temperature. From the few data points which were obtained before the difficulty occurred, an apparent viscosity of about 2×10^{-3} kg/m·s (2 cp) at a shear rate of 300 s^{-1} was calculated. This is less than the 6.6×10^{-3} kg/m·s value determined for the slurry at 500 K and the same shear rate. Therefore, at 700 K the slurry appears to have passed through the gel phase and dropped down in viscosity. Further testing will be necessary to adequately characterize the slurry at 700 K. In order to preheat the slurry to 700 K, an additional length of preheater was added; this increased the length from 4.3 m to 11.9 m.

2.2.2 Work forecast

Work planned for the next month includes (1) continuation of slurry phase testing and data collection at temperatures up to 700 K, (2) testing and operational checkout of combined phase, hydrogen-slurry flow at various temperatures, and (3) heat transfer analysis of the data collected.

2.3 New Liquefaction Techniques

J. W. Larsen* and B. R. Rodgers

Several reactions of Bruceton coal with phenol have been carried out under varying conditions and are being worked up to compare with earlier data for Wyodak coal. A run with Wyodak coal and phenol under H_2 pressure has been completed and the gases produced have been found to be largely light paraffins (Table 1).

Table 2.1. Gases formed during the reaction of Wyodak coal and phenol under H_2 pressure

Compound	Vol %
CH_4	67
C_2H_4	0.7
C_2H_6	20
C_3H_6	1
C_3H_8	9
C_3H_8	~2

*Chemistry Division

The pyridine extractable products from the Wyodak coal-phenol reactions contain up to 12 wt % mineral matter. Since this material passes through the Soxhlet thimble, it might be possible for colloidal carbonaceous particles of similar size to pass through the thimble as well. To see whether this was occurring, two samples of the pyridine extractables were ultracentrifuged (168,000 x g, 3 hr) to precipitate colloidal material. Samples 18 and 21 (see previous reports) contained 22.5% and 17.9% total colloidal material and 11.7% and 7.9% mineral matter respectively. Assuming that all of the mineral matter was precipitated on centrifugation, in the two samples 10.8% and 10% of the extractable carbonaceous material was colloidal. For such short reaction times, this is a remarkably small amount of colloidal material, considered in the context of other coal degradation reactions.

2.4 In-Plant Environmental Monitors

D. D. Schuresko and M. L. Bauer*

Fabrication of the prototype electronics unit and rechargeable battery pack continued during March. The lamp regulator and igniter circuit was modified in order to accommodate lamps with various operating characteristics, and to produce a more energetic lamp ignition pulse. A 2 ohm, 25 watt resistor was connected across the lamp current regulating pass transistor in order to boost the lamp current to 4 amps during the warm-up period immediately after ignition. Various modifications were made to the printed circuit phase sensitive demodulator in order to increase the phase stability and range of phase adjustment. Final assembly of the complete electronics package is near completion; thus one complete spotter unit will probably be available for field testing by June 1.

2.5 Experimental Engineering Support of In Situ Gasification Processes

P. R. Westmoreland, L. S. Dickerson, and B. R. Rodgers

Experiments and analyses were continued during this period to improve the understanding of physical processes and reactions in underground coal gasification (UCG). Items presented in this report are:

- Summary data on 7 tests of overburden from the Hoe Creek No. 2 site (Sec. 2.5.1) and
- Physical property measurements for Wilcox lignite, Wyodak subbituminous coal, and Pittsburgh bituminous coal (Sec. 2.5.2).

*Instrument and Controls Division

This research program supports both the modeling and field development of in situ (or underground) coal gasification, and emphasizes study of the pyrolysis of large coal blocks. Pyrolysis of overburden and measurements of physical properties are also parts of the program.

In experiments which began at ORNL in 1975, 150-mm (6-in.-diam) right circular cylinders of lignite, subbituminous coal, and bituminous coal have been pyrolyzed by heating the blocks at 0.3-14 K/min (surface temperature) from ambient temperature to maximum temperatures of 773-1273 K (500-1000°C). Using an inert (argon) or reducing (hydrogen) purge gas at atmospheric pressure, gas- and vapor-phase reaction products are continuously swept from the reactor. Water, oils, and tars, are collected in a water-cooled condenser and by filters, and the remaining non-condensable gases are metered and periodically sampled. In many of the experiments, block temperature profiles have been measured by internal thermocouples. These tests are designed to support modeling of field UCG experiments by Laramie Energy Technology Center (LETC), Lawrence Livermore Laboratory (LLL), Morgantown Energy Technology Center (METC), and Gulf Research & Development Company (GR&DC).

2.5.1 Properties and pyrolysis of overburden

Six samples of overburden strata from LLL's Hoe Creek No. 2 site have been characterized in recent months. This characterization has included measurements of moisture, carbon and hydrogen content; of wet and dry solid densities; of shrinkage; and of decrepitation and gas evolution during heat-up to 1273 K (1000°C; experiments OB-1 through OB-7).

In Figure 2.2a, location of these six cores is shown in sample well SS-2. By comparison to Figure 2.2b, location of the rubble cavity after the Hoe Creek No. 2 UCG experiment can be compared to the original strata. Clearly, all of the previously cited properties can become important since each stratum that is represented by these cores also collapsed into the cavity.

Cores were inspected at the drilling site and visually characterized. Several bands of unconsolidated sand were observed, but most of the strata of interest were siltstone and claystone. After descriptions were logged, the 60-mm-diam (2 3/8-in.) cores were cut in approximately 140-mm lengths (5 1/2-in.), wrapped in plastic and aluminum foil, and sealed in a layer of wax. At ORNL, the cores were drilled with 1-mm-diam (0.047-in.) thermocouple holes and x-rayed.

Before heating the core, a segment was sliced from the bottom for other tests. Analytical results (Table 2.2) showed that moisture content was fairly constant at 13-16%, but carbon and hydrogen content varied, reflecting apparent differences in amount of organic matter. Density of the wet solid was 2190-2200 kg/m³ except for core 79, a more carbonaceous sample which was 2000 kg/m³. Shrinkage after drying varied from no shrinkage to 2.0%, so the calculated density of dry solids was 1800-2000 kg/m³.

Fig. 2.2. Location of overburden core samples from Hoe Creek 2 site, Gillette, Wyoming — (a) before field test (at time of sampling); (b) after field test (reference 1).

Table 2.2. Description and properties of overburden samples from the Hoe Creek 2 site

Core number	79	76	61	55	49	48
Experiment	OB-4	OB-5	OB-6	OB-7	OB-3	OB-1 & OB-2
Location in well SS-2 (m) ^a						
Depth	38.9	38.4	35.1	33.8	28.4	28.1
Height above Felix No. 2	0.2	0.7	4.0	5.3	10.7	11.0
Distance from Felix No. 1	5.7 beneath	5.3 beneath	2.0 beneath	0.6 beneath	1.7 above	2.0 above
Description: ^a	Dark black, carbonaceous, slightly silty claystone. Carbonaceous material increases with depth and color darkens.	Thinly-bedded clayey siltstone and claystone; medium black with brownish cast; tends to disk with stress relief.	Very silty claystone or very clayey siltstone; medium brown; very thinly bedded; slightly calcareous.	Medium brown to buff with black carbonaceous speckles; thinly-interbedded, very fine-grained silty sand and claystone; dries quickly with formation of shrinkage cracks; ^a broke into pieces, so placed in a mesh basket for experiment.	Slightly silty claystone: light brown to light black, slightly carbonaceous, thin-bedded.	
Analyses						
Moisture (wt %)	15.6	13.4	13.0	14.3	13.3	-- ^e
Carbon (% moisture-free) ^b	5.02	2.04	1.26	1.75	3.63	-- ^e
Hydrogen (% moisture-free)	1.03	0.42	0.42	0.65	0.58	-- ^e
Density (kg/m ³) and shrinkage						
Bulk density of wet solid	2000	2190	2200	2190	2200	-- ^e
Shrinkage from drying (%)	1.5 ^c	0.6	0.8-2.0	--	None	-- ^e
Bulk density of dry solid ^d	1800	1930	2000	--	1900	-- ^e

^aReference 2.^bIncludes carbon in carbonates.^cAverage linear shrinkage, three dimensions; sample of core dried in vacuum at 107°C for 16 hr.^dCalculated from moisture content, wet bulk density, and shrinkage.^eShould be same as for core 49.

Each core was heated to 1000°C in an inert purge gas while internal temperatures were measured and gas evolution was measured. Although no organic liquids were detected as products, significant amounts of H₂, CO, and CO₂ were released along with small amounts of CH₄, C₂'s, and C₃'s (see Table 2.3); gas yields (dry, wt % basis) were as high as one-third of those from Wyodak coal.

After heat treatment, the solid residue was photographed and described to compare decrepitation. Cores 55 and 79 flaked apart at bedding planes, while large cracks formed in cores 48, 49, and 61. The material in cores 48, 49, and 76 hardened, forming a brick-like residue. Photographs of the residues from all experiments will be reproduced in the Quarterly Report for this quarter.

2.5.2 Physical property measurements on coals

Density, shrinkage, and porosity have been measured for three coals of interest: lignite from the Wilcox (Texas) formation, Wyodak subbituminous coal from the Roland-Smith (Wyoming) seams, and bituminous coal from the Pittsburgh (West Virginia) seam. These measurements are described here and compared.

Density of water-saturated chunks of coal was determined in a large water pycnometer. After drying these chunks in a vacuum at 106°C for 16 hr, shrinkage was measured in each of three orthogonal dimensions; density and shrinkage measurements are shown in Table 2.4. Shrinkage is particularly interesting since the lignite shrank 8.4% in each dimension (sample standard deviation 3.0), the subbituminous coal shrank 9.3% $\pm$ 3.3, and no shrinkage of the bituminous coal was observed.

Density of dry powders from the shrinkage tests was measured in a mercury porosimeter and in a helium densitometer to characterize pore volume in the dried coal. Helium is able to penetrate pores easily, so the densitometer gives a reasonable intrinsic density for the solid itself, excluding pores. In contrast, mercury penetration depends on applied pressure, so that measurement at 15 psi gives a bulk particle density, while measurement at 15000 psi approximates the intrinsic density. Pore size distribution can be determined by applying gradual increases to the applied mercury pressure, but these distributions are subject to error in easily-crushed low-rank coals.

