U.S. DEPARTMENT OF ENERGY
Division of Coal Conversion

QUARTERLY REPORT

July-September 1977

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COAL

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COAL GASIFICATION

MASTER

QUARTERLY REPORT

JULY - SEPTEMBER 1977

U.S. DEPARTMENT OF ENERGY

Division of Coal Conversion

Washington, D.C. 20545

Publication Date: February 1978

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FOREWORD

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

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

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EXECUTIVE SUMMARY

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

ERDA's program for the conversion of coal to gaseous fuels was started by two of its predecessor agencies: the Office of Coal Research (OCR) and the Bureau of Mines, U.S. Department of the Interior. Both high- and low-Btu gasification processes are being developed. High-Btu gas can be distributed economically to consumers in the same pipeline systems now used to carry natural gas. Low-Btu gas, the cheapest of the gaseous fuels produced from coal, can be used economically only on site, either for electric power generation or by industrial plants.

HIGH-BTU GASIFICATION

High-Btu natural gas has a heating value of 950 to 1,000 Btu per standard cubic foot, is composed essentially of methane, and contains virtually no sulfur, carbon monoxide, or free hydrogen. The conversion of coal to high-Btu gas requires a chemical and physical transformation of solid coal. However, because coal has widely differing chemical and physical properties, depending on where it is mined, it is difficult to process. Therefore, to develop the most suitable techniques for gasifying coal, ERDA, together with the American Gas Association (AGA), is sponsoring the development of several advanced conversion processes.

Although the basic coal-gasification chemical reactions are the same for each process, the processes under development have unique characteristics. There are, for example, important differences in reactor configurations and methods of supplying heat for gasification. Moreover, because these processes

require high temperatures and some require high pressures, temperature-resistant alloys and new pressure vessels must be developed to obtain reliable performance.

A number of the processes for converting coal to high-Btu gas have reached the pilot plant stage. Laboratory research is also continuing in order to develop data for verifying the feasibility of the specific purposes and for supporting the operation of the plant. Responsibility for designing, constructing, and operating these pilot plants is assigned to Conoco Coal Development Company for the carbon dioxide acceptor pilot plant at Rapid City, South Dakota; Bituminous Coal Research, Inc., for the BI-GAS pilot plant in Homer City, Pennsylvania; Institute of Gas Technology for the HYGAS pilot plant and steam-iron system for the production of hydrogen in Chicago, Illinois; and The Lummus Company for the Synthane pilot plant in Allegheny County, Pennsylvania.

The final scheduled run was completed in the *Carbon Dioxide Acceptor Process* pilot plant during the quarter. The effect of higher steam partial pressure on acceptor activity and gasifier kinetics were studied in Run 46. Run 47 demonstrated the use of reconstituted acceptor.

The major objective of the tests completed during the quarter in the pilot plant of the *BI-GAS Process for the Generation of Pipeline Gas* was to maintain slag tapping for a 24 hour period. Laboratory testing continued catalyst life tests as well as operation of the methanation PEDU.

The *HYGAS Process* continued testing Peabody No. 10 mine coal under a contract extension effective from the beginning of the quarter. The liquid phase methanation unit received purified product gas from the HYGAS plant for the longest extended period to date.

Three ore circulation tests were completed during the quarter in the pilot plant for the *Steam-Iron System For Production of Hydrogen*. The Reactor Variables Study, Task 2, was initiated and two producer reactor tests completed. Laboratory work continued with kinetic studies, char evaluation, attrition studies, and lift line studies.

The *Synthane Process* pilot plant completed studies of Western subbituminous coal during the quarter. Testing of Illinois No. 6 coal began. Attempts to operate the pretreater were unsuccessful, however.

Battelle Memorial Institute is responsible for the design, construction, and operation of a process development unit (PDU) in West Jefferson, Ohio for demonstrating the *Agglomerating Burner Process*. Work continued toward achieving an integrated combustion/gasification run during the quarter.

The *Liquid Phase Methanation Process* is being developed by Chem Systems, Inc. The longest run to date using HYGAS product as feed was completed during the quarter. Catalyst carryover and/or attrition, as well as low catalyst activity, continued to be a problem during the quarter.

C. F. Braun and Company is providing *Technical Evaluation of High-Btu Gasification Processes* and is developing conceptual designs of commercial plants for producing pipeline-quality gas as a basis for evaluating the technical and economic feasibility of each process. Operations at the HYGAS, carbon dioxide acceptor, BI-GAS, and Synthane plants were monitored by Braun engineers during the quarter. Studies continued on the process specifics as well as the conceptual design of commercial plants.

LOW-BTU GASIFICATION

Low-Btu gas, with a heating value of up to 350 Btu per standard cubic foot, is an economical fuel for industrial use as well as for power generation in combined gas-steam turbine power cycles. On an equivalent Btu basis, conversion of coal to low-Btu gas is less complex than conversion to high-Btu, and the associated capital costs are lower. Because different low-Btu gasification processes are optimum for converting different types of coal, and because of the need to provide commercially acceptable process at the earliest possible date, ERDA is sponsoring the concurrent development of several basic types of gasifiers (fixed-bed, fluidized-bed, and entrained-flow). At the same time, hot-gas cleanup systems are being studied for use with these low-Btu gasifier systems.

Atomics International Division (AI), Rockwell International Corp., has the responsibility for designing, construction, and operating facilities for the development of the *Molten Salt Gasification Process*. Design and construction of the facility continued throughout the quarter.

An *Advanced Coal Gasification System For Electric Power Generation* is being developed by Westinghouse Electric Corporation. During the quarter three reactor design tests and one materials test were completed. Design and procurement continued in preparation for integrated operation.

Combustion Engineering, Inc. is responsible for the construction of the pilot plant for the *Low-Btu Gasification of Coal for Electric Power Generation*. Construction of the pilot plant was substantially completed by the end of the quarter.

Two three-stage tests were conducted by Bituminous Coal Research, Inc. during the quarter to evaluate the design and operability of the equipment for the production of *Low-Btu Fuel Gas*. Two batch tests were also conducted.

Data continued to be collected for the *Coal Conversion Systems Technical Data Book* being developed by the Institute of Gas Technology to provide a single, comprehensive source of data on coal conversion processes.

Systems, Science, and Software are developing a general *Computer Model of Coal Gasification Reactors*. The programming of the chemistry and transport for steam-oxygen gasification was completed during the quarter. A three dimensional version of the entrained flow model was also completed.

The *Modification and Operation of An Atmospheric Pressure Ash-Agglomerating Gasifier* by the Institute of Gas Technology continued. Work during the quarter concentrated on determining if size requirements govern ash agglomerating conditions.

I. CARBON DIOXIDE ACCEPTOR COAL GASIFICATION PROCESS

CONOCO COAL DEVELOPMENT COMPANY
LIBRARY, PENNSYLVANIA

Plant Site: Rapid City, South Dakota

Contract No.: E(49-18)-415

Contract Funding: \$27,751,622
ERDA: \$18,501,081
AGA: \$ 9,250,541

Contract No.: E(49-18)-1734

Contract Funding: \$3,607,660
ERDA: \$2,405,107
AGA: \$1,202,553

INTRODUCTION

The carbon dioxide acceptor process is being developed by the Conoco Coal Development Company (CCDC) under the joint sponsorship of ERDA and the American Gas Association (AGA). ERDA is providing two-thirds of the funds and AGA, one-third.

The objectives of this contract are to (1) demonstrate the operability of all features of the carbon dioxide acceptor process through operation of a pilot plant and (2) obtain adequate data to design a commercial plant capable of producing 250 million standard cubic feet of high-Btu gas per day. Specifically, CCDC is to:

- Test several types of lignite and acceptors.
- Design, construct, and operate methanation facilities in conjunction with the gasification pilot plant.
- Use process data derived from pilot plant runs to improve the process and prepare the conceptual design for a commercial sized coal gasification plant.

Figure I-1 shows the development schedule.

**Figure I-1. CARBON DIOXIDE
ACCEPTOR PROGRAM SCHEDULE**

PROCESS DESCRIPTION

A diagram of the carbon dioxide acceptor process is shown in Figure I-2. In this process, raw coal is crushed to 8 x 100-mesh in hot-gas-swept impact mills, where the moisture content is also reduced from approximately 38

raised to pipeline quality, approximately 1,000 Btu per standard cubic foot. The methanation facilities include a shift converter, carbon dioxide absorber, hydrodesulfurizer, zinc oxide sulfur guard, and a packed-tube methanator. A Dowtherm system is used to remove the heat generated by the strongly exothermic methanation reaction.

Some of the advantages of the carbon dioxide acceptor process are:

- An oxygen plant is not needed because the acceptor is heated and calcined in a separate reactor where air can supply oxygen for combustion without contaminating product gas.
- The circulation rate is lower than that required in other high-Btu gasification processes that circulate solids for heat transfer because the acceptor supplies heat through chemical reaction with carbon dioxide.
- Product gas cleanup requirements are minimized because the acceptor reacts with both hydrogen sulfide and carbon dioxide, the principal impurities in gasifier product gas. In addition, no condensable hydrocarbon liquids are generated during the gasification process.
- Raw gasifier product gas contains enough hydrogen to methanate all of the carbon monoxide and part of the carbon dioxide without requiring water-gas shift conversion prior to methanation.

HISTORY OF THE PROJECT

Bench-scale development of the carbon dioxide process was completed in 1968. Feasibility studies indicated that the process had potential commercial possibilities. Construction of a pilot plant to test the process was completed (except for the methanation facility) in October 1971. Construction of the methanation facilities was completed in late 1974. The pilot plant is designed to use 40 tons of coal and three tons of dolomite per day to produce 500,000 standard cubic feet of high-Btu gas.

Pilot plant shakedown operations began in January 1972 and were completed in April 1972. A series of start-up attempts were initiated followed by the experimental run program. In conjunction with the operation of the pilot plant, CCDC has been continuing its laboratory research to resolve problems and improve the overall process design. Also, the South Dakota School of Mines and Technology has a subcontract with CCDC to (1) conduct studies of dolomite sources, activity, and reconstitution, (2) study sodium removal from lignite, (3) investigate the environmental aspects of the acceptor

process, and (4) conduct verification analyses using test samples provided from pilot plant operation.

Two other subcontractors were initiated during 1976. The Radian Corporation contracted to conduct an intensive analytical program pertinent to an environmental analysis of the carbon dioxide acceptor process. Stearns-Roger Company initiated a detailed economic analysis of the process, completing Phase I of the study by the end of the year.

Recent laboratory research has concentrated on studies of acceptor activity and reconstitution as well as the development of synthetic acceptors.

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

During July and August, Run 46 was conducted to determine the effect of higher steam partial pressure on acceptor activity and gasifier kinetics. The purpose of Run 47 was to demonstrate the use of reconstituted acceptor in the pilot plant. Run 47B was the last scheduled run for the pilot plant operations. The plant will be mothballed during the next quarter.

Radian Corporation continued sampling pilot plant runs. Stearns-Roger Company completed the final version of the Carbon Dioxide Acceptor Commercial Design Study.

Pilot Plant Operations

All of the Run 46 series used Velva lignite and Minnekahta limestone as feedstocks. Runs 46A and 46B achieved integrated plant operation at normal steam partial pressure, but both ended before the pressure could be increased. Run 46A was interrupted by a steam line rupture during a severe thunderstorm. Run 46B was terminated when a major upset occurred in the gasifier boot section.

