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

L. E. McNeese

MASTER

**OPERATED BY
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FOSSIL ENERGY PROGRAM
PROGRESS REPORT FOR OCTOBER 1979

L. E. McNeese
Program Director

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FOSSIL ENERGY PROGRAM REPORT FOR OCTOBER 1979

ABSTRACT

This report - the sixty-third 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, chemical research and development, and technical support to major liquefaction projects.

1. Summary

L. E. McNeese

Highlights of our progress in October are as follows:

Coal Conversion Development - Installation of the gamma radiation liquid density instrument in the Coal Liquids Flow System was completed and operational check-out is in progress. Measurements will be made on Wilsonville recycle solvent and on 35 wt % coal-solvent slurry from 450 K. to 700 K. The trifluoroacetic acid-hydrogen peroxide oxidation method for coal analysis was applied to the pyridine-soluble and pyridine-insoluble material formed during the liquefaction of Wyodak coal with phenol. The appearance of saturated cyclic compounds in the liquified material, coupled with the loss of nearly all the small aliphatic components, shows that the liquefaction process alters dramatically the aliphatic structure of coal.

Chemical research and development - The major final products from thermolysis of pure 1-naphthol at 400°C are dinaphtho[1,2-b; 2',1'-d]-furan, naphthalene, and water. The product distribution at low conversion is markedly different. The mechanism and generality of this condensation-hydrogen redistribution reaction of phenols will be studied further because of its implications for coal conversion. A new project to elucidate the role of olefins as reaction intermediates during Fischer-Tropsch reactions has been initiated.

Materials Engineering - The study on hydrogen attack in pressure vessel steels continued. Activities this month concentrated on modifications to the autoclave used for hydrogen exposure. In the task on welding and cladding development, work was initiated to develop procedures for welding modified 9 Cr-1 Mo alloy to an austenitic stainless steel in preparation for fabricating a test assembly for insertion into a TVA boiler. The examination of AFBC heat exchanger materials exposed in the Fluidyne AFBC continued, but no new information to explain the severe sulfidation-oxidation corrosion of the type 316 stainless steel tube reported previously was found. In the failure prevention and analysis task, the examination of materials from the fractionation area of SRC plants to determine the cause of the excessive corrosion continued. Attempts are also being made to identify the corrodent in the fractionation column feed. The study of materials for use in the regenerator and condenser vessels of the Zinc Chloride Liquefaction Process continued. During the thermal checkout of the quartz loop, the loop plugged and then cracked, possibly due to degradation of the quartz because of water in the system. A second loop was modified to eliminate the plugging problem and system checkout is again under way. In the task to develop materials to resist stress-corrosion cracking in coal liquefaction pilot plants, about 100 U-bend specimens are under exposure in the Wilsonville and Ft. Lewis SRC pilot plants. Final checkout of the autoclaves for use in laboratory exposure tests is nearly complete. In the program to develop a modified 9 Cr-1 Mo structural steel, the six ingots from two 14 Mg heats were delivered to ORNL. These ingots are waiting shipment for fabrication. Preliminary mechanical property data on these heats is reported. In the ceramic recuperator task, the 500-h test of candidate structural ceramics at 1100 to 1250°C was completed. Post-test analyses will begin following furnace cool down and disassembly. A 200-h exposure of pressurized SiC heat exchanger tubes to the products of combustion of coal-oil mixtures was initiated at Hague International.

Component and Process Evaluation Studies - The final report for the Survey of Industrial Capability for Coal Handling (ORNL/TM-6929) has been completed in draft form and submitted to DOE. A seed money proposal was approved for a bench scale system designed to simulate pressure letdown of a coal liquefaction plant slurry product from the dissolvers. Support for the H-Coal Materials and Technology Task Force continued and included trips to the H-Coal Process Development Unit at Trenton, New Jersey; the Hydrocarbon Research Inc. offices at Lawrenceville, New Jersey; and the SRC pilot plant at Ft. Lewis, Washington. A new project in support of the Economic Regulatory Administration is being defined. It is concerned with the conversion of power plants from oil to coal in accordance with the Fuel Use Act. In the Performance Assurance study, lists of critical items common to the H-Coal and SRC projects are being prepared to expedite selection of a critical system to be used as the basis for a generic Failure Modes and Effects Analysis.

Process and Program Analysis - This month we published report ORNL-5558, A Review of the Badger Report FE-2416-24, Conceptual Design of a Coal to Methanol Commercial Plant, February 1978. The report gives a review of the technology and economics of the proposed plant and a critical assessment of the Badger-proposed program for concurrent development and construction.

Fossil Energy Environmental Project - In the Stored Solids Study, soil samples were obtained from the proposed CONOCO site in Noble County, Ohio. The first continuous-flow leaching column experiment was completed. In the Resource Recovery work, results of leaching three gasification wastes with hydrochloric acid at ambient temperature are reported.

Work is underway on EIS preparation for all six demonstration projects. Draft Environmental Reports or their equivalent have been received from the industrial partners for five of the projects.

Coal Preparation and Waste Utilization - Sala Magnetic has received 25 tons of TVA coal for crushing and classification. Pennsylvania Power and Light has agreed to supply another coal. Powell Construction company is continuing their design study and economic analysis, with the addition of a wet magnetic circuit to the study. Final installation of the superconducting magnet is now in progress. It is expected that we will be able to incorporate the solenoid calculation into our trajectory simulation during the coming month. A review has begun on a complete state-of-the-art assessment of coal preparation plant automation. E. C. Hise attended the Coal Conference and Expo in Louisville, Kentucky, October 23-25. John Thomas toured the United Coal Companies, Number Eight, coal preparation plant, October 16.

Atmospheric Fluidized Bed Coal Combustor for Cogeneration (AFBCCC) - The revised draft of the work statement for the subcontract was accepted by Westinghouse and Babcock and Wilcox. The completion of the subcontract package has been delayed pending the receipt of Government cost audits of the subcontractors. A meeting was held at DOE in Germantown on October 30, to discuss commercialization of CCC systems.

Tennessee Valley Authority (TVA) Fluidized Bed Combustion (FBC) Demonstration Plant Program Technical Support - In the 4 x 4 cold flow model, task 3, tests were conducted to investigate the effects of slumping a portion of the bed while continuing operation of the remainder. Observations were 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 1/4-scale-factor slumping tests were completed at the end of last month. The data are being analyzed and a report is in preparation.

The AFBC modeling and simulation, Task 4, has successfully run a limestone-ash elutriation and attrition code. Also, the combustion code was developed and is now running.

Work has begun on characterization of TVA limestone "A" from Three Rivers Company in Smithland, Kentucky, with the AFBC bench scale combustor. Room temperature fluidization tests were performed after blowing the green limestone placed in the bed at 1.5 gm/sec (5 ft/sec) for eight hours. Approximately 16% of the initial charge of limestone was elutriated from the bed. A cursory sieve analysis yielded a 200 μ m top size for the elutriated material. This loss of material resulted in a shift of the harmonic mean particle size to 724 μ m. The median size changed to 1124 μ m. A minimum fluidization velocity of 0.55 m/sec (1.8 ft/sec) was obtained for this material.

Work on the final report on PFBC systems is continuing. Representatives from General Electric visited the Engineering Technology Division to discuss PFBC systems and to provide an update on the 1000-hr turbine materials tests at Leatherhead. The 1000-hr test is near completion and the results indicate satisfactory particulate removal with a combination of conventional cyclones and the G.E. electrostatically augmented cyclone. Deposits on the cascade were, for the most part, soft and apparently removable.

In the analytical support and alternate design concepts evaluation, Task 7, the most recent calculations still show that deep beds may offer significant advantages over shallow beds, especially when the combustion efficiency can be increased to the point where recycle and carbon burnup beds are unnecessary. The major uncertainty here is the effect of higher gas residence time on combustion efficiency. The correlation used in this study assumes that combustion efficiency is a strong function of the gas residence time. If a significant fraction of the coal is burned above or near the top of the bed, this assumption is highly questionable.

The draft of the fluidization section of the source book is undergoing final revision before being presented to TVA.

A control system was added to the dynamic model of the pilot plant. The major control loops included are firing rate, secondary (and primary) air control, draft control, steam temperature control, and throttle valve control. The control systems shown in the vendors' pilot plant proposals appear to simulate load following by manually positioning the throttle valve. In a sense, this is the reverse of true load following, since the condenser load (air flow) is made to follow the valve setting (steam flow). The control action used in the model allows variation of condenser air flow to be the load change stimulus, which the throttle valve and other controllers then follow.

Construction of the basic coal feed test facility is nearing completion. Two long radius bend pipe sections ($R/D = 12$) are being fabricated for use during the first four test series. Calibration tests will be conducted for the rotary feeder in order to determine the maximum inlet pipe size, surface moisture content, and coal flow rate. The rolling blade valve feeder which is on order has the potential for operation over a greater range of test conditions.

Coal Cogeneration/District Heating Plant Assessment - A delegation affiliated with the St. Paul project traveled to Sweden to tour the Swedish hot water district heating systems (October 13 - 27). Sweden has 66 hot water systems which serve 25% of the country's heating demand. The contract procedure was initiated to do a study on the retrofitting of Northern States Power Company's Prairie Island Nuclear Power Plant to a cogeneration unit for district heating. The performance comparison between the recuperated closed-cycle gas turbine and combined cycle cogeneration plants has been completed.

Technical support to major liquefaction projects - Plans for engineering and evaluation support in FY 1980 are being developed. Environmental support has continued for the SRC projects. Public scoping meetings were held in Morgantown, West Virginia, Pittsburgh, Pennsylvania, Owensboro, Kentucky, and Louisville, Kentucky, to solicit public input for the SRC-I and SRC-II environmental impact statements. The H-Coal Materials and Technology Task Force has continued to review technical data and to visit related facilities. A letter report summarizing the preliminary evaluation of the materials of construction for the H-Coal pilot plant has been submitted. Support is being provided in the areas of reliability, safety, and quality assurance. A list of recommended tasks to be performed by the SRC-I and SRC-II contractors during the Phase-I effort has been prepared. Work has been initiated on generic failure mode and effects analyses for selected components and systems.

2. COAL CONVERSION DEVELOPMENT

J. R. Hightower, Jr.

Coal conversion development activities are carried out in the Chemical Technology Division. This section discusses two projects conducted for the Division of Fossil Fuel Processing -- Physical Properties of Coal Liquids and New Liquefaction Techniques.

2.1 Physical Properties of Coal Liquids

G. E. Oswald, E. L. Youngblood, M. R. Gibson,
L. S. Dickerson, and R. L. Andrews

The objective of this project is to measure and correlate physical properties (viscosity, density, thermal conductivity, and heat capacity) of various coal-solvent slurries and solids-free, coal-derived liquids at typical processing conditions, up to 31 MPa (4500 psig) hydrogen pressure and 810 K (1000°F) in a bench-scale, continuous flow system. This system includes a slurry preheater 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 ultimately be correlated with chemical characteristics of the test liquid to provide information useful to designers.

Installation and proposed operations for the gamma radiation absorption liquid density instrument are discussed in this section.

2.1.1 Work accomplished

The gamma radiation absorption liquid density instrument has been installed at the preheater discharge and operational check-out tests are in progress.

