DEMONSTRATION STRAITS PLANTS

U.S. DEPARTMENT OF ENERGY
Division of Coal Conversion

QUARTERLY REPORT

April-June 1977

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COAL DEMONSTRATION PLANTS

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APRIL - JUNE 1977

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Division of Coal Conversion

Washington, D.C. 20545

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FOREWORD

This document was prepared by the Energy Research and Development Administration (ERDA) prior to the activation of the Department of Energy (DOE) by P.L. 95-91 on October 1, 1977. Therefore, wherever ERDA is mentioned, it should be noted that its functions have been transferred to DOE.

The technical reviews contained in this document were prepared by Cameron Engineers, Inc., Denver, Colorado, based on information supplied by DOE and its various contractors. The reviews, as they appear herein, have been authorized for publication by representatives of DOE. Cameron Engineers, Inc. assumes responsibility for the accuracy of the reviews but not for the accuracy of the information provided by either DOE or its contractors.

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EXECUTIVE SUMMARY

The United States has more energy available in coal than in petroleum, natural gas, oil shale, and tar sands combined. Nationwide energy shortages, together with the availability of abundant coal reserves, make commercial production of synthetic fuels from coal vital to the Nation's total supply of clean energy. In response to this need, the Division of Coal Conversion — U.S. Department of Energy (DOE) is conducting a research and development program to provide technology that will permit rapid commercialization of processes for converting coal to gaseous and liquid fuels and for improved direct combustion of coal. These fuels must be suitable for power generation, transportation, storage, and residential and industrial uses.

The technologies selected for development in the areas of gasification, liquefaction, and direct combustion will satisfy an urgent need for a particular type of fuel. The emphasis given each technology varies, depending on such things as technical complexity, development stage (laboratory research, including bench-scale tests and experiments with process development units, and pilot plant design, construction, and operation), variety of uses for the fuel produced, and urgency of the need that the technology is designed to satisfy.

DOE's demonstration plant program was started in 1974 by one of DOE's predecessor agencies: the Office of Coal Research, U.S. Department of the Interior. The objective of the program is to establish the technical and financial feasibility of coal conversion technologies proven during pilot plant testing. Demonstration plants will minimize the technical and economic risks of commercialization by providing a near commercial size plant for testing and production. Thus, DOE is sponsoring the development of a series of demonstration plants, each of which will be a smaller version of commercial plants envisioned for the 1980's. These plants will be wholly integrated, self-sufficient in terms of heat generation, and dependent only on feedstock of coal, water, and air.

Under the DOE program, contracts for designing, constructing, and operating the demonstration plants will be awarded through competitive procedures and will be jointly funded. The conceptual design phase will be funded by the government, with the detailed design, procurement, construc-

tion, and operation phases being co-funded, 50 percent from industry and 50 percent from the government. The cost involved in building and operating a demonstration plant will probably be between \$200 million and \$500 million, depending on the size of the plant.

I. CLEAN BOILER FUEL DEMONSTRATION PLANT

UNION CARBIDE CO., INC.
NEW YORK, NEW YORK

Plant Site: New Athens, Illinois

Contract No.: E(49-18)-1736

Total Funding: \$ 15,150,000*
Phase I: \$ 4,750,000**
Phase II: \$ 17,700,000**
Phase III: \$142,300,000**
Phase IV: \$ 72,472,300**

INTRODUCTION

The Coalcon Department of Union Carbide was under contract with DOE to design a demonstration plant for producing clean boiler fuels from high-sulfur coal. The plant was to be fully integrated in all phases of processing, from receipt of coal to delivery of a finished product. The design was geared to be environmentally acceptable by cleanup of all waste streams, and energy efficient by recovery of all by-products. Coalcon was organizing financial support for the program in the form of a consortium of energy and power companies and public agencies that would provide funds for the 50-50 government/industry cost sharing portion of the program.

The overall objective of the project was to verify, through a demonstration size plant, the commercial economics, technical scale-up potential, and the physical and chemical feasibility of a process for producing clean liquid boiler fuel pipeline gas and other useful products in a commercial-size plant. The plant was to be designed to convert 3901 tons per day of high sulfur coal into 2990 barrels per day of heavy oil, 1192 barrels per day of a gasoline fraction, 1088 MMSCFD of liquefied petroleum gases and 28.39 MMSCFD of high Btu pipe-

line quality gas. 126.6 tons per day of elemental sulfur would have also been produced.

The project was to be conducted in four phases. Phases I and II were funded entirely by ERDA, while Phase III and IV were on a 50-50 cost sharing basis with ERDA and industry.

Phase I involved evaluation of various processes for commercial feasibility, process design of a commercial plant, preliminary commercial plant design, and preliminary process design for the demonstration plant. The preliminary process evaluation effort was designed to increase the potential for creating a clean boiler fuel industry. Variations to the basic concept were evaluated to determine their impact for increasing production flexibility, improving cost effectiveness and reducing sulfur content in the primary products. Some of the variables that were evaluated include:

- Size of plant, degree of modularization
- Coal type, size, mixture, composition, and cost
- Alternative process trains and steps
- Process operating conditions (e.g., temperature, pressure, residence time, thermal efficiency, etc.)
- Product quality and yield

The preliminary commercial plant design provide a detailed process design based on maximum use of proven, commercially available components and equipment on

*Present Year Dollars

**Original Planning

which to base detailed cost estimates. The end use of this design was used in evaluating the economic and technical feasibility for commercial plants and to recommend changes to the overall commercial plant concept. The demonstration plant design was to be based on a system that used commercially available equipment. This effort included process flow charts and schematics for the plant, and for each major process train and subsystem. Major process and utility piping, electrical networks, process operating conditions, and mass and heat balances, were a part of the effort.

Phase II work would have involved the preparation of the complete plant design, including drawings, specifications, and definitive cost estimates.

PROCESS DESCRIPTION

Initially, the coal is crushed, milled and classified under flue gas to decrease the moisture. The coal is then fed to the feed hopper before it is pressurized to the operating pressure of the system plus pressure to allow feed to the reactor. The coal is dropped from the lock hoppers to a fluidized feeder vessel. From the feeder vessel, the coal is fed by dense phase flow in hydrogen gas by one inch lines through a heater and to the reactor. The coal is fed at temperatures to 450°F. The hydrocarbonization reactor is fluidized by hydrogen and operates at 555 psi and 1040°F. The solid residence time is 35 minutes, the gas residence time in the bed is 42.5 seconds. The char from the reactor is removed from the top of the bed with provision at the bottom of the reactor for removal of agglomerates. The char is used to produce hydrogen for the reactor by means of a Texaco gasifier.

The gases existing the reactor are laden with solids which are removed by two cyclones in series. The cleaned gas/vapor is sent to the fractionation system for cooling and separation. The basic purpose of the fractionation system is to cool the reactor products, to stop reaction and to split the reactor product into four streams.

- Overhead Gas (N₂, CO, CO₂, CH₄)
- Light Liquid
- Heavy Liquid
- Waste Water

The reactor product gases are initially cooled by a venturi quench which is fed by the cooled bottom of the primary tower. The products are further refined by successive operations.

The gas product is sent through acid gas removal

(Shell Sulfinol), gas separation (cryogenic) and methanation. The cryogenic system separates LP fuel gas, synthesis gas and a hydrogen rich stream. The hydrogen rich stream is recycled back to the hydrocarbonization reactor. The synthesis gas is sent to the methanation reactor for upgrading to high Btu pipeline gas. The LP fuel gas is also sold as a product. The process is shown in Figure I-1.

HISTORY OF THE PROJECT

Work under this contract was initiated in January 1975 when ERDA selected the Union Carbide Hydrocarbonization Process as the one to be used in DOE's first demonstration plant project.

During 1975, work on the project involved preliminary process design and engineering of a commercial plant. This effort included a review and evaluation of all hydrocarbonization subsystems to minimize capital investment and maximize subsystem operability and reliability. By early 1976, design and engineering for the commercial plant were complete. A process evaluation report was prepared and submitted to ERDA. This report included preliminary data on plant design and provided a basis for starting the design of the demonstration plant.

Unfortunately, a number of technical problems plagued the Coalcon project throughout 1976. The lack of data needed to produce the process design for agglomerating coals delayed completion of the Phase I effort. Based on mid-year ERDA evaluations, and technical data produced in 1976, the Union Carbide process for hydrocarbonization of agglomerating coals were determined to be a high risk technology. In addition, an economic analysis based on completed design data showed that the economics of a full scale commercial plant were marginal when compared to the projected economics of other processes currently under development. Because of these findings and associated technical problems, ERDA suspended project activity beyond the Phase I process design.

Union Carbide facilities used in support of the program included the Tonawanda, New York, and the South Charleston, West Virginia, laboratories. The Tonawanda minitest facility was directing its work toward confirming kinetics and yield data for agglomerating high-sulfur bituminous coal. The South Charleston facility was being used to evaluate alternative methods for deagglomerating high-sulfur bituminous coals in the hydrocarbonization process.

Figure I-1. HYDROCARBONIZATION PROCESS SCHEMATIC

PROGRESS DURING APRIL-JUNE 1977

The effort for the Phase I preliminary design for the demonstration plant continued in April and May and was completed in June.

A re-evaluation by DOE of the technical and economic factors surrounding the Union Carbide hydrocarboniza-

tion process led to the decision to abandon the project on June 15, 1977, at the end of the preliminary design stage.

The technical feasibility of the hydrocarbonization process is still under study by Union Carbide Corporation in a small scale unit in an attempt to provide data to justify co-funding of a process development program by DOE.

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II. DEVELOPMENT OF COAL FEEDERS FOR COAL GASIFICATION OPERATIONS

FOSTER-MILLER ASSOCIATES, INC.

WALTHAM, MASSACHUSETTS

Contract No.: E(49-18)-1793

Total Funding: \$799,545
(100% DOE)

INTRODUCTION

Under the sponsorship of DOE, coal feeders for use in all coal gasification plants are to be developed through the pilot plant stage by Foster-Miller Associates, Inc. The project recognizes the coal feeder as one element common to all gasification processes and that no currently available system can handle the quantities of coal, about 1,000 tons per hour, that will be used in commercial processes. These processes require the injection of coal, crushed to 1/8-inch and below, from an atmospheric-pressure hopper into a gasifier whose pressure may be as high as 100 atm.

Feed methods currently being used in pilot and demonstration plants depend on the coal size and gasifier pressure. Low-pressure units use lock hoppers which must be operated at low temperatures with batch feeding of the coal. Slurry-feed techniques used in high-pressure gasifiers require energy to vaporize the liquid used to transport the coal. Both of these techniques are inefficient but can be tolerated in small-scale gasifiers. It will, however, be necessary to develop a technique to provide a continuous, high-pressure flow of coal to commercial-scale units at reasonable efficiencies and capital costs.

PROGRAM DESCRIPTION

The project to develop coal feeders was initiated in May 1975. It consists of three phases, with Phases I and II

to be completed by December 1977. In Phase I, Foster-Miller visited and studied gasification plants and consulted with DOE personnel and consultants to prepare a list of coal feeder requirements for DOE approval. Foster-Miller then prepared a report based on information concerning existing equipment and new conceptual designs. This report included a list of candidate equipment and an evaluation of that equipment.

In Phase II, critical components of the equipment selected in Phase I will be tested in the laboratory. Equipment of four different designs will be constructed, and each laboratory-scale feeder will be tested for approximately two months. These tests will be conducted to determine the ability of the equipment to control the flow of coal with accuracy, maintain stability, seal effectively against the gasifier pressure, provide economic operation in terms of equipment life and power requirements, and deliver to the gasifier coal having the desired characteristics. Data from laboratory research will be used to design feeders compatible with existing and projected pilot plant operations.

During Phase III, feeder concepts that have demonstrated a strong possibility of commercial-scale usage will be integrated into current and projected pilot plants as directed by ERDA. Feed rates will be in the range of three to five tons per hour. The final report of this phase will contain design specifications, assembly drawings and procedures, installation and functional test procedures, and operation and maintenance manuals.

A fourth phase, not part of this contract, design of demonstration scale feeders, will use the results of pilot

plant testing. It is to include the development, design fabrication, and delivery to DOE of coal feeders compatible with demonstration plant requirements. Feed rates in this phase are anticipated to be 50 tons per hour and greater.

PROJECT ACCOMPLISHMENTS

Foster-Miller Associates completed the Phase I program effort in March 1976, with the release of the Phase I report. The results from the evaluation of coal feeder requirements and existing feeders revealed that no suitable dry coal feeders were available that could operate at gasifier pressures above 20 atmospheres. As part of this initial effort, literature searches, patent reviews, and consultation with manufacturers were made to determine what particular concepts should be studied in Phase II. Results from these activities led to the selection of four methods:

- Coal plug feeders
- Centrifugal feeders
- Positive displacement feeders
- Conveyor feeder

Evaluation of these concepts are currently being carried out during Phase II.

PROGRESS DURING APRIL-JUNE 1977

Pilot-Scale Coal Feeder Development

Centrifugal Feeder

The modifications to the centrifugal feeder prototype to improve the reliability of coal feed to the feeder sprues were completed in April and successfully tested at ambient pressure. Pressure differential testing was resumed in May and the modified feeder was operated with differentials up to 30 pounds per square inch at 1500 rpm. The coal feed rate was one ton per hour. Foster-Miller stated that the test results indicated that the problem of sharply

reduced feeder output at significant pressure differentials which were encountered in the first series of prototype tests had been alleviated.

