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U.S. DEPARTMENT OF ENERGY
Division of Coal Conversion

QUARTERLY REPORT

MASTER

October - December 1977

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Publication Date: May 1978

DEMONSTRATION STRAITS PLANTS

COAL

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COAL DEMONSTRATION PLANTS

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OCTOBER-DECEMBER 1977

U.S. DEPARTMENT OF ENERGY

Division of Coal Conversion

Washington, D.C. 20545

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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, construction, 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.

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I. SYNTHESIS GAS FOR AMMONIA PRODUCTION DEMONSTRATION PLANT

W. R. GRACE & CO.
NEW YORK, NEW YORK

Plant Site: Baskett, Kentucky
Contract No.: EF-77-C-01-2577
Total Funding: \$318,358,000
Phase I: \$10,198,000 (100% DOE)
Phase II: \$233,060,000 (50% DOE/50%
Grace)
Phase III: \$75,100,000 (50% DOE/50%
Grace)

INTRODUCTION

W. R. Grace & Co. has been chosen by the Department of Energy for design, construction, and operation of a demonstration plant for conversion of coal to synthesis gas for use in ammonia production. This synthesis gas/ammonia production portion of the overall DOE demonstration program is aimed at producing a synthesis gas that is a direct substitute for natural gas in ammonia production thereby freeing this scarce natural resource for higher priority use. The overall objective of the program is the construction of an integrated facility that will convert 1,700 tons-per-day of coal into 1,200 tons-per-day of ammonia and yield 60 tons-per-day of sulfur as a by-product. Ebasco Services, Inc. is the architect and engineering firm and construction manager for the project.

As now planned, the project will be carried out in three phases. Phase I will be 100 percent funded by government with Phases II and III a 50-60 cost sharing with industry and government.

The auxiliary ammonia plant will be funded 100% by W. R. Grace at a cost of about \$40 million. A provision is also in the contract for W. R. Grace to ultimately buy back and have complete ownership of the entire facility.

Phase I involves seven major tasks which include:

- Conceptual design and evaluation of a commercial plant
- Demonstration plant conceptual design
- Current estimate of Phases II & III
- Site evaluation and selection
- Demonstration plant environmental analysis
- Demonstration plant concentration and operation plan
- Economic reassessment of commercial & demonstration plant design.

The purpose of the preliminary commercial plant design is to obtain a detailed process design based on maximum use of proven, commercially available components and equipment on which to base detailed cost estimates. The end use of this design will be to evaluate the economic and technical feasibility for commercial plants and to recommend changes to the overall commercial plant concept. The demonstration plant design will also be based on a system that will integrate commercially available components and equipment. This effort will include 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, will be a part of the effort.

The conceptual demonstration plant design will establish the basis for designing the actual demonstration plant. The conceptual design will include estimated operating life of the plant, selection of the plant size, and development of the preliminary heat and material balances for the plant using the coal selected.

Phase II work will involve the preparation of the complete plant design, including drawings, specifications, and definitive cost estimates. A bid package will be prepared and the physical plant will be constructed. Phase III, the ultimate objective of the project, will be the operation of the plant. Experience gained during this period will be used to determine the technical and economic performance and assess the project with regard to the scale-up of the operation to larger commercial plants. The project schedule is given in Figure I-1.

PROCESS DESCRIPTION

The Texaco Coal Gasification Process (TCGP) was chosen for use in the project. The process has been demonstrated on heavy oils and light feedstocks and is considered a second generation technology. The proposed plant will operate on Kentucky number 9 coal feedstock which is ground to 70 percent minus 200-mesh and then slurried in water to 50-60 percent solids for high pressure pumping and atomized injection into the gasifier. The slurry and pure oxygen enter at the top of the gasifier. In the presence of steam derived from the water of the coal slurry feed, they react to produce hot gases and molten slag, which are quenched in the lower section of the generator. The cooled gases leave the generator saturated with steam. The slag is removed through a lock hopper system to recover and recycle unconverted carbon.

The raw gas from the gas generator is rich in CO which reacts with water to produce H_2 and CO_2 . The CO_2 and

any hydrogen sulfide (H_2S) produced are absorbed in refrigerated methanol (Rectisol process) to remove them from the gas stream. The clean gas is scrubbed in liquid nitrogen which removes any residual CO, methane or argon. Adding the liquid nitrogen also produces the product gas, which is feedstock for the ammonia synthesis step.

The ammonia synthesis reaction in the proposed design is conducted at 3000 pounds-per-square-inch. The gas from the ammonia converter is cooled by heat exchange and refrigeration to condense the ammonia. The generalized process flow diagram is shown in Figure I-2.

PROGRESS DURING OCTOBER-DECEMBER 1977

Conceptual Commercial Plant Design

Initial technical efforts were directed toward preparation of a trade-off study plan for determination of optimum gasifier operating pressure. The broad parameters of study for the assessment of technical and economic optimizations under varying gasifier operating pressure levels were established. Based on previously developed information regarding coal gasification, the initial pressure levels to be investigated were selected as 800, 1200, 1500 and 2500 psig. The primary areas of investigation will include:

1. heat and material balances
2. equilibrium calculations
3. power consumption
4. reliability analysis, and
5. capital and operating cost analysis

Current efforts are underway utilizing available data on product gas stream compositions, oxygen and water

Figure I-1. W. R. GRACE PROJECT SCHEDULE

requirements and burner operating conditions. For the purpose of initial studies, assumptions have been incorporated with regard to flame temperature in order to establish the quantity of quench water and gasifier exit crude gas temperature. Further studies aimed at determining the effect of quench water temperature on the steam/dry gas ratio outlet are progressing. To be included in the study currently underway is an analysis of the effect of gasifier operating pressure on the waste heat recovery system including the development of an enthalpy and temperature diagram for each pressure level. Based on the information gained in these studies, heat and material balances for each of the four pressure levels will be developed along with equipment size determinations and utility requirements. The culmination of the gasifier

Auxilliary Facillties Design and Evaluation

A preliminary docking facilities study of a potential plant site location in Western Kentucky was undertaken. The study's objective was an evaluation of regulations governing construction and operation of a combined coal unloading/ammonia loading dock facility and a determination if existing regulations bar such construction. It has been tentatively determined that the site being evaluated is satisfactory for the required docking facility.

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II. PIPELINE GAS DEMONSTRATION PLANT

ILLINOIS COAL GASIFICATION GROUP
CHICAGO, ILLINOIS

Plant Site:	Perry County, Illinois
Contract No.:	EF-77-C-01-2012
Total Funding:	\$293,215,609
Phase I:	\$22,691,309 (96% DOE/4% ICGG and CDC)
Phase II:	\$199,386,300 (50% DOE/50% ICGG)
Phase III:	\$71,138,000 (50% DOE/50% ICGG)

INTRODUCTION

The Illinois Coal Gasification Group (ICGG) consisting of a joint venture on the part of subsidiaries of the Northern Illinois Coal Gas Co., Peoples Gas Light & Coke Co., Central Illinois Light Co., Inc., Central Illinois Public Service Co., and North Shore Gas Co. was selected by DOE to design, construct, and operate a pipeline gas demonstration plant with the objectives of demonstrating the commercial feasibility and economic attractiveness of a chemical process for conversion of high sulfur coal to clean pipeline gas. The primary process licensor (pyrolysis, gasification and liquid product recovery) is the COGAS Development Company, and the architect/engineering firm is the Dravo Corp., Synfuels Division.

This comprehensive program includes a number of specific objectives which are to:

- Confirm design criteria, demonstrate technology and obtain experience which will yield those characteristics required to establish and/or define plant

- investment and operating costs for future clean pipeline gas commercial production plants
- Project plant investment, operating and end-product costs for full-scale commercial production plants
- Provide technology, performance, reliability and maintenance characteristics which will permit the design of a full-scale clean pipeline gas commercial production facility
- Investigate the general applicability and limits of the selected process and plant design for a variety of coal types
- Determine scaling parameters (with respect to the commercial production of the primary product) and sizing of major process components, such as those for gasification, hydrogenation, etc.
- Provide finished marketable clean pipeline gas in quantities sufficient for end-use evaluations
- Determine the general characteristics, composition and quality of the end-product(s)
- Assess and/or evaluate characteristics and suitability of the product in actual representative end-use applications
- Establish guidelines for by-product use and/or disposal

- Obtain data which will permit design of an environmentally acceptable commercial plant
- Establish the design compatibility with Occupational Safety and Health Administration (OSHA) requirements

PROGRAM PLAN

The overall effort on the program has been divided into three distinct phases, these are:

- Phase I - Development and Engineering - 22 months
 - Stage 1 conceptual design
 - Stage 2 final engineering design
- Phase II - Demonstration plant construction - 34 months
- Phase III - Demonstration plant test, evaluation and operation - 42 months

The following is a brief description by phase, of the total program.

Phase I - Development and Engineering

Stage 1 - Conceptual Design

A conceptual design for a Commercial Plant using second generation gasification technology will be prepared. This design will be based on the maximum use of proven, commercially-available components and equipment. The capital and operating cost estimates, as well as the economic analysis, will consider various process trade-off and design studies. Based on a favorable economic evaluation of the conceptual design for a Commercial Plant, a conceptual process design for a Demonstration Plant will be developed. A site evaluation study and an environmental analysis, as well as preliminary plans for resources (coal, water, etc.) and water pipeline right-of-way acquisition, will be prepared. A recommendation for a Demonstration Plant will be submitted to DOE at the end of Stage 1.

Stage 2 - Final Engineering Design

During Stage 2, bid packages, construction plans and an economic reassessment will be prepared. In addition to the possible procurement of long lead time equipment, plans for procuring raw materials, permits, and easements will be finalized.

Phase II - Demonstration Plant Construction

Phase II encompasses the actual detailed design and construction of the Demonstration Plant. The contractor will finalize the site acquisition and agreements related to feedstocks, product transportation, by-products sale, wastes, permits, licenses, easements and rights-of-way. After competitive bidding, the construction subcontract(s) will be awarded. The contractor will be responsible for procurement of equipment and facilities, preparation of the site, inspection of the work, and construction management.

Operation, training and maintenance manuals required for the start-up, testing and operating during Phase III will be developed. Training programs will be implemented with the specific objective of developing the necessary skills required for the operation and maintenance of the Demonstration Plant. The training program will emphasize both the safety features and the hazards of the equipment. A final economic reassessment of the investment and the operating costs of both the Demonstration Plant and a Commercial Plant will be performed.

Updated "as-built" drawings will be submitted to DOE. After the approval by DOE of a check-out and acceptance plan, necessary mechanical testing of the plant will be performed prior to start-up.

Phase III - Demonstration Plant Test, Evaluation and Operation

A plant shakedown test plan will be submitted to DOE for approval before the plant components are tested. A detailed report summarizing the six months of testing will be submitted to DOE. Two months are planned for establishing the operating conditions and operating variables for the primary coal type, after which the plant will be operated for twelve months to demonstrate the long term operating characteristics of the plant. At the conclusion of the testing of the primary coal type, DOE may direct the contractor to test one or both of the alternate coals for a period of six months each. At the end of Phase III, DOE has the option to extend the period of performance

for a period not to exceed eighteen months in accordance with terms and conditions mutually agreed upon by the contractor and DOE.