During Run 46C, the inlet steam partial pressure to the gasifier was increased from the normal 11.6 atm to 12.5 atm. Integrated pilot plant operation at process conditions was maintained for 186 hours and two eight-hour balance periods were obtained. The ultimate goal for Run 46C was to gradually increase the gasifier boot

steam flow to 100 percent steam (14.4 atm). The run ended due to a boot upset which occurred when the steam partial pressure was increased from 12.5 atm. A control valve malfunction caused the shutdown.

Runs 47A and 47B were completed in September with reconstituted acceptor made from spent acceptor from previous runs. During the run, the entire gasifier heat duty was supplied for periods of 80 and 90 hours while feeding the reconstituted acceptor. Both runs were ended by small chunks of agglomerated material forming in the gasifier boot which then plugged the acceptor standleg.

Related Studies

Radian Corporation continued their analysis of samples from pilot plant runs. Analysis of the effluent liquors from the leaching columns was completed.

The Stearns-Roger Company completed the final version of the Carbon Dioxide Acceptor Commercial Design Study in August. The report was submitted to ERDA for approval. Two alternate cases were subsequently added:

- A plant estimate and operating costs for a one-quarter size plant.
- A case for using fresh makeup acceptor rather than reconstituted stone.

II. BI-GAS PROCESS FOR THE GENERATION OF PIPELINE GAS

BITUMINOUS COAL RESEARCH, INC.

MONROEVILLE, PENNSYLVANIA

Plant Site: Homer City, Pennsylvania

Contract No.: E(49-18)-1207

Contract Funding: \$66,000,000

ERDA: \$44,000,000

AGA: \$22,000,000

INTRODUCTION

The BI-GAS process is being developed by Bituminous Coal Research, Inc. (BCR), under the auspices of ERDA and the American Gas Association (AG) as part of the effort to develop a method for producing high-Btu pipeline gas from coal. The pilot plant operational program is being managed by Phillips Petroleum Company.

The principal objective of this program is the development of the BI-GAS process. Specifically, BCR is directed to:

- Conduct laboratory-scale coal gasification experimentation, together with process and equipment development, to verify the technical and economic feasibility of producing high-Btu gas using the BI-GAS process.
- Design, construct, and operate a multi-purpose research pilot plant with the aid of engineering subcontractors.

Figure II-1 shows the overall program plan.

PROCESS DESCRIPTION

The BI-GAS process is a two-stage, high-pressure, oxygen-blown system using pulverized coal and steam in an entrained flow. A diagram of the BI-GAS process is provided in Figure II-2.

Raw coal is first pulverized so that approximately 70 percent will pass through 200-mesh. The coal, mixed with water, is fed to a cyclone, where the solids are concentrated into a slurry. Coarse underflow from the cyclone is sent to a wet grinding mill for further crushing. The slurry is further concentrated in a thickener and centrifuge, repulped and mixed with flux to generate the desired concentration, and fed to the downstream high pressure feed system.

A high pressure slurry pump picks up the blended slurry and transports it under pressure to a steam preheater. The hot slurry is then contacted with hot recycle gas in a spray dryer for nearly instantaneous vaporization of the surface moisture. The coal is conveyed to a cyclone at the top of the gasifier vessel by the stream of water vapor and inert recycle gas, as well as additional recycled gas from the methanator. The coal is separated from the hot recycle gas in the cyclone and flows by gravity to the gasifier.

The coal enters the gasifier through injector nozzles near the throat separating the stages. Steam is introduced through a separate annulus in the injector. The two streams combine at the tip and join the hot synthesis gas rising from Stage 1. A mixing temperature of about 2200°F is attained rapidly and the coal is converted to methane, synthesis gas, and char. The raw gas and char rise through Stage 2, leave the gasifier at about 1700°F, and are quenched to 800°F by atomized water prior to separation in a cyclone. The Synthesis gas (containing

Figure II-1. BI-GAS PROGRAM SCHEDULE

Figure II-2. BI-GAS PROCESS SCHEMATIC

carbon monoxide, carbon dioxide, hydrogen, water, hydrogen sulfide, and methane) passes through a scrubber for additional cooling and cleaning. The clean gas, along with the desired amount of moisture, is sent to a carbon monoxide shift converter to establish the proper ratio of carbon monoxide and hydrogen required in the methanation process.

Three process steps follow shift conversion: hydrogen sulfide removal, carbon dioxide removal, and methanation. Three process alternatives are planned for investigation. In Alternative 1, the hydrogen sulfide and carbon dioxide are removed in a Selexol unit, and the sulfur is subsequently recovered in a Claus plant. The gas stream passes through a fluidized-bed, catalytic methanation

system for conversion to high-Btu gas. In Alternative 2, hydrogen sulfide is removed in the Selexol unit, sulfur is recovered, and the gas stream (still containing carbon dioxide) goes to the methanator. Carbon dioxide is then removed following methanation. Alternative 3 allows the gas stream to pass directly from the shift converter through the methanator. The hydrogen sulfide and carbon dioxide are removed in a later step. Of the three options, Alternative 1 is the process that is currently being used in the pilot plant.

The BI-GAS process has several advantages:

- A high yield of methane is obtained directly from coal, minimizing subsequent processing of the product gas.
- All types of coal can be gasified without prior treatment, since the process uses an entrained rather than a fixed- or fluidized-bed system.
- The reaction conditions in the upper stage of the gasifier are such that no tar and oils are formed in the gasification process.
- All the coal charged into the process is consumed; the principal by-products are slag for disposal and sulfur for sale.
- Gas generated at high pressures is adequate for transport in existing gas distribution systems without further compression.

Potential operating problems are:

- The slagging section of the gasifier has never been tested under operating conditions similar to those of the BI-GAS reactor. Slagging has been conducted at low pressures in cyclone boilers but slagging at high pressures without a proved reliable method of temperature control may be troublesome. Proper control of slag removal will be necessary to prevent the slag tap hole from plugging.
- The coal feed system for the pilot has not been tested.
- Char particles may strike the wall of the reactor, adhere to the wall, or cause erosion of the refractory material.

HISTORY OF THE PROJECT

This project was started in December 1963. BCR's first experiments confirmed the basic assumption that a high yield of methane could be obtained directly from coal by reaction with steam at elevated temperatures and pressures. BCR next conducted continuous flow experiments in an externally heated reactor processing five pounds of

coal per hour. The experimental data were extrapolated to design a process development unit that would simulate the conditions of Stage 2 of the BI-GAS process. The unit was internally fired and could process 100 pounds of coal per hour. Experiments were designed to determine the optimum residence time, coal rank, and processing conditions (pressure, temperature, and hydrogen partial pressure) that would produce the greatest yield of methane. North Dakota lignite, Wyoming subbituminous C coal, and Pennsylvania high volatile A bituminous coal were used in the experiments. During these experiments, BCR found that the physical design of the Stage 2 process development unit influenced methane yield. Therefore, a cold flow model of Stage 1 and the bottom of Stage 2 was developed to investigate methods for improving the flow patterns in Stage 2 and to establish design criteria for the slagging section of the gasifier.

BCR developed the basic design criteria for a fully-integrated pilot plant capable of processing five tons of coal per hour and producing 100,000 standard cubic feet of clean pipeline-quality gas per hour. Stearns-Roger was awarded the contract for constructing the \$34 million facility on July 11, 1972. The pilot plant management contract was subsequently awarded to Phillips Petroleum Company in November 1974. The gasification vessel to be used in the pilot plant was designed and built by Babcock and Wilcox, a Stearns-Roger subcontractor. The pilot plant was completed in 1976 and start up operations began. Formal acceptance of the plant from Stearns-Roger Construction Co. was made by Phillips Petroleum Company on September 15. By the end of the year the flash drying system and gasifier system were operated successfully. Baseline conditions were established and maintained until the objectives had been achieved.

BRC continued to supply laboratory support as needed to pilot plant operations. On the basis of the laboratory research, Harshaw Chemical Company's type M-647A-3-18-6P catalyst was selected as the first charge of the pilot plant methanator. Optimum operating conditions were determined by testing the catalysts in a process development unit operating in both continuous and semi-continuous modes.

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

Ten tests periods were completed during the quarter at the BI-GAS pilot plant. Tap hole plugging continued to

be a major problem. BCR continued catalyst life testing as well as analysis of methanation PEDU test data.

Pilot Plant Operations

Major objectives of the tests performed during the quarter were to operate Stage I with char feed while using fuel gas as supplemental fuel, and to maintain steady slag tapping for a 24-hour period. Tests were continued at 750 psig with attempts to establish a coal feed rate of 2000 pounds per hour. Tests were completed in July and August without a steady slag tapping operation being achieved.

In September, tests were run with limestone flux in the coal feed to lower the viscosity and melting point of Stage I slag. Results of these tests showed considerable improvement over previous operations.

Laboratory Research

Methanation catalysts studies continued throughout the quarter. Life tests of two new experimental catalysts were completed. Attrition tests were conducted on a non-inorganic substance being considered for a catalyst substrate. One of four samples tested proved to be better than alumina, but not as good as silica-alumina.

A new clear plastic model for studying heat transfer characteristics in a fluidized bed was completed. Initial operations were hampered by mechanical problems. Initial tests will involve determining the bedside heat transfer coefficient for a bare heat tube at various flows and with the tube at different axial locations in the model.

Maintenance work on the PEDU resulted in modifications to the unit before Test No. 26 was conducted in August. The test employed the fourth batch sample of the Homer City methanation catalyst BCR Lot No. 3926. Catalyst activation was achieved under conditions approximating those expected to result during startup operations at the BI-GAS pilot plant. These include a reactor pressure of 750 psig; initial bed temperature of 550°F; and a feed gas composition of 47 percent hydrogen, 16 percent carbon monoxide, 14 percent carbon dioxide, 8 percent methane, and 15 percent nitrogen. The catalyst was activated with no particular difficulties and higher bed temperatures were maintained throughout most of the test, resulting in improved conversion. Operating data were obtained, with feed hydrogen to carbon monoxide ratios in the range of 1.1 to 1.5, by adding supplemental carbon monoxide to the feed gas from gas storage cylinders. One of these feeds was equivalent to the BI-GAS pilot plant shift converter feed on a steam-free basis, and an unusually high useful conversion (96 percent) was achieved under these conditions.

III. PIPELINE GAS BY HYDROGASIFICATION (HYGAS PROCESS)

INSTITUTE OF GAS TECHNOLOGY
CHICAGO, ILLINOIS

Plant Site: Chicago, Illinois
Contract No.: EF-77-C-01-2434
Contract Funding: \$22,718,212
ERDA: \$15,145,475
AGA: \$ 7,572,737

INTRODUCTION

The HYGAS process is being developed by the Institute of Gas Technology (IGT) as part of the joint program of ERDA and the American Gas Association (AGA). ERDA is providing two-thirds of the funds and AGA, one-third.

The objective of this contract is to operate the HYGAS pilot plant facility with a mildly caking Illinois Bituminous Coal in order to develop an improved data base for the design of a commercial demonstration plant based on the HYGAS process. The overall program plan is shown in Figure III-1.

PROCESS PILOT PLANT DESCRIPTION

Several processing steps are required to convert coal to high-Btu gas with the HYGAS process. A diagram of the process is provided in Figure III-2. Coal preparation involves crushing the coal to -14 mesh. Caking coal is pretreated in a fluidized bed at temperatures between 750°F and 850°F at atmospheric pressure to destroy caking tendencies and produce a free-flowing coal. Noncaking coal is fed directly to the slurry tank. The coal is slurried in this tank with an aromatic recycle oil to form a thick slurry. This slurry is then pumped to 1000 psig and

Figure III-1. HYGAS PROGRAM SCHEDULE

injected into the top section of the gasifier (slurry dryer) which contains a fluidized bed of hot coal particles. Oil is vaporized and removed, together with the hot gases passing upward from the lower stages of the gasifier.* Vaporized oil is recovered for reuse by quenching the effluent from the gasifier.

