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**Fossil Energy Program
Progress Report for May 1980**

L. E. McNeese

MASTER

**OPERATED BY
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FOSSIL ENERGY PROGRAM
PROGRESS REPORT FOR MAY 1980

L. E. McNeese
Program Director

Date Published: August 1980

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FOSSIL ENERGY PROGRAM REPORT FOR MAY 1980

ABSTRACT

This report - the seventieth 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, chemical research and development, materials technology, component and process evaluation studies, technical support to major liquefaction projects, process analysis and engineering evaluations, fossil energy environmental analysis, coal preparation and waste utilization, coal preparation plant automation, technical support to the TVA fluidized bed combustion demonstration plant program, coal cogeneration/district heating plant assessment, atmospheric fluidized bed coal combustor for cogeneration, performance assurance system support and international energy technology assessment.

1. Summary

L. E. McNeese

Coal conversion development - A series of pipeline viscometer differential pressure measurements is being made by varying the slurry temperature while the feed rate is held constant. During the month one run was completed with 35 wt % Illinois No. 6 coal slurry at 0.855 g/s feed rate and 13.9 MPa pressure and temperatures in the range of 450 to 725 K. Work has now been started on the rheological characterization of Kentucky No. 9 coal and SRC-I recycle solvent produced from Kentucky No. 9 coal. The recycle solvent was found to be a Newtonian liquid as expected. Preliminary results indicate that the peak viscosity of 35 wt % Kentucky No. 9 slurry is somewhat higher than that for Illinois No. 6 coal slurry. Construction of the electronic network for the transient hot-wire thermal conductivity instrument has been completed and checkout tests are being performed.

Reducing the phenol/coal ratio from 10/1 to 2/1 at the same vapor density reduced the conversion from 79 to 55% MAF. Hydroquinone was found to be relatively stable under anticipated reaction conditions opening the possibility of the use of multihydroxy benzenes in the phenol/coal reaction. Preoxidation with HNO_3 did not increase the chloroform solubility of the phenol/coal products enough to justify the technique. Silylation of the products proved to be an effective preparation for NMR analyses and some general conclusions from these results are given.

Chemical research and development - Preliminary thermolysis studies of neat 1,3-diphenylpropane have revealed a long-chain, free-radical decomposition pathway. Use of ^{14}C tracer studies applied to the Kerr-McGee Critical Solvent Deashing Process showed that chemical bonding of solvent to SRC under simulated CSD conditions is negligible but retention of solvent by strong physical binding is significant. Our pulsed reactor-mass spectrometer for Fischer-Tropsch mechanism studies has now been fully checked out, and reproducible results are easily obtained.

Materials technology - The study of the effect of coal conversion environments on the hydrogen attack of pressure vessel steel was continued. The report describing the computer program for calculating the thermodynamic properties of complex alloys was revised. The run exposing samples of various microstructures to hydrogen at 540°C and 13 MPa was terminated after 60 days, and examination of the specimens for hydrogen attack is under way. In the welding and cladding development task, a 30-cm-thick section of 2 1/4 Cr-1 Mo weldment supplied by a commercial vendor is being machined into specimens for mechanical property testing and microstructure examination. In addition, samples with a weld overlay cladding of type 320Cb stainless steel are being prepared for testing in a liquefaction environment. Efforts in the study of fireside corrosion of AFBC heat exchanger materials involved the preparation of the paper "Heat Exchanger Materials for Fluidized-Bed Coal Combustors" for inclusion in the proceedings of the 6th International Conference on Fluidized Bed Combustion. In the failure prevention and analysis task, the examination of the transfer line between the preheater and the dissolver of the Wilsonville SRC Pilot Plant was completed. Although chloride stress-corrosion cracking is suspected, the examination did not conclusively prove that chlorides were responsible for the cracking. Additional examination of this potential problem is needed. The investigation of materials performance in liquefaction systems continued. These studies include general corrosion and stress-corrosion cracking in liquefaction environments, corrosion in the fractionation area of SRC plants, and the evaluation of materials proposed for the regeneration and condenser vessels of the Zinc Chloride Hydrocracking Process. In the latter study, results of a 500-h exposure of various alloys to HCl, dry air, and ZnCl_2 at 560 to 970°C are described. In the task for development of modified 9 Cr-1 Mo steel, the fabrication of the two 14-Mg heats procured previously into plate, bar stock, and tubing continued. Preliminary testing and evaluation of these heats have shown that the mechanical properties of the commercial heats meet the values expected based on experimental and intermediate-size commercial heats. In the ceramic recuperator task, the examination of ceramic specimens exposed to the products of combustion of No. 6 fuel oil at about 1200°C for 500 h continued. A report on the results of this test is in preparation. Studies were initiated to determine the feasibility of adding a powdered coal injection system to the Ceramic Recuperator Analysis Facility.

Component development and process evaluation - Discussions were held with TVA regarding their interest in providing a site for the proposed dry coal feeder test facility. A seed money proposal is being prepared for carrying out a feasibility study of a novel slurry feed/letdown system incorporating the flow work exchanger concept.

Technical support to major liquefaction projects - Support is provided by Oak Ridge National Laboratory and Union Carbide Nuclear Division Engineering for the major liquefaction projects being managed by DOE Oak Ridge Operations--SRC-I and SRC-II Demonstration Plants and H-Coal Pilot Plant projects. Activities are reported in twenty-four specific subtasks grouped into seven broad categories--engineering and design review, technology overview, design data validation, components, materials, environmental and health, and general technical support.

A draft report on selection of feed coals for SRC demonstration plants was submitted to DOE for review. An engineer has been proposed to provide technical representation at the H-Coal pilot plant; DOE has requested that efforts be suspended for placing technical representatives at Wilsonville, Ft. Lewis, and Harwarville. Design objectives for the coal slurry mixing tests have been discussed with P&M and ICRC. The apparatus for study of packed-bed pressure let down is nearly completed. In further tests on corrosion in the fractionation area of liquefaction plants, chloride is implicated as an important causative factor. The draft environmental impact statement for the SRC-II project has been issued; that for the SRC-I project will be issued shortly. A draft report assessing the safety of the H-Coal reactor was issued.

Process analysis and engineering evaluations - The draft final report for Phase I of the Liquefaction Technology Assessment (LTAS) project was completed and limited distribution within DOE and ORNL was made for review and comment. The report, Liquefaction Technology Assessment. Vol. I: Indirect Liquefaction of Coal to Methanol and Gasoline Using Available Technology, ORNL-5564/V1 (Draft), will be made available for proponent review in early June, following receipt of reviewer comments.

Fossil energy environmental analysis - In the Stored Solids Study, additional analytical measurements have been completed on column leachates and tests have been initiated on the shipment of SRC-II slag. In the EIS work for coal conversion demonstration plants, a review draft of the MLGW statement was sent to DOE on May 9. The SRC-II Draft EIS was accepted by DOE/EV and EPA on May 23 and was distributed to the public and other agencies on May 26.

In the ERA Support Project several engineering studies were received from our subcontractor and are being reviewed and revised. Various coal supplies have been identified and work is proceeding on the fuel supply studies for the Arthur Kill and Ravenswood power-plants.

During the month the second document in the NEPA Fossil Energy series was completed and distributed. The Environmental Program Compliance Handbook for Tennessee is nearing completion. Speakers and topics for the IH/OM workshop have been finalized and confirmed.

Coal preparation and waste utilization - The continuous separation test series at Sala Magnetics has been completed and the bulk of the chemical analyses completed. A new set of experimental equipment has been designed and fabricated for open-gradient separation testing in the laboratory superconducting magnet. This equipment will permit exploration of a broader range of separating parameters as well as investigating the capacity. Several industrial concerns have inquired regarding separation of materials other than coal, and test separations of samples have been performed for one.

Coal preparation plant automation - Development studies on sensors and instruments to monitor level, density, and particle size continued. Work on the state-of-the-art assessment continued with visits to two coal preparation plants and the ongoing review of the open literature. A visit to one coal preparation plant provided insight into the problem of control of the moisture content of the fine coal circuit. Evaluation of plants within a 100-mile radius of ORNL as locations for on-site testing began. Several small data acquisition systems were studied as candidates for use in preliminary on-site tests, and a tentative selection was made. Work continued on the study of the potential of x-ray diffraction as a technique for on-line monitoring of the mineral content of coal.

Atmospheric fluidized bed coal combustor for cogeneration (AFBCCC) - Submission of the revised cost estimate by Westinghouse was delayed by a request by Babcock and Wilcox to submit new cost figures with a lower overhead rate. A Letter of Intent has been signed by UCC-ND and the Westinghouse team that will permit them to begin limited work on June 2 for a period of 60 days.

Tennessee Valley Authority (TVA) fluidized bed combustion (FBC) demonstration plant program technical support - During this month, work continued on the development of the sulfur capture model and the freeboard model. The sulfur capture model, based on the grain model, was debugged and used to generate some typical results. In the freeboard modeling, methods of simplifying and modifying the code were investigated. A paper entitled "Elutriation and Attrition Phenomena in Industrial Atmospheric Bed," by J. W. Wells and R. P. Krishnan, was presented at the International Bulk Solids and Powder Conference in Chicago, Illinois.

TVA sulfur capture testing in the bench scale facility was continued during May with limestone from the Reed quarry in Gilbertsville, Kentucky. Forty-eight hours of coal combustion were accumulated during the month; data were obtained for superficial velocities of 1.2, 1.5, and 1.8 m/s (4, 5, and 6 ft/s) at bed temperatures near 840°C (1550°F). The performance of the Reed limestone compares favorably with that of Fredonia Valley and Vulcan, two of the best limestones tested to date.

In the materials support task, examination of the Leatherhead tube specimens has focused on the calcium sulfate deposits from both the steam-cooled sample tubes and the uncooled high-alloy coupons. Samples of the deposit are being analyzed by a variety of techniques including quantitative chemical analyses, x-ray diffraction and fluorescence, energy dispersive x-ray analyses (EDX), and optical microscopy. The chemistry (and structure) of this deposit is very pertinent to the thermodynamic calculations performed under Task 12 because the presence or absence of CaO in the deposit seemingly controls sulfidation of the alloy constituents. Thus far, evidence indicates very little or no CaO is present. Surprisingly, however, the analyses show about 1% C in the deposit. If this carbon is in a reactive form, it could serve to hold a very low oxygen activity at the alloy surface.

A series of three tests is currently being carried out in the muffle furnace facility to determine the corrosion response of a variety of CaSO_4 -coated alloys in a simulated AFBC environment of progressive severity. In each test, two samples of each alloy type are exposed in the as-received condition. At this time the first test has been completed and the second test is underway. Analysis of these samples revealed weight changes for all samples of 1/2% or less; therefore, no significant corrosion attack has occurred. Since the last reporting period, significant progress has been made in modifying the Fluidyne facility for the eight 200-h tests. Approximately one-third of all the needed sample tubes for the eight 200-h tests were shipped to Fluidyne.

Coal cogeneration/district heating plant assessment - The work is essentially completed; all that remains to be done is the documentation. Two of the four volumes of the documentation are in draft form. The review letter describing the closed-cycle turbine concept was completed by the end of May and was sent to a gas turbine manufacturer (Rocketdyne) on June 6, 1980.

Performance assurance system support for fossil energy projects - Work on the failure mode and effects analysis (FMEA) for a generic slurry preheater has continued. FMEA work sheets have been redone with four high-severity failure modes identified. Three additional tasks descriptions have been developed for review and approval.

International energy technology assessment - ORNL is supporting the Lawrence Livermore Laboratory in making an assessment of international energy technology. A research and development subcontract with Gilbert/Commonwealth to review the state-of-the-art of coal liquefaction was approved. A request for information on various gasifiers was submitted to the ORNL/DOE representative of the International Energy Agency in London, England.

In the area of coal liquefaction materials, information gathering is progressing, but limited published information appears to be available on materials development programs and material selections. To assist in the assessment, a cross-reference tabulation of United States alloy data with similar foreign materials has been initiated.

The survey of atmospheric fluidized bed combustion technology will be identifying and describing development work and application of AFBC systems in foreign countries. A detailed assessment of the state-of-the-art in particular categories of technical problem areas and developmental projects will be provided. A search for published information in the literature has been initiated and letters of inquiry have been sent to various individuals and agencies in foreign countries. The Sixth International Conference on Fluidized Bed Combustion held last April in Atlanta, Georgia, provided an excellent opportunity to meet representatives from foreign countries. Discussions were held with one or more individuals from these countries: United Kingdom, West Germany, India, Ireland, Japan, Denmark, Finland, and the Netherlands. ORNL is working closely with Argonne National Laboratory (ANL) which is conducting a similar survey on pressurized fluidized bed combustion technology.

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 Office of Coal 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, and L. S. Dickerson

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.

Results of pipeline viscometer differential pressure measurements on 35 wt % slurry from 400 to 725 K at a constant slurry feed rate are presented. Thermal conductivity instrument development is discussed.

2.1.1 Work accomplished

As outlined in the last quarterly report,¹ a series of runs are being made in which the slurry feed rate to the system will be held constant, and the slurry will be preheated with incremental increases in preheater discharge temperature. The heated slurry is passed directly through the pipeline viscometer located at the preheater exit. Viscometer temperature is controlled to match the preheater discharge temperature, and the viscometer differential pressure is recorded as a function of temperature from 400 to about 730 K. At each measurement temperature, the preheater is operated with constant heat flux along its length. If possible, this procedure will be repeated over the range of slurry feed rates possible with the positive displacement feed pump (0.4 - 1.0 g/s). These measurements will characterize the flow behavior of slurry in the gelation region and will provide broad rheological characterization information on slurry outside of this area.

A run was completed on 35 wt % Illinois No. 6 coal/Wilsonville recycle solvent slurry at 0.855 g/s slurry feed rate and 13.9 MPa (2000 psig) pressure. Results are presented in Figure 2.1 — a plot of viscometer differential pressure vs slurry temperature. This curve is nearly identical to the curve at 0.793 g/s slurry feed rate reported in the last monthly report.² For both runs, peak viscometer differential pressure was about 2.48 kPa (10 in H₂O) at 650 K. The estimated viscosity of the slurry at the gelation peak was 10 mPa·s (10 cp) for both runs. This was the last run using Illinois No. 6 coal (River King mine) and Wilsonville recycle solvent (SN 39731, run 142) produced during operations with Indiana No. 5 coal. The results of the constant flow rate, variable temperature measurements with this slurry mix will be summarized in the next quarterly report.

Because Kentucky No. 9 coal is the planned SRC-I demonstration plant feed material, future rheological characterization runs will be made on slurry prepared from Kentucky No. 9 coal (Pyro mine) obtained from the Wilsonville SRC-I facility and Wilsonville recycle solvent (SN 55602) produced during operations with Kentucky No. 9 coal.

Some preliminary rheological characterization measurements were completed on the Kentucky No. 9 derived recycle solvent and on 35 wt % Kentucky No. 9 coal (-170 mesh)/Kentucky No. 9 Wilsonville recycle solvent slurry. As expected, the solvent was found to be a Newtonian liquid. Pipeline viscometer rheological characterization measurements were made at constant temperature 340 K (150°F), and variable flow rate (0.2 - 0.9 g/s) at 13.9 MPa pressure; a linear regression on these data (15 data points) in flow curve form ($\log \tau_w$ vs $\log 8V/D$) had a slope of 1.008 with correlation coefficient of $r^2 = 0.993$. The slope of a flow curve is 1.0 for Newtonian liquids. Viscosity was 4.0 mPa·s (4 cp) from the flow curve analysis.

To investigate operability of the Coal Liquids Flow System with the new slurry mix, a constant flow rate-variable temperature rheological characterization run was made on 35 wt % Kentucky No. 9 coal (-170 mesh)/Kentucky No. 9 Wilsonville recycle solvent slurry. A temporary blockage developed somewhere in the preheater system as temperature was increased to about 700 K (800°F). It could not be determined if the blockage resulted from coke formation or by malfunction of a check valve in the preheater feed system. Up to this point operation was very smooth. Peak gelation occurred at ~640 K; viscometer differential pressure was 4.1 kPa (16.4 in H₂O). Allowing for the differences in mass flow rate through the viscometer, this is about 40% higher than the most recent measurements on Illinois No. 6 coal slurry at peak gelation. The shape of the viscometer differential pressure-slurry temperature profile was similar to that observed for Illinois No. 6 slurry. Minimum differential pressure, 1.1 kPa (4.5 in H₂O), occurred at the 500 K measurement. This is about the same temperature and minimum differential pressure as observed for the Illinois No. 6 slurry.

ORNL-DWG 80-842

35 % ILL. NO. 6 (-170 MESH) COAL /
WILSONVILLE RECYCLE SOLVENT
PRESSURE = 13.9 MPa (2000 PSIG)
SLURRY MASS RATE = 0.855 g/s
VISCOMETER DIMENSIONS =
2.77 mm ID x 0.61 m LONG

Fig. 2.1. Viscometer differential pressure vs slurry temperature.

Construction of the electronics network for the transient hot-wire thermal conductivity instrument was completed. The instrument uses a 7.6×10^{-5} m diameter platinum wire 0.2 m long as a line heat source. A schematic of the instrument is shown in Figure 2.2. The circuit consists of a Hewlett-Packard 6140A digital current source, a switching circuit, precision voltage suppression circuits for removing the large dc component from the signal, and signal amplifiers. A ballast resistor is provided to minimize the transient in the circuit as current is applied to the platinum wire. Before measurements are made, the resistance of the ballast resistor is matched with the platinum wire by matching the voltage drop across each when a low-level current is applied. When measurements are made, current is initially routed through the ballast resistor. A high-speed mercury relay is then activated to switch the current flow through the platinum wire, and the voltage drop across the wire is amplified and recorded by oscilloscope or by the on-line PDP-11/34 computer to produce a plot of temperature rise versus the logarithm of time from which the thermal conductivity of the fluid can be calculated.

Measurements are being made to determine the temperature coefficient for wire resistance. This parameter is required for the thermal conductivity calculations. Initial thermal conductivity measurements will be at ambient conditions on toluene, an accepted standard. This will establish the accuracy of the instrument.

2.1.2 Future work

Continuation of rheology measurement on Kentucky No. 9 materials will be postponed. Work on measuring the rheology and density of H-coal reactor samples will be initiated. Thermal conductivity development will continue.

2.2 New Liquefaction Techniques

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

The purpose of these research studies is to provide a better understanding of the chemical processes involved in the liquefaction of coal based on recent advances in knowledge of the structure of coal. The technical approach includes exploitation of the chemistry advances to develop new process concepts based on rapid conversion without the addition of external hydrogen.

*Chemistry Division

Fig. 2.2. Electronics circuit for transient hot-wire thermal conductivity instrument.

Present research is aimed at exploring the conversion of sub-bituminous and bituminous coals by the use of supercritical phenol, including the mechanisms of hydrogen transfer and structural studies of the converted products. Production of phenol from coal is also being explored at a reduced pace since this is the necessary step to utilization of the above reaction in a process scheme.

2.2.1 Hydrogen transfer mechanisms

While phenol is instrumental to the conversion of coal by the process discussed previously, it is not known whether its action is due to the vapor or the liquid. During heat-up phenol is a liquid, but at reaction temperatures (460°C) it is above its critical temperature (421.1°C) and exists as a dense gas. If its action is through the gas phase, the density of this phase should affect conversion. Preliminary results were reported last month. The results were quite encouraging because of the potential for reducing the amount of phenol required for the conversion. By changing the volume, a 2/1 phenol/Wyodak run was made where the density was held the same as for a 10/1 phenol Wyodak run. The result was a 55% MAF conversion of Wyodak coal to pyridine soluble products in only 15 minutes at 454°C. This is significantly higher than would have occurred without the density adjustment (previous runs with a 5/1 ratio at 427°C and 482°C gave 8% and 42% conversions respectively). However, it is less than the 79% conversion obtained at a 10/1 ratio and 454°C. While encouraging, further experimentation is needed to find the conditions necessary to increase yields at these low ratios.

2.2.2 Phenol from coal

While producing phenol from coal, a number of multihydroxy benzenes will also be produced. Hydroquinone (1,4-dihydroxy Benzene) is expected to be present in significant quantities. This compound was heated for 15 minutes under typical phenol/coal reaction conditions (10/1 coal, 460°C) to determine its stability. Only 3% of the starting material was converted to pyridine insoluble material under these conditions.

2.2.3 Structural studies

Wyodak coal was subjected to a liquefaction process involving phenol and heat as described in previous reports. The reacted material was fractionated into two portions on the basis of pyridine solubility. The extent of pyridine solubility defined conversion and was dependent on at least three variables: (1) phenol:coal ratio, (2) temperature, and (3) contact time. The degree of conversion was divided into three ranges for subsequent analyses. High conversion resulted in a yield of pyridine solubles >60% of the weight of coal in the feed. Medium conversion yields were in a range of 30-60% pyridine soluble material, while low conversion yields contained <30% pyridine soluble material. ¹H and ¹³C nuclear magnetic resonance (NMR) analyses on high conversion samples reported

previously were encouraging in that the technique appeared to be a promising method for determining structures present in reacted coal products. However only a limited proportion of the sample was run and further studies are reported below.

To prepare the samples discussed previously for NMR analysis, the pyridine soluble portion from the phenol/coal reaction was exhaustively extracted with CDCl_3 . Unfortunately only 30% of the coal-derived material was soluble and it was the results on this material that were reported. To examine all structures in the products, a method that increases the solubility in CDCl_3 without interfering with the subsequent NMR analyses is necessary. This was accomplished by silylating the OH group of alcohols (mostly phenols) in the coal-derived products by refluxing pyridine in a mixture containing Hexamethyl-Di-Silazane under a nitrogen atmosphere. This converts phenols to the following structure

and increases the solubility of the coal-derived products in CDCl_3 from 30% to nearly complete solubility for the Wyodak/phenol runs. Solubility of Bruceton/phenol reaction products are also significantly increased by this technique.

Samples utilizing the above technique were analyzed on NMR and although a thorough digest of the NMR data in conjunction with the C/H analyses is not available, some general observations can be made. The most prominent changes observed for Wyodak coal after liquefaction are the decreases in the fraction of protons from aromatic species from 65% in the parent coal to 50% in the high conversion samples, and the increase in the length of aliphatic chains. The CH_2/CH_3 ratio increases from about 2.5 in low conversion materials to 7 in the high conversion samples. Likewise, there was a significant change in the amount of aromatic material extracted from Bruceton coal into CDCl_3 . The spectrum of the parent coal showed that about 30% of the protons were associated with aromatic material.