As a result of the experience gained from constructing and operating the Demonstration Plant, the contractor will conduct process trade-off studies and an economic re-analysis for the optimization of the design, construction and operation of a commercial plant.

The program schedule is given in Figure II-1.

PROCESS DESCRIPTION

Technology to be used by the contractor includes the COGAS coal gasification concept, licensed by COGAS Development Company, a partnership comprised of the FMC Corporation; Consolidated Gas Supply Co.; Panhandle Eastern Pipe Line Co., and the Tennessee Gas Pipeline Co. The concept for pyrolysis and gasification (shown in Figure II-2) consists of three sub-units: multi-stage fluid bed pyrolyzers (COED Process), a fluid bed gasifier, and a slagging char fines combustor.

The multi-stage fluid bed pyrolyzers are vertical cylindrical steel vessels. For most coals three pyrolysis stages are used. Coal is transported to the first stage using a suitable carrier gas. Temperature of pyrolysis increases from the first stage through the third stage. Coal is fluidized and pyrolyzed in the first stage by a portion of gas from the third stage. The char from the first stage flows to the second stage, where it is fluidized and pyrolyzed by the remainder of the gases from the third stage. In the third stage, the char is fluidized and pyrolyzed by a portion of hot synthesis gas. Char from the third stage then feeds the gasifier, where the synthesis gas is pro-

duced. Gas from the first two pyrolysis stages, i.e. the pyrolysis gas, is water scrubbed and quenched to condense out most of the condensibles and water. It is then compressed and sent to the purification section for acid gas removal.

The char fed into the gasifier is fluidized by steam injected at the bottom of the gasifier. The hot char is more reactive than coal and reacts to produce synthesis gas by the following endothermic reaction:

The heat for this endothermic reaction is obtained by circulating a hot char stream through the combustor lift tube into the gasifier (See Figure II-3). As the hot char mixes with the char to be gasified, in the gasifier, it provides the heat for the endothermic reaction mentioned above. Char from the gasifier lift tube is recycled to the combustor for reheating. Char fines in the char stream and those collected in synthesis gas and flue gas cyclones are burnt in the combustor to produce hot flue gas and molten slag. The molten slag flows out of the bottom of the combustor into a slag quench tank where circulating water quenches the slag to a solid form. It is then settled and sent to disposal.

The hot flue gas from the combustor rises through the lift tube and heats the entrained circulating char. The char stream is separated from the flue gas at the top of the lift tube. The char is then fed to the gasifier. The flue gas, after passing through cyclones, is cooled in a waste boiler to produce high pressure superheated steam and expanded through power recovery turbines. The flue gas is then used in coal driers to dry and preheat the feed coal.

The char fines in the synthesis gas produced in the gasifier are eliminated by passing the gas through cyclones. A portion of the gas is sent to the third stage pyrolyzer to provide the heat for pyrolysis. The remainder of the gas is cooled in two waste heat boilers to

Figure II-1. ICGG PROJECT SCHEDULE

Figure II-2. PYROLYSIS UNIT

Figure II-3. GASIFIER/CHAR COMBUSTION SYSTEM

PROGRESS DURING OCTOBER-DECEMBER 1977

Task I - Conceptual Design and Evaluation of Commercial Plant

Task III - Site Evaluation and Selection

Task IV - Demonstration Plant Environmental Analysis

Task V - Materials and Licenses

Task IX - Technical Support

Task XI - Project Management

Efforts were directed toward completion of the process evaluation report for the conceptual design and evaluation of the commercial plant. Process design work was continued in the following areas:

- Coal Unloading and Handling
- Coal Preparation
- Pyrolysis and Gasification
- Oil Recovery and Treatment
- Gas Purification
- Hydrogen Generation
- Shift and Methanation
- Bulk CO₂ Removal
- Gas Compression and Dehydration
- Flue Gas Power Recovery
- SO₂ Removal
- Sulfur Recovery
- Ammonia Recovery
- Thermal Oxidizer and Flare
- Utilities
- Water Supply
- Water Treatment Systems
- Waste Treatment and Disposal

Similar progress was made on the demonstration plant process design. Engineering was conducted on the coal preparation pyrolysis and gasification, oil recovery and treatment and flue gas power recovery. Demonstration plant site evaluation and selection and environmental analysis was also conducted during the quarter.

Figure II-4. ICGG PIPELINE GAS DEMONSTRATION PLANT

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III. PIPELINE GAS DEMONSTRATION PLANT

CONTINENTAL OIL COMPANY
STAMFORD, CONNECTICUT

Plant Site: Noble County, Ohio
Contract No.: EF-77-C-01-2542
Total Funding: \$371,590,000
\$198,790,000 (DOE)
\$172,800,000 (Industry)

INTRODUCTION

The Conoco project is part of the DOE high-Btu gasification program which will develop new and improved second generation gasification technology necessary to build commercial scale plants for processes that convert coal to Substitute Natural Gas (SNG) of pipeline quality. The project will utilize the slagging Lurgi gasification process and will employ Foster Wheeler Energy Corp. as the architect-engineering firm.

As with the other demonstration plants, the project will be conducted in three phases. Phase I will consist of commercial and demonstration plant conceptual designs. Phase II will involve three major tasks which are demonstration plant detailed design, initiation of long lead procurement, and demo plant construction. Phase III, the end result of the project, will be shakedown and operation of the plant. The project schedule is shown in Figure III-1.

PROCESS DESCRIPTION

The technology chosen to be demonstrated in this project is the slagging Lurgi process. This process (shown in Figure III-2) is a modification of the existing com-

mmercial Lurgi process in that will accept caking coals and operate at higher temperature over a slagged ash bottoms. The slagging process reduces the carbon content of the molten ash stream and thereby increases the conversion of coal to gas. The process also produces less tar, phenol, and heavy hydrocarbons than the older commercial Lurgi process units.

Gases leaving the gasifiers are cooled by quenching with a gas liquor (recycled water) spray. The H_2/CO rate as required for downstream methanation is adjusted by shift conversion. A major portion of the crude gas passes through the converter while the remainder bypasses the converter. In the purification step, naphtha and water are separated by condensation, while hydrogen sulfide and carbon dioxide are removed by the Lurgi-rectisol process. In the methanation step, methane is produced from carbon monoxide and hydrogen over a fixed-bed nickel catalyst.

In the gas liquor separator, coal fines, tar and tar oil are removed from water. The fines with tar and oil are recycled to extinction in the gasifiers. The Lurgi-phenol-solvan process extracts phenols from the water. Ammonia is removed from the gas by the CLL process to produce aqueous ammonia. An air separation plant will produce oxygen which is a necessary part of the process in making pipeline quality gas.

In addition to tar precipitation, oil separation, and phenol extraction processes, the plant will include all the

HIGH BTU PIPELINE GAS "A"

Figure III-1. CONOCO PROJECT SCHEDULE

Figure III-2. CONOCO HIGH BTU PIPELINE GAS "A"

service sections required, such as steam production, water purification, air separation plant, incineration, waste treatment, as well as product loading, tankage, and buildings.

As currently planned, the plant will have a feed rate of 3,783 tons of coal per day producing 58.9 million standard cubic feet per day of 950 Btu/SCF pipeline gas.

PROGRESS DURING OCTOBER-DECEMBER 1977

Commercial Plant Design and Evaluation

The gasifier design was completed by Lurgi in December on schedule. The overall task is about two weeks behind schedule because of design delays experienced by Foster-Wheeler in the Rectisol, gas cooling, sulfur recovery, slag handling, and waste treatment sections.

Demonstration Plant Process Design

Lurgi and Foster-Wheeler continued work on the demonstration plant design. However, this task is about two weeks behind schedule.

Site Selection and Evaluation

The site selection task force recommended selection of a 1,157 acre tract in Marion and Center townships in Noble County, Ohio. The selected site was accepted by Conoco Coal Development and submitted to DOE for approval.

Work was initiated on a transportation study and real estate report and subcontracts were let for a soil survey and topographic mapping of the area. In addition, Westinghouse began preparation of a water resources study report for submittal to the Muskingum Water Conservancy District.

Environmental Analysis

Initial field programs at the proposed site were completed and the data gathered are being tabulated and assessed. Laboratory work and modeling using samples and information collected is currently in progress as is preparation of a draft environmental report.

Demonstration Plant Engineering and Design

Work on this task remains temporarily suspended and is approximately 3 months behind schedule.

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IV. FUEL GAS DEMONSTRATION PLANT

MEMPHIS LIGHT, GAS, AND WATER

MEMPHIS, TENNESSEE

Plant Site: Memphis, Tennessee

Contract No.: ET-77-C-01-2582

Total Funding:

Phase I: \$6,500,00 (100% DOE)

Phase II: \$115,000,000 (50% DOE/50%
Memphis Light, Gas & Water)

Phase III: \$ 58,000,000 (50% DOE/50%
Memphis Light, Gas & Water)

INTRODUCTION

Memphis Light Gas and Water, a municipal utility, was awarded a contract by the DOE to design an advanced demonstration plant to convert coal into fuel gas for industrial use. Under the terms of the contract, Memphis Light, Gas and Water will prepare a conceptual design of a demonstration facility which would utilize the U-Gas process developed by the Institute of Gas Technology with DOE funding. If the DOE and Memphis decide to proceed with the project following the conceptual design phase, the plant would be built on city owned property adjacent to the Frank C. Pidgeon Industrial Park on the Mississippi River. Fuel gas produced at the plant would be distributed by relatively short (less than 15 miles) pipeline to industries on President's Island and new industry locating in Pidgeon Park. The medium Btu fuel gas produced by the facility would have a heat content of approximately 300 Btu's per cubic foot, converted from 2800 tons-per-day of high sulfur coal. Approximately 175 million cubic feet of an equivalent of 50 billion Btu's of fuel gas would be produced daily.

As with the other major demonstration projects, this program will be carried out in three phases. These will be accomplished as follows:

Phase I — Program Development and conceptual design.

Task I — Conceptual design and evaluation of commercial plant.

Task II — Demonstration plant process design.

Task III — Demonstration plant process and mechanical design package.

Task IV — Site evaluation and Selection.

Task V — Demonstration Plant environmental analysis.

Task VI — Materials and Licenses.

Task VII — Construction and Operation Planning.

Task VIII — Economic Assessment.

Task IX — Technical Support.

Task X — Long lead items.

Task XI — Program Management.

Phase II — Demonstration plant final design procurement and construction.

Phase III — Demonstration plant operation.

The program schedule is shown in Figure IV-1.

ACTIVITY	FISCAL YEAR						
	77	78	79	80	81	82	83
PHASE I - CONCEPTUAL DESIGN	△	→	▽				
PHASE II - ● DETAILED DESIGN ● LONG LEAD PROCUREMENT ● CONSTRUCTION		△	→	▽			
		△	→	▽			
			△	→	▽		
PHASE III - SHAKEDOWN & OPERATION					△	→	

Figure IV-1. PROJECT SCHEDULE

Figure IV-2. MEMPHIS LIGHT, GAS & WATER DIVISION LOW BTU FUEL GAS INDUSTRIAL "A"

DEMONSTRATION PLANT PROCESS DESCRIPTION

The demonstration plant process will be based on the U-Gas process. The U-Gas gasifier is of vertical cylindrical construction with external cyclones for returning elutriated fines to the bed. A sloped grid at the bottom, containing one or more inverted cones, serves as the oxygen and steam distributor and the agglomerated ash outlet.