Testing of the unit continued in June and a major breakthrough was achieved when the feeder was operated against a 36 psi receiver pressure at 2000 RPM with a 1/4-inch outlet diameter sprue set. The coal feed rate was in excess of 1 ton per hour with four sprues. A 15-inch outlet diameter sprue set fed approximately 1/4-ton per hour against a receiver pressure of 185 psi.

Positive Displacement Feeder

Testing of prototype feeder unit continued in April. Attempts to improve the feeder operating conditions performance above the 250 psi feed pressure which had been achieved previously were hampered by intermittent failure to achieve complete flushing of the feed cylinder. Attempts to correct the condition occupied most of April. Further tests were conducted in May in an attempt to operate the feeder at differentials above 250 psi. The tests were not successful because of valve leakage problems. The remainder of the month was spent investigating design changes to alleviate the problems.

The piston feeder was tested again in June and a substantial improvement was made in operation as a result of reworking the existing valves.

Sealed Conveyor Feeder

The feeder parts were delivered in April and the unit assembled and operated in May. However, the pressure vessel components had not yet arrived by the end of the quarter, and consequently, the feeder was operated against ambient pressure only. Initial testing was done with 3/4 x 1/16-inch coal. No problems were encountered with the feeder and the measured drive forces were well within projected values.

Further testing of the unit in June led to jamming problems when the feeder conveyor flights were completely filled. Removal of redundant metal sealing rings from the conveyor piston eliminated the problem.

III. DEVELOPMENT OF A CONTINUOUS DRY COAL SCREW FEEDER

INGERSOLL-RAND RESEARCH, INC.

PRINCETON, NEW JERSEY

Contract No.: E(49-18)-1794

Total Funding: \$1,168,719
(100% DOE)

INTRODUCTION

Development of a continuous dry coal screw feeder is being conducted by Ingersoll-Rand Research, Inc. through DOE sponsorship. The feeders are to be developed through the pilot plant stage, with the engineering and economic viability evaluated throughout the development process. The end result of the research will be a recommendation by Ingersoll-Rand of coal feed injector equipment that will be compatible with projected demonstration plant requirements. The successful development of a continuous dry coal feeder would have a significant impact on coal processing. The equipment could be used in both high- and low-Btu gasification plants and also in coal liquefaction systems.

PROGRAM DESCRIPTION

Under the current contract with DOE started in July 1975, Ingersoll-Rand is conducting a three-phase development program to refine and scale-up a screw feeder that could be used in a demonstration plant. Tests initially conducted by Ingersoll-Rand indicated that screw feeders could be used in full size coal gasification and liquefaction plants in place of pressurized lock hoppers and slurry systems. The feeder currently being developed is a modified injection molding machine, operating like an extruder.

Phase I of the program involves the establishment of the coal feeder requirements imposed by the various processes being considered for commercial scale coal conversion operations. Literature searches, consultations with DOE personnel and consultants, studies of plant operations, etc., will be used to obtain information on the feeder requirements. Using the information gathered, Ingersoll-Rand is to examine existing equipment and conceptually design new approaches to coal feeders.

In Phase II, critical components of the candidate equipment selected in Phase I will be tested. In addition, two laboratory scale, coal feeder prototypes, a Negri-Bossi V-12 injection molding machine and an IMPCO 1500, will be designed, fabricated, and tested. Among the characteristics to be investigated are:

- Feeder stability and degree of control
- Seal effectiveness
- Coal metering accuracy
- Life expectancy of critical components
- Mechanical power requirements
- Methods for reducing the feed coal size to meet process requirements

The data resulting from laboratory testing will be used to design feeders for use in existing and projected pilot plant operations. Recommendations will be made to DOE for further development of promising screw feeder concepts.

During Phase III, IMPCO screw feeder will be installed and operated in a pilot plant selected by DOE. Feed rates

will be in the range of 0.5 to 5.0 tons per hour. A report will be prepared that will include design specifications, installation drawings, assembly procedures, installation and functional test guides, and operation and maintenance manuals. The performance of the feeder in the pilot plant tests will be assessed based on the test data. A final report will be prepared which will include the design of equipment sized for a demonstration plant.

A fourth phase, not part of the current contract, will use the results of pilot testing for development, design fabrication, and delivery to the DOE of coal feeders compatible with demonstration plant requirements. Coal feed rates in this phase will be 50 tons per hour or greater.

PROJECT ACCOMPLISHMENTS

Ingersoll-Rand Research developed, during Phase I, three conceptual designs for coal feeding. These concepts included a single-acting piston feeder, double-acting piston feeder, and a rotary valve piston feeder.

A comparative evaluation of coal feeder systems was completed using the technical and economic criteria established during the fourth quarter of 1975. Existing coal feed systems, lock hoppers and slurry pumps were compared with new feed system concepts. The evaluation indicated that the piston feeders as a class seem to offer advantages over the lock hopper and slurry pump methods of feeding coal to high-pressure gasifiers. The screw feeder concept, although not as dramatic, also showed advantages over existing methods. A proposal is to be submitted for further evaluation of the piston feeder concepts.

DOE received the Phase I report in March 1976 for review and comment.

PROGRESS DURING APRIL-JUNE 1977

Summary

The 1.5-inch diameter screw feeder (NB V-12) development testing progressed satisfactorily during this quarter. Several conclusions were drawn from these experiments and are as follows:

- With external heat operation.
 - Only a minor portion of the total power (energy) is consumed mechanically in driving the screw.

However, a large amount of energy is used to heat the coal and evaporate the moisture in the input coal.

- The operation without conical tip at screw discharge end yields better performance in comparison with the conical tip.
 - The overall performance of increasing volume screw is slightly better than that of 3/4 pitch length screw and the 3/4 pitch length screw requires substantially more mechanical specific power in comparison with the increasing volume screw.
 - The injection mode yields slightly better performance and is less sensitive to the screw configuration in comparison with the extrusion mode.
- Without external heat operation.
 - The coal output is essentially independent of gas back pressure and is directly proportional to the cycle rate in injection mode.
 - The feeder operation is independent of the coal properties at elevated temperature and hence this operation offers considerable advantage over that with external heat operation.

The shakedown testing of 5.5-inch diameter screw feeder and its test system continued. The tests to date have provided valuable information for design alterations to the feeder and system which should greatly improve overall operation; however, it has delayed the program.

Feeder Development

1.5" Diameter Screw Feeder (NB V-12) Development

Extrusion Mode With External Heat

The test effort was directed toward achieving steady state operation with Pittsburgh Seam #8 "as received" (Lot #7) coal in extrusion mode. The plug length, barrel temperature profile and screw rotational speed were selected based on previous experience with Illinois #6 coal. With these settings, however, the steady state operation was not possible. The coal plug length was changed. Steady state operation was achieved at atmospheric back pressure and also at 100, 200, 300 and 450 psig gas back pressures. The coal output at 11 rpm (approximately 14.5 lbm/hr) remained constant during these tests. In addition to recording the usual test data, the operating time of each heater band was also recorded during these tests, permitting the determination of the

electrical heat input to the coal. The results indicate that only a minor portion of the total power is consumed mechanically in driving the screw. A large amount of energy, however, is used to heat the coal and evaporate the moisture in the input coal.

Effect of Screw Tip - Most of the testing to date has been with the screw which has a conical tip at the discharge end. The conical tip was removed from the screw discharge end and steady state operation tests were carried out with a flat end (without conical tip). It was noticed that the quality of extrudate improved significantly. Examination of the cross section of the extrudate indicated that the coal particles were more uniformly compacted and agglomerated when compared to those produced by the screw with conical tip. In addition, steady state operation against gas back pressure was easier to achieve. Further tests were conducted without the conical tip.

Increasing Volume Screw - The test effort was directed towards increasing the coal output rate by operating the screw at higher speed. The barrel temperature profile was correspondingly raised to obtain desirable extrudate. As observed during previous testing, coal output remains virtually constant over the back pressure range of 0-450 psig for each screw speed tested. However, the output is not proportional to the screw speed. This situation may be due to the decrease in coefficient of friction between the coal and barrel at higher speeds due to the higher barrel temperatures and shear rate.

Injection Mode With External Heat

For the first time, an attempt was made to obtain steady state operation in this mode. The increasing volume screw was used during this testing. The first trial was made with a screw rotational speed of 20 rpm, injection time of 11.0 seconds, and temperature settings the same as those used in the extrusion mode with external heat testing. It was noticed that the quality of the extrudate was inadequate to provide a seal against gas back pressure. The barrel temperatures were then adjusted and steady state operation was achieved.

Extrusion vs. Injection (With External Heat)

The performance of extrusion mode with external heat and injection mode with external heat was compared for increasing volume screw and 3/4 pitch length screw. In the case of the increasing volume screw the injection mode performance is only slightly better than extrusion mode. However, in the case of the 3/4 pitch length screw the injection mode yields approximately 14 percent better

performance over the extrusion mode. In addition, with both screws the extrudate from the injection mode has a better quality with respect to uniformity in compaction and agglomeration of coal particles.

Injection Mode Without External Heat

A cycle in this mode includes all the processes from filling the screw and forming the coal plug to injecting the plug. Initial steady state operating tests were carried out with Illinois #6 coal at 143 cycles per hour with an injection time of 11.1 seconds and screw speed of 20 rpm. A constant channeled depth screw with length-to-diameter ratio of 6 was used.

The test effort was directed towards increasing the coal output rate at atmospheric back pressure by varying the filling and injection time of the cycle while keeping the stroke constant. The filling time was varied by varying the screw rotational speed and the injection time was varied (5.2 to 15.6 seconds) by controlling the hydraulic oil flow to the injection cylinder. The maximum attained coal output rate was 27 lbm/hr. The quality of the extrudate was examined after each test. It was noticed that the extrudate formed during the tests with low injection time (5.2 to 5.8 seconds) and maximum flow rate (27 lbm/hr) were not sufficiently compacted so as to provide an effective seal against gas back pressure. An injection time of approximately 8.7 seconds and a screw speed of 40 rpm (217 cycles per hour) were selected for further testing against gas back pressure. Steady state operations were achieved against 200 and 450 psig gas back pressure.

5.5 Inch Diameter Screw Feeder Development

Testing was resumed in the month of April after the damaged barrel heaters, wiring and thermocouples were replaced. Initial testing was done without venting the moisture and other volatile vapors from the barrel. The following observations were made:

- Occasional gas pressure release caused the plug to blowout at the screw discharge end
- The vapors tended to slow down the coal feed from the feed hopper into the screw

Vapors were then vented through two 23/32-inch diameter holes drilled in the barrel. 16 mesh screens were used to avoid excessive coal loss. The screw was operated at 20 rpm screw speed and the screw heater was not operational.

During the test occasional plugging of the screen was observed and as a result the feed rate changed from

approximately 200 to 300 pounds per hour and the extrudate quality changed from a compacted core to a loose core respectively. Loose core resulted in a blowout from the discharge end. These tests indicated that the venting area was not sufficient and that the screw temperature has to be maintained constant for consistent extrudate quality.

In late June, the spare screw cartridge heater was made operational. Only 8 kW screw heater power was available due to the problems with the heater solid state power modules.

The following observations were made during the test:

- With 8 kW heat input from the screw heater, the screw temperature at the tip of the heater could not be maintained above 710° F.
- Coal feed rate at 10 rpm was measured to be about 277 pounds per hour. The extrudate plug core was not well compacted.
- Barrel temperatures (1/8-inch from the inner surface) fluctuated over a wide range (50° F - 80° F) due to time lag in the temperature control system. This caused a variation of feed rate and extrudate quality.
- Screw stalling and blowouts from the discharge end prevented a steady state operation.

IV. COAL FEEDER DEVELOPMENT PROGRAM

LOCKHEED MISSILES AND SPACE COMPANY,
INC.

SUNNYVALE, CALIFORNIA

Contract No.: E(49-18)-1792

Total Funding: \$1,000,000
(100% DOE)

INTRODUCTION

Lockheed Missiles and Space Company, Inc., a subsidiary of Lockheed Aircraft Corporation, is conducting a coal feeder development program under the auspices of DOE. A need exists for this development effort because current lock hopper or slurry concepts for coal feeding are inadequate. The feeder system is a critical component of a coal conversion plant, affecting equipment and maintenance costs, plant efficiency, and down time. An improved coal feeder that is applicable to all processes using dry pulverized coal at reactor pressures up to 100 atm must be developed.

PROGRAM DESCRIPTION

Work under this three-phase program was initiated in July 1975. Phase I, which was completed in March 1976, involved the selection of candidate coal feed injector concepts based on a detailed examination of the system requirements imposed by the various coal conversion processes.

The examination included:

- Screening potential candidates
- Investigating existing equipment
- Synthesizing feeder system designs
- Assessing problem areas

- Defining laboratory evaluation techniques
- Preparing a final report

Phase II studies will involve tests on four coal feeder systems. These include a fluid dynamic look, kinetic extruder, ball conveyor, and an ejector. To establish a firm basis for the design of the coal feed systems for use in commercial plants, testing efforts for this phase will include:

- Laboratory tests, using simple bench-scale equipment, to answer questions pertinent to equipment design.
- Supporting analysis provided by mathematical models developed for optimizing equipment design, projecting operating efficiency, and updating economic data generated during Phase I.
- Design of test equipment
- Fabrication, including procurement of materials.
- Installation of test equipment followed by testing as outlined in the test plan and data reduction and analysis.
- Documentation.
- Design, procurement, and installation of equipment for the test loop facility.
- Assurance that hardware is manufactured to applicable specifications and that all operations and specifications adhere to safety requirements.