Dry coal particles, at approximately 600°F from the slurry drying section, flow by gravity through a dipleg into a lift pipe. This lift pipe serves as the first stage of hydrogasification. In this stage, the heated coal comes in contact with a hot gas from the lower sections of the reactor. This gas contains methane, carbon oxides, hydrogen, and steam. The hydrogen chemically reacts with the more reactive part of the incoming coal, forming additional methane. Approximately one-third of the methane in the final product gas is produced in this step.

*Gas, passing through the bed of coal particles, fluidizes or agitates it, thus facilitating heat exchange and gas-solids contact.

Figure III-2. HYGAS PROCESS SCHEMATIC

In the second stage hydrogasification section, the partially converted coal from the first stage mixes with the rising hydrogen-rich gas at about 1400-1700°F. Part of the hydrogen and steam react chemically with the coal, forming methane and carbon oxides. Approximately one-third of the methane in the final product gas is produced in this step. Hot residual char is then transferred to the third stage. Here the steam and oxygen react with the char in a fluidized bed to produce a mixture of gases rich in hydrogen. This mixture is passed upward into the hydrogasification sections. Ash is removed from the bottom of the steam-oxygen zone.

The raw product gas leaving the top of the reactor at about 600°F is cooled and rinsed in a water quench, purified, and passed to a methanator. The ratio of hydrogen to carbon monoxide in the purified gas entering the methanator is adjusted to about three to one. The purified gas passes through a nickel catalyst at 800-900°F and is transformed to pipeline quality gas with an average heating value of 930 to 950 Btu per standard cubic foot.

HISTORY OF THE PROJECT

Development of the HYGAS process by IGT under the sponsorship of AGA began in 1946, and continued under joint sponsorship with the Office of Coal Research (OCR), now a part of ERDA, in 1964. The pilot plant was designed and built to convert 75 tons of coal per day to 1.5 million cubic feet of clean high-Btu gas. During 1973, the plant produced pipeline-quality gas from the coal in sustained test operations. Since then, the duration of the test runs has increased, and longer, more stable operating periods have been achieved.

During 1975, eleven test runs were made in the HYGAS pilot plant. The longest run (Test 37) was made in July, demonstrating the technical feasibility of using lignite. Fifteen days of self-sustained operation were achieved with over 1000 tons of lignite processed. The entire plant was on stream for 92 percent of the time, or 333 hours. Steady-state conditions were achieved for 160

hours. The heat and material balances were within ± 5 percent of closure. Subsequent to Test 37 with lignite, IGT was authorized to start testing with high caking Illinois No. 6 bituminous coal.

Twenty-six runs were made with the ash-agglomerating gasifier during 1975, also. Process parameters were varied to determine the optimum operating conditions. Using coke breeze, agglomerates were successfully produced for a 200-hour steady state period and full dust recycle was maintained.

Concurrent laboratory research was directed toward the study of the penetration of slurry liquid into coal pores, effects of acidic condensing atmospheres on castable insulations, and methanation catalyst evaluation.

Of major technical and economic importance to this process is the production of the hydrogen-rich gas required for hydrogasification. Shakedown runs and batch tests of the two-megawatt electrothermal gasifier for producing hydrogen-rich gas were completed in early 1974. Although this technique has been demonstrated to be technically feasible, it was found to be too costly due to the large quantity of electric power required. No further investigations of this unit will be made. Two techniques for producing this gas are now being investigated: steam-oxygen and steam-iron. A steam-oxygen unit, which gasifies char, was constructed and installed in the base of the HYGAS pilot plant hydrogasification reactor during 1974 and has been operated successfully. The steam-iron technique is being developed by IGT under a separate contract (see Section IV). Currently, a pilot plant for demonstrating this technique has been constructed adjacent to the HYGAS pilot plant site.

Data obtained during integrated operations of the entire HYGAS pilot plant continue to be used to formulate engineering design bases and to establish reliability trends in operating equipment.

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

After a contract extension effective at the beginning of the quarter, the HYGAS pilot plant completed test 64,

the longest to date with Peabody No. 10 mine coal. The entire plant, including the liquid phase methanation unit (Section VII) was on-line.

Pilot Plant Operation

Following the annual plant turnaround completed in August, Test 64 was conducted. The test achieved eight and one-half days self-sustained operation, the longest to date with Peabody No. 10 mine bituminous coal, with coal conversion ranging from 77 to 84 percent for certain steady state periods. Smooth solids flow throughout the reactor was attained for several days. The entire plant, including the coal mill, the pretreatment section, the gasifier, the purification section, and the liquid-phase methanation sections, was on-line. However, the test was terminated when it was not possible to obtain smooth solids flow due to clinker formations in the steam-oxygen tone. In addition, clinker formation was found in the bottom of the char cooler despite the 50/50 mixture of nitrogen and air used during Test 64. Consequently, 100 percent nitrogen gas will be used to fluidize the char-cooler solids in future tests.

Test 65 was conducted during September, but was terminated by an electrical power failure after only nine tons of coal had been processed through the gasifier. The power failure was caused by an equipment malfunction in the main power supply to the plant.

Liquid Phase Methanation Unit

Piping modifications for Chem Systems' liquid phase methanation (LPM) unit were completed in July. The LPM unit operated for 69 continuous hours prior to the shutdown of Test 64. Carbon monoxide conversion levels in the pilot unit ranged from 45 to 98 percent. This was the first time the unit had received purified product gas from the HYGAS plant for an extended period.

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IV. STEAM-IRON SYSTEM FOR PRODUCTION OF HYDROGEN

INSTITUTE OF GAS TECHNOLOGY
CHICAGO, ILLINOIS

Plant Site: Chicago, Illinois
Contract No.: EF-77-C-01-2435
Contract Funding: \$9,282,647
ERDA: \$6,188,431
AGA: \$3,094,216

INTRODUCTION

The steam-iron process is being developed by the Institute of Gas Technology (IGT) as a possible alternative for producing hydrogen for use in the HYGAS pilot plant (Section III) and as a means of producing hydrogen for industrial or other coal conversion processes. The process is being developed under the auspices of ERDA and the American Gas Association (AGA). ERDA is providing two-thirds of the funds and AGA, one-third.

The objectives of this contract are to design, construct, and operate a steam-iron pilot plant facility for the production of hydrogen. The system will provide process and design data for a commercial-size facility. The development schedule for the process is shown in Figure IV-1.

PROCESS DESCRIPTION

The steam-iron process is a system for producing hydrogen for the hydrogasification of coal, and it is also hoped that it may be an attractive source of hydrogen for the petrochemical and other industries requiring hydrogen. A flow diagram of the steam-iron pilot plant is shown in Figure IV-2.

In the pilot plant, a char-water slurry containing from 35 to 50 percent char is heated in a direct fired furnace to produce a lean-phase mixture of char and steam. The steam lifts the char to the preheater bed at the top of the producer vessel. There it is fluidized with air and steam, thereby combusting approximately ten percent of the feed char and raising the temperature from 600°F to approximately 1750°F.

The preheated char then enters the producer bed where it is gasified at approximately 2000°F with air and steam to yield a reducing gas. Spent char is cooled with additional steam and discharged from the producer vessel at about 1000°F. The 2000°F reducing gas is then fed to the reducer bed of the steam-iron reactor.

The producer gas enters the reducer/oxidizer reactor vessel in the lower part of the reducer section, where it reacts with a recirculating stream of iron oxides, converting FeO to Fe. The producer gas reaches a conversion level of about 20 percent in the lower stage before entering the upper stage. The bulk of the conversion (65 percent) is attained by the conversion of Fe₃O₄ in the upper stage. Steam fed to the lower oxidizer section converts FeO to Fe₃O₄ and conversion of up to 30 percent of the feed occurs in this stage. Further conversion of steam occurs in the upper oxidizer, where Fe is oxidized to FeO. The system is designed for a final steam conversion of up to 60 percent.

PROJECT	FY 75	FY 76	TR. Q.	FY 77	FY 78	FY 79
STEAM IRON UNIT	CONSTRUCTION		▽	OPERATION		ENGINEERING EVALUATION ▽ ↓ ○
		△	▽			

LEGEND: △ BEGIN MILESTONE ○ DECISION MILESTONE
 ▽ COMPLETE MILESTONE

Figure IV-1. STEAM-IRON SYSTEM PROJECT SCHEDULE

Figure IV-2. STEAM-IRON PILOT PLANT SCHEMATIC

Four fluidized beds are used in the steam-iron process to obtain full countercurrent operation. The reducing stages are located above the oxidizing stages with external recirculation of the Fe_3O_4 -rich solids from the bottom to the top of the vessel. This configuration avoids dual, vertical solids transport systems that would be required if the oxidizing and reducing stages were located side by side. The advantages of the steam-iron system include:

- Elimination of the need for a large oxygen plant.
- Reduction in the amount of carbon dioxide scrubbing required since most of the carbon dioxide produced in the system is vented in the spent reducing gas which by-passes the purification system.
- Elimination of the downstream shift reactors.
- Energy recovery and sale of by-product electricity may lead to an overall coal-to-energy conversion of greater than 70 percent.

It is believed that these benefits may lead to a more economical overall process which more than compensates for the additional costs of the auxiliary steam-iron reaction system.

HISTORY OF THE PROJECT

Steam-iron process research has been conducted periodically for many years. The earliest use of the steam-iron process featured a fixed, packed bed of iron ore that was reduced to iron with gases containing carbon monoxide and hydrogen. The iron was then oxidized with steam to produce iron oxide plus a mixture of hydrogen and unreacted steam. Continuous hydrogen production was provided by using two beds that were cyclically reduced and oxidized. This process was neither economic nor compatible with high pressure operations and was dropped in favor of steam reforming of natural gas as a method for producing hydrogen. The process was revised in the late 1950's by the U.S. Bureau of Mines for use in producing hydrogen for coal gasification. In 1961, IGT began working on the process and continued until 1971. This work was performed under the sponsorship of Fuel Gas Associates. In 1973, IGT resumed work on the project and has been developing the process under the joint sponsorship of the Office of Coal Research (OCR, now a part of ERDA) and AGA.

The pilot plant was completed in 1976, concluding the tasks under contract E(49-18-)-1518. Subsequent operations were continued under a new contract. The first iron ore solids circulation tests were made late in 1976.

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

Three ore circulation tests were completed during the quarter. The Reactor Variables Study, Task 2, was initiated and two producer reactor tests completed. Laboratory work continued with kinetic studies, char evaluation, and attrition studies. All of the scheduled lift-line tests were completed during the quarter.

Pilot Plant Operation

Two ore circulation tests, Tests 6 and 7, were completed during July. The effect of varying the amount of aeration gas on ore circulation in the lift line was studied in Test 6. Reactor pressures for this test were controlled at 125 psig, and fluidized-bed temperatures were maintained above 500° F. A total of 45 hours of ore circulation were accumulated during this test. The fluidizing gas was switched from air to steam for a period of 24 hours, more closely duplicating the molecular weight and gas composition during integrated operations with the producer, in order to study the effect on ore circulation and possible plugging problems. No plugging occurred, indicating that the 500° F fluidized-bed temperatures were sufficient to maintain free-flowing solids circulation.

The objective of ore circulation Test 7 was to obtain closer control of the differential pressure across the reactor and of the aeration of the seal legs between beds. In Test 7, the best ore circulation test to date, continuous circulation was achieved for a period of 80 hours. Reactor pressures were maintained at 300 psig, and bed temperatures were held between 500° and 600° F. Solids circulation for the entire test averaged six tons per hour. The data indicated that the circulation rate increased as the total pressure difference across the reactor increased.