The U-Gas process is shown schematically in Figure IV-2. Raw coal is crushed to 1/4 inch size. The feed may contain up to 10% <200 mesh material as generated in the crushing step. Non-caking, subbituminous coals or lignite can be fed directly to the gasifier from the crusher. Caking coals (Eastern bituminous, for example) may have to be pretreated by contact with oxygen and steam in a fluidized bed operating at gasifier pressure at 700° to 800° F. An oxidized outer layer forms on the coal particles, and this prevents agglomeration and possible

blockage in the gasifier. However, experimental data to date indicate this step may be eliminated.

Coal fed to the gasifier is gasified with a mixture of oxygen and steam in a single stage fluidized bed. The residence time of the coal is about 45 minutes to an hour. Fluidizing velocity is in the order of 2 to 4 feet per second.

The key to operation of the gasifier is the agglomeration and separation of the low carbon content ash from the bed. The U-Gas gasifier accomplishes this and maintains a bed of approximately 70% carbon and 30% ash by proper design and operation of the grid and the fines return system in the bottom of the gasifier. The grid is sloped toward one of more inverted cones contained in the grid. Part of the fluidizing steam and oxygen flow through the grid while the remaining fluidizing gas flows upward at high velocity through the throat at the cone apex. The ratio of steam to oxygen in the fluidizing gas fed to the cone is chosen so that the resulting submerged jet in the cone is hotter than its surroundings. The temperature of the jet is maintained near the softening point of the ash particles for the specific coal being gasified. Ash particles preferentially stock together, and the agglomerates grow until they are heavy enough to move downward counter to the force of the gas stream in the apex of the cone and, thus, fall out of the fluidized bed. steam to oxygen in the fluidizing gas fed to the cone is chosen so that the resulting submerged jet in the cone is hotter than its surroundings. The temperature of the jet is maintained near the softening point of the ash particles for the specific coal being gasified. Ash particles preferentially stock together, and the agglomerates grow until they are heavy enough to move downward counter to the force of the gas stream in the apex of the cone and, thus, fall out of the fluidized bed.

Fines elutriated from the fluid bed are separated from the product gas by two cyclones in series. Fines removed by the first cyclones are returned to the bed by a standleg. Fines removed by the external cyclone are entrained in the inlet oxygen/steam to the gasifier grid cone where they are instantly gasified.

The hot product gas, after fines removal in the two cyclones, is cooled via waste-heat recovery and the result is a medium-Btu fuel.

PROGRESS DURING OCTOBER-DECEMBER 1977

Task I - Design and Evaluation of Commercial Plant

The commercial plant gasifier heat balances, material balances and utility requirements have been prepared based on a Western Kentucky No. 9 coal. Heat and material balances for an integrated gasifier-pretreater system are being prepared for a trade-off study to assess the effect of pretreatment on the overall process efficiency and economics. The characteristics and quantities of coal fines and other expected trace gas impurities present in the raw gas effluent from the gasifier are being defined.

Conceptual Design of the Commercial Plant is proceeding utilizing IGT's revised design basis. In addition, study activity proceeded on a trade off between sulfur removal and sulfur plant alternatives. The alternatives being investigated are as follows:

Base Case:	Selexol, Claus, Scot, Incinerator
Alternative 1:	Selexol, Claus, Beavon
Alternative 2:	Selexol, Sulfuric Acid
Alternative 3:	Benfield, Stretford, Product Gas Drying

Work is proceeding on these studies to develop capital and operating costs for these alternatives.

Task IV - Demonstration Plant Site Evaluation and Selection

A preliminary site survey has begun with the objective of identifying any major problems associated with the delivery of equipment or construction at the proposed site.

Efforts on other tasks in the program have not yet begun or are in the preliminary planning stages.

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V. DEVELOPMENT OF COAL FEEDERS FOR COAL GASIFICATION OPERATIONS

FOSTER-MILLER ASSOCIATES, INC.
WALTHAM, MASSACHUSETTS

Contract No.: E(49-18)-1793
Total Funding: \$2,729,149
(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 DOE. 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 projected 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 OCTOBER-DECEMBER 1977

Pilot Scale Coal Feeder Development

The linear pocket feeder testing is the last task under Phase II of the contract and has been delayed four

months due to late receipt of needed pressure vessel components.

Testing was finally initiated in November with the use of pressurized shop air in order to determine gas leakage rates for the feeder as a function of conveyor velocity and receiver pressure. The tests were conducted at speeds to 1.5 feet per second and pressure 100 pounds per square inch. Initial results indicate that as chain speeds increase, gas leakage rates drop. At 1 foot per second chain speed, the feeder can sustain a feed differential in excess of 40 pounds per square inch with no leakage. At a 2 feet per second chain speed, this figure increases to almost 80 pounds per square inch.

Initial checkout in December of the feeder system with coal gave no problems. Testing of the device will continue in January.

Pilot Plant Feeder Performance Testing

Efforts on this phase of the contract have been limited to design, layout and fabrication of feeders and the testloop. Assembly of feeders is not being pushed at this time since testing of the units must await completion of the linear pocket feeder testing.

VI. 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. was used to obtain information on the feeder requirements. Using the information gathered, Ingersoll-Rand examined existing equipment and conceptually design new approaches to coal feeders.

In Phase II, critical components of the candidate equipment selected in Phase I was 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 development unit 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 for review and comment.

PROGRESS DURING OCTOBER-DECEMBER 1977

Coal Feeder Development

Screw Concept

Testing of the 5.5 inch diameter screw feeder continued during the quarter utilizing Pittsburgh #8 coal. The test effort was concentrated on the attainment of steady state

operation against gas back pressure in the extrusion mode with external heat. Several initial tests against 100 pounds per square inch gas back pressure were carried out. These tests had to be terminated, however, because of extrudate jamming in the breaker device. The problem was investigated in detail and it was determined that the problem resulted from a build up of coal particles in a part of the pressure vessel assembly just below the breaker device. To alleviate the problem, a number of design and operating changes were made and testing was resumed. Several steady state operating periods of approximately three hours duration were achieved against 100 pounds per square inch gas back pressure with a coal flow rate of 300 pounds per hour.

Due to a shortage of IRRI lot #8 coal, an additional 25 tons of Pittsburgh #8 coal was procured (Lot #9) and testing was resumed. Although this coal was obtained from the same vendor, the coal performed differently during testing and operating temperatures had to be adjusted to obtain steady state conditions. Several successful runs were made with the Lot #9 coal at 300 pounds per square inch back pressure.

Near the end of the quarter, testing was directed towards increasing the coal flow rate by increasing the screw speed (from 10 to 15 rpm) and barrel temperatures. To date, steady state operations with these changed conditions have not been obtained. Problems related to screw stalling or insufficient heat input to the coal were encountered. Preparations are now being made to pre-heat the coal with the coal dryer system. These preparations include shakedown testing of dryer system and insulating the feeder hopper and the coal dryer bin.

Piston Concept

This part of the feeder program was initiated during the first week of October as a modification to the existing contract. The activities in this area have been primarily concentrated on the engineering evaluation of the concepts and the design detailing of experimental models. In addition, preliminary design of the pilot plant feeder was initiated.

Plasticized Coal Delivery Development

During this quarter, most of the machine modifications required to operate the Negri Bossi V-12 machine for delivering fully plasticized coal were completed.

Feasibility testing with coal was initiated towards the end of this quarter. The testing is being done in two steps:

- Produce fully plasticized coal in steady state.
- Spray or disintegrate the liquid plastic coal into fine droplets/particles.

The immediate objective of the testing is to fully plasticize the coal in the injection mode operation and to deliver it at high injection speeds through a small, sharp edged, round orifice to produce a spray. In order to deliver plasticized coal through a small, practical-sized orifice, high coal pressure and velocities are necessary, indicating that high flow rates are required. The high flow rates can be achieved in the machine only by injection, since, in plain extrusion mode the maximum flow rate is limited by the plasticized coal flow capacity of the machine. For example, extrusion at a flow rate of 40 lbs./hour (volume flow rate of .436 cubic in./sec. at 44 lbs/ cu. ft assumed melt density) will result in a maximum velocity of 51.4 ft./sec. through a .030" diameter orifice. As compared to this, the maximum injection rate in the present machine is about 5.73 cu. in./sec. which will result in a maximum velocity of 675.5 ft./sec. through a .030" orifice. In order to achieve higher velocities in the extrusion mode with this machine, very fine orifice nozzles would have to be used which is undesirable due to the possibility of plugging and the necessity for feed coal pre-screening. Larger sized screw feeders with higher coal flow capacity could be used in the plain extrusion mode to achieve higher velocities.

Before and after each test with coal, the screw was purged with polystyrene granular resin. Polystyrene was used since it does not cause spontaneous combustion problems (such as observed with polyethylene) at the discharge end. Volatiles and vapors from coal were not vented from the barrel. Instead, they were allowed to escape through the feed throat.

Steady state plasticizing of coal has been achieved for most test conditions and effort is being made to arrive at satisfactory starting conditions. Several important observations were made during this preliminary testing and they are summarized below:

- The viscosity (not measured) of the plastic coal appears to drop with increased temperature up to 900°F although it tends to resolidify much more quickly when exposed to air than that produced at lower temperature.
- Occasionally, the open discharge end (1.5" straight nozzle) became blocked with quickly-resolidified, hard packed semi-coke. When it was cleared, the extrudate trapped inside was of very low viscosity and density. This condition indicates that viscosity drop substantially and resolidification is minimized when one or more of these conditions are present:

- plastic coal is under pressure.
- volatile gases do not escape out of the plastic mass.
- plastic coal is not allowed to cool due to contact with air.

- The effect of screw rotational speed on viscosity was not conclusive. Viscosity appears to drop slightly with increased speed.
- Lower feed rate (4 lb/hr) tended to cause coking in the screw.
- Gradual coking in the last 3 to 4 flights (especially at the trailing edge) was observed under several test conditions thus partially blocking the channel. Since each time this happened, the screw had to be taken out for cleaning, the effect has not been fully investigated.
- Substantial screw wear on the last few flights was observed. The Nitralloy screw flights were flame hardened.

In addition to making observations for extrudate form, some preliminary power input data for the 9 lb/hr. feed rate case was also taken.

Several preliminary conclusions were drawn:

- Electrical heat input into the coal from the band heaters is larger than the mechanical heat input through the screw for these test conditions.
- The ratio of electrical heat input to total heat input decreases with increasing speed.
- There appears to be an optimum screw speed for minimum total specific power consumption to fully plasticize the coal. This is between 90-110 rpm for both sets of temperature.
- Mechanical power input increases with speed at a constant feed rate.
- Electrical power input appears to be minimum at about 90-110 rpm.
- Electrical and total power inputs appear to be lower for higher barrel temperatures at speeds less than about 115 rpm above which the reverse seems to be true.