During Phase III, candidate feeder concepts showing promise for commercial scale use will be designed and operated in current and/or projected pilot plants. Feed

rates for these feeders are expected to be in the range of three to five tons per hour. As part of this phase, Lockheed will also prepare a report that will include design specifications, assembly and detail drawings, assembly procedures, installation and functional test procedures, and operation and maintenance manuals. The data obtained in the pilot plant tests will be analyzed, and a final report including an engineering design of equipment for a demonstration plant will be prepared.

A fourth phase, not part of this contract, will utilize the results of pilot plant testing, and is projected to include the development, design, fabrication, and delivery to ERDA of coal feeders compatible with demonstration plant requirements. Feed rates in this phase are anticipated to be 50 tons per hour and greater.

PROJECT ACCOMPLISHMENTS

Lockheed completed Phase I of the contract and issued the Phase I report in December 1975. Literature and patent searches were conducted which established fundamental principals used in the design of the feeder. Operating requirements were established via field trips to various coal conversion installations in the U.S. As a result of these efforts, various candidate concepts were selected for further evaluation and were segregated into low pressure and high pressure usage. Cost data were subsequently generated to compare the equipment and operating costs of each of the feed systems. From these studies, four feeder concepts emerged as the most promising for further laboratory testing. The four systems selected for Phase II investigation were:

- Ejector, based on the use of jet pumps
- Kinetic Extruder, a system based on the use of centrifugal force to reduce the permeability of the compacted coal to prevent net back flow of gases
- Ball Conveyor, using large metal balls snugly fitting into a standpipe and conveying coal in the interspace, designed to overcome net gas leakage by the downward motion of the column and the static pressure by the weight of the column. The return leg uses a liquid seal to prevent gas flow.
- Fluid Dynamic Lock, a system based on the use of a bladeless, disk type compressor

To establish a firm basis for the design of the coal feed systems for use in commercial plants, Phase II will include:

- Laboratory tests, using simple bench-scale equipment, to answer questions pertinent to equipment

design.

- Supporting analysis provided by mathematical models developed for optimizing equipment design, projecting operating efficiency, and updating economic data generated during Phase I.
- Design of test equipment.
- Fabrication, including procurement of materials.
- Installation of test equipment followed by testing as outlined in the test plan and data reduction and analysis.
- Documentation.
- Design, procurement, and installation of equipment for the test loop facility.
- Assurance that hardware is manufactured to applicable specifications and that all operations and specifications adhere to safety requirements.

PROGRESS DURING JANUARY-MARCH 1977

Prototype Feeder Testing

Steam Driven Ejector

Ejector testing was conducted during April and coal-feeding data was obtained at two levels of steam-driven pressure and with two different coal grinds. In addition, data were obtained for the same steam-driven conditions with water and air as the secondary fluids. The particle size distributions for the two coal grinds were 59 percent passing 200 mesh for the fine coal and 12.6 percent passing 200 mesh for the coarse coal.

Operation of the bench-scale ejector with saturated steam as the driving fluid resulted in successful feeding of pulverized coal into a pressurized receiver tank. No plugging or fouling problems due to coal-condensate buildup were experienced during the test series.

Some influence of coal properties on performance was observed. Slightly better performance was obtained with a coarser coal grind having a higher bulk density. Data were also accumulated with water and air used as the secondary fluids for comparison purposes. Steam condensation effects were observed with the water secondary flow leading to very large increases in pressure-flowrate performance at low pumping pressure ratios. Some indication of condensation effects was observed in the coal flow tests, but comparable performance increases were not observed.

Using perfect gas assumptions for the steam driver in the existing mathematical model provided reasonable

correlation of the data under various experimental conditions in regions where steam condensation phenomena did not predominate.

Theoretical comparison between performance of steam and nitrogen drivers at constant driver pressure showed an advantage for steam over low-temperature nitrogen. Predicted performance was about the same when the nitrogen was heated to the same temperature as that of the saturated steam at the selected driver pressure.

Kinetic Extruder Model Testing

Initial tests with coal flow, conducted in May, showed that the sprue discharge coefficient was greater than anticipated. The rotor demand was larger than the nominal capacity of the feed pipe. The total sprue discharge area was reduced from 0.17 square inch to 0.053 square inch by the use of restricting orifices similar to those used during the test series with the first model of the Kinetic Extruder.

During the test runs, it was observed that higher than predicted gas flow into the rotor was being measured. Examination of the rotor head showed that undesired gas passages existed between the sprues because of adhesive failure between the two bonded and bolted disks forming the rotor head. The two disks were therefore separated for rebonding. This procedure provided the opportunity to change the sprue shape since easy access was provided to the interior of the rotor before rebonding the two disks. A castable epoxy was used to block part of the sprue channel, effectively reducing the cross sectional area by 50 percent over the last 4-1/2 inches of the sprue and reducing the total sprue exit area to 0.079 square inch.

The tests reported herein have been obtained with this modified rotor configuration.

- **Kinetic Extruder Model No. 2 Test Results** - A number of successful pressure feed tests were obtained with Kinetic Extruder No. 2 after the aforementioned sprue modifications. Coal was delivered against pressures up to 155 psig. The preliminary data are generally consistent with the Lockheed theoretical model predictions.

Higher pumping pressures would be achieved with Kinetic Extruder No. 2 by increasing wheel speed.

However, with the present prime mover (534 cubic inch Ford gasoline engine), and relatively inefficient hydraulic drive system, wheel input power is limited to about 35 hp. This was only sufficient to obtain 3200 rpm while feeding coal against 155 psig.

A problem encountered during these tests was occasional bridging or jamming of coal in the sprues. Generally, during each test run, one or two (out of 12) sprues would plug and cease flowing coal. Furthermore, they could not be cleared even by overspeeding the wheel at zero back pressure or by other means short of removal of the wheel from the lower tank. Based on early laboratory centrifuge experiments, Lockheed did not expect this sprue plugging to occur.

The sprue plugging tendency is probably related to sprue size, shape, surface finish, and coal properties such as moisture content, grind, and type. A systematic investigation aimed at solving the problem should be carried out early in the Phase III effort.

In conclusion, the Kinetic Extruder No. 2 tests have successfully demonstrated the basic feasibility of the Kinetic Extruder as a pressure coal feeder and have verified the adequacy of the theoretical model used for analysis and design scaleup. The one unforeseen problem, occasional sprue plugging during operating transients, can be attacked in a number of ways. Lockheed is confident that it can be overcome.

Fluid Dynamic Lock

Lockheed engineers concluded that the fluid dynamic lock does not look attractive as a feeder because of the low-pressure use through a single stage. The low performance is mainly caused by the relatively large disk spacing required to accommodate the coal particles.

This type of device, however, can find applications when particle-laden gas streams must be recirculated, requiring low-pressure rises, as may be encountered in fluidizing coal prior to pneumatic transfer. Here, the fact that no blades are used in the machine, and wear is therefore minimized, can be used to good advantage—no extensive gas cleanup equipment is required. Other applications should be considered. Design tools exist for the optimization of this type of equipment, and no further effort is required at this time.

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V. ENGINEERING AND TECHNICAL SUPPORT

U.S. ARMY CORPS OF ENGINEERS, HUNTSVILLE DIVISION
HUNTSVILLE, ALABAMA

Contract No.: E(49-18)-1759

Funded by Individual Task

INTRODUCTION

Under an interagency agreement between DOE and the Office of the Chief of Engineers, U.S. Department of the Army, the U.S. Army Corps of Engineers is providing DOE with engineering and technical support. This contract, initiated in mid-1974, involves the services of the Corps of Engineers engineering forces to provide technical services for demonstration plant design, construction, and related support for such projects and at such locations as requested by DOE.

Demonstration plant assistance requests are made in the form of task assignment letters describing the scope of services desired. The task letter defines the specific function requested, the proposed location of the project, funding limitations, and designates the individual or office responsible for furnishing any requested ERDA direction. DOE is billed by the responsible Field Operating Agency for actual expenses incurred.

PROGRAM DESCRIPTION

Under the current task letter, the Corps of Engineers is supporting DOE in the areas of advance planning for several demonstration plants and preliminary engineering for the Clean Boiler Fuel Demonstration Plant (see Section I). The specific scope of services requested is as follows:

Advance Planning

- Assist in the preparation of requests for proposals (RFP) for three demonstration plants.
- Participate in the review and evaluation of proposals received in response to RFP's.
- Perform special studies, e.g., specific concept designs, relating to design and construction on a task basis.

Preliminary Engineering

- Review and/or prepare design criteria.
- Review preliminary engineering designs.
- Review and validate cost estimates and schedules.
- Review and/or assist in development of environmental impact statements.
- Review the results of site investigations and evaluations performed by contractors.
- Provide assistance in the development of reliability and quality assurance plans, configuration management plans, and computer programming for resource management.

The Huntsville Division was designated as the Field Operating Agency responsible for performing these tasks.

PROGRESS DURING APRIL-JUNE 1977

Support activities by the Corps of Engineers were continued on the Coalcon project, Pipeline Gas Demon-

stration plant, Fuel Gas Demonstration plant and the Preliminary Planning and Engineering Program as tasked by ERDA.

Support for the Coalcon project was limited due to the finalization of the demonstration plant design by Coalcon. However, the Army did continue to monitor the design progress and review Coalcon expenditures. CE also participated in the monthly ERDA management team coordination reviews.

Because negotiations between ERDA and Conoco for the pipeline gas demonstration plant have been completed, the Army's involvement with the plant centered on development and revision of the network (logic) diagrams

for the contract. Army engineers also participated in Conoco/subcontractor planning meetings.

Activities related to the Illinois coal gasification group project included aid in preparation of the ICGG program management plan, development of network diagrams and support to ERDA program director in the development of real estate requirements and water rights on the Mississippi river for the demonstration plant.

CE activity in the Fuel Gas Demonstration Plant Program was limited because of the near completion of the evaluation of the proposals for a demonstration facility. CE did continue to monitor utility projects and provide assistance to ERDA as required.

VI. TECHNICAL ASSISTANCE SERVICES

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

Contract No.: E(49-10)-1775

Total Funding: \$2,990,892
(100% DOE)

INTRODUCTION

The Ralph M. Parsons Company is providing technical assistance services to DOE with the objective of developing and demonstrating practical processes for producing liquid and/or solid fuels from coal. Under this program, initiated in 1972 and updated in 1974, Parsons is:

- Preparing conceptual designs and economic evaluations for commercial plants.
- Evaluating pilot plant performance and other experimental programs.
- Evaluating unit operations and processes for possible applications in coal processing, including design and construction of pilot plants.
- Evaluating proposals for new work and for changes in ongoing work.

The development of commercial design concepts and technical evaluations involve:

- Review of chemical, mechanical, and material problems associated with the design of large plants and equipment
- Identification of problems in sizing, safety factors, and instrumentation of equipment, which must be resolved before equipment is specified for manufacture
- Identification of equipment design problem areas, and development of programs for solution of those problems
- Identification of construction problems, including

availability of materials, type of land base, and area required for construction, that must be solved before large equipment can be fabricated in the field

- Establishment of overall utility requirements. This effort will provide a common economic basis for comparing capital and operating costs of the processes. Ultimately, the commercial design concepts will serve as guides for selecting the best coal processes to be demonstrated in commercial-sized plants.

PROGRAM DESCRIPTION

Parsons has two primary tasks: (1) development of conceptual designs and economic evaluations of commercial plants and (2) technical evaluations.

Conceptual designs and economic evaluations of commercial-scale plants are being developed for the Char-Oil Energy Development (COED) process, an oil-gas process based on the Solvent-Refined Coal (SRC) process, the Fischer-Tropsch process, and a combined POGO (Power, Oil, Gas, and Other Products) process. The conceptual designs and economic evaluations are based on engineering data such as process yields, conversion efficiency, plant economics, and environmental analysis from pilot plant operations.

The overall objectives of the individual tasks are given below. The idea behind the Coal Mining/Coal Preparation task is to design and evaluate, as feed facilities to

conversion plants, coal mine and preparation facilities for five geographic areas where conversion facilities are being studied. Plant capacities of up to 100,000 tons per day of coal feed are being considered.

Oil/Gas Plant efforts will be preliminary design and economic evaluation for a commercial plant to produce synthetic fuels and SNG from coal, and to define the maximum practical capacity of a single train plant using the selected process. The purpose of the Fischer-Tropsch plant task will be to develop a conceptual commercial plant design and economics for production of pipeline gas, motor fuel, distillates and other hydrocarbon fractions.

The objectives of the POGO, (Power, Oil, Gas, and Other) plant design is to develop a preliminary design of a coal processing plant which will produce power, oil, gas and other products. The chosen process will be based on economic evaluations of the candidate coal processes available. Other areas of effort will include the development of a model capable of calculating material and heat balances for a number of coal conversion processes using computer capability and to estimate the overall utility balance for the complex.

Parsons is also developing a computerized process simulation program capable of estimating fixed capital investment, material and energy (utility) balances, and potential profitability of various coal conversion complexes. The program will be available to this project.

Among the technical evaluation activities is the development of functional and preliminary specifications for equipment and control apparatus required in the candidate conversion processes. All the components of a plant, from coal handling through production of fuel, are being considered, along with the associated units for power generation and waste treatment. Another technical evaluation activity is the investigation of materials for construction of equipment to determine which are preferred for use in coal conversion processes. Parsons is also defining facilities required to control air, water, and solid waste pollution to assure that plant operations are within applicable state and EPA environmental standards. Finally, Parsons is providing general support activities and preparing reports as appropriate or requested by DOE.