Density and particle porosity of lignite and subbituminous coal powders are reported in Table 2.5. Intrinsic densities for the materials are nearly the same, but bulk density of the lignite particles is more than that of the subbituminous coal particles. As a result, particle porosity of the lignite is half that of the subbituminous coal; however, dried lignite is generally considered to be more porous than dried subbituminous coal.

Table 2.3. Results of heating tests for overburden from Hoe Creek 2 site

Core experiment	79 OB-4	76 OB-5	61 OB-6	55 OB-7	49 OB-3	48 OB-1 & OB-2 ^a
Sample weight (kg)	0.6577	0.8183	0.7561	0.7830	0.7287	0.9323
(kg, H ₂ O-free)	0.555	0.709	0.658	0.671	0.632	0.808 ^b
Product yields (kg)						
Solid residue	0.4679	0.6437	0.6161	0.6051	0.597	0.7332
Oil and tars	0 ^c	0 ^d	0 ^c	0 ^c	0 ^c	0 ^c
Gases	0.0322	0.059	0.0297	0.0366	0.0352	0.082
Yields (wt %, H ₂ O-free)						
Solid residue	84.3	90.8	93.6	90.2	94.5	90.7
Oils and tars	0 ^c	0 ^d	0 ^c	0 ^c	0 ^c	0 ^c
H ₂	0.357	0.219	0.143	0.243	0.205	0.105
CH ₄	0.104	0.075	0.056	0.105	- ^e	- ^e
C ₂ 's	0.052	0.045	0.030	0.094	0 ^c	0.040
C ₃ 's	0.040	0.035	0.024	0.013	0 ^c	0 ^c
CO	2.61	3.50	1.610	1.469	- ^e	- ^e
CO ₂	2.61	4.44	2.63	3.26	4.73	3.61
H ₂ S	0.018	0 ^c	0.022	0.003	0 ^c	0 ^c
Total gases	5.79	8.31	4.52	5.19	5.7	10.1
Total balance	90.1	99.1	98.1	95.4	100.2	100.8
Characteristics of solid residue	Spalled at bedding planes; 3.6% shrinkage in each dimension.	Solid with no signs of flaking or shrinkage. Hard, breaking smoothly when struck by a hammer.	Several large cracks, vertical and horizontal, splitting the block into hard segments. Complete break-off of top two-thirds. Broke into powder when struck.	Layered spalling along bedding planes; very easily crumbled into dust.	Hardened into a strong, brick-like material with no detectable shrinkage.	

^a Core was heated in OB-1 at 3°C/min to 800°C, then cooled and reheated at 3°C/min to 1000°C in OB-2.

^b Assumes 13.3% moisture, same as for core 49.

^c Not detected.

^d Condensed water was dark and contained small black particles, possibly carbon from CO decomposition.

^e Errors in analysis by gas chromatograph.

Table 2.4. Wet density and shrinkage measurements

Coal	Density of wet coal (kg/m ³)	Shrinkage from drying (linear %)		
		Length	Width	Thickness
Wilcox lignite A	1217	- ^a	9.53	- ^a
	1234	- ^a	7.08	- ^a
	-	12.78	8.98	- ^a
	-	5.7	7.11	6.11
	-	4.42	13.42	4.23
	-	10.19	8.83	10.84
Wyodak subbituminous C coal	1263	7.39	4.00	13.28
	1283	8.80	11.46	10.61
Pittsburgh bituminous coal (hvAb)	1302	ND	ND	ND
	1306	ND	ND	ND

^aChips fell off during drying.^bND = Not detected.

Table 2.5. Density and porosity of coal powders

	Wilcox lignite		Wyodak subbituminous coal
	Sample 1	Sample 2	
Density by mercury porosimeter (kg/m ³)			
At 15 psi	1240	1250	1039
At 75 psi	1257	1264	1069
At 250 psi	1274	1275	1124
At 15000 psi	1462	1369	1455
Density by helium densitometer (kg/m ³)	1449	1423	-
Particle porosity (%)	14.4 ^a	12.2 ^a	28.6 ^b

^aUsing helium density as intrinsic density.^bUsing mercury density at 15000 psi as intrinsic density.

This discrepancy is explained as a difference in pore type when Table 2.6 is considered. In it, data for the three coals is summarized and bulk density of the dried coal chunks is calculated. When this bulk density is compared to intrinsic density, high porosities for both low-rank coals result. These data can be explained by considering that the bulk particle density (as measured in mercury at 15 psi) includes the solid volume and the volume of pores 3 μm or less in diameter. Larger pores in lignite would be filled by the mercury, and the volume of large cracks, which open up when the low-rank coals are dried, are eliminated by crushing the coal into powder.

2.5.3 Other work; future plans

Other work during this reporting period includes shakedown tests for block pyrolysis experiments in a simulated UCG product gas. In addition, modeling of the block drying process has begun, using the mechanistic model proposed by Lyczkowski.³ Based on detailed block pyrolysis data and collaborative discussions of them, researchers at the University of Texas at Austin have modeled the thermal data in a Wyodak coal block heated at 3°C/min.⁴ Temperatures predicted by their radial model were in good agreement with experimental data at 600°C surface temperature, but agreement was unsatisfactory at 900°C. Most probably, the radial model of a shrinking cylinder of wet coal is still valid at 600°C, while at 900°C, heating of the block's ends has caused the shrinking core to assume a more spherical shape. Convection would no longer be directed radially outward from the cylinder axis, so the model would break down.

During the next reporting period, equilibration of the simulated UCG product gas (in the absence of coal) will be studied and a test with bituminous coal will be conducted. Modeling of the block processes will continue.

2.6 References for Section 2

1. LLL In Situ Gasification Program Quarterly Progress Report, April through June 1978, UCRL-50026-78-2, Lawrence Livermore Laboratory, Livermore, California (October 1978).
2. H. C. Ganow, Lawrence Livermore Laboratory, personal communication of drilling log to P. R. Westmoreland, October 11, 1978.
3. R. W. Lyczkowski, A Mechanistic Theory for Drying of Porous Media, Report UCRL-52456, Lawrence Livermore Laboratory, Livermore, California (April 1978).
4. T. H. Tsang and T. F. Edgar, "Modeling of Drying and Pyrolysis During Underground Gasification," to be presented at 86th National Meeting of AIChE, Houston, Texas, April 1-4, 1979.

Table 2.6. Physical properties of wet and dry coal

Coal type	Lignite A	Subbituminous C	High-volatile A bituminous
Seam	Wilcox, TX	Roland-Smith, WY	Pittsburgh, WV
Density of wet coal (kg/m ³)	1230	1270	1304
Average linear shrinkage (%)	8.4 ± 3.0	9.3 ± 3.3	ND
Moisture content (wt %)	37.48	33.42	1.77
Calculated bulk density of dry coal (kg/m ³) ^a	1000	1130	1280
Intrinsic density (kg/m ³)	1425	1455	-
Calculated porosity (%) ^b	30	23	- ^c

^aCalculated by (wet density) x (100 - moisture)/(100 - shrinkage)³.

^bCalculated by (intrinsic density - bulk density)/(intrinsic density) x 100%.

^cTypically 3% or less for bituminous coals.

ND = Not detected.

3. MATERIALS ENGINEERING

R. A. Bradley

The materials engineering and associated technology reported here are in support of activities directed or coordinated by the Materials Engineering Branch, Division of Planning and Systems Engineering, Fossil Energy. Other related work funded by the Division of Fossil Fuel Utilization and the Division of Fossil Fuel Processing is also included.

3.1 Pressure Vessel and Piping Materials

W. J. Stelzman, R. O. Williams, and D. A. Canonico

The objective of this task is to determine the fracture toughness of pressure vessel steels and to study their susceptibility to hydrogen attack. Charpy V-notch and miniature tensile specimens have been machined from bars which were fast and slow cooled (3 K/s and 0.3 K/s, respectively) from 1830 and 927°C. Some bars duplicate previous heat treatments and will be used to provide additional static fracture toughness data. Other bars were aged and will be used to provide Charpy and fracture toughness data.

In the experiment to measure the effect of microstructure on the susceptibility to hydrogen attack, a set of samples has been heat treated, instrumented, and installed in the test rig. The test will be started shortly.

In the continuing effort to measure the carbon activity at low temperatures using the hydrogen-methane equilibrium, we have considered the use of a catalyst. In consultation with experts at ORNL, it was suggested that nickel may be a good catalyst for this reaction. Plans are under way to nickel plate a sample and evaluate this suggestion.

3.2 Fossil Energy Welding and Cladding Development

D. P. Edmonds

We have performed a metallographic analysis of specimens from the type 320 stainless steel clad deposits made with the experimental heat of powder-cored filler wire. These submerged-arc deposits were made using a nickel-fortified flux, on 25.4-mm-thick 2 1/4 Cr-1 Mo steel base plate. No cracks were previously observed by visual and dye penetrant examination of the clad surface. However, metallographic examination revealed fissures in the clads in areas where base metal dilution was high.

Also, we are negotiating with a commercial heavy-section manufacturer to develop cladding techniques for type 320 stainless steel using the submerged-arc strip cladding process. Strip has been ordered, and the feasibility of strip cladding with these materials will be evaluated when materials are received.

3.3 Fireside Corrosion of Atmospheric-Fluidized Bed Combustor Tubes

T. G. Godfrey and J. H. DeVan

Examination of the heat exchanger tubes from the 4500-h experiment in the Fluidyne atmospheric-fluidized bed combustor (AFBC) is continuing. A number of samples from the first 500-h and 1500-h portion of the test were repolished and subjected to metallographic and electron microprobe examinations. Results show that nearly every sample contains small sub-surface precipitates confirmed to be manganese sulfides. This observation indicates that all samples must be re-examined, and this is now in progress.