In order to deliver plastic coal in a particle size range suitable for coal gasification (60 mesh and minus) using the modified Negri Bossi V-12 machine, several different approaches to spray/disintegrate the liquid coal were examined. A literature search was conducted to investigate the various spraying methods used. Liquid plastic coal exhibits a very high viscosity in the range of 10 to 1000 poise and this varies substantially depending on coal type, operating temperatures, shear rate and several other variables. Attention was focused on methods used to break up highly viscous liquids.

In order to evaluate various spraying methods and to study the effect of nozzle design, pressure, flow rate, etc.

on spraying performance (droplet size, pattern, etc.) it was found easier to use a synthetic fluid having properties similar to those of liquid plastic coal. Since resolidification will not be a problem, a separate study of the spraying process itself, independent of the plasticizing of coal to produce the liquid coal can be made. The significant liquid properties to be duplicated with a synthetic fluid are - viscosity, surface tension, density and gas content. Viscosity is the most important parameter for atomization of very high viscosity liquids. No data is available about the surface tension of liquid coal. The liquid coal density is apparently very low due to large gas content and no definitive data is yet available.

Several liquids were investigated. Some of the liquids having similar viscosity to that of liquid coal are blackstrap molasses, liquid glucose, sucrose, asphalt, etc. Blackstrap molasses was procured. Its viscosity at room temperature (72°F) is about 28 poise. Following heating, the viscosity at room temperature was found to have increased to about 140 poise. Molasses of two or three different viscosities will be used.

A Cannon-Manning vacuum type capillary viscometer was procured to measure the viscosity of synthetic liquids.

Several options were considered for bench scale spray testing of synthetic liquids. Due to the need to inject the liquid at large flow rates and develop high pressures comparable to those available on the machine (up to 5.73

cu. in/sec and 20,000 psi) the time and expense required to build a bench scale set-up were excessive. It was decided to use the Negri Bossi machine itself for testing with the synthetic fluids.

Blackstrap molasses at room temperature of 72°F (viscosity $\approx$ 28 poise) was fed to the compression screw at the feed throat. A .030" diameter, sharp edged orifice nozzle was used at the barrel end. After the screw conveyed the liquid to fill the cavity in front, it was injected at various injection speeds. A non-return valve had to be used at the end of the screw to prevent the liquid from leaking back during injection, especially at high speeds. At the highest injection rate ($\approx$ 5.73 cu.in/sec), the maximum pressure developed in the liquid was about 10,000 psi. This liquid at 28 poise viscosity atomized into a very fine spray at pressures above approximately 4,500 psi. Without the non-return valve at the screw tip, the pressure in the liquid did not build up over 3000-4000 psi and most of it leaked back through the screw channel and the clearance in the barrel.

Spraying by high speed injection through a .030" orifice nozzle was also attempted using polystyrene resin. It was heated to about 500°F - 600°F to achieve a liquid plastic having a viscosity comparable to that of liquid coal. Injection at high speeds occasionally atomized the plastic, although steady state, consistent run was not achieved due to the feeding problem. In the future, polyethylene resin (which is easier to feed) will be used. No non-return valve was used for testing with plastic.

VII. COAL FEEDER DEVELOPMENT PROGRAM

LOCKHEED MISSILES AND SPACE COMPANY,
INC.

SUNNYVALE, CALIFORNIA

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

Total Funding: \$2,591,640
(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 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 lock, 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 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

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 OCTOBER-DECEMBER 1977

The effort on Phase III of this contract, which was initiated in July 1977, involved Preliminary Design and Parametric Testing.

Preliminary Design

Initial activities in October involved design concepts for commercial sized feeders which are to be used in establishing feeder sizes to be used in the bearing and seal study for the Kinetic Extruder. A base line feed train was established (Figure VII-1) with a capacity of 100 tons/hour. Three feeders of 50 tons per hour capacity each are used to pressurize the coal. Two feeders are used during normal operation and the fluid feeder is a spare. A high pressure hopper of 25-ton capacity is provided which will allow for a 30 minute period to bring the spare feeder on line in case one of the active feeders needs maintenance or repairs.

During Phase III, provisions are made to investigate the following feeder concepts:

1. A single-stage Kinetic Extruder
2. A two-stage Kinetic Extruder
3. A hybrid system using a Kinetic Extruder for the first stage followed by an Ejector booster stage.

Two types of Kinetic Extruders are presently being considered. These are shown in Figure VII-2. These designs were conceived in an effort to reduce the aerodynamic drag on the rotor by reducing the solids loading of the gases in the immediate vicinity of the rotor.

Figure VII-1. SCHEMATIC OF BASELINE FEED SYSTEM

Figure VII-2. KINETIC EXTRUDER CONCEPTS

In the case of the integrated Kinetic Extruder design, this is accomplished by the use of internal baffles. These baffles reduce the solids loading of the gases being induced into the rotor shroud by the pumping action of the rotor. The alternative design recirculates the gases through an externally mounted separator, such as a cyclone separator.

The Ejector topping stage may be combined with the metering and distribution system. If this is done, it should be located between the accumulator and the reactor.

Tests have been planned to determine the contribution of coal particles to the aerodynamic drag and to determine the pumping action of the rotor when mounted

inside a shroud. These tests will help to select preferred equipment designs.

Closures for the Kinetic Extruder - To determine the bearing and seal sizes and induced loads, the type of closure used needs to be examined. Candidate concepts are shown in Figure VII-3 for the alternative Kinetic Extruder design. For each closure type, the rotor may be cantilever-mounted or a straddle mount can be used. Figure types of basic concepts are being evaluated at this time. These are shown in Figure VII-4. For screening the designs and the selection of promising candidates for further study, sketches have been prepared for each type of rotor support.

Figure VII-3. POTENTIAL CLOSURES FOR THE KINETIC EXTRUDER

Figure VII-4. POTENTIAL BEARING AND SEAL GEOMETRIES

The preliminary sketches will be used as a starting point for the selection of bearing and seal designs. As this study progresses, the concepts will be refined. Emphasis during the initial design study will be placed on a 50-ton/hr Kinetic Extruder with a delivery pressure of 600 psi. This design represents the first stage of a high-pressure, two-stage system or a single-stage intermediate pressure feeder.

A computer program was developed to aid in the design of efficient rotors. The aim is to minimize power consumption subject to a number of constraints such as adequate operating stability and allowing no gas leakage into the rotor. The computer output permits selecting the optimum design considering critical geometric factors

such as: sprue cross-sectional areas to avoid plugging, angles of the sprue walls to ensure smooth flow, and a sufficiently large spinup region to deaerate the coal entering the sprue. The necessary input data include the properties of the feed coal, the required feed rate, and delivery pressure and a description of the type of sprue to be used.

The program is being used to size the baseline 50-ton/hr rotor. Similar studies are carried out for 5-ton/hr and 1-ton/hr rotors. Results to date indicated that rotors for low-capacity high-pressure applications must be optimized to reduce the aerodynamic drag on the rotor (external work) while rotors for high throughputs are optimized to reduce the kinetic energy imparted to the coal (internal work).

The computer program was developed to aid in the design of efficient rotors to arrive at a baseline design for the 50 ton per hour rotor. The unit designed will form the basis for the bearing and seal study.

In other areas, design tradeoff studies continued in an effort to develop better sprue concepts that lead themselves to economical manufacturing. A number of designs were evaluated and as more data are obtained on feed stock properties and Kinetic Extruder performance. The studies will be refined to reflect the new information.

Since efficient sprue designs must take into account the coal permeability, the capability to measure permeability under compacting conditions representative of the coal in the Kinetic Extruder sprues is needed. In an effort to meet this need, a small test apparatus was constructed. The equipment was designed to measure the permeability of coal samples which have been compacted by centrifuging. A number of coal samples were tested in the device and test results indicated that the test method works well in terms of generating accurate and reproducible data. Lockheed plans to continue to use it to test all coal feeds to be used in the test program to determine lot-to-lot variations in permeability.

Parametric Testing - Due to a two-month strike by The International Association of Machinists and Aerospace Workers, the testing schedule was delayed. Testing was resumed in December with a test series with shaft covers was initiated.

To measure the power losses in the gear box drive shaft system under operating conditions, a shaft cover was fabricated. This cover replaces the rotor and permits operating the gear box/drive shaft under conditions that closely simulate the operating environment when used with the Kinetic Extruder rotor in place. In particular, the gear box can be pressurized to slightly above tank

pressure maintaining the proper pressure difference across Seal No. 3. Seal No. 4 is exposed to atmospheric pressure through the feed tube and Seals No. 1 and No. 2 support to total pressure difference between the gear box pressure and atmosphere pressure.

With the shaft cover in place, test runs were performed at various tank pressures and shaft speeds. Torque was measured during these tests, and the temperature of the

seals recorded. Attempts had been made to attach thermocouples to the carbon member of the face seals No. 2 and No. 3, since this part of the seal tended to reach the highest temperature in the seal assembly. One of these thermocouples attached to Seal No. 3 gave indications of fast response, while the one attached to Seal No. 2 was sluggish and appeared to have separated from the surface. During steady-state operation, good agreement was reached between thermocouples.

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VIII. TECHNICAL ASSISTANCE SERVICES

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

Contract No.: E(49-18)-1775
Total Funding: \$3,280,154
(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 OCTOBER-DECEMBER 1977

Conceptual Design of Commercial Plants

Power, Oil, Gas and other Products Plant (POGO)

The final draft of the sections for the R & D report covering the Southern Appalachian and Rocky Moun-

tain Region plant and location cases was completed and submitted to DOE. Pre-publication work was initiated on the final R & D report including final typing and artwork on figures.

Multi-Process Demonstratin Plant

A number of process areas were redesigned or reviewed in an effort to improve the overall process design.

The heat recovery system for the Phase II plant was redesigned in order to produce an increased quantity of distilled water to meet increased boiler feedwater requirements.

Parsons reviewed alternate high temperature gas cooling methods to eliminate the gas to air heat exchange. Methods considered were:

- A double tube sheet heat exchanger with an inert monitored gas filling the center space.
- Molten salt or molten metal system loops were considered. Available salt systems will not operate at the high temperature of 1800° F. Other salt systems are highly corrosive.
- A circulating helium gas heat exchange loop was considered to be as workable method at a premium cost.

Alternate cases of feeding coal slurry directly to the medium pressure Phase II gasifier to eliminate the drying step were investigated; these included:

- Direct feeding of slurry preheated to just below vaporization temperature, 480° F.
- Direct feeding of slurry preheated to 100% water vaporization, 480° F.

Material balances indicate a 4% increase in oxygen requirements for full vaporization and an increase of 17% for preheating with no vaporization.

Equipment requirements for either of the alternates would be considerably reduced over the entrainment type flash dryer.

Environmental Activities

Preparation began on the environmental section of the R & D report for the POGO design and Parsons completed review of the process flow diagrams for environmental effects for the POGO design.