PROGRESS DURING APRIL-JUNE 1977

Conceptual Design of Commercial Plants

Basic process design activities continued on the major engineering sections of the plant and a number of unit designs were completed. These included:

- Pyrolysis
- Process Gasification
- Naphtha Reformer
- Hydrogen Recovery and Purification
- SRC Dissolving
- Pyrolysis Atmospheric Distillation
- Acid Gas Removal
- SNG Purification
- LPG Fractionation
- SRC Atmospheric Distillation
- SRC Vacuum Distillation
- Thermal Cracking
- Coking

The design for the conceptual Rocky Mountain region coal mine in support of the Alternate 2 POGO design case was completed. The final design called for 75,000 tons per day using two mining faces. Also completed for the Rocky Mountain Region was the coal storage, grinding, and drying unit. The final design called for the use of fluid bedstream tube driers, using low pressure steam, to minimize powdering of the subbituminous coal during drying operations.

Multi-Process Demonstration Plant

Design activities continued in a number of plant areas. The preliminary material balances for the three phases of the facility were completed. Preliminary utilities production and requirements for the program were developed and used as the basis for development of the overall power generation facilities diagram. The design of coal receiving and preparation units for the 3 phases of the program was also advanced.

Environmental Considerations

The preliminary designs of the Multi-Process Demonstration plant and the POGO complex were reviewed for environmental acceptability and for compliance with specific environmental laws and regulations. The environment standards issued by the states where the facilities could be located were collected and used as assessment guidelines.

VII. CONCEPTUAL DESIGN FOR ADVANCED COAL LIQUEFACTION COMMERCIAL PLANT

FLUOR ENGINEERS AND CONSTRUCTORS
IRVINE, CALIFORNIA

Contract No.: EX-77-C-01-2251

Total Funding: \$1,906,800
(100% DOE)

INTRODUCTION

Fluor Engineers and constructors are currently under contract to the Division of Coal Conversion, Department of Energy to prepare a conceptual design package for a commercial facility to produce liquid synthetic fuels by an advanced coal liquefaction scheme. The process currently under study is similar to the hydrogen donor solvent concept.

PROGRAM DESCRIPTION

The contract involves a series of closely related tasks which are expected to require about 18 months for completion. The initial task involves a screening study to select an overall plant configuration and liquid product slate. The objective is to establish a basis for design and selection of both basic and unit processes for the final design. The result of the effort will be an overall plant configuration plus an overall material and energy balance, capital and operating cost estimate. The technology to be used for each key step will have been identified. Following the initial screening study, the process design phase for the plant will commence. Material and energy balances will be developed and process flow diagrams prepared for non-proprietary units. In addition, utility consumptions, effluent streams, and catalyst and chemical requirements will be defined as well as specification of feed, product, and by-product streams.

The third task to be undertaken will involve equipment specifications for the plant. An outline of process duty specifications and dimensional drawings will be prepared for all mechanical equipment and vessels. Duty specifications will be written for conventional pre-engineered package systems such as water treating, instrument air, oxygen plants, and ash or slag handling. The specifications produced will not be complete in all details. However, sufficient information will be included so that a competent engineering contractor could complete the detailed engineering design without recourse to any substantial additional process design.

In addition to development of the basic engineering package, efforts will be expended in identification of those areas of process and mechanical design where additional development work is required before promising technology can be applied commercially.

After completion of the above tasks, a technical and economic evaluation will be made to determine the production rate and the number of parallel trains for each key unit within the commercial facility. The task also includes an evaluation to arrive at a recommendation for the size of a demonstration plant. In addition, a number of auxiliary studies will be carried out to supplement the plant design. These tasks include:

- Mine and plant site
- Environmental assessment
- Operating and maintenance instructions
- Final economic assessment

The mine and plant design activity cover a number of design functions which include:

- Preliminary engineering of a coal mine to be developed for a hypothetical typical coal deposit in the Appalachian region. Work will include a mining method, a mining plan for long term exploitation of the mine, a reclaiming plan, and a solid waste disposal plan.
- Transportation method from mine to plant.
- Coal storage and coal preparation.
- Plot plan development for mine and plant.
- Narrative specifications covering all support facilities.
- Preliminary single line electrical diagram.
- Scale model of the proposed plant.

The environmental effort will involve:

- Determination of applicable environmental regulations.
- Identifications of all gaseous, liquid and solid effluents.
- Determination of Procedures of processes for pollution abatement.
- Preparation of descriptive material to demonstrate that the plant can meet the applicable environmental regulations.

A complete plant description will be prepared which will include operating and maintenance instructions, flexibility and performance limits of plant operations, anticipated start up problems and critical areas of design and safety.

Finally, a capital cost estimate for the mine and plant will be developed. It will cover estimation of all fixed and operating costs and determination of product prices using discounted cash flow procedures.

PROJECT ACCOMPLISHMENTS

The process configuration tasks were completed during the sixth month of the contract. The processing scheme chosen by Fluor were determined to be as follows:

Extraction

Fluor developed a procedure for characterizing extract

as a function of time and temperature in the extractor. As a result of this effort, extractor conditions were chosen at 700° F, 15 minutes residence time, and a 60 percent depth of extraction. The basic design consists of separate vessels, each with mechanical agitation.

Solids Separation

An extensive study was carried out to evaluate rotary precoat and horizontal leaf filtration, solvent deashing using an anti-solvent, and deashing by means of settling, by one or two stages. The results showed that single stage settling was the preferred route for the type of coal chosen for the project. The reduced capital cost, which is estimated to be several hundred million dollars, was the major incentive for selection of the system.

Low Temperature Carbonization (LTC)

The proposed design consists of a single vessel which is operated at 400 psig with oxygen addition. The incentive for this particular high pressure system is that it permits direct transport of char from the LTC to the gasifier which eliminates lock hoppers and other mechanical feeders.

The fluidized-bed, agglomerating ash process was incorporated into the processing scheme. An operating pressure of 400 psig was selected as a practical level since overall thermal efficiency is relatively insensitive to gasification pressure. The gasification of vacuum resid as an auxiliary feedstock to the gasifier was adopted. Fluor stated that gasifying resid rather than burning it provided added assurance that the plant would be environmentally acceptable for sulfur, nitrogen oxide and particulate emissions.

The total plant configuration was studied using a computerized technique developed by Fluor for determining overall and interunit material and energy balances. Conclusions reached by Fluor were listed as follows:

- Maximum gasoline should be produced with no production of either diesel or heavy fuel oil by-products.
- Conventional coal cleaning procedures should be used rather than feeding ROM coal directly to the liquefaction process.
- Depth of extraction has only a minor effect upon overall thermal efficiency.
- The efficiency penalty resulting from the use of settling is small, since the extract contained in the underflow is converted to useful materials, char and gas.

- There is no significant efficiency penalty associated with the use of water slurry vaporization (as a means of feeding LTC char to the gasifier) for producing hydrogen since the water is useful as shift steam. For fuel gas production, however, water slurry vaporization entails a substantial thermal penalty.
- There is no advantage to coking of the vacuum resid. Since resid may be used either as an in-plant fuel or as a gasification feedstock, other streams must be found to replace any resid that is coked.
- Combined cycle gas turbines display the greatest overall efficiency and their use should be maximized.

A summary of the product slate and process features selected to date and discussed previously are given below.

Product Slate:

Gasoline, 10 Reid Vapor Pressure

89	$\frac{R+M}{2}$	66,532	Barrels per Stream Day
SNG		68.5	Million Std. Cubic Ft. Day
Ethane		12.0	
Propane		8,089	
Butane		8,557	Tons per Stream Day
Sulfur		1,193	Long Tons per Stream Day
Ammonia		240	

Process Features:

Depth of Extraction	- 60%
Solids Separation	—Single stage settling
Solids Disposition	—Converted to char in 400 psig LTC
Feed to H ₂ Plant	—LTC char plus vacuum resid
Extract Hydrogenation Conversion	—73.4%
Gasifier	—Fluid Bed, Agglomerating Ash
Power Generation	—Combined Cycle Gas Turbine

PROGRESS DURING APRIL-JUNE 1977

The design phase activities for the commercial plant continued through April and May. However, during June the task force efforts were placed on analyses, evaluation and reporting rather than design since by the end of the quarter the design phase of the project was better than 90 percent complete. Minor cleanup work remained in the areas of equipment selection, flow sheet drafting, emissions data tabulations, and electrical drawings.

The cleanup work and cost estimates will be handled during the next few months as well as preparation of the final report. The final plant design and costs will be presented here when it is released.

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VIII. LOCK HOPPER VALVE DEVELOPMENT

CONSOLIDATED CONTROL

EL SEGUNDO, CALIFORNIA

Contract No.: EX-76-C-01-2355

Contract Funding: \$2,547,000
(100% DOE)

INTRODUCTION

The goal of this lock hopper valve development contract is to design, test, and evaluate 8-inch and 12-inch coal gas valves that would be compatible with operating conditions found in various coal gasification plants. The project was initiated in June 1976 because reliable coal gas valves will be required to assure the efficient, continuous and safe operation of coal conversion processes in future plants.

PROGRAM DESCRIPTION

The specific objectives of the project are threefold. It is designed to:

- Provide reliable data sufficient to permit the confi-

dent design of coal gas valves compatible with existing and projected pilot plant operations.

- Produce reliable coal valves suitable for commercialization.
- Provide for the orderly transfer of the demonstrated technology to private industry.

The project will be conducted in three phases. Phase I preliminary design will evaluate the proposed design based on engineering analysis. A review of and determination of the availability of special hardware and test procedures will be conducted. Phase II, prototype design and pretest, will involve the fabrication and testing of an 8-inch prototype valve. In addition, analysis of test results will be conducted in order to identify areas where modifications may be necessary in the final prototype design. A 12-inch valve (based on Phase II tests results) will be fabricated and tested in a pilot plant during Phase III. A review and evaluation of the test results will be made and a report published concerning the test data.

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IX. CONCEPTUAL DESIGN FOR AN ATMOSPHERIC FLUIDIZED BED DIRECT COMBUSTION ELECTRIC POWER GENERATING PLANT

STONE & WEBSTER

BOSTON, MASSACHUSETTS

Contract No.: EF-77-C-01-2583

Contract Funding: \$1,354,000
(100% DOE)

INTRODUCTION

Stone & Webster is currently under contract to DOE to provide a conceptual design for an Atmospheric Fluidized Bed Direct Combustion (AFBC) Electric Power Plant that will combust high-sulfur coal in an AFBC boiler and generate electric power in an environmentally acceptable manner. The effort on this project will also focus on improving existing boiler technology to produce a conceptual design of a boiler with sufficient integrity and reliability for integration with power generating equipment which will operate between 560-580 megawatts (MW).

The specific objectives are:

- To project capital, operating and product costs for a central power plant
- To design a technically feasible and efficient combination of unit processes and equipment that will directly combust high sulfur coal and produce electric power in an environmentally acceptable manner

The work to attain the overall objective falls into two overlapping phases. Phase I involves the development of conceptual designs and examination of merit of a contemporary size (560 MS) plant including an atmospheric fluidized bed boiler of designs projected by each of the major boiler manufacturers, specifically Babcock & Wilcox and Foster-Wheeler. The purpose of this phase is to provide convincing evidence to the electric utilities to

show that fluidized bed combustion is a better choice for future coal burning facilities than current conventional methods such as suspension burning of pulverized coal.

Phase II will be based on the development of Phase I, particularly with regard to the examination of risks associated with scale up of design features beyond the extent of their present demonstrated success. The objective of the second phase is the compilation of the conceptual design of an atmospheric fluidized bed combustion demonstration plant of size and extent acceptable from the standpoint of risk and attainment of goals to its owner and sponsors.

PROJECT ACCOMPLISHMENTS

The total project input has been planned in terms of nine major tasks designated 1000 through 9000. Work of Phase I has focused mainly on Tasks 1000, to establish a broad background for the work, and 2000, base plant definition.

Subcontract work by Pope, Evans and Robbins, under Task 3000 has been applied largely to development of a current state-of-the-art report on atmospheric fluidized combustion in anticipation of consultations upcoming with the boiler manufacturers as they firm up the basic concepts from which their individual designs will evolve.

Subcontracts with the boiler manufacturers have been initiated under Task 4000, but their work has only been started as of the close of March 1977. Tasks 5000, 6000, and 7000 relate to the specific AFB plant designs and descriptions which remain to be undertaken in the 2nd Quarter 1977. Task 8000 reports have been limited in

issue to the three each preceding monthly technical and financial reports. However, two supplemental reports are substantially complete and will be issued soon. These are Base Plant Report and the FBC State-of-the Art Report. Finally, Task 9000 relating to the demonstration plant, remains scheduled to start about the first of June.

X. CONCEPTUAL DESIGN OF A COAL MINE COAL CONVERSION PLANT INTERFACE SYSTEM

BECHTEL, CORPORATION
SAN FRANCISCO, CALIFORNIA

Contract No.: EX-76-C-01-2370
Contract Funding: \$576,633
(100% DOE)

INTRODUCTION

Bechtel Corporation is under contract to the Division of Coal Conversion to investigate the coal mine-coal conversion plant interface and develop conceptual designs to identify and correct interface inefficiencies.

The mine-plant interface is a physical installation which, once installed, will serve the life of the plant. Inefficiencies built into the conceptual configuration design will result in financial penalties within the process by increased cost in the feedstocks. Further, it is expected that the volumes of coal required by commercial coal conversion plants will exceed that of existing plants and it is anticipated that a complex of mines will be required. This increase in volume introduces complications in the concepts of mine-plant interface, materials handling, coal preparation, and stockpiling.

The specific objectives of the contract are:

- To provide a conceptual design of coal mine-coal conversion plant interface.
- To demonstrate the technical and economic viability of coal mine-coal conversion plant interface processes.