Task 2, Reactor Variables Study, was initiated in August. The objective of this task is to obtain data necessary for determining the effects of the major operating variables on hydrogen production in the Steam-Iron Process. These variables include bed temperatures and velocities in the producer reactor, ore circulation rates and ore bed heights in the steam-iron reactor, and total system pressure.

In August, Test 8 was completed to study the effects of bed temperatures and velocities in the producer reactor. A total of 57 tons of char was fed to the reactor during the test, and producer bed temperatures were raised to 1450° F.

Test 9 was conducted in September to establish self-sustained producer operation at 1900° F to determine the effects of temperature on reducing gas quality. Previous tests had been limited to about 1450° F. Self-sustained operation was achieved at 1650° F before the run had to be terminated because of a gas leak at a manway. During this test, 105 tons of char were fed to the producer over a period of 107 hours. A reducing gas containing 25 percent carbon monoxide plus hydrogen was produced.

One ore circulation test was conducted in the steam-iron reactor in September. Smooth iron ore circulation was achieved for 133 hours in the test, Test 10. Circulation rates as high as 70 tons per hour were obtained at a reactor pressure of 250 psig and temperature of 600° F.

Laboratory Tests

Kinetic Studies

The objective of the kinetic studies in July were to continue the development of silica reinforced iron solids and also to investigate the catalytic potential of elements other than transition elements. Thirteen reactivity and thirteen attrition tests were completed. None of the materials tested were significantly better than siderite.

The objective of the test in August was to determine the effects of copper, barium, potassium, and silica on the reactivity and attrition resistance of various Iron-Chromias. None of the materials tested were significantly better than siderite. IGT Iron-Copper 3 and Iron-Chromias 34 and 38, containing 2.0, 0.5, and 1.0 weight percent of copper, silica, and potassium, respectively, were found to be as good as siderite.

Nineteen reactivity and an equal number of attrition tests were conducted in September, but none of the materials was found to be better than siderite.

Char Evaluation

Four char evaluation tests were conducted during the quarter with Kentucky bituminous char. The first three tests were conducted to determine the fluidization velocity at which the char would begin to sinter. In the last test, ash sintering was achieved by allowing the bed ash content to rise gradually by discharging char at the lowest

possible rate while feeding char at a rate sufficient only to maintain the bed level.

Attrition Studies

Seven tests were conducted with Husky lignite char to determine the effects of solids loading and gas density on attrition in the cyclone and at the gas distributor. Results showed that increasing solids loading from 20 to 80 grams of solids per cubic foot of gas increases the reduction in particle size from 15 to 20 percent.

Seven additional tests were conducted to determine the effect of gas density alone. Results showed that increasing gas density tends to decrease attrition in the cyclone and increase attrition at the gas distributor.

Eight tests were conducted with Husky lignite char to determine the effects of inlet velocity and solids loading on the attrition characteristics of this char in the cyclone. The results showed that increasing the gas velocity from 25 to 85 foot per second increased particle size reduction from 8.1 to 22.8 percent of the original feed size. The results also showed that increasing solids loading from 20 to 75 grams per cubic foot of gas increased particle size reduction only from 14 to 18 percent.

Lift-Line Studies

Five tests were conducted to determine the effects of fines content and circulation rates on the flow characteristic of iron ore. Results showed that about eight weight percent of fines were essential for achieving smooth flow down the standpipe and that increasing the solids circulation rate increased the pressure gradients in the transition zone and lean-phase lift.

Seven tests were conducted to determine the effects of solids circulation rates and lift-gas velocities on the operation of the transition zone between the lean and dense-phase lifts.

Eight tests were conducted in September, completing all the tests scheduled in this task. Four of these tests were made to determine the effects of lift-gas velocities of 30 and 34 feet per second on the operational characteristics of the transition zone. The other four tests were conducted to determine the choking velocities of siderite at solids mass velocities of 48, 77, 91, and 124 pounds per square foot.

V. SYNTHANE PROCESS

THE LUMMUS COMPANY
BLOOMFIELD, NEW JERSEY

Plant Site: Allegheny County, Pennsylvania
Contract No.: EX-76-C-02-0003
Contract Funding: \$28,000,000
(100% ERDA)

INTRODUCTION

The Synthane process was developed by the Bureau of Mines and is now the responsibility of ERDA. The government-owned Synthane pilot plant is being operated by The Lummus Company. The objective of this contract is to obtain definitive process information, sufficient for commercial design purposes, on the conversion of coal to gas of pipeline quality. The overall program plan for the development of the Synthane process is shown in Figure V-1.

PROCESS DESCRIPTION

A key feature of the Synthane process is that pretreatment of caking coals is integrated with gasification. Another feature is that gas with a relatively high methane content is produced directly. A schematic of the Synthane process is provided in Figure V-2. There are four major steps in the process: coal pretreatment, coal gasification, shift conversion and purification, and methanation.

Coal, crushed to -20-mesh, is dried, pressurized to approximately 40 atm, and is transferred into the fluidized-bed pretreater by means of high pressure steam and oxygen. Pretreatment provides mild oxidation of the coal particle surface so that caking coals will not agglomerate

in the gasifier. The coal overflows from the pretreater into the fluidized-bed gasifier through an injection pipe. Steam and oxygen enter the gasifier just below the fluidizing gas distributor. The gasification reaction occurs within the fluidized bed. Unreacted char flows downward into a bed fluidized and cooled with steam, and is removed with transport steam, slurried in water, and depressured through let down valves. This char can then be burned to produce process steam. The product gas, containing methane, hydrogen, carbon monoxide, carbon dioxide, ethane, and impurities, is passed through a venturi scrubber and a water scrubber to remove carry-over ash, char, and tars. The concentration of hydrogen and carbon monoxide in the gas is adjusted to a three-to-one ratio in a shift converter. The acid gases are absorbed in a hot-potassium carbonate scrubber. Carbon dioxide is reduced to 40 parts per million. Regeneration of the potassium carbonate solution produces a hydrogen sulfide-rich gas, which is converted to elemental sulfur by the Stretford process. The remaining traces of sulfur in the product gas are removed by passing the gas through activated charcoal. The purified gas must be reacted catalytically to convert the hydrogen and carbon monoxide to methane.

Two alternative methanation systems are being investigated: the hot gas recycle (HGR) system and the tube wall reactor (TWR) system. The HGR methanator is composed of parallel plates that are flame sprayed with Raney nickel catalyst. Excellent temperature control is achieved by recycling some of the exit gas that has been cooled in a separate heat exchanger. Because the pressure

Figure V-1. SYNTHANE PROGRAM SCHEDULE

Figure V-2. SYNTHANE PROCESS SCHEMATIC

drop in the HGR is less than in conventional reactors, the compression costs are relatively low. The TWR methanator is composed of two-inch-diameter tubes with the Raney nickel catalyst flame sprayed on the inside, a practical technique that allows easy replacement of the catalyst. The TWR system removes the heat of reaction by means of conduction through the catalyst-coated tubes, which are in contact with boiling Dowtherm. The purified gas entering the methanator is diluted by recycled gas to increase the reaction rate by reducing the water content. Long-term catalyst life of over 2,800 hours has been successfully demonstrated in the TWR system in the laboratory. The plant has also yielded large quantities of high-Btu gas per unit weight of catalyst (240,000 standard cubic feet per pound of catalyst). As a final step, the gas produced with both the TWR and the HGR methanators is passed through a small vessel packed with

conventional methanation catalyst to minimize residual carbon monoxide in the product gas.

The Synthane process offers several advantages in the production of high-Btu gas:

- Caking coals can be used directly as can a wide range of other coals, including lignite.
- Hydrocarbons released during pretreatment are retained within the system, thereby maximizing the efficiency of coal conversion to gas.
- More than half of the methane is produced directly in the gasifier. By maximizing methane production in the gasifier, oxygen requirements are reduced. Therefore, the investment for an oxygen plant is lower and the sizes of all process vessels downstream from the gasifier are reduced by 30 to 50 percent,

compared to processes in which the raw gas from the gasifier contains little or no methane.

- The process flow system and equipment are relatively simple.
- No tar and oil with deep bed coal feeding.

Some of the disadvantages of the process are:

- Char is produced which must be utilized for steam production in an environmentally acceptable manner.
- Without deep bed coal injection, some tars and oils are produced which must be disposed of or utilized.
- More economical coal feeding methods than the currently used lock hopper system must be developed.

HISTORY OF THE PROJECT

The Synthane process was developed by the Bureau of Mines at the Pittsburgh Energy Research Center, Bruceton, Pennsylvania. Development work started with scattered research in several areas.

In 1961, work was started on methods of pretreating caking coals in fluidized beds. A preliminary design contract was awarded to M. W. Kellogg Company in August 1970 to determine if the data were sufficiently complete to proceed with design of the pilot plant. The contract was extended for additional gasifier tests and further evaluation of the Synthane project. Based on the results of the gasifier tests and the evaluation, the Bureau of Mines concluded that the process was feasible and the design could begin.

In June 1971, a contract was awarded to Lummus for obtaining process information and designing the pilot plant. The contract was modified several times to increase its scope to include rating and sizing heat exchangers, purchasing equipment, preparing a bid package, preparing a final report, additional engineering, inspecting and control monitoring, etc. Rust Engineering was awarded a contract to construct a pilot plant from the design information obtained by Lummus.

Construction of the Synthane pilot plant was completed in March 1975, and all areas and systems were transferred from the construction contractor to ERDA. Through 1975 work concentrated on installation of auxiliary equipment and the repair and modification of the plant due to faulty equipment and design changes. During the first quarter of 1976 these repairs and changes were made and initial testing began. Gas was first produced from Rosebud Coal on July 7, 1976. The efforts

for the remainder of the year were directed toward making the gasifier operational and reliable.

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

The Synthane plant remained down through the month of July for replacement of all Incoloy 800 nozzles with fittings of carbon steel overlaid with Monel. The studies of Western subbituminous coal were completed during August with a successful run that produced ten steady state periods. Testing of Illinois No. 6 coal began in September. Attempts to operate the pretreater were unsuccessful, and the plant was down for cleanout and revisions at the end of the quarter.

Pilot Plant Operations

The replacement of all the Incoloy 800 nozzles on the gasifier with carbon steel nozzles overlaid with Monel were completed in July. During this extended outage, which lasted two months, all mechanical equipment was overhauled.

The successful completion of the run in August finished the studies of Western subbituminous coal. Bed temperatures and feed rates were varied to study the effect of these variables on the process. Coal and oxygen were fed at two to three tons per hour for a total of 190 hours, gasifying 465 tons of Rosebud coal. The gasifier ran continuously for 98 hours and the run produced ten steady state periods. Carbon conversions of 75 to 78 percent were achieved for extended periods. The pretreater was placed in service during the run to test controls and operating procedures before being used for the gasification of Illinois No. 6 coal. Despite the fact that a clinker formed in the bottom section, the gasifier operated successfully throughout the run.

Testing of Illinois No. 6 coal began in September. The program first provides for the testing of the pretreater before attempting gasification. With minor modifications to the grinding mill, 130 tons of Illinois No. 6 coal were successfully ground to specification. Four attempts were made to operate the pretreater. Agglomeration caused the unit to be shut down in each instance. The entry of coal feed into the bottom of the pretreater caused the bottom temperature of the pretreater to cool below the condensation temperature of the steam. At the end of the quarter, the plant was down for cleanout and revisions.