This figure decreased to 9% in the high conversion samples. The aromaticity value will be calculated when the C/H analyses are completed. The carbon aromaticity for the liquified Bruceton samples is about 0.37. The length of the aliphatic chains also increased substantially after liquefaction.

These results suggest for both coals that some ring structures are being opened and that aliphatic material is being formed, presumably by H transfer reactions.

Another technique for increasing the solubility of coal-derived products in chloroform was reported by Darlage, Weidner and Block in 1974. This procedure involved nitric acid oxidation before liquefaction. In addition to aiding in preparation of NMR samples this technique, if applicable, should increase the conversion (pyridine solubility) in the subsequent phenol/coal reaction by producing lighter weight products. Following Darlage's procedure for the coals used in these experiments gave the results shown in Table 2.1. The results are disappointing. Conversion without nitric acid oxidation at these reaction conditions (10/1 phenol/coal, 460°C, 15 min) was 69% or 25-30% higher than after nitric acid treatment. While the chloroform extractability was increased somewhat, it was not nearly as successful as silylation. Some reasons for the discrepancy from Darlage's results are being explored.

Table 2.1. CHCl_3 and pyridine extractability of two coals after nitric acid oxidation^a and (phenol) liquefaction^b

Coal	Pyridine solubility % by wt	Chloroform solubility ^e % by wt	Gas Make-up (%)		
			CO	CO ₂	NO, N ₂ O ₄
Wyodak ^c	45	9	18.0	23.5	58.5
Wyodak ^d	40	47	14.6	37.0	48.4
Illinois No. 6 ^c	5	5	11.9	8.8	79.3
(Parent Wyodak)	(12)	(9)	11.9	8.8	79.3

^aAfter L. J. Darlage, J. P. Weidner and S. S. Block, Fuel, 1974, 53, 54: L. J. Darlage and M. E. Bailey, Ibid., 1976, 55, 206.

^bPhenol/coal ratio = 10/1, reaction time = 15 min., reaction temperature = 460°C.

^c60°C in 2N HNO₃, four days.

^dReflux in 2N HNO₃, four days.

^eExtracted after acetylation.

2.2.4 Future plans

Structural studies will continue to emphasize NMR since the results of current studies of silylated products are encouraging. The HNO₃ oxidations discontinued unless new evidence surfaces upon further analyses of the results.

The OH group was previously shown to be very instrumental in the H-transfer mechanism. Two methods to examine exchange reactions and functionality are to be studied: deuterization of the hydrogen in the OH group and replacing the OH group with an SH group. A mercaptobenzene/Wyodak run is planned for the coming month.

The distribution of multihydroxy benzenes produced from coal is needed to determine their importance to the phenol/coal reaction. This will be determined as resources permit.

2.3 References

1. L. E. McNeese (ed.), Fossil Energy Program Quarterly Progress Report for the Period Ending March 31, 1980, ORNL-5658, Oak Ridge National Laboratory, Oak Ridge, Tennessee (in process).
2. L. E. McNeese (ed.), Fossil Energy Program Monthly Progress Report for the Period Ending April 30, 1980, ORNL/TM-7375, Oak Ridge National Laboratory, Oak Ridge, Tennessee (in process).

3. CHEMICAL RESEARCH AND DEVELOPMENT

M. L. Poutsma

3.1 Chemistry and Structure of Coal

M. L. Poutsma and C. L. Wolf

Three "solvents" have been evaluated for use in kinetic studies of liquid phase thermolysis of 1-naphthol. None of these (*m*-terphenyl, triphenylene, phenanthrene) appears to be totally inert, and scouting studies are continuing.

Preliminary studies of thermolysis of carefully purified 1,3-diphenylpropane have shown that this reaction proceeds by a *long-chain* pathway to give toluene and styrene. This behavior contrasts with the nonchain decomposition of the next lower homologue, bibenzyl. Detailed studies are in progress.

3.2 Investigations of Solvent Losses During Critical Solvent Deashing of SRC

B. M. Benjamin, T. L. Sams,* and B. R. Rodgers*

We began a ^{14}C tracer investigation of the subject solvent losses under Kerr-McGee CSD conditions on April 7 at the request of Air Products Corp./DOE-ORO and completed the defined task on May 3. Carbon-14-labeled Kerr-McGee solvent was synthesized in the Chemistry Division. Use of the solvent in the simulated deashing process and initial separations were done in the Chemical Technology Division. Additional separations and radioactivity analyses were then done in the Chemistry Division. Experimental details will not be given here but a flow sheet of the procedure is included as Chart 3.1.

Only a very small percentage of the K-M solvent used (0.04%) is chemically bound in the SRC product. However, the amount of K-M solvent adsorbed plus reacted (0.4%) is not negligible. The demonstration plant design value is 0.17% K-M solvent lost to product. For the design feed rate of 11,650 tons/day of solvent to the first stage, the design loss is 19.8 tons/day, but if all the material adsorbed plus reacted in our experiments was lost to the product the K-M solvent make-up would increase to 48.9 tons/day, which represents an increase in operating cost of nearly four million dollars per year.

Fortunately there is good indication that the adsorbed solvent is recovered in the steam-stripper. The hot SRC product taken after the Wilsonville stripper showed only 0.26% K-M solvent by gas chromatography

* Chemical Technology Division.

Chart 3.1

and some of that could have been inherent in the product. Thus, our value of 0.04% chemically bound material indicates that their design value of 0.17% is realistic and can be reached or bettered by more efficient stripping.

However excessive losses are suffered at Wilsonville. The best case value is reported to be 1.77% loss based on K-M solvent fed to the first stage. If the known losses to SRC product and chemical reaction are subtracted, the unexplained loss remaining is 1.4%. Kerr-McGee has reduced this further by identifying a 0.7% loss due to the seals in the ash concentrate recovery system. The latter should be correctable. The remaining 0.7% is still a mystery. More than likely they are fugitive losses, which are correctable, but this must be ascertained before the construction of the demonstration plant.

The next logical step is to look at authentic materials collected from the Wilsonville unit. We might be able to do this by an "isotopic dilution" technique. Careful sampling and complete sealing of samples would be essential. We could then equilibrate these samples with labeled K-M solvent and determine the amount present originally in the sample by calculations after equilibrium adsorption exchange. We could also provide duplicate gas chromatograph results to corroborate the Wilsonville values. This should be sufficient to show whether the unexplained losses are fugitive, in which case it is simply a matter of isolating the leaks at Wilsonville for final proof.

In summary, our results support the conclusion that the Kerr-McGee solvent losses are not inherent in the nature of the process and should be correctable by proper attention to mechanical design.

3.3 Indirect Liquefaction Chemical Research

R. A. Strehlow and E. C. Douglas

This study is now funded for the remainder of FY 1980 by the ORNL Exploratory Studies Program and is focused on the role of olefins as reaction intermediates during Fischer-Tropsch reactions. The apparatus for these studies consists of a gas blending section, an injector for addition of test compounds, a reactor with a volume of 2-3 cc, and a dedicated mass spectrometer. The system was operated with a CO/H₂ ratio of 1:2 at gas hourly space velocities of 175-2000 hr⁻¹ over an Fe-based catalyst. Conversions of CO of as much as 50% were observed and the system functioned properly.

The principal question addressed during this period concerned the reproducibility of experimental results, at least over the period of several days to a week. The catalyst had been reduced earlier with hydrogen at 420°C and subsequently conditioned (carbided) with carbon monoxide at 200°C. The reduction was repeated twice with carbiding being accomplished with butane and butene-1. No difference in the catalytic behavior was observed in the Fischer-Tropsch activity for these methods of conditioning from that of the catalyst as originally conditioned.

The conclusions reached so far are that the test catalyst when conditioned by carbon monoxide after hydrogen reduction can be readily reactivated to a state which permits experimental conditions and results to be duplicated. We concluded also that in order to study the possible effects of activation conditions, we will have to begin with virgin catalyst for each study. The next steps in this series of experiments will be to measure the extent of hydrogenation or Fischer-Tropsch chain initiation for selected butenes.

4. MATERIALS TECHNOLOGY

R. A. Bradley

This section describes the research and development performed by the Metals and Ceramics Division on the Fossil Energy Materials Program supported by the Department of Energy's Office of Advanced Research and Technology. It includes tasks on pressure vessel and piping materials, welding and cladding development, corrosion of AFBC materials, failure prevention and analysis, materials research for liquefaction systems, development of modified 9 Cr-1 Mo alloy, and materials for ceramic recuperators.

4.1 Pressure Vessel and Piping Materials

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

This task is concerned with the safety and reliability of the vessels and piping for second-generation coal conversion systems. While there are many aspects of this problem, we are currently concerned with the effects of hydrogen. At low temperatures, hydrogen contributes to the brittle fracture of steels; this effect is most prevalent when a steel is heat-treated to high strength levels. At elevated temperatures and high pressures, hydrogen will react with carbon in low-alloy steels to form methane bubbles at the grain boundaries and cause a general degradation of properties.

Generally such steels are not in internal equilibrium. Holding at elevated temperatures will cause the partitioning of the chromium and molybdenum to the carbide, the coarsening of the carbide particles, and in some cases the formation of new carbide phases. These processes are controlled by the diffusion of the chromium and molybdenum in the ferrite, by the degree of dispersion of the carbide phase, and perhaps by the nucleation of new phases. The partitioning of the chromium and molybdenum lead to a reduction of the carbon activity. The formation of a new carbide phase may also lead to a further reduction in carbon activity. The problem is complex because of the wide range of structures that are possible in steels.

During this reporting period, the report covering the documentation of the computer program for calculating the thermodynamic properties of complex alloys was revised and expanded based on reviewers comments.

The run exposing samples of differing microstructures to hydrogen at 540°C and pressures to 13 MPa (1930 psi) has been terminated after 60 days. Density measurements show modest decreases in roughly one-third of the samples. The final analysis of this series will be completed when the metallographic samples have been prepared.

ORNL has received a section of a 305-mm-thick (12-in.) 2 1/4 Cr-1 Mo steel weld from Chicago Bridge & Iron. We are in the process of having Charpy V-notch specimens prepared from the base metal, which has been processed to meet the requirements of SA-387 Grade 22 Class 2.

Lukens Steel Company has provided ORNL with sections of two "rich" compositions of 2 1/4 Cr-1 Mo steel. These sections have carbon contents near the limits of SA-387 Grade 22. DATA TRAK specimen blanks [13 × 13 × 125 mm (1/2 × 1/2 × 5 in.)] have been prepared. We have 54 blanks from one heat (0.12% C) and 45 blanks from the other (0.14% C).

4.2 Welding and Cladding Development

D. P. Edmonds and G. M. Goodwin

The objective of this task is to develop techniques for weld overlay cladding of components for coal conversion systems and to characterize welds of thick-section steels. We are presently concentrating on the evaluation of welded and clad materials supplied by outside vendors. A section of a 30-cm-thick 2 1/4 Cr-1 Mo steel (from Chicago Bridge & Iron) weldment is presently being machined into specimens for impact testing, metallographic analyses, Gleeble studies, and heat-treatment studies. The metallographic evaluation has begun for a slice from the weldments taken transverse to the axis of the weld. Clad plates, received from Sandvik, Inc. are presently being machined into specimens for corrosion testing in solvent-refined coal environments. Tensile specimens are also being machined for accelerated corrosion tests at ORNL.

4.3 Fireside Corrosion of AFBC Heat Exchanger Materials

T. G. Godfrey and J. H. DeVan

The Engineering Technology Division at ORNL is developing an AFBC to cogenerate electricity and process heat for an industrial complex in the size range 5 to 50 MWe capacity. Further information on the Coal Combustion for Cogeneration (CCC) Program may be found in Section 11 of this report. Our support of this program involves materials compatibility tests conducted in a 0.46- by 0.46-m (18- by 18-in.) AFBC at the Fluidyne Corporation of Minneapolis. This AFBC was used to conduct five sequential tests of heat exchanger materials for a total of 4500 h. The five test intervals were 500, 1000, 500, 1000, and 1500 h, respectively. The paper "Heat Exchanger Materials for Fluidized-Bed Coal Combustors" presented at the 6th International Conference on Fluidized Bed Combustion (Atlanta, April 9-11, 1980) has been completed and forwarded to the publisher for inclusion in the proceedings of the Conference. More discussion and details are being incorporated into this paper to expand it into the ORNL technical memorandum report on the 4500-h Fluidyne test.

4.4 Failure Prevention and Analysis

R. W. Swindeman

4.4.1 Examination of pipe from Wilsonville SRC Pilot Plant - J. R. Keiser, R. W. Swindeman, V. B. Baylor, and M. D. Allen

This effort has consisted of examination of four pieces of type 316 stainless steel pipe that were sent to us by operating personnel at the Wilsonville SRC Pilot Plant. The examinations were performed at their request and results have been provided to them.

The only results not previously reported are those for the electron microprobe study of the material found in cracks in the pipe connecting the preheater to the dissolver. These results show the major constituents of the corrosion product as Cr, Fe, and S. A lesser but measurable amount of chlorine was also found. Unlike the vent line cracks which we examined, no cracks were found in which we could find Cl but not S. Consequently, although we suspect chloride stress-corrosion cracking, we are not able to confirm it. Additional examination of this potential problem is needed.

4.4.2 Examination of dissolver vessel from Wilsonville SRC Pilot Plant - J. R. Keiser, M. D. Allen, and J. R. Mayotte

During the Wilsonville plant shutdown in May, a team of metallurgists from ORNL examined several vessels. A metallographic examination of a small area near the bottom of the dissolver showed that microstructure appeared like that of a casting although the material was thought to be forged type 347 stainless steel. Because strange microstructures have been reported by Gulf Science and Technology personnel on the bottom of the Fort Lewis dissolver, it is felt that a more thorough examination of the Wilsonville dissolver is warranted. Our observations and opinions have been discussed with Pat Barnett of the Wilsonville plant.

4.5 Materials Research for Liquefaction Systems

R. W. Swindeman

4.5.1 Materials to resist stress-corrosion cracking in coal liquefaction pilot plants - J. R. Keiser and V. B. Baylor

This work is being performed to assess the resistance of various materials to stress-corrosion cracking in coal liquefaction plants. Efforts this month were directed toward preparing the safety assessment for the laboratory autoclave facility and examining three racks of U-bend specimens which had been exposed in the Wilsonville fractionation column.

Weight change results, given in Table 4.1, for U-bend specimens which had been exposed 5341 h in the Wilsonville fractionation column show the corrosion rate was greatest in the middle of the column. Corrosion rates were all fairly low, but it should be noted that during the greatest majority of the time sodium carbonate was being used to prevent corrosion. Specimens will next be examined for evidence of cracking. No coupons are currently being exposed in the fractionation column, but new coupons are on hand at Wilsonville for use in the new fractionation column they expect to receive in July.

Table 4.1. Corrosion rates of U-bend specimens exposed in the Wilsonville fractionation column

Alloy	Corrosion rate	
	mm/year	mil/year
<u>Top Manway</u>		
E-Brite 26-1	<0.02	<0.01
Type 304L stainless steel	<0.02	<0.01
Type 310 stainless steel	<0.02	<0.01
Carpenter 20Cb3	<0.02	<0.01
Type 317L stainless steel	<0.02	<0.01
Type 347 stainless steel	<0.02	<0.01
Type 321 stainless steel	<0.02	<0.01
Inconel 600	<0.02	<0.01
Type 316 stainless steel	<0.02	<0.01
Incoloy 800H	<0.02	<0.01
<u>Middle Manway</u>		
Inconel 600	0.01	0.21
Carpenter 20Cb3	0.01	0.53
Incoloy 800	0.26	1.03
Type 321 stainless steel	0.38	1.48
Type 310 stainless steel	0.38	1.50
Type 347 stainless steel	0.43	1.69
Type 316 stainless steel	0.47	1.85
Type 304L stainless steel	0.48	1.89
Type 317L stainless steel	0.55	2.15
E-Brite 26-1	>1.10	>4.32
<u>Bottom Manway</u>		
E-Brite 26-1	a	a
Type 316 stainless steel	a	a
Type 317L stainless steel	a	a
Type 304L stainless steel	a	a
Type 321 stainless steel	0.002	0.07
Carpenter 20Cb3	0.002	0.07
Type 347 stainless steel	0.003	0.10
Type 310 stainless steel	0.003	0.11
Inconel 600	0.005	0.19
Incoloy 800	0.304	11.96

^aSlight weight gain.

Table 4.2. Corrosion rates for coupons exposed in the Wilsonville T-105 fractionation column

Alloy	Corrosion rate	
	mm/year	mil/year
<u>Top Manway</u>		
Inconel 625	<0.001	<0.01
Alloy 904L	<0.001	<0.01
Incoloy 825	<0.001	<0.01
Titanium	<0.001	<0.01
2RE69	<0.001	<0.01
Type 321 stainless steel	<0.001	<0.01
SC-1	<0.001	<0.01
Hastelloy C-276	<0.001	<0.01
Hastelloy G	<0.001	<0.01
26 Cr-1 Mo stabilized	<0.001	<0.01
Haynes 20 mod	<0.001	<0.01
Hastelloy G-3	<0.001	<0.01
Nyby Monit	<0.001	<0.01
Type 304 stainless steel	<0.001	0.01
18 Cr-2 Mo	0.001	0.02
Type 317 stainless steel	0.005	0.19
<u>Middle Manway</u>		
Hastelloy C-276	<0.001	0.01
Inconel 625	0.006	0.25
Hastelloy G-3	0.007	0.28
Hastelloy G	0.008	0.32
Incoloy 825	0.031	1.22
Carpenter 20Cb3	0.043	1.70
Haynes 20 mod	0.043	1.72
Monel 400	0.065	2.54
Alloy 904L	0.066	2.58
Type 321 stainless steel	0.169	6.66
Type 317 stainless steel	0.275	10.83
Type 317LM stainless steel	0.297	11.70
2RE69	0.319	12.59
Type 304 stainless steel	0.337	13.30
Type 310 stainless steel	0.454	17.89
<u>Bottom Manway</u>		
26 Cr-1 Mo	<0.001	<0.01
18 Cr-2 Mo	<0.001	<0.01
Type 317 stainless steel	<0.001	<0.01
Incoloy 825	<0.001	<0.01
SC-1	<0.001	<0.01
Nyby Monit	<0.001	<0.01
Inconel 625	<0.001	<0.01
Haynes 20 mod	<0.001	<0.01
Hastelloy G-3	<0.001	<0.01
Titanium	<0.001	<0.01
Hastelloy G	<0.001	<0.01
Hastelloy C-276	0.002	0.08
Type 304 stainless steel	0.006	0.25
2RE69	0.131	5.15

Table 4.3. Weight change results for coupons exposed in the
Wilsonville T-102 vacuum column.

Alloy	Weight change (g)
<u>Top of Column</u>	
Hastelloy G	+0.0049
Type 410 stainless steel	+0.0040
29 Cr-4 Mo	+0.0040
18 Cr-2 Mo	+0.0037
2RE69	+0.0029
Incoloy 800	+0.0028
Titanium	+0.0028
Inconel 600	+0.0027
Type 304 stainless steel	+0.0025
Type 316 stainless steel	+0.0025
Type 317 stainless steel	+0.0024
Hastelloy C-276	+0.0023
Incoloy 825	+0.0023
Type 347 stainless steel	+0.0018
Type 321 stainless steel	+0.0018
Carbon steel	-0.0125
<u>Bottom of Column</u>	
29 Cr-4 Mo	+0.0114
Type 317 stainless steel	+0.0103
18 Cr-2 Mo	+0.0062
Hastelloy C-276	+0.0054
Hastelloy G	+0.0038
2RE69	+0.0028
Incoloy 825	+0.0026
Type 304 stainless steel	+0.0020
Incoloy 800	+0.0008
Type 347 stainless steel	+0.0007
Titanium	+0.0006
Type 316 stainless steel	+0.0005
Type 321 stainless steel	-0.0026
Inconel 600	-0.0179
Type 410 stainless steel	-0.0226
Carbon steel	-11.2169

Table 4.4. Weight change results for coupons exposed in the
Wilsonville V-103 high-pressure separator

Alloy	Weight change (g)
2RE69	+0.0059
SC-1	-0.0007
26 Cr-1 Mo stabilized	-0.0040
E-Brite 26 Cr-1 Mo	-0.0149
29 Cr-4 Mo	-0.0284
Hastelloy G-3	-0.2735
Type 317LM stainless steel	-0.7241
Type 317L stainless steel	-0.9131
Incoloy 825	-0.9598
Type 316L stainless steel	-1.6112
Type 347 stainless steel	-1.6137
Type 304L stainless steel	-2.1553

4.5.2 Studies of general corrosion in coal liquefaction pilot plants - J. R. Keiser, V. B. Baylor, M. Howell, and J. F. Newsome

The purpose of this work is to determine the potential for general corrosion in coal liquefaction pilot plants. The corrosivity of the fluids is measured by exposing corrosion coupons in a number of vessels in the Fort Lewis, Wilsonville, and Catlettsburg plants. During the last month, we have measured the corrosion rates of coupons exposed in the T-105 fractionation column, T-102 vacuum column, and V-103 high-pressure separator at Wilsonville. Results are given in Tables 4.2, 4.3, and 4.4. For the fractionation column, Table 4.2 shows that significant weight losses occurred for the middle manway samples, where the consistent pattern of nickel-base alloys having greater corrosion resistance than austenitic stainless steels was again demonstrated.

As shown in Table 4.3, samples exposed in the top of the vacuum column had very little weight change, and carbon steel was the only alloy to show a weight loss. Of the coupons exposed in the bottom of the column, except for carbon steel no serious weight loss was measured on any of the samples.

Table 4.4 shows that for the coupons exposed in the high-pressure separator, all but Sandvik 2RE69 showed a weight loss. The ferritic alloys generally lost the least weight while the austenitic alloy's weight loss relationship was inversely proportional to the molybdenum content.

4.5.3 Materials for the Zinc Chloride Hydrocracking Process - V. B. Baylor, and J. R. Keiser

The purpose of this work is to evaluate materials proposed for use in the regeneration and condenser vessels of the zinc chloride coal liquefaction process. Corrosion coupons are being exposed in a quartz experimental loop to an environment containing HCl, dry air, and $ZnCl_2$ at temperatures ranging from 560 to 970°C. A 500-h exposure was completed last month using 5% HCl in air. Several coupons were lost from the hot leg and were identified as Incoloy MA956. Many specimens on the cold leg were appreciably attacked, making identification difficult. The Hastelloy N specimen was completely consumed.