- To produce new or modify existing equipment and techniques to meet the requirements of the project.
- To provide for the orderly transfer of the demonstrated technology to private industry.

PROGRAM DESCRIPTION

The project will be carried out in two phases. Phase I will involve a interface overview investigation. This will entail the identifications of specific coal mine-coal conversion plant interface concept for which a conceptual design will be developed during Phase II. Activities will include identifications of viable mine configurations and conversion plants; analysis of transportation, mine delivery, and feed materials system concepts, and evaluation of alternative mine-conversion plant interface concepts.

The phase II effort will center on interface conceptual engineering and cost estimating. This will involve preparation of designs for mine handling, and transportation, preparation of process flow diagrams, operating costs and descriptions of each unit. Additionally, a detailed economic evaluation of the conceptual system will be made.

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XI. CONCEPTUAL DESIGN OF A COAL TO METHANOL COMMERCIAL PLANT

BADGER PLANTS

CAMBRIDGE, MASSACHUSETTS

Contract No.: EX-76-C-01-2416

Contract Funding: \$1,650,000
(100% DOE)

INTRODUCTION

The goal of this project is to prepare a conceptual design for a coal-to-methanol commercial plant, and to make recommendations for a demonstration plant to produce methanol fuel and other synthetic liquids and their precursors by advanced coal conversion techniques. This effort will include a study of various gasifiers and synthesis processes in order to arrive at optimum process selections and configurations. In addition, it is anticipated that cost estimates and economic evaluations to be derived will aid in technical and economic feasibility analysis.

PROGRAM DESCRIPTION

Badger plants, under the current contract to DOE which began in July 1976, is conducting a three-phase program to define and engineer a conceptual coal-to-methanol plant. The three phases will consist of a preliminary engineering stage, the development of a conceptual design, and analysis and evaluation of the overall design. The Phase I preliminary engineering will involve an evaluation of a full scale commercial production plant process design. This will include identification of the characteristics and requirements for an initial plant

of a size suitable for demonstrating the economic utility of future commercial plants. This effort will also include process selection and configuration.

Phase II, development of a conceptual design, will center on preparation of structural specifications and drawings that are fixed to process requirements, process flow diagrams describing the overall material and energy balance, operating conditions and descriptions for each unit process selected.

Phase III is planned to be used for analysis and evaluation of the completed conceptual design.

PROGRESS DURING APRIL-JUNE 1977

Badger Engineers continued to advance the design of the coal-to-methanol commercial plant throughout the quarter. Progress was made on each section of the plant without any major delays. The status of each section of the plant as of the end of the quarter is listed below.

Coal Preparation

A number of study layouts have been prepared that reflect coal delivery, coal storage, belt conveyor layouts, pulverization and pneumatic conveying systems. These layouts will be used to determine the optimum system.

Gasification

The mechanical design concept was under review. Refractory, cooling coils, and materials of construction were being investigated. Write-ups were also initiated to develop the gasification area process description for the final report.

Shift and Acid Gas Removal

Work continued on the shift unit material balance and the design of the shift converter as a radial flow reactor was initiated. Contacts with licensors for the Rectisol and Claus-Scot systems continued so that the proper information for development of process flow diagrams could be obtained.

Methanol Synthesis

Development of a general process flow diagram was

initiated for the Lurgi low-pressure methanol synthesis unit.

Methanol Purification and Methyl Fuel Units

The economics of methyl fuel drying was evaluated based on lowering the water content from 6.5 to 0.5 weight percent. Badger determined that a payout is realized within four years with the following advantages:

- Reduction of shipping and tankage costs
- Utilization of excess low-pressure steam, thereby improving the overall plant energy balance

Environmental

Design work on the environmental protection systems that would be required for a commercial plant was continued with a number of designs and evaluations being made. All aspects of environmental hazards and control are being considered.

XII. CONCEPTUAL DESIGN FOR ATMOSPHERIC FLUIDIZED BED DIRECT COMBUSTION ELECTRIC POWER GENERATING PLANT

BURNS AND ROE, INC.
ORADELL, NEW JERSEY

Contract No.: EF-77-C-01-2455
Contract Funding: \$1,321,000
(100% DOE)

INTRODUCTION

The overall goal of this project, initiated in January 1977, is to prepare a conceptual design for an electric power generating plant that will directly combust high-sulfur coal in an atmospheric fluidized bed boiler and generate electric power in an environmentally acceptable manner.

A key aspect of this effort will be the development of a generic design of a boiler. The concept and design features including the shape and size of the boiler will be new. Also, recent studies and research indicate that polluting substances can be eliminated at the combustion source by rising a fluidized bed in the coal reactor and this project is being initiated to produce a design that will allow determination of the feasibility of the direct combustion process.

The specific objectives of the contract are to:

- Produce a conceptual design for an atmospheric fluidized-bed direct combustion (AFBC) electric power plant
- Validate and provide a generic concept and design of an atmospheric fluidized-bed boiler and peripheral equipment that will directly combust high-sulfur coal in an environmentally acceptable manner
- Project the capital, operating and product costs for a central station electric power generating plant

The project will be conducted through a number of tasks over a 13-month period. These tasks include:

- Definition of initial plant criteria
- Definition of design alternatives
- Fuel preparation
- Atmospheric fluidized bed boiler and accessories
- Sorbent systems
- Definition of major equipment and system design parameters
- Specifications and equipment costs
- Commercial plant design
- Environmental impact
- Economic analysis
- Demonstration plant design
- Final report and recommendations

PROGRESS DURING APRIL-JUNE 1977

A number of reports were completed and submitted to ERDA during the quarter. These included the Initial Plant Criteria and Design Alternatives report and the Coal Supply Systems effort. These reports completed Tasks 1, 2 and 3 of the overall project.

The Initial Plant Criteria report presents the initial plant criteria alternatives which will serve as the basis for engineering decision making during the conceptual design

of the AFB atmospheric fluidized bed combustion electric power generating plant.

The coal supply systems report presented the rationale in selecting the design coal for the program, the basis for the coal cost, and equipment selected for receiving, unloading and handling the coal for a 600 megawatt AFBC power plant and the equipment cost. The analysis of the design coal on an as-received-basis is as follows:

Moisture (%)	28.0
Volatile matter (%)	31.7
Fixed Carbon (%)	32.5
Ash (%)	7.8
Sulfur (%)	0.89
Heating Value (Btu/lb)	8053

Other areas of the project continued to be advanced with a draft of the report on "Sorbent Systems" being completed. The report covered such areas as limestone sorbent supply, analysis and cost, sorbent supply systems such as sorbent waste and regeneration systems. The draft report also included cost analysis and recommendation. The draft is currently under review.

Work was initiated on the definition of major equipment and system design parameters during the quarter. The report, which is scheduled to be issued at the end of July will include the following analysis:

- Plant size - plant size selection will be based on plant availability and on utility preference
- Steam Conditions - Selection of a superheated cycle or a super critical cycle will be made on an economic basis
- Reheat Cycles - Selection between 0.1 or 2 reheat cycles will be made on an economic basis
- Feedwater Heaters - Selection will be made on using either 6, 7 or 8 feedwater heaters based on an economic evaluation
- Cooling Towers - An economic evaluation will be made between natural draft, round mechanical draft, or rectangular mechanical draft cooling towers

Efforts on the commercial plant design proceeded with plant drawings. The design effort is expected to continue on schedule.

Work on the economic analysis task was begun during this quarter. Burns & Roe determined that all economic analysis would be performed using current (mid-1977) equipment and operating costs. The following economic criteria were chosen for use for the project.

- Plant life - 20 years (1985-2005)

- Project life - 25 years (1980-2005)
- Interest rate - 8%
- Fixed-charge rate - 13%
- Replacement energy costs - 20 mills/kilowatt/hour
- Capacity charge - \$670/kilowatt

A number of conclusions and recommendations were presented by Burns & Roe in their AFBC State-of-the-Art Report as submitted to DOE. They are as given below.

"Atmospheric fluidized-bed combustion is a promising near-term technology that can effectively utilize our vast reserves of non-compliance coal in an efficient, economical, and environmentally acceptable manner. It therefore offers an attractive alternative to the use of scrubbers with such fuels in power generating plants.

"It must be emphasized, however, that the development of AFBC technology is viewed as a near-term solution, and if AFBC is not developed by 1990, AFBC may lose its value in the USA's total energy program. In order to achieve this goal of near-term AFBC commercialization, the following recommendations are presented."

1. AFC Design

- a. AFC units must be capable of achieving combustion efficiencies comparable to current pulverized units.
- b. AFBC units must be competitive in total cost of electricity and must be capable of economically generating power for a 30-year life.
- c. AFBC unit must be capable of achieving reasonable availability, load following characteristics, controllability, and maintainability.
- d. The optimization of coal and sorbent feed systems is of paramount importance to AFBC commercialization. The current criteria of one feed point for every nine square feet of bed is unacceptable for commercialization.

2. Demonstration Plants

- a. ERDA should provide funding for multiple (preferably three) demonstration plants which would permit each of the boiler manufacturers now working in AFBC technology (Foster Wheeler, Combustion Engineering, and Babcock & Wilcox) to proceed with the development of large scale boilers.

Successful achievement in AFBC technology by all three of these manufacturers is necessary to assure

the utilities that they will be entering a competitive market.

- b. ERDA should accept the technical and economic risks associated with an expanded and accelerated AFBC demonstration plant program.
- c. ERDA should provide for total funding of all demonstration plants with provisions for the utility to pay back commercial value of the plant if successful.

3. *Pilot Plants and Research*

- a. Added research and development is needed in a number of areas listed below. This effort, however, should not in any way slow down the design of AFBC demonstration plants.

- (1) Hardware for handling high-temperature materials
- (2) Gas cleanup systems
- (3) Sensor, measurement and control systems
- (4) In-bed heat transfer programs
- (5) Reduction of Ca/S mole ratio
- (6) Development of an economic sorbent regeneration system.

- b. ERDA should expand its proposed activities at the Rivesville Plant to include testing and evaluation of various feed systems and various control systems. This must be done at the Rivesville Plant as the earliest predicted operation date for the MERC Plant is at least three years away (and even the 6 ft x 6 ft MERC unit will be of limited use for evaluating feed points).

4. *Miscellaneous*

- a. All efforts must be made to have federal laws modified to specify that current allowable sulfur emission levels be frozen until 1985, and that reduction of these levels occur no more often than once every ten years. A "moving SO₂ target" that might result in an obsolete plant is a great concern to the electrical utility industry.
- b. ERDA contracting and funding must be accelerated to avoid excessive delays.
- c. Information transfer is essential to the early commercialization of AFBC. Current distribution methods are totally unacceptable.
- d. Future AFBC workshops and conference should include active participation of utilities.

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XIII. COAL GRINDING EQUIPMENT DEVELOPMENT

KENNEDY VAN SAUN

DANVILLE, PENNSYLVANIA

Contract No.: EX-76-C-01-2475

Contract Funding: \$808,000

INTRODUCTION

Kennedy Van Saun is under contract to DOE to modify and develop improved coal grinding equipment and procedures for the coal conversion industry to meet the needs of demonstration and commercial coal conversion plants. The efficient conversion of coal to clean synthetic fuels is very dependent on achieving and maintaining a continuous and controllable reaction process which is in turn dependent on uniform size and feed rate of the coal feedstock. Currently, there are no grinding or presizing equipment available which can prepare feed coal without excessive amounts of fines and undersized particles. This project is therefore designed to alleviate the abovementioned deficiencies associated with the coal grinding processes and produce a coal grinding handbook which can be utilized by process engineers for grinding system selection.

PROGRAM DESCRIPTION

It has been anticipated by Kennedy Van Saun that the project will be carried out in four phases in order to meet the project objectives. These objectives, as formulated by DOE, are:

- To produce reliable coal grinding equipment for the controlled grinding and preparation of feed coal for demonstration and commercial size plants
- To provide a controlled size output with a minimum of undesirable or unusable fines

The project, initiated in September 1976, is expected to be completed in September 1978. Phase I, the study phase will require approximately a year and one-half to complete. This will involve categorizing existing equipment by output spectrum, volume rate, and the driving power required. A study on the state-of-the-art on commercial coal grinding equipment will also be performed. Further, three types of coal will be selected for later experimentation and classification and Penn State University will perform laboratory analysis to determine the mechanical properties of the coal, the kinetic parameters of communication, and perform rate testing.

Phase II, will be the preparation phase where the selection, design, layout and modification of coal grinding equipment to be used in Phase III will be carried out. The actual grinding experiments with the coal will take place during Phase IV. Wet grinding tests in water and coal derived oil will be made and the results recorded. Phase IV will involve documentation and reporting on the findings during the first three phases of the contract. A handbook will be prepared which will describe modifications of equipment and selected grinding procedures, required safety items, and will also include economic analysis comparing various grinding procedures.

PROGRESS DURING APRIL-JUNE 1977

During the quarter, work was conducted mainly on the study and preparation phases of the project although work was initiated on the testing phase.

Work under the Study Phase has been involved with the subtasks State-of-the-Art Survey and Laboratory Analysis. The laboratory analysis continued to center on developing the grinding kinetics of the test coals.

Work under the preparation phase was directed at completing the testing facility. However, due to a series of delays, preliminary completion of the facility to allow testing of the air swept ball mill has fallen behind schedule. Efforts under the testing phase has been involved with modification of the size reduction systems, specifically the hammer mill and wet ball mill.

Laboratory Analysis

Ball and race mill grinding studies of the Western Kentucky coal for wet conditions were conducted and completed. The tumbling ball mill grinding studies, both dry and wet, were conducted on 8 x 12 mesh and 20 x 30 mesh size fractions. The test conditions were 4 percent by volume powder filling in the mill with 20 percent ball filling. The mill was rotated at 70 percent of critical speed. For wet grinding, 45 percent solids by volume was used. The data from the tests were used to modify and improve the computer grinding simulation program.