2.1.2 Future work

Density measurements will be made on Wilsonville recycle solvent and on 35 wt % coal-solvent slurry from 450 K (350°F) to 700 K (800°F) at 13.9 MPa (2000 psig) pressure. Test liquid will be heated to measurement temperature in the preheater and then passed through the density instrument. The density instrument pressure vessel is maintained at test temperature by surface electrical heaters.

2.2 New Liquefaction Techniques

J. W. Larsen,* R. K. Hessley,* T. L. Sams, and B. R. Rodgers

There are a variety of chemical oxidants which have been used to elucidate the structure of coals. Such common oxidants as O_2 , HNO_3 , $Mn(VII)$, and CrO_3 have all provided useful information in this regard, but are less than ideal principally because they destroy much of the aliphatic structure in coal, but do not degrade the more complex aromatic structure.¹

Deno and co-workers have developed an oxidative technique which uses $CF_3COOH/H_2O_2/H_2SO_4$ as the oxidizing species.² They report that this reagent is unique in that it preferentially attacks aromatic structures, but preserves most of the aliphatic moieties.^{3,4} Further, they have demonstrated that when coal is subjected to trifluoroacetic acid (CF_3COOH) oxidation, benzene polycarboxylic acids are formed only from polyaromatic clusters.²⁻⁴

Such a process provides a means both of elucidating the highly informative aliphatic character of coal and also revealing, indirectly, the aromatic structure. The technique also has the advantages of being relatively uncomplicated and rapid.

Our coal liquefaction studies, using phenol and heat, has shown that a hydrogen shuffling process occurs within the coal and results in the formation of a high yield of lower molecular weight, pyridine-soluble products. It is believed that determining the aliphatic (hydrogen) structure in the parent coal, in the soluble products and in the insoluble residue, will provide the most valuable information about the origin of the hydrogen which participates in the shuffling process.

Using Deno's method,² we initially investigated Wyodak coal. Our liquefaction technique was highly successful with that subbituminous coal. We have now applied the method to the analysis of the soluble extract and insoluble residue of Wyodak coal after liquefaction and also to a bituminous coal, Bruceton.

The oxidation and esterification reactions were carried out with the post-liquefaction, pyridine-soluble fraction of three samples of Wyodak coal. Two samples (No. 26 and No. 18) were from liquefaction trials that resulted in a high yield (>60%) of soluble product, and one sample (No. 16) was from an earlier liquefaction run that gave a low yield (25%) of soluble product.

*Chemistry Division

The gas chromatographic separation showed 15 peaks for sample 26 and 21 peaks for sample 18. The retention time of the major peaks was virtually identical for both samples. The mass spectra of all the peaks are extremely fragmented. The molecular weight was determined with certainty for four components. By comparison with the individual spectra of the parent Wyodak coal, these compounds are believed to be the aliphatic compounds M.W. 218b, $C_3H_5(COOCH_3)_3$; M.W. 262, $C_2H(COOCH_3)_4$; M.W. 276, $C_3H_4(COOCH_3)_4$, and the aromatic species, M.W. 310, benzene tetracarboxylic acid, $\phi(COOCH_3)_4$. The mass spectra of all remaining compounds have an essentially unique fragmentation pattern which likewise corresponds to the highest molecular weight compound in the parent Wyodak coal.

The third sample, No. 16, also shows 15 separated peaks on the gas chromatogram. The mass spectrum of one species has a molecular weight 372 which can be assigned to the methyl ester of cyclohexenepentacarboxylic acid. All the others are identical to each other and to the high molecular weight Wyodak compound.

There are two other important features of this data. Because the mass spectra of these many components show the same apparent molecular weight, and have the same fragmentation pattern, it is likely that the material is a series of isomers. From the analysis of the parent Wyodak coal, this high molecular weight species was assigned a formula of a penta-carboxylic cyclohexane, $C_6H_6(COOCH_3)_5(CH_2OH)$. A compound of this type could have a variety of isomeric forms that would result in a multiplicity of separate components. Chemical-ionization mass spectroscopy is being carried out in an attempt to determine precisely the molecular weight of the apparent isomeric species.

The second feature of this analysis is the apparent loss of the lighter weight, aliphatic, compounds in the solubilized fraction.

The insoluble residue from Wyodak samples No. 18 and No. 16 were analyzed in the same manner. Table 2.1 summarizes the data for sample No. 16. The data for No. 18 had all the same components except dimethylsuccinate and the species 204. It can be seen that both the low molecular weight acids as well as an apparently substantial amount of the unidentified high molecular weight species appear in these insoluble fractions.

Two trials were carried out with Bruceton coal. The results are summarized in Table 2.2. The data indicates that the structure of Bruceton coal is very much like that of Wyodak coal. Chemical-ionization mass spectroscopy will be used to verify the molecular weight of the heavier species, and the analysis of Bruceton coal after liquefaction and extraction into pyridine will be carried out.

Further investigations with coal and with model compounds will be necessary to establish the structural modifications of the liquefaction process more precisely.

Table 2.1. A summary of the analysis of two pyridine-insoluble fractions of Wyodak coal after liquefaction

Retention time (min)	Molecular weight	Compound
1.7	132	$\text{CH}_3\text{OOCCH}_2\text{COOCH}_3$
2.2	146	$\text{CH}_3\text{OOCCH}_2\text{CH}_2\text{COOCH}_3$
3.9	204	$\text{C}_2\text{H}_3(\text{COOCH}_3)_3$
4.8	2186	$\text{C}_3\text{H}_5(\text{COOCH}_3)_3$
4.9	2186	$\text{C}_3\text{H}_5(\text{COOCH}_3)_3$
6.5	?	
7.7	276	$\text{C}_3\text{H}_4(\text{COOCH}_3)_4$
10.3	252	$\phi(\text{COOCH}_3)_3^{**}$
13.6	310	$\phi(\text{COOCH}_3)_4$
14.2	(404)*	
16.5	(404)	
17.4	(404)	
18.2	(>404)	
19.3	(>404)	
22.1	(404)	
26.1	(404)	

*Highest ion fragment + 31.

** ϕ = benzene.

Table 2.2. A summary of the analysis of Bruceton coal
after oxidation and esterification

Retention time (min)	Molecular weight	Compound
1.5	132	$\text{CH}_3\text{OOC CH}_2 \text{COOCH}_3$
1.9	146	$\text{CH}_3\text{OOCCH}_2 \text{CH}_2 \text{COOCH}_3$
2.8	160	$\text{CH}_3\text{OOC}(\text{CH}_2)_3\text{COOCH}_3$
3.9	204	$\text{C}_2\text{H}_3(\text{COOCH}_3)_3$
4.9	218a	$\text{C}_3\text{H}_5(\text{COOCH}_3)_3$
5.3	218b	$\text{C}_3\text{H}_5(\text{COOCH}_3)_3$
5.6	(232)	
6.4	(392)	
6.7	(373)	
7.1	?	
7.7	276	$\text{C}_3\text{H}_4(\text{COOCH}_3)_4$
10.3	252	$\phi (\text{COOCH}_3)_3^{**}$
13.7	310a	$\phi (\text{COOCH}_3)_4^{**}$
15.0	310b	$\phi (\text{COOCH}_3)_4^{**}$

*Highest ion fragment + 31.

** ϕ = benzene.

2.3 References

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2. Deno et al., Fuel, 57, 455 (1978).
3. Deno et al., Tet. Lett., 1703 (1977).
4. Deno and L. A. Messer, Chem. Comm., 1051 (1976); Deno, E. J. Jedzimiak, L. A. Messer, M. D. Meyer, S. G. Stroud, and E. S. Tomezsko, Tetrahedron 33, 2503 (1977).

3. CHEMICAL RESEARCH AND DEVELOPMENT

M. L. Poutsma

3.1 Chemistry and Structure of Coal

M. L. Poutsma and C. L. Wolf

Studies of the thermolysis pathway for 1-naphthol continued, although progress was seriously impeded by a series of glpc malfunctions. Besides dinaphtho[1,2-b; 2',1'-d]furan (1) identified earlier, the other dominant products at high conversion level have been shown to be naphthalene and water. For example, in a 25.7-hr run at 400°C in a stainless steel tube under conditions where 93% of the starting 1-naphthol would have been in the liquid phase, the conversion based on unreacted 1-naphthol was 90%. Furan 1 and naphthalene (1.00:0.42 molar ratio) accounted for 76% of the 1-naphthol consumed and the molar ratio of H₂O: 1 was $\geq 0.8:1.0$. However, from results of low conversion runs, naphthalene does not appear to be a primary product. Instead a product appears whose glpc retention time coincides with that of 1-tetralone. The initial stoichiometry and secondary reactions remain to be identified.

This thermolysis has been carried out with qualitatively similar results in both Pyrex and stainless steel tubes. However, quantitative reaction rates remain erratic, behavior suggestive of some uncontrolled wall effect.

3.2 Indirect Liquefaction Chemical Research

R. A. Strehlow and M. L. Poutsma

Planning has begun for a new project concerning the mechanism of the Fischer-Tropsch reaction with particular emphasis on elucidating the role of olefins as reaction intermediates in determining the molecular weight distribution of the products and the catalyst aging performance. An existing pulsed microreactor interfaced with a quadrupole mass spectrometer is being adapted to the initial phases of this study.

4. MATERIALS ENGINEERING

R. A. Bradley

The materials engineering and associated technology reported here are in support of activities directed or coordinated by the Materials Section, 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.

4.1 Pressure Vessel and Piping Materials

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

The program is concerned with the influence of an operating environment on the in-service reliability and safety of large pressure vessels for use in second-generation coal conversion systems. The candidate steels from which these vessels will be constructed are subject to an environmentally induced embrittlement at the currently projected operating condition of these units. Of prime concern is the effect of the coal conversion environment, in particular hydrogen, on both low- and high-temperature properties of these steels.

We have reworked the autoclave closure surfaces to avoid hydrogen leakage which occurred during the previous run. In addition, we upgraded the specimen holder to assure more uniform temperature control. This modification consisted of installing additional baffling. During the previous run, we also encountered a weakness in the lead wires. In the past month, we developed an improved lead wire configuration which should provide increased strength to the lead wire and improve its hydrogen resistance.

4.2 Fossil Energy Welding and Cladding Development

J. F. King and G. M. Goodwin

Plans are being developed to place modified 9 Cr-1 Mo steel tubing in a commercial fossil-fired power plant. Welding development and characterization will be required to join the 9 Cr-1 Mo alloy to an austenitic stainless steel. Dissimilar metal welds are required for insertion of this alloy into the superheater section where it is desirable to test the material. No major problems are anticipated at this point in developing a dissimilar metal weld.

The contract with Sandvik, Inc., which was discussed in detail last month, is now under way. Evaluation and testing of the strip clad deposits to be obtained from this contract will begin as materials are received. Samples are scheduled to be delivered in about one month.

4.3 Fireside Corrosion of AFBC Heat Exchanger Materials

T. G. Godfrey and J. H. DeVan

Metallographic examination of the specimens from the 4500-h test in the Fluidyne AFBC has been slowed due to other commitments. From the observations made to date, no clear correlations have been found that bear on the severe sulfidation-oxidation corrosion of the type 316 stainless steel tube (No. 9-B) detected at the end of the test.