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VI. AGGLOMERATING BURNER PROCESS

BATTELLE MEMORIAL INSTITUTE
COLUMBUS LABORATORIES
COLUMBUS, OHIO

Plant Site: West Jefferson, Ohio
Contract No.: EF-77-C-01-1513
Contract Funding: \$15,379,885
ERDA: \$14,707,576
AGA: \$ 672,309

INTRODUCTION

The agglomerating burner gasification process is being developed by Battelle Memorial Institute, under the sponsorship of ERDA. The objective of the current contract is to develop a two-stage process using a self-agglomerating fluidized-bed combustor as part of a practical and economical means for producing synthesis gas by steam gasification of coal. A process development unit is to be designed, constructed, and operated, and the following aspects of the process are to be explored:

- Operability of self-agglomerating fluidized-bed coal combustor that operates on eastern bituminous coal under pressure and uses air for combustion.
- Mechanical feasibility of continuous circulation of hot ash agglomerates between fluidized-bed combustor and gasifier vessels at seven atm pressure and at flow rates and temperatures required for effective heat transfer.
- Operability of integrated fluidized-bed burner and gasifier vessels both fed by eastern bituminous coal (or char in the case of the combustor) and operating at seven atm pressure.

Concurrent with the operation of the process development unit, Battelle will perform process engineering studies which will result in a conceptual design of a scaled-up version of the agglomerating burner process.

Also, Battelle will perform the necessary engineering, design, and related technical effort to enable the procurement of a small gas turbine (which can be installed in the system for more efficient utilization of process energy), but will not include the actual purchase of the unit. Figure VI-1 shows a revised schedule for the development of the agglomerating burner process for the latest contract modification.

PROCESS DESCRIPTION

Conversion of coal to pipeline-quality gas using the agglomerating burner process requires completion of five steps: coal preparation, coal pretreatment, coal gasification, gas cleanup, and methanation. Figure VI-2 shows a diagram of the process.

In the coal preparation section, coal is crushed and separated into two sizes: -100 mesh and -8 +100-mesh. Caking coal in the -8 +100-mesh range is fed to a fluidized bed pretreater where it is mixed with gas and air at atmospheric pressure and 750°F. It is cooled, fed to the gasifier, and reacted with steam in a fluidized bed. The -100-mesh coal is burned with air in a fluidized-bed combustor in a manner allowing agglomeration of the ash at a temperature approaching the ash fusion point (2100°F). Combustion of coal in this self-agglomerating

PROJECT	FY 75	FY 76	TR. QR.	FY 77	FY 78	FY 79
PROCESS DEVELOPMENT UNIT	CONSTRUCTION			FEASIBILITY DEMONSTRATION PHASE		
INPUT: 25 TONS/DAY COAL						
OUTPUT: 0.8×10^6 SCFD HIGH-BTU GAS						

LEGEND:

△ BEGIN MILESTONE
▽ COMPLETE MILESTONE

⬡ DECISION MILESTONE

Figure VI-1. AGGLOMERATING BURNER PROGRAM SCHEDULE

Figure VI-2. AGGLOMERATING BURNER PROCESS SCHEMATIC

mode yields hot flue gases that, because they are sufficiently free of fly ash, can be expanded in a gas turbine for energy recovery. Hot ash agglomerates are transferred continuously from burner to gasifier by means of a steam lift. Superheated steam enters the gasifier below the distributor plate. Coal is fed through lock hoppers and is

conveyed by inert gas to the gasifier. Hot agglomerated ash flows downward and transfers a portion of its sensible heat to support the coal gasification reactions. The temperature of the hot ash agglomerates decreases to 1600° F or 1500° F. Product gas from the gasifier is sent to the gas cleanup section. Most of the agglomerated ash is

recycled to the burner for reheating. Ash equivalent to the ash content of the coal fed to the burner is removed from the system continuously to maintain a constant quantity of ash agglomerates in the cycle.

Burner flue gas, after passing through a cyclone, is scrubbed in a venturi and sent to the stack. There is also a provision for sending the flue gas through a heat exchanger and a gas turbine for energy recovery. The product gas, after leaving a cyclone at the gasifier, also passes through a venturi scrubber system. Gas purification, shift conversion, and methanation system for the treatment of the product gas are not part of the present program and no facilities are being provided for these operations. There is, however, ample space at the plant site for future incorporation of these functions.

Three advantages of the agglomerating burner process are:

- Recirculation of hot ash to supply heat in the gasifier eliminates the need for partial oxidation and, thus, the need for an oxygen plant.
- Hot flue gas (free of fly ash) can be expanded through a turbine, thus increasing the overall thermal efficiency of the process.
- Self-agglomerating coals such as eastern bituminous may be converted to synthesis gas by this process.

HISTORY OF THE PROJECT

Initial research on the gasification process was sponsored by the Union Carbide Corporation at Battelle in the early 1960's. That work included the study of agglomerating ash burner performance in bench scale reactors a few inches in diameter using a bituminous coal (Pittsburgh No. 8) and a subbituminous western coal from Lake DeSmet, Wyoming. Gasifier performance was studied in a three-inch diameter bench-scale reactor in which the hot circulating agglomerated ash was simulated by circulating heated sand. Lake DeSmet subbituminous coal was used in these experiments. Other experiments were conducted to estimate turbine-blade erosion by fly ash in the gaseous products of combustion from powdered Lake DeSmet coal burned under ash agglomerating conditions. All the experimental work sponsored by Union Carbide was done at atmospheric pressure. A U.S. patent covering the work at Battelle was issued in March 1965 and assigned to Union Carbide. The Government has a royalty-free license under this patent.

After several attempts, beginning in 1965 by Union Carbide and later by Battelle, to interest the Office of Coal Research (OCR) in the process, OCR and the American Gas Association agreed in 1972 to sponsor further development jointly. Under this agreement, the development work was supervised by an operating committee drawn from AGA and OCR and financed one-third by AGA and two-thirds by OCR. AGA withdrew its support in August 1974 and the work has since been supervised and financed entirely by OCR and, more recently, by ERDA.

The preparation of a bid package for the engineering design and construction of a process development unit for operation under pressure began in the fall of 1972 through an interim authorization of AGA. A contract was awarded to Battelle by the Office of Coal Research (OCR) in January 1973 to install and operate the unit. Chemical Construction Corporation (Chemico) was selected as the engineering contractor to prepare the detailed engineering design and to construct the process development unit at Battelle's Engineering Station in West Jefferson, Ohio. Design work began in February 1973, and was essentially completed in January 1975. Field construction began in June 1974 and was successfully completed by a local subcontractor in mid-August 1976.

Commissioning of the available sections of the PDU continued concurrently with the completion of construction and all scheduled commissioning was completed by the end of August. Heat up of the burner/ gasifier system to condition the refractories was initiated late in that month and completed early in September 1976.

Controlled circulation of solids, with stable bed conditions, was achieved at relatively low temperatures and pressure over several periods of continuous operation, each in excess of 100 hours. The effect of primary process control points on solids circulation was established. Preliminary calculations indicated that design circulation rates of up to 20 tons per hour were achieved.

Work to date demonstrated that Rosebud subbituminous coal can be fed to, ignited, and burned in the fluidized bed of the burner. Coal ignition took place smoothly and dependably at bed temperatures as low as 1000°F. The burner bed was heated autogeneously with the combustion of the Rosebud coal, and the desired temperature was maintained and controlled throughout runs exceeding 100 hours in duration.

Research activities have included evaluation of alternatives for the use of natural gas, analysis of sulfur dioxide emission levels (the concentration was well below governmental limits), and studies dealing with alternative designs for the power recovery turbine.

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

Previous attempts to achieve an integrated gasification run were retarded by continued spalling of refractory from the burner and gasifier linings. The chunks of refractory entered the solids transfer pipe and blocked circulation. As a temporary solution to this problem, stainless steel liners were installed in the combustor and gasifier. Work continued with the goal of achieving an integrated combustor/gasification run with subbituminous coal prior to proceeding with the bituminous coal. The goal is to produce synthesis gas continuously, rather than producer gas.

Process Development Unit

Continued difficulties with spalling of the refractory linings in the burner and gasifier prevented successful demonstration of gasification during July. The two vessels need to be relined; however, before undertaking this major maintenance, attempts will be made to demonstrate the basic operability of the process. Stainless steel liners were installed in the vessels in an effort to exclude the refractory spalls from the beds for sufficient time to permit an integrated run.

Extensive solids circulation tests were completed in August, and a correlation relating solids circulation rate to pressure loss in the vertical riser was developed. Efforts to complete an integrated gasification run were retarded by failure of a section of steel pipe in the solids transfer line and failure of portions of the combustor distributor plate.

Two gasification runs were made in September. One run was terminated when solids circulation lines were plugged with fused bed material. The other run was also terminated prematurely when the make-gas scrubber system failed. While not entirely successful, the two runs provided useful information on controlling free-board burning and solids circulation. Another run is planned with the subbituminous coal next quarter.

Related Studies

Assembly of the erosion test rig was completed during the quarter. Hot calibration of the unit was delayed due to an inadequate supply of pressure gas. An alternative source is being investigated.

E. I. DuPont de Nemours and Company continued their assistance and guidance of PDU operations throughout the quarter.

VII. LIQUID PHASE METHANATION PROCESS

CHEM SYSTEMS, INC.

HACKENSACK, NEW JERSEY

Plant Site: Hackensack, New Jersey

Contract No.: E(49-18)-1505

Contract Funding: \$2,170,000
ERDA: \$ 723,333
AGA: \$1,446,667

Contract No.: EX-76-C-01-2036

Contract Funding: \$1,483,744
ERDA: \$1,303,996
Industry: \$ 179,748

INTRODUCTION

The liquid phase methanation process is being developed by Chem Systems, Inc., under the auspices of ERDA and the American Gas Association (AGA). ERDA is providing two-thirds of the funds and AGA, one-third.

The overall objective of this contract is to develop a practical and useful process for converting coal-derived synthesis gases to methane as the major constituent of synthetic natural gas, using liquid fluidized beds.

The work is divided into three phases. The first phase is a laboratory investigation to establish the technical feasibility of methanation of synthesis gases by passing them through a liquid containing solid catalyst particles. The specific objectives are to:

- Develop an acceptable process liquid (to suspend catalytic particles) and investigate the use of aromatic and paraffinic hydrocarbons as possibilities.
- Investigate various catalytic materials that can be used in the methanation process.
- Determine the catalyst particle size that will produce the optimum process reaction.

- Develop a reaction correlation model for investigating the mass transfer from gas to liquid, the mass transfer from liquid to catalyst, and the catalytic surface reaction.

The second phase includes the design, procurement, construction, and operation of a process development unit having a design feed gas rate of 1,500 standard cubic feet per hour. The specific operational objectives were to determine:

- Catalyst life, recovery, and regeneration methods.
- Liquid life and effectiveness.
- The effect of all process variables on performance.
- The correlation between the laboratory reaction models and process development unit performance data.
- Data needed for engineering designs and cost estimates of large plants.

The third phase includes the design, procurement, technical supervision, and construction of a pilot plant methanation unit. The unit will be used to (1) demonstrate the liquid phase methanation process on a synthesis gas actually produced in a coal gasification process and (2) obtain data for detailed design and engineering of a methanation unit for a coal gasification plant

having a capacity of about 250 million standard cubic feet per day.

The schedule for the development of the liquid phase methanation process is shown in Figure VII-1.

PROCESS DESCRIPTION

The key feature of the liquid phase methanation process is the use of a liquid phase that removes the heat generated by the highly exothermic methanation reaction and also serves as the fluidizing medium for the reaction catalyst. A schematic of the process is shown in Figure VII-2.