XIV. CRITICAL COMPONENT TEST FACILITY ADVANCE PLANNING FOR TEST MODULES

OAK RIDGE NATIONAL LABORATORY

OAK RIDGE, TENNESSEE

Contract Funding: \$280,000

INTRODUCTION

The design of plants for the production of synthetic gas and oil is currently being sponsored by DOE under an agreement for joint government and private construction funding of promising designs. The time scales for these plants require dependence on existing and near-term equipment technology, much of which has not been proved for the intended applications. The economic and environmental risks associated with dependence on available and newly developed equipment in unprecedented service applications have stimulated interest within DOE and the equipment design communities in performance, reliability, and safety testing. DOE has taken the main role in this testing because of its involvement in all areas of coal technology. In this regard, ORNL was authorized by DOE to pursue, in an accelerated time frame, an advanced planning study for the conceptual design of a test facility for evaluating demonstration-plant-scale coal conversion equipment.

The major goals of the study were to survey the range of performance criteria for several classes of coal conversion equipment in pending demonstration plants, to develop preliminary engineering concepts and cost estimates for test modules having these capabilities, and to consider the effects of an integrated test facility on site-dependent resources.

The scope of the design study did not include consideration of all components which might be deemed critical to the coal-conversion demonstration plants. For the purpose of this analysis, those components which directly

affect successful operation of the process system were selected. In this category are lock hoppers valves, slurry pumps, continuous dry-coal screw feeders, and gas-cleanup systems which were selected to define test module requirements. Testing requirements for components yielding increased process efficiency or for improved equipment currently visualized, but not yet in the market, were given less priority and were not covered in the study.

PROJECT PROGRESS

Hopper Valves

The most commonly proposed method of solids feeding and removal systems for use in coal-conversion processes is the lock hopper system. Most of the pilot plants have used 4- to 8-inch pipe size valves at low flow rates relative to the anticipated conditions of demonstration- and commercial-scale plants. Typical flow rates for a single feeder in a 250-MM Btu/day gasification plant with three parallel trains would be in the range of 50 to 150 tons per hour (TPH). First-generation demonstration plants would be expected to be designed for the lower end of this range, with second-generation plants designed for the upper end. Valve sizes up to 24 inches are anticipated for commercial plants.

Coal-conversion pilot plants have experienced numerous valve problems due to erosion, corrosion, and seal leakage; the erosion problems have been particularly noticeable on valve seats and stem seals because of the coal

finer that serve as a grinding medium during valve cycling in the normal lock hopper operation. The major difficulties are associated with developing a suitable valve seat, reliable seal systems, and adequate materials to withstand the severe operating conditions. These difficulties are compounded by the back-pressure pulsing that the lock hopper valves are subjected to during each cycle. Lock hopper feed systems in the steel and chemical industry are operated at lower flow rates, temperatures, and pressures and do not appear to present the complex design problems encountered in coal-processing feed systems. The Lurgi coal-conversion plants, which have been in production for many years, use the lock hopper method of introducing coal into the gasifier; however, these systems are generally smaller, operate at only intermediate pressure levels, and restrict operating conditions, such as coal preheat temperature, to give acceptable valve life. Certain of these restrictions could be introduced into projected demonstration plants, but optimum system design and performance would not be achieved. Therefore, there is an economic incentive to develop maximum valve performance capabilities.

Most hopper valves that will be used for solids feeding and let-down applications in the immediate future will be modified industrial valves. Valve manufacturers have standard recommended combinations of materials, disk assemblies, guides, and packing arrangements applicable to various process requirements. Each combination and modification responds differently in service depending upon the materials, temperature, pressure, valve orientation, loadings applied to the valve, induced vibration in the valve assemblage, and speed of operation. The lock hopper valve is in use on many commercial blast furnace systems, such as those at Port Pirie, South Australia; and lock hopper feeders have been used on pilot-plant size gasifiers, such as Synthane. Several of the coal-conversion pilot plants and process development units have used in-house-designed lock hopper systems. Most of these systems, however, have experienced many problems with valve seating and external leakage. Also, these systems are designed for lower flow rates than those required for commercial-scale coal-conversion plants. Consequently, valve improvements are needed, especially if large size valves are to operate reliably for thousands of hours.

A program is in progress at Morgantown Energy Research Center (MERC) for development of valves of the size needed in pilot and demonstration plants, and the valve designs are to be capable of scaleup to the sizes anticipated for commercial plants. The effect on various valve configurations can best be determined by establishing a highly flexible, controlled-conditions test facility to simulate coal-conversion operating conditions and installation restraints.

However, until improved valves are developed, the suitability of and constraints to the coal-conversion process imposed by the valve industry must be considered. Until the process conditions have been ascertained, a known market has been established, and valve manufacturers can be assured of a return on their investment in money, manpower, and equipment, special valves developed specifically for coal-conversion process applications will not be available in production quantities.

Valve Test Module

The hopper valve test module designed by ORNL was designed to test the following range of conditions and characteristics for valves which control the flow of solids.

- Flow materials - The test unit is planned to test valves which control the flow of pulverized coal (1/4-inch and smaller) provisions were made to include dolomite, char, ash, and etc.
- Flow rate up to 170 tons per hour (TPH) during a 2.6 minute open-close cycle.
- Module has capability of testing valves to 24-inch size, however, a 12-inch valve will be utilized.
- Pressure differential will be as high as 600 psig.
- The system temperature maximum is designed at 500° F.

The scope of the tests will be to determine whether the valves can function properly under typical heads of pulverized solids, properly seal against streams of solids, accommodate large let-down pressure gradients, and seal against typical gas pressure after exposure to wear and abrasion.

The cost estimates prepared for the preliminary conceptual modules amounted to \$7,349,000. This included a 30 percent contingency factor because of the conceptual nature of the design. This cost included buildings and structures, process equipment feeds, and engineering costs.

Slurry Pumps

Several of the many different proposed methods of converting coal into gaseous or liquid fuels require transfer of slurries by pumping. Slurries may be composed of various combinations of coal, char, or ash in water, oil, or solvent.

The primary reasons for testing slurry pumps is to demonstrate whether they are durable and reliable enough to withstand extended periods of operation in

continuous service applications in coal-conversion processing plants. Slurry pumps can fail for the conventional reasons that ordinary pumps do or may fail due to excessive erosion and corrosion of internal parts. For this reason, endurance testing is especially important in qualifying a new slurry pump design or in requalifying an existing design for pumping a new and different type of slurry.

There are more than 50 companies in the United States that manufacture and supply slurry pumps for moving a large variety of slurries. In practice, slurry pumping has been accomplished with varying degrees of success because of the unpredictable effects of slurry constituents and characteristics on pump components. The expansion of a coal-based energy industry will introduce more severe service requirements than are normally encountered by slurry pumps in current industrial applications. Pipeline transport of coal as a slurry is already practiced. On a recent pipeline installation in the United States, the Black Mesa pipeline in Arizona, coal is transported at a rate of 550 TPH (3800 gpm) through an 18-inch diameter line over a distance of 273 miles. Slurry pumps in this type of service (i.e., coal in water at 50 percent concentration) are performing well, with a reasonably high degree of reliability. Standby pumps are provided, however, so that routine maintenance can be performed while pipeline operation continues.

Also, slurry pipelines are used in several locations in the United States and in other countries for bulk transport of limestone and concentrated iron and copper ores. These pipelines range in length from six to 240 miles, and diameters range from four to 20 inches.

In addition to long-distance pipeline transport, slurries of a wide variety are pumped in many manufacturing plants. These applications range from relatively dilute slurries to those with a consistency of paste. The slurries also vary widely with respect to abrasion and corrosion properties and to viscosity of the carrier fluid. Slurries often must be pumped at temperatures up to several hundred degrees Fahrenheit due to the need for reasonable viscosities or due to other manufacturing limitations.

The pumping of coal-water slurries at ambient temperatures might be acceptable in the present state-of-the-art except that variations in ash content and the degree of beneficiation performed can affect the abrasive nature of the coal and can also affect the slurries in which such coal is used. The various coal-conversion processes involve the pumping of slurries composed of various combinations of coal, char, or ash in water, oil, or solvent.

Slurry Pump Test Module

The slurry pump test module will be capable of testing either centrifugal or reciprocating pumps. The pumping rate may be varied within the range of 500 to 2500 gpm. The module will accept discharge pressures up to 4000 psia. For centrifugal pump tests, the suction pressure may be varied from atmospheric pressure to 2000 psia. For reciprocating pump tests, the suction pressure will be fixed at 50 psig because the reciprocating pump will be supplied with a forced circulation suction. Experience with reciprocating pumps in similar slurry services indicates the necessity of having circulation through the inlet valve area.

Slurries were considered to involve coal, char, mineral residue, or ash with either water or heavy oil. Heavy-oil slurries may be used to test pumps up to 650°F. Equipment is included to remove the solids for reuse of either the oil or the water.

It was assumed that presized dry solids could be purchased; therefore, equipment for sizing and drying is not included. Solids were assumed to be in the range of 300 mesh to 1/4 inch. An elutriator is included in the unit to allow a slight variation in the average particle size of fresh slurry.

The basis for the foregoing design capabilities was a tabulation of "at hand" knowledge of present or forecast service requirements for commercial or demonstration-size synthetic fuel coal plants. Certain adjustments to the operating ranges were necessary to keep the concept of the module reasonable. Four principal adjustments are listed below:

- High flow rates at low discharge pressure were considered a common service that did not require testing.
- Flows of 4000 gpm and high discharge pressure were considered a reasonable and necessary test. However, it was felt that these rates would be produced by two or more pumps operating in parallel and that a test facility having a 2500-gpm capability would be adequate.
- A service involving very low suction pressure (less than 1.0 psia) was omitted because it also involves low flow rate and discharge pressure (325 gpm and 50 psig). The assumption is that in practice, one pump will be used to remove slurry from a vacuum vessel and a second will be used to inject the slurry into another process system. It seems unlikely that complete service would be provided by one pump.
- A service requiring 850°F operating temperature was also omitted because this is an extreme for a

single case. Since the module involves recirculation of the slurry, this temperature would cause oil-coking problems.

The estimated cost for the system is \$23,000,000. The estimate includes allowances for the special nature of piping, thermal insulation, and electrical requirements. As with the hopper valves, a contingency of 30 percent was included.

Gas Clean-Up Systems

Several coal-gasification processes and pressurized fluidized bed boilers that require some form of hot gas cleanup are being developed. These processes generally operate at high temperature and pressure and include one or more power generation cycles to improve overall thermal efficiency. Power-recovery gas turbines, coupled to gasifiers or pressurized fluidized beds, are usually desired to recover some work before the off-gas stream enters a steam-power cycle or waste heat recovery process. Gas stream temperatures from several proposed high-temperature-high-pressure gasifiers range from 1200° to 2100°F which is sufficiently high to recover power using a gas turbine before entering a more conventional process. This power recovery approach is designed into several systems for some of the major gasification processes now under development or near commercialization. However, these systems require development of advanced methods of hot gas cleanup to be workable. Other high-temperature-high-pressure gasification processes now under development would probably use hot-gas cleanup methods if they were commercially available.

Gas turbine power technology is well developed for use in clean gas streams at temperatures up to around 1750°F. This technology is expected to be expanded within a few years with the development of air-cooled turbine blades. Gas turbines available today and in the foreseeable future that operate at this temperature encountered severe erosion when exposed to particulate-loaded streams. The highest temperature successfully used to date with power recovery gas turbines in dirty streams is around 1275°F. This is typically used with single-stage power recovery turbines on catalytic cracking units in the petroleum industry using two to three stages of cyclone particulate removal. The state-of-the-art for these single-stage expanders is a temperature of approximately 1275°F and a pressure ratio of 2.8. Some proposed coal-conversion processes operate at pressures which would require multistage gas turbines for pressure ratios exceeding 2.8. The multistage units at temperatures above 1275°F are not as tolerant of particulates and encounter

more severe erosion. Thus, the temperatures for which advanced hot-gas cleanup methods are needed extends above 1200°F. This means that some form of advanced hot-gas cleanup method is needed for essentially all the processes which recover power from the gasifier off-gas stream.

Presently there is no high-efficiency equipment commercially available for application at high pressure and in the temperature range of 1200° to 1800°F. Cyclones have been used, but they are not efficient enough for inlet streams to multistage gas turbines. The separation efficiency of cyclones decreases sharply for particles less than five microns; particles on the order of one micron are essentially unaffected. Cyclones have been used for the first stage of cleanup in demonstration plants and should be tested in this facility as well as higher performance gas cleanup methods.

Coal gasification and pressurized fluidized bed process designers are faced with severe design restraints due to the unavailability of hot-gas cleanup equipment for high-pressure operations.

Among currently available equipment items, cyclones are very common particulate removal devices but have not been employed on a commercial scale for the projected combination of elevated temperatures and pressures. The most stringent common application for cyclones to date has been on fluidized catalytic cracking units in the petroleum industry at temperatures up to 1275°F.

Many kinds of filters have been designed for various ranges of conditions. The ordinary fabric filter materials, however, cannot withstand the high temperatures. Several companies are now trying to develop filters for high-temperature operations. Silica fiber and metal-felted fabric are some of the materials being investigated. Porous ceramic tubes have also been proposed. Bed filters offer another possibility of particulate removal for high-temperature service. Electrostatic precipitation is a very efficient particulate removal process at low temperature and atmospheric pressures. In research studies the temperature limit has been raised in one case and the pressure limit in another. To date, an electrostatic precipitator that will withstand high temperature and high pressure simultaneously has not been designed but such a device is being developed.