4.4 Failure Prevention and Analysis

R. W. Swindeman

During October, personnel visited the H-Coal Pilot Plant at Catlettsburg, Kentucky, the Institute for Mining and Minerals Research at Lexington, Kentucky, and the H-Coal Process Demonstration Unit at Trenton, New Jersey. Further, several of our staff attended the Fourth Annual Conference on Materials for Coal Conversion and Utilization held in Gaithersburg, Maryland, on October 8-11.

4.4.1 Examination of materials from fractionation area of SRC plants - (J. R. Keiser and V. B. Baylor)

Because of the very serious nature of the corrosion that has been observed in the fractionation areas of the solvent-refined coal (SRC) plants, a concentrated effort is being made to determine the cause of this corrosion.

Three specimens removed from the Wilsonville fractionation column due to excessive corrosion were examined metallographically. This analysis showed a very rough surface with some scale remaining in the lower areas. This scale will be examined by electron microprobe. These three specimens were part of a rack of 14 corrosion coupons that were brushed to remove the scale and weighed to permit weight loss determination. A sample of this scale was analyzed and found to contain 23% S, 12% O, 8% Cr, and 8% H₂O. Analysis of the scale for Ni, Mo, and Fe showed each was less than 3%.

As a result of extensive corrosion, the upper portion of the Ft. Lewis wash solvent column was recently replaced. A piece was cut from the removed lower portion and sent to ORNL for examination. A piece of Hastelloy G tray from an area of the wash solvent column that experienced severe corrosion and a piece of badly corroded downcomer support were also sent. Scale from these pieces has been submitted for chemical and x-ray analyses, and component pieces have been submitted for metallographic and electron microprobe examination.

Samples of the fractionation column feed from two separate runs using Indiana V coal and Kentucky 9 coal were submitted for thorough analytical chemistry analyses. Special attention will be given to identify sulfur-bearing compounds.

Twenty-four corrosion coupons were supplied to the University of Kentucky's Institute for Mining and Minerals Research to be included on corrosion racks being provided to the H-Coal Pilot Plant in Catlettsburg, Kentucky.

In order to bring together parties interested in corrosion problems in fractionation areas of SRC plants, a meeting is planned at ORNL on November 29. Most workers in this area have been contacted and are expected to attend.

4.5 Materials for Zinc Chloride Liquefaction Process

V. B. Baylor and J. R. Keiser

The purpose of this task is to evaluate materials for use in the regenerator and condenser vessels of the Zinc Chloride Liquefaction Process. A quartz test loop to be used for exposing corrosion coupons to the environment of the regenerator and condenser vessels was charged with zinc chloride and brought to operating temperature. Plugging problems occurred; as these were being eliminated, cracks in the quartz were found. Subsequent examination of the quartz loop revealed evidence of degradation of the quartz, possibly because of water in the system. A second loop system has been modified to eliminate the problems that caused plugs to form in the first loop, zinc chloride has been added, and the system is being prepared for specimen insertion.

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

J. R. Keiser and V. B. Baylor

About 100 U-bend specimens for studying stress-corrosion cracking remain in place in both the Wilsonville and Ft. Lewis SRC plants. Specimens from the Ft. Lewis dissolver and separator vessels have been returned to ORNL for examination. A cursory examination showed Inconel 600 specimens exposed in several vessels were severely attacked. Thirteen racks with ten U-bend specimens per rack were assembled and shipped to the University of Kentucky's Institute for Mining and Minerals Research for inclusion in the shipment of corrosion coupons being supplied to the H-Coal Pilot Plant in Catlettsburg, Kentucky.

Final checkout of our laboratory facility is nearly complete, and operations will begin when approval is obtained from the High-Pressure Experiment Review Committee.

4.7 Development of Advanced 9 Cr-1 Mo Structural Steel

V. K. Sikka

Large heat procurement, fabrication, mechanical property characterization, weldability, and steam-corrosion studies continued during the last month. Several accomplishments made during the last month are as follows:

All six ingots from two 15-ton heats were delivered to ORNL during the last month. These ingots are waiting shipment for fabrication.

The plate from the 4 × 4 in. test ingot from the argon-oxygen-deoxidation (AOD) portion of heat No. 1 was machined into Charpy, impact, and steam-corrosion specimens. Charpy specimens tested thus far showed a 50 ft/lb transition temperature of +4°C and upper shelf energy of about 80 ft/lb. These properties were measured on the transverse specimens; specimens parallel to the rolling direction are expected to yield lower transition temperature and higher upper shelf energy than the transverse specimens.

One creep rupture test at 649°C and 21 Ksi was also completed on this material. This test showed a reduction of area of 86.4% and its rupture life is close to the ASME minimum stress-rupture curve for type 304 stainless steel. Three additional creep rupture tests are currently in progress.

Creep testing also continued on several experimental heats with intentional variations in Si and N content. Results available thus far show that high silicon content lowers the rupture time, while higher nitrogen content lowers the ductility. These observations, along with other tests to be conducted, will be used in optimizing the specifications for the modified 9 Cr-1 Mo alloy.

4.8 Ceramic Recuperators (Heat Exchangers)

V. J. Tennery, G. C. Wei, and G. W. Brassell

The 500-h Ceramic Recuperator Analysis Facility (CRAF) Test No. 1 using a high vanadium (300 ppm) No. 6 oil was completed on October 31, 1979. Following furnace cool down, CRAF disassembly is scheduled the week of November 5. Subsequent post-test analyses including visual inspection, x-ray radiography, measurements of permeability, fracture stress, and thermal expansion coefficient, and examinations of microstructure, phase composition, and chemical composition of the 14 ceramic heat exchanger tubes are planned. Throughout the test, there were no significant changes in the tube inner or outer diameter temperatures which ranged from 1100 to 1250°C. The bumps or blisters observed on the outer diameter of some of the SiC tubes appeared to grow and exhibited a morphology change as the test proceeded. Determination of the nature of these objects will be made during analysis of the tubular specimens.

In this period, flue gas and preheated air temperatures and air velocity were measured using a Land® suction pyrometer* and a Pitot tube in the gas channels of the CRAF. The temperatures of flue gas entering and leaving the CRAF test chamber were 1410 and 1385°C, respectively. The secondary air flowing through the ceramic tubes was heated from the ambient temperature (21°C) to 340°C. Air velocity in the air inlet duct was 8.1 m/s (1600 f/m). Calculations based on these parameters and the formula listed in a previous report¹ indicated that the total heat transmission in the CRAF was about 23.7 kW (1350 Btu/min), the effectiveness[†] was about 0.23, and the average heat flux through the ceramic heat exchanger tube wall was about 54 kW/m² (2 Btu/in.² per minute). Both condensable and noncondensable species in the flue gas were collected and submitted for chemical analysis.

At Hague International, a heat exchanger module consisting of an array of SiC tubes utilizing SiC (sintered- α) insertable seals has been assembled and mounted on a coal-oil-mixture (COM) fired forge furnace for testing at 1095°C (2000°F). The 200-h COM (60 wt % No. 6 oil and 50 wt % bituminous coal with acidic ash) test of pressurized (0.52 MPa or 60 psig secondary air) SiC heat exchanger tubes was initiated on October 29 with data obtained thus far revealing acceptable leakage rates (<2%).

4.9 References for Section 4

1. V. J. Tennery and G. C. Wei, *Recuperator Materials Technology Assessment*, ORNL/TM-6227 (February 1978).

*Land® suction pyrometer, product of Land Instrument, Inc., Tullytown, Pennsylvania.

[†] $(T_{2a} - T_{1a}) / (T_{1g} - T_{1a})$ where T_{2a} is the maximum air temperature, T_{1a} is the ambient air temperature, and T_{1g} is the temperature of flue gas entering the recuperator.

5. COMPONENT AND PROCESS EVALUATION STUDIES

J. M. Holmes

Component and Process Evaluation Studies in progress in the Engineering Technology Division Fossil Energy Program include the following.

- Survey of Industrial Capability for Coal Handling Equipment
- Slurry Pressure Letdown Studies
- Support for the H-Coal Project
- Engineering for the Economic Regulatory Administration Project
- Fossil Energy Performance Assurance Support

5.1 Coal Handling/Preparation and Ash/Slag Removal Equipment Survey

D. A. Dyslin, F. C. Zapp, O. W. Thomas
M. D. Silverman, and J. M. Holmes

The final report has been completed in draft form and has been submitted to DOE for approval. It is entitled "Survey and Conceptual Flow Sheets for Coal Conversion Plant Handling - Preparation and Ash/Slag Removal Operations," ORNL/TM-6929. The report covers the preparation of conceptual flow sheets, including major equipment lists, and a survey of equipment availability for future coal conversion plant handling-preparation and ash/slag removal operations.

5.2 Slurry Pressure Letdown Studies

P. K. Carlson and J. M. Holmes

A seed money proposal entitled "Slurry Pressure Letdown System" was presented to the coordinating committee and approved. It includes the completion and instrumentation of a test loop located in Building 9201-3, construction of a packed bed pressure letdown device, and a program for testing the device. The packed bed device, as envisioned, would replace a more complicated system of valves and vessels used in the letdown of hot, high pressure reactor effluent coal slurry at direct liquefaction plants or the char/ash water slurry of coal and gasifiers. Design data will be developed (pressure drop as a function of gas, liquid and solid throughput) and the problems of plugging and packing erosion will be explored. This testing is expected to extend well into 1980.

5.3 Support for the H-Coal Project

L. F. Parsly and P. K. Carlson

Visits were made (along with others of the task force) to the Hydrocarbon Research Inc. research and development offices at Lawrenceville, New Jersey; the 2.5 ton/day H-Coal PDU at Trenton, New Jersey; and the Solvent Refined Coal pilot plant at Ft. Lewis, Washington. In-depth discussions of process and equipment performance were held at both locations. Trip reports are being prepared and will be issued early next month.

The major topics discussed concerning the H-Coal PDU included:

- Hydroclones
- Distillation column corrosion
- Letdown valves
- Slurry pumps
- Slurry metering systems

Topics discussed at the Ft. Lewis SRC Pilot Plant included:

- Slurry mix system
- Slurry pumps
- Letdown valves
- Block valves
- Vacuum flash system plugging
- Pump seals
- Slurry metering
- Level controllers on vessels
- High-pressure sampling

An initial list of components considered critical to the operation of the H-Coal Pilot Plant is in preparation.

5.4 Engineering for the Economic Regulatory Administration Project

W. L. Greenstreet and M. L. Myers

This is a new project which is currently being defined. Background information is being obtained concerning the first two power plants to be converted from oil to coal in accordance with the Fuel Use Act. Negotiations are underway to initiate support subcontracts for the study.

5.5 Fossil Energy Performance Assurance Support

L. F. Parsly

Draft specifications for Quality Assurance, Reliability and Systems Safety were reviewed. Tables of equivalent systems in the H-Coal Pilot Plant and the SRC I and SRC II Phase 0 demonstration plant designs were prepared. These will serve as the basis for choosing systems on which Failure Modes and Effects Analysis will be performed. Preference will be given to critical systems or components found in all three projects in order to determine where a generic FMEA can be performed.