IX. CONCEPTUAL DESIGN FOR ADVANCED COAL LIQUEFACTION COMMERCIAL PLANT

FLUOR ENGINEERS AND CONSTRUCTORS
IRVINE, CALIFORNIA

Contract No.: EX-77-C-01-2251
Total Funding: \$2,701,024
(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 chemi-

cal 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:

- Determinations 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. The project schedule is illustrated in Figure

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 computertized 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	
Sulfur	1,193	Long Tons per Stream Day
Ammonia	240	Tons per Stream Day

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 Hydrogen- ation Conversion	— 73.4%
Gasifier Type	— Fluid Bed, Agglomerating Ash
Power Generation	— Combined Cycle Gas Turbine

PROGRESS DURING OCTOBER-DECEMBER 1977

Fluor completed the draft of the final report in October and transmitted it to DOE for correction and comment. Volumes II and III were approved for publication in December and final comments on Volume I were received. It is expected that the entire report will be released for publication in January.

Fluor has been instructed by DOE to reexamine two process configurations previously held in abeyance because of funding uncertainties. The two new studies are described below.

Study of Refining Sequence

Objective

The purpose of this task is a screening type evaluation of whether catalytic cracking should be included in the refining sequence in the conversion of coal to gasoline. The current Advanced Coal Liquefaction configuration employs hydrocracking and excludes the catalytic cracking step.

Work Plan

Catalytic cracking can be incorporated in the coal liquefaction configuration in a number of different ways. The contractor shall select, in his judgement, the most promising case for analysis against the basic hydrocracking scheme. Only schemes which maximize the production of gasoline will be considered.

This new case will involve the development of new process modules such as: resid hydrotreating, catalytic cracking, alkylation, butane isomerization, and other facilities as may be required. Modifications to the existing modules will be made to the extent required.

An approximate economic comparison will be made against the base design developed previously. This analysis will be done on a differential basis using simple economic comparison techniques.

The data for use in module development will be derived from generalized non-proprietary data and the public literature to the maximum extent practicable. Where considered advisable, licensed process owners will be contracted on an informal basis for additional information.

Purchased Power/SNG

Objective

The objective of this case is a screening type evaluation of purchasing electric power as opposed to on-site generation. In the current Advanced Coal Liquefaction configuration, the design philosophy was that all electric power required for the facility, including the mine, is generated on site to provide a completely self-sufficient

facility not dependent upon outside energy sources. If large coal-fired power plants can be shown to be environmentally acceptable and capable of generating power more economically, it would be feasible to purchase power, thereby making the fuel gas currently used for power generation available for export as SNG. This economic evaluation of such a tradeoff depends to some extent upon what unit values are assigned to purchased power and to product SNG.

Work Plan

In the current configuration, electric power is derived from three sources: (1) gas expansion turbines, (2) turbo-generators driven by low pressure steam raised in process waste heat boilers, and (3) combined cycle gas turbine power plant. In the proposed new case, Item 3 would be eliminated and Item 1 slightly reduced. Out of a current total power generation of 325 MW, it appears that roughly 175 MW would be eliminated and would have to be replaced by an equal amount of purchased power. At the same time, a fraction of the gasifier effluent, perhaps 10 to 15% of the total, no longer needed to fire the gas turbine, could be processed to produce SNG. Preliminary rough calculations indicate that the additional amount of SNG that would be produced is about 35 MMSCFD.

The use of the major portion of the gasifier effluent would be unchanged, i.e., (1) to produce hydrogen, (2) for fired heaters, and (3) to generate steam needed by the process for gasification and shift conversion. Only the fuel gas used by the combined cycle gas turbine can be diverted to SNG production.

In the new work, the fluid bed agglomerating ash bottom gasifier and the operating pressure used in the previous configuration shall be retained. The new study shall involve the study of a single methanation system to be designated by DOE, either:

- Combined shift/methanation in a fixed bed system (RMP).
- Conventional shift and maintenance in a recycle system.

A methanation module will be developed in the course of the work.

Maximum practical similarity will be maintained to the current configuration, including depth of extraction and extract hydroconversion. Fuel gas steam, and electric power will have to be rebalanced.

An approximate economic comparison will be made against the base design developed previously. This analysis will be done on differential basis using simple economic comparison techniques. This case will further include a sensitivity analysis of the impact of a range of potential SNG and electric power costs.

The data for use in module development will be derived from generalized non-proprietary data and the public literature to the maximum extent practicable. Where considered advisable, licensed process owners will be contacted on an informal basis for additional information.

X. LOCK HOPPER VALVE DEVELOPMENT

CONSOLIDATED CONTROLS

EL SEGUNDO, CALIFORNIA

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

Contract Funding: \$2,574,669

INTRODUCTION

The objective of this lock hopper valve development contract is to design, manufacture, test and evaluate 8 and 12-inch valves that would be compatible with operating conditions found in numerous coal gasification plants. This development program was initiated in June, 1976 because such 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 confident design of solids handling 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 8-inch prototype valves. In addition, analysis of test results

will be conducted in order to identify areas where modifications may be necessary in the final prototype design. 12-inch valves (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.

ACCOMPLISHMENTS TO DATE

Of the four types of lock hopper valves in the 8-inch class, the Type III was chosen for preliminary design studies and prototype development since it had the most stringent requirements. Because of these requirements, this valve will incorporate high alumina ceramic and commercial refractory parts of higher reliability and longer life because of its higher resistance to corrosion and erosion over metal parts.

An extensive material survey and evaluation was conducted by Consolidated Controls to select a refractory material or materials, other than for its insulating qualities, that would retain a high degree of structural integrity as finished components when used at elevated temperatures and pressures under the highly erosive and corrosive environments. Other prerequisites are the permanence in dimensional stability, non-spalling and non-fracturing from temperature fluctuations, low permeability and cast of fabricability.

Though published reports have been completed encompassing the above criteria, the testing and evaluation still continuous to date.

High alumina ceramic components are used in areas where strength greater than that offered by any refractory material is required. These components include such items as the seats, the sealing disc in the gate, stop rings, and most noticeably the ceramic spring. All components have evolved from the preliminary design conception to its final configuration with little design change because of the long manufacturing time by the ceramic industry.

With all material and components on hand, assembly of the first Type III prototype valve has begun with about 50% completion to date.

PROGRESS DURING OCTOBER-DECEMBER 1977

Design

Analyses

Results of the transient thermal analysis indicate a maximum operating temperature of about 1600°F in the ceramic spring cavity. This temperature was derived from a worst-case flow condition in which the valve was programmed to open for 15 minutes and close for 5 minutes for a total of 5 actuation cycles. The temperatures in all areas of the spring cavity appeared to approach a steady-state level after the five cycling process. Although more computer time could have been bought to let the temperature reach steady state, it was unnecessary because the ceramic spring in its present configuration was adequate under the present loading condition. It had previously been statically tested to 1700°F with little deformation as documented in past monthly reports. Therefore, the present spring design needs no further modifications.

The overall transient thermal analysis report is now being prepared.

Redesign of the Gate Closure

The 3-inch-thick ceramic disc (closure) was modified to incorporate a circumferential groove 2 inches deep by 1-1/2 inches wide. This configuration will be cast into the gate with an additional longitudinal reinforcing rod through the groove. The axial strength of the gate will increase and the cracking problem in the narrow section should be eliminated. In essence, the groove in the closure resulted in a much larger refractory section area than before. The gate as a whole will be structurally tested to verify this new design. Two ceramic discs were ordered with the groove incorporated for development testing.

Redesign of Gate Assembly

The gate for the Type III Lock Hopper Valve was further modified during this period. Based upon the structural gate test, the reduced number of ceramic reinforcement rods did not decrease the tensile strength of the gate. However, failure did occur at the identical place as before, i.e., in the clamped area. Preliminary analysis indicates that the jaws of the loading machine were slightly misaligned, thereby creating a bending moment in the gate.

This type of failure is not likely to occur in the valve because the maximum tensile load in the gate during actuation is about 650 lb. However, to increase the strength in the clamped area, CCC has decided to add high temperature stainless steel fibers during the fabrication phase. A structural gate test will certify this increase in strength.

Component Testing

Ceramic/Refractory Adhesion Test

Six test specimens, each consisting of a cylindrical refractory bar with 1/4" diameter ceramic rod imbedded 1-1/2 inch deep were sent to Smith Emery Test laboratory for determination of the adhesion strength, between refractory and ceramic. The refractory and ceramic used for this test was Greencast 94 and 99.5% Alumina respectively. Three of the test samples yielded no data because the ceramic rods were broken due to misalignment of the rod to the refractory bar. The other three samples took 650, 720 and 535 pounds of force to pull the ceramic rod out of the refractory.

Based on the depth of the imbedded rod and diameter, the adhesion strength is calculated to be about 500 psi. This figure will vary with such factors as the amount of shrinkage and porosity of the refractory and the roughness and diameter of the ceramic rods. Additional tests will continue with other test samples fired to different temperature levels.

Structural Gate Test

In October, the redesigned gate was subjected to an ultimate tensile strength test in a setup similar to the other gates. The gate failed in the clamped area at 1750 lbs. The failure is attributed to the 1/4-inch-diameter ceramic rods placed laterally in this area. As stated before, these rods will be omitted in all future gate fabrication. It was also determined that the presence of the lateral rods lowered the gate strength during the fabrication process because air gaps.

The redesigned gate with four longitudinal reinforcement rods and no lateral rods across the clamped area was subjected to an ultimate tensile strength test in December. Failure occurred in the clamped area at 4300 lb. The lack of the rods in the clamped area was not a contributing factor for failure but, rather the misalignment in the testing apparatus. One can conclude that the gate with the groove is as strong with four reinforcement rods as the previous configuration with six, since failure occurs in the clamped area first. As previously mentioned, the clamped area of the next gate will have stainless steel reinforcement fibers added to increase strength in that area. That test will be scheduled for January, 1978.

Prototype Development

Prototype Assembly

The assembly of the first prototype lock hopper valve had previously been held up for the procurement of a finished gate. During this period, a gate was completed, so the initial assembly could proceed. This assembly revealed a previously undetected misalignment of the

sealing surfaces, so that the gate was binding at the far end of the seats. Apparently due to this binding, excessive force was required to remove the gate, with a resulting failure in the clamped area (the same area which fails in structural testing). The sealing surfaces are being reworked to meet the alignment requirements, and a steel gate is being procured to allow developing assembly procedures with a more durable piece of hardware. The ceramic disc seal was cracked in the salvage attempt, just as was the structural test specimen.

During assembly the ceramic spring was compressed by spreading the inlet and outlet seats to make room for the gate. This operation was performed without incident on several occasions, but in the last attempted assembly, the spring broke. Since the spring is designed to allow compression to solid height without overstressing, this breakage is difficult to understand. Preliminary analysis would indicate that a small chip of foreign matter (dirt, refractory, or other) between the coils could cause such a breakage. It has been decided to use the older configuration spring, which has undergone considerable hot testing, for installation procedure development, along with the steel gate.

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XI. VALVE DEVELOPMENT FOR COAL GASIFICATION PLANTS

FAIRCHILD STRATOS DIVISION
MANHATTAN BEACH, CALIFORNIA

Contract No.: EX-76-C-01-2356

Contract Funding: \$2,238,023

INTRODUCTION

The goal of this valve development contract, is to design, develop, test, and evaluate 8-inch and 12-inch solid handling valves scaleable to 24-inch that would be compatible with operating conditions found in various coal gasification plants. The project was initiated in June 1976 because reliable valves to handle abrasive solids were not available for pilot plants and even larger valves will be required to assure the efficient, continuous and safe operation of coal conversion processes in future plants.