The samples were cleaned and weighed this month, and corrosion rates were calculated (see Table 4.5). The Udimet 720 alloy (18% Cr, 15% Co, 5% Ti, 2.5% Al, 3% Mo, 1.5% W, and bal Ni, by weight) demonstrated the best overall corrosion resistance in both locations tested. This alloy was not exposed in previous tests. Not including the Udimet 720, in agreement with the prior test run of 140 h, the Hastelloy C-276 and Inconel 617 showed the best corrosion resistance in the cold leg (500 to 800°C) and the Stellite 6B and the experimental coated alloys provided by Lockheed performed best in the hot leg (925 to 975°C). There were some differences in the reaction of other alloys to the two exposures.

Table 4.5. Calculated corrosion rates for third zinc chloride experiment

Alloy	Exposure Temperature (°C)	Corrosion rate		Alloy	Exposure Temperature (°C)	Corrosion rate	
		mm/yr	mil/yr			mm/yr	mil/yr
Hastelloy N	650	>14.4 ^a	>565	MA-956	925	>9.3 ^a	>366
Stellite 6B	800	17.1	672	MA-956	925	>9.3 ^a	>366
Stellite 6B	700	16.7	658	Haynes 25	950	4.8	189
Lockheed ^b	600	12.2	479	Haynes 188	950	4.0	159
Haynes 25	750	11.9	468	Inconel 600	970	2.9	113
Inconel 690	600	10.0	394	Incoloy 825	970	2.2	85
Inconel 625	650	8.6	339	Haynes 188	970	2.0	79
Hastelloy G	650	8.2	324	Multimet	970	1.9	76
Multimet	600	4.3	170	Inconel 601	925	1.9	73
Hastelloy G	560	3.6	144	Multimet	925	1.8	72
Inconel 625	560	3.6	143	Haynes 25	970	1.7	66
Inconel 600	560	2.6	103	MP-35N	950	1.6	61
MP-35N	750	1.9	77	Inconel 617	950	1.4	56
Hastelloy C-276	800	1.0	41	Lockheed ^b	925	1.2	49
Hastelloy C-276	700	0.9	35	Stellite 6B	950	1.2	48
Inconel 617	800	0.7	29	Udimet 720	970	1.2	47
Inconel 617	700	0.6	22	Lockheed ^b	925	1.0	38
Udimet 720	750	0.2	9.4	Udimet 720	950	0.8	32

^aSample completely consumed.

^bIncoloy 800 coated with Cr-Si.

The corrosion rate was plotted as a function of Ni, Cr, Co, and Mo content of the alloys at 500°C and 975°C. At 500°C, no correlation was observed between corrosion rate and either Co or Cr contents (if anything, the corrosion rate increased with increasing Co content). However, the corrosion rate decreased slightly with increasing Ni and Mo content. The best correlation was observed with the Ni+Mo content which increased with decreasing corrosion rate (see Fig. 4.1). At 975°C, completely different correlations were found between corrosion rate and alloy content. No relationship was observed to either Ni or Mo content, but the corrosion rate tended to decrease with Co+Cr content.

Also this month, the program was reviewed by DOE/HQ personnel during the annual review of liquefaction materials work. It was decided to continue the work on a limited scale through the end of FY 1980. Two new loops were completed by the glass shop. Preparations are being made for two more test runs this year of 500 h each.

Fig. 4.1. Correlation of Ni+Mo content and corrosion rate of coupons exposed in the quartz experimental loop.

4.6. Development of Modified 9 Cr-1 Mo Structural Steel

V. K. Sikka

Large heat fabrication, mechanical property characterization, weldability, and steam corrosion studies continued during the last month.

The fabrication order for the conversion of ingots from the two 14-Mg heats was placed near the end of January and the delivery of various products is expected by June 1980. Meanwhile, we have cut two 30-cm-thick sections from the electroslag-remelted (ESR) ingots of the two heats. These sections have been fabricated to plate stock for preliminary testing and evaluation. The plates were fabricated by hot-forging followed by hot-rolling. As a part of the preliminary testing and evaluation, we have completed the following properties on the two 14-Mg commercial heats.

1. Charpy-impact curves were developed for both heats. Results show that the same chemical composition ESR material showed lower transition temperature and higher upper-shelf energy as compared to the

argon-oxygen-decarburization (AOD) process melted material. Furthermore, for the ESR material, impact properties are the same for both the low silicon (0.2%) and high silicon (0.5%) heats.

The low silicon ESR heat was also tested after making the plate by different fabrication processes. Results of this study show that the highest transition is obtained for plates finished either by hot-forging or hot-extrusion. Hot- or cold-rolling after hot-forging or hot-extrusion produced a significant lowering in transition temperature.

2. Tensile tests were completed on both heats at room temperature and 593°C. Results show that the tensile properties were the same for both the AOD and ESR melted heats.

3. Several creep tests were completed at 538, 593, 649, and 677°C on both commercial heats of the modified alloy. Results show that the rupture life of both heats exceeded the ASME Code Case N-47 minimum values of 649°C. At 677°C, the rupture values for these heats were slightly below the minimum. Reduction of area for both heats exceeded 70% for all tests ruptured thus far.

In summary, the preliminary testing and evaluation have shown that the mechanical properties of the commercial heats meet the expected results based on the experimental- and intermediate-size commercial heats.

As a part of the new strategy to obtain an earlier ASME Code case approval of modified 9 Cr-1 Mo, mechanical property testing was started on the tube heats. Tubes from the heat used in making the Tennessee Valley Authority tubing were the first of these heats to be tested. Tensile tests on this heat were completed in February. Three creep tests on this heat are currently in progress. Additional tube heats from Combustion Engineering, Chattanooga, Tennessee, are expected at ORNL during the first week of June 1980.

4.7 Ceramic Recuperators (Heat Exchangers)

V. J. Tennery and G. C. Wei

The objective of this task is to evaluate the behavior of candidate structural ceramic materials for use as recuperators or heat exchangers in fossil fuel combustion environments. In this period, we completed differential thermal analyses (DTA) of nodules from post-test sintered- α , KT, NC 430, Refel CVD SiC, and SVD SiC on SiC tubes from the Ceramic Recuperator Analysis Facility (CRAF) Test 1. A glass transition behavior was observed in materials from these nodules which formed during the long-term exposure of these SiC materials to the combustion products of No. 6 fuel oil. The glass transition temperatures of the nodule materials were as follows: 1063°C (sintered- α), 1088°C (KT), 1070°C (NC 430), 1117°C (Refel), 1076°C (CVD SiC), and 1126°C (CVD SiC on SiC),

and are below the temperatures (about 1200°C) of the nodules during the CRAF Test 1 exposure. This result indicated that all these nodules were present as relatively fluid melts during the CRAF Test 1 exposure.

A topical report on the results of CRAF Test 1 is in preparation. We expect to complete the draft of this report by the end of June 1980.

Thin specimens of post-test sintered- α SiC tube were in preparation for transmission electron microscopic examination to determine details of the grain boundary microstructure of this material with the objective of explaining the observed large increases in helium permeability and grain size of this structural ceramic during the CRAF Test 1 exposure.

In this month, sintered- α SiC and Sialon tubes for CRAF Test 2 were received. This completes receipt of all of the tubular ceramic specimens planned for this test. Preliminary studies of adding a powdered coal injection system to the existing CRAF/Refractory Test Facility (CRAF/RTF) were performed. Major technical areas considered included prevention of interference of the oil flame by the injected coal, maintaining uniform flow of powdered coal to the combustor, controlling furnace pressure and temperature control, and controlling the length of the coal flame. These factors were discussed with pertinent firms experienced in coal combustion and coal handling and recommendations received as to equipment which should function satisfactorily on the CRAF.

On May 22, 1980, an order was placed with Dravo/COMCO of Pittsburgh for about 10,000 gal of coal-oil-mixture fuel to be used in CRAF Test 2. Preliminary tests will be done with 500 gal of the fuel to ensure that its combustion can be adequately controlled in the CRAF; following that, the remainder of the fuel will be delivered in two shipments for the purpose of the long duration materials exposure test. It is now anticipated that the long-term combustion exposure test will be started by early July.

5. COMPONENT DEVELOPMENT AND PROCESS EVALUATION

D. M. Eissenberg

The objective of component development and process evaluation activities is to ensure that coal conversion (liquefaction, gasification, pyrolysis) processes, subsystems, and components have satisfactory functional performance, lifetime, reliability, and safety for their intended applications, and that sufficient component and subsystem performance data are available to permit process design optimizations. Activities to be carried out include performance and cost analyses; assessments of operating plants; field tests; operation of test loops; and the development of advanced processes, subsystems, and components.

Present activities are primarily those carried out as part of the technical support to large liquefaction projects. In addition, studies are being initiated aimed at the development of processes, subsystems, and components for more generic coal conversion applications.

5.1 Technical Support to Large Liquefaction Projects

P. K. Carlson, W. A. McAuley, L. F. Parsly, and A. N. Smith

Activities in this area are in support of the H-coal and SRC Demonstration Projects, and are described in more detail in Chapter 6. Work in support of the H-coal reactor safety assessment (6.7.2) was completed, and the report has been submitted to DOE for approval. Slurry pressure letdown loop (6.4.3) construction is nearly complete. Computer analysis is underway to determine the control range of the system for coal conversion plant application. A contractor has been selected for the wet grinding study (6.3.2). A review of a design basis memorandum for SRC-I was completed (6.1.1).

5.2 Component Test Facilities

D. M. Eissenberg

Discussions were held with TVA regarding their interest in providing a site for the proposed dry coal feeder test facility. Discussions were held in Washington to further define the requirements for the ash letdown and solid waste disposal test facility.

5.3 New Initiatives in Coal Conversion Component Development

D. M. Eissenberg

As part of the Engineering Technology Division strategic planning activities, an assessment is being carried out to identify and propose new initiatives in coal conversion component development.

A seed money proposal is being prepared for carrying out a feasibility study of a novel slurry feed/letdown system incorporating the flow work exchanger concept. Incorporating such a device into a coal liquefaction plant would (1) eliminate pressure letdown valves, (2) reduce the size or possibly exclude high head pumps, and (3) reduce power consumption associated with slurry feed pumps.

6. TECHNICAL SUPPORT TO MAJOR LIQUEFACTION PROJECTS

H. D. Cochran

Support is provided by Oak Ridge National Laboratory and Union Carbide Nuclear Division Engineering for the major liquefaction projects being managed by DOE Oak Ridge Operations--SRC-I and SRC-II Demonstration Plants and H-Coal Pilot Plant projects. Activities under twenty-four specific subtasks are reported in seven broad categories--engineering and design review, technology overview, design data validation, components, materials, environmental and health, and general technical support.

6.1 Engineering and Design Review

This section reports on three subtasks whose objectives are focused on review of engineering and design of the SRC-I and SRC-II demonstration plants and the H-Coal pilot plant: engineering design review, SRC/H-Coal process and design review, and solid-liquid separations design review.

6.1.1 Engineering design review - J. J. Kurtz

Objective - This activity consists of providing technical assistance to the DOE-ORO SRC 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 (SCS), Inc., and the SRC-II project contract is with the Pittsburgh and Midway (P&M) Coal Mining Company.

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.

Status summary - the SRC-I and SRC-II project technical status review meetings were monitored. Badger Engineering provided a summary evaluation of SRC-II design studies and concluded that changes will be required in major process areas when data become available on such concerns as decoupling, in-house power generation, fuel balance, zero discharge, and pipeline gas.

An information copy of the SRC-II statement-of-work draft by P&M, dated April 17, was reviewed, and comments were transmitted informally to the DOE-ORO SRC Projects Office.

In May, a draft of the Catalytic DBM Revision 1, for the SRC-I Process Area (Area 12) and Deashing Area (Area 13), was reviewed at the request of the DOE-ORO SRC Projects Office. Comments were forwarded to the requesting office.

6.1.2 SRC/H-Coal process and design review - A. R. Irvine, J. F. Fisher, W. R. Gambill, H. F. Soard

Objective - The objective of this activity is to provide review and analysis of key process areas of the SRC demonstration plants and those aspects of the H-Coal pilot plant that will provide information useful in the design and evaluation of the SRC-I and SRC-II demonstration plants.

Status summary - Feed coals for the SRC-I and SRC-II demonstration plants should be selected to provide the maximum amount of information concerning the use of the processes for the range of applicable coals. A study was completed and a draft report issued concerning the availability of bituminous coals in the eastern and central states and appropriate future actions concerning feed coal selection. The most significant finding of the study was that the available knowledge of coal performance characteristics is so limited as to be inadequate for selection of demonstration plant feed coals without prior testing in a PDU or pilot plant.

The Mobil report EPRI-AF-1298, Vols. 1, 2, and 3, "The Nature and Origin of Asphaltenes in Processed Coals," was reviewed. This report was found to contain a great deal of useful information; however, the information that is presented is principally of a basic nature and is not sufficient for use in selection of a feed coal or for establishing process conditions.

6.1.3 Solids/liquid separations - J. R. Hightower and B. R. Rodgers

Objective - The objective of this project is to provide technical support to DOE-ORO in the area of solids/liquid separations. The first request was to determine to the extent possible in the laboratory, the fate of the Kerr-McGee solvent lost in their deashing process, or at least if it was chemically reacted. The time frame was to be two months.

Status summary - The report on the Kerr-McGee tagged solvent discussed last month was distributed a month early. No new tasks have been agreed upon but discussions are continuing.

Future plans - When new tasks have been decided by DOE/ORO, a work plan will be drafted.

6.2 Technology Overview

This section reports on five subtasks whose objectives are to provide a broad overview of direct liquefaction technology — Direct Liquefaction Technology Overview and four technical field representation tasks.

6.2.1 Direct liquefaction technology overview — R. W. Glass, K. H. Lin, A. R. Irvine, J. P. Belk, K. K. Chipley, J. R. Horton, J. K. Huffstetler, B. Niemann, W. R. Reed, and B. T. Thompson

Objectives — The objectives of this task are:

1. To keep abreast of significant developments in coal conversion R&D activities, to monitor progress in coal liquefaction facilities, and to derive and document technical data of importance to design and operation of pilot, demonstration, and commercial plants. This will also assist in preventing duplication of efforts at various facilities.
2. To prepare a source book of data base and technical information for DOE management and other participants in DOE-funded programs.
3. To conduct short- to intermediate-term studies on subjects which could have major impact on coal liquefaction technology and economics.

Scope — The role of this subtask is an overview of a wide range of activities relevant to coal liquefaction technology. The major effort will be directed toward the following areas of activities and types of information:

1. R&D activities relevant to (a) modification and improvement of key unit processes and associated equipment, (b) physical and chemical properties of major process streams and products, and other process data base, and (c) processes for upgrading of liquefaction products.
2. Plant experience data from pilot plants and PDUs that are crucial to the design and operations, including (a) significant operation and maintenance experiences, and (b) technical problems encountered due to deficiency in the design or to abnormal process conditions, and specific solutions to the problems.

Status summary — Progress has been made in the following areas:

1. Review of developments at coal conversion facilities — Recent progress reports issued during the past year by Pittsburgh & Midway Coal Mining Co. (Ft. Lewis Pilot Plant and PDU-99), Catalytic, Inc. (Wilsonville Pilot Plant), and Exxon (EDS process development) have been reviewed primarily to determine (1) the format of a digest that periodically consolidates important developments at liquefaction pilot plants

and PDUs, which would be of immediate use to DOE/ORO and UCC-ND/ORNL personnel in maintaining awareness of these developments (short-range goal) and (2) the specific types of technical information to be selected for further studies, and for systematic documentation to serve as a reference in plant design and operation (intermediate- to long-range goal). The tentative subject areas to be focused in reviewing the progress reports include: (a) overall plant test runs — coal types, process condition, and results; (b) test programs for critical components and systems — reasons for testing (e.g., acquisition of design data, demonstration of process, problem solution, etc.), progress, and results; (c) significant problems and solutions (actual or proposed); (d) future plans (Plant test runs, component or system testing programs, etc.); (e) areas of possible duplication of efforts.

2. Source book — Preparation of the source book covering the following areas of the SRC process has already begun: (1) mass and energy balances; (2) coal feeding and handling; (3) coal slurry mixing; (4) coal slurry preheater; (5) hydrogen recovery system; (6) liquefaction residue gasification; and (7) Kerr-McGee critical solvent deashing. Additional areas to be covered in the subsequent work will include: (a) coal dissolver; (b) product upgrading processes; and (c) Lummus antisolvent deashing process. (Note: The source book will contain no proprietary information.) Studies on all of the subject areas listed above will require one to three months, which will be followed by preparation of materials for inclusion in the source book.

3. Liquefaction technology file — A separate space has been reserved for filing technical literature relevant to direct liquefaction technology. The work on acquisition and filing of pertinent meeting, progress, and topical reports is being continued as time permits.

4. Technical assistance to DOE-ORO — Review of the Design Basis Memorandum for the SRC process and deashing areas of the 6000 TPD SRC-I Demonstration Plant has been completed.

Also completed was a suggested program (Instrumentation for Level/Interface Detection in Coal Conversion Applications) for the Fossil Energy Instrumentation and Controls Technology Base Assessment for FY-1982.

6.2.2 Technical representation at field sites — R. W. Glass

Objective — The objective is to place a UCC-ND technical representative at each of the major development sites — H-Coal, Exxon Coal Liquefaction Plant, Harmarville, Ft. Lewis, and Wilsonville. The purpose is to facilitate the flow of information between the above-mentioned sites, DOE and ORNL.

Status summary — We have designated a member of the Chemical Technology Division to pursue the possibility of placing a technical representative at the H-Coal pilot plant. The technical representative is also expected to serve as the site representative for the Health and Environmental Assessment (H&EA) activities to be performed at the H-Coal pilot plant. The H&EA activities are part of a related Fossil Energy program effort.

The placement of a technical representative at the EDS pilot plant in Baytown, Texas will be initiated following receipt of clearance from DOE/ORO.

Following a directive from DOE, we have suspended plans to place technical representatives at the Ft. Lewis, Harmarville, and Wilsonville sites.

6.3 Design Data Validation

This section reports on three subtasks whose objectives are aimed at providing experimental measurements to answer questions which have arisen in designing the SRC demonstration plants. These subtasks are: Coal Slurry Mixing Tests, Wet Grinding for SRC Processes, and Vacuum Bottoms Viscosity Measurement.

6.3.1 Coal slurry mixing tests - J. R. Hightower, E. L. Youngblood, and L. S. Dickerson

Objective - The objective of this project is to study the changes that occur in physical properties (particularly viscosity) in coal slurries during mixing at temperatures up to 533 K (500°F). The system includes a small scale mix tank with an agitator and slurry circulation system of the type used for feed makeup in the SRC processes. Continuous viscosity measurements will be made with an on-line pipeline viscometer. The ultimate objective of the study is to establish conditions that will permit the slurry preparation system in the SRC demonstration plants to be operated at increased temperature thereby improving the overall process thermal efficiency and cost.

Status summary - Work continued on the design and construction of equipment for the slurry mixing system. The electrical wiring has been completed on a panelboard containing temperature controllers, variacs and recorders for the electrical heaters. The mixing vessel has been constructed of 12 in. carbon steel pipe and fittings. The top of the vessel which will support the agitator is now being constructed. An agitator with a 3/4 HP drive unit that was used on a previous experiment will be used temporarily until a more suitable unit can be procured. Work has begun on the supports for the mixing vessel and piping for the circulation loop. Kentucky No. 9 coal (from the Pyro and Dotiki mines) and recycle solvent from Wilsonville and Powhatan coal and recycle slurry from Ft. Lewis have been received for use in the tests. Preparation of a safety summary for the experiments has begun.

A meeting was held at ORNL with members of the International Coal Refining Company to discuss the slurry mixing test conditions that are needed by the SRC-I design group. These include tests with 38.5 wt % Kentucky No. 9 coal and Wilsonville recycle solvent at temperatures from 394 to 505 K (250 to 450°F). The design group is also interested in monitoring the coal concentration in the feed makeup system by using a gamma radiation absorption density instrument similar to the one used in the Coal Liquids Flow System. A similar density instrument will be installed in the slurry mixing system.

During the next month installation of the electrical supply system will continue. The mixing vessel will be put in place and piping of the circulation loop and instrument lines will be started. The equipment item with the longest lead time will apparently be the Moyno slurry circulation pump with approximately a 16 week delivery time. We will attempt to find an alternate pump to use until this pump is received.

6.3.2 Wet Grinding for the SRC II Process - D. M. Eissenberg and W. A. McAuley

Objective - This study will investigate the feasibility of incorporating a wet grinding process into the SRC II Demonstration Plant. The presently proposed dry grinding/mixing system has encountered problems such as coal swelling and gel formation.

Status summary - An evaluation team consisting of W. A. McAuley, L. F. Parsly, Jr., and D. M. Eissenberg was formed to appraise five (5) proposals received as a result of Request for Proposal (RFP) M-1032. An evaluation team report was sent to Art Hopson (UCC-ND Purchasing) on May 23, 1980, outlining the team's selection of the successful bidder. Battelle Columbus Laboratories was selected among proposals received from Arthur D. Little, Inc. - Cambridge, Massachusetts; the MITRE Corporation - McLean, Virginia; Econergy Associates - New York, New York; and Burns & Roe Industrial Services Corporation - Paramus, New Jersey. The subcontract work is scheduled to begin on July 1, 1980.

6.3.3 Vacuum bottoms viscosity measurement - J. R. Hightower, J. H. Wilson, and B. R. Rodgers

Objective - The objective of this project is to provide a tested and calibrated instrument for installation at the Ft. Lewis SRC pilot plant or other suitable site which is capable of providing on-line viscosity measurement of residuals obtained from the vacuum still of the SRC-II process. This type instrument is necessary to provide indication of the onset of irreversible polymerization or coking problems which would interfere with controlled feeding of vacuum still bottoms to a gasifier.

Status summary - A preliminary flowsheet and design criteria have been prepared for the vacuum still bottoms (VSB) viscometer. As shown in Figure 6.3.1, the flowsheet includes equipment necessary for laboratory testing and calibration (shown within the dotted lines) along with the equipment that constitutes the system to be shipped to Ft. Lewis. A "pipeline" viscometer is depicted in Figure 6.3.1, but the design is to allow the use of alternative viscometers. The basic concept is to measure the pressure drop that results from pumping VSB at a calibrated rate through a length of capillary tubing. VSB at approximately 50 psig pressure from a pump-around loop on the vacuum tower bottoms will be metered by a Bran and Lubbe positive displacement pump through the tubing and returned to the loop. A let-down tank is provided to permit calibration of the Bran and Lubbe pump. Flush oil will be available to flush the system of the VSB. Although not indicated in Figure 6.3.1, a process control computer will be supplied to (1) make changes in pump setting, temperature set-points, etc., while recording pressure drop across the capillary as a function of flow rate and temperature, (2) calculate and print out values of viscosity vs shear rate, (3) provide proper sequencing of valve openings and closings in order to flush the system either routinely or upon operator command, and (4) take appropriate steps in emergency situations such as loss of power, high pressure, low temperature, etc.