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 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, and 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

Lehigh Programs

A new improved version of the DSS-2 program with 15 differentiation subroutines was received from Lehigh. Included with the program were 28 test examples. The new version is in the process of being adapted to and compiled on the ORNL IBM-360 system. About 80% of the routines have been successfully compiled thus far. Execution of the test examples will be undertaken when compilation is complete.

Purdue Programs

Final delivery of the Purdue steady-state simulation programs and revised physical properties package is expected around the end of November. No new or revised programs were received.

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-DFFP by preparing digest reviews of current or potential subjects relating to coal conversion technology.

6.2.2 Status Summary

Internal and external reviews of the article "Depolymerization of Coal" were returned, and revision of the manuscript to incorporate the reviewers' suggestions was begun.

A search of the RECON data base was conducted to identify published literature on the subject "Chemical Reaction Kinetics of Coal Liquefaction," the title of the second article of the upcoming Digest issue. Collection of the identified literature was begun, and an outline for the article was developed.

7. PROCESS AND PROGRAM ANALYSIS

R. W. Glass

Process and program analysis studies are being conducted for the DOE Fossil Energy Division of Planning and Systems Engineering. 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 Liquefaction Technology Assessment (LTAS)

R. C. Forrester III, R. Salmon, A. R. Irvine, S. P. N. Singh,
J. F. Fisher, R. M. Wham, and S. L. LeStrange

7.1.1 Contract Objective

The objective of this study is to provide a comparative assessment of the technical feasibility, economic competitiveness, and environmental acceptability of selected coal liquefaction processes representing different process classes on a uniform, consistent, and impartial basis.

The assessment encompasses four phases of work, identified as Phase 0, Phase I, Phase II, and Phase III. Each phase includes development of process designs, capital and operating cost estimates, process economic analysis, sensitivity studies, and assessment of technical feasibility and risk on as consistent a basis as possible. Existing process designs and cost estimates will be used whenever possible, with modification as necessary.

7.1.2 Status Summary

Revision of the Phase 0 draft report is continuing, with particular attention directed toward developing a set of process contingency factors for the processes examined which might reflect differences in development status. Numerous reviewer comments have been received from DOE and these are also being incorporated in the revised draft report which will be made available for limited proponent review near the end of the year. Final changes to the report will then be made and the publication process will begin early next year.

Phase I of the project has continued to proceed with preparation by Fluor Engineers and Constructors, Houston Division, of detailed process designs for the indirect synthesis plants of interest:

1. ICI methanol synthesis, followed by drying to turbine specifications, drying to gasoline blending specifications, and gasoline synthesis via the Mobil MTG process.

2. ICI methanol synthesis, followed by gasoline synthesis via Mobil MTG, but with coproduction of SNG allowed.

All designs incorporate Lurgi dry-bottom gasifiers with a Western sub-bituminous coal feed.

An interim report describing the completed capital and operating cost estimates will be prepared in December and ORNL will begin examination of process economics under various financial assumptions. Due to the unavailability of a definitive design for the direct liquefaction processes of interest, examination of a representative of that class will be deferred until later in the fiscal year. Other indirect processes of interest will be examined, as will the methanol cases described above, but with the use of alternative gasification systems in place of Lurgi.

7.2 Direct Combustion

E. C. Fox and T. D. Anderson

7.2.1 Contract objective

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.

7.2.2 Status summary

The main report "Conversion to Direct Coal Combustion in the Industrial and Commercial/Residential Sectors - A Study of the Barriers to Implementation in the Near Term," ORNL/TM-6139, is being prepared for final publication.

7.3 Advanced Power Conversion Systems

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

7.3.1 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.

7.3.2 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. The report entitled "Summary of the Research and Development Effort on Open-Cycle Coal-Fired Gas Turbines," ORNL/TM-6253, has been completed and is being prepared for final publication.

^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., E. C. Davis, C. W. Francis, S. K. Hall,
S. Y. Lee, and H. W. Wilson, Jr.

Soil samples were collected at the proposed CONOCO site in Noble County, Ohio during the month of October. Two soils predominate at this site: the Lowell and the Richland. Both bulk and core samples were obtained for each of these soil types and were returned to ORNL for analysis. Assistance in obtaining the core and bulk samples was provided by the local U. S. Soil Conservation Service (James Forshey) and the CONOCO Coal Development Company (Robert Schlessman and George Heunisch). Arrangements have been made to sample the proposed SRC-II site in West Virginia as soon as the exact location of the ash disposal area has been established. Soils from the proposed MLGW site will be collected when confirmation has been obtained on how the ash disposal area will be prepared (area may be located on dredged fill material).

A continuous-flow leaching column using waste H has been completed and samples have been sent to Analytical Chemistry for elemental analysis. A tracer test has also been completed to determine the liquid residence time in the column.

A scoping study has been completed on the treatability of the runoff from the coal storage pile at Y-12 in order to determine sludge handling problems and complexity of treatment required to meet current NPDES effluent release guidelines. It has been found that the runoff can be neutralized by the addition of either NaOH or Ca(OH)_2 , and that sludge volumes (after 24 hr. settling time) could range from 43 to 71% when NaOH is used as the neutralization agent. Although the use of Ca(OH)_2 requires longer mixing times, the resulting reduced sludge volumes may make its use more attractive than NaOH. In any case raising the pH from 6 to 9 produces a clear effluent which will meet the current NPDES criteria (pH and TSS). Maintaining the pH above 7 essentially removes all dissolved iron from the runoff.

8.2 Processing of Coal Conversion Wastes for Disposal and Resource Recovery

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

Leaching of three gasification wastes with hydrochloric acid has been performed at ambient temperature. Results for several trace and major metals are shown in Table 8.1. The uncertainties in removal are a result of nonclosure of material balances and are most significant for zinc. The leachability of these metals increased with increasing calcium content of the ash, indicating that significant quantities of calcium can prevent the formation of the high-fired metal silicates typical of fly ash. Calcium probably enters the matrix to form calcium-metal silicates which are much more easily dissolved. These results indicate that a heap-leaching operation on some gasification wastes could result in significant removal of metals. They also offer encouragement that fluidized bed combustion wastes (being high in calcium) may be more easily processed for metal recovery.

8.3 Coal Conversion Demonstration Projects

8.3.1 Liquefaction projects - S. G. DeCicco

This activity is reported in Chapter 13.

8.3.2 Gasification projects - A. J. Witten

Grace - The Final ER was received on October 5. Several copies were lost in transmittal and have not yet been located. A meeting was held on October 9 at ORNL with representatives of Grace and DOE to discuss the traffic problem and the required additional studies. A letter of recommendation was sent on October 10 outlining what work ORNL believes should be performed. It is our understanding that these recommendations have been endorsed by Grace; however, it is unlikely that this work can be completed for inclusion in the PDEIS.

A meeting was held at ORNL on October 30 to brief DOE and Grace on the status of PDEIS preparation. The PDEIS is approximately 40% complete.

MLGW - A meeting was held at EIA in Pittsburgh on October 4 to discuss the ER. ORNL had several questions regarding the process description. Responses were anticipated by October 14, however, only partial responses have thus far been received.

Table 8.1. Metals Removal from Gasification Ash by
HCl Acid Leaching at Ambient Temperature

Metal	Removal (%)		
	GA2	GA3	GA4
Al	0 - 2	82 - 84	35 - 58
Ba	3	79 - 84	40 - 63
Be	2 - 3	83 - 95	62 - 70
Cr	52 - 57	77 - 100	74 - 85
Cu	14 - 20	0 - 2	8 - 15
Fe	5 - 7	72 - 100	71 - 86
Ni	59 - 65	52 - 100	88 - 94
Sr	5	85 - 87	45 - 63
Ti	1 - 2	71 - 72	40 - 62
V	3 - 5	83 - 86	46 - 64
Zn	5 - 17	50 - 100	59 - 81
Avg. (excluding Cu)	14 - 17	73 - 91	56 - 73
Ca content of ash	3%	19%	7%

A meeting was held at ORNL on October 30 to present the status of PDEIS preparation to DOE and MLGW. At this time, a meeting was scheduled for November 8 at Foster-Wheeler to obtain the outstanding process information.

The PDEIS is approximately 40% complete.

ICGG - The Final EAR was received on October 5. A meeting was held at the Dravo offices in Pittsburgh on October 5 to discuss required process description information. Responses were promised within two weeks but have not been received as of 11/1/79.

The PDEIS is approximately 30% complete.

CONOCO - A meeting was held at EIA in Pittsburgh on October 4 to brief ORNL and DOE on the CONOCO environmental monitoring program and status of ER preparation. Several preliminary ER sections were received.

8.4 TVA Gasification Project

S. G. DeCicco

On October 18 Bob Evers from TVA came to ORNL to meet with the FEPP team and solicit advice on schedules, site, data needs, plant design information needs, and the NEPA process.

TVA is hoping to satisfy the NEPA requirements for this project with a three month effort. DOE's six coal conversion demonstration projects have each invested approximately two years to complete this work adequately.

8.5 Communications

a. Kornegay attended the American Meteorological Society Conference on Severe Local Storms in Kansas City, Missouri, on October 1.

b. Boston, Ketelle, Kornegay and Witten attended a CONOCO status review meeting in Pittsburgh on October 4.

c. Boston, France, and Witten attended a meeting with Dravo Corporation in Pittsburgh on October 5 to again request details of the proposed plant design and alternatives and other related information on the ICGG project. Earlier requests through DOE-ICGG-Gibbs and Hill have gone unheeded.

d. DeCicco participated in additional public scoping meetings on successive evenings at Morgantown, West Virginia, and Pittsburgh for SRC-II and Owensboro, KY. and Louisville, KY. for SRC-I on October 22-25.

e. DeCicco and Zittel attended an SRC meeting in D. C. to discuss project schedules on October 15.

f. Witten attended the monthly progress review meeting for MLGW held in Livingston, N. J., on October 24-25.

g. EIS progress review meetings were held at ORNL for MLGW and Grace on October 30.

8.6 Milestones

Preliminary draft environmental statements (PDES's) will be completed three months after receipt of acceptable, final environmental reports (FER's) from the industrial partners. Current schedules, contingent on delivery of FER's, call for PDES's, as follows: Grace, 1/2/80; SRC-I, 3/7/80; SRC-II, 2/1/80; ICGG, 1/2/80; MLGW, 1/2/80; CONOCO, 4/15/80.

9. COAL PREPARATION AND WASTE UTILIZATION

E. C. Hise, A. S. Holman, and J. F. Thomas

The objectives of this program are: to develop, demonstrate, and bring to commercial viability, processes and equipment for the removal of pyrite and ash-forming minerals from dry crushed coal by either or both processes of high-gradient magnetic separation (HGMS) and open-gradient magnetic separation (OGMS); to integrate the magnetic process into the coal preparation system to achieve the most effective and economic preparation of the raw coal; and to develop processes to minimize the refuse disposal by efficiently utilizing the heating value and concentrated mineral resources in that refuse.

9.1 High-Gradient Magnetic Separation

E. C. Hise, M. T. McFee, and D. L. Mailen

Sala Magnetics has received 25 tons of Western Kentucky seam No. 9 coal from the TVA Paradise Steam Plant and a set of screens from the Derrick Manufacturing Company. They are now crushing and classifying the TVA coal for the continuous separation tests. Pennsylvania Power and Light has agreed to supply 25 tons of a Lower Kittanning coal from Lady Jane mine, for continuous separation testing.