Presently available valves are not suitable for prolonged trouble-free service in the hostile environment encounters in coal gasification service. Through a program of extensive material testing, thermal and structural analysis, a valve design will be developed for this type of service.

PROGRAM DESCRIPTION

Phase I Conceptual Design

During Phase I different concepts will be evaluated, trade-off studies will be conducted to arrive at the most promising design.

Erosion and corrosion resistant materials will be investigated and tested in order to determine that most promising materials for critical parts such as seats and bearings. Thermal and structural analysis of the valve components will be conducted.

Phase II Prototype Testing

From the experience gained in Phase I, a total of eight 8-inch prototype valves will be designed and manufactured, two each for Type I, II, III and IV service conditions. (Feed System, Injection Hopper, Ash Removal and Slurry Discharge respectively.)

These valves will be tested at MERC. Failures and shortcomings experienced during this testing program will be analyzed. The design will be modified to incorporate any recommended changes.

Phase III Pilot Valve Testing

After demonstration of the performance of the Phase II valves eight 12-inch valves will be designed and manufactured for Type I, II, III and IV service conditions. These valves will be tested in a pilot plant and experience from operating these valves will be incorporated into a Demonstration Plant Size design. All findings of the testing programs will be incorporated in a final report.

PROJECT ACCOMPLISHMENTS

Phase I

A trade-off study was conducted to determine the most promising valve design. Candidate seat and bearing materials were tested for abrasion and impact resistance.

A valve design layout was completed and a thermal and structural analysis of the valve was conducted. A prototype valve was manufactured and the assembly was tested at ambient temperature and cycled approximately 1000 times to verify the operation of the actuator mechanism.

Test fixtures for evaluating the seats and bearings were manufactured. Boron carbide seats were tested in this fixture and cycled 500 times at room temperature. At this time the seat showed no signs of wear. A borided 502 steel seat was tested and showed signs of wear and was therefore eliminated as a candidate material.

Tungsten carbide coated shafts, Stellite No. 6 and tungsten carbide bearings were tested in the bearing test fixture at simulated operating conditions.

The tungsten carbide coated shaft with tungsten carbide bearings performed for 2000 cycles with no visible deterioration.

PROGRESS DURING OCTOBER-DECEMBER 1977

Seat testing continued. The boron carbide seat was tested in the seat test fixture. The Titanium Carbo Nitride coating on the Titanium visor continued to be unsatisfactory, and progressive "chipping" of the coating in the seat area was observed.

Efforts to apply a Titanium Carbo Nitride coating to the Inconel visor were not successful. The procedure in coating this visor consists of applying a flash coating of nickel before applying Tungsten carbonitride. It was concluded that impurities in the nickel coating are the

cause of poor adhesion. A high purity coating will be applied in order to improve the final coating of TCN. The complete valve assembly was subjected to a hot test.

The hot seat test fixture was completed. The layout of the changed drive mechanism was completed.

Hot Test

For the hot test, eight electrical heating elements are installed in the top closure of the valve. The internal temperature of the valve was measured at three locations.

The objective of the test was to cycle the valve with the internal surfaces of the valve at 850°F. After heating the valve for 6-1/2 hours, the following temperatures were measured:

Location #1 425°F
Location #2 500°F
Location #3 160°F

The valve was cycled 93 times.

Visual inspection after the test revealed spalling of the coating on the visor.

The seat was in good condition.

For future tests the heating system will be redesigned. A circulation system will be added to provide a better temperature distribution.

The Titanium visor with TCN coating was cycled against the boron carbide seat in the ambient seat test fixture. The visor was cycled 117 times at a pressure of 1600 psig.

The leakage rate was:

Before cycling: .37 SCFH (GN₂)
After cycling: .44 SCFH (GN₂)

The increased leakage rate is due to further deterioration of the seating surface of the visor. The boron carbide seat was in good condition.

XII. COAL GRINDING EQUIPMENT DEVELOPMENT

KENNEDY VAN SAUN
DANVILLE, PENNSYLVANIA

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

Contract Funding: \$840,000

INTRODUCTION

Kennedy Van Saun is under contract to DOE to develop and modify coal grinding equipment and procedures 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 and optimum size consists of the coal feedstock. Current practice is to size grinding equipment without regard for excessive amounts of fines and undersized particles. This project is therefore designed to alleviate the abovementioned deficiencies associated with the coal grinding processes. A coal grinding handbook which can be utilized by process engineers for grinding system selection will be published at the end of this project.

PROGRAM DESCRIPTION

It has been anticipated 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 requires approximately eighteen months to complete. This will involve a study on the state-of-the-art of commercial coal grinding equipment. Further, three to five types of coal will be selected for experimentation. The Pennsylvania State University, under subcontract to Kennedy Van Saun, will perform laboratory analysis to determine the mechanical properties of the coal, the kinetic parameters of comminution, and perform rate testing.

Phase II, is 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 III. Dry and wet grinding tests (in water and oil) will be made. Phase IV will involve documentation and reporting on the findings during the first 3 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 and equipment.

PROJECT ACCOMPLISHMENTS

Summary of Past Work

The testing facility layout for the four grinding systems — dry ball mill, ball and race mill, hammer mill and

wet ball mill—was completed and the dry ball mill grinding system installed. Since the feed material handling system is common to all grinding systems and the product material handling system is common to all dry grinding systems, the other grinding systems are also almost completed.

Five coal samples were selected and delivered to the testing site. The types of coal and delivered tonnages, in order of decreasing Hardgrove Index, are washed Lower Freeport bituminous (108), washed Western Kentucky #9 bituminous (99), unprepared Ohio #9 bituminous (86), unwashed Belle Ayre South subbituminous (80) and washed Pennsylvania anthracite (44).

Numerous manufacturers of coal size reduction devices were contacted and a brief literature search conducted. This information was assembled into a report and a draft copy issued.

The main thrust of the laboratory analysis, being performed by the Pennsylvania State University, is the investigation of the breakage characteristics of the coals in order to assist the testwork at KVS. This work has centered on the grinding of the coals in a ball mill (dry and in water) and a ball and race mill (Hardgrove Machine).

PROGRESS DURING OCTOBER-DECEMBER 1977

Study Phase

State-of-the-Art Study

The initial rough draft of the study was critiqued by DOE and their comments incorporated into the final manuscript. Some equipment manufacturers were being recontacted to assure that their information is complete. Additionally, energy consumption and economic data were being reanalyzed to determine if all possible data sources were covered.

Laboratory Analysis

Grinding studies were focused on the mechanisms responsible for non-first order breakage phenomena

found in the ball and race mill (Handgrove) machine. From studies done previously, it has been established that the cause is environmental and not due to components with different grindability within each coal sample.

In order to determine the role of agglomeration in the environmental effects, Kennedy Van Saun performed tests using ultrafine coal particles (-10 microns) and long grind times with dry screening.

To obtain the minus 10 micron sample, a set of micro-mesh sieves containing 30, 20, and 10 micron apertures was used.

In order to determine the role of agglomeration in the environmental effects, tests using ultrafine coal particles (-10 microns) and long grind times with dry screening were performed.

The results indicate that the agglomeration suggested would account for only a small part of the non-first order behavior. The non-first order behavior is still being investigated.

Preparation Phase

All original equipment is installed and operational. Only minor ancillary aspects remain which will be completed as required.

Testing Phase

Benchmark testing - variation of feedrates, air rates, classifier settings and types of coal - on the air swept ball mill was continued during which the classifier was changed (the classifier change produced a finer cut point). However, erratic energy measurements required removal of the device from service, temporarily.

Shakedown and operation of the ball and race mill grinding system was started.

Coal materials produced during these tests are being shipped to other DOE contractors requesting such samples.

The wet ball mill grinding system was modified to conduct coal in oil grinding tests.

XIII. COAL PUMP DEVELOPMENT AND TECHNICAL SUPPORT

JET PROPULSION LABORATORY
PASADENA, CALIFORNIA

Interagency Agreement No.: EF-77-A01-2616
Total Funding: \$2,176,000

INTRODUCTION

In support of the Department of Energy, Division of Coal Conversion, the Jet Propulsion Laboratory has been awarded a contract to assist DOE in the development of coal feeder devices and to lend technical support to DOE in evaluating new feeder technology.

The objectives of the contract are two-fold. One concerns the analysis, evaluation, feasibility assessment, and selection of general coal feeder and related peripheral equipment and technology. The other objective concerns the assessment of the technical feasibility of developing on a commercial scale, a coal extruder or "coal pump" based on the plastic properties of coal.

The first objective consists of two separate tasks and is based on engineering analysis and evaluation. Task I, coal feed program support, will provide to DOE by:

- Analyzing coal-feeding requirements for scaled-up coal plants with particular emphasis on pressurized converters.
- Formulating engineering and performance criteria to guide the subsequent selection, development, and commercialization of coal-feeder systems.
- Monitoring the technical progress of the feeder developments: evaluating performance of ongoing coal-feeder programs, comparing development progress against the criteria.
- Formulating and recommending program plans for the development of selected feeder systems

Task 2, facilities development requirements study, will be carried out by:

- Identifying equipment deficiencies for demonstration facilities
- Recommending equipment development actions to DOE

The second objective will be accomplished by establishment of a base engineering experience in the continuous extrusion of coal in the plastic state through use of a modified thermoplastic extruder, and assessment of the feasibility of developing large commercial size coal feeding systems based on this approach. Also, JPL will attempt to acquire the data required to initiate the design of a commercial-size coal extruder.

PROGRESS DURING OCTOBER-DECEMBER 1977

During this reporting period most of the coal delivery and extrudate receiving equipments for the 2.5 in. coal pump have been assembled and checked-out both separately and in the experimental extrusion system. Polyethylene and predried coal have been extruded for short periods to shake-down the equipment operation and to develop detail operation procedures. The major element of the coal delivery equipment yet to be incorporated is the Conveyor-Drier which will enable hot dry coal to be fed to the extruder. This equipment has been assembled

and is now ready for installation and checkout. The major element in the coal receiving equipment which has not yet been installed is a High Pressure Receiver which will permit pumping into a backpressure simulating reactor pressures up to 1500 psi. This equipment is nearing completion of fabrication and proof testing. The pump has been operated only in the starved-feed mode (screw channel partially filled) with coal. Attempts to reach the flood-feed mode with ambient temperature coal have been unsuccessful. Based on the 1.5 in. coal pump testing, the coal must be preheated before entering the extruder to obtain full flow. Addition of the Conveyor Drier should reduce this problem.

Measurements of the absolute viscosity were made on Kentucky No. 9, Ohio No. 9 and Pittsburgh No. 8 coals. The Kentucky coal was the most viscous. A contract was negotiated with the Institute for Mining and Minerals Research (IMMR) for the classical characterization of various coals and their extrudates. Initial work has been concerned with Pittsburgh 8 and Ohio 9 coals. Runs were made on the 1.5 in. coal pump with Kentucky No. 9 coal to support the computer simulation modeling. Also Ohio 9 coal was extruded in the 1.5 in. pump. Build up was

begun on a test bay for the new, high-pressure, 1.5 in. coal pump which will be used in support of PERC.