A flowsheet and a complete list of design criteria are being prepared by Engineering for use in obtaining a conceptual type cost estimate for design and fabrication. An estimate for the instrumentation and control design is being developed by Instrument and Controls Division. This work should be completed within four to five weeks.

Orders have been placed for a Bran and Lubbe positive displacement pump, a melting point apparatus, and a high temperature Brookfield viscometer.

6.4 Components

Activities in this area include review and evaluation of component performance in operating coal liquefaction pilot plants and PDU's, assessment of the adequacy of critical components selected for use in SRC-I and II Demonstration Plants, and the development and testing of improved components for use in the Demonstration Plants.

Three elements are currently authorized: component and technology workshop, component design review, and packed bed pressure let down system study.

6.4.1 Components and technology workshop - M. Siman-Tov

Objective - To provide a forum for information dissemination and exchange on critical coal conversion equipment availability, reliability, and operating experience among the various groups involved in development and demonstration of major coal liquefaction processes.

Fig. 6.1. Schematic flow diagram of VSB viscometer.

Status summary - A decision was made to stop activities on the local workshop to avoid overlap with a similar but more general workshop that is now being planned for October 1-3, 1980, in Huntington, West Virginia. ORNL is participating in the planning of that workshop and will provide the technical support and state-of-the-art presentations.

6.4.2 Component design review - D. M. Eissenberg

Objective - The objective of the component design review is to identify critical components in the SRC-I and SRC-II Demonstration Plants and to provide assessments as to their expected performance based on Phase I design specifications and analysis of similar components utilized in pilot plants or other comparable service. Where appropriate, recommendations will be proposed for alternate specifications, alternate component selection or development and testing programs which would lead to improved components.

Status summary - Effort in this activity has just been initiated, and there is no technical progress to report.

6.4.3 Packed bed pressure letdown study - D. M. Eissenberg and P. K. Carlson

Objective - The objective of this study is to develop an improved slurry pressure letdown system for possible application to the SRC-I and II Demonstration Plants. The improved system utilizes a packed bed for pressure drop, with flow control provided by addition of clean liquid which volatilizes at the temperature/pressure conditions within the packed bed.

Status summary - The high pressure gas system was being installed as of the end of May. Numerous short delays have resulted from problems in acquiring equipment, i.e. fittings, valves, instruments, which are both economical (such as surplus from other experiments or salvage) and capable of meeting pressure code requirements, in the time frame required. Nevertheless, we fully expect to be operational in June and will begin taking three-phase packed-bed pressure drop data as soon as the construction is complete.

It is planned that various rates of N_2 gas and water-based slurry will be pumped through a 2.5-cm diameter packed column and pressure drops will be measured. The data will be used to verify and extend currently available correlations for a co-current flow through packed beds and ultimately to design such devices for use in coal liquefaction letdown systems.

Work continues on computer modeling aimed at sizing a packed bed for use in an SRC type dissolver letdown stream as well as predicting the quantities of clean condensate necessary to achieve a desired control range with the device. It is necessary, in order for the system to work as planned, that the flow of condensed material available from the overhead of the high pressure separator be sufficient to displace normal

fluctuations in flow of slurry through the packed bed. The computer program will give as output, among other things, the quantity of condensate necessary to make up a given reduction in slurry, maintaining pressure boundary conditions at the inlet and outlet of the bed.

A program which sizes the packed bed for a maximum flow of flashing slurry is currently complete. The routine actually builds a packed bed of sections of constant ID pipe joined by conical reducers and filled with uniform spheres. The design limits $\Delta P/L$ to achieve more uniform wear while keeping overall length as short as practical.

6.5 Materials

This section reports on four subtasks whose objectives are focused on the materials of construction for coal liquefaction plants - materials design review and coordination of materials R&D for SRC projects, quality assurance support for H-Coal pilot plant welding, H-Coal materials testing and failure analysis, and investigation of corrosion in fractionation areas of liquefaction plants.

6.5.1 Materials design review and coordination of materials for SRC projects - R. R. Judkins and A. R. Olsen

Objective - The objectives of this task are to assist in the review of contractor documents for materials selection, to review and provide input to materials testing and failure analysis plans, and to coordinate materials R&D for SRC projects.

Status summary - Meetings were held with the SRC-I and -II contractor organizations to initiate the materials design review activities. On May 22, 1980, a meeting was held at the Englewood, Colorado, offices of the Pittsburg and Midway Coal Mining Company; and on May 30, 1980, a meeting was held at the Allentown, Pennsylvania, offices of the International Coal Refining Company. These meetings were primarily for the purpose of establishing a work plan and the logistics for performing the materials design review. In addition, the design of the reaction vessels (dissolvers) for the plants was discussed.

Analytical data for coal from several seams including Kentucky No. 9 and Pittsburgh seams were obtained from the Tennessee Valley Authority and the Pittsburgh Mining Technology Center of DOE. The primary interest in these data was the chlorine content of the coal because of its apparent impact on the corrosion of materials, particularly in the fractionation area, in the SRC pilot plants. These data were provided to DOE-ORO.

6.5.2 Quality assurance support for H-Coal pilot plant welding -
K. K. Klindt

Objective - The objective of this activity is to provide technical support to DOE-ORO in the resolution of weld quality problems in the piping system at the H-Coal pilot plant.

Status summary - No support was needed during the month of June 1980.

6.5.3 H-Coal materials testing and failure analysis - A. R. Olsen,
J. R. Keiser, V. B. Baylor, and R. W. Swindeman

Objective - The objective of this task is to provide assistance to the Ashland Synthetic Fuels, Inc. (ASFI) in developing and implementing a materials testing, surveillance, and failure analysis plan for the H-Coal Pilot Plant at Catlettsburg, Kentucky. The scope of work involves the review of the materials of construction, participation in the materials testing effort, the preparation of a failure analysis plan acceptable to the participants of the H-Coal Project, and the provision of failure analysis service to the H-Coal Pilot Plant on request.

Status summary - At the request of ASFI, personnel from ORNL attended an internal ASFI meeting on May 13, 1980, that reviewed the performance of valves at the H-Coal Pilot Plant. The purpose of ORNL attendance was to obtain information so that we can provide advice and assistance should future problems develop. As a result of the meeting, ORNL will examine items including the following:

1. suitability of brazing alloys for joining ceramics to ferritic stainless steels in letdown valves.
2. suitability of commercially available "grease-sealants" for use in packing valves that operate in slurry streams.

6.5.4 Investigation of corrosion in fractionation areas of liquefaction plants - J. R. Keiser, V. B. Baylor, M. Howell, and
R. W. Swindeman

Objective - Severe corrosion has been observed in the fractionation area of the SRC pilot plants. A concentrated effort is being made at ORNL to discover both the corrosion mechanism and a means to control the corrosion.

Status summary - During the past month, our efforts have been directed toward analysis of liquids from the pilot plants, operation of laboratory experiments, and conduction of a workshop on corrosion in the fractionation area of the SRC pilot plants.

The most significant results of the fluid analyses indicate that the total and water-soluble chlorine contents are maximums (for both Wilsonville and Fort Lewis samples) in the areas where corrosion is the greatest. These results are shown in Tables 6.1 and 6.2. As shown in Tables 6.3 and 6.4, the maximum neutralization number also matches with the area of greatest corrosion at both pilot plants. Additional analyses are in progress which should permit us to trace the path of chlorine in the pilot plants.

The most significant of the laboratory experiments determined whether hydrogen was produced during corrosion of carbon steel in the Fort Lewis overhead fluid. Preliminary results indicate an appreciable amount of hydrogen was produced which means the type of reaction occurring is:

In other laboratory experiments, we have not been able to find a mixture of phenolic compounds which cause significant corrosion of carbon or type 304 stainless steel. All mixtures of these phenolic compounds became more corrosive if ammonium chloride was added.

A workshop on SRC fractionation area corrosion was held at ORNL on May 29, 1980. Participants included representatives from the pilot plants, demonstration plant design groups, and other laboratories studying the problem. It was proposed that another meeting be held in about six months.

Table 6.1. Analyses for chlorine in Wilsonville SRC Pilot Plant liquids show maximum chlorine in lower portion of column

Sample Date	Chlorine content, ppm					
	Tray 1		Tray 9		Tray 15	
	Total	Water-Soluble	Total	Water-Soluble	Total	Water-Soluble
01/14/80 no CO ₃ =	211	234	315	87	376	25
12/14/79 10 lb CO ₃ =	83	19	140	51	696	444
12/10/79 10 lb CO ₃ =	182	15	284	53	470	235

Table 6.2. Analyses for chlorine in Fort Lewis SRC Pilot Plant liquids show that chlorine concentrates at the top of the wash solvent column

Sample Date	Chlorine content, ppm					
	Overhead		Feed		Bottoms	
	Total	Water-Soluble	Total	Water-Soluble	Total	Water-Soluble
01/14/80	133	120	133	67	27	16
02/06/80	139		117	97	241	41
04/23/80	417	574	203	262	117	99

Table 6.3. Neutralization numbers for Wilsonville SRC Pilot Plant liquids show the liquids are most acidic in the areas of highest corrosion (lower portion of the column)

Sample Date	Neutralization number, mg KOH/g sample		
	Tray 1	Tray 9	Tray 15
01/14/80 no CO ₃ =	0.29	0.29	0.41
12/14/79 10 lb CO ₃ =	0.66	0.36	1.37
12/10/79 10 lb CO ₃ =	0.19	0.20	0.54

Table 6.4. Neutralization numbers for Fort Lewis SRC Pilot Plant liquids show maximum values for the top of the column (which is the area of greatest corrosion)

Sample Date	Neutralization number, mg KOH/g sample		
	Overhead	Feed	Bottoms
01/14/80	0.20	0.13	0.06
02/06/80	0.186	0.175	0.068
04/23/80	0.81	0.29	0.13

6.6 Environmental and Health

The objectives of this task are: (1) to assist DOE in the preparation of the NEPA-required Environmental Impact Statements for the SRC I and SRC II demonstration plants; (2) to provide environmental technical assistance to DOE in support of these projects; (3) to assist DOE in the review of plans for landfilling of solid wastes from H-Coal operations; (4) to provide support to DOE in the accumulation, synthesis, and interpretation of environmental and health data related to direct coal liquefaction technologies, especially SRC and H-Coal processes.

6.6.1 SRC I and SRC II environmental impact statements - C. R. Boston and S. G. DeCicco

SRC I demonstration project - The Preliminary Draft Environmental Impact Statement (PDES) went to DOE on May 5, 1980. The PDES is an internal review document. DOE will coordinate the review (including cooperating agencies) and will forward the comments to ORNL. After responding to comments ORNL will assemble the Draft EIS (DES) for approval and signature by Ruth Clusen (Assistant Secretary for Environment) and issuance for public review. The DES is expected to go to DOE near the end of June. The Monthly Report for June will summarize the findings.

SRC II demonstration project - On May 23, 1980 DOE issued the Draft Environmental Impact Statement for the SRC II project -- the first site and project specific DES to be issued in DOE's synfuels from coal demonstration program. The findings are summarized below.

Description of the proposed action - The proposed action evaluated by this statement is the construction and short-term operation of a 6000 tons of coal per stream day (tpsd) capacity facility to demonstrate the technical operability, economic viability, and environmental acceptability of the SRC II solvent-refined coal (SRC) process. This process converts high-sulfur coal into a low-sulfur, low-ash primary liquid fuel product; secondary gaseous and liquid fuel products; and by-product sulfur, ammonia, and tar acids. A goal of the demonstration program is to facilitate the construction and operation of a commercial facility, e.g., 30,000 tpsd. Should the demonstration prove successful it is anticipated that the first commercial SRC II plant of about 30,000 tpsd capacity will be constructed at the demonstration facility site by the industrial participant. The impacts likely to arise should the plant be commercialized, converted to another government use, mothballed, or decommissioned are also addressed in the EIS.

The proposed site is bounded on the southeast by the Monongahela River, on the east by the Fort Martin Power Plant (Monongahela Power Company), on the north by the West Virginia-Pennsylvania state line, and on the west and south by land in private or corporate ownership.

Alternative actions available to DOE - The environmental impacts of the proposed action are evaluated in comparison with the impacts of the alternative actions which may be taken by DOE:

- o Select an alternative design or site to further reduce environmental impacts and proceed with construction.

- o Terminate the contract and take no further action on the project.

Impacts and benefits during the demonstration - Construction and operation of the plant in accordance with the proposed design and site are expected to result in the following impacts:

- o Production of a broad range of complex organic materials including polynuclear aromatic compounds, aromatic amines, and heterocyclic sulfur compounds which are known or suspected to be either (1) mutagenic or teratogenic in microbial systems, or (2) carcinogenic and/or toxic in laboratory animals.

- o Conversion of 115 ha (285 acres) of land from rural agricultural and residential use to industrial use for the life of the plant. Removal of 540 ha (1350 acres) of land (primarily pasture) from agricultural production.

- o Displacement of approximately 60 persons (24 residences) from the unincorporated community of Fort Martin, which will probably cease to exist as a definable community.

- o Increased erosion and resultant sediment loads to surface waters during construction.

- o Reduction in vegetative communities and available wildlife habitat. This will not impact any Federal or state listed endangered or threatened species.

- o The emission of criteria and non-criteria air pollutants. These emissions are not predicted to cause violation of National Ambient Air Quality Standards (NAAQS) or available Prevention of Significant Deterioration (PSD) increments.

- o The consumptive use of $1.6 \times 10^4 \text{ m}^3$ ($4.3 \times 10^6 \text{ gal}$) per day of water from the Monongahela River during periods of low precipitation.

- o The proposed mechanical draft evaporative cooling tower system is the major source of consumptive water use. Operation of the cooling system will result in localized increases in fogging and icing and in salt deposition as a result of drift. The impacts of increased fogging, icing, and drift deposition are expected to be low and will be mitigated by appropriate location and design of the system.

- o Construction and operation of the plant will result in increased noise levels on the plant site. These levels will be assessed and, if necessary, mitigation will be provided in the design of the system.

- o Construction employment will peak at 3170 in 1983. Labor shortages expected in four key crafts (ironworkers, boilermakers, pipefitters, insulators) will result in an estimated 845 construction workers moving to the general site area. This population increase will likely cause shortages in housing unless mitigating actions are taken.

- o Removal of the proposed site from the local tax base for the duration of demonstration operation. As a result, there will be no direct tax payments.

- o Additional traffic on local roads leading to the site.

- o Increased river traffic for coal delivery by barge. The U.S. Army Corps of Engineers has determined that the existing river navigation system is adequate to accommodate the coal transportation needs for the demonstration plant.

- o Increased rail traffic for product shipment. The existing rail system is considered adequate to accommodate the added traffic without significant impact.

- o Construction in a floodplain/wetland and potential impacts on historic and cultural resources.

- o Benefits - Direct employment of approximately 460 persons during the operation phase and an additional 465 persons due to secondary employment. The Morgantown-Monongahela County area is expected to have the capacity to absorb all long-term project related growth without major negative impact.

Impacts of selecting an alternative plant design or site - The EIS evaluates the feasibility of using alternative plant designs to lessen the environmental impacts of plant operation, and compares the impacts of locating the proposed facility at the proposed site and the two alternative sites.

Based on this evaluation, it was concluded that the proposed design includes the environmentally preferable alternative for: separation and disposition of mineral residue, hydrogen production, wastewater treatment and plant fuels.

Evaluation of alternatives for sulfur recovery and emission control, process hydrocarbon emission control, waste heat rejection and particulate emission control indicated the availability of design alternatives which appear to offer potential for significantly reducing emissions of sulfur dioxide, particulates and hydrocarbons and for reducing consumptive water use.

Based on a comparison of the predicted impacts produced by construction and operation at the alternative sites with those predicted for the proposed site, it is concluded that, although the significance of specific impacts varies between sites, construction and operation of the proposed plant at one of the alternative sites would not produce appreciably lower environmental impacts, and further study of the alternative sites is not warranted.

6.6.2 Environmental review for H-Coal landfill - T. H. Row

The initial review of landfill plans for the H-Coal project was completed in July 1979. No further activity is expected on this task until the summer of 1980.

6.6.3 Coal liquefaction project: critical review on mutagenesis - R. F. Kimball, N. B. Munro, C. J. Oen, and L. W. Rickert

The literature search for pertinent information has reached about two-thirds to three-quarters completion. Hard copy of many of the identified documents are on file. An initial form for a computer-assisted data base has been developed, and a trial set of documents is being entered to test the suitability of this form. A search of the Environmental Mutagen Information Center (EMIC) files for pertinent information on compounds identified through chemical analysis as pertinent to coal liquefaction was begun with a small trial list. A longer, more comprehensive list is being prepared for further search. Contacts have been made with a number of potential sources of information from outside the Laboratory and pertinent information has been received or promised. A number of persons has been consulted within the Laboratory for additional information. A first draft of the Introduction section (Section I of the outline) has been prepared and is being reviewed for further improvement. A draft has been prepared of most of the section on Sources of Products and Byproducts Section (Section II of the outline) and work will start very shortly on the description of mutagenesis protocols called for in Section III.

Research relating to this topic area has been identified at several institutions, including Argonne National Laboratory, Lawrence Berkeley Laboratory, Oak Ridge National Laboratory, and Pacific Northwest Laboratories. Entry of material to the computerized data base has been through use of typing that was scanned by an optical character reader. This permits input work from standard typewriters in any location.

6.7 General Technical Support

General technical support is provided for the SRC-I and SRC-II projects and for the H-Coal project as requested.

6.7.1 SRC-I and SRC-II general technical assistance - H. D. Cochran

There is no current activity in this area.

6.7.2 H-Coal general technical assistance - H. D. Cochran

The following activity on H-Coal reactor safety assessment is in progress in this area.

6.7.3 H-Coal reactor safety assessment - H. A. Mitchell, B. L. Booker, R. C. Cwaltncy, R. A. Just, L. F. Parsely, A. N. Smith, R. W. Swindeman

Objectives - The major objective of the reactor safety assessment is to determine the adequacy of the vessel for the two-year duration of the H-Coal project. In addition, the Task Force was asked to identify any significant failures which could affect reactor operation and to determine the adequacy of systems to limit or control those effects.

The safety assessment encompasses the major reactor components and subsystems, the instrumentation directly associated with the reactor and normal, upset, and emergency procedures.

In order to achieve the objective of the Task Force, four tasks were identified and are described briefly below.

1. The significant failures of process equipment which could affect the reactor temperatures and pressures and the systems important for safety of the reactor were identified. Transient analyses of process conditions were performed for selected normal, upset, and emergency events. The analyses provide information about the expected temperature and pressure changes for various events. Based on these analyses, a histogram of umbrella events was developed which conservatively represent the operation of the reactor.

2. Materials data were gathered on the alloys used to fabricate the H-Coal reactor. Creep, fatigue, and creep-failure interaction data were assembled, and curves developed for comparison with the design data in Section VIII, Division 1 and Division 2 of the ASME Boiler and Pressure Vessel Code for service in the temperature range of 400 to 900°F.

3. A thermal analysis of the internal support ring and vessel wall was performed based on the histogram developed for the various operating conditions. This analysis provides information about potentially severe temperature distributions in the material.

4. A one-dimensional inelastic (elastic-plastic-creep) analysis of selected regions of the vessel was made to assess accumulation of creep-fatigue damage. This analysis was based on the temperature pressure history for the umbrella events described above. The results of these analyses will indicate whether there is need for more detailed analyses.

Status summary - A draft of the H-Coal reactor safety assessment was submitted to DOE-ORO for review and comment. The report includes the results of process transient analyses, development of materials data for the reactor vessel, thermal analyses of the vessel and a simplified creep-fatigue analysis of the vessel wall.

Based on the preliminary assessment of the reactor, it appears there are potential failures which could affect the reactor; however, adequate information is available to the operators to observe and control the reactor under upset and emergency conditions. In addition, systems and components which are important to the safety of the reactor have been identified and actions by the operators should prevent a more serious event from occurring.

A number of events have been considered in developing a set of design transients for the stress analysis including upset and emergency events. A loss of electric power appears to cause the most severe temperature excursion, since it implies the immediate loss of capability to cool the reactor. The creep-fatigue damage factors for the stainless steel overlay and the vessel wall were calculated.

The same factors were used to calculate the psuedo life remaining in the vessel. The stainless steel overlay has a calculated pseudo remaining life of 27 cycles and the vessel wall has a remaining pseudo life of 106 cycles. These remaining lives would tend to indicate that the vessel would safely operate for the life of the "umbrella" transients. However, the following should be considered.

1. The material data used in the analyses were for different materials which closely approximate how we think the materials act conservatively, but they could act significantly different after a long period of time.
2. The loading transients were assumed based on calculations at ORNL.
3. The effect of the residual stresses in the overlay and the heat affected zone of the vessel wall caused by the welding could not be included in the analysis.
4. The effect of corrosion, erosion, and hydrogen attack of the material are not included in the analysis.

In conclusion, the H-Coal reactor can be started up on coal if the vessel is not subjected to operating temperatures and pressures beyond those defined by the "umbrella" transients and no greater number of events occur than those listed in the histogram. Also, the stainless steel overlay should be inspected, because the inelastic strain accumulation in the overlay could lead to cracking and then even greater damage to the main vessel wall. In fact, most of the calculated structural damage occurs in the overlay. The maximum damage in the vessel wall occurred right under the overlay in the heat affected zone. It should be pointed out again that the material in a heat affected zone is likely metallurgically degraded and not even the same material as the base metals.

7. PROCESS ANALYSIS AND ENGINEERING EVALUATIONS

R. W. Glass

Process analysis and engineering evaluations studies are being conducted for DOE/FE to provide on a consistent basis, technical and economic assessments and evaluations of processes and systems for coal conversion and utilization.

7.1 Liquefaction Technology Assessment (LTAS)

R. C. Forrester III, R. Salmon, S. P. N. Singh, J. F. Fisher,
R. M. Wham, and W. C. Ulrich

7.1.1 Objective

The objective of the Liquefaction Technology Assessment is to provide technical information, cost information, and economic evaluations needed by the Department of Energy (DOE) to compare, on a consistent basis, coal liquefaction processes. The assessment will be carried out in several phases, starting with processes employing available technology and progressing to those which are in earlier stages of development. Technical and cost information will be provided by Fluor Engineers and Constructors through a contractual agreement with the Oak Ridge National Laboratory (ORNL). ORNL will provide the process design bases, conceptual design philosophy guidance, and economic evaluations based on the cost information provided by Fluor.