3.4 Failure Analysis and Prevention

J. H. DeVan

3.4.1 Examination of corrosion coupons from solvent-refined coal plants (V. B. Baylor, R. S. Crouse, M. D. Allen)

The analysis of the second set of surveillance coupons from the Wilsonville SRC plant is proceeding. This analysis will be incorporated into the preliminary report that has been drafted on the first set of coupons received. This report is still being reviewed by Catalytic personnel at Wilsonville and Philadelphia. In meetings with Catalytic personnel following the recent corrosive failure of the T105 fractionation column (see Sect. 3.4.2), ORNL was asked to assume responsibility for the materials surveillance and testing program. Catalytic will advise on materials selection and receive reports on analyses. Our having responsibility for this program enables us to control weld quality, choice of materials tested, coupon configuration, i.e., flat versus U-bend, and other important parameters.

A third set of coupons from the Wilsonville dissolver was received for evaluation, particularly for stress-corrosion cracking. A third set from the failed fractionation column has been promised to us by Air Products. These coupons were exposed to the processing of the high chlorine content coal suspected as the agent of the recent corrosion problem.

The microprobe analysis on the corrosion coupons received from the Fort Lewis SRC plant is in progress. Efforts are being made to collect pertinent process information for eventual analytical reports.

3.4.2 Examination of failed Tl05 fractionation column at the Wilsonville SRC plant (V. B. Baylor, J. R. Keiser, B. C. Leslie, M. D. Allen)

The Tl05 fractionation column at the Wilsonville SRC plant was found to be severely corroded. Plant management requested the assistance of ORNL personnel on repair of the column and on identification of the offensive species. Three trips to Wilsonville were taken.

The Tl05 fractionation column, which separates process solvent from wash solvent, was especially attacked in the middle region. General corrosion of internals was observed (severe thinning of the type 316 stainless steel trays caused enlargement of the holes), as well as localized attack on weldments and heat-affected zones adjacent to welds. The type 304 stainless steel cladding was also subjected to general thinning and pitting. Some corrosion has also been noted in piping to the column and in the Tl02 vacuum column.

As part of the investigation, the column is being examined metallographically as well as visually. Tray pieces have been mounted and polished and replicas taken of the side walls.

We have been assured that the only operational change at Wilsonville has been the use of a coal containing at least ten times more chlorine than any coal used previously. Consultations with representatives from the Exxon, Gulf, and Fort Lewis SRC plant, as well as experiences at U.S. Steel, lead one to believe that the corrodent is either naphthenic acid (somehow accelerated by the chloride) or ammonium chloride. If chloride is indeed a factor, the liquid should display some electrochemical activity. Samples of previous and current process and wash solvents were brought back to ORNL for electrochemical analysis.

The column will not go on-stream until it has been repaired. Recommendations were made to either line or replace the column with type 316 stainless steel and to replace the internals with Incoloy 825 or Hastelloy G. It was recommended that at least three corrosion probes be installed.

3.4.3 Examination of dissolver at Wilsonville SRC plant (B. C. Leslie, J. H. Smith, M. D. Allen)

Nondestructive evaluation of two areas of the Wilsonville dissolver was performed at the request of George Usnick, Production Superintendent. A similar examination was made in July 1977.¹ The purpose was to determine if the cracking observed during the first investigation had become more extensive.

Dye penetrant tests and replicas taken of the welds of interest, near the thermowell on the inside of the head and connecting the flange to the vessel, showed that the amount of cracking had not changed significantly since the first investigation. However, pitting on the inside of the head was observed which was not seen in the previous evaluation.

3.5 Materials for ZnCl_2 Liquefaction Process

V. B. Baylor and J. R. Keiser

The quartz loop testing apparatus is being simplified to facilitate construction by the glass shop. Heat flow both in and out of the system is being evaluated to determine if the current design will be adequate. More materials to be tested have been received.

3.6 Materials to Resist Stress-Corrosion Cracking in Coal Liquefaction Pilot Plants

J. R. Keiser and V. B. Baylor

The U-bend specimens which were inserted into three vessels at the Fort Lewis SRC plant were removed and shipped to ORNL for evaluation. After seeing 700-1200 h of service, visual examination showed no evidence of cracking. After measuring stress relaxation, the specimens will be examined metallographically. New racks of specimens were replaced into these vessels and two racks were inserted into the dissolver. They are expected to be removed this summer.

The rack for the T105 fractionation column at Wilsonville will be inserted as soon as the vessel is repaired (see Sect. 3.4.2). Three racks were inserted into the dissolver when it was opened for inspection (see Sect. 3.4.3). These racks will be removed at the next major shutdown. Racks of U-bends and flat specimens are being prepared for insertion into other vessels this spring (see Sect. 3.4.1).

A list of fabricated U-bend specimens on hand is being readied for personnel at Exxon. They will modify their racks to be used for surveillance testing in the Exxon Donor Solvent (EDS) pilot plant to accommodate several U-bends to be provided by ORNL. These racks are being prepared this spring for insertion into vessels in the fall.

In light of current knowledge about materials testing in liquefaction pilot plants, the proposed program for the H-Coal Pilot Plant was evaluated and some changes were recommended.

3.7 Development of Advanced 9 Cr-1 Mo Structural Steel

V. K. Sikka

Mechanical property characterization, heat treatment, and weldability studies continued on experimental heats of 9 Cr-1 Mo steels. The effect of tempering temperature, cooling rate from normalizing temperature, and post-weld heat treatment on toughness properties of one heat were completed during this month. Data indicated that 760°C is an optimum tempering temperature. Furthermore, the cooling rates (different by an

order of magnitude) and post-weld heat treatment of up to 40 h at 732°C have only minor effects on Charpy toughness properties. Effect of austenitization temperature for a given tempering temperature will be investigated during the next few months.

Four additional creep tests ruptured on two of the four DOE-Reactor Research and Technology Division commercial argon-oxygen-deoxidization (AOD) process heats that are being evaluated prior to procuring two 14-18 Mg (15-20 ton) Fossil Energy-funded heats. Six additional tests are in progress on these heats. Specimens ruptured from these heats are showing greater than 80% reduction of area values independent of the test temperature and time.

One plate from the Quaker heat was successfully welded using the GTA process. Specimens from this plate are being machined for both the Charpy and creep testing of the weldment.

The purchase order for two large heats was sent out during the last month. Ingots from these heats are expected to be delivered by August 1979.

3.8 Ceramic Recuperators (Heat Exchangers)

V. J. Tennery and G. W. Weber

Following discussions to evaluate the recuperator program at Hague International of South Portland, Maine, outlined in the previous monthly, an assessment was made in conjunction with DOE/Fossil personnel and W. Thielbahr of NWD, China Lake, as to whether additional contracted ceramic heat exchanger work at Hague would be of value within the DOE/Fossil heat exchanger programs. We have concluded that additional work at Hague would be useful if it can be accomplished with available funds. A proposed statement of work for a subcontract to Hague from ORNL was drafted and transmitted to them for formal reply. The key items of the proposed new work are: (1) static permeability tests of silicon carbide heat exchanger tubes, (2) fabrication of silicon carbide heat exchanger tubes, (3) exposure to coal/oil mixture combustion products for ≥ 200 h, (4) leakage tests of silicon carbide heat exchanger tubes in the Hague header, (5) coal/oil mixture sampling and analysis, and (6) reporting. The primary thrust of the effort is to accumulate significant exposure times for ceramic silicon carbide heat exchanger tubes with coal/oil mixture at representative temperatures and flow rates to determine the suitability of silicon carbide and the Hague mechanical heat exchanger tube to header joint in this environment as well as to evaluate the current sealing technology under operating conditions that approximate gas turbine heat exchanger operating conditions. Response is expected from Hague by March 30, 1979.

Discussions with Garrett-AiResearch (Torrance, California) have defined the final details of their subcontract with ORNL to complete a preliminary design study for selected ceramic heat exchanger configurations. Items discussed included anticipated markets and yearly duty cycles for

recuperators in the glass, steel, and aluminum industries; anticipated fuel costs for each application; and utilization of materials other than silicon carbide for the glass furnace recuperator design. Completion of the designs for each application is anticipated by May 1, 1979.

The modification to the Refractories Test Facility is proceeding. Drawings and specifications have been completed and are in the review process at ORNL. Several items including a radiation-shielded suction pyrometer, Carborundum (Niagara Falls, New York) Fiberfax insulation, a 1-hp 3450-rpm blower and A-P Green (Mexico, Missouri) Mizzou castable refractory have been ordered.

3.9 References

1. S. D. Snyder and B. C. Leslie, *In-Service Inspection of the Dissolver Tank in the Solvent-Refined Coal Pilot Plant at Wilsonville, Alabama*, ORNL/TM-6277 (April 1978).

4. COAL EQUIPMENT TEST PROGRAM

J. M. Holmes and R. E. MacPherson

Work under the Coal Equipment Test Program (CETP) is currently divided into three sections:

- Coal Feeder Test Program
- Survey of Industrial Capability for Coal Handling Equipment
- Support for the Solvent Refined Coal Project

4.1 Coal Feeder Test Program

B. T. Thompson and A. R. Sadlowe

Final comments have been incorporated into the report on the Dry Coal Handling/Feeding Test Facility Feasibility Study. Preconceptual cost estimates for four alternate cases have been prepared. The final draft has been transmitted to Information Services for editing and publishing. For next month it is planned to present results of the study to program personnel at METC (Morgantown Energy Technology Center).

4.2 Survey of Industrial Capability for Coal Handling Equipment

F. C. Zapp, O. W. Thomas, and M. D. Silverman

Questionnaires were developed for eight types of coal preparation equipment based on the latest coal conversion plant system design flow-sheets provided by Bechtel National, Inc. The equipment included rod mills, cage mills, air separators, screens, fluidized bed dryers, bowl coal pulverizers, ball tube mill coal pulverizers, and ball mills.

Several vendors for each of the above types of equipment were contacted during a phone survey in an attempt to obtain the desired information. All information obtained during the survey is being organized in tabular form for inclusion in the final equipment survey report.

A preliminary draft of the ash/slag equipment survey section of the report has been completed, including a tabulation of equipment information.

Bechtel National continues to work on the final draft of their report which will be completed in April.