Correlation of the performance of the 1.5 in. screw extruder on Kentucky No. 9 coal with the analysis of the computer program EXTRUD has been accomplished. The main difference between prediction and experiment is 6 percent and the standard deviation is 27 percent. This indicated that while the EXTRUD program is applicable, the reliability of the performance estimate is poor. Studies on improving the reliability and accuracy of modeling include a research project contact with Rennselaer Polytechnic Institute on frictional and melting properties of coal, an analysis of the effect of pressure on the melting properties of coal, an analysis of the effect of pressure on the melting rate of rigid polymers (i.e., coal), further studies on the modeling of starved feed mode, and continued studies on the modeling of kinetic effects on melting. A literature survey on means of spraying coal has been completed, and an experimental study on the spraying of coal using an experimental rig is being evaluated. A paper on the effect of pressure on the melting rate of a rigid solid has been completed.

XIV. INSTRUMENTATION AND PROCESS CONTROL FOR FOSSIL DEMONSTRATION PLANTS

ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS

Contract No.: ANL 189a 49622R2
Contract Funding: \$1,000,000 FY-77

INTRODUCTION

The Department of Energy, Division of Coal Conversion, is funding Argonne National Laboratory efforts in the development of instrumentation and process control for large scale gasification, liquefaction, and direct combustion plants. The object of the program is to insure timely availability from commercial sources of process control instruments needed for these facilities.

PROGRAM DESCRIPTION

This program will develop instruments not currently available but ultimately needed for coal conversion and/or combustion demonstration plants. Several general types of instruments are needed to improve safety and to optimize operation: mixed-phase mass-flow, on-line composition, level of fluidized beds, and temperature (particularly when rapidly fluctuating) in vessels and on vessel walls. These instrument systems are required for process monitoring and control in each phase of the plant operation: initial startup and operation, operational reliability improvement, and process efficiency optimization.

The development program will involve continuing information exchange and cooperation with commercial instrument suppliers and final plant users through symposium sponsorship, industrial subcontracts, and industrial participants at Argonne National Laboratory (ANL). The program will ultimately transfer the knowledge and designs to instrument suppliers for instrument production. Using unique test facilities constructed during the program, instrument testing and calibration will continue after the development of the instruments.

The program will be carried out under five major tasks. Task I, update the State-of-the-Art Report, will involve incorporating the latest information on process needs and developments in commercial instrumentation into the recent ANL study of instrumentation for fossil demonstration plants and will provide an information base for future efforts. Task II, develop mixed phase mass flow instruments, represents the heart of the overall hardware development program. This task includes development at ANL and in industry of several promising techniques for measuring the flow of solids in fluids. It includes the design and fabrication of mixed solids/fluids loops for instrument development, testing, evaluation, and calibration. Task III, develop other on-line instruments, includes on-line composition analysis, level measurement, and temperature monitoring. Task IV, perform process control analysis, will give guidance on

instrument performance requirements in support of the hardware development tasks. Task V, organize instrumentation and control symposia, is an important part of the information exchange aspect of the overall program.

PROGRAM ACCOMPLISHMENTS

- Issue Initial State-of-Art Study on Instrumentation Needs for Coal Conversion Plants (ANL-76-4)
- Initiate Construction of Solids/Gas Flow Test Facility (S/GFTF)
- Visits to Pilot Plants and Identification of Specific Points in the Systems where Instrument Needs Exist and where Instrument Tests are Planned
- Initial Lab Tests of Capacitive Density and Flow Instrument Concept

A commercial capacitive oil/water interface monitor was purchased and will be tested in the separator vessel at HYGAS. It is believed that this instrument will be capable of solving the oil/water interface location problem without modification.

An industrial subcontract for continued development of an optical particulate monitor was awarded to Spectron Development Laboratories, Inc. The device will have extended capabilities as far as particle size range and changing sample location within the pipe are concerned.

Non-penetrating analysis of process streams was shown to be feasible for a number of major and ash-forming elements in coal via analysis of gamma rays produced by neutron capture. An improved irradiation facility using a Californium 252 source of neutrons was completed during this quarter. The portable neutron generator was operated for the first time and initial data from irradiation of coal is being collected.

Software to be used for quantifying instrumentation requirements for specific coal conversion processes was developed and tested on two simple system models. Work was completed on a methanation process reactor model to be used in further tests of the code.

The first draft of chapters on instrumentation for temperature, level, and flow for the updated State-of-the-Art Report were done. Work continues on chapters on other types of instrumentation. The first draft will be completed in January.

A trailer to be used as a mobile laboratory during field tests of instruments was procured during the quarter.

PROGRESS DURING OCTOBER-DECEMBER 1977

During the period, work was performed in a number of nonexperimental areas. This included report preparation, construction, design and cost estimates for experimental installations. The draft state-of-the-art report on instrumentation for Fossil Demonstration Plants was completed in December.

Construction continued on the Solids/Gas flow test facility (S/GFTF). However, the construction was delayed in November due a strike although most of the required hardware had been received by November 1. Equipment installations and calibration of instruments was conducted on various experimental units.

Laboratory tests of correlation type flow measurement using capacitive density signals were conducted simulating the HYGAS solvent/coal feed line conditions. These tests were conducted using a Lucite bench model capacitor. This involves utilizing a lucite rod having an outside diameter sufficiently close to the inside diameter of the capacitor to just allow free fall was used to represent the coal/solvent slurry. The dielectric constant of the Toluene used at HYGAS is approximately 2.4 and the dielectric constant of the Lucite rod used in test is approximately 3. For the tests the capacitor was mounted virtually such that the rod could be dropped through it from various initial heights to obtain a range of velocities up to 3 meters per second, corresponding to the pilot plant velocities. Holes were also drilled in the side of the rod to simulate regions of fluctuating coal concentrations (or dielectric constant) in the slurry.

Most of the drop tests were made with the dielectric bubble angle set to zero. Bubbles of different sizes were used. The data showed that the magnitude of the deflection on the oscilloscope was directly related to the size of the bubble. In addition, the data indicated that the deflection amplitude was directly related to the radial position of the bubble in the Lucite rod. Finally, data was obtained which indicated that the deflection amplitude was related to the dielectric constant of the substance in the bubble. A polarity change in the deflections was observed as the bubble was filled with various substances having dielectric constants lower than that of Lucite to those with higher dielectric constants including metals.

A 1978 Symposium on Instrumentation and Control for Fossil Demonstration Plants was being organized.

The Second I & C symposium is cosponsored by DOE - Fossil Energy, Argonne National Laboratory, and the

Instrument Society of America. It will be held on June 19-21, 1978 at Newport Beach Marriott Hotel, Newport Beach, California.

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XV. DEVELOPMENT OF CONCEPTUAL DESIGNS FOR WATER TREATMENT IN DEMONSTRATION PLANTS

WATER PURIFICATION ASSOCIATES
CAMBRIDGE, MASSACHUSETTS

Contract No.: EF-77-C-01-2635

Contract Funding: \$263,000 (100% Transfer
Funds From EPA)

INTRODUCTION

The program objective is to produce six conceptual designs for integrated water treatment plants in coal conversion demonstration plants. The water treatment plant designs will be developed so that disposal of all residuals can be made in an environmentally acceptable manner.

The program will be carried out under the following five major tasks:

- *Process and Site Selection.* Selection of six demonstration coal conversion plant site combinations.
- *Conceptual Designs for Water Treatment Technologies.* Develop designs for building an integrated water treatment plant.
- *Ultimate Disposal of Residuals.* Provide designs to accomplish the following: reduce mass and water to relatively harmless soluble and insoluble organic wastes and inorganic salts; destroy toxic organic wastes; and render insoluble, recover, and segregate non-destructible toxic metal wastes.
- *Integrated Water Treatment Plants.* Selection and explanation of specific designs to create an integrated water treatment plant for coal conversion plants.
- *Development of Test Program.* Develop a test program which incorporates the following: type and size

of equipment to be installed; specific measurements to be made and the necessary measurement techniques and equipment; and specific calculations to be made to optimize the next generation of the water treatment section.

PROJECT ACCOMPLISHMENTS

The coal conversion process, coal type, site location, and water source for six coal conversion plants were identified by WPA and approved by DOE. The criteria used for selection included a mix of technology and geographic siting of plants in both the east and west. A summary of this effort is given in Table 15-1.

PROGRESS DURING OCTOBER-DECEMBER 1977

Ammonia Removal

The parametric study of design variables for both ammonia stripping and ammonia fractionation has been completed. Specific stripper and distillation column design suitable for anhydrous ammonia recovery by the

Phosam-W Process for the Commercial Lurgi Plant, New Mexico is currently being costed.

Phenol Removal

Consultations were held with Lurgi and Chem-Pro Equipment Corporation to obtain information on their respective phenol solvent extraction schemes. However, due to the proprietary nature of these processes only limited data was obtained. WPA will use the information acquired to check their own designs. Engineering in this area is expected to be initiated in January.

Biological Treatment

The design of an air activated sludge biochemical treatment plant for process condensate in the HYGAS

demonstration plant, western site has continued through the quarter and is about 85% complete.

Boiler Feedwater and Cooling Tower Water Treatment

An economic study of boiler feedwater treatment has been made for the HYGAS eastern site and a design of boiler feedwater treatment is completed for the HYGAS western plant.

Table XV-1 Process and Site Selection

PROCESS	HYGAS	HYGAS	LURGI	SRC	BIGAS	SYNTHANE
Site	North-Dakota Montana	Western Penn. Eastern Kentucky West Virginia	New Mexico	Western Penn., Eastern Kentucky West Virginia	Montana Wyoming	Illinois
Size	Demonstration 50 × 10 ⁵ scf/day	Demonstration 50 × 10 ⁶ scf/day	Commercial 250 × 10 ⁶ scf/day	Demonstration 2000 tons/day	Demonstration 50 × 10 ⁶ scf/day	Demonstration 50 × 10 ⁶ scf/day
Product Energy 10 ⁹ Btu/day	43.5	49.6	238	63.2	47.5	47.0
Water Source	Lake Sakakawea	Ohio river	San Juan river	Allegheny river	Sewage	Brackish
Water Availability	Adequate	Adequate	Medium stringent	Adequate	Very stringent	Stringent, water treatment expensive
Water Streams (10³ lb/hr)*						
Boiler Feed Water, Total	203	287	1640	4	138	247
Clean Water from Methanation Reaction Returned to Boiler	(40)	(36)	(270)	0	(47)	(26)
Makeup to Boilers	163	251	1370	4	91	221
Other Water Input	0	0	0	35	261	0
Output Waters						
Worst Quality	59	0	130	8	0	119
Next Worst	0	107	950	0	0	0
Not so Bad	0	0	0	16	254	23
Cooling Waters						
Minimum	180	210	—	290	140	120
Reasonable	290	340	1220	370	—	220
Probably Wasteful	370	450	(commercial design)	450	—	—
Minimum Water for Ash Disposal	12.3	13.6	187	12.8	10	4
F.G.D.	13	11.5	240	0	22	48
Other Net Requirements for Full Scale Plant	—	—	220	—	—	—

*1 × 10³ lb/hr = 2 gpm = 2.880 gals/day

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XVI. CONCEPTUAL DESIGN OF A COAL TO METHANOL COMMERCIAL PLANT

BADGER PLANTS

CAMBRIDGE, MASSACHUSETTS

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

Contract Funding: \$2,585,610
(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 demonstration 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 OCTOBER-DECEMBER 1977

Coal to Methanol Plant

This portion of the contract is being completed as the draft of the Interim final report is being prepared. The Babcock & Wilcox report pertaining to the gasifier system design was issued to Badger and will be included in the interim report. In addition to the B & W design, initial concepts from Shell-Koppers and Winkler are under review for presentation in the interim final report as an alternate design.