Powell Construction Company presented a status review of the design study and economic analysis to compare dry magnetic processing of fine coal with conventional wet fine coal circuits. They have prepared and balanced flow sheets based on the washability analysis of the raw coal and have developed capital and operating costs. The meeting concluded to request several changes to the flow sheets and to add a wet magnetic circuit to the study.

Final installation of the superconducting magnet, in Bldg. 9201-3, Room 193A, is in progress. Most major items ordered have arrived. All craftwork necessary to begin operation has been ordered and most have been completed. It is expected that some shakedown tests will be performed during early November without energizing the coil and the coil will be tested in late November.

9.2 Open-Gradient Magnetic Separation

A. S. Holman, M. T. McFee, and D. L. Mailen

As was reported during the preceding month, work is progressing on the development of a code to simulate various types of magnets. We are currently working with Dr. Fritz Friedlander of Purdue University to verify that our solenoid calculations are correct. It is expected that this will be accomplished during the coming month and that we will be able to incorporate the solenoid calculation into our trajectory simulations.

The Frantz magnetic separator, petrographic equipment, and scales have been set up in Building 9201-3, Room 193B. Further modifications are being made on the splitter and splitter bracket of the Frantz.

9.3 Material Preparation

M. T. McFee and D. L. Mailen

The hammer mill, jaw crusher, gilson screen tester, and rotary sieve are all in operating order in the Crushing and Classifying Lab, Building 9201-3, Room 197. We are awaiting the arrival of additional screens for the gilson.

9.4 Coal Preparation Plant Automation

J. F. Thomas

John Thomas has begun working with Norman Bradley and Ken Carr of the Instrumentation and Controls Division in the area of coal preparation plant instrumentation and automation. In the next six months, approximately 25 coal preparation plants will be visited and a review will be written to complete a state-of-the-art assessment of coal preparation plant automation. Information will also be gathered concerning unit operation performance. Mathematical modeling of overall preparation plants and individual unit operations will be necessary to develop instrumentation and control systems.

9.5 Conferences and Trips

E. C. Hise, A. S. Holman, and J. F. Thomas

E. C. Hise attended the Coal Conference and Expo in Louisville, Kentucky, October 23-25, and presented a paper entitled "Correlation of Physical Coal Separations." Mr. Venkatesan, of Powell Construction Company, presented a paper on the design study. Two copies of the collected papers from the Coal Preparation and Utilization symposium were obtained.

John Thomas, Norm Bradley, and Ken Carr toured the United Coal Companies (UCC) No. 8 coal preparation plant near Big Rock, Virginia, on October 16. This relatively modern plant features heavy media washers, deister tables, flotation cells, disc filters, and centrifugal dryers. Up to four different coals can be blended to make the feed stream in order to meet product specifications.

A meeting with Mr. Lowell Hess, Vice President of UCC coal preparation, proved beneficial. Mr. Hess had many useful ideas concerning preparation plant automation and would like ORNL and UCC to work together in the future.

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

R. S. Holcomb, R. H. Guymon, N. W. Durfee, and W. A. Hartman

10.1 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.

10.2 Status Summary

The revised draft of the work statement for the subcontract was accepted by Westinghouse and Babcock and Wilcox (B&W), and has been incorporated into the subcontract. Completion of the subcontract package has been delayed pending the receipt of cost audits of the subcontractors from the Government agency performing the audits for DOE. Upon receipt of the audits, the subcontract package will be sent to Westinghouse for their acceptance and signature. When the signed subcontract is received from Westinghouse, it will be submitted to DOE-ORO for approval.

A meeting was held at DOE in Germantown on October 30, with DOE-FE Combustion Branch Management and representatives from Project Management of METC and from ORO and ORNL to discuss ways in which the realization of the commercialization of CCC systems might be accelerated. METC raised the question as to whether or not building a demonstration plant as the first operating unit would lead to commercialization more quickly. ORNL pointed out that a number of key technology questions are unanswered, such as erosion and corrosion of the tubes and coal feeding, that will be addressed by the test unit. ORNL proposed that a PON or RFP be prepared to solicit proposals for designs of two or more candidate demonstration plants. These designs should be complete soon after the test unit is in operation. Favorable early test results could then lead to a decision for the Government to authorize construction of a demonstration plant at an industrial site with minimum delay.

At the conclusion of the meeting, ORNL was instructed by DOE-FE to accelerate Task 6 - Extended Application Studies, and reschedule Task 5 - Site Specific Demonstration Plant Design, to match the schedule of the parallel demonstration plant designs under a PON, in the event that the

plans for such a PON are adopted. METC was asked by DOE-FE to evaluate the proposed PON schedule and revise if necessary, and to assess the DOE cost requirements of a cost-shared demonstration plant. It was agreed that a meeting to discuss the CCC program further will be held soon after the Westinghouse subcontract has been signed and approved by DOE-ORO.

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

E. C. Fox

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'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 TV-48296A, Subagreement 5).

11.1 AFBC Technology Support - Task 2

M. Siman-Tov and E. C. Fox

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

Support in evaluation of proposals for the TVA Pilot Plant and follow-on activities in assessing the scope of the facility have been completed. No additional activities are underway in this task.

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 x 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 were conducted to investigate the effects of slumping a portion of the bed and continuing operation of the remainder. Observations were 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 was then turned on to the slumped portion, and the action of the two sections was studied during refluidization. Cold flow model slumping tests have been conducted 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 were obtained incidental to these tests.

Progress to Date - The 1/4-scale-factor slumping tests were completed at the end of last month (See the September monthly report). The data are being analyzed and a report is in preparation.

The approximately 500- μ m limestone that was used for the 1/4-scale-factor test was removed from the bed and replaced with limestone that has a particle size of approximately 1000 μ m. This material will be used to determine the effects of particle size upon the amount of material that is removed from the fluidized bed and deposited in the slumped bed when operating in the slumped mode.

11.3 AFBC Modeling and Simulation - Task 4

M. Siman-Tov, J. W. Wells, and R. P. Krishnan

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 burnup 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, a successful run was made with the limestone-ash elutriation and attrition code. Details of the code have been described in previous monthly and quarterly reports. The equations used in the code for elutriation and attrition are described by Highley and Merrick.¹ The input data for the code were obtained from the series 5 test run in the Babcock and Wilcox (B&W) 6 ft x 6 ft AFBC.² The input data are summarized in Table 11.1.

Table 11.1 Input to Limestone-Ash Elutriation and Attrition Code

Temperature of bed	= 1117°K (1550°F)
Expanded bed height	= 121.2 cm (4 ft)
Density of sorbent	= 2.6 gm/cm ³ (162.2 lbm/ft ³)
Density of coal ash	= 3.0 gm/cm ³ (187.2 lbm/ft ³)
Bed voidage at minimum fluidization	= 0.4
Superficial velocity	= 234.7 cm/sec (7.7 ft/sec)
Density of flue gas	= 0.00032 gm/cm ³ (0.0199 lbm/ft ³)
Viscosity of flue gas	= 0.00045 gm/cm-sec (0.11 lbm/ft-hr)
Cross sectional area	= 33445.1 cm ² (36 ft ²)
Shape factor of limestone	= 0.83
Shape factor of ash	= 0.83
Feed rate of limestone	= 94.5 gm/sec (750 lbm/hr)
Feed rate of ash	= 16.88 gm/sec (134 lbm/hr)

The output material balance information obtained from the code is given in Table 11.2. The total solids being "blown out" of the bed consist of two types: first, the solids fed to the bed with a size small enough to be quickly elutriated; and second, particles formed into that size by attrition. In this model, the assumption is made that all attrition products are elutriated. A comparison of the output to B&W's data² is given in Table 11.3. The B&W runs were without reinjection of the elutriated fines. Figs. 11.1 and 11.2 show the size distribution of the bed as calculated by the code for the limestone solids and the coal ash.

The comparison given in Table 11.3 shows that the present code underpredicts the total solids "blown out" of the bed by 23%. Analysis of B&W's data has shown attrition and elutriation possibly depends upon:

1. feed system,
2. bed hydrodynamics, and
3. freeboard cooling.

(See the August 1979 monthly report.) Highley and Merrick's equations for the attrition and elutriation were developed for a different feed system and no freeboard cooling. The feed system may cause the size distribution of the limestone and coal entering the bed to be significantly different from that in the storage bunkers. This change is caused by numerous bends, elbows, and splitters in the feed system. This results in substantial attrition and, consequently, a higher amount of solids blown out of the bed. In Fig. 11.1, the calculated bed particle size distribution is compared with the experimental bed particle size distribution (B&W's data). The shape of the particle size distribution curve calculated by the code is similar to that found with no fines recycle. However, the B&W experimental particles size distribution on the bed has the shape which is typical of fines recycle.¹ Since no recycle of fines occurs in this series of tests, it is possible that freeboard cooling results in an indirect recycle of fines back to the bed (see August monthly report).

Also during this month, the combustion code was developed and is now running. In order to develop the model, certain assumptions were made. The major assumptions are listed and discussed below.

First, the system (FBC) is assumed to be at steady state (i.e., the conditions of a point do not vary with time). Next, two separate phases are proposed in the bed: the emulsion phase and bubble phase. The emulsion phase is characterized as the region of the bed devoid of bubble which contains the solids present in the bed (limestone, coal ash and char). The solids presented in the emulsion phase are assumed to be back mixed. Gas flows through the emulsion phase in upward direction assuming plug flow. The voidage of the emulsion phase is assumed to be the voidage observed at minimum fluidization in accordance with the two-phase theory. The velocity of the gas flow through the emulsion phase corresponds to the minimum fluidization velocity. The reactions considered in the emulsion phase are:

Table 11.2 Output from Limestone-Ash Elutriation and Attrition Code

Underflow from FBC

Limestone solids	coal ash
66.3 gm/sec (526.2 lbm/hr)	5.0 gm/sec (39.4 lbm/hr)

Elutriated Solids from FBC

Limestone solids	coal ash
12.5 gm/sec (99.2 lbm/hr)	8.7 gm/sec (69.0 lbm/hr)

Attrited and Elutriated Solid from FBC

Limestone solids	coal ash
15.8 gm/sec (125.4 lbm/hr)	3.3 gm/sec (26.2 lbm/hr)

Weight of Bed

Limestone solids	coal ash
3,218,366 gm (7095.2 lbm)	214,834 gm (473.6 lbm)

Surface Mean Particle Size

Limestone solids	coal ash
1550 mm (0.061 in)	1062 mm (0.042 in)

Table 11.3 Comparison of Attrition-Elutriation Code
Results to B&W's DataTotal Solid "Blown Out" of FBC

B&W	ORNL Model
52.4 gm/sec (415.9 lbm/hr)	40.3 gm/sec (319.8 lbm/hr)
% difference = 23.1%	

Percent Feed Limestone-Ash Solids "Blown Out"

B&W	ORNL Model
47.0%	36.2%

Weight of Bed

B&W (pressure drop)	ORNL Model
3.295×10^6 gm (7264.1 lbm)	3.433×10^6 gm (7568.3 lbm)
% difference = 4%

Figure 11.1 Particle size distribution for limestone solids.