7.1.2 Status Summary

Revision of the Phase 0 draft report is complete and the manuscript has been submitted for final editing. Publication is expected this quarter.

Phase I continued to proceed with issuance by ORNL of the Phase I draft final report in mid-May. Copies of the draft were distributed to members of the LTAS steering committee. Following receipt of comments by DOE, the draft will be sent out for a limited proponent review.

The final report includes an Appendix containing preliminary cost estimates for a facility producing 13,000 BPSD (nominal) of methanol for gasoline blending which were requested by DOE. These preliminary estimates were prepared by scaling down one of the Phase I conceptual designs prepared by Fluor. (Details of the Fluor design are given in the January 1980 report of this series and in ORNL-5664/V1.)

The cost estimates were prepared by using a combination of factoring techniques to scale down the design provided by Fluor. However, the estimating done by ORNL is a rough approximation and does not take into

account optimum equipment sizes, nor have internal mass and energy balances been recalculated as would be required for a more precise estimate.

The capital costs were scaled down using a scaling factor of unity for cases where a reduction in the number of trains was made. Cases requiring a reduction in the size of the process unit were estimated using a power factor method. In those cases where the ratio of the capacity of a process unit from the 52,000 BPSD to the capacity of a process unit from the 13,000 BPSD plant is four to one or greater, a power factor of 0.6 was used. A power factor of 0.7 was used elsewhere. In estimating operating costs, the operating and maintenance labor requirement was adjusted to maintain constant manhours attention for each unit based upon the original Fluor design. Supervisory labor was based on the size of the recomputed labor force. Other estimates of operating costs were made using the same techniques utilized by Fluor.

The total capital investment for the quarter-size facility is estimated by ORNL to be 814 million or about 38% of the \$2132 million required for the full-size facility designed by Fluor. The operating cost estimates for the two plants are \$109.8 and \$331.0 million, respectively. A summary of capital costs, operating costs, and an overall material balance for both designs is given in Table 7.1.

After development of capital and operating cost estimates, the price of product methanol was calculated using the financial ground rules summarized in Table 7.2. (More details on the financial ground rules are given in the January 1980 report in this series.) As shown in Table 7.1, the resultant price of methanol from the scaled-down facility has increased by 53%, going from \$0.57/gal in the 53,000 BPSD (nominal) facility to \$0.87/gal. While "utility" financing results in lower product price for both facilities, methanol from the quarter-size plant will still be 50% more expensive to produce.

After calculation of the base case results, a limited sensitivity analysis was performed. The sensitivity of methanol price to coal price was examined and the results are shown graphically in Fig. 7.1. The price of methanol is only moderately dependent on coal price. The sensitivity of methanol price to SNG market price was also examined since the base case assumed a high price for SNG (\$12.16/10⁶ Btu). The results are shown graphically in Fig. 7.2. As expected, the price of methanol is quite sensitive to changes in SNG market price.

Since the accuracy of the ORNL cost estimates is uncertain, the influence of a 20% change in total depreciable capital is also examined in Fig. 7.1 and 7.2. The dashed lines show a difference of 20% in total depreciable capital. As can be seen from Fig. 7.1 and 7.2, a 20% change in total depreciable capital yields a significant change in methanol price; however, an assumption of an alternate method of financing (75% debt and 25% equity) can have a far greater influence on product price than a 20% change in total depreciable capital.

Table 7.1 Capacity and cost summary for gasoline blending
grade methanol production facilities
(in mid-1979 dollars)

	13000 BPSD Nominal	52000 BPSD Nominal (case B-1)
Coal feed rate (TPSD of MAF coal):		
Coal to gasifiers	4000	16,000
Coal to power plant	1052	4,210
Total coal feed	5052	20,210
Products:		
Methanol (BPSD)	13192	52770
SNG (10^6 SCFD)	38	153
Crude diesel (BPSD)	975	3,900
Crude phenols (10^3 lb/SD)	96	384
Ammonia (TPSD)	28	110
Overall thermal efficiency, %	64.8	64.8
Total capital cost (10^6 \$) ^a	814	2,132
Annual operating cost (10^6 \$) ^b	109.8	331.1
Investment, dollars per daily barrel (FOE) ^c	59400	39400
Product prices for base case ^d		
Methanol (\$/gal--\$ 10^6 Btu)	0.87--13.36	0.57--8.81
SNG (\$/ 10^6 Btu)	12.16	8.02
Product prices for utility case ^e		
Methanol (\$/gal--\$ 10^6 Btu)	0.54--8.37	0.36--5.64
SNG (\$/ 10^6 Btu)	7.62	5.13

^aThis includes a 20% estimating allowance.

^bBased on a stream factor of 95%.

^cProduct fuel oil equivalent (FOE) based on 6×10^6 Btu/bbl.

^dBase case assumed: 100% equity financing; 12% annual after-tax of return on equity; 1990 price scenario given in January 1980 monthly report, 25-year operating life; 5-year construction; 48% federal income tax; 3% state income tax; 2.75% local property tax and insurance; mid-1979 dollars; sum-of-years' digits depreciation for 16 years; \$1/ 10^6 Btu coal; no salvage value.

^eUtility case assumed. 75% debt and 25% equity, 12% annual after-tax rate of return on equity, 9% interest on debt, all other assumptions are the same as for the base case.

Table 7.2 Economic base conditions

Percentage of equity financing	100
Annual after-tax rate of return on equity, %	12
Operating life, yrs	25
Construction period, yrs	5
Federal income tax rate, %	48
State income tax rate, %	3
Investment tax credit, %	10
Local property tax and insurance cost, % ^a	2.75
Estimating allowance, %	20
Depreciation method	Sum of years digits over 16 yrs
Coal cost, \$/10 ⁶ Btu	1
Dollar value base	mid-1979

^aTaken as a percentage of total depreciable capital.

Fig. 7.1. Preliminary examination of the effect of coal price on methanol price for a 1/4 size methanol production facility.

ORNL DWG 80-575

Fig. 7.2. Preliminary examination of the effect of SNG market price on methanol price for a 1/4 size production facility.

7.2 Direct Combustion

E. C. Fox and T. D. Anderson

7.2.1 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 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 reports entitled "Summary of the Research and Development Effort on Open-Cycle Coal-Fired Gas Turbines," ORNL/TM-6253, and "Summary of Research and Development Effort on Air and Water Cooling of Gas Turbine Blades," ORNL/TM-6254, have now been published.

^aConsultant

7.4 Process Modeling

R. Salmon, D. M. Lister, P. J. Johnson, and W. C. Ulrich

7.4.1 Objective

The objective is to assist DOE/FE in its plan for computer analysis and computer support of coal conversion studies. Past work included assistance to Purdue and Lehigh Universities in the development of computer programs for this plan. Physical property data were collected and computerized primarily by Purdue and will be used in support of future process modeling efforts. Purdue's general design program was aimed at material and energy balances, equipment sizing and costing, plant capacity, and general economics. Lehigh's dynamic simulation programs addressed plant design primarily from the standpoint of process performance during transient operations, but can also be used for steady-state conditions. Current work includes process modeling and systems engineering support to Morgantown Energy Technology Center (METC). This comprises implementation of codes delivered by Purdue and Lehigh Universities onto the computer system at METC and development, testing, implementation and use of new process models.

7.4.2 Status Summary

Evaluation of Physical Property Package PPROP

A draft report on the evaluation of the physical property package PPROP (described in some detail in the last monthly report of this series) is being reviewed internally prior to transmittal to METC.

Addition of Solids Handling Capability to PPROP

1. Subroutine LOADP is being rewritten to select pure species properties from a library held on disk.
2. Space has been reserved in the library for solid component properties including particle size distribution. Special storage techniques are being developed to handle the extra data required to define the particle size distribution. Space will be provided to allow for up to 30 size increments in the distribution.
3. Among the solids to be considered will be coal, char, ash, limestone and dolomite.
4. A routine called UPDATE has been written to add new components to the library.
5. A routine called INITIAL has been written to initialize and keep track of the status of the library.

Evaluation of Rajan-Wen-Krishnan FBC Computer Program

Review and evaluation of the elutriation-attrition portion of the program has been completed. A number of serious deficiencies were found:

1. The method of Merrick and Highley for calculating attrition was incorrectly applied, giving attrition rates of zero for the larger size fractions.
2. In spite of this, positive rates of shrinkage were shown for the larger size fractions in the close-fraction material balance calculations.
3. The elutriation constant used was too small by a factor of about 7.
4. The iterative calculation of carbon content of the bed does not converge satisfactorily. Using the example problem furnished with the program, three different "converged" solutions were obtained, depending on the initial trial value used. Elutriation and discharge rates differed widely for the three solutions.

Evaluation of the combustor section of the program is now in progress.

7.5 Coal Liquefaction Advanced Research Digest

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

7.5.1 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.

7.5.2 Status Summary

Updating and rewriting to incorporate reviewers' comments were completed for the article "Chemical Reaction Kinetics of Coal Liquefaction," and the article was circulated for external review. External reviewers' comments on the article "Coal Depolymerization" were received, and the manuscript was appropriately adjusted prior to submission for editorial review and typesetting. Writing continues on the articles "Chemical Characterization of Coal-Derived Liquids" and "Free-Radical Chemistry of Coal Liquefaction."

8. FOSSIL ENERGY ENVIRONMENTAL ANALYSIS

C. R. Boston, T. H. Row

Environmental support is provided to DOE/Fossil Energy and DOE/Economic Regulatory Administration. The effort includes: (1) preparation of NEPA-required assessments and statements related to synfuels demonstration programs and fuel conversion implementation; (2) programmatic environmental studies that are critical to the early realization of advanced fossil technologies and minimization of the use of petroleum and natural gas; and (3) general environmental technical assistance.

8.1 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.

8.1.1 Stored solids study - W. J. Boegly, Jr., F. S. Brinkley, E. C. Davis, C. W. Francis, and H. W. Wilson, Jr.

Revised RCRA regulations were issued by EPA during the month. Based on these revised regulations, which increase the leachate limits to a factor of 100 times the Interim Primary Drinking Water Standards instead of the factor of 10 previously allowed, none of the six slags tested would be classified as a hazardous waste.

Additional analytical studies have been completed on the leachates from column leaching tests. The main purpose of this study was to evaluate the concentrations of certain parameters listed in the Secondary Drinking Water Standards which had not been investigated in our earlier RCRA compliance studies. The results indicate that certain of the wastes will produce column leachates that exceed the Standards for the initial few water applications.

EP and ASTM leaching has been initiated on the new shipment of SRC-II slag (Powhatan Coal). Elemental analysis of the slag has also been requested.

8.1.2 Coal conversion demonstration projects

Liquefaction projects - S. G. DeCicco

This activity is reported in Chapter 6.

Gasification projects - A. J. Witten

MLGW - A DES review draft was sent to DOE on May 9. We are expecting to receive comments on this in mid-June. The Phase II contract signing took place in Memphis on May 21 followed by the monthly meeting the next day.

Grace - This project is on hold.

ICGG - DES preparation is underway. The target date for completion of a review draft is June 16.

CONOCO - Assistance by HDR in preparation of the DES for CONOCO is currently in progress. A review copy for the ORNL team is due on June 9 and it is expected that the revised document will go to DOE on June 11.

8.1.3 Communications

a. Boston and Martin participated in SRC-II DES review meetings in D.C. on May 5-7, 1980.

b. Witten attended the monthly progress review meeting for MLGW in Memphis on May 21-22, 1980.

c. Boston participated in the final review of the SRC-II Draft EIS and delivered the printed copies for sign-off by Assistant Secretary Clusen and delivery to EPA, in D.C. on May 23, 1980.

d. DeCicco attended a meeting with Air Products in Allentown, Pennsylvania to discuss SRC-I plant design information on May 29, 1980.

8.2 Economic Regulatory Administration Support Project

R. C. Martin and R. M. Rush

The purpose of this project is to provide technical assistance to the Economic Regulatory Administration (ERA) of the Department of Energy in its implementation of the Powerplant and Industrial Fuel Use Act of 1978 (FUA). This act has as a general purpose the minimization of the use of petroleum and natural gas as a primary energy source in a manner consistent with applicable environmental requirements. The scope of FUA includes both new and existing electric powerplants and

new and existing major fuel burning installations. Within ERA the Office of Fuels Conversion (OFC) is responsible for implementing FUA and meeting the requirements of the National Environmental Policy Act. The Fuels Conversion Analysis Division supplies the technical support for OFC.

The initial assignment for this project relates to the conversion of two existing powerplants in the New York City area (Arthur Kill and Ravenswood) from oil as the primary fuel to coal or other alternate fuel.

8.2.1 Environmental analysis section - N. E. Hinkle

A draft noise impact assessment for the Arthur Kill powerplant fuel conversion prepared by UE&C has been reviewed by the Section leader, by the community impact subcontractor, and by the health analyst. Suggestions for improvement were transmitted to the Subcontractor. UE&C was also requested to include a summary of the off-site noise impact in the appendix of the Engineering Analysis Technical Report.

A method for evaluation of occupational noise exposure has not been determined. The present course of action is to continue requesting baseline noise level and noise exposure information from Con Ed and independently obtaining similar information for coal-fired and oil-fired plants from other utility systems such as TVA.

A second solid waste disposal feasibility study, this one for the Lovett station of Orange and Rockland, has been received from the New York State Department of Public Service (NYS-DPS) and circulated to the team and other sections of the project. The Section leader met briefly in New York City with Bill Lilley of NYS-DPS on May 21 and presented a number of suggestions from the ORNL team for potential improvements in the solid waste disposal survey studies, particularly for use when the NYS-DPS staff prepares the study for the Con Ed facilities (Arthur Kill and Ravenswood).

On May 21, N. E. Hinkle, R. C. Martin, and D. J. Wilkes attended a joint meeting of the State Coal Conversion Task Group, DOE/ERA, and other interested Federal and State agencies.

On May 27, N. E. Hinkle, R. C. Martin, W. L. Greenstreet, and D. J. Wilkes met in Washington with the ERA Fuel Conversions Analysis Division to establish the final list of fuel scenarios to be evaluated in the engineering and environmental reports. The results of this meeting have been reported to the staff of the ORNL program and the subcontractors.

A preliminary draft of an emissions and waste report prepared by UE&C as an engineering environmental resource has been received, reviewed, and critiqued by the Section leader. Because this document was prepared before the final list of fuel scenarios was established, there will need to be changes made before a final report will be available.

Portions of the baseline socioeconomic descriptive text for the statements for both plants were received from the subcontractor (Radian), reviewed, and returned for final preparation. Community impact analysis has been initiated.

Development of the environmental impact reports has been slowed by the delay in finalizing fuel scenarios, developing emissions/effluents characteristics for a coal converted plant, identifying transportation modes for fuel supply and solid waste removal, and identifying potential solid waste disposal sites. Early resolution of these problems is necessary for completion of the draft environmental reports by October.

8.2.2 Air quality analysis section - F. C. Kornegay

Work is underway on the analysis of the impacts from fugitive dust for the Arthur Kill and Ravenswood powerplants. The air quality information required for health effects and ecological effects analyses were discussed with these analysts.

8.2.3 Engineering analysis section - W. L. Greenstreet

The emphasis in May was on developing consensus identifications of fuels to be used in the Arthur Kill and Ravenswood powerplant studies. Meetings were held with DOE/ERA personnel in Washington, D.C., on May 2 to discuss the fuels to be addressed, fuel supply determinations, and transportation modes for fuel, FGD sorbent, and solid wastes. Subsequently, a proximate analysis and other relevant characteristics to be used in the coal supply investigations were determined on the basis of limitations on ash, moisture, and volatile matter contents as well as other considerations. Information from equipment designers and Con Ed personnel along with requirements of New York City Law No. 49 were also factored in. However, initial indications from coal supply investigations suggested that the proximate analysis was too restrictive, and the requirements to meet the New York City law were waived because deviations from this law are necessary for coal burning at the two plants. A revised proximate analysis, more in line with that of the coal used in establishing the original steam generator performance guarantees, was therefore adopted.

Parametric studies were done to aid in the selection of engineering analysis studies to be carried out on mixtures, and the feasibility of intermittent burning of coal and gas was examined. In the case of intermittent burning, coal would be used during periods of low air

pollution levels and gas during periods of high level. This type of firing would result in derating for only one unit, Arthur Kill Unit No. 20. The derating was estimated to be about 5%, and the scheme was adjudged to be feasible. In addition, changes in space requirements for wet and dry FGD systems as a function of percentage of flue gas scrubbed were determined to examine potential advantages associated with partial scrubbing of the flue gas from Ravenswood Unit No. 30. Sufficient motivation for adopting a partial scrubbing option was not indicated from this study.

A second meeting was held with DOE/ERA personnel in Washington, D.C. on May 27 for finalizing the fuel descriptions. A meeting was then held in Oak Ridge with UE&C personnel on May 30 to discuss the fuels selected and the engineering analysis reports for Arthur Kill and Ravenswood.

Information requests on a number of aspects of the work assignments were received from UE&C. Some of the information needed was obtained through conversations between UE&C and Con Ed personnel; requests for other items not obtainable by other means were relayed to DOE/ERA personnel. Information on transportation modes, costs incurred by Con Ed for coal conversion work done, and unit capacity factors is of prime importance at this time.

During this period, three reports on noise associated with the two plants were received from Con Ed. These are:

1. "Ravenswood Station Community Environmental Noise Survey," Consolidated Edison Company, February 1980.
2. "Arthur Kill Station Community Environmental Noise Survey," Consolidated Edison Company, February 1980.
3. "Noise Assessment of Coal Unloading Facilities," Stone and Webster Engineering Corporation, February 1980.

In addition, UE&C submitted two draft documents:

1. "Draft Noise Impact Assessment Arthur Kill Power Plant," May 1980.
2. "Draft Occupational Hazards Evaluation for Arthur Kill Power Plant," May 1980.

and a preliminary version of:

3. "Draft Determination of Stack Emissions and Solid and Liquid Waste Discharges for Arthur Kill Power Plant," May 1980.

All of these documents have been reviewed, and comments on the draft noise impact assessment document have been given to UE&C.

Stack performance requirements and methods for mitigating undesirable effects have been studied at ORNL. A write-up summarizing the results of this study and the need for stack qualification was sent to UE&C for consideration.

An investigation of FGD systems which have acceptable SO₂ removal efficiencies and on-line time with minimal effect on steam generator operation was concluded. Principal factors which control FGD system operations are selection of materials of construction, operator attitude toward use of the system additions to the power plant, and management of the reagent-byproduct material cycle.

The importance of pyrite rejection at the pulverizer was briefly examined. It was concluded that this factor will not be significant for the quality of coals expected to be used at Arthur Kill and Ravenswood.

8.2.4 Fuel supply and waste disposal analysis section - A. S. Loeb

Subsequent to the decision in April that ORNL and TERA will select coal origins for the transportation studies, specifications for the coal types to be considered were transmitted to TERA. A preliminary list of coal origins was developed and is being reviewed for final selection of coal sources.

Work is now proceeding on the coal transportation studies (subtasks 9 and 10). Additional data have been collected on truck costs and rail rates for coal. As with the rail rates for shipment of wastes, the rates found for coal are subject to negotiations by the parties involved. The results of these negotiations can only be estimated using existing published rates. The report on these subtasks should be completed in June.

Estimates of ash and sludge volumes (subtask 5) is proceeding now that preliminary coal sources have been selected. A report on this subtask should be completed in June.

Work is continuing on the development of rail rates and problems associated with waste transportation (subtask 6). Data have been collected on rail rates to the selected candidate disposal sites and truck costs from which rates/costs may be synthesized. All such rates are based on prevailing conditions which could change significantly upon conversion of any one of the Con Ed powerplants to coal. In that case a special commodity rate would be negotiated. For barge and truck carriers, costs would represent the "shadow" rate if the equipment were owned by the utility. It would be the lower bound for a commercial rate as the actual rail rate would be subject to negotiation. Data have been collected on site restrictions at the powerplants and at some of the candidate disposal sites. It is anticipated that the report on this subtask will be completed in June.

Work on the generic study of the uses of ash (subtask 7) has been delayed until the other, more urgent, subtasks are completed.

No comments from ERA have been received on the draft report on the Port Reading facility (subtask 8) which was transmitted to ERA on April 22.

8.2.5 Northeast regional analysis

Air quality - F. C. Kornegay

New SIP emission factors were received on May 21. Since these are different from those received previously, the analyses need to be redone. Preliminary results will be available early in June.

A visit was made to ANL on May 21 to discuss the SIP emission scenarios.

8.2.6 Electric utility dispatch analysis - C. R. Hudson

The base case simulation of NYPP is being reviewed by ERA. Additional data from Long Island Lighting Company was received and will be used to make this utility a separate area in the simulation. Con Ed will also be a separate area when similar data are received from them.

Work continues on the NEPOOL and PJM regions. Due to delays in data acquisition, studies of these regions will not be completed until July.

8.2.7 Annual reports preparation - T. H. Row

The final Federal Facilities Annual Report was delivered to ERA at the end of May.

8.2.8 Milestones

The following dates have been established for delivery of the first draft of the indicated reports to ERA. Unless otherwise noted, work on these reports is on schedule.

Arthur Kill Powerplant		
Fuel Scenario Evaluation	March 20, 1980	delivered
Environmental Regulations		
Technical Report	March 25, 1980	delivered
Fuel and Waste Technical		
Report	May 31, 1980	parts delivered parts delayed
Engineering Analysis		
Technical Report	March 28, 1980	delivered
Environmental Impact Report	October 1, 1980	
Ravenswood Powerplant		
Fuel Scenario Evaluation	March 20, 1980	delivered
Environmental Regulations		
Technical Report	March 25, 1980	delivered
Fuel and Waste Technical		
Report	May 31, 1980	parts delivered parts delayed
Engineering Analysis		
Technical Report	May 16, 1980	delayed
Environmental Impact Report	October 1, 1980	
Northeast Regional Study		
Air Quality Technical Report	September 15, 1980	
Transportation Technical		
Report	September 1, 1980	
Health Effects Report	September 1, 1980	
Electric Utility Dispatch Study		
New York Power Pool	April 14, 1980	delivered
New England Power Pool	June 1, 1980	delayed
PA-MD-NJ Interconnection	June 1, 1980	delayed
Annual Reports Preparation		
Draft FUA Annual Report	January 28, 1980	delivered
Final FUA Annual Report	February 29, 1980	delivered
Draft Federal Facilities		
Annual Report	March 15, 1980	delivered
Final Federal Facilities		
Annual Report	May 15, 1980	delivered
Small Utilities Study		
Draft Report	July 31, 1980	

8.3 Fossil Energy Program Support

T. H. Row

This program was initiated with a series of visits to the Energy Technology Centers (ETC) and various Operations Offices to discuss the environmental requirements and projects of Fossil Energy Programs. These discussions resulted in a consistent set of suggested activities designed to provide the environmental effort necessary to assure commercialization of the major coal conversion programs. The ideas generated from these contacts coupled with the defined responsibilities of the Environmental Activities Branch resulted in five specific work areas:

Research planning - Provides for ongoing review of projects coupled with close project interaction to provide the insight needed to assure that all necessary environmental work is initiated.