Methanol to Gasoline Plant

Process design continued on the plant in most major plant sections. The overall coal conversion schemes have been developed based on integrating the Mobile M-Gasoline Process into the Methanol to Gasoline Com-

plex. Process design work commenced on a second plant configuration which is based on the production of gasoline, by-product LPG, and high-Btu gas. Other

process work included studies on the alkylation and isomerization units.

XVII. HIGH BTU PIPELINE GAS, HYGAS CONCEPTUAL DESIGN

PROCON, INC.

DES PLAINES, ILLINOIS

Contract No.: EF-77-C-01-2618

Total Funding: \$7,540,000 (Design Phase
Authorization Only)

INTRODUCTION

Procon, Inc. was selected to design a coal gasification plant to demonstrate the HYGAS process, developed by the Institute of Gas Technology (IGT) and DOE. The contract calls for preparation of a conceptual design of a 250 MMSCFD commercial plant and from that design, a conceptual design, some detail or a process design, and economic evaluations. Illinois #6 coal will be the principal design basis.

Unlike the other demonstration contracts, this project is funded only for Phase I, with detailed design, construction, and operation contracts to be awarded at a later date. A project schedule is given in Figure XVII-1, which illustrates the planned activities for the entire HYGAS demonstration program.

PROCESS DESCRIPTION

The process flow diagram for an agglomerating coal (Illinois 6) is shown in Figure XVII-2. In the process crushed coal from the feed hopper is screened to remove (+) 14 mesh and fed to a pretreater where its agglomerating tendency is eliminated by heat from the reaction with a limited amount of air. The resultant char is slurred with the light by-product oil. A positive displacement pump meters this slurry into the high pressure

(800-1200 psi) fluidized hydrogasifier. It enters the upper, drying bed of a stacked series of four in the gasifier. As the solids move by gravity down through the reactor's beds, heat is carried up with the gases originating in the lowest bed where oxygen and steam react with the residual carbon at 1800°F. The temperature of the successive beds is set to maximize the formation of methane in the reactor through reaction of the coal with the hydrogen formed in the lower beds. About half the methane produced is formed in the reactor. For this, the second bed down, which is a disperse phase, riser reactor at about 1200°F, is particularly effective.

Ash and residual carbon are removed dry from the bottom bed. It is discharged through a control valve to the waste treatment section.

The raw gas including the vaporized slurry oil leaves the top of the reactor and passes through a quench section where coal fines, slurry oil, and excess steam are removed. A shift converter adjusts the hydrogen to carbon monoxide ratio for proper methanation feed. The acid gas removal system removes hydrogen sulfide and bulk of the carbon dioxide present. The methanation section reacts the hydrogen and carbon monoxide to methane and water and the drying section removes the water from the pipeline quality gas.

By-product recovery will include provisions for the production of elemental sulfur, anhydrous ammonia, phenol, and light oils. The usual utilities such as air, service water, cooling water, refrigeration, steam and

ACTIVITY	FISCAL YEAR							
	77	78	79	80	81	82	83	84
PHASE I CONCEPTUAL DESIGN	△	→	▽					
PHASE II ● DETAILED DESIGN ● LONG LEAD PROCUREMENT ● CONSTRUCTION		△	→	▽				
			△	→	▽			
				△	→	▽		
PHASE III SHAKEDOWN & OPERATION						△	→	▽

Figure XVII-1. PROJECT SCHEDULE

Figure XVII-2. PROCON, INC. HIGH BTU PIPELINE GAS, HYGAS (PILOT PLANT CONFIGURATION)

power will be provided as required. Waste treatment sections to permit the maximum recycle of water, acceptable disposal of solids, and optimum treatment of gaseous vents will be included.

The Commercial Plant will provide a nominal 250 million standard cubic feet per day (MM SCFD) of substitute natural gas with a heating value of approximately 930 BTU/SCF. Typically, there might be three gasification trains with an output of about 84 MM SCFD each. This will require 6525 tons per day of coal feed per train or about 19,600 tons per day for the entire plant exclusive of any fuel required for steam and/or power generation. In addition, about 1210 tons per day of 98% pure oxygen and 6350 tons per day of steam (about 529,400 pounds per hour) are required for each reactor. This amounts to about 3640 tons per day of oxygen and 19,050 tons per day of steam (about 1,588,000 pounds per hour) for all reactors in the entire plant. Also, about 1450 tons per day of spent char (75% by weight ash) per reactor will need to be disposed of properly. Other products will include approximately 138

tons per day of ammonia and 350 long tons per day of sulfur on a total plant basis.

PROGRESS DURING OCTOBER-DECEMBER 1977

At the end of December, the process flow diagrams for the lignite feedstock case were issued to DOE. All process flow diagrams and piping and instrument diagrams for the bituminous coal feedstock case were being prepared.

The tradeoff study for the shift and methanation units were nearly complete. The sulfur management study is waiting for information from several process licensors in order to make a final selection. At this time, the project is on schedule and the major milestone for the project appear realistic.

XVIII. SURVEY OF INDUSTRIAL COAL CONVERSION EQUIPMENT CAPABILITIES

OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

Contract No.: W-7405-eng 26

Contract Funding: \$700,000

INTRODUCTION

In FY 1977, the Oak Ridge National Laboratory undertook a 2-year survey of industrial coal conversion equipment capabilities for the Major Facilities Project Management Division of the Energy Research and Development Administration. This survey is being continued for the Division of Coal Conversion of the Department of Energy.

The objective of this project is to conduct surveys of industrial equipment capabilities that will identify the present capability of industry to supply the equipment needed. The project will also determine research and development needs, including lead time requirements, for producing equipment of advanced design for the various unit operations of critical importance to the Division of Coal Conversion.

PROGRAM DESCRIPTION

This survey was begun in November of 1976 (FY 1977) with four principal areas of interest: (1) rotating components (pumps, compressors, hydraulic turbines and gas expanders), (2) valves, (3) hot gas clean-up and (4) heat recovery. Equipment requirements for each of these four areas were determined from several conceptual designs of commercial scale coal liquefaction and gasification plants. Questionnaires were prepared and sent to

equipment manufacturers concerning their capability to supply equipment to meet the requirements which had been determined. These questionnaires also addressed problem areas affecting equipment availability, research and development needs and lead times for procuring equipment. In addition to using questionnaires, visits were made to a number of leading equipment manufacturers to discuss the various aspects of their capabilities to supply equipment. The results of these four surveys, completed at the end of FY 1977, are given in the next section.

During FY 1978, surveys concerning let-down valves, expansion joints and mechanical connectors, including seals, are to be undertaken. Also, surveys of equipment cost, equipment operating experience in pilot plants and equipment development programs and alternatives are to be conducted.

PROGRAM ACHIEVEMENTS

The FY 1977 surveys on rotating components, valves, hot gas clean-up and heat recovery and utilization resulted in the following conclusions.

1. Rotating Components

It has been concluded that equipment should be available for essentially all clean stream applications likely to be encountered in coal conversion facilities except

for oxygen compressors. Slurry pumps and oxygen compressors need to be developed or very significantly upgraded. Also, fans and blowers for dirty gas streams need development work as do expanders for high temperature service, although this latter equipment is critical to only a few processes. Hydraulic turbines which were not specified but which might be used for slurry applications in future coal conversion plants are not available.

2. Valves

Results indicate that the valve and valve actuator industry is capable of manufacturing, in quantity, equipment of the size and for the pressure and temperature range which would be required in the coal conversion industry; valve manufacturers do not have product application experience to predict the continuing functional ability of valves used for lock hopper feeders, and for slag/char let-down service. Developmental and testing efforts to modify existing valve design or develop new valve concepts for these applications were estimated to range from 1 to 6 years. A testing facility to simulate actuation of critical valves under service conditions, such as that planned for lock hopper feeder service at MERC, would be beneficial.

3. Hot Gas Clean-Up

If existing turbine tolerances (0.0002 gr/scf) were increased by two orders of magnitude and the particulate carryover from either a low Btu gasifier or a pressurized fluidized bed combustor were held to 5 gr/scf, an overall clean-up efficiency of at least 99% would have to be achieved. The use of high temperature-high pressure (HTHP) filtration in gasification applications appears to be limited. Inertial separation devices have most likely achieved their maximum levels of efficiency with existing designs, and research aimed at dramatically improving their performance appears to be unwarranted. Surface filters (either metal or unique high temperature fabrics) have potential in HTHP gas cleaning. Granular bed filters are at the stage where on-line operational testing is needed. Major engineering and operational problems need to be resolved before electrostatic precipitators become viable HTHP filtration devices. Commercial equipment for the removal of H_2S at high temperatures is unavailable at this time. From an environmental point of view, any HTHP filtration system capable of satisfying turbine particulate allowances will more than likely be able to meet any EPA emissions constraints.

4. Heat Recovery and Utilization

A large variety of equipment types is available for many applications, including feed/effluent interchange, combustion air preheating, and heat-recovery steam generation. Collective vendor fabrication capability is quite extensive, but proper thermal design of some units poses problems. Needs include better steam characterization, viscosities of heavy oils and slurries, multiphase heat transfer correlations, and rates of fouling, erosion, and corrosion.

During the first quarter of FY 1978, work plans were prepared and some preliminary work on those surveys mentioned in the section on Program Description has been accomplished. The status of existing pilot plant projects has been reviewed and eight pilot plants have been tentatively selected to be contacted concerning their experience in operating coal conversion equipment. Methods of presenting equipment costs are also being reviewed prior to requesting such information from manufacturers. All tasks planned for FY 1978 are to be initiated by early January.

Also during this period, a presentation of the results of the FY 1977 surveys were made to the Department of Energy in Washington, D.C., and ORNL personnel who worked on the valve survey participated in the "Workshop on Valves for Solids Handling Service in Coal Conversion Processes" held in Morgantown, WV. DOE comments were being incorporated into draft reports of the four FY 1977 surveys at the end of the quarter prior to editing and publication.

PROGRESS DURING OCTOBER-DECEMBER 1977

A draft work statement was prepared by Oak Ridge and presented to DOE for review during November for the proposed survey work in FY 1978 on the project.

All tasks planned for FY 1978 due to be initiated by early January. These tasks include availability surveys of let-down valves, mechanical connectors and expansion joints, surveys of equipment costs and of equipment development programs, and a survey of equipment operating experience in coal conversion pilot plants. A review of the availability of equipment for the DOE demonstration plants is to be made on the results of the FY 1977 surveys.

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.

caloric 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.

syncrude—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.

tail 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.