Figure 11.2 Particle size distribution for coal ash solids.

1. devolatilization,
2. $C + 1/2 O_2 \rightarrow CO$,
3. $CO + 1/2 O_2 \rightarrow CO_2$,
4. $CO_2 + C \rightarrow 2CO$.

The devolatilization reaction is assumed to occur uniformly throughout the emulsion phase in the bed. The carbon released during devolatilization is assumed to form carbon monoxide (CO) instantaneously. Reactions 2 and 4 are heterogeneous gas-solid reactions. Their overall rates are, therefore, dependent on both the chemical reaction rate at the solid surface (intrinsic) and mass transfer rate of gaseous species to the solid surface. For the intrinsic reaction rate of reaction 2, the bituminous kinetics of Smith³ were used, and for the Boudouard reaction (reaction 4) the expression given by Caram and Amundson⁴ was used. The expression for the Boudouard reaction has been found to be ten times too high.⁵ Therefore, this expression has been reduced by a factor of ten. For both heterogeneous reactions, the particle surface temperature was calculated via the equation given by Smith.³ The rate expression for gas species mass transfer to the surface was obtained from Field.⁶ The kinetics for the gas phase reaction (reaction 3) were obtained from Horio, et al.⁵ The mass transfer term is not required.

In addition to the emulsion phase, the bubble phase is present throughout the bed. The bubbles are assumed devoid of all solids and the only reaction occurring is the gas phase combustion of carbon monoxide. The rate constant of this reaction is given by Horio, et al.⁵ Also, the bubble is assumed to have a very thin cloud. This assumption allows the interchange coefficient to be estimated from the Davidson model.⁵ The bubble size and bubble velocity have been estimated from the ORNL bubble growth model.⁷ This model was described in the July monthly report. Two types of bubbles are assumed in the bed: fast and slow bubbles. Slow bubbles are voids in the bed traveling upward at a velocity less than the interstitial velocity in the emulsion phase gases. This region is generally found right above the distributor plate. Gas flow passes through these voids and is not trapped in the voids. At some height (roughly 10 cm), the bubble velocity increases to a velocity greater than the interstitial gas velocity. At this point, the gas in the bubble becomes "trapped." This type of bubble is characterized as a "fast" bubble. These criteria are discussed by Catipovic, et al.⁸ In addition, it was assumed that the elutriation of char from the bed can be characterized by the elutriation constant of Wen and Hashinger.⁹

Based on the above assumptions, a series of three differential equations was developed for the slow bubble region (O_2 , CO, CO_2 balances), and six differential equations were developed for the fast bubble region (O_2 , CO_2 balances for emulsion and bubble phase). These equations will be derived and summarized in the final report. The solution to the equations gives profiles of the O_2 , CO, and CO_2 through the emulsion phase and bubble phase in the bed. Also, the rate of consumption of carbon for each particle size is determined from the above mass balances. This information is used with the differential particle

balance¹⁰ to determine the weight of the bed and the amount of carbon blown out of the cell. The logic flow diagram of the combustion code is given in Fig. 11.3. Input data and preliminary output from this code are given in Table 11.4. Also, Fig. 11.4 gives the predicted concentration profiles through the bed and Fig. 11.5 shows the calculated bubble diameter as a function of height.

During the next month, preparation of the final report for calendar year 1979 will begin. This report will include background information, code results, and detailed derivations for the system code and performance subcodes.

Table 11.4 Input Conditions and Preliminary Results of Combustion Code

<u>Input</u>	
Coal Feed Rate	= 112.4 gm/sec 892.0 lbm/hr)
Superficial Velocity	= 243.8 cm/sec (8 ft/sec)
Height of Bed	= 121.9 cm (4 ft)
Mean Diameter of Sorbent Bed Material	= 0.149 cm (0.06 in)
Bed Temperature	= 1117°K (1550°F)
<u>Preliminary Results</u>	
Weight of Char in Bed	= 22745.3 gm (50.1 lbm)
Weight Percent of Char in Bed	= 0.7%
Elutriation Rate of Char	= 19.2 gm/sec (152.4 lbm/hr)
Combustion Efficiency	= 91.5%

Figure 11.3 Logic flow diagram.

Figure 11.4 Calculated gas phase profiles.

Figure 11.5 Predicted bubble diameters as a function of height.

11.4 AFBC Bench Scale Facility - Task 5

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

11.4.1 Contract objective

The objective of this task is to investigate experimentally 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.

Scope - The scope of work includes tests to determine sulfur capture and carbon loss over a range of fluidizing velocities of about 4 to 10 ft/sec, combustion of recycle carbon over a velocity range of 4 to 8 ft/sec, and bed temperatures of 1450 to 1650°F. Several combinations of coal and sorbent of interest to TVA will be tested at several values of Ca/S. Carbon loss will be measured for each coal for several values of fluidizing velocity. Recycle carbon will be fed to the combustor to study its combustion.

Progress to date - Work was begun on characterization of TVA limestone "A" from Three Rivers Company in Smithland, Kentucky. The material was prepared and used for 17 hours of coal combustion during October in an effort to bring the limestone to a well-sulfated equilibrium.

The TVA limestone "A" was prepared by drying and sizing the stone to below 6 mesh. The material required no further crushing from the "as-received" condition. A screen analysis of the material "as-fed" into the combustion chamber appears in Table 11.5. The harmonic mean particle size of the "as-fed" limestone is 260 μm . The median (50 percent) size is 889 μm . The bulk density of the limestone is 1474 kg/m^3 (164.1 lb/ft^3). This yields a void fraction for the bulk material of 43.9 percent.

Room temperature fluidization tests were performed after blowing the green limestone placed in the bed at 1.5 m/sec (5 ft/sec) for 8 hours. Approximately 16 percent of the initial charge of limestone was elutriated from the bed. Reference to Table 11.5 indicates that this material was below 180 μm in size. A cursory sieve analysis yielded a 200- μm top size for the elutriated material. This loss of material resulted in a shift of the harmonic mean particle size to 724 μm . The median size changed to 1124 μm . A minimum fluidization velocity of 0.55 m/sec (1.8 ft/sec) was obtained for this material.

Table 11.5. Sieve Analysis for TVA Limestone "A", As-Fed

Sieve Size		Weight Percent on Sieve
U.S. No.	Opening, μm	
6	3350	-
8	2360	6.52
12	1700	17.76
16	1180	15.76
20	850	11.29
30	600	9.84
40	425	8.34
50	300	7.17
80	180	7.46
100	150	2.44
140	106	3.25
200	75	2.83
Thru 200	Below 75	<u>7.35</u>
		<u>100.00</u>

Seventeen hours of coal combustion were accumulated in an effort to calcine the limestone and to drive the sulfation reaction toward equilibrium. When the bed is well-sulfated, sulfur capture tests on limestone "A" will begin.

At the end of October, the new Beckman stack gas analyzer system was installed, field checked and calibrated by a Beckman engineer. This new instrumentation allows for the continuous measurement of O_2 , SO_2 , NO and NO_2 (combined and reported as NO_x), and CO concentrations in the flue gas from the fluidized bed combustor.

The new analyzer will be used next month to measure sulfur capture of limestone "A" during combustion of Kentucky No. 9 coal at 1.2 m/sec (4 ft/sec) and 815°C (1500°F). It is also anticipated that a large amount of time in November will have to be devoted to preparation and crushing of the remaining three limestones, since the "as-received" particle sizes are unacceptable for fluidization at velocities less than 3.0 m/sec (10 ft/sec).

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

Work on the final report on PFBC systems is continuing. Curtiss-Wright was contacted to learn of the status of their test program. After some early problems with the cyclone separators and subsequent modifications about 500 hours have been accumulated on their small gas turbine with no significant erosion.

Representatives from General Electric visited the Engineering Technology Division to discuss PFBC systems and to provide an update on the 1000 hour turbine materials tests at Leatherhead. They also noted some initial problems with the cyclones which accounted for the destruction of a cascade. The 1000 hour test is near completion and the results indicate satisfactory particulate removal with a combination of conventional cyclones and the G.E. electrostatically augmented cyclone. Deposits on the cascade were, for the most part, soft and apparently removable. The Leatherhead facility is now using a rotary valve coal feeder which is proving to be superior to the Petrocarb system. The system feeds to the combustor at 0.6 MPa (6.0 atm) pressure.

^aConsultant

11.6 Analytical Support and Alternate Design Concepts Evaluation - Task 7

E. C. Fox, C. S. Daw, and R. P. Krishnan

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

With the help of TVA project manager Ed Ball, a minor error in the main bed energy balance has been found and corrected. All calculations are being rerun with this correction, and the effects of the heating by the forced draft air fan are also being added. This latter factor is especially important for deep beds because the temperature rise due to compression can be recovered as heat input to the bed.

The most recent calculations still show that deep beds may offer significant advantages over shallow beds, especially if the combustion efficiency can be increased to the point where recycle and carbon burnup beds are unnecessary. The major uncertainty here is the effect of higher gas residence time on combustion efficiency. The Babcock and Wilcox (B&W) combustion efficiency correlation used in this study assumes that combustion efficiency is a strong function of the gas residence time. If a significant fraction of the coal is burned above or near the top of the bed, this assumption is highly questionable.

Another complication is that deeper beds will allow more bubble coalescence, which will in turn reduce the effective gas residence time. The simplified approach taken in this study does not consider the effects of bubbles. This kind of analysis will require a more rigorous fluid dynamics model, such as that being developed in Task 4.

The deep bed concept must ultimately be tested in an operating bed. The TVA pilot plant design should place high priority on having sufficient bed depth capability to confirm the link between residence time and combustion efficiency.

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: 1) to develop a single comprehensive source book of technical data for design procedures and evaluation of AFBC facilities and programs, 2) to review and evaluate existing and proposed AFBC facilities to perform research and development for TVA, and 3) 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

The draft of the fluidization section of the source book is undergoing final revision before being presented to TVA.

In preparation for starting the combustion section, some preliminary work is being done which includes setting up the computational scheme for mass transfer of solids presented by B. W. Overturf and F. Kayihan.¹¹

The overall mass flow of solids is shown in Fig. 11.6. In this figure, F_0 is the feed rate, F_2 represents entrained solids removed overhead, and F_1 represents the solids in the off-take. To calculate the solids mass transfer, one proceeds as follows, assuming a feed rate F_0 , particle size distribution P_0 , and bed weight W .

Figure 11.6 Steady-state flow of particles through a well mixed fluidized bed reactor.

1. Calculate the particle size distribution using the following.

$$p_1(\bar{R}_i) = \frac{F_0 p_0(\bar{R}_i) \Delta R_i - W R(\bar{R}_{i+1}) p_1(\bar{R}_{i+1})}{-W R(\bar{R}_i) + F_1 \Delta R_i + W K(\bar{R}_i) \Delta R_i - (3W/\bar{R}_i) R(\bar{R}_i) \Delta R_i},$$

where:

$p_1(\bar{R}_i)$ = the particle size distribution for the particles of average size $\bar{R}_i$,

$p_1(\bar{R}_{i+1}) = 0$ for the size of the largest particle,

F_0, F_1, F_2 = feed and exit mass flow rates, mass/time,

$R(\bar{R}_i)$ = the rate of shrinkage of particles of average size $\bar{R}_i$, and

K = elutriation rate constant, as defined in Kunii and Levenspiel.^{1,2}

2. Include the constraint

$$\sum_i p_1(\bar{R}) \Delta R_i = 1,$$

to calculate F_1 and $p_1(R_i)$.