4.3 Support for the Solvent Refined Coal Project

P. K. Carlson, L. F. Parsly, and J. M. Holmes

In response to a request from Oak Ridge Operations Office, a technical study of the SRC I and SRC II processes is in progress. Engineering Technology Division is concerned with an assessment of current research and development of components deemed critical to the successful operation of the SRC Demonstration Plants.

A group consisting of J. Hubacher of TRW, J. Gardner of METC, and P. K. Carlson of ORNL visited Fisher Controls, Inc., at Marshalltown, Iowa. Fisher is manufacturing a control valve, which, with trim and port modification, is designed for demo-scale SRC II dissolver slurry letdown. Fisher valves in the SRC I and SRC II pilot plants have been among the most successful to date in longevity, and larger-scale valves of the same design in a multistaged configuration are being proposed. A trip is planned to Willis Choke Co., supplier of another valve which has demonstrated good durability potential in the SRC slurry letdown application.

None of the designs at the pilot plant level have, however, approached the target lifetime specified as 10,000 hrs. Therefore, further R&D has been suggested in order to reduce failure rates. The preferred type of developmental work is pilot plant testing of proposed valve designs under actual SRC slurry letdown conditions. However, research of a more basic nature and testing which isolates on a particular problem area, such as erosion, is being considered. This type of R&D would involve substantially less cost and provide data applicable to more general sets of problems.

A visit was made to Argonne National Laboratory concerning the current status of advanced slurry metering instrumentation for the SRC process. Information was obtained on the following types of mass flow instruments:

- Acoustic
- Capacitive
- Neutron Activation
- Gamma Densitometer

Also under development are cross correlation techniques which utilize several of the above techniques for observing local fluctuations in the slurry flow patterns at two locations along the flow path. A comparison of the two signals from these points using cross correlation techniques on a computer results in a direct measurement of the slurry flow rates. Estimates of the time and resources required to develop advanced flow meters for installation in the SRC demo plants were obtained.

5. ATMOSPHERIC FLUIDIZED BED COAL COMBUSTOR FOR COGENERATION (AFBCCC)

R. S. Holcomb

5.1 Objective

The Coal Combustor for Cogeneration (CCC) Program is directed at the development of a fluidized bed coal combustion system heating air inside tubes to provide high temperature clean air to drive a gas turbine to generate electricity. The heat in the air leaving the turbine exhaust would be recovered to supply industrial process heat. The gas turbine is very well suited for cogeneration since the ratio of thermal to electrical energy is about 3 to 1 for the gas turbine cycle as compared to a ratio of about 5 to 1 for a back-pressure steam turbine, and the exhaust heat from the gas turbine is available at a higher temperature. The scope of the program includes the study of industrial cogeneration plants in the size range from 5 to 50 MW(e) and the construction and testing of a 0.3 MW(e) technology test unit.

5.2 Status Summary

A number of vendors have indicated that they intend to submit proposals for the CCC program. A few questions about the AiResearch 831-200 gas turbine and the building space available at the Oak Ridge site have arisen. In answer to these, a supplementary information package including the engineering study report on the 831-200 gas turbine, a drawing showing Building 9401-1, and a paper summarizing the program status has been sent to all the prospective vendors.

A request was received from one of the vendors for a two-week extension of the deadline for submitting a proposal. They had not been sent the RFP on the original mailing list, but had requested it as a result of the notice in the Commerce Business Daily Bulletin. The deadline for submission of proposals has been extended to May 14, and all the prospective vendors have been notified.

5.3 Supplemental Oil Firing

A variation of the coal-fired indirect-heated gas turbine cycle is a cycle where a gas or oil direct-fired combustor is placed between the FBC and the gas turbine to raise the gas to a higher temperature than the 1400 to 1500°F level that can probably be obtained from the coal-fired FBC. While this approach would not provide total substitution of coal for gas or oil, it would nevertheless represent a marked decrease in gas or oil consumption. For example, if the compressed air were heated to 1500°F in the FBC and then to 1800°F in an oil-fired combustor, about two-thirds of the heat would be supplied by coal and about one-third by oil in a typical gas turbine cycle. This type of system should be equally or more acceptable than plants employing coal-oil mixtures in

the new plant category under the regulations of the Power Plant and Industrial Fuel Use Act of 1978.

In examining the gains that might be accrued from the higher turbine inlet temperature, the electrical efficiency is calculated to increase from about 25% for 1500°F to about 31% for 1800°F turbine inlet temperature for a typical recuperated gas turbine cycle. This increase is not of very great economic importance for applications involving cogeneration of electric power and process heat. It would make the cogeneration system more attractive for industrial applications that have an unusually high ratio of electric power to process heat needs.

An increase in efficiency from 25 to 31% would be important, however, in the case of installations producing only electric power. The coal-fired FBC gas turbine system has been studied for possible use as a substitute for oil-fired gas turbines for peaking power service. A much larger increase in efficiency could be obtained by employing a gas-steam turbine combined cycle. The electrical efficiency for a 1500°F gas turbine inlet temperature is calculated to be about 37% for a combined cycle with a 1000°F, 2400 psi bottom steam system. With a combined cycle only, a small gain is realized by increasing the gas turbine inlet temperature to 1800°F. An electrical efficiency of about 39% is calculated for this case.

The question has been raised by some vendors as to whether or not supplemental gas or oil firing would be acceptable as a feature of their proposed concept for the CCC program proposal. It would appear to be acceptable under two conditions; (1) that the compressed air to the turbine is heated to 1400 to 1500°F in the fluidized bed coal combustor in their proposed system and (2) that the proposed outlet temperature from the supplemental combustor would not be so high as to require advanced gas turbine development.

6. ENGINEERING STUDIES AND TECHNICAL SUPPORT

R. W. Glass

Engineering studies and technical support are provided primarily for the DOE/FE Division of Fossil Fuel Processing. The effort includes: the development of analytical tools for use in the evaluation of processes and equipment; the technical and economic evaluation and comparison of coal conversion processes and subprocesses on a uniform basis; surveys of the need for coal conversion equipment and the capability of industry to provide such equipment; and studies of the magnitude and control of coal conversion plant emissions.

6.1 Process Modeling

R. Salmon, D. M. Lister, O. L. Culberson,
D. G. Ball, K. W. Childs

6.1.1 Contract Objective

The objective is to assist DOE/FE 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. Physical property data are being collected and computerized primarily by Purdue and will be used in support of programs prepared by both universities. Purdue's general design program will aim at material and energy balances, equipment size and costing, plant capacity, and general economics. Lehigh's dynamic simulation programs will address plant design primarily from the standpoint of process performance during transient operations, but can also be used for steady-state conditions. A single flowsheet will be selected to assess the operability and complementary utility of both design programs.

6.1.2 Status Summary

Purdue Physical Properties Package (PPROP): Failure of a V/L (vapor-liquid) flash calculation in a test problem devised by ORNL was traced to negative arguments to the ALOG function caused by trying to raise the expression $1-TR$ to a real power when TR (the reduced temperature) was greater than 1. Changes were made to bypass this difficulty by using the coding for $TR=1$. It is expected that the solution of the test problem will be obtained during April.

Lehigh DSS/2 Program: We have developed a new program called "D.P. Converter-1" to process a source code and convert all hard coded floating point constants to double precision. It has been used to convert the real constants in the DSS/2 code. The new version of the DSS/2 is currently being tested. Documentation of the DPC-1 code has commenced.

No work was performed on the extended precision version of the Lehigh Methanation Model during the reporting period.

6.2 Coal Liquefaction Advanced Research Digest

F. M. O'Hara, Jr., and R. W. Glass

6.2.1 Contract Objective

The objective is to provide continuing technical assistance to DOE/FE by preparing digest reviews of current or potential subjects relating to coal conversion technology.

6.2.2 Status Summary

Researchers currently examining the kinetics and mechanisms of coal hydrogenation and liquefaction were surveyed by telephone, and several very recent publications, drafts of articles in preparation, and other sources of unpublished information were discovered. This additional information is currently being collected and evaluated for inclusion in the articles on kinetics and mechanisms in the upcoming issue of the Digest. An additional writer for the Digest was also selected and arrangements were made for him to start work in April.

Production of the Digest was reviewed on March 20 as part of an on-site visit by the DOE project manager, John Shen, and his associates. He was unable to provide guidance at that time concerning topics to be covered in the fourth issue of the Digest. The second issue of the Digest, which included the following articles:

- (i) "Liquid Fuels from Coal by the SRC-II Process,"
- (ii) "Consol Synthetic Fuel Process," and
- (iii) "Fischer-Tropsch Synthesis,"

was distributed during this reporting period.

6.3 Survey of Industrial Coal Conversion Equipment Capabilities

W. R. Williams, T. M. Andress, W. F. Boudreau, W. A. Bush,
D. W. Hatcher, J. R. Horton, W. R. Reed, C. B. Tolliver

6.3.1 Contract Objective

The 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 Division of Fossil Fuel Processing.

6.3.2 Status Summary

Technical Publications has completed editing of the report on mechanical connectors and expansion joints. During April, a camera-ready copy of the report will be prepared and final approvals for publication will be requested, with publication expected in May. Other reports on (1) letdown valves, (2) equipment operating experience, prices, and development programs, and (3) an executive summary are in various stages of review.

An annual report covering FY 1978 survey activities was written and a paper was also prepared for presentation at the 86th National Meeting of AIChE in Houston, Texas. Coauthors are J. L. Powell,* W. R. Williams, T. K. Lau,* and H. T. Jones.* The paper will be presented in the technical session on critical components for synthetic fuel plants.

A detailed agenda for a workshop on critical coal conversion equipment was drafted and presented to L. E. McNeese, ORNL Fossil Energy Program Director. Further workshop planning awaits management decisions expected in early April.

The study of pump system costs is being extended to examine lower pressure applications. These and other survey activities and findings were discussed with John C. Young and Stephen P. Rochereau of International Energy Associates, Limited (Washington, D.C.) on March 7 and with Geoff Kimber and John Whitehead of Stoke Orchard (United Kingdom) on March 19.

6.4 Environmental Controls for Low-Btu Gasification

S. P. N. Singh, M. S. Edwards, J. F. Fisher,
G. R. Peterson, and R. Salmon

6.4.1 Contract Objective

The objective of this project is to evaluate the various environmental control processes that might be used in connection with low-Btu gasification facilities and to determine the economic tradeoffs for various processes and levels of control.