Liquid phase methanation is a three-phase process: gas (primarily carbon monoxide and hydrogen), liquid (aromatic hydrocarbon or paraffinic oil), and solid (nickel catalyst). The process consists of five steps:

- Absorption of reactants from the gaseous phase.
- Diffusion of reactants through the liquid phase.
- Chemical reaction on the solid surface.
- Diffusion of products through the liquid phase.
- Desorption of products to the gaseous phase.

In this process, inert liquid is pumped upward through the reactor (which operates at 20 to 68 atm and 570°-650° F at a velocity sufficient to both fluidize the catalyst

and remove the reaction heat. At the same time, the low-Btu feed gas (carbon monoxide and hydrogen) is passed upward through the reactor where it is converted to methane in the presence of the fluidized catalyst. The heat of the exothermic reaction is absorbed by the inert liquid as sensible heat. The liquid is then circulated through a heat exchanger to maintain the desired temperature, and the cooled inert liquid stream is recycled to the reactor.

Conversion of carbon monoxide and hydrogen to methane is on the order of 95 to 99 percent complete, depending on the pressure, temperature, and space velocity of the inlet gas. Other components of the product gas are water vapor and vaporized inert liquid, hydrogen, and carbon dioxide. There may be minute quantities of ethane and propane also. Most of the inert liquid condenses in the primary cooler and the remainder condenses in the secondary cooler along with the water.

The reactor effluent gases are cooled. Any water produced in the reaction is condensed along with the process liquid that was vaporized in the reactor. The liquids are phase separated. The process liquid is recycled back to the reactor. Part of the water can also be recycled back to the reactor as required with the remainder being sent to the plant's condensate system. The cooled gases can then be sent to a small trim methanator for final conversion of carbon monoxide and hydrogen to methane. Carbon dioxide may be removed either prior to or after the final methanation step. The final methanator is a fixed bed unit where complete reaction occurs adiabatic-

LEGEND:
 ▲ BEGIN MILESTONE
 ▼ COMPLETE MILESTONE

Figure VII-1. LIQUID PHASE METHANATION PROGRAM SCHEDULE

Figure VII-2. LIQUID PHASE METHANATION PROCESS SCHEMATIC

ally in a single pass through the reactor. The effluent gases from this polishing reactor are cooled by preheating feed gas and then against cooling water or air. The product SNG (HHV > 950 Btu/SCF) is dried and compressed (if required) to pipeline gas pressure.

There are several advantages to the liquid phase methanation process:

- Inert liquid circulation provides excellent temperature control in the system.
- The uniform temperature of the system permits optimum reaction conditions.
- Small particles of catalyst contained by the liquid make it possible to achieve a higher rate of reaction than is possible with gas-solid methanation, using larger catalyst particles.
- Catalyst attrition is usually much lower than it is for gas fluidized beds due to the cushioning effect of the liquid.
- Catalyst activity is maintained and the necessity

of overdesigning the reactor to accommodate declining catalyst activity levels is eliminated.

- The methanation reaction is nearly complete in a single pass, eliminating the need for recycle or multiple reactors.
- Higher conversion per pass is achieved because the axial diffusivity of the reactants is relatively low compared to a gas-solid fluidized bed.

HISTORY OF THE PROJECT

In addition to an extensive literature search of both the methanation reaction and the fluidization of solids, Chem Systems initially conducted studies on the thermal stability of liquids and selected a number of potentially suitable liquids for further experimentation. A small reactor was constructed and put on stream in July 1972. The initial feasibility studies demonstrated that (1) there

are commercially available liquids capable of withstanding the reaction temperatures and pressures (480° F to 660° F, 35 to 70 atm) without being degraded, and (2) the rate of methane formation in the presence of the liquid phase was well above the original estimates of the rate required to make this process commercially attractive.

In screening studies designed to narrow the choice of liquids and catalysts, Chem Systems determined that aromatic and paraffinic hydrocarbon liquids can be used without being subjected to noticeable degradation and that commercially available catalysts are equally flexible. However, to maintain catalyst activity, it is necessary to maintain a hydrogen atmosphere when the system is not in operation.

Development of the liquid phase methanation process has continued on three levels: bench-scale unit, process development unit, and pilot plant. The bench-scale unit has been used for experiments with process liquids and catalysts and for the development of a reaction model correlating the physical and chemical aspects of the liquid phase methanation reaction process. The model was also used for developing data for designing the larger units. The process development unit was used to:

- Measure density differences in the fluidized catalyst bed height under various reaction conditions.
- Determine optimum process performance values.
- Determine criteria for reliable design of larger plants.
- Determine catalyst life and effectiveness.
- Determine catalyst regeneration techniques.
- Determine liquid life and effectiveness.
- Assess correlations between laboratory and performance data.

Work with the process development unit was completed in early 1975.

Davy Powergas, Inc., Houston, Texas, was the subcontractor selected for constructing the pilot plant methanation unit. The reactor for the unit has a diameter of two feet, is 15 feet high, and has a capacity of approximately two million standard cubic feet per day of feed gas. The unit is skid-mounted so that it can be shipped to and operated at any site that can provide a supply of synthesis gas.

All tasks under contract E(49-18)-1505 were completed during 1976 and work under contract E(49-18)-2036 was initiated. The Liquid Phase Methanation (LPM) pilot plant was completed and shipped to the IGT HYGAS plant in Chicago, Illinois. It was reassembled and shake-down operations begun. By the end of the year all systems had been checked out.

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

The liquid phase methanation (LPM) unit used HYGAS product as feed in the longest run to date in August. Catalyst carryover and/or attrition, as well as low catalyst activity, continued to be a problem during the quarter.

Pilot Plant Operations

Work at the beginning of the quarter was devoted to main process oil filter revisions including piping, insulation, and hydrotreating. During the first week of August, the entire system was filled with water and flushed. After inspection and modifications, the pilot plant was filled with Freezene -100 oil and heated to 500° F and 700 psi to check for leaks and to check out process instrumentation.

Run No. 3 began on August 22. Reactor conditions ranged up to 675° F and 750 psig. Carbon monoxide conversions ranging from 46 to 96 percent were obtained depending upon flow rates and reactor conditions. A limited process variable scan was conducted to determine catalyst activation energy, fluidization parameters, and the effects of other process variables on catalyst activity.

Feed gas to the LPM unit had a hydrogen to carbon monoxide mole ratio of 2.7 to 3.1 and contained small amounts of carbon dioxide and ethane as well as approximately 12 percent nitrogen and 28 percent methane. Methanation product had a methane concentration ranging up to 64 percent. Carbon monoxide conversions ranged up to 96 percent and selectivity to methane ranged from 85 percent at 657° F to 96 percent at 600° F. The remainder was mostly carbon dioxide resulting from shift reaction. Conversion of ethane in the feed was negligible.

While considerable information was gained from the run, catalyst carryover resulted in inaccuracy in the results. Measurements made at the end of the run revealed a settled bed height of 1.0 feet or 590 pounds. PDU fluidization studies with the catalyst showed that oil velocities must be maintained lower than originally anticipated to prevent catalyst carryover. Below 500° F, the catalyst used was easily carried out of the reactor with very low Freezene -100 flow rates.

The pilot plant was prepared for Run No. 4 in September. During the run, filter plugging was a problem and the run was terminated when a fire developed at a leaking flange. Inspection revealed no visible damage caused by the fire. Upon completion of shutdown, all lines were

flushed to remove catalyst deposit. Only 40 percent of the original catalyst bed remained at the end of the run.

Laboratory Studies

Testing of the catalyst used in the first two pilot plant runs during the last quarter was conducted in July on the bench-scale unit in order to determine if poor perfor-

mance was due to incomplete reduction and activation. Results showed that the reduction procedure was not a serious problem, but rather the poor gas distribution in the reactor was the major cause of lower catalyst activity.

A series of fluidization tests were performed in the PDU in order to provide some insight into the problems encountered with the runs during the quarter. The tests indicated that startup problems could be allowed by simply preheating the Freezene -100 to about 300°F.

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VIII. EVALUATION OF HIGH-BTU GASIFICATION PROJECTS

C. F. BRAUN AND COMPANY
ALHAMBRA, CALIFORNIA

Project Site: Alhambra, California
Contract No.: EX-76-C-01-2240
Contract Funding: \$5,729,518
ERDA: \$3,819,679
AGA: \$1,909,839

INTRODUCTION

Several high-Btu coal gasification projects are being evaluated by the engineering firm of C. F. Braun & Co. The project, initiated in March 1972, is sponsored by ERDA and the American Gas Association (AGA). ERDA is providing two-thirds of the funds and AGA, one-third.

The overall objective of the project is to monitor operations at the selected gasification pilot plants and determine the processes or individual unit operations most applicable for inclusion in a commercial facility. In addition, Braun is preparing a conceptual commercial process design for each of the selected processes using different coal feeds. These evaluations and concept designs will permit early identification of problem areas so as to develop solutions through accelerated mechanical development programs.

PROGRAM DESCRIPTION

The tasks performed by Braun fall into two general categories: technical evaluations and conceptual designs. The technical evaluations are being performed on the following pilot plants.

- HYGAS Steam-Oxygen
- HYGAS Steam-Iron
- Carbon Dioxide Acceptor
- Synthane
- BI-GAS

Braun monitors the operation of the plants and evaluates the plant performance as it relates to the achievement of operational objectives. Based on the evaluations, Braun provides recommendations to ERDA on any redefinition of effort related to the projects. Braun also provides assistance to operators for improving, changing, or adding equipment and procedures to more efficiently achieve the project objectives.

In addition to the evaluation of overall processes, Braun performs design review, data analyses, and engineering evaluations of proposals, cost estimates, and monthly reports to provide information considered essential to the overall objectives of the program. These reviews include in-depth component analyses and studies of specific conversion processes and subprocesses required to establish feasibility, safety, and applicability. The unit operations investigated to determine the most practical means of performing the operations in a demonstration or commercial facility include:

- coal preparation and handling
- coal pretreatment
- coal feed injection

- gas purification
- shift conversion
- methanation
- effluent treatment

In the area of conceptual designs, Braun is responsible for the development of conceptual commercial process designs for each of the gasification processes listed above using both Eastern and Western coals as feed and for Lurgi gasification plants as a basis for comparison. Factored estimates and gas cost calculations are also being developed for each of the process/feed combinations for comparison of gas costs with the Lurgi technology.

PROGRESS DURING JULY-SEPTEMBER 1977

In support of the technical evaluation effort, Braun engineers visited the HYGAS, Carbon Dioxide Acceptor, and BI-GAS pilot plants during the quarter. Arrangements were made to monitor the Synthane plant in the same manner as the other plants are monitored. Impact data for the conceptual design of commercial size plants were obtained by visits and phone monitoring.

Work also continued in process study areas during the period. The final Gas Purification report was submitted to ERDA-AGA. Work also continued on papers for the Ninth Synthetic Pipeline Gas Symposium. The paper on

Process Alternatives of Sulfur Management in Coal Gasification Plants was reviewed and drafts began on the paper for Acid Gas Removal and the panel presentation on methanation. Ten reports were submitted by Braun to the AGA project advisors for their review and comments.

Work began on Phase II of the Plant Size Study in September. All design work on the Steam-Iron and Koppers-Totzek processes was completed and reviewed. The safety analysis of the BI-GAS gasifier was completed and a report drafted. Testing of the vertical lift dryer at the BI-GAS plant also began.

During the quarter, the revisions of the commercial concept designs for the HYGAS, BI-GAS, and Synthane processes using Eastern coal was completed for the main process units, other than acid gas removal. Revisions were also completed on the Lurgi lignite commercial concept design for a mixed air and water cooling basis.