Gas Clean-Up Test Module

The purpose of the module is to test devices which are likely to be proposed or installed to remove particulate

matter from major gas streams that will be inherent in large energy plants. These devices include electrostatic precipitators (ESP), bag filters, cyclones, multiclones, and sand filters. The core of the gas cleanup module consists of several interrelated systems. There is a 60-inch OD piping loop for gas supply to the test device with a bypass to reduce the test device flow rate. There is a gas cleaning and compression loop to provide motive power for the educator, a solids withdrawal system and a nitrogen lock gas system, and a combustion air and LPG fuel supply system to the loop in-line burner to provide temperature control for the test gas.

The total cost for the test loop has been estimated a \$40,000,000.

Solids Feeders

Several of the more promising coal liquefaction and gasification systems depend on a feed of dry coal crushed or pulverized to a size not exceeding 1/4 inch. Depending on the process, the coal is fed progressively into a pretreater, preheater, and a gasifier or other type of reactor. These systems operate at inlet pressures up to 1500 psig, and for some systems coal preheated to temperatures exceeding 250°F is desirable. The anticipated feed rate of individual feeders for future coal processing plants is 150 TPH. However, for some near-term plants the required feed rate may be only 50 TPH if multiple units are used for each coal-conversion reactor.

At present there are no commercially available, continuous dry-coal feeders for the above applications. Basically the problems are development and subsequent testing of feeder systems at existing technology levels. Because there are numerous coal processes, a variety of feed conditions must be met by commercial equipment to supply the plants of the future. For this reason several feeder concepts should be developed and tested. Table XIV-1 lists the more promising feeder concepts recommended for testing with a coal feeder module.

Present-day equipment uses the batch-feed approach to feed dry particulate material into process equipment at high pressures. To feed coal into a processing plant at 150 TPH would require enormous high-pressure lock hoppers. The manufacture and use of these would entail very high capital and operating costs. Lock hopper value performance and reliability also present serious problems for this type of feed system because the required feed rate must be considered to be beyond the present state of the art. The valve test module is expected to resolve the valve problems, but the economic penalties make it imperative that a different approach be taken to feed commercial-size coal-processing plants of the future.

Table XIV-1. Feeders Recommended for Testing

Feeder Type	Testing Proposed by	Operating Principle
Gas-solid injector	Lockheed	Jet pump
Kinetic extruder	Lockheed	Bladeless centrifugal
Fluid dynamic lock	Lockheed	Bladeless compressor
Screw type extruder	Ingersoll-Rand	Plastic extruder
Centrifugal (closed passages)	Foster-Miller	Two 180° spaced tubular passages
Positive displacement	Foster-Miller	Closed plunger, fluidized coal
Plug feeder	Foster-Miller	Reciprocating ram or screw
Pocket flight conveyor	Foster-Miller	Pockets on a chain

Slurry pumps represent an alternative means of providing a continuous high-pressure feed stream. There are also significant problems associated with using a slurry pump for this application, but the slurry pump test module should resolve these. However, the cost of separating the slurrying fluid and drying the coal represents a substantial economic penalty for use of this method.

At this time, continuous dry coal feeders for the application described above are of laboratory-scale size or exist only as concepts. Numerous concepts have been reviewed and the more promising ones recommended for further testing and evaluation. Extensive development and testing are required before industry will be in a position to furnish this equipment for a commercial coal plant of the size anticipated for the foreseeable future.

Laboratory-scale equipment testing is now under way through programs sponsored by ERDA. The three companies participating in these programs are Lockheed Missile and Space Corporation, Foster-Miller Associates, and Ingersoll-Rand Research Corporation. These programs are covered in this publication. The results of these programs should enable pilot-plant-size equipment to be designed and tested in existing pilot plants. Demonstration and commercial plant feeders designed from extrapolated pilot-plant data should be proof-tested for performance and reliability.

ORNL defines the "module" as the operating systems within a 250-foot-high structure. From the feed bins, the solids enter the test device by gravity. They leave the test device by gravity, if necessary through the grinder,

passing by gravity to the discharge lock hoppers. From the discharge lock hoppers, the solids flow by gravity to the discharge bins and then to the discharge conveyor.

The design of this module is controlled by the selection of a lock hopper to discharge solids from the high-pressure outlet of the feed device. Recycling of solids to size classification and reheat is considered possible with some feed devices. To retain this capability, it is necessary to discard letdown devices based on throttling slurries. A lock hopper appears to be the only remaining option. By very preliminary examination, a 15-minute lock-hopper cycle is about the shortest that can be achieved. This cycle time sets the operating sequence and batch capacities of the feed and withdrawal equipment. The achievable cycle time for equipment as supplied sets the maximum feed rate for the test device.

The lock hoppers discharge their total load in about 5 minutes. The discharge bins accept this load and deliver it

to the discharge conveyor at the steady 150-TPH rate, thus permitting consideration of the largest standard size Redler conveyor. To keep the feed bin size as low as reasonable, the feed bins also have been put on a 15-minute feed and 15-minute discharge cycle.

Vessel cycles should be on automatic sequence controls. The feed rate to the test module is measured by weigh cells on the feed bins. Feed solids properties are measured by examining samples taken from the outlet of the bins. The current design does not define the means of maintaining the discharge pressure on the test device. In some cases, such a control will be inherent in the device; in others, it will probably be advisable to superimpose an inert-gas supply system onto the test-device discharge itself, with an allowance for a fairly high leak rate. The design calls for a differential pressure control between the test device and the lock hoppers during the lock hopper charging step.

Costs for the module were estimated at \$52,000,000.

GLOSSARY

absorption — an imprecise term suggesting the taking up of one substance by another by either a physical process or a chemical combination.

acceptor — calcined carbonate that absorbs carbon dioxide evolved during gasification, liberating heat.

acid gas removal — the process of selectively removing hydrogen sulfide and carbon dioxide from a gas stream.

activated carbon — carbon obtained by carbonization in the absence of air, preferably in a vacuum; has the property of absorbing large quantities of gases, solvent vapors; used also for clarifying liquids.

adiabatic — any process where heat is neither given off nor absorbed.

adsorption — the process by which the surface of a solid or liquid attracts and holds any atom, molecule, or ion from a solution or gas with which it is in contact.

agglomerate — assemblage of ash particles rigidly joined together, as by partial fusion (sintering).

anthracite coal — hard coal containing 86 to 98 percent fixed carbon and small percentages of volatile material and ash.

API — American Petroleum Institute.

API gravity — a scale adopted by the API for measuring the density of oils; $^{\circ}\text{API} = \frac{141.5}{\text{Specific gravity, } 60^{\circ}\text{F}/60^{\circ}\text{F}} - 131.5$

aromatic hydrocarbon — a cyclic hydrocarbon containing one or more six-carbon (benzene) rings.

ash — solid residue remaining after the combustion of coal.

ASTM — American Society for Testing Materials.

autoclave — a vessel, constructed of thick-walled steel, for carrying out chemical reactions under high pressures and temperatures.

bench-scale unit — a small-scale laboratory unit for testing process concepts and operating parameters as a first step in the evaluation of a process.

binder — carbon products, tars, etc., used to impart cohesion to the body to be formed; a coal-extract binder may be used to prepare formed-coke pellets from non-coking coals.

bituminous coal — a broad class of coals containing 46 to 86 percent fixed carbon and 20 to 40 percent volatile matter.

blow down — periodic or continuous removal of water from a boiler to prevent accumulation of solids.

bottoming cycle — the lower temperature thermodynamic power cycle of a combined-cycle system.

Btu — British thermal unit, the quantity of energy required to raise the temperature of one pound of water one degree Fahrenheit.

BTX — benzene, toluene, xylene; aromatic hydrocarbons.

caking — the softening and agglomeration of coal as a result of the application of heat.

calcination — the process of heating a solid to a high temperature to cause the decomposition of hydrates and carbonates.

calorific value — the quantity of heat obtained by the complete combustion of a unit mass of a fuel under prescribed conditions.

carbon fiber — fine filaments of carbon about eight microns in diameter which are used in composite materials, being bound with resins.

carbonization — destructive heating of carbonaceous substances with the production of a solid, porous residue, or coke, and the evolution of a number of volatile products. For coal, there are two principal classes of carbonization, high-temperature coking (about 900°C) and low-temperature carbonization (about 700°C).

catalyst — a substance that accelerates the rate of a chemical reaction without itself undergoing a permanent chemical change.

centrifuge — an apparatus rotating at high speed which utilizes the centrifugal force generated to separate materials of different densities, e.g., undissolved residue from coal solution in the SRC process.

char — the solid residue remaining after the removal of moisture and volatile matter from coal.

Claus process — industrial method of obtaining elemental sulfur through the partial oxidation of gaseous hydrogen sulfide in air followed by catalytic conversion to molten sulfur.

coal — a readily combustible rock containing more than 50 weight percent and more than 70 volume percent of carbonaceous material including inherent moisture, formed from compaction and induration of variously altered plant remains similar to those in peat.

coalification — metamorphosis of vegetable debris into coal.

coke — strong porous residue consisting of carbon and mineral ash formed when bituminous coal is heated in a limited air supply or in the absence of air. Coke may also be formed by thermal decomposition of petroleum residues.

coke breeze — the fine screenings from crushed coke usually passing a 1/2 inch or 3/4 inch screen opening.

combined cycle — two sequential thermodynamic power conversion systems operating at different temperatures.

combustion gas — gas formed by the combustion of coal, e.g., burning.

combustor — a vessel in which combustion takes place.

coupon — a polished metal strip used to measure the rate of corrosion of the metal in a specific gaseous or liquid environment.

cracking — the partial decomposition of high-molecular-weight organic compounds into lower-molecular-weight compounds, generally as a result of high temperatures.

crude gas — impure gas produced in a gasifier.

culm — the waste or slack from anthracite mines or preparation plants consisting of fine coal, coal dust, and dirt.

cyclone separator — essentially a settling chamber to separate solid particles from a gas, in which gravitational acceleration is replaced by centrifugal acceleration.

degasification — a process for removing naturally occurring methane from coal seams.

delayed coking — a process wherein coal is subjected to a long period of carbonization at moderate temperatures to form coke.

demineralization — removal of mineral matter (ash) from coal by solvent extraction, usually under hydrogen atmosphere.

depolymerization—the change of a large molecule into simpler molecules usually accompanied by the substitution of hydrogen for oxygen in the molecular structure.

destructive distillation—the distillation of coal accompanied by its thermal decomposition.

desulfurization—the removal of sulfur from hydrocarbonaceous substances by chemical reactions.

devolatilization—the removal of a portion of the volatile matter from medium- and high-volatile coals.

diatomaceous earth—a yellow, white, or light-gray, siliceous porous deposit made up of opaline shells of diatoms; used as a filter aid, paint filler, adsorbent, abrasive, and thermal insulator. Also known as kieselguhr.

diatomite—See Diatomaceous Earth.

dissolution—the taking up of a substance by a liquid with the formation of a homogeneous solution.

distillation—a process of vaporizing a liquid and condensing the vapor by cooling; used for separating liquids into various fractions according to their boiling points or boiling ranges.

dolomite—a carbonate of calcium and magnesium having the chemical formula $\text{CaMg}(\text{CO}_3)_2$.

Dowtherm—trademark for a series of eutectic mixtures of diphenyl oxide and diphenyl used as high-temperature heat-transfer fluids.

ebullated bed—gas containing a relatively small proportion of suspended solids, bubbles through a higher density fluidized phase with the result that the system takes on the appearance of a boiling liquid.

economizer—heat exchanging mechanism for recovering heat from flue gases.

effluent gas—gas given off from a process vessel.

elutriation—the preferential removal of the small constituents of a mixture of solid particles by a stream of high-velocity gas.

endothermic reaction—a process in which heat is absorbed.

enthalpy change—the increase or decrease in heat content of a substance or system which accompanies its change from one state to another under constant pressure.

entrained bed (flow)—a bed in which solid particles are suspended in a moving fluid and are continuously carried over in the effluent stream.

eutectic—that combination of two or more components which produces the lowest melting temperature.

exothermic reaction—a process in which heat is liberated.

extraction—a method of separation in which a solid or solution is contacted with a liquid solvent (the two being essentially mutually insoluble) to transfer components into the solvent.

extractive coking—similar to delayed coking process, with the emphasis on high tar yields to produce liquids.

filter aid—finely divided solids used to increase efficiency of filtering.

filter cake—the moist residue remaining from the filtration of a slurry to produce a clean filtrate.

filtrate—a liquid free of solid matter after having passed through a filter.

filtration—the separation of solids from liquids by passing the mixture through a suitable medium, e.g., cloth, paper, diatomaceous earth.

Fischer assay—method for determining the tar and light oil yields from coal or oil shale; conducted in a retort under an inert atmosphere with a prescribed increase in temperature to 500°C.

Fischer-Tropsch catalyst—catalysts developed for the catalytic synthesis of liquid fuels from coal-derived synthesis gas; catalysts contain principally iron, cobalt, nickel, or ruthenium.