Critical issues - Provides a detailed critical review of identified environmental problem areas with documentation of findings.

NEPA coordination - Provides assistance in scheduling required NEPA activities in support of major programs or projects.

Regulatory and legislative reviews - Provides a continuing review of all regulatory and legislative items, present and planned, and their effects on fossil energy programs.

Consultation assistance - Provides for identification of a team of experts in the environmental field available to respond rapidly to requests for assistance from the Environmental Activities Branch.

During the month the second document in the NEPA Fossil Energy series was completed and distributed. The Environmental Program Compliance Handbook for Tennessee is nearing completion. Speakers and topics for the IH/OM workshop have been finalized and confirmed.

8.3.1 NEPA compliance coordination - W. W. Goolsby

During this reporting period, the second document for the NEPA Fossil Energy Series was distributed. Approximately 260 copies of this document entitled, "Representative Fossil Energy Projects - Fuel Extraction and Advanced Utilization", dated April 1980, were distributed to project personnel, project managers, and other interested DOE and ORNL personnel, locally and throughout the country. Projects included in this document involved the following Fossil Energy Technologies: oil shale, enhanced gas recovery, enhanced oil recovery, mining R&D, combustion, heat engines and heat recovery, magnetohydrodynamics, and fuel cells.

Data sheets were developed on each project to provide basic information such as project title, project location, estimated project cost, technology involved, and names and location of responsible project personnel. The schedules define project milestones with respect to conceptual design, detailed design, procurement, and construction. The environmental schedule depicts NEPA activities past, present and future. The information provides an inventory and data base of energy research and development projects in operation, under proposal for funding, or funded in part or whole by DOE. The inventory includes projects large enough for process development, pilot demonstration, or commercial application which require(d) environmental assessments and/or environmental impact statements. Verification and documentation of project data and schedules were confirmed through numerous reference and source documents and by personal contact, phone conversation, and visits to DOE Headquarters, DOE Energy Technology Centers, and other involved agencies and personnel.

Also, during this reporting period, a third document is in preparation covering non-fossil energy projects funded in part or whole by DOE with potential NEPA requirements. The technologies involved include geothermal, solar, wind, ocean, biomass, and low-head hydroelectric. This document will contain approximately 90 projects and should be ready for distribution in June 1980. Following this event it is planned to develop and distribute a fourth document covering the remaining technologies such as conservation, energy storage, energy transmission, conversion facilities, and ERA. Long range plans include development of computerized updating and reporting of all NEPA projects.

8.3.2 Regulatory and legislative review - J. K. Huffstetler and C. J. Oen

Work on the Tennessee volume of the "Environmental Compliance Program Handbook" is essentially completed. Draft copies should be ready for transmittal to Washington late next week. Abstracting of the laws and pertinent environmental regulations for the states of West Virginia and Ohio is completed. Some sections remain to be indexed and entered into the computer file. Currently, the computer file contains over 500 entries, with a considerable backlog of work yet to be done. Publication of draft handbooks for West Virginia and Ohio, the last of the primary states, should take place during the month of July.

8.3.3 Industrial Hygiene/Occupational Medicine Workshop - T. H. Row

Copies of the proceedings from past symposia covering similar topics were obtained and reviewed to aid in the selection of speakers, topics, etc. Recommendations on particular speakers were solicited from several DOE, ORNL and other personnel. All speakers and topics were finalized and potential speakers were contacted by telephone. Follow-up letters were prepared and mailed to all participants confirming their invitation to participate in the workshop.

The conference coordinator at the Boars Head Inn was contacted and room rates were negotiated and firmed up. A room reservation form for inclusion in the workshop registration package was developed.

A trip is planned to DOE to finalize the list of invited attendees. A letter of invitation from DOE and program descriptive material is being developed.

8.3.4 Milestones

A trip was made to McLean, Virginia by T. H. Row for coordination of the IH/OM Workshop.

9. COAL PREPARATION AND WASTE UTILIZATION

E. C. Hise

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

The continuous carousel separation test series at Sala Magnetics, Inc., is complete and the bulk of chemical analyses have been performed. The data will be available for analysis in June. About 20 Mg of product coal, refuse, and feed samples are being shipped to ORNL.

The major short term efforts in the HGMS program are the analysis and reporting of the continuous separation tests, and the completion and reporting of the design study and cost estimate of the pilot plant.

9.2 Open-Gradient Magnetic Separation

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

The primary effort during the month has been directed toward the circular feed test series with our superconducting magnet which will be performed in early June. The feed mechanism for this test series has been fabricated and tested. Based on these tests, it has been determined that a flow straightener should be fabricated before the test series with the superconductor is begun. The flow straightener has been designed and is currently being fabricated. It will be tested before the superconducting test series.

Work is underway on a report on the OGMS work, which should be available in the fall. This report will cover all the work to date including the upcoming test series.

9.3 Material Preparation

M. T. McFee and D. L. Mailen

Preparation of 180 kg of Kentucky seam #9 coal, for the upcoming superconducting magnet test series, has now been completed.

9.4 Industrial Contacts and Cooperation

E. C. Hise and A. S. Holman

The public release of information concerning the magnetic separation program has resulted in a number of requests for information and several inquiries concerning specific materials. The Stackpole Corporation has sent samples of natural graphite and petroleum coke for an assay of the magnetic separability of the contaminants. Microscopic examination of the separated materials indicate a significant removal of the contaminants. Three representatives of Stackpole visited to observe the separations and to discuss possible applications of the technology. They were given separated samples for quantitative analysis.

9.5 Visitors

Dr. W. Nystrom and Messrs. J. W. Goetz and L. Lanzel of the Stackpole Corporation visited our laboratory on May 29 to discuss magnetic separation of natural graphite and petroleum coke.

10. COAL PREPARATION PLANT AUTOMATION

K. R. Carr

The Coal Preparation Plant Automation Program is being conducted at Oak Ridge National Laboratory for the DOE Pittsburgh Mining Technology Center (PMTIC). The objectives of this program are to develop instrumentation for the automatic control of coal preparation processes and to demonstrate overall plant automation in a typical coal cleaning plant.

Three coal preparation plants were visited by project personnel during the month:

1. The Homer City, Pennsylvania, facility owned by the Pennsylvania Electric Co. and the New York State Electric and Gas Company,
2. The Greenwich Collieries facility at Barnesboro, Pennsylvania, owned by the Pennsylvania Mines Corporation, and
3. The Wellmore No. 7 plant at Big Rock, Virginia, owned by the United Coal company.

The first two listed visits were made as a part of the state-of-the art assessment, and the visit to the Wellmore No. 7 plant was primarily to obtain detailed information on tests being conducted at that plant to evaluate the effectiveness of various surfactants added to the feed pulp of the vacuum disk filter in reducing the moisture content of the clean coal product. Observation of these tests, being done in a joint effort of the plant management and representatives of surfactant manufacturers, was to provide insight valuable to our general planning of the automation effort. (The selection of plant locations at which to perform on-site testing has not yet been finalized). Although the surfactant manufacturers' representatives did not arrive at the plant during our visit, plant management provided much useful information. A report of this trip is being forwarded to PMTIC.

We are continuing to visit and evaluate coal preparation plants with potential as locations for on-site testing. Several plants are within 100 miles of ORNL, and some are as close as a 45-minute drive. Since a test site near ORNL would be both convenient and time-efficient, we are determining the suitability of nearby plants. In this regard, consideration is being given to the possibility of initiating a subcontract with Roane State Community College to obtain their assistance in finding and evaluating local plants and, possibly, in later data-gathering activities. Roane State Community College is located in Harriman, Tennessee, about 15 miles from ORNL, and offers a two-year associate degree in coal mining and preparation technology. The staff of the college has worked with the coal industry in the past and is currently continuing this relationship.

Work was continued on sensors and instruments for several physical measurements. An on-line viscometer was ordered.

Several small data acquisition systems were studied as candidates for use in the preliminary on-site tests, and a tentative selection was made.

Work continued on the study of the potential of x-ray diffraction as a technique for on-line monitoring of the mineral content of coal. It was decided that a limited amount of laboratory work would be useful to support the evaluation. This effort will be finished in June and the results will be transmitted to PMTC.

10.1 Physical Measurements

R. L. Anderson, W. H. Andrews, and M. J. Roberts

10.1.1 Objectives

The objectives of this work area are to define deficiencies of existing on-line and laboratory instrumentation for physical measurements and to develop instruments needed to accomplish the physical measurements required for automation of coal preparation plants. Physical measurements include all measurements in the plant except those in the analytical instruments category described below. Examples of plant physical measurements are particle size, mass flow, viscosity, and density.

10.1.2 Status summary

Work is continuing on the sensors and instruments reported last month, i.e., ultrasonic level and density probes, suspended particle monitor, and microprocessor-based signal cross-correlator. The design of the cross-correlator printed circuit was finished, and the fabrication is nearing completion. We have delayed the order for an ultrasonic particle size and slurry concentration sensor until further study can be done on alternative methods for making these measurements.

10.2 Analytical Instruments

L. H. Thacker, L. N. Klatt, D. D. McCue, and D. S. Walia^a

10.2.1 Objectives

The objectives of this work area are to define deficiencies of existing on-line and laboratory analytical instrumentation and to develop instruments needed to accomplish the analytical measurements required for automation of coal preparation plants. Analytical instruments are defined as those instruments that provide information on the chemical constituents of the coal or have a principle of operation based on nuclear methods; examples of analytical instruments are ash monitors, sulfur monitors, and nuclear density gages.

^a Oak Ridge Associated Universities

10.2.2 Status summary

The major activities this month were a visit to United Coal Company's Big Rock, Virginia, Wellmore No. 7 coal preparation plant (L. N. Klatt), visits to the two Pennsylvania plants described above (L. H. Thacker), and the continuation of the state-of-the-art literature survey. The purpose of the Wellmore visit was to obtain operational information on the fine coal cyclones, the froth flotation cells, and the clean coal vacuum disk filters, and how these units influence the moisture content of the combined clean coal product. Samples were taken around each of the above unit operations and are available for study by other members of the project team. A report summarizing the information gathered on this trip was submitted to the project management.

10.3 Systems Applications

R. L. Moore, L. E. Ottinger, and G. R. Wetherington, Jr.

10.3.1 Objectives

The objectives of this work area are to acquire and maintain an in-depth knowledge of the features of the coal preparation plant environment and overall operation which affect the selection and application of instrumentation and controls, to evaluate the suitability of commercial and developmental devices for installation in coal preparation plants, and to provide the coordination to ensure compatibility and proper interfacing of the various systems and devices to be installed for demonstration in operating coal preparation plants.

10.3.2 Status summary

A major activity this month was our participation in establishing the requirements for a data acquisition and control system for installation in a coal preparation plant. This work is reported in Section 10.6.

L. E. Ottinger was part of a team visit to United Coal Company's Wellmore No. 7 plant to gain information and participate in tests being performed on the froth flotation cells and the clean coal vacuum filter. Surfactants from several chemical suppliers are being evaluated by United Coal Company as a possible means of reducing the surface moisture content of the clean coal filter cake. This trip was especially valuable since we were able to monitor the operation of classifying cyclones, froth flotation cells, and disk filters, and to observe, first hand, the interaction between these unit operations.

R. L. Moore accompanied another team which visited the Greenwich Collieries and the Homer City, Pennsylvania, preparation plant on May 8 and 9. The Greenwich plant, located in Barnesboro, Pa., differs from other plants visited in that separation is accomplished primarily by means of two Batac jigs with no heavy media, Deister table, or froth flotation equipment

in use. Another interesting feature of the plant is a plant simulator used to train operating personnel. Among instrumentation needs cited by the operators was that for monitoring the thickener underflow water specific gravity and feed rate. The Homer City plant supplies cleaned coal to the adjacent power plant. This plant utilizes heavy media cyclones and spiral classifiers for coarse separation and Deister tables for fines. Gamma densitometers and magnetic flowmeters are used to monitor density and flow at a number of locations throughout the plant. These devices did not perform satisfactorily during initial operations because the pipes did not run full. This problem was overcome by installing downstream restrictions to ensure a full pipe at the point of measurement. Another problem with the densitometer is that the flow calculator presently used is too slow to give a good average. Other instrumentation problems cited by the operators included valve wear and solids level indication.

10.4 Mathematical Methods

W. R. Hamel, G. O. Allgood, C. H. Brown, and G. S. Cairright

10.4.1 Objectives

The objectives of this work area are to utilize mathematical analysis as a tool to study processes, develop control models, and evaluate the technical and economic merit of existing and potential instrumentation devices and systems in the coal preparation plant application. This work area includes the evaluation of existing computer models of coal preparation plants, modification of existing computer programs as required for use, and development of programs and techniques needed to support the coal preparation plant automation effort.

10.4.2 Status Summary

The information-gathering phase for the process analysis aspects of the state-of-the-art assessment is essentially complete. A number of equipment manufacturers are being contacted for experimental results on steady-state performance data. As expected, the bulk of analytical work on coal cleaning processes has been steady-state and empirical. As a result, it appears that the only practical approach for process modeling (particularly the complex separations processes) will be to use available steady-state results in conjunction with simple deadtime (pure time delay) and volume capacitance (first order lags) transfer functions to describe overall circuit dynamic behavior to upsets (feed variations, etc.).

Priority in the analysis effort has been shifted to the fine coal circuit. It is interesting to note that in comparison to the coarse circuit the fine circuit appears to be considerably simpler hydraulically (homogeneous fluid assumptions should work) but more complex chemically, due to the kinetics of the frothing and sedimentation processes.

C. H. Brown participated in the visit to the Wellmore No. 7 plant.

10.5 Information and Reports

G. M. Caton and E. R. Rohrer

10.5.1 Objectives

The objectives of this work area are to compile information related to coal preparation plant design and operation, to develop a system for making information readily available to members of the project team, and to assist in the preparation of reports describing work in progress, technical developments, and milestone achievements.

10.5.2 Status summary

Work was continued on building the computer data base concerned with coal preparation and instrumentation documents. The data base is in three separate parts: Part 1, with 205 pertinent references from a retrospective search of the Energy Data Base; Part 2, with 128 references from continuing computer searches; and Part 3, with 218 bibliographic descriptions of acquired documents. After the formats of all three data bases are converted into a common format, they will be merged into a single data base. The format of Part 1 is presently being converted. IBM cards with reference information on beneficiation processes and instrumentation documents were gathered and arranged in order by category and reference number. One hundred and sixty-one requests for documents and information were processed. Ten current contents routings and seven selective routings of the coal preparation search, journals' table of contents, and coal show preview were disseminated to team members.

10.6 Data Acquisition

J. M. Jansen and J. T. Hutton

10.6.1 Objectives

The objectives of this work area are to determine, select, and apply the appropriate data acquisition and processing equipment consistent with the needs for automation and compatible with the physical environment of coal preparation plants. Support activities leading to the implementation of the full-scale demonstration of an automated plant will include assistance in the selection of data acquisition equipment and techniques for use at coal plants and ORNL in the study of processes, the evaluation of installed instruments, and the development of control methods.

10.6.2 Status summary

Several small data acquisition systems available on the market were considered as candidates for purchase and use in the preliminary on-site tests to be done at one or more operating coal preparation plants. The

system tentatively selected consists of remote multiplexers located in the plant near the unit processes to be monitored and a central processing unit (CPU) located in an area isolated from the plant environment. The CPU will communicate with the multiplexers over remote serial data lines to collect data from the process sensors and provide control signals to the process actuators. The survey of several equipment manufacturers indicates that "off-the-shelf" equipment will meet our requirements. The evaluation of a suitable software operating system will be initiated next month. Final selection of data acquisition equipment and the start of procurement is planned for June.

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

R. S. Holcomb

11.1 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 .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.

11.2 Status Summary

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

The submission by Westinghouse of the revised cost proposal has been delayed because of a change in the cost figures for the work at Babcock and Wilcox (B&W). B&W is submitting new costs with lower overhead rates. Westinghouse will finalize the cost proposal when they have the new cost data from B&W, which is expected within about a week.

In view of the delays that have occurred in preparation of the amended subcontract, both UCC-ND and the Westinghouse team have been anxious to begin work on the program. Westinghouse indicated that they would be willing to begin work on the basis of a Letter of Intent to reach agreement on a subcontract. Accordingly, a Letter of Intent was sent and has been signed by all parties. The letter permits them to begin work on June 2 and is effective for a period of 60 days with a cost ceiling of \$50,000. This allows them to receive payment for the work performed under the letter if and after such time as an approved subcontract is put into force. Every effort will be made to get the subcontract completed and signed as quickly as possible.

The initial work on the program will be focused on the conceptual design of the 20 to 25 MW(e) Reference Design Plant, Task 1. Results from this effort will be utilized in beginning work on design of the test unit as soon as is practical. An initial planning meeting will be held with the Westinghouse team early in June.

12. 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).

12.1 AFBC Technology Support - Task 2

M. Siman-Tov and E. C. Fox

12.1.1 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.

12.1.2 Status summary

There was no activity under this task during this month.

12.2 4 x 4 Cold Flow Model - Task 3

M. E. Lackey and R. S. Holcomb

12.2.1 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.

12.2.2 Status summary

The 1/4 scale test report by M. E. Lackey entitled "Cold Slumping Characteristics of a Fluidized Bed," has been approved for publication by TVA.

12.3 AFBC Modeling and Simulation - Task 4a

J. W. Wells, A. A. Khan, and R. P. Krishnan

12.3.1 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.

12.3.2 Status summary

Overview - During this month, work continued on the development of the sulfur capture model and the freeboard model. The sulfur capture model, based on the grain model, was debugged and used to generate some typical results. In the freeboard modeling, methods of simplifying and modifying the code were investigated. A paper entitled "Elutriation and Attrition Phenomena in Industrial Atmospheric Bed," by J. W. Wells and R. P. Krishnan, was presented at the International Bulk Solids and Powder Conference in Chicago, Illinois. Also during this month, the TVA AFBC pilot plant project test program meeting on May 19 to 21 was attended by J. W. Wells.

Sulfur Capture Modeling - Many previous investigators¹⁻³ have found that the grain model was useful in analyzing the capture of sulfur dioxide (SO₂) by calcium oxide (CaO). The model considers each calcium oxide (CaO) particle to consist of small spheres (grains) of CaO crystal (much like a basketball filled with small marbles). Petrographic examination of calcined limestones shows a structure similar to that proposed in the grain model. Specifically, the calcined particle shows a spongy structure composed of small but highly dense grains of calcium oxide.⁴ At present, a grain model code similar to those proposed by Hartman and Coughlin² and MIT^{3,5} has been written.

In this code several assumptions are made. First, calcination is assumed to be uniform and instantaneous. The resulting particle is a porous lime sphere with grains of calcium oxide dispersed uniformly throughout the particle. Second, diffusional resistance at the surface of the particle is negligible. Third, the pore diffusion mechanism is Knudsen diffusion. Fourth, the temperature is uniform throughout the calcium oxide particle. And fifth, the sulfur-capture reaction is first order and follows the unreacted shrinking core mechanism.

Based on these assumptions, a mass balance within a spherical porous particle of radius, R_p , yields the following equation.

$$(\partial^2 C / \partial R^2) + (2/R)(\partial C / \partial R) - (N/D_e) = 0, \quad (1)$$

with the following boundary conditions:

$$C = C_0 \text{ at } R = R_p, \text{ and } \partial C / \partial R = 0 \text{ at } R = 0.$$

The solution of this equation gives the concentration of SO_2 (C) as a function of position (radius, R) within the particle.

This equation describes the diffusional and chemical processes occurring within the particle. The term D_e is the effective diffusion coefficient in the pores of the particle. This term takes into account that (1) not all of the area normal to the molecular flux is available for molecules to diffuse (porosity), (2) the paths are tortuous, and (3) the cross-section area of the pores varies.

The equation relating the effective diffusivity (D_e) to the bulk of Knudsen diffusivity (D_A) is:

$$D_e = (D_A \epsilon \bar{v}) / \tau, \quad (2)$$

where

$$\tau = \text{tortuosity} = \frac{\text{actual distance traveled by molecules}}{\text{shortest distance between two points}},$$

$$\epsilon = \text{porosity} = \frac{\text{volume of void space}}{\text{total volume}},$$

$$\bar{v} = \text{constriction factor}.$$

The constriction factor accounts for the variation in the cross-sectional area. Fogler⁶ has given a typical value of $\bar{v} = 0.8$. Campbell et al.⁷ measured the effective diffusion coefficients of carbon dioxide in unconsolidated lime. Their data indicated that the diffusion process was governed by Knudsen diffusion, and the tortuosity of the solid was 1.5. If the data are corrected for molecular weight (i.e., SO_2 versus CO_2) and temperature difference via the following proportionality, the effective diffusional coefficient becomes $0.075 \text{ cm}^2/\text{s}$.

$$D_A \propto \sqrt{T/M_{wt}}, \quad (3)$$

where

T - absolute temperature, $^{\circ}\text{K}$,

M_{wt} = molecular weight, gmole.

The porosity (ϵ) of the sorbent in Eq. 2 depends on the initial porosity of the calcined stone and the conversion of the calcium oxide to calcium sulfite. Hartman et al.⁸ gives the following equation for the prediction of porosity.

$$\epsilon_X = 1 - (1 - \epsilon_C) \left\{ YX[(V_{CaSO_4}/V_{CaO}) - 1] + 1 \right\}, \quad (4)$$

where

X = local conversion of calcium oxide to calcium sulfate, unitless,

Y = weight fraction of calcium oxide in calcine, unitless,

ϵ_C = porosity of calcined limestone, unitless,

ϵ_X = porosity of sulfated limestone, unitless,

V_{CaSO_4} = molar volume of pure calcium sulfate, 52.2 cm³/gmole,

V_{CaO} = molar volume of pure calcium oxide, 16.9 cm³/gmole.

This expression assumes that particle is completely calcined before sulfation begins. Hartman et al.⁸ also give an equation to estimate the initial porosity of the calcine stone (ϵ_C).

$$\epsilon_C = 1 - (1 - \epsilon_{LS}) \left\{ Y[(V_{CaO}/V_{CaCO_3}) - 1] + 1 \right\}, \quad (5)$$

where

ϵ_{LS} = porosity of the limestone, unitless,

V_{CaCO_3} = molar volume of pure calcium carbonate, 36.9 cm³/gmole.