The project is divided into two phases: Phase I consists of Tasks 1 through 5 of the work statement, and covers the preparation of a detailed work plan and the selection of gasification and environmental control processes for use in the study. Phase II consists of Tasks 6

* DOE/FFP, Washington, D.C.

through 8 in the work statement, and covers the collection and analysis of technical and economic data on the various environmental control processes and the preparation and analysis of flowsheets showing overall systems of environmental control processes used with various gasifiers.

6.4.2 Status Summary

DOE/Fossil Energy approval on the two draft reports titled Costs of Environmental Control Processes for Low-Btu Coal Gasification Plants (ORNL-5425), and Evaluation of Eight Environmental Control Systems for Low-Btu Coal Gasification Plants (ORNL-5481) has been received.

Copies of these reports are currently being prepared for distribution for proponent review. In-house editing will take place concurrently and issuance of the final reports is expected in July.

6.5 SRC R&D Assessment

M. S. Edwards, B. R. Rodgers, J. M. Holmes,
W. R. Gambill, T. M. Gilliam

6.5.1 Contract Objective

This project is an intensive, short-term assessment of current research and development activities of importance to the SRC Demonstration Program. The assessment includes acquisition and review of published information, discussions with R&D personnel involved in relevant activities, visits to sites of important R&D activities, monitoring of critical R&D operations, accessing, to the extent possible, the proprietary information of importance to the Program, and cross-matching R&D activities to the technical data of the industrial partners in the Demonstration Program. Based on the assessment of R&D activities against the data needs of the SRC Demonstration Program, recommendations will be formulated, including: priority of activities; adequacy of the R&D program; the need for possible acceleration, extension, or redirection of current activities; and possible new activities required beyond the current program.

6.5.2 Status Summary

The Phase I Report submitted to DOE/Oak Ridge Operations in February was reviewed with the Assessment Program Manager, J. A. Reafsnyder. The expected content of the Interim Phase Report, due June 1, 1979, and our plans for obtaining the necessary information were also discussed.

Team members have been contacting institutions working in areas related to the problems identified in the Phase I Report. The present and potential applicability of such work in support of the SRC Demonstration Plants Project will be described in the Interim Phase Report. Detailed recommendations will be offered for the more significant problem areas. Where necessary, trips are being scheduled to obtain the required input for the Interim Phase assessment. Trips to DOE pilot plants and to prime subcontractor installations are scheduled through DOE/ORO to facilitate overall coordination.

7. PROCESS AND PROGRAM ANALYSIS

R. W. Glass

Process and program analysis studies are being conducted for the DOE Fossil Energy Engineering Economics and Standards Section of the Planning and Systems Engineering Division. 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 In Situ Coal Gasification

M. S. Edwards and W. C. Ulrich

7.1.1 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. During FY 1977, technical and economic evaluations of the linked vertical well process applied to subbituminous coal were addressed. Three alternative end product configurations were considered — electricity, SNG, and syngas. In FY 1978, an evaluation was conducted of an in situ facility for producing gasoline from methanol via the Mobil-M process.

7.1.2 Status Summary

The draft 1977 report, Process Designs and Economic Evaluations for the Linked Vertical Well In Situ Coal Gasification Process, ORNL-5341, and the draft 1978 report, Evaluation of an In Situ Coal Gasification Facility for Producing M-Gasoline via Methanol, ORNL-5439, have been edited. Distribution lists are currently being prepared. Corrections of drawings and figures and final preparation of the reproducible copies will be pursued in April.

7.2 HYGAS Modeling

J. P. Meyer, G. C. Frazier, J. W. Wells, and J. P. Belk

7.2.1 Contract Objective

The objective of this project is to develop a computer model of the HYGAS gasifier.

7.2.2 Status Summary

A copy of the HYGAS draft final report Mathematical Model of the HYGAS Pilot Plant Reactor (ORNL-5475) has already been forwarded to DOE for review and comment, but material to be included in the Appendix was not included. That material has been prepared for transmittal and final revision and publication is expected during the next quarter.

7.3 Liquefaction

R. W. Glass

7.3.1 Contract Objective

The objective of this project is to provide technical and economic evaluation of coal conversion liquefaction processes. Ralph M. Parsons Company is working under subcontract on the project with J. B. O'Hara as Project Manager. Major tasks included in the subcontract are: (1) a Survey of Liquefaction Processes, and (2) a Detailed Review of High Potential Liquefaction Processes.

7.3.2 Status Summary

The revised final draft report for this project, Liquefaction Technology Assessment (ORNL/Sub-7186-30) has been received from Parsons and has been subjected to detailed internal review at ORNL. Copies have also been made available to DOE and comments of both review organizations will be forwarded to Parsons for inclusion in the final report. Issue is expected in 3 to 5 weeks.

7.4 High Btu Gas

R. W. Glass

7.4.1 Contract Objective

This subprogram is being analyzed under subcontract by the Scientific Design Company, Incorporated (SD) with A. S. West as Project Manager. The present work is divided into three phases as follows:

1. The objective of Phase I is to provide technical and economic evaluations of competing processes, concepts and systems for the production of high Btu gas from coal.
2. The objective of Phase II is to monitor and analyze data from the HYGAS Pilot Plant.
3. The objective of Phase III is to perform a technical and economical evaluation of the Battelle Agglomerating Ash Burner Process for the production of medium Btu fuel gas, synthesis gas and hydrogen from coal.

7.4.2 Status Summary

As mentioned in previous progress reports, Phase I activities in this project have resulted in the issue of a final report, Battelle Agglomerating Ash Burner Process for High-Btu Gas Applications, ORNL/Sub-7240/1. Further evaluation of the Battelle process for medium-Btu gas applications (Phase III) has also been completed and suggested changes in the draft report following ORNL staff technical review have been forwarded to SD.

HYGAS pilot plant operations during Test Run No. 78 have been monitored by SD engineers on site and preliminary reports of test results will soon be available. The test objectives were to examine gasification behavior of run-of-mine coal at 500 psig operating pressure over a range of superficial velocity (1.0 to 1.2 ft/sec) utilizing steam feed without nitrogen dilution. Target char conversion was 85%.

Operation of the test was to consist of three phases: Phase 1 duplicating Test No. 74 conditions (3500 lbs char/hr, 5000 lbs steam/hr, and 750 lbs oxygen/hr) with an anticipated char conversion approaching 80%; Phase 2 resulting from an increase of char and oxygen rates (to 4100 and 800-850 lbs/hr, respectively) with maximum SOG zone temperatures approaching 1800°F and char conversion rising to 85%; and Phase 3 resulting when steam flow rate is reduced sufficiently to produce superficial velocities of 1.0 ft/sec in the SOG zone. In Phase 3, the steam-to-char ratio will be maintained constant at the value (1.21) existing during Phase 2 by reduction of char feed rate from 4100 to 3300 lbs/hr. Table 7.4.1 summarizes these conditions.

Test Run No. 78 began on February 10. The test was expected to last only about two weeks, but major damage was discovered in the coal mill shortly after startup and production of milled coal had to be substantially reduced. In addition, the following problems were encountered:

1. Instrument purge system plugged.
2. Slurry leak below the feed slurry tank.
3. Pretreatment quench tower leak.
4. Char cooler and, subsequently, pretreater plugged by mud. (In these cases, both vessels have to be shut down and dug out manually.)
5. Torn screens.
6. Coal mill electrical failure.

The slurry leak, coupled with uncontrollable bed levels in both the slurry dryer and the low temperature reactor, forced termination of the

test on March 11. A post-run inspection was scheduled for March 15 and results will be detailed in the next monthly report. Scheduled startup for Test No. 79 is uncertain as IGT are awaiting completion of a 400 ton coal/char storage system before proceeding.

Table 7.4.1. Test Run No. 78 nominal operating conditions

Feed coal	ROM	ROM	ROM
Net char feed rate, lb/hr	3500	4100	3300
Steam feed, lb/hr			
SOG distributor	3500	3500	2800
Fluidizing distributor	1500	1500	1200
Steam/char weight ratio	1.43	1.22	1.21
Oxygen flow, lb/hr	750	850	800
O ₂ /char weight ratio	.21	.21	0.24
Steam/O ₂ weight ratio	6.67	5.88	5.00
Maximum average temperature, °F	1750	1800	1800
Superficial velocity, ft/sec			
SOG zone	1.2	1.2	1.03
Fluidizing zone	0.3	0.3	0.24
SOG distributor nozzles	83	83	68
Pressure, psig	500	500	500
Char conversions, %	80	85	85

7.5 Direct Combustion

E. C. Fox and T. D. Anderson

7.5.1 Contract objectives

The purpose of this study program is to assist DOE/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 DOE/FE relative to the most promising approaches to increasing the near-term use of coal.

7.5.2 Status summary

The report "Conversion to Coal in the Industrial Sector," ORNL/TM-6131, is being prepared for publication.

7.6 Advanced Power Conversion Systems

J. E. Jones Jr. and A. P. Fraas^a

7.6.1 Contract objective

The objectives of this project are to review selected major advanced power conversion systems and to assess these systems with respect to their basic R&D status.

7.6.2 Status summary

A total of eleven systems or components of systems were evaluated. Draft reports covering all of these topics, an overall summary report, and an executive summary report have been completed and are undergoing final review.

^aConsultant

8. FOSSIL ENERGY ENVIRONMENTAL PROJECT

C. R. Boston

The Fossil Energy Environmental Project provides DOE with program assistance in the performance of environmental assessment functions related to the expansion of fossil energy conversion technologies, performs assigned technical assistance tasks, and conducts programmatic environmental investigations that are critical to the early realization of advanced fossil energy technologies.

8.1 Stored Solids Study

W. J. Boegly, Jr.

Physical and chemical characterization of U-Gas process solid waste and all analytical chemistry determinations on batch and column leachates have been completed. All data have been reported to DOE, and efforts have been made to obtain waste products from a pressurized U-Gas pilot plant run.