Fischer-Tropsch process—method of hydrogenating mixtures of

carbon monoxide and hydrogen produced from coal, lignite, or natural gas by means of steam, at 1-10 atmospheres and 360-410°F to yield liquid and gaseous fuels, and a wide spectrum of industrial chemicals.

fixed-bed—stationary solid particles in intimate contact with fluid passing through them.

fixed carbon—the solid residue, other than ash, obtained by destructive distillation; determined by definite prescribed methods.

flash carbonization—a carbonization process characterized by short residence times of coal in the reactor to optimize tar yields.

flue gas—gaseous combustion products.

fluidization (dense phase)—the turbulent motion of solid particles in a fluid stream; the particles are close enough as to interact and give the appearance of a boiling liquid.

fluidization (entrained)—gas-solid contacting process in which a bed of finely divided solid particles is lifted and agitated by a rising stream of gas.

fluidized-bed—assemblage of small solid particles maintained in balanced suspension against gravity by the upward motion of a gas.

fly ash—a fine ash from the pulverized coal burned in power station boilers, or entrained ash carried over from a gasifier.

fractionation—distillation process for the separation of the various components of liquid mixtures.

freeboard—the space in a fluidized-bed reactor between the top of the bed and the top of the reactor.

free swelling index—a standard test that indicates the caking characteristics of coal when burned as a fuel.

Friedel-Crafts reaction—a substitution reaction, catalyzed by aluminum chloride in which an alkyl (R-) or acyl (RCO-) group replaces a hydrogen atom of an aromatic nucleus to produce a hydrocarbon or a ketone.

fuel cell—a galvanic cell in which the chemical energy of a conventional fuel is utilized to produce electricity.

fuel gas—low heating value (150-350 BTU/scf) product generally utilized on site for power generation or industrial use.

gasification of coal—the conversion of solid coal into a gaseous form by various chemical reactions with steam.

gasifier—a vessel in which gasification occurs, usually utilizing fluidized-bed, fixed-bed, or entrained-bed units.

heat capacity—quantity of heat required to raise the temperature of one pound of a substance one degree Fahrenheit.

high-Btu gas—a gas having a heating value of 900 to 1,000 Btu per standard cubic foot, which approaches the value for natural gas.

higher-heating value (HHV)—the heat liberated during a combustion process in which the product water vapor is condensed to a liquid and the heat of condensation is recovered.

hydroclone—a small cyclone extractor for removal of suspended solids from a flowing liquid by means of the centrifugal forces set up when the liquid is made to flow through a tight conical vortex.

hydrocoking—coking of tars, SRC, etc., under hydrogenating conditions to form liquid products.

hydrocracking—the combination of cracking and hydrogenation of organic compounds.

hydrogasification—gasification that involves the direct reaction of fuels with hydrogen to optimize formation of methane.

hydrogenation—chemical reactions involving the addition of gaseous hydrogen to a substance in the presence of a catalyst under high temperatures and pressures.

hydrogen donor solvent—solvent, such as anthracene oil, tetralin (tetrahydronaphthalene), decalin, etc., which transfers hydro-

gen to coal constituents causing depolymerization and consequent conversion to liquid products of lower boiling range which are then dissolved by the solvent.

hydrotreating—a process to catalytically stabilize petroleum or other liquid hydrocarbon products and/or remove objectionable elements from products or feedstocks by reacting them with hydrogen.

ideal gas—any gas whose equation of state is expressed by the ideal gas law, namely $PV = nRT$ where P is the pressure, V is the volume, R is the gas constant, T is the absolute temperature, and n = number of moles.

ignition temperature—the minimum temperature necessary to initiate self-sustained combustion of a substance.

industrial gas—see fuel gas.

inerts—constituents of a coal which decrease its efficiency in use, e.g., mineral matter (ash) and moisture in fuel for combustion.

in situ—in its original place, e.g., underground gasification of a coal seam.

intermediate-Btu gas—synthesis gas product with a higher heating value between 350 and 500 Btu per standard cubic foot.

lignite—brownish-black coal containing 65-72 percent carbon on a mineral-matter-free basis, with a rank between peat and subbituminous coal.

limestone—sedimentary rock containing 50 percent carbonate (CO_3) of lime or magnesia. Chemical formula (for calcite limestone) is CaCO_3 .

liquefaction—conversion of a solid to a liquid; with coal, this appears to involve the thermal fracture of carbon-carbon and carbon-oxygen bonds, forming free radicals. These radicals abstract hydrogen atoms yielding low molecular weight gaseous and condensed aromatic liquids.

liquefied petroleum gas (LPG)—those hydrocarbons that have a vapor pressure (at 70°F) slightly above atmospheric (such as propane and butane); kept in liquid form under a pressure higher than 1 atm.

lock hopper—a mechanical device that permits the introduction of a solid into an environment of different pressure.

low-Btu gas—a gas having a heating value up to 350 Btu per standard cubic foot.

lower heating value—the heat liberated by a combustion process assuming that none of the water vapor resulting from the process is condensed, so that its latent heat is not available.

MAF—moisture and ash-free; a term that relates to the organic fraction in coal.

mesh—measure of fineness of a screen, e.g., a 400-mesh sieve has 400 openings per linear inch.

methanation—the production of methane (CH_4) from carbon monoxide or dioxide and hydrogen.

methane— CH_4 , a colorless, odorless, and tasteless gas, lighter than air; the chief component of natural gas.

methanol—methyl alcohol, CH_3OH .

micron—a unit of length equal to one millionth of a meter; 10^{-6} meter.

moving bed—particled solids in a process vessel that are circulated (moved) either mechanically or by gravity flow.

natural gas—naturally occurring gas extracted from sedimentary structures consisting mainly of methane and having a higher heating value of approximately 1,050 Btu per standard cubic foot.

noncoking coal—a coal that does not form coke under normal coking conditions.

olefinic hydrocarbon—a class of unsaturated hydrocarbons containing one or more double bonds and having the general chemical formula C_nH_{2n} .

open cycle—a thermodynamic power cycle in which the working fluid passes through the system only once and is then exhausted to the atmosphere.

peat—an unconsolidated, hydrophilic, yellowish-brown to brownish-black, carbonaceous sediment, formed by accumulation of partially fragmented and decomposed plant remains in swamps and marshes which retains more than 75 percent inherent moisture and less than 12 percent mineral matter in saturated natural deposits.

petrochemicals—those derived from crude oil or natural gas, or their coal-derived substitutes; they include light hydrocarbons such as butylene, ethylene and propylene, the raw materials for the production of plastics by polymerization.

phenols—a group of aromatic compounds having the hydroxyl (OH) group directly attached to the benzene ring.

pilot plant—a chemical process plant containing all the processes of a commercial unit, but on a smaller scale, for the purpose of studying the technical and economic feasibility of the process.

pipeline gas—a methane-rich gas that conforms to certain standards and has a higher heating value between 950 and 1,050 Btu per standard cubic foot.

plenum chamber—an enclosed space through which air is forced for slow distribution through ducts.

precoat—layer of suitable filtering medium, e.g., diatomaceous earth, laid down on a rotary filter cloth prior to operation.

prilling tower—a tower that produces small solid agglomerates by spraying a liquid solution in the top and blowing air up from the bottom.

process development unit—a system used to study the effects of process variables on performance; sized between a bench-scale unit and a pilot plant.

proximate analysis—analysis of coal based on the percentages of moisture, volatile matter, fixed carbon (by difference), and ash, using prescribed methods. Reported on different bases, such as as-received (or as-fired), dry, mineral-matter-free (mmf), and dry mineral-matter-free (dmmf).

purification—removal of a wide range of impurities present in gases from coal gasification.

pyrolysis—thermal decomposition of organic compounds in the absence of oxygen.

quenching—cooling by immersion in oil, water bath, or water spray.

Raney nickel catalyst—specially prepared nickel catalyst used in the hydrogenation of organic materials and the methanation of synthesis gas to methane.

raw gas—see crude gas.

reactivity—susceptibility to chemical change; for example, in coal liquefaction, the reactivity of the coal for conversion to liquid products is a function of the coal rank, among other things.

reactor—vessel in which coal-conversion reactions take place.

Rectisol process—a process for the purification of coal-gasification gas based on the capability of cold methanol to absorb all gas impurities in a single step; gas naphtha, unsaturated hydrocarbons, sulfur compounds, hydrogen cyanide, and carbon dioxide are removed from the gas stream by the methanol at temperatures below 0°C.

reducing gas—a gas which, at high temperatures, lowers the state of oxidation of other chemicals.

reforming processes—a group of proprietary processes in which low-grade or low molecular weight hydrocarbons are catalytically converted to higher grade or higher molecular weight materials; also applies to the endothermic reforming of methane, for the production of hydrogen, by the reaction of methane and steam in the presence of nickel catalysts.

refractory—a material capable of withstanding extremely high temperatures and having a relatively low thermal conductivity.

residence time—time spent by a typical particle in a particular zone.

saturated hydrocarbon—a carbon-hydrogen compound with all carbon bonds filled; that is, there are no double or triple bonds as in olefins and acetylenes.

scrubber—apparatus in which a gas stream is freed of tar, ammonia, and hydrogen sulfide.

seam coal—coal which is intermediate in rank between bituminous coal and anthracite; contains 8 to 22 percent volatile matter and from 91 to 93 percent carbon.

semi-water gas—a mixture of carbon monoxide, carbon dioxide, hydrogen, and nitrogen, obtained by passing an air-stream mixture through a hot bed of coke, having a higher heating value of about 120 Btu per standard cubic foot.

sensible heat—that heat which results in only the elevation of the temperature of a substance with no phase changes.

shift conversion—process for the production of gas with a desired carbon monoxide content from crude gases derived from coal gasification; carbon monoxide-rich gas is saturated with steam and passed through a catalytic reactor where the carbon monoxide reacts with steam to produce hydrogen and carbon dioxide, the latter being subsequently removed in a scrubber employing a suitable sorbent.

sintering—the agglomeration of solids at temperatures below their melting point, usually as a consequence of heat and pressure.

slag—molten coal ash composed primarily of silica, alumina, iron oxides, and calcium and magnesium oxides.

slurry—a suspension of pulverized solid in a liquid.

solvation—the association or combination of molecules of solvent with solute ions or molecules.

solvent—that component of a solution which is present in excess; liquid used to dissolve a substance.

solvent extraction—selective solution of coal constituents from finely divided coal particles into a suitable solvent after intimate mixing, usually at high temperatures and pressures in the presence of hydrogen, with or without a catalyst, followed by phase separation.

solvent refined coal (SRC)—a coal extract derived by solvent extraction; a brittle, vitreous solid (m.p. 300°F to 400°F) containing about 0.1 percent ash and about 10 percent of the sulfur in the original coal feedstock; calorific value is about 16,000 Btu per pound; may be used as a clean fuel for power generation by combustion; utilized for the production of high-grade metallurgical coke, anode carbon, and activated carbon by coking, or hydrogenated to produce synthetic crude oil.

space velocity—volume of a gas (measured at standard temperature and pressure) or liquid passing through a given volume of catalyst in a unit time.

specific gravity—ratio of the weight of any volume of a substance to the weight of an equal volume of water at 4°C.

specific heat—heat capacity of a substance as compared with the heat capacity of an equal weight of water.

standard cubic foot (SCF)—the volume of a gas at standard conditions of temperature and pressure. The American Gas Association

uses moisture-free gas at 60°F and 30 inches of mercury (1.0037 atm) as its standard conditions. The pressure standard is not universal in the gas industry: 14.7 psia (1.000 atm) and 14.4 psia (0.980 atm) are also used. The scientific community uses 32°F and 1 atm as standard conditions.

stoichiometry—the definite proportions in which molecules react chemically to form new molecules.

stripping—the removal of the more volatile components from a liquid mixture of compounds.

subbituminous coal—the rank of coal between bituminous and lignite, classified by ASTM as having a range of heating values between 8,300 and 11,000 Btu per pound on a moist mineral-matter-free basis.

substitute natural gas (SNG)—a gas produced from coal, oil sands, or oil shale conforming to natural gas standards.

superficial velocity—the linear velocity of a fluid flowing through a bed of solid particles calculated as though the particles were not present.

superheater—a heat exchanger which adds heat to the saturated steam leaving a boiler.

syn crude—synthetic crude oil; oil produced by the hydrogenation of coal, coal extracts, oil sands, or oil shale, which is similar to petroleum crude.

synthesis gas—a mixture of hydrogen and carbon monoxide which can be reacted to yield a hydrocarbon.

tall gas—a gas issuing from a gas-treatment unit which may be recycled to the process or exhausted.

tar (coal)—a dark brown or black, viscous, combustible liquid formed by the destructive distillation of coal.

therm—a unit of heat used as a basis for the sale of natural gas; equal to 100,000 Btu.

topping cycle—the higher temperature thermodynamic power cycle of a combined-cycle system.

turndown ratio—the minimum ratio of actual flowrate to design flowrate at which a process unit can be operated.

ultimate analysis—the determination by prescribed method of carbon and hydrogen in the material as found in the gaseous products of its complete combustion, the determination of sulfur, nitrogen, and ash in the material as a whole and the estimation of oxygen by difference; may be reported on different bases, such as as-received (or as-fired), dry, mineral-matter-free (mmf), and dry mineral-matter-free (dmmf).

Venturi scrubber—a gas cleaning device which involves the injection of water into a stream of dust-laden gas flowing at a high velocity through a contracted portion of a duct, thus transferring the dust particles to the water droplets which are subsequently removed.

volatile matter—those constituents of coal, exclusive of moisture, that are liberated from a sample when heated to 1750°F for seven minutes in the absence of oxygen.

water gas—gas produced by the reaction of carbon (in coal or coke) and steam to yield mixtures of carbon monoxide and hydrogen; similar to synthesis gas.

water gas shift—the reaction between water vapor and carbon monoxide to produce hydrogen and carbon dioxide or the reverse: $\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2 + \text{CO}_2$.

working fluid—a gas stream which directly does work, e.g., powering a gas turbine.