In September, a crash study of comparative gas costs for the Steam-Oxygen and Steam-Iron HYGAS processes was started for Eastern coal. The Steam-Oxygen-HYGAS gas cost basis was to be the-preliminary draft flow scheme, modified by the use of a more nearly optimized Selexol design, and water-cooled steam surface condensers. The basis for the Steam-Iron HYGAS gas cost was to be a Benfield unit for acid gas removal, water-cooled surface condensers, and a revised energy recovery system designed by Braun and based on Bechtel's review of the Steam-Iron factored estimate design.

IX. MOLTEN SALT GASIFICATION PROCESS

ATOMICS INTERNATIONAL DIVISION
ROCKWELL INTERNATIONAL CORPORATION
CANOGA PARK, CALIFORNIA

Plant Site: Santa Susana, California
Contract No.: EF-77-C-03-1429
Contract Funding: \$9,729,990
(100% ERDA)

INTRODUCTION

The molten salt coal gasification process is being developed by the Atomics International Division of Rockwell International Corporation. This 45-month project, initiated in March 1976, is sponsored by ERDA. Figure IX-1 shows the program schedule.

The objective of this project is to demonstrate the feasibility of the molten salt coal gasification process for use in environmentally-acceptable generation of electric power. Atomics International is to design and construct a process development unit (PDU) which will convert one ton of coal per hour to a non-polluting low-Btu fuel gas. The PDU will be located at the Santa Susana Test Site of Atomics International. In addition, Atomics International is to operate the plant to obtain data for evaluating the process and designing a full-scale commercial plant.

As part of the PDU development, Atomics International is also conducting experimental and analytical development work on an older reactor with a capacity of 470 pounds per hour operating to a maximum of three atm. Among the key areas being studied in this program are:

- Air and solids feed system design and operating parameters.

- Melt withdrawal and quench system design requirements.
- Entrainment of particulates in the product gas and purification requirements.
- Optimum sodium carbonate regeneration process flow scheme.

PROCESS DESCRIPTION

In the molten salt gasification process, coal is gasified to produce electricity through gas and steam turbines. Three major steps are required: (1) molten salt coal gasification, (2) electric power generation, and (3) sodium carbonate regeneration. Figure IX-2 provides a schematic of the process.

In the gasification section, coal and sodium carbonate are transported by compressed air (10-20 atm) into the bottom of the melt bed in the molten salt furnace. The molten pool is composed of sodium carbonate along with sodium sulfide, and sodium sulfate formed during the process. Gasification reactions (partial oxidation and pyrolysis) take place at 1800°F and 20 atm. The fuel gas produced has a heating value of approximately 150 Btu per standard cubic foot and is predominantly carbon monoxide, hydrogen, and nitrogen. Because the melt retains the ash and sulfur from the coal, the melt must be

PROJECT	FY 76	TR. QR.	FY 77	FY 78	FY 79	FY 80
PHASE I - PRELIMINARY ENGINEERING		△				
PHASE II - DETAILED ENGINEERING AND DESIGN		△				
PHASE III - PROCUREMENT		△				
PHASE IV - PLANT ERECTION			△			
PHASE V - STARTUP				△		
PHASE VI - OPERATION AND EVALUATION				△		

LEGEND : △ BEGIN MILESTONE
▽ COMPLETE MILESTONE

Figure IX-1. MOLTEN SALT GASIFICATION PROGRAM SCHEDULE

Figure IX-2. MOLTEN SALT GASIFICATION PROCESS SCHEMATIC

continuously withdrawn from the furnace so that fresh sodium carbonate can be added. The melt stream is subsequently regenerated.

The hot fuel gas from the molten salt furnace is combusted in a gas turbine which converts the energy of the fuel gas to electric energy. After passing through the turbine, the exhaust gas is used to produce steam for operating a steam turbine, thereby producing additional electricity. Flue gas (primarily carbon dioxide) leaving the boiler heats incoming combustion air and is then used for sodium carbonate regeneration.

In the regeneration section, the melt withdrawn from the molten salt furnace is transported to a quench tank where the salt is dissolved in water. The resulting slurry is then passed through a filter for removal of ash. The filtrate, containing dissolved sodium sulfide, is carried to the stripper where sulfur is stripped off as hydrogen sulfide and subsequently converted to elemental sulfur in a Claus plant. The remaining solution is carbonated, crystallized, centrifuged, dried in a rotary kiln, and recycled to the molten salt furnace as regenerated sodium carbonate.

The key advantages of the molten salt coal gasification process include the following:

- The process allows the use of a complete range of coal particle sizes, from $\sim 1/4$ in. down to fines. There is no requirement for close sizing of the coal, removal of fines, or coal pulverization. Only crushing is required to a size small enough to allow pneumatic transport of the coal ($< \sim 1/4$ in.).
- The process is well suited to the gasification of all types of coals, from anthracite through lignite. Pretreatment is not required for caking coals, and, therefore, there is no associated loss of heating value.
- The gasification is carried out in a thoroughly mixed, three-phase turbulent bed environment, allowing excellent temperature control and precluding the occurrence of hot spots.
- Practically all the sulfur and ash of the coal are retained in the melt, minimizing the requirements for product gas cleanup.
- The sulfur of the coal is recovered in elemental form, minimizing storage, handling, and marketing problems.
- The molten salt gasifier operates in a stable manner over a wide range of air and coal feed rates, indicating the potential for good load following capability.
- The overall process has a high thermodynamic efficiency.
- The process shows a good potential for the economic generation of electric power.

HISTORY OF THE PROJECT

Before December 1974 (when ERDA and industry began co-sponsoring the previous project), Atomics International did extensive experimental work to develop the molten salt combustion and gasification process. Tests were initially conducted in a laboratory-scale unit and then in a bench-scale combustor. The purpose of the experimentation was to determine combustion rates, conditions for obtaining different ratios of carbon monoxide to carbon dioxide, ash-melt interaction, ash capacity of melt, chemical reaction of sodium carbonate with ash, and suitable metal to withstand corrosion. The tests revealed that the combustion rates achieved for various feedstocks such as char, coal, coke, etc., with wide ranges of fixed carbon, volatile matter, sulfur, and ash contents were much greater than with conventional burning. In addition, the tests showed that the process was environmentally acceptable as well. Atomics International concluded that the molten salt process was sound and that a pilot plant should be constructed and operated to further explore and demonstrate its potential for commercialization.

To obtain the necessary design data for a pilot plant, Atomics International constructed a molten salt test reactor capable of processing 250 pounds of coal per hour. This reactor is eight feet high and has an inside diameter of three feet. Experimental and analytical development work was also conducted to provide design data and confirm key assumptions. Some of the areas investigated are:

- Effects of pressure on gasifier operation and performance.
- Air and solids feed system design and operating parameters.
- Melt withdrawal and quench system design requirements.
- Entrainment of particulates in the product gas and purification requirements.
- Optimum sodium carbonate regeneration process flow scheme.

In the previous project, the preliminary design of a pilot plant was completed during the third quarter of 1975 and the plant cost estimated. Because these new costs were considerably higher than the original estimates, alternative approaches were evaluated in order to select a program which would enable the objectives to be met at a lower cost. Based on these studies, it was decided to move the pilot plant from Norwalk Harbor, Connecticut, to the Atomics International (AI) field laboratory in Santa Susana, California. It was further decided that a one-ton-per-hour plant would be constructed rather than the

original five-ton-per-hour facility. During the first quarter of 1976, the proposal to construct the one-ton-per-hour plant was reviewed by ERDA and the development contract for the five-ton-per-hour facility was terminated.

Phase I, preliminary engineering, was completed in August 1976. It was decided that AI would be responsible for the entire detailed design and this work began in November.

PROGRESS DURING JULY-SEPTEMBER 1977

The selection of the balance of plant construction contractor was approved during the quarter, and the con-

tract awarded. Reviews of vendor data submittals continued throughout the quarter.

ERDA approval was received to procure the product gas combustor system from the selected vendor, and the purchase order placed. This is the last major process equipment item requiring procurement. Major effort during the quarter was expediting software submittals and scheduled delivery of hardware.

Fabrication of the quench tank was completed and the vessel delivered to the job site in September. Civil construction work was completed at the PDU site, including final grading and asphalt/concrete work, by the end of the quarter.

X. ADVANCED COAL GASIFICATION SYSTEM FOR ELECTRIC POWER GENERATION

WESTINGHOUSE ELECTRIC CORPORATION
LESTER, PENNSYLVANIA

PDU Site: Waltz Mill, Pennsylvania
Contract No.: EF-77-C-01-1514
Contract Funding: \$33,303,105
(through fiscal year 1977)
ERDA: \$29,303,105
Industry: \$4,000,000

INTRODUCTION

The advanced coal gasification system for electric power generation is being developed by Westinghouse Electric Corporation. ERDA is providing the major portion of the funds through the pilot development unit. Industrial contributions to date include expenditures of \$4 million as well as various related test facilities. The industry team is composed of the following firms:

Public Service Company of Indiana
Westinghouse Electric Corporation
Amax Coal Company
Bechtel, Incorporated
Peabody Coal Company/Kennecott Copper Corporation

The primary objective of this contract is to develop a fluidized-bed system for producing low-Btu gas from coal and apply the system to a combined-cycle electric generation system. Westinghouse is to:

- Conduct laboratory research to refine the advanced gasification process.
- Design and construct a process development unit with a capacity of 12 tons of coal per day.
- Operate the process development unit to establish the operating characteristics of the gasification system. This will provide data for developing scale-up

factors for the design and construction of a future 120-ton-per-day pilot plant.

The successful operation of the pilot plant will demonstrate the technical and economic feasibility of generating electric power from coal while meeting anticipated environmental emission regulations. The overall program is directed toward the operation of a combined-cycle power plant integrating a gasifier with a 130 Mw-range state-of-the-art turbine. The schedule for development of the advanced coal gasification system is provided in Figure X-1.

PROCESS DESCRIPTION

A schematic of the advanced coal gasification system for electric power generation is provided in Figure X-2. Production of low-Btu gas by this process requires completion of three operations: coal preparation, devolatilization-desulfurization, and gasification-combustion. In the coal preparation section, the coal is crushed to -6+100-mesh, dried, and transported to a reactor vessel for devolatilization-desulfurization and partial hydrogasification. A central draft tube is used primarily for recirculating solids. Recycled solids required to dilute the feed coal and temper the hot inlet gases flow downward in the fluidized bed surrounding the draft tube. The fluid-

PROJECT	FY 74	FY 75	FY 76	TR. QR.	FY 77	FY 78	FY 79
PROCESS DEVELOPMENT UNIT	BENCH STUDIES AND DESIGN		OPERATION

	PROGRAM STATUS AND FUTURE PLANS IN REVIEW						

LEGEND: $\triangle$ BEGIN MILESTONE
 ∇ COMPLETE MILESTONE

Figure X-1. ADVANCED COAL GASIFICATION PROGRAM SCHEDULE

Figure X-2. SCHEMATIC OF THE GASIFICATION PROCESS DEVELOPMENT UNIT

izing agent is a portion of the gases entering the unit. Recirculating solids have flow rates up to 100 times the coal feed rate to prevent the agglomeration of the feed coal as it devolatilizes and passes through the plastic or sticky phase. Dense, dry char collects in the fluidized bed at the top of the draft tube and is withdrawn at this point. Dolomite or calcium oxide (sorbent) is added to the

fluidized bed to absorb the sulfur present as hydrogen sulfide in the fuel gas. Spent sorbent is withdrawn from the bottom of the reactor and regenerated. Heat for devolatilization is supplied primarily by the high-temperature fuel gas produced in the gasifier-combustor. After separation of fines and ash, product gas is cooled and scrubbed with water for final purification.