In addition to diffusion, Eq. 1 also considers the rate at which sulfur dioxide is consumed in the porous particle. The term N , defined by the following equation, is the rate at which the sulfur dioxide reacts with the solid to form calcium sulfate.

$$N = (K)(F)(C_C), \quad (6)$$

where

N = rate of disappearance of sulfur dioxide, gmole/cm³-s,

K = chemical reaction rate constant, cm/s,

F = specific reaction interfacial area, 1/cm,

C_C = sulfur dioxide concentration at interface surface of grain, gmole/cm³.

This expression is first order with respect to SO₂ concentration. The term K represents the ability of calcium oxide to consume sulfur dioxide. Based on kinetic data of Borgwardt, reported by Wen and Ishida,¹ the variation of K with temperature can be expressed as:

$$K = (k_0/V_{CaO}) \exp(-17,500/R_g T), \quad (7)$$

where

- k_0 = frequency factor, $2770 \text{ cm}^4/\text{gmole-s}$,
 V_{CaO} = molar volume of pure calcium oxide, $16.9 \text{ cm}^3/\text{gmole}$,
 R_g = universal gas constant, $1.987 \text{ cal/}^\circ\text{K-gmole}$,
 T = temperature, $^\circ\text{K}$.

The term F in Eq. 6 represents the interfacial area of the grains per unit volume of the grains and can be written as:

$$F = 3(1 - \epsilon_c)(r^2/r_g^3), \quad (8)$$

where

- ϵ_c = initial porosity of the calcined limestone, unitless,
 r = reaction interface radius within spherical grain, cm,
 r_g = grain radius, cm.

The reaction interface concentration of the sulfur dioxide (C_c) can be found by applying the shrinking core model to the grain. This gives:

$$C_c = \frac{D_s C}{D_s + Kr(1 - r/r_g)}, \quad (9)$$

where

- C = SO_2 concentration at radius R , gmole/cm^3 ,
 D_s = diffusion coefficient through the calcium sulfate product layer, cm^2/s ,
 K = chemical rate constant defined by Eq. 7, cm/s .

In the above equations, the sulfur dioxide concentration (C) and the reaction interface grain radius (r) are functions of radial position within the particle. For a given reaction interface grain radius profile $[r(R)]$, Eq. 1 can be solved to give the concentration profile through the particle. In addition to being a function of position (R), the reaction interface grain radius is also a function of exposure time (t). The profile of r can be determined as a function of exposure time (t) by solving the following equation for the rate at which the grain reaction interface changes:

$$\partial r / \partial t = -KV_{\text{CaO}} \frac{D_s C}{D_s + Kr(1 - r/r_g)}, \quad (10)$$

I.C. $r = r_g$ at $t = 0$,

where

C = SO_2 concentration at radius R , gmole/cm³,

K = chemical rate constant defined by Eq. 7, cm/s,

D_s = diffusion coefficient through the calcium sulfate product layer, cm²/s,

r = reaction interface radius within spherical grain, cm,

r_g = grain radius, cm,

t = exposure time, s.

As can be seen, Eqs. (1) and (10) are coupled. The profile of r must be known before the SO_2 concentration profile (C) can be found via Eq. (1). But the SO_2 concentration profile (C) must be known before the interfacial grain radius (r) can be found via Eq. (10). In order to solve these equations, a pseudo-steady state approximation was made. The method used to integrate these equations was a modified shooting technique. The flow diagram for this procedure is shown in Fig. 12.1. Initially, the particle radius is divided up into 30 increments. A time step of 1 second is set and an initial SO_2 concentration at the particle center is assumed. Based on the center concentration, Eq. (10) is integrated between t_0 to t_1 (1 s) via the Runge-Kutta method to find the interfacial grain radius (r). This value of r is stored and used in Eqs. (8) and (9) and also to evaluate the local conversion of calcium oxide to calcium sulfate, given as:

$$X = 1 - r^3/r_g^3. \quad (11)$$

The value of X is then used to evaluate the local porosity as given by Eq. (4). These values [results from Eqs. (4), (8), and (9)] are then used to evaluate the term N/D_e in Eq. (1). Equation (1) is then integrated between R_1 and R_2 via the Runge-Kutta method to determine the SO_2 concentration in the next particle radius increment (R_1 to R_2). This concentration is then used to determine the interfacial grain radius (r) between R_1 and R_2 by integrating Eq. (10) between t_0 and t_1 . This r value is stored and used to integrate Eq. (1) between R_1 and R_2 . This procedure continues until the surface of the particle is reached. At this point the calculated surface SO_2 concentration is compared to the specified surface SO_2 concentration. If they do not agree, the SO_2 concentration at the particle center is varied via the Regula Falsa method. If the calculated and specified surface SO_2 concentrations agree within tolerance, the time step is changed from t_1 to t_2 . The interfacial grain radius stored previously for time step t_0 to t_1 is now used as the initial value of grain radius in integration of Eq. (10). The above procedure is repeated until either the exposure time exceeds the specified residence time or the outer surface of the particle plugs. Plugging of the particle occurs when the local porosity as calculated by Eq. (4) becomes zero. The plugging is caused by the increase in the molecular volume during the conversion of calcium oxide to calcium sulfate ($V_{\text{CaO}} = 16.9 \text{ cm}^3/\text{gmole}$ versus $V_{\text{CaSO}_4} = 52.2 \text{ cm}^3/\text{gmole}$).

Fig. 12.1. Flow diagram for sulfur capture subcode.

And, finally, the overall calcium oxide conversion (X_0) is found as:

$$X_0 = (3/R_p^3) \int_0^{R_{PR}} R^2 [1 - (r^3/r_g^3)] dR, \quad (12)$$

where

R = radial position within particle, cm,

R_p = particle radius, cm,

r = interfacial grain radius, cm,

r_g = grain radius, cm.

The sulfur capture subcode described above has been used to analyze the sulfur-capture data of Hartman and Coughlin.² The input parameters for this code are given in Table 12.1. The results from this code are compared to experimental data for three different particle sizes (0.0565 cm, 0.090 cm, and 0.112 cm) in Fig. 12.2. The agreement between the experimental results and the computational results is good and comparable to the agreement found by other modelers.^{2,7,9} The calculated calcium oxide conversion increases until the surface of the particle plugs. In the figure this corresponds to an exposure time of 17.3 min. The experimental data show that the conversion does not stop abruptly but slowly increases as exposure time increases. This is probably due to the very slow diffusion of SO_2 through the essentially plugged surface of the particle.

During the next month, optimal time steps and particle radius increments will be determined to lower the sulfur code computational time. At this point the sulfur code will be combined with the coal combustion and elutriation and attrition codes. The resulting code should be a valuable tool for the prediction of sulfur capture and carbon utilization in atmospheric fluidized bed combustors.

12.4 Analytical Support and Alternative Design

Concepts Evaluation - Task 4b

C. S. Daw, W. K. Kahl, and E. C. Fox

12.4.1 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.

Table 12.1. Typical input parameter for
sulfur capture subcode

Temperature, °K	1117
Molar volume of CaSO_4 , cm^3/gmole	52.2
Molar volume of CaO , cm^3/gmole	16.9
Pore diffusion coefficient, cm^2/s	0.075
Constriction factor	0.8
Tortuosity	1.5
Porosity of limestone	0.0
Porosity of calcined stone	0.52
Diffusion coefficient through product on grain, cm^2/s	4.0×10^{-9}
Grain radius, cm	1.0×10^{-5}
Bulk gas SO_2 concentration, gmole/cm^3	3.2×10^{-8}
Surface reaction rate coefficient, cm/s	0.05

Fig. 12.2. A comparison of sulfur capture subcode results with data of Hartman and Coughlin².

12.4.2 Status summary

The final report has been delayed pending resolution of ambiguities and uncertainties within the B&W correlations for sulfur capture and combustion efficiency. The necessary revisions are anticipated to be complete in the next two to three weeks.

12.5 AFBC Bench Scale Facility - Task 5

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

12.5.1 Objective

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

12.5.2 Status summary

TVA sulfur capture testing in the bench scale facility was continued during May with limestone from the Reed quarry in Gilbertsville, Kentucky. Forty-eight hours of coal combustion were accumulated during the month; data were obtained for superficial velocities of 1.2, 1.5, and 1.8 m/s (4, 5, and 6 ft/s) at bed temperatures near 840°C (1550°F). The performance of the Reed limestone compares favorably with that of Fredonia Valley and Vulcan, two of the best limestones tested to date.

The chemical analysis of the Reed limestone as it was fed into the combustor is shown in Table 12.2. The combustion fuel for the tests was a Kentucky #9 coal with about 4% sulfur.

A consistent set of sulfur capture data was obtained for a superficial velocity of 1.2 m/s (4 ft/s). These results are presented in Table 12.3. A limited amount of data was obtained at 1.5 m/s (5 ft/s), and the results appear in Table 12.4. Sulfur capture results for tests at 1.8 m/s (6 ft/s) are shown in Table 12.5. The sulfur capture characteristics of the Reed limestone (based on Tables 12.3, 12.4, and 12.5) are presented in Fig. 12.3. Figure 12.4 is a semi-logarithmic plot of the sulfur capture data. The sulfur capture character of the Reed limestone (Fig. 12.4) is almost identical to that of Fredonia Valley limestone at 1.2 m/s (4 ft/s). This performance is only slightly worse than that of the Vulcan limestone.

Testing during the month of June will involve a limestone from the lower ledge of the Fredonia quarry. At the end of this test series, recycle capability will be added to the combustor, and the best limestones will be re-tested in the recycle mode.

Table 12.2. Chemical analysis of
Reed limestone

Calcium carbonate (CaCO_3), %	92.63
Magnesium carbonate (MgCO_3), %	1.07
Silia (SiO_2), %	4.94
Sulfur (SO_3), %	0.64
Aluminum (Al), %	0.34
Iron (Fe), %	0.30
Moisture (H_2O), %	0.12
Potassium (K), %	0.22
Sodium (Na), ppm	370
Chlorine (Cl), $\mu\text{g/g}$	288

Table 12.3. AFBC sulfur capture results for Reed limestone

	Date, time				
	4-30-80 12:30	4-30-80 14:27	4-30-80 15:17	5-1-80 12:10	5-1-80 13:30
Bed temperature, °C (°F)	839 (1542)	835 (1535)	830 (1525)	829 (1525)	831 (1527)
Superficial velocity, m/s (ft/s)	1.3 (4.2)	1.3 (4.2)	1.2 (4.1)	1.2 (4.1)	1.2 (4.1)
Static bed depth, m (in.)	0.52 (20.5)	0.62 (24.5)	0.66 (26.0)	0.74 (29.0)	0.81 (32.0)
Gas residence time ($\bar{t}/V_0$), s	0.41	0.49	0.53	0.59	0.65
Coal feed rate, kg/h (lb/h)	8.2 (18.1)	8.2 (18.1)	8.2 (18.1)	8.0 (17.6)	7.4 (16.3)
Limestone feed rate, kg/h (lb/h)	3.2 (7.1)	2.9 (6.3)	2.9 (6.3)	2.0 (4.5)	3.9 (8.7)
Calcium to sulfur mole ratio	3.0	2.7	2.7	1.8	3.8
Combustion air flow, kg/h (lb/h)	72.1 (159)	72.6 (160)	71.2 (157)	70.7 (156)	71.2 (157)
Flue gas components					
Oxygen, %	3.2	3.4	4.0	3.6	3.5
Sulfur dioxide, ppm	820	595	550	880	308
Oxides of nitrogen (NO _x), ppm	920	880	880	880	900
Carbon monoxide, ppm	560	560	535	848	490
Sulfur in coal, wt %	3.88	3.88	3.88	4.21	4.21
Sulfur capture, %	74.3	81.2	82.0	75.2	91.3

Table 12.3. Continued

	Date, time				
	5-1-80 14:53	5-5-80 10:26	5-5-80 11:40	5-5-80 13:06	5-5-80 14:00
Bed temperature, °C (°F)	822 (1511)	827 (1520)	816 (1500)	822 (1511)	821 (1510)
Superficial velocity, m/s (ft/s)	1.2 (4.0)	1.2 (4.1)	1.2 (4.0)	1.2 (4.1)	1.2 (4.1)
Static bed depth, m (in.)	0.91 (36.0)	0.76 (30.0)	0.84 (33.0)	0.89 (35.0)	0.97 (38.0)
Gas residence time (H/V_0), s	0.76	0.61	0.68	0.72	0.78
Coal feed rate, kg/h (lb/h)	9.4 (20.8)	7.9 (17.4)	7.9 (17.5)	7.6 (16.7)	7.6 (16.7)
Limestone feed rate, kg/h (lb/h)	5.1 (11.2)	2.8 (6.2)	3.6 (8.0)	4.4 (9.6)	5.9 (12.9)
Calcium to sulfur mole ratio	3.8	2.5	3.2	4.0	5.4
Combustion air flow, kg/h (lb/h)	69.8 (154)	71.7 (158)	71.2 (157)	71.7 (158)	71.2 (157)
Flue gas components					
Oxygen, %	3.4	4.0	3.4	3.4	3.2
Sulfur dioxide, ppm	172	615	370	186	120
Oxides of nitrogen (NO_x), ppm	910	880	860	870	890
Carbon monoxide, ppm	490	542	595	500	410
Sulfur in coal, wt %	4.21	4.21	4.21	4.21	4.21
Sulfur capture, %	95.2	82.2	89.6	94.8	96.6

Table 12.3. Continued

	Date, time			
	5-5-80 15:15	5-9-80 12:56	5-9-80 14:25	5-9-80 15:30
Bed temperature, °C (°F)	820 (1508)	822 (1512)	814 (1498)	823 (1514)
Superficial velocity, m/s (ft/s)	1.2 (4.0)	1.2 (4.0)	1.2 (4.0)	1.2 (4.0)
Static bed depth, m (in.)	0.86 (34.0)	0.76 (30.0)	0.84 (33.1)	0.90 (35.5)
Gas residence time ($H/\bar{v}_0$), s	0.71	0.62	0.69	0.73
Coal feed rate, kg/h (lb/h)	7.6 (16.7)	7.6 (16.7)	7.9 (17.4)	7.9 (17.4)
Limestone feed rate, kg/h (lb/h)	5.9 (12.9)	3.0 (6.6)	3.2 (7.1)	4.1 (9.1)
Calcium to sulfur mole ratio	5.4	2.8	2.9	3.7
Combustion air flow, kg/h (lb/h)	69.8 (154)	70.7 (156)	70.3 (155)	71.2 (157)
Flue gas components				
Oxygen, %	3.5	4.0	4.0	3.25
Sulfur dioxide, ppm	93	565	416	307
Oxides of nitrogen (NO _x), ppm	910	840	860	875
Carbon monoxide, ppm	392	560	500	440
Sulfur in coal, wt %	4.21	4.21	4.21	4.21
Sulfur capture, %	97.3	83.6	87.9	91.4

Table 12.4. AFBC sulfur capture results for Reed limestone

	Date, time						
	5-13-80 11:50	5-13-80 13:10	5-13-80 14:40	5-13-80 15:45	5-14-80 11:55	5-14-80 13:25	5-14-80 14:55
Bed temperature, °C (°F)	837 (1539)	831 (1527)	835 (1535)	831 (1527)	836 (1537)	842 (1548)	833 (1532)
Superficial velocity, m/s (ft/s)	1.5 (4.9)	1.5 (4.9)	1.5 (4.9)	1.5 (4.9)	1.5 (5.0)	1.5 (5.0)	1.5 (5.0)
Static bed depth, m (in.)	0.75 (29.5)	0.84 (33.0)	0.90 (35.5)	0.90 (35.5)	0.74 (29.0)	0.84 (33.0)	0.94 (37.0)
Gas residence time (H/V ₀), s	0.50	0.57	0.60	0.61	0.48	0.55	0.61
Coal feed rate, kg/h (lb/h)	10.1 (22.3)	7.4 (16.3)	9.1 (20.0)	8.0 (17.6)	9.0 (19.9)	9.0 (19.9)	8.5 (18.8)
Limestone feed rate, kg/h (lb/h)	3.6 (7.9)	3.8 (8.4)	4.5 (9.9)	5.2 (11.5)	3.4 (7.5)	4.5 (10.0)	5.4 (11.9)
Calcium to sulfur mole ratio	2.5	3.6	3.4	4.5	2.6	3.5	4.4
Combustion air flow, kg/h (lb/h)	84.4 (186)	84.8 (187)	85.7 (189)	84.8 (187)	86.6 (191)	86.6 (191)	87.1 (192)
Flue gas components							
Oxygen, %	3.2	3.6	3.25	3.2	3.55	3.6	3.8
Sulfur dioxide, ppm	740	500	365	308	720	515	255
Oxides of nitrogen (NO _x), ppm	830	800	830	860	800	870	845
Carbon monoxide, ppm	565	383	327	316	380	315	287
Sulfur in coal, wt %	4.21	4.21	4.27	4.27	4.27	4.27	4.27
Sulfur capture, %	79.5	85.8	89.6	91.2	79.2	85.0	92.5

Table 12.5. AFBC sulfur capture results for Reed limestone

	Date, time					
	5-20-80 11:43	5-20-80 12:46	5-20-80 13:55	5-20-80 15:08	5-22-80 13:30	5-22-80 14:55
Bed temperature, °C (°F)	854 (1570)	855 (1571)	848 (1558)	838 (1540)	854 (1570)	848 (1559)
Superficial velocity, m/s (ft/s)	1.8 (6.0)	1.8 (6.0)	1.8 (5.8)	1.8 (5.8)	1.8 (6.0)	1.8 (6.0)
Static bed depth, m (in.)	0.67 (26.5)	0.74 (29.0)	0.83 (32.5)	0.90 (35.5)	0.76 (30.0)	0.90 (35.5)
Gas residence time (H/V_g), s	0.37	0.41	0.46	0.51	0.42	0.49
Coal feed rate, kg/h (lb/h)	10.1 (22.2)	11.3 (26.3)	10.7 (23.6)	10.7 (23.6)	10.7 (23.7)	11.5 (25.4)
Limestone feed rate, kg/h (lb/h)	3.0 (6.6)	4.3 (9.4)	4.9 (10.8)	6.3 (14.3)	6.7 (14.7)	7.8 (17.3)
Calcium to sulfur mole ratio	2.1	2.5	3.2	4.2	4.5	4.9
Combustion air flow, kg/h (lb/h)	101 (223)	101 (223)	100 (220)	100 (220)	102 (225)	102 (226)
Flue gas components						
Oxygen, %	3.6	3.2	3.55	3.4	3.4	3.75
Sulfur dioxide, ppm	1130	1000	615	390	485	246
Oxides of nitrogen (NO_x), ppm	810	820	810	820	810	820
Carbon monoxide, ppm	535	635	365	250	297	289
Sulfur in coal, wt %	4.27	4.27	4.27	4.27	4.08	4.08
Sulfur capture, %	67.4	71.7	82.2	88.8	85.6	92.6

Table 12.5. Continued

	Date, time		
	5-28-80 11:55	5-28-80 12:58	5-28-80 14:40
Bed temperature, °C (°F)	851 (1564)	852 (1566)	851 (1564)
Superficial velocity, m/s (ft/s)	1.8 (6.0)	1.8 (5.9)	1.8 (5.9)
Static bed depth, m (in.)	0.67 (26.5)	0.72 (28.5)	0.84 (33.0)
Gas residence time (H/V_G), s	0.37	0.40	0.47
Coal feed rate, kg/h (lb/h)	12.0 (26.5)	12.0 (26.5)	12.1 (26.6)
Limestone feed rate, kg/h (lb/h)	5.9 (13.0)	7.7 (16.9)	8.6 (19.0)
Calcium to sulfur mole ratio	3.6	4.6	5.2
Combustion air flow, kg/h (lb/h)	102 (225)	102 (224)	101 (222)
Flue gas components			
Oxygen, %	3.3	3.2	3.2
Sulfur dioxide, ppm	720	395	164
Oxides of nitrogen (NO_x), ppm	800	840	875
Carbon monoxide, ppm	390	512	269
Sulfur in coal, wt %	4.08	4.08	4.08
Sulfur capture, %	78.9	88.4	95.2

Fig. 12.3. Sulfur capture characteristics of Reed limestone.

ORNL-DWG 80-5183 ETD

Fig. 12.4. Sulfur capture characteristics of Reed limestone.

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

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

12.6.1 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.

12.6.2 Status summary

The final report for Task 6, State-of-the-Art of Pressurized Fluidized Bed Combustion Systems, is in the final stages of publication.

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

M. Siman-Tov and A. A. Kahn

12.7.1 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.

12.7.2 Status Summary

We are awaiting comments and approval of the draft interim report from TVA before any major headway can be made. Meanwhile, the effort is limited to keeping up to date with the state-of-the-art.

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

R. H. Cooper, Jr., T. G. Godfrey, M. D. Allen,
J. H. DeVan, and R. A. Bradley

12.8.1 Objective

The objective of this task is to provide TVA technical assistance in the AFBC materials area, particularly with respect to strength and corrosion requirements. The principal focus of the work is the area of in-bed

^aConsultant

heat exchanger tubes and hangers, air distributors, side walls, coal feed line nozzles, spent bed removal hardware, and cyclones for separating elutriated materials. With regard to this task, two areas have been and/or continue to be active. The first is the review of recommendations for the materials of construction for the pilot and demonstration plants as made to TVA in proposals, contracts, and vendor designs. The second area involves the metallographic analysis of an array of alloys exposed in an AFBC located in Leatherhead, England, and is part of a joint TVA/EPRI materials program.

12.8.2 Status summary

There is no activity to report in the area of materials reviews.

In the materials support task, examination of the Leatherhead tube specimens has focused on the calcium sulfate deposits from both the steam-cooled sample tubes and the uncooled high-alloy coupons. Samples of the deposit are being analyzed by a variety of techniques including quantitative chemical analyses, x-ray diffraction and fluorescence, energy dispersive x-ray analyses (EDX), and optical microscopy. The chemistry (and structure) of this deposit is very pertinent to the thermodynamic calculations performed under Task 12 because the presence or absence of CaO in the deposit seemingly controls sulfidation of the alloy constituents. If CaO is present, the sulfur activity should be below the level required to form nickel or iron sulfides; if absent, these sulfides may form. Thus far, evidence indicates very little or no CaO is present. Surprisingly, however, the analyses show about 1% C in the deposit. If this carbon is in a reactive form, it could serve to hold a very low oxygen activity at the alloy surface. The material balance is not very satisfactory at this time, and some additional analyses will be required to resolve the discrepancy.