A shipment of four 55-gallon drums of Grace-Ebasco process solid waste was received at ORNL. This waste was produced at the Texaco gasifier located in Montebello, CA., with Kentucky #9 used as the feed coal. The shipment consisted of samples of two runs performed under differing operating conditions; the waste from each run was separated into coarse and fine fractions before shipment to ORNL. Physical and chemical characterizations of each fraction of the solid material and batch leaching are being completed. No column leaching has been initiated as yet, pending the verification of the representativeness of the waste samples received from Grace.

Column leaching runs have been completed (20 column volumes) on British Gas/Lurgi process waste and samples of leachate have been sent for analysis. No waste/soil column leaching has been initiated due to the lack of landfill site soils from the proposed demonstration plant site.

Analysis of the factorial coal leaching experiment has been completed and a draft report is under review.

8.2 Technical Assistance

S. G. DeCicco and A. J. Witten

8.2.1 Interaction with demonstration plant contractors

SRC-I and SRC-II - For SRC-I on March 26 an information transfer meeting for members of the FEEP team was held to review the monitoring program, the characteristics of the site and the impacts to be addressed in the EIS.

The principal activity during this month has been establishing a role for ORNL in preparing the EISs for the two SRC demonstration plants. DOE wants comprehensive scientifically sound analyses of the environmental impacts of each project and would like to have ORNL be prepared to defend those analyses.

At a meeting on March 12 DOE/ORO and ORNL derived a plan for proceeding which is subject to DOE-HQ approval. The plan is as follows:

1. DOE-ORO, ORNL, and the environmental subcontractor scope the issues to be covered in the EIS and the relative importance of each issue.
2. ORNL prepares detailed, written impact analyses for all issues deemed critical during the scoping step. This provides DOE & ORNL material for comparison with the subcontractor's analyses.
3. For descriptive sections, ORNL would simply review the contractor's work and provide written comments to DOE. This would eliminate redundant effort on "boiler-plate" items.
4. ORNL would be listed as the principal contributor to the EIS with the subcontractor as the supporting contributor.

DOE sees this arrangement as a means of saving time (as no Environmental Report would be generated), and as a means of arriving at the most comprehensive document. This type of arrangement is being recommended in a letter from ORO to HQ being drafted at this time.

Grace/Ebasco - A meeting was held at DOE/CH on March 16 to discuss with DOE the Notice of Intent and Implementation Plan. A scoping meeting is tentatively scheduled for May 16-17, 1979 in the Evansville, Indiana, area. ORNL is assisting DOE in the preparation of the Implementation Plan.

MLGW - A meeting was held at DOE/CH on March 16 to discuss the Notice of Intent and Implementation Plan. A scoping meeting tentatively was scheduled for June 6-7, 1979 in Memphis. ORNL will assist DOE in the preparation of the Implementation Plan.

The Site Evaluation Report was received and is currently being reviewed by the task group.

CONOCO - Deficiencies with the baseline monitoring program have been established. Work is proceeding on resolving these problems.

ICGG - A number of Draft ER sections have been received and these have been distributed to the team for comment.

8.3 Gasification Test Facility (GTF)

S. G. DeCicco

During this month we completed the final tasks in preparation for an environmental program for the GTF project. The commencement of all environmental work now awaits DOE authorization of the project.

On March 2, DOE/CH staff visited ORNL to discuss requirements of the new CEQ regulations to implement the National Environmental Policy Act (NEPA). An implementation plan for carrying out the regulations relative to the GTF project was discussed in considerable depth. The discussion included the preparation of a Notice of Intent to prepare an EIS, the public scoping process, treatment of alternatives, choice of a waste disposal site (as yet unnamed), baseline environmental monitoring, the availability of reconnaissance information at alternate sites, ORNL's role in the overall environmental program for GTF, the schedule impact of collecting or missing the spring 1979 monitoring data; and the EIS. This information transfer should help DOE-CH to carry out the GTF project in an environmentally conscious manner.

On March 7, ORNL team members visited the Chicago site. Although the site was covered with snow to a depth of 6 to 30 inches, we were able to observe all the surrounding surface water bodies at their high-flow stage. We also visited nearby residential communities, the water intake location, and all public roads bordering the site.

On March 13, ORNL team members joined DOE/CH for a meeting with Radian Corporation at their offices in Austin, Texas. At this meeting DOE-CH proposed the roles and responsibilities for ORNL and Radian. Although Radian will be under contract with DOE, their technical direction will come from ORNL. The meeting was devoted largely to formulating a spring baseline environmental monitoring

program for the Chicago site. The program was developed in a conservative fashion, as it precedes the public scoping process, the selection of a waste disposal site, and the specification of processes.

Later in the month, at the request of DOE-CH, ORNL developed a list of siting criteria that can help DOE select a waste disposal site in accordance with the Resource Conservation and Recovery Act (RCRA).

8.4 Processing of Coal Conversion Wastes for Disposal and Resource Recovery

R. M. Canon, C. Jones, Jr., and J. S. Watson

This program develops and evaluates processes for removing and/or fixing hazardous metals and recovering useful materials from solid coal conversion wastes. The principal objective is to reduce the hazard and cost of solid waste disposal by removing enough hazardous metals that the residue is nonhazardous to the Resource Conservation and Recovery Act regulations. However, significant economic benefits can be achieved if the processes can recover significant quantities of useful and salable minerals of Al, Fe, and Ti. Current activities are focused upon wastes from SRC-II and the leading gasification process(es).

Work Accomplished

Initial experiments have been performed with ash from COGAS process and from Slagging Lurgi. Tests with COGAS include leaching with sulfuric acid and a sinter-leach operation with CaSO_4 and CaCO_3 . Samples have been sent for analysis and preliminary results indicate that this material is more inert than fly ash. Studies of the slagging Lurgi waste have just begun and no analyses are available at this time. Qualitative observations indicate that this material is considerably more reactive than COGAS ash. Experiments utilizing the waste from SRC-II will be initiated in the near future.

9. MAGNETIC PREPARATION OF DRY CRUSHED COAL

E. C. Hise and A. S. Holman

9.1 Objective

The objective of this program is to develop, demonstrate, and bring to commercial viability technology for the removal of pyrite and ash-forming minerals from dry crushed coal by either or both processes of high-gradient magnetic separation and open-gradient magnetic separation.

9.2 Status Summary

Delivery of the superconducting laboratory magnet is expected in mid-May. It has a 3 1/2-in. diam warm bore, a 12-in. long magnet, and can be operated as a single solenoid to develop a 6-in. long uniform field of up to 60 kilo Gauss, or as opposing solenoids to develop gradients of up to 5 kilo Gauss per cm. The test loop design is complete, and most of the components are on hand or on order. Floor space with the required headroom has been obtained and will be cleared for the installation. The initial testing will be in the high-gradient magnetic separation (HGMS) mode to extend the range of investigations performed at Sala. Open-gradient magnetic separation (OGMS) is being mathematically modelled to seek an operating mode and configuration that will exert on a free-falling particle forces comparable to those attained in our present small laboratory magnet. Promising configurations will be constructed and tested.

We have now demonstrated in our present small laboratory magnet OGMS of coal in the free-fall mode. Figure 9.1 shows the machine set up for this mode of operation. In Figs. 9.2 and 9.3, the flow splitter and buckets have been removed to show the coal exiting the magnet pole pieces. The falling coal stream is continuous, but only the illuminated portion is visible. The grid divisions are 0.1 in. In Fig. 9.2, the magnet is off, and the stream is falling vertically with some scatter due to air drag and particle collisions. In Fig. 9.3, the magnet is on, and the force exerted by the shaped magnetic field deflects the particles from vertical fall as a function of their positive or negative magnetic susceptibility spreading the stream into a spectrum about 1.4 in. wide. The bulk of the stream is relatively clean coal having a negative susceptibility and is deflected down gradient (to the left) 0.2 to 0.3 in., thus accomplishing a diamagnetic separation. The chemical analyses from a preliminary series of separations performed in this fashion indicate that free-fall OGMS has the potential to achieve separations comparable to specific gravity or vibrating tray OGMS.

Figure 9.1. Free-Fall Open-Gradient Magnetic Separation.

Figure 9.2. Free-Fall Separation, Magnet off.

Figure 9.3. Free-Fall Separation, Magnet on.

The proposal for the demonstration of continuous separation at 1 ton/hr has been received from Sala and is being processed. It is anticipated that a contract can be completed by May 1, with initial testing beginning August 1.

TVA-Chattanooga has assigned Mr. Steve Smith to our laboratory for several months to learn separation techniques and to then evaluate the degree of mineral liberation achieved by chemical comminution as opposed to mechanical crushing. We have been supplied with 50-lb samples each of a chemically comminuted coal and the raw coal feed. Following the separability analyses of these samples, TVA will select several coals of major importance to their system for chemical comminution and analysis.

A narrated, color motion picture depicting the objectives of the coal preparation program, the several experimental techniques used here and at Sala, and quantitative analyses of the separation results attained are now being filmed. It is expected to be about 15 minutes long and to be available for viewing in early May.

10. FBC INDUSTRIAL APPLICATIONS PROJECT SURVEY

K. K. Chipley, N. W. Durfee,
and M. E. Lackey

10.1 Objective

Part of Fossil Energy decentralization includes the transfer of FBC industrial applications projects to Morgantown Energy Technology Center (METC). A review team has been organized by METC to provide a snapshot status with respect to cost, schedule, and technical problems of eight projects being transferred. After reviewing background information of each project, the team visits the contractor site for several days of intensive interaction with the contractor. A report of the findings of each project is then written and issued to METC.

10.2 Status summary

The review team has had briefing sessions in Morgantown on most of the projects and has made site reviews of Georgetown University in Washington D.C., Exxon in Florham Park, New Jersey, and Combustion Engineering in Windsor, Connecticut. In March, two different trips were made to Curtiss-Wright to review their PFB and anthracite culm AFB projects. Battelle will be reviewed in April, and Wilksboro and Fluidyne will be reviewed in May.

11. TENNESSEE VALLEY AUTHORITY (TVA) FLUIDIZED BED COMBUSTION (FBC) DEMONSTRATION PLANT PROGRAM TECHNICAL SUPPORT

J. E. Jones Jr.

Tennessee Valley Authority has assumed a lead role in the demonstration of FBC technology for application in large utility boilers. ORNL will provide technical support and services to TVA in FBC systems. This work is to support TVA Energy Research's objective to develop FBC systems for utility electric power generation which will burn high sulfur coal and meet environmental emission standards.