3. Compute F_2 from the following.

$$F_1 + F_2 - F_0 = 3W \sum_{i=1}^N \frac{p_1(R_i) R(R_i) \Delta R_i}{R_i}.$$

The above procedure is a simplification of the approach taken by Jan Wells in his ORNL AFBC modeling effort (see Section 11.3). This procedure will be compared with and modified to yield relative agreement with more sophisticated trial and error methods. These calculations represent the first step towards setting up a simplified design procedure for calculation of combustion efficiencies.

Next month an attempt will be made to formulate the basis for a design procedure for the combustion section and also include the R&W empirical correlation.

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

T. G. Godfrey, J. H. DeVan, R. H. Cooper,
and R. A. Bradley

11.8.1 Contract objective

ORNL proposed 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

There are no significant accomplishments to report this month.

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

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

A control system was added to the model of the pilot plant. The following major control loops are included.

1. Firing rate. Boiler demand (target load) is determined from the superheater outlet steam flow and throttle pressure error. Boiler demand is compared with fuel flow, and firing rate is adjusted to eliminate throttle pressure error.
2. Secondary (and primary) air control. At a given excess air set point, boiler demand determines the needed air flow. This is compared with the existing air, and the inlet damper is positioned to zero the flow error.

3. Draft control. Furnace pressure is regulated by a two element controller that combines pressure error and a feedforward signal from boiler demand as inputs to the outlet damper.
4. Steam temperature control. Steam temperature error at the throttle provides the signal to position the attemperator valve. Additionally, throttle pressure error is used as a trim on the steam temperature set point to provide over- and underfiring as needed during load changes.
5. Throttle valve control. Because the pilot plant replaces a steam turbine with a condenser that has somewhat different thermohydraulic dynamics, changes in throttle valve setting will not necessarily produce the same responses as in a utility plant. For purposes of load following simulations, it would seem desirable to choose a throttle valve control mode for the pilot plant that mimics the behavior in a utility plant in important ways. With the scheme currently used in the model, the throttle valve is controlled to maintain the condenser outlet steam temperature at a set point. This forces the load (condenser heat transfer) to be proportional to steam flow rate, a major characteristic of turbines. Without this control action, the condenser outlet steam temperature varies with flow, and load is not proportional to flow.

The control systems shown in the vendors' pilot plant proposals appear to simulate load following by manually positioning the throttle valve. In a sense, this is the reverse of true load following, since the condenser load (air flow) is made to follow the valve setting (steam flow). The control action used in the model allows variation of condenser air flow to be the load change stimulus, which the throttle valve and other controllers then follow.

Each of the controllers uses proportional plus integral action. Ideal controllers are used to maintain drum and bed levels.

With the addition of the control system, the preliminary model of the pilot plant contains all its major parts. Simulations are under way, and detailed reporting of the calculations will begin next month.

11.10 Coal Feed Tests - Task 11

J. A. Stevens and V. R. Brantley

11.10.1 Contract objective

The objective of this task is to experimentally investigate feeding techniques and equipment for AFBC application. Fundamental tests will be conducted in order to establish the key operating variables over which reliable coal and limestone pneumatic feeding can be achieved.

11.10.2 Status summary

Construction of the basic test facility is nearing completion. Two long radius bend pipe sections ($R/D = 12$) are being fabricated for use during the first four test series. The first test configuration modification being considered consists of increasing the line size from the feed hopper to the coal pickup tee which includes making changes to the feed tank, the rotary feeder adaptors, and the coal pickup tee.

Calibration tests will be conducted for the rotary feeder in order to determine the maximum inlet pipe size, surface moisture content, and coal flow rate. A 6-in. x 6-in. rolling blade valve feeder has been ordered. Its potential for operation over a greater range of test conditions will be investigated.

Coal preparation procedures have been initiated which include drying, crushing, screening and sizing. The first four test series will make use of 1/4-in. x 0-in. size Kentucky No. 9 coal. Test series 1 to 3 will have a normal size distribution whereas test series 4 will allow for an increased percentage of fines (-200 mesh).

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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

At the Board of Director's meeting (October 5, 1979) of the St. Paul District Heating Development Company, the staff made a presentation comparing the energy costs related to the development of the 200 MW hot water district heating systems with cogeneration to the energy cost related to an expansion and renovation of the steam district heating system. The results were in favor of the hot water system and the Board unanimously agreed to pursue the development of a hot water system. The staff has since initiated work on a viable financial package. This is quite complicated since it could involve the municipality, the investor-owned utility, the State of Minnesota, HUD, and DOE.

Thirteen people (including one ORNL staff member and two DOE representatives)^a all affiliated with the St. Paul project traveled to Sweden to tour the Swedish hot water district heating systems (October 13-27, 1979). Sweden has 66 hot water systems which serve 25% of the country's heating demand. At the present time, they have a total of 12,000 MW of connected load and plan to expand to 30,000 MW by the year 2000. We visited several construction sites where they were laying new pipelines. All of the pipe was of the thin wall design and laid in extremely shallow trenches. These are two of the major cost-saving techniques utilized by the Swedes. A full trip report will be available by mid-November.

The contract procedure was initiated to do a study on the retrofitting of Northern States Power Company's Prairie Island Nuclear Power Plant to a cogeneration unit for district heating. As an electric-only unit, Prairie Island's thermal efficiency is approximately 32% whereas its potential as a cogeneration unit is as high as 85%. The contract will be with KVB, Inc. The anticipated starting date for the work is January 1, 1980.

^aThe others represented and were supported by various state and private agencies.

The performance comparison between the recuperated closed-cycle gas turbine and combined cycle cogeneration plants has been completed. As would be expected when designed for a specific maximum heat load, the combined cycle offers greater power output at low heat demands. The combined cycle, however, does not offer large advantages in power output or overall efficiency when the heat demand is high which is the condition which the Twin Cities district heating plants will see for a large part of each year. Preliminary cost estimates showed that the combined cycle and simple cycle were comparable on a unit power basis (\$/kW(e)). It was decided, however, that the higher cost per thermal output and additional complexity of the combined cycle were not justifiable for this application. Future refinements to design and cost estimate should emphasize the simple, recuperated cycle. Both closed-cycle systems appear to have higher fuel efficiency at maximum heat load than the conventional extraction steam turbine plants when simultaneous 400 MW(e) and 700 MW(e) output is required.

13. TECHNICAL SUPPORT TO MAJOR LIQUEFACTION PROJECTS

T. W. Pickel

Technical support is being provided for the major liquefaction projects being managed by the Oak Ridge Operations Office of DOE. Current activities are related to the Solvent Refined Coal Demonstration Plant Projects, SRC-I and SRC-II, and the H-Coal Pilot Plant Project. Major parts of the current effort are concerned with SRC environmental support and H-Coal materials and technology review. Support is being provided in the areas of reliability, safety, and quality assurance.

13.1 SRC Demonstration Plants Design Review

J. J. Kurtz

13.1.1 Contract objective

This activity consists of providing technical assistance to the DOE-ORO Solvent Refined Coal Projects Office on the SRC-I and SRC-II projects. The SRC-I project involves the design, construction, and operation of a coal liquefaction plant for the production of a clean solid boiler fuel. The SRC-II project is for the production of a clean liquid boiler fuel. The government-funded preliminary design of the SRC-I project is contracted with the Southern Company Services, Inc. (SCS), and the SRC-II project contract is with the Pittsburgh and Midway Coal Mining Company (P&M).

The principal purposes of the SRC projects review and evaluation activities are to provide objective assessments of the contractors' technical progress, identification of potential problems, and critiques of project deliverables.

13.1.2 Status summary

The monthly technical status review meetings for the SRC-I and SRC-II projects were monitored in Allentown, Pennsylvania, and Denver, Colorado, respectively. The major topics addressed in the SRC-I status review were filtration and deashing. Air Products and Chemicals, Inc. (APCI), was informed that the DOE position is to support the concept favoring deashing over filtration. The SRC-II status review addressed a number of problem areas and design options under consideration or resolved. Problem areas which were reviewed included dissolver feed coal size, slurry mixing, vacuum bottoms storage and pumping, pressure letdown, and waste treatment. The design options addressed were plant fuel priorities, H₂ cryopurification, Texaco gasifiers, and oxygen plants.

Effort was initiated to develop a UCC-ND plan for more formalized support to the DOE-ORO SRC Projects Office for Phase I of the SRC-I and

SRC-II projects and the H-Coal pilot plant project. The formalization involves the designation of a dedicated functional support group and a charter of activities to provide continuity in support activities on all coal liquefaction projects managed by the DOE-ORO SRC Projects Office.

13.2 Direct Liquefaction R&D Review

M. S. Edwards, B. R. Rodgers, C. H. Brown, W. R. Gambill

13.2.1 Contract objective

This project is an assessment of current research and development activities of importance to the SRC demonstration plants projects. 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 project, and cross-matching R&D activities to the technical data needs of the industrial partners in the demonstration project. Based on the assessment of R&D activities against the data needs of the SRC demonstration project, 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.

13.2.2 Status summary

The draft report, ORNL/TM-6952, "Technical Support to the SRC Demonstration Projects: Assessment of Current Research and Development," has been widely distributed, particularly to those institutions whose activities in coal conversion research are described within the report. Comments and updates have been incorporated in the report. Recommendations have been revised and reordered based on latest plans and progress of the SRC industrial participants in both R&D and demonstration plant designs. The final report has been completed with respect to technical revisions and is in final stages of preparation.

13.3 SRC Source Data Book

J. P. Belk, M. H. Culver, J. R. Horton, M. R. Lambert, H. A. Mitchell, B. Niemann, W. R. Reed, J. R. Tate, B. T. Thompson, W. T. Thompson

13.3.1 Contract objective

The objective of this project is to develop and to make available in one package an independent source of technical information and data base as an aid to DOE program management and other participants in the DOE program to design, construct, and operate SRC demonstration plants.

13.3.2 Status summary

Activity on this project for the month of October has included updating and extension of the literature collection in the Engineering Library at Bldg. 1000; preliminary development of a new work statement, work breakdown structure, and activity description for FY 1980; and further work on the source book format.

13.4 SRC Environmental Support

S. G. DeCicco

13.4.1 Contract objective

The objective of this project is to provide DOE with program assistance in the performance of environmental assessment functions related to the SRC projects. Assessment functions include review of environmental monitoring programs and results, guidance to DOE's industrial partners in their environmental impact analyses, review of environmental permits and licensing requirements, review of SRC contract deliverables, and providing the lead role in fulfilling DOE's responsibilities under the National Environmental Policy Act (NEPA).

13.4.2 Status summary

On October 2 we received a draft of the SRC-II environmental analysis report from Stearns-Roger. This document was to serve as the data base and supplementary text to ORNL's preliminary draft EIS. The document was not adequate, however, especially in its analysis of impacts. The document was critically reviewed by the ORNL team and comments identifying the inadequacies was sent to DOE-ORO.