John Stringer of EPRI in his paper at the Atlanta FBC Conference April 9-11, 1980, and additional information contained in a draft of the Coal Research Establishment report on the Leatherhead 2000-h test called attention to a deep corrosion feature on type 310 stainless steel tube samples exposed in the Leatherhead test. This prompted us to re-examine the companion samples provided to ORNL. We found the same deep penetration in these samples, but concluded that they were mill defects and not corrosion resulting from exposure in the AFBC. When these deep penetrations are excluded from the metallographic determinations of attack depths, corrosion resistance of type 310 stainless steel is shown to be better than or equal to that of the other high-alloy specimens. A letter report describing these observations was sent to W. D. Goins, TVA Project Engineer.

Metallographic examination of the specimens selected from both the second 1000-h and full 2000-h CURL-Leatherhead AFBC test is under way and should be completed in June. Thus far, no unusual corrosion response has been observed on these samples.

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

O. L. Smith

12.9.1 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.

12.9.2 Status summary

There is no activity under this task.

12.10 Coal Feed Tests - Task 11

C. S. Daw, J. F. Thomas, and V. R. Brantley

12.10.1 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.

12.10.2 Status summary

Based on discussions with TVA, the coal-limestone dual feed test plan has been revised, and we have started the test runs. Table 12.6 outlines the final test plan approved by TVA. The primary changes from the preliminary test plan were an increase in the limestone-to-coal feed ratio from 0.45 to 0.50 and the addition of several runs with limestone sized 6 mesh $\times$ 0 instead of 3 mesh $\times$ 0.

After reviewing the results of preliminary coal-limestone testing, we also decided to revise the pipe configuration between the screw feeder and the rotary valve. The new configuration has a 5.08-cm (2-in.) line between the two pick-up tees instead of the original 2.54-cm (1-in.) line. This eliminates the "jet" of high velocity air and limestone going into the rotary valve pick-up tee. Since the high velocity was found to be unnecessary in getting good coal entrainment, it was eliminated to make interpretation of pressure drop and saltation data easier.

Table 12.6. Coal and limestone test plan

Limestone type — Three Rivers
 Limestone moisture — Air-dried
 Coal type — Western Kentucky No. 9
 Coal size — 3 mesh x 0
 Feed Arrangement — Limestone fed by screw feeder
 Coal fed by rotary valve
 Feeders in series, screw feeder first
 Air velocity — At each feed condition run 30.5, 22.9, 15.2 m/s and on down to saltation

Test No.	Test conditions			
	Coal surface moisture (%)	Coal feed rate (kg/h)	Limestone size	Limestone feed rate (kg/h)
1	1	227	3 mesh x 0	113
2	1	227	6 mesh x 0	113
3	5	227	6 mesh x 0	113
4	5	454	6 mesh x 0	227
5	5	454	3 mesh x 0	227
6	5	907	3 mesh x 0	453
7	8	227	6 mesh x 0	113
8	8	227	6 mesh x 0	57
9	8	454	6 mesh x 0	227
10	8	454	6 mesh x 0	113
11	8	454	3 mesh x 0	227
12	8	454	3 mesh x 0	113
13	8	907	3 mesh x 0	454
14	8	907	3 mesh x 0	227
15	—	—	3 mesh x 0	113

The remainder of this month has been spent preparing an interim report on Phase I testing for TVA. Phase I covers all of the coal testing up through the 8% moisture plugging tests.

12.11 Materials Evaluation and Testing - Task 12

R. H. Cooper, Jr., R. E. Potter, J. H. DeVan, and R. A. Bradley

12.11.1 Objective

The objective of this task is to experimentally determine the envelope of operating conditions which will result in safe and reliable performance of in-bed materials. This goal is to be met with a three-phased program. The first phase involves thermodynamics calculations including all likely reactants and products from combinations of selected candidate alloys and in-bed environmental conditions. The second phase includes exposures of candidate materials in carefully controlled environments simulating the range of possible AFBC environments that could be envisioned in normal and off-normal operation. The third phase will be made up of eight 200-h exposures of materials in an actual fluidized bed. Operating conditions for these runs will progressively vary from normal to off-normal.

12.11.2 Status summary

To ensure that materials information generated by this activity is provided to TVA in a manner that will have a meaningful impact on the operation of the pilot plant facility, an accelerated schedule for all three subtasks has been adopted. As a result of this accelerated schedule, some aspects of all three subtasks are being carried out concurrently. A summary of the progress on each of the three subtasks follows.

Subtask I. Thermodynamic Calculations - An in-depth summary of these calculations was reported in the last quarterly report.

Subtask II. Muffle Furnace Tests - Since the last reporting period, some questions have been raised regarding the responsiveness of the zirconia probe to track oxygen partial pressures across the range of CO/CO₂ ratio planned for this facility. The effects of N₂/SO₂ addition to the CO/CO₂ mixtures and the presence of coated (CaSO₄) and uncoated metal surfaces on the resulting oxygen partial pressures are additional areas of concern. To answer these questions, the results of the zirconia probe were monitored for a range of CO₂/CO ratios ranging from 80 to 2.4×10^5 for three different conditions. These conditions evaluated were as follows:

1. Mixtures containing CO and CO₂ only.
2. Mixtures containing an equal volume of CO+CO₂ and N₂+SO₂.

3. Mixtures containing equal volumes of CO+CO₂ and N₂+SO₂ flowing over metal samples having a coating of CaSO₄.

All three tests revealed only minor departures from the expected P_{O_2} for CO₂/CO ratio ranging from 80 to 10⁴. However, significant departures from the expected P_{O_2} were noted for CO₂/CO ratios ranging from 10⁴ to 2 × 10⁵. This situation is not thought to have any significant impact on the test plan proposed to TVA because these deviations are a factor only at P_{O_2} of 10⁻⁸ and higher. The proposed TVA tests call for testing at oxygen pressures of 10⁻¹⁰ or lower.

A series of three tests is currently being carried out in the muffle furnace facility to determine the corrosion response of a variety of CaSO₄-coated alloys in a simulated AFBC environment of progressive severity. In each test, sixteen 1/2-in.-diam by 1/2-in.-long tube sections are being tested. The alloys being tested are types 304H and 310H stainless steel, Inconel 600, and Incoloy 800H. In each test, two samples of each alloy type are exposed in the as-received condition. The remaining two samples are portions of tubes previously exposed in the Fluidyne test and have a thick CaSO₄ surface deposit. Test conditions are 150 h at 1650°F in oxygen partial pressures of 10⁻¹¹, 10⁻¹⁵, and 10⁻²² for the first, second, and third tests, respectively. At this time the first test has been completed and the second test is underway. Analysis of these samples revealed weight changes for all samples of 1/2% or less; therefore, no significant corrosion attack has occurred. The most significant observations were associated with the CaSO₄ seals. Going into the test, the CaSO₄ deposit on all samples was dark olive to dark red. Following the test, the deposit was a light tan or straw color. Feasibly more important, after the test significant quantities of the deposit have spalled off the samples.

Subtask III. In-bed Tests — Since the last reporting period, significant progress has been made in modifying the Fluidyne facility for the eight 200-h tests. This progress includes performing a heat balance and identifying the number of low temperature, high temperature, uncooled, and trimmer tubes needed in the bed to maintain adequate in-bed temperature control. Also during this reporting period, approximately one-third of all the needed sample tubes for the eight 200-h tests were shipped to Fluidyne. The remaining types 304H and 210H stainless steel and Incoloy 800H have been prepared and are ready for shipment. At this time, 20 composite tubes of 2-1/4 Cr-1 Mo to type 304 stainless steel tubes are being prepared for welding. The remaining two-third shipment will be made in about two weeks. At this time, there is a sufficient number of each type of tube stock at Fluidyne to prevent any delays in the Fluidyne schedule.

12.12 References for Section 12

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13. COAL COGENERATION/DISTRICT HEATING PLANT ASSESSMENT

M. A. Karnitz and R. L. Graves

13.1 Objective

The objective of this work is to provide the Office of Coal Utilization 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.

13.2 Status Summary

The work is essentially completed; all that remains to be done is the documentation. Two of the four volumes of the documentation are in draft form. Work remains to be done on the executive summary and the economic summary. Draft reports on the 200 MW(e) to 300 MW(t) reference design and the 400 MW(e) to 700 MW(t) reference design will be distributed during the month of June.

The review letter describing the closed-cycle turbine concept and the operating mode was delayed; however, it was completed by the end of May. The letter was sent to a gas turbine manufacturer (Rocketdyne) on June 6, 1980.

Additional calculations describing the part load operation of the closed-cycle gas turbine were performed by ORNL. The results confirmed the flexibility of the system and its ability to maintain high fuel utilization at part load. A new map of operating conditions was sent to UE&C, NSP, and DOE along with a description of the computer model of the gas turbine system. Samples of the part-load operating data are provided in Table 13.1.

During the month of May, NSP requested an increase in funding for the subject project in the amount of \$24,000, which will increase the total project to \$254,000. The need for additional funding was caused by (1) delays in initiating the project, (2) UE&C inability to obtain vendor information in a timely manner which caused project delays, and (3) additional minor tasks added to the work scope. UE&C diligently tried to stimulate the vendors to respond; however, since there is no fee related to supplying this information, it is sometimes difficult to obtain immediate response from the vendors. Approximately \$20,000 of the \$24,000 cost overrun were due to the delays. ORNL is in the process of negotiating this request for additional funds with NSP.

Table 13.1. Summary of closed-cycle gas turbine
cogeneration system operation.

<u>Percent of Maximum Design Furnace Power</u>	<u>Maximum Power Output - MW(e)</u>	<u>Maximum Heat* Output - MW(t)</u>	<u>Power at* Maximum Heat Output - MW(e)</u>	<u>Overall* Efficiency - %</u>
100	520	700	400	74
80	430	575	330	76
60	330	440	250	77

*Values are for 31% recuperator bypass which was design condition for 400 MW(e)/700 MW(t). Higher and lower values of bypass are feasible. The power/heat ratio is inversely proportional to recuperator bypass.

14. PERFORMANCE ASSURANCE SYSTEM SUPPORT FOR FOSSIL ENERGY PROJECTS

T. W. Pickel, H. A. Mitchell, V. H. Guthrie,
L. Parsley, A. N. Smith

Performance assurance support is being provided for major DOE-Fossil Energy projects. This support covers the areas of reliability, system safety, and quality assurance. Current activities include support for the liquefaction projects being managed by DOE and a failure modes and effects analysis.

14.1 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 (ORO) 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.

14.2 Status Summary

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 ORO projects to review contracts and deliverables. In May, there was no activity associated with the second task.

Work on the failure mode and effects analysis (FMEA) for a generic slurry preheater has continued. Functional block diagrams were prepared, and the FMEA work sheets were redone. The analysis identifies four high-severity failure modes: explosion in the firebox, leaking coil, plugged coil, and ruptured coil.

The first two are considered to have moderate to high probability of occurring; the last two are low to moderate probability of occurring. Firebox explosion and a ruptured coil are potentially the most serious events. Additional effort is being made to identify specific recommendations for actions to be taken to limit or control the effects of critical failures and to reduce the probability of failures occurring.

Three additional tasks descriptions have been developed for review and approval by the DOE Program Manager. The effort to develop failure modes and effects analyses will be expanded to include a larger section

of the plant if these tasks are accepted. In conjunction with that analysis, reliability criteria will be identified for key components in a liquefaction plant. Component reliability characteristics will be gathered where available, and this information will be utilized in a subsystem reliability model. The new tasks, in addition to the two existing tasks, are described below.

Task 1: Assistance to SRC to Projects to Review Contracts and Deliverables

The ORNL Performance Assurance Support Group shall work with and provide assistance to the SRC Project Manager by reviewing the project contracts for Phase 1 to assure adequate and proper coverage of reliability, quality assurance, and safety. This shall go beyond mere contract review and shall include assurance that adequate procedures, approach, and manpower are to be provided.

Deliverables

- a. Reports on the adequacy of contract language and implementation of performance assurance functions of Phase 1.
- b. Recommendations for modifications, additions, or deletions of contract language deliverables, project procedures, and approaches.
- c. Specific topical reports as applicable.

Task 2: Generic Failure Modes and Effect Analyses (FMEA)

The ORNL Support Group will review the system and equipment under the SRC-I, SRC-II, and H-Coal projects to identify components or equipment common to all systems. Generic FMEAs will be prepared for selected components of systems.

Deliverables

- a. Generic failure modes and effects analysis for directed items.
- b. Topical reports if appropriate (e.g., discussion of items of interest pertinent to projects or program discovered during analyses and of sufficient importance to merit dissemination).

Task 3: Reliability Criteria for Demonstration Plants

The ORNL Support Group will review the operating objectives, administrative constraints and logistic and maintenance policy for systems and components under SRC-I, SRC-II, and H-Coal projects. This information will be used to determine overall reliability criteria for demonstration plants.

Deliverables

- a. Summary of reliability objectives and constraints described in project literature.
- b. Summary of reliability criteria for demonstration plants.

Task 4: Collection of Component Reliability Characteristics for Conversion Systems

The ORNL Support Group will develop a data base of reliability characteristics for selected components from coal liquefaction systems. These data will be based on information from existing data sources, engineering judgment, and experience in pilot plants. An effort will be made to identify differences in environment and applications and to judge the effect of those differences. A methodology will be developed for interpreting data from similar components and applying this information to coal conversion systems.

Deliverables

- a. Summary classification of generic components.
- b. Summary results of data collection of generic components.

Task 5: Generic Subsystems Reliability Assessment

The ORNL Support Group will review the systems and equipment under the H-Coal, SRC-I, and SRC-II projects to identify problems common to all systems. A generic reliability assessment will be prepared for a subsystem selected by the support group and approved by the Technical Project Monitor.

Deliverables

- a. System description and logic model of the system.
- b. Results of reliability assessment including best estimate performance, trade-offs, or optimum actions.

15. INTERNATIONAL ENERGY TECHNOLOGY ASSESSMENT

The Oak Ridge National Laboratory is supporting the Lawrence Livermore Laboratory in a broad program funded by the DOE Office of International Affairs. The program is designed to alert DOE management to foreign energy-related technologies of potential interest to the United States.

ORNL has responsibility for the following three areas of work: coal liquefaction including gasifier development status, coal liquefaction materials, and atmospheric fluidized bed combustion. These efforts are closely coordinated with similar activities underway at Argonne National Laboratory in the areas of pressurized fluidized bed combustion and coal gasification materials.

15.1 Liquefaction Technology Including Gasifier Development Status

W. C. Ulrich

15.1.1 Objective

Broad objectives of the IETA program are to report foreign technology developments of current interest and to identify and assess those developments of significance to U.S. programs. Detailed assessments in selected areas will also be provided. A specific objective of the ORNL effort is to provide a substantive technical review of the status of foreign technology for the liquefaction of coal, including gasifier development status.

15.1.2 Status summary

The research and development subcontract with Gilbert/Commonwealth (G/C), which was described in the monthly report for April, was approved on May 19. G/C has since performed an initial literature search and is currently acquiring references and other information related to indirect coal liquefaction processes, with primary emphasis on those employed in the SASOL complex in South Africa. Secondary effort was directed toward processes for the production of methanol from coal.

A preliminary outline was prepared for the report on indirect liquefaction processes and writing of some of the background sections, such as those describing the historical development of the SASOL project and of processes on which the plant is based, was also started. G/C plans to submit a draft version of the report about June 15.

Information and references are also being collected on various gasifiers that are being used or that offer potential for use in direct and indirect coal liquefaction processes. A request was submitted to the ORNL/DOE representative of the International Energy Agency in London, Dr. John Holmes, for assistance in this effort. Information was solicited on the status of development of the following gasifiers:

- Dry-ash Lurgi
- British Gas Corporation Slagging Lurgi
- Shell-Koppers
- Texaco
- Saarberg-Otto

Dr. Holmes stated that he recently attended a conference in London at which papers were presented on SASOL and on the Shell-Koppers and Texaco gasifiers and that he would forward a summary of the information he obtained. He is also planning to visit Saarbrücken, West Germany in June to discuss the status of the Saarberg-Otto gasifier with its developers and will transmit the results of the discussion to ORNL.

15.2 Coal Liquefaction Materials

A. R. Olsen and G. M. Caton

15.2.1 Objective

The objectives of this phase of the assessment program are to identify materials research and development programs in foreign countries in support of liquefaction processes and to assess the programs and findings in terms of their status, applicability to United States coal liquefaction development and commercialization programs, and the potential value of possible cooperative agreements.

15.2.2 Status summary

Information-gathering activities have continued. The published literature search has concentrated on, but has not been limited to, the time period from January 1978 to date. Computer data bases are searched monthly for new additions. These include the American Petroleum Institute and the Energy Data Base. During the past month the manual search was extended to IEA Coal Abstracts from May 1978 through January 1980 and Corrosion Abstracts for 1978 and 1979, in addition to selected journals and books. A significant bibliography of printed data has been scanned for materials information, and more is on order. Specific published information on materials development programs, materials choices, and resolutions to materials problems still appears to be severely limited.

At the suggestion of the program manager, we have initiated a compilation of standard metallic alloy designations of interest to the coal liquefaction processes and will match these with comparable information on similar materials with appropriate designations in such foreign countries as France, Germany, Japan, and Russia where possible.

15.3 International Survey of Atmospheric Fluidized Bed Combustion Technology

R. P. Krishnan, E. C. Fox, R. S. Holcomb, and K. O. Johnson

15.3.1 Objective

The objective of this program is to provide an international assessment of the status of atmospheric fluidized bed combustion (AFBC). The assessment will describe the applications, critical problem areas, and the current developmental projects that address these problem areas in AFBC technology in foreign countries.

15.3.2 Status Summary

The literature search is in progress. We have received published information related to AFBC work from personal contacts in West Germany and Brazil. These articles are being translated. A list of organizations involved in fluidized bed research abroad has been prepared. The organizations are being contacted by letter.

We have received a trip report prepared by A. A. Pitrolo, Director, Morgantown Energy Technology Center, covering his visit to U.K., Sweden, Denmark, and West Germany in December 1978. The report contains brief reviews of the status of FBC and gasification efforts in those countries. Also on file is a trip report covering the visit of Alex Mills to India in February 1978. An update of the information contained in these trip reports is in progress.

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173. L. Batta, Union Carbide Corp., 61 E. Park Dr., Tonawanda, NY 14150
174. H. Beuther, Gulf Research and Development Co., P. O. Box 2038, Pittsburgh, PA 15230
175. A. A. Bishop, Chemical Engineering Dept., Univ. of Pittsburgh, Pittsburgh, PA 15213
176. N. S. Boodman, U. S. Steel Corp., Applied Research Laboratory, 125 Jamison Lane, Monroeville, PA 15145
177. E. L. Clark, Chemical Engineering Services, 4615 North Park Ave., Chevy Chase, MD 20015
178. R. C. Corey, Mitre Corp., Metrek Division. 1820 Dolley Madison Blvd., McLean, VA 22101
179. B. Crynes, School of Chemical Eng., Oklahoma State Univ., Stillwater, OK 74074
180. V. J. DeCarlo, Regional Assessment Div., DOE, MS E-201, Washington, DC 20545
181. A. K. Dubberly, 650 S. Cherry St., Suite 400, Denver CO 80222
182. P. Dunne, Pope, Evans and Robbins Inc., 320 King St., Alexandria, VA 22314
183. W. R. Epperly, Exxon Research and Engineering Co., P. O. Box 101, Florham Park, NJ 07932
184. O. F. Ghaly, Bechtel Corp., P. O. Box 3695, San Francisco, CA 94119
185. T. M. Godbold, Sta. B, Box 1735, Vanderbilt Univ., Nashville, TN 37235
186. R. A. Greenkorn, Chemical Engineering Dept., Purdue Univ., West Lafayette, IN 47907
187. L. R. Harris, National Institute of Occupational Health and Safety, MS 8A-45, 5600 Fishers Lane, Rockville, MD 20857
188. G. Heunisch, Research Division of Conoco Coal Development Co., Library, PA 15129
189. E. Huffman, Southern Company Services, Fuel Processing Programs, P. O. Box 2625, Birmingham, AL 35202

190. J. E. Jones, Kentucky Center for Energy Resources, P. O. Box 11888, Ironworks Pike, Lexington, KY 40502
191. R. A. Laza, DOE-Chicago Operations, 9800 S. Cass Ave., Argonne, IL 60439
192. W. J. Lochmann, Ralph M. Parsons Co., 100 W. Walnut St., Pasadena, CA 91124
193. T. Modrak, Babcock & Wilcox Res., 1562 Beeson St., Alliance, OH 44501
194. G. Morales, Junta de Energia, Avda, Complutense, S/N, Madrid-3, Spain
195. J. Morhall, Heat Research Corp., 3440 Richmond Ave., Houston, TX 77046
196. T. E. O'Hare, Dept. of Energy and Environment, Brookhaven National Laboratory, Associated Universities, Inc., Upton, LI NY 11973
197. E. G. Pierick, General Electric Co., M/C V02, Vallecitos Nuclear Center, P. O. Box 460, Pleasanton, CA 94556
198. D. Rimmer, City Svc. Co., 1305, 4-ND, Box 300, Tulsa, OK 74102
199. M. Saddy, Senior Engineer, Centro de Tecnologia Promon-CTP, Praia do Flamengo, 154-120 Floor, Rio de Janeiro, RJ-Brazil 22210
200. T. E. Scott, Ames Laboratory, 126 Metals Development Bldg., Iowa State University, Ames, Iowa 50011
201. M. Semchyshen, Climax Molybdenum Res. Lab., 1600 Huron Parkway, P. O. Box 1568, Ann Arbor, MI 48106
202. W. R. Siegart, Texaco, Inc., 2000 Westchester Ave., White Plains, NY 10650
- ~~203. W. K. Stair, Univ. of Tenn., College of Eng., 101 Perkins Hall, Knoxville, TN 37915~~
204. C. Streed, Process Res. and Dev. Div., Mobil Res. and Dev. Corp., Billingsport Rd., Paulsboro, NY 08066
205. J. R. Thurgood, Utah Power and Light Co., 1407 West North Temple, P. O. Box 899, Salt Lake City, UT 84110
206. B. M. Weiss, Catalytic, Inc., Centre Sq., West, 1500 Market St., Philadelphia, PA 19102
207. C. Y. Wen, Dept. of Chem. Eng., West Virginia Univ., Morgantown, WV 26506
208. C. Wysoki, Stearns-Roger, P. O. Box 5888, Denver, CO 80217
209. Assistant Manager for Energy Research and Development, DOE-ORO
- 210-236. Technical Information Center