TVA will be the lead agency in this work and will reimburse DOE for the work to be performed by ORNL. This work is to be conducted by ORNL under the terms and conditions of the Interagency Agreement between TVA, DOE, and ORNL regarding support for FBC research (reference: Agreement TV48296A, Subagreement 5).

11.1 AFBC Technology Support - Task 2

M. Siman-Tov and J. E. Jones Jr.

11.1.1 Contract objective

The objective of this program is to provide technical support of a general nature in FBC systems and respond to specific requests from TVA personnel. Such requests may include reviews, assessments, participation in TVA tasks, and similar activities.

11.1.2 Status summary

TVA personnel have visited ORNL for general briefings on the TVA-ORNL AFBC activities. Task 2 was discussed with Joe Castleberry who was designated as the TVA contact point for this task. No new subtasks have been requested or outlined during this month.

11.2 4 x 4 Cold Flow Model - Task 3

R. S. Holcomb and M. E. Lackey

11.2.1 Contract Objective

The objective of this task is to experimentally investigate slumping of a portion of a fluidized bed using a sub-scale cold flow model. The scope of work includes design and minor modification of the 4 x 4 cold flow model for slumping and refluidization tests and conducting bed slumping tests.

11.2.2 Status Summary

Design and Modifications - The fluidizing air plenum will be redesigned so that the air can be shut off to a portion of the 4×4 bed with the air flow continuing to the other portion. A new simulated tube bundle will be designed for the slumping tests. The design will be based on a $1/4$ scale factor - i.e., the tube diameter, bed depth, and fluidizing velocity will be $1/4$ that of the full-scale FBC boiler. The cold flow model will be modified to incorporate the design changes.

Testing - Tests will be conducted to investigate the effects of slumping a portion of the bed and continuing operation of the remainder. Observations will be made to study mixing between the active and slumped portions, fluidizing air bypass through the slumped section, elutriation from the fluidized section and deposit in the slumped section, and maximum buildup of the slumped bed. The fluidizing air will then be turned on to the slumped portion, and the action of the two sections will be studied during refluidization. These tests will be done over a range of fluidizing velocities from 1 to 2 ft/sec and bed depths from 1 to 1.5 ft to represent scale studies of values four times as large. Other operating data will be obtained incidental to these tests.

Progress to Date - The shop fabrication of new air piping components was completed this month. The existing inlet air piping was removed and installation of the new piping is 50% complete. The partition has been installed in the air plenum. The drawing for the new mockup tube bundle was completed, and the order was sent to the shop.

It is expected that the piping installation will be completed and the mockup tube bundle will be fabricated before the end of next month.

11.3 AFBC Modeling and Simulation - Task 4

M. Siman-Tov and J. W. Wells

11.3.1 Contract objective

The objectives of this program are to develop a simple steady-state model for conceptual design of the main cell and carbon burn-up cell and to incorporate in this model the ability to predict trends in bed performance under various feed and operating parameters.

11.3.2 Status summary

During this month, the heat transfer coefficient calculation package was successfully run in the modular AFBC simulation. Two cases were studied incorporating two different equipment arrangements in cells. The results are now being analyzed.

Work was continued on the kinetic modeling of the cell. An effort is being made to obtain two major AFBC models: MIT's model and Wen's model (West Virginia State University). A phone conversation was held with Professor Tung of MIT. He stated that the MIT model was not ready at present for release, but when it becomes available, we would receive the model. Also, conversations were held with Professor Wen of West Virginia State University. As a result, Professor Wen has promised to send his model and the necessary documentation. It is hoped that this model will be received in the next month.

In-house development of the combustion efficiency model continued. The approach is based on MIT's model which is not yet available. During this month, the present code was debugged and used to predict the char particle size distribution in the bed and to close the material balance about the bed.

11.4 AFBC Bench Scale Model — Task 5

R. S. Holcomb, R. H. Guymon, and G. P. Zimmerman

11.4.1 Contract Objective

The objective of this task is to experimentally investigate heat transfer, sulfur capture, carbon loss, and combustion of recycle carbon using the ORNL AFBC bench scale combustor.

11.4.2 Status Summary

Test Facility Description - The combustor is 10-in. ID and about 15-ft tall. The combustor is designed for burning 10 to 30 lb/hr of coal and is equipped for limestone addition. The system is designed to operate with a bed fluidizing velocity in the range of 4 to 10 ft/sec and bed temperatures up to 1600°F. The bed is cooled by compressed air flowing through 0.5 in. OD tubes immersed in the bed.

Test Program - Heat transfer tests will be done for 1000 and 1900 μm mean size limestone over the fluidizing velocity range of 4 to 10 ft/sec at bed temperatures of 1400–1600°F. Sulfur capture and carbon loss tests will be run for selected coals and limestones of interest to TVA for several values of Ca/S over a fluidizing velocity and temperature range similar to that for heat transfer. Tests to investigate the combustion of recycle char removed by the cyclone separator will be run for various operating conditions.

Progress to Date - Heat transfer tests with 1900 μm limestone were completed during the first part of this month. Heat transfer coefficients from the bed to the outside surface of the cooling tubes were calculated from the measured data. The two bed heat exchanger tube bundles, lower and upper, were analyzed separately. An overall heat transfer coefficient

was calculated from the air flow and temperature data for each of the bundles. The heat transfer coefficient inside the tubes was calculated from the air flow rate and physical properties of the air at the measured temperatures using the equation:

$$\frac{h_i D_i}{k_f} = \frac{0.034}{(L/D_i)^{0.1}} Re_f^{0.8} Pr_f^{0.8}$$

where the air physical properties are evaluated at the boundary film temperature, given by the average of the bulk air and tube wall temperatures.

The outside, or bedside, heat transfer coefficient was then calculated from the difference between the inside heat transfer coefficient and the overall heat transfer coefficient taking into account the tube wall conductance. The bedside heat transfer coefficient for the lower tube bundle is shown in Fig. 1. There is considerable scatter in the data among the different runs, but there appears to be no trend with fluidizing velocity over the range tested. Most of the results lie in the range of 75-80 Btu/hr-ft²-°F.

The results for the upper tube bundle are still in question. These data are not in good agreement with those for the lower bundle. The temperatures indicated for the air at the inlet to the upper bundle appear to be unaccountably higher than those for the lower bundle. This fact places doubt on the heat balance for the upper bundle and, consequently, the heat transfer coefficients are questionable.

Analysis of the earlier test runs with the 1000 μ m limestone yielded inconsistent results that indicated that some of the data were taken before steady state conditions were established. Consequently, a second series of heat transfer tests were run with 1000 μ m limestone following the completion of the 1900 μ m limestone tests.

The results of the second series of heat transfer tests with the finer limestone is shown for the lower air heat exchanger tube bundle in Fig. 2. The bedside heat transfer coefficient was calculated to be in the range of 87-93 Btu/hr-ft²-°F for most of the test runs. No variation with fluidizing velocity was observed over the range tested, 2.5 to 7 ft/sec. The heat transfer coefficients are somewhat higher for this particle size than those observed for the larger limestone, as had been expected from results of previous investigators. In both cases, the heat transfer coefficient may tend to be higher in the lower part of the bed than the bed average because of an entrance effect on the first few rows of tubes.

AFBC BENCH TEST
Coal Combustion/Heat Transfer
Franklin Limestone, Size 6x16 mesh (1900 μm)

ORNL-DWG 79-5422 ETD

Figure 11.1. Heat transfer coefficients from fluidized bed to outer tube wall for the lower tube bundle with 6x16 mesh, 1900 μm mean particle size, limestone.

AFBC BENCH TEST
Coal Combustion/Heat Transfer
Franklin Limestone, Size 12x30 mesh (1000 μm)

ORNL-DWG 79-5423 ETD

Figure 11.2. Heat transfer coefficients from fluidized bed to outer tube wall for the lower tube bundle with 6x16 mesh, 1900 μm mean particle size, limestone.

As was the case for the larger limestone, the heat transfer results for the upper tube bundle are questionable for these runs because of the unaccountably high inlet air temperatures indicated for the upper bundle. The cause for this high indicated temperature will be investigated, and steps will be taken to correct this problem and resolve the heat transfer results for the upper bundle.

The next phase of the test program will be primarily concerned with sulfur capture and carbon loss tests. An SO₂ analyzer has been secured on a loan basis. It will be used on an interim basis until the analyzer that has been ordered for this system is delivered.

Drawings are being prepared for the screw feeder to provide continuous limestone addition for the sulfur capture tests. It is expected that the feeder will be installed by the end of April.

11.5 Assessment of the State-of-the-Art of PFBC Systems - Task 6

R. L. Graves, M. E. Lackey, and A. P. Fraas^a

11.5.1 Contract objective

The purpose of this program is to provide TVA with an assessment and overview of the state-of-the-art for PFBC systems and their associated components.

11.5.2 Status summary

Combustion Power Company in Menlo Park, California, was visited to review their granular bed filter development program. They are currently testing an updated design of a screenless granular bed filter and are obtaining particulate removal efficiencies of 95+%. A trip report and sample data have been forwarded to TVA.

Development of the PFBC combined cycle model has been started. Initial runs to characterize the basic steam power cycle are expected to be in progress during April.

The preliminary PFBC report (ORNL/TM-6633) has obtained reviewer's signatures and will be released upon receipt of the TVA distribution list.

^a Consultant

11.6 Analytical Support and Alternate Design Concepts Evaluation - Task 7

E. C. Fox

11.6.1 Contract objective

The objectives of this task are to assist TVA in determining the design parameters which are critical to an effective AFBC system from the standpoints of efficiency and cost and to provide direction as to better design options.

11.6.2 Status summary

A brief review of fluidized bed combustor design correlations is being performed. An initial cost model is being formulated to evaluate the design parameters.