On October 9 a meeting was held with R. C. Martin (ORO) and J. J. Nelsen (CHO) to discuss the combined traffic impacts of the W. R. Grace coal-to-ammonia demo plant and the SRC-I demo plant. The proposed sites for the two plants are within 15 miles of one another in northern Kentucky, and will draw from the same labor shed and rely on the same road system (which is already at capacity).

An EIS status meeting for SRC-I and SRC-II was held on October 11, providing an opportunity for DOE-ORO to discuss current findings and problems with individual team members.

During the week of October 22, 1979, the following public scoping meetings were held to solicit public input for the SRC-I and SRC-II environmental impact statements.

October 22, 1979	SRC-II	Morgantown, WV
October 23, 1979	SRC-II	Pittsburgh, PA
October 24, 1979	SRC-I	Owensboro, KY
October 25, 1979	SRC-I	Louisville, KY

A panel consisting of Bob Martin (DOE-ORO), Bill Ichord (DOE-Office of NEPA Affairs), a representative of the industrial participant (Gulf or Air Products), a representative for Kentucky Department of Energy (for SRC-I only), and S. G. DeCicco presented the status of the project. The meetings held close to the proposed sites (the Morgantown and Owensboro meetings) attracted the largest crowds. Pittsburgh and Louisville were selected as meeting locations to attract nationally-based interest groups. Attendance at these locations was under one dozen per meeting. In general, regardless of the size of the crowd, well informed citizens were present and expressed rather sophisticated questions and points of view. The most informative and dramatic meeting was the Morgantown meeting where organized citizens disrupted DOE's opening presentation and insisted that they restructure the meeting beginning with a reading of their list of demands.

The risk of cancer was the dominant theme at each meeting. Citizens were aware of and concerned about the presence of carcinogenic substances in products, by-products, internal streams, waste products, and fugitive emissions. Their concerns were exacerbated by the inability of the scientific community to quantitatively assess the risks. Many comments left the implication of, "Why are you spending one billion dollars to build this plant if you can't answer our questions about the risk of cancer?"

Another recurring suggestion was the treatment of the commercial-scale facility in the ETSS since the demo plants are planned as modules of future commercial-scale plants at the same sites. Also, the synergistic effects of emissions from these plants and other existing and planned facilities (especially the Ohio River Valley for SRC-I) troubled citizens at several of the meetings. These comments centered around the cumulative and secondary impacts brought on by the project such as increased coal mining impacts, increased impacts from barge traffic, increased emissions from power plants supplying energy to the facility, and increased industrialization of the surrounding area. Some citizens asked where the alternatives of solar and conservation would be addressed, bringing up the need for a good programmatic EIS. Another citizen questioned DOE's obligation to maintain tight emission control in a future scenario where "synfuel fever" causes the relaxation of environmental quality standards.

One citizen posed the question of whether the by-product sulfur would be a salable material or a solid waste. Another citizen expressed concern about long-term effects generated by decommissioning. After hearing the plans for groundwater monitoring during operation, another citizen asked how contaminated groundwater could be cleaned up once the problem is detected by the monitoring program. Several citizens asked how and why the proposed site was selected, verifying the need for a strong alternative site analysis in the EIS.

Several other citizens were uneasy about the role of the EIS in decision making: "If the EIS concludes that the project will cause serious environmental impacts or subject us to serious risks, can the plant be built anyway?"

13.5 SRC Net Energy Analysis

W. P. Huxtable

13.5.1 Contract objective

The objective of this project is to evaluate the overall energy efficiency of solvent refined coal (SRC) processes from coal mining to electricity production and delivery. Analysis will consider not only plant efficiency but will also encompass energy requirements of raw material acquisition, product distribution, plant construction, and other factors.

13.5.2 Status summary

The report covering this study has been edited and is being given a final review by Engineering management. During this past month, a computer program was developed to perform some of the more complex net energy analysis computations. This program estimates the amounts of energy resources, including coal, crude oil, gas, and electricity required for building and operating a specified plant or transport system. The input information required for the estimate includes a detailed cost estimate of the facility or transport system. The program's main function will be to replace tedious and error prone hand calculations and to provide error bounds on net energy estimates. This program includes the latest available net energy analysis data including price deflators up to the year 1977 that were developed by the University of Illinois specifically for net energy analyses.

The program is fully operational and should prove useful for updating the current SRC study and other net energy studies. A letter summarizing its capability is being prepared for future users.

13.6 H-Coal Materials and Technology Review

R. A. Bradley, K. H. Lin, P. Carlson, V. Guthrie, J. R. Horton,
H. A. Mitchell, B. Niemann, L. Parsly, W. R. Reed,
R. W. Swindeman

13.6.1 Contract objective

Overall objective - Evaluation of the materials of construction and the coal liquefaction technologies planned for use in the H-Coal pilot plant relative to the available data and experiences. The evaluation

will attempt to ensure the maximum utilization of the existing information and experiences from other liquefaction pilot plants and process demonstration units (PDUs), and to provide the bases for efficient and reliable operation of the plant.

Scope - The project activities will cover the following five subjects pertaining to the H-Coal pilot plant:

1. materials of construction and potential materials-related problems in the plant;
2. reliability of critical components in the pilot plant design;
3. potential problems associated with the plant equipment and accessories due to deficiencies in the engineering design;
4. significant operating and maintenance experiences from other liquefaction pilot plants, which will be useful to the H-Coal pilot plant; and
5. an "incident report" system to distribute information on technical problems.

13.6.2 Status summary

Review of technical data on H-Coal pilot plant - Comprehensive review of the engineering drawings and documents pertaining to operation and design has continued. The preliminary results of the review were also used as the basis for compilation of the comments and questions to be discussed during our visits to selected coal liquefaction facilities.

Visits to coal liquefaction facilities - Representatives of the Task Force visited three different facilities this month, including the PDU of the Hydrocarbon Research, Inc. (HRI, Trenton, New Jersey), the C. E. Lummus Company (Bloomfield, New Jersey), and the Ft. Lewis, Washington, SRC pilot plant. Highlights of the meetings and plant tours at these facilities are summarized below.

1. HRI-Trenton PDU

Date of visit: October 26, 1979

Meeting participants: HRI (10), DOE (2), Task Force (7)

Main subjects of discussion: (a) HRI-PDU experiences in critical coal liquefaction equipment, (b) questions on selected units of equipment in various areas of the H-Coal pilot plant (e.g., coal slurry preparation, high pressure pumping, fired heater, H-Coal reactor, letdown valves, hydroclones, etc.), and (c) tour of PDU.

2. C. E. Lummus

Date of visit: October 23, 1979

Meeting participants: Lummus (6), DOE (1), Task Force (4)

Main subjects of discussion: (a) historical background on deashing process development, (b) development of antisolvent deashing process data for H-Coal pilot plant, (c) design basis for H-Coal deashing system, (d) operating data and experiences from deashing system for SRC-Ft. Lewis pilot plant, (e) LC-Fining process, and (f) expanded bed coal liquefaction process.

3. SRC-Ft. Lewis

Date of visit: October 29-30, 1979

Meeting participants: Pittsburg & Midway (10), DOE (2), Exxon (10),
Task Force (8)

Main subjects of discussion: (a) brief technical description of SRC-II process and plant operation, (b) effect of slurry viscosity behavior on performance of various pumps, (c) significant experience in slurry mixing, control valves and flow meters, pumps and compressors, and slurry piping, (d) normal procedures for start-up and shutdown, (e) general planning and scheduling for operations and maintenance, (f) significant operating and/or failure events, and recommended recovery procedures, (g) potential problems resulting from failure of certain components or systems in plant, (h) materials of construction, and erosion/corrosion problems experienced with critical components, (i) recommended design practice in pumps, and (j) tour of pilot plant.

Identification of potential materials-related problems - A letter report summarizing the preliminary evaluation of the materials of construction for the H-Coal pilot plant has been submitted by R. W. Swindeman to DOE-ORO. The evaluation was focused on the materials for process vessels and piping. Two potential problem areas identified thus far are: (a) high thermal stress in the H-Coal reactor vessel, possibly leading to fatigue failure, and (b) possible corrosion or stress-corrosion cracking of the low pressure regions in Section 200, e.g., around the fractionator. Item (a) is based on consideration of the materials of construction and operating conditions (especially temperature) for the reactor, while item (b) is based on the reported experiences of the SRC plant.

13.7 Materials Testing and Failure Analysis

V. B. Baylor, J. R. Keiser, R. W. Swindeman

13.7.1 Contract objective

The objective of this activity is to provide technical assistance to the H-Coal pilot plant project in the areas of materials testing and failure analysis.

13.7.2 Status summary

Representatives from ORNL visited the University of Kentucky Institute for Mining and Minerals Research (IMMR) on October 1 and the H-Coal pilot plant on October 2. Plans were finalized regarding the ORNL supplied corrosion coupons. Thirteen racks of ten specimens each will be inserted in six different vessels. In addition, 24 corrosion coupons will be installed on racks furnished by IMMR in three vessels. The framework for the H-Coal failure analysis plan has been developed and reviewed. Efforts are now underway to develop more specific details.

13.8 Performance Assurance System Support

H. A. Mitchell, W. K. Crowley, B. L. Greenstreet, V. H. Guthrie,
H. A. Nelms, L. F. Parsly

13.8.1 Contract objective

The ORNL Performance Assurance System Support Office is responsible for acquiring, generating, and disseminating information relating to performance assurance (PA). The Support Office will provide performance assurance related technical support services to those Fossil Energy programs under the decentralized management control of the Oak Ridge Operations Office and to programs under the direct management control of the Washington Headquarters Office. The Support Office will, as required, design and develop appropriate procedures, tools, and methodology necessary to provide the PA support services indicated.

Two specific tasks have been initiated at the request of Fossil Energy Headquarters Office: (1) preparation of generic failure modes and effects analyses and (2) assistance to SRC projects to review contracts and deliverables.

13.8.2 Status summary

An action plan was developed describing the preparation of a generic failure mode and effects analysis (FMEA). The major tasks begun include the review of systems and components in the SRC-I and SRC-II designs and the H-Coal project to identify components common to all systems. When approved by the project technical monitor, the support group will perform generic FMEAs on selected components and systems.

The performance assurance support group assisted in the preparation of rough drafts of standard requirements for safety, reliability, and quality assurance at the requests of Fossil Energy Headquarters Office. The scope of the standards includes the minimum management and technical requirements necessary to provide an adequate performance assurance program.

Based on these standards and discussions with the SRC contractors and project management, the support group has developed a list of recommended tasks to be performed during Phase-I efforts by the two contractors. A continuing effort is being made to provide assistance to the project manager in preparation of contract language describing these tasks. The results of this effort will be a definitized statement of work describing activities related to performance assurance.

In addition to providing support to the SRC Project Manager, the group was requested to review the quality assurance plan for the operations phase of the H-Coal pilot plant. The review was performed based on the contract statement of work and general guidelines described

in DOE Manual OR-IMD-02XX. Based on the review, it was recommended that the following activities be included in the operations phase effort.

1. A quality assurance manager and appropriate staff should be provided.
2. An incident and failure reporting system should be established.
3. A quality assurance assessment and audit program should be required.

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