11.7 AFBC Technical Source Book and R&D Evaluation - Task 8

M. Siman-Tov and A. A. Khan

11.7.1 Contract objective

The objectives of this program are to develop a single comprehensive source book of technical data for design procedures and evaluation of AFBC facilities and programs, to review and evaluate existing and proposed AFBC facilities to perform research and development for TVA, and to interpret and translate results of test studies performed for TVA and further the knowledge in AFBC research and development activities.

11.7.2 Status summary

AFBC literature assembly and review were continued. The design philosophy of Babcock and Wilcox was studied in detail. A meeting with Henry Withers of TVA resulted in the following emphasis to be made.

1. Contents would be brief but contain information useful to the designer.
2. In recognition of the fact that it is an expanding task, a few topics will be covered in detail so that they would serve as examples as to what is to follow.

In view of this emphasis, the rest of the month was spent in collecting, reviewing, and summarizing design information.

For next month, the design information collected will be written up in outline form. This will be expanded and modified later on.

11.8 Materials Support for TVA Pilot and Demonstration AFBC Plants - Task 9

T. G. Godfrey and R. A. Bradley

11.8.1 Contract objective

ORNL proposes to assist TVA technically in the materials area. The unique part of an AFBC is the fluidized bed combustor and its associated hardware, since the balance of the plant closely resembles a conventional pulverized-coal supply system. The principal areas of concern are the in-bed heat-exchanger tubes and hangers, the air distributor, side walls, coal feed lines and nozzles, spent-bed removal hardware, and cyclones for separating elutriated material.

11.8.2 Status summary

As part of our objective, we are to critically evaluate all information pertaining to alloy performance in the AFBC environment with particular emphasis on heat exchangers (boiler) and structural (support) materials under TVA 200 Mw conditions. This effort will serve to identify those areas where data are lacking or are in conflict and to propose requisite experiments, both in-house and at outside facilities.

As a result of several meetings with TVA personnel and in light of the above assessment, ORNL is formulating a program to investigate the corrosion potential on boiler materials of the AFBC environment that obtains during bed slumping. Muffle furnace-type experiments under a range of $\text{CaO-SO}_2\text{-O}_2$ conditions on alloy samples of various surface conditions (CaSO_4 scale, oxide scale, and no scale) will be conducted for moderate times ($\sim 100\text{h}$) in order to assess general effects and to direct the follow-on work.

11.9 Dynamic Modeling of the TVA Fluidized Bed Combustion Demo Plant - Task 10

N. C. Bradley and O. L. Smith

11.9.1 Contract objective

The objective of this task is to provide dynamic modeling and transient systems analysis directly applicable to the TVA pilot plant. As an important benefit, the information obtainable from a dynamic model would help in the specification of such features as function, range, and type of instrumentation required to provide the desired plant operating characteristics.

11.9.2 Status summary

The ORNL computer library routine HYBRDL, which was being used in the TVA pilot plant model to solve a coupled set of algebraic equations, proved to be generally inadequate for the types of problems posed by the model. Because of peculiarities of HYBRDL, the routine lost its way during the iteration process and failed to converge properly. This reflects not so much a complexity of the equations as weakness of the numerical procedures in HYBRDL. It was necessary therefore to seek an alternate method for solving the algebraic equations. There are 44 equations in the model, defining new equilibrium conditions following a power plant transient. After considerable manipulation of the equations, it was possible to reduce the number from 44 elementary equations to three relatively more complex ones. It should be possible in a short period of time to devise a simple yet powerful triple iteration scheme to solve these. Development is in progress.

12. COAL COGENERATION/DISTRICT HEATING PLANT ASSESSMENT

M. A. Karnitz and R. L. Graves

12.1 Objective

The objective of this work is to provide the Fossil Fuel Utilization Division of DOE with an evaluation of the coal-fired closed cycle gas turbine as a cogeneration power plant specifically for district heating in the Minneapolis-St. Paul area. This entails a preliminary design study, including a cost estimate. The design study is a cooperative effort between ORNL, United Engineers and Constructors (UE&C), and Northern States Power (NSP). Design of an extraction steam system for the same application is being carried out simultaneously by UE&C and will allow a comparative evaluation of both cogeneration plants. These design studies are part of a considerably larger program involving other divisions of DOE with the objective of evaluating district heating in Minneapolis-St. Paul.

12.2 Status summary

Northern States Power Company is negotiating a contract with United Engineers and Constructors. We did not anticipate this delay; however, we did expect UE&C to start work in early April. NSP has completed the task of investigating the siting of new units at existing facilities and has started the task of investigating new sites near the twin cities.

The cogeneration power plant model, consisting of a combined closed-cycle gas turbine and steam bottoming cycle, is complete. Minor changes in component parameters and flow rates have been checked for their influence on the design point heat rate. First results indicate only a small improvement in overall efficiency as compared to conventional plants.

13. CHEMICAL RESEARCH AND DEVELOPMENT

M. L. Poutsma

13.1 Chemistry and Structure of Coal

M. L. Poutsma

Last month we described the primary products from pyrolysis of bibenzyl (1) at $\sim 400^\circ\text{C}$ and 1 atm pressure to be compounds 2-5. We stressed the need to limit conversion levels to a few percent to obtain the distribution among these primary products because products 4 and especially 5 are thermally more labile than bibenzyl itself. Preparative glpc has now given concentrated fractions from which we hope to get nmr and ms information to confirm the structural assignments of 4 and 5; these results will be reported next month. However, we now have some evidence for two additional primary products which will be pursued. One, of glpc retention time very similar to bibenzyl, appears to be significant only in liquid-phase runs (see below). The second, of retention time between 4 and 5, appears in significant amounts only in the lowest conversion ($\sim 1\%$) runs and hence may be even more unstable than 5.

The minimum free-radical reaction network to rationalize the products identified to date was outlined last month:

The major external variables are temperature, which should have its greatest impact on k_1 (the process with the largest E_a), and the pressure

of 1. The effects of pressure and phase at $366 \pm 1^\circ\text{C}$ are now shown in Table 13.1 for 8 runs at 1.5-2.5% conversion and 3 additional runs at 1% conversion. Because our analytical procedures still appear somewhat less precise than we would like, especially for the most volatile product 2, we have not attempted any complete solution of the complex reaction scheme; however, certain semiquantitative conclusions are noteworthy:

- (1) There is no discontinuity in passing from vapor phase reactions to those largely in the liquid phase, except for the minor "extra" product mentioned above. Such behavior is supportive of free radical rather than ionic intermediates.
- (2) The overall kinetic dependence on bibenzyl is close to first-order (conversion at constant time is relatively independent of pressure). This must result from some compensation among terms in the complex rate law resulting from the reaction scheme.
- (3) The major effect on product distribution of increasing pressure of 1 is a smooth decrease in 4/5. This behavior is qualitatively in accord with the proposed scheme: increased pressure of 1 will increasingly convert radical 6 into radical 7 by step 2. Thus product formation via step 5 to give 7 will increase compared with step 4 to give 6. In the neat liquid, steps 3 and 4 become negligible.

When product 4 becomes negligible in the predominantly liquid-phase runs, the ratio 5/3 should approach the value of $g/(1-g)$, the combination: disproportionation ratio for radical 7. In the other extreme of very low pressures of (1) (which we cannot approach very closely with present equipment), the ratio 4/3 should approach $f/(1-f)$, the cross combination: disproportionation ratio for radicals 6 and 7. A least-squares treatment between these extremes for the data shown at 5.5 hr gave $g/(1-g) \approx 1.6$ and $f/(1-f) \approx 2.9$. However, these values are only moderately satisfying because the ratio $(\underline{4} + \underline{5})/\underline{3}$ does not span the extremes smoothly, suggestive of an analytical problem or an incomplete reaction scheme. Also, they are both lower limits since even at these low conversions (1.5-2.5%), some of the initially formed 4 and 5 will have already been lost, probably to form "excess" 3. In fact, note that $g/(1-g)$ from the runs at 1% conversion appears to be ≈ 2.4 instead of 1.6. In any case however, the combination: disproportionation ratio for radical 7 at 316°C appears significantly lower than that reported (1) at 118°C : 8.9. In decomposing coal, such disproportionation of benzylic radicals formed by hydrogen transfer from polymethylene linking units would introduce olefinic unsaturation and associated reactivity into the coal backbone.

Table 13.1

Product Distributions from Pyrolysis of Bibenzyl (1)
as a Function of Pressure of 1

Vapor Phase Pressure (atm) ^a	Phase Distribution of <u>1</u> (%) ^b		Conversion (%)	Product Distribution, "Equivalents of <u>1</u> "				Product Ratios, molar	
	Vapor	Liquid		<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>4/5</u>	(<u>4</u> + <u>5</u>)/ <u>3</u>
<u>366 ± 1°C; 5.5 hr</u>									
0.21	100	0	2.3	0.41	0.14	0.24 ₅	0.20	1.63	1.85
0.64	100	0	2.4	0.37	0.13	0.18 ₅	0.31 ₅	0.77	2.19
1.31	100	0	2.3	0.31 ₅	0.12	0.12	0.44 ₅	0.36	2.51
1.82	100	0	2.6	0.37	0.11 ₅	0.11 ₅	0.40	0.39	2.42
4.16	100	0	2.5	0.39	0.17 ₅	0.10	0.33 ₅	0.39	1.33
5.6 ^b	68	32	2.3	0.43 ₅	0.17	0.05 ₅	0.34	0.20	1.25
5.6	17	83	1.8	0.38 ₅	0.15 ₅	0.03	0.42 ₅	0.10	0.49
5.6	<10	>90	1.6	0.42	0.13 ₅	0.02 ₅	0.42	0.08	1.70
<u>366 ± 1°C; 3.0 hr</u>									
0.10	100	0	1.0	0.30	0.11 ₅	0.24	0.34 ₅	0.93	2.90
0.34	100	0	0.9	0.17 ₅	0.12	0.19	0.51 ₅	0.49	3.18
5.6	30	70	0.9	0.34 ₅	0.11 ₅	0.01 ₅	0.52	0.04	2.35

^aPressure calculated from ideal gas law applied to amount of 1 charged to tube of known volume.

^bCalculated from a vapor pressure of 1 at 366°C of 5.6 atm; extrapolated from published data at lower temperatures.

13.2 References for Section 13

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