Final gasification occurs in a fluidized-bed gasifier-combustor. Char from the devolatilizer-desulfurizer is burned with air in the lower leg of the gasifier at 1900-2000°F. to provide the heat for gasification. Heat is transported from the combustor to the gasification zone by combustion gases flowing upward and by char circulating between the combustion and gasification zones. Ash from combustion of fines agglomerates on the ash from the char and segregates in the lower bed leg for removal.

There are several advantages to the advanced coal gasification system for electric power generation. For example, the system:

- Uses a variety of coals, including caking and high-ash coals, without costly pretreatment.
- Utilizes a wide range of coal particle sizes without extraction of fines.
- Operates at high thermal efficiency.
- Reduces heat losses by conducting desulfurization at an elevated temperature.
- Produces a clean fuel that meets present and future environmental emission control standards.
- Reduces gaseous and particulate emissions from electric power plants.
- Eliminates the need for utility stack gas cleaning processes.

The potential economic advantages of the system include reduction of the rate of consumption of natural gas, environmental costs normally associated with cheap fuels, and the operating cost of an electric power generating plant by 20 to 30 percent.

HISTORY OF THE PROJECT

Initial development of the advanced coal gasification system involved laboratory research, including the design and construction of a process development unit. The process development unit was completed in 1974, and a test program was initiated to establish the operating characteristics of the system and provide data for developing scale-up factors for a pilot plant. Other laboratory research has involved:

- Fluidized bed desulfurization with dolomite.
- Development of scale-up design correlations for fluidized beds.
- Combustion of coal-derived fuel in diffusion-flame gas turbine combustors.
- Identification and testing of apparatus for high-temperature gas stream particulate control.

- Development of a specification for the tolerance of a modern utility gas turbine to particulates, vaporized alkali metals, and other gaseous contaminants.

In addition to laboratory research, work on developing conceptual designs of the combined-cycle generating plant was initiated in 1974. These designs will be used to estimate costs, system control requirements, mass balances, site requirements, etc., for a commercial-sized facility.

During 1975, the process development unit was modified and repaired. The modifications included the installation of a computer control and data monitoring system. Corrective designs were completed and modifications were made to various process and utility subsystems including the cooling water and waste handling subsystems. A number of design modifications were also made on the gas generator system.

Laboratory research in 1975 focused on providing design data for the process development unit, and on providing data and predicting operating conditions for the conceptual design of a commercial sized plant.

Studies of the gas turbine combustor system were performed to determine the operational conditions necessary to ensure efficient, stable, durable, and environmentally acceptable performance. Tests were conducted on two dual-fuel coal gas/distillate oil combustors. Combustion stability was studied by measuring carbon monoxide emissions. It was determined that moisture content affected combustion stability and consequently required regulation. A new second-generation combustor was designed on the basis of these tests.

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

During the quarter, three reactor design tests and one materials test were completed. The control of combustion in the unit was demonstrated; ash agglomeration and withdrawal was studied and successfully achieved; the reactor geometry was optimized to some extent; operating procedures were established; and the ability to achieve high fines utilization and high carbon utilization was demonstrated. The problem of ash build-up on vessel walls, outlet piping and the cyclone was being investigated. Design and procurement continued in preparation for integrated operation. Laboratory support studies continued the development of recommendations

on operating and design parameters for process development unit (PDU) tests.

Process Development Unit

Gasifier air tube evaluation tests with coke breeze continued in July. Test TP-012-3 was conducted with the air tube outlet positioned 36 inches below the inlet plane of the steam grid. A total of 80 hours of operating time was achieved; 41 hours was of steady state operation with continuous withdrawal of ash from the annulus. The test was terminated voluntarily when large agglomerates were observed in the sample taken from the bed. The one-inch diameter agglomerates were much larger than those found in previous tests and created problems in withdrawing bed samples.

Based on results from the previous three tests, the "optimum" location for the top of the air tube was selected as 15 inches below the grid plate for Test TP-012-4. The purpose of the test was to evaluate the air tube height at operating bed temperatures of 1900°F and 1950°F. During the test, 45 tons of -6 mesh coke breeze material was processed during 146 hours of sustained gasifier operation. An 80, $\pm$ 10 percent, ash content in agglomerates was achieved for 100 hours. No major hardware problems were encountered and the test was automatically shut down.

The first gasifier feedstock evaluation, Test TP-013-1, was conducted in August. The objectives were to study the effect of finer sized coke breeze feedstock, to assess process capacity for consuming recycled fines and to attempt, for the first time, to process PDU fines and FMC fines. Problems in the fines collection cyclone cut short the evaluation of the impact of char reactivity on the process using PDU fines.

The primary significance of the test was the demonstration that all fines elutriated from the reactor and collected in the cyclone could be recycled to the reactor without quenching combustion or interfering with ash agglomeration. During that period, the net fresh char feed to the reactor was 500 pounds per hour and the recycled

fines rate was from 600-800 pounds per hour. All fines were consumed and no net build-up in the system occurred. Although the ash particle size decreased slightly with the increased fines load to the reactor, ash concentration in the withdrawal stream remained at the nominal 80, $\pm$ 10 percent, set point.

Test TP-012-5 was conducted in September. The primary goal of this test was to examine operational techniques and reactor geometry modifications designed to lower the gasifier freeboard velocity and reactor heat load. Operational techniques explored included the use of air as a transport medium for the coaxial fines feed line. Replacing recycle gas as a conveying gas with air could result in substantial savings in reactor throughput. Other process benefits were reduction in solids carryover to the cyclone due to a lower freeboard velocity and better distribution of air in the reactor.

Design and procurement of hardware for integrated operation of the gasifier and devolatilizer reactors continued throughout the quarter.

Support Studies

Development of recommendations on operating and design parameters for PDU tests continued during the quarter. Particular parameters of interest were the gasifier air jet location, air jet velocity and flow, and steam distribution and flow. Data developed on the semi-circular model and PDU data were analyzed to develop recommendations for future tests. Work was initiated to develop an improved understanding of the reactor performance. Factors being considered include char particles heatup rate, combustion rate, and the effect of residence time on the jet location and jet character. Work was also carried out to develop an understanding of the mechanism of deposit formations observed in some PDU tests.

Tests on the semi-circular model during the quarter were directed toward the development of a distributor design for integrated operation. The experimental program on the kinetics of carbon gasification reactions with coke breeze neared completion.

XI. LOW-BTU GASIFICATION OF COAL FOR ELECTRICITY GENERATION

COMBUSTION ENGINEERING, INC.

WINDSOR, CONNECTICUT

Plant Site: Windsor, Connecticut

Contract No.: E(49-18)-1545

Contract Funding: \$24,609,084

ERDA: \$16,439,389

Industry: \$ 8,169,695

INTRODUCTION

A method for the production of low-Btu gas from coal for electricity generation is being developed by Combustion Engineering, Inc., under the sponsorship of ERDA and an industry team composed of Combustion Engineering and the Electric Power Research Institute. ERDA is providing two-thirds of the funds and the team, one-third. The overall objective of this program is an economical low-Btu coal gas to generate electricity in an environmentally acceptable manner, with a minimum of process development. Combustion Engineering is conducting a three-phase program involving the design, construction, and operation of a coal gasification pilot plant. The objectives of this program are to:

- Demonstrate the capability and suitability of the process and equipment to produce low-Btu gas of the predicted composition, heating value, and cleanliness from the design coal.
- Provide data to be used as the design basis for commercial-scale equipment that would process about 110 tons of coal per hour and result in an electrical generating capacity of 300 Mw.

Combustion Engineering also has a continuing research program to refine the process and verify its technical and economic feasibility. The schedule for development of this low-Btu gasification process is provided in Figure XI-1.

PROCESS DESCRIPTION

The Combustion Engineering gasification process is based on an air-blown, atmospheric-pressure, entrained-bed gasifier. A schematic of the process is provided in Figure XI-2. In the process, a portion of the pulverized coal and recycled char are fed to the combustion section of the gasifier and burned to supply the heat necessary for the endothermic gasification reaction. In the combustion section, nearly all of the ash in the system is converted to molten slag, which is then drawn off the bottom of the gasifier. The remainder of the pulverized coal is fed to the reduction portion of the gasifier where it is contacted with hot gases entering the reduction zone from the combustor. The gasification process takes place in the entrainment portion of the reactor where the coal is devolatilized and reacts with the hot gases to produce the desired product gas. This 1700°F product gas is then cooled to 300°F. At this point, the gas contains solid particles and hydrogen sulfide that must be removed. Solids are removed and recycled by means of a spray drier, cyclone separators, and venturi scrubbers. Hydrogen sulfide is removed and elemental sulfur is produced by the Stretford process. The clean low-Btu gas (127 Btu per standard cubic foot) can then be delivered to the burners of power boilers, gas turbines, or combinations of the two in a combined-cycle power generator.

Operating conditions will have a variety of effects on the cost and quality of the gas produced in this system.

Figure XI-1. LOW-BTU GASIFICATION PROGRAM SCHEDULE

Figure XI-2. SCHEMATIC OF LOW-BTU GASIFICATION OF COAL FOR ELECTRICITY GENERATION

For example, oxygen could be substituted for air in the gasifier combustor, thereby increasing the heating value of the product gas from 127 to 285 Btu per standard cubic foot. Conversely, this change will also increase the cost of producing the gas, depending on the price of oxygen and the quantity used.

The value of the atmospheric gasification system is that development work is only necessary on the opera-

tion and control of the gasifier. All other components are commercially available items with predictable operating characteristics.

HISTORY OF THE PROJECT

Initial work on the development of a system for the low-Btu gasification of coal for electricity generation

involved the economic evaluation of various coal gasification and energy conversion systems for the production of electricity. The primary criterion for the systems selected was the maximum use of proved processes. Of the systems selected for use in this process, the only unproved component was the gasification process. All other components were of established and proved design.

Two gasification processes, differing only in operating pressure, were considered: one at atmospheric pressure and the other at ten atm. It was determined that if the gasification pressure were increased from one to ten atm the total plant cost would be reduced by eight percent. This savings results from the ten-fold reduction of gas volume and, hence, equipment size. Conversely, much of the process simplicity would be lost and additional development would be required for:

- Lock hoppers for feeding solids into pressure vessels.
- A more complex gasifier to withstand more severe operating conditions.
- Heat exchangers to withstand greater erosion due to higher solids concentration in the gas stream.
- Techniques for char recovery at elevated pressures.
- Processes for removal of liquid slag from the pressurized gasifier.

Because of these complications, entrainment gasification of coal at atmospheric pressure was the process selected for development. The gasifier may be air blown or oxygen blown, depending on the particular requirements of the plant in which it would be installed. It was determined that the air-blown version would be developed initially because it appeared to be the most economical for application to the majority of electric power plants.

Design of the process development unit began in 1974. The unit, located at Windsor, Connecticut, has a capacity of five tons of coal per hour. The objectives of this phase included (1) development of component and process concepts and details necessary for the design and operation of gasification systems of this type and (2) completion of the engineering required for construction of the unit.

By the end of 1975, the designs of many of the subsystems were nearly completed, and request for quotations

were issued for various components. About 30 percent of the major equipment for the process development unit had either been approved for purchase or released for fabrication by the end of 1975. Plot plans and general equipment arrangements were completed, and preparation of the construction site for excavation and foundation installation was started. Some work had been done on establishing operating procedures and developing a test plan for evaluating the performance of the gasifier during steady state operation. Construction was completed in Fall 1977 and operations are expected to continue until early-1978.

Laboratory research during 1975 included the investigation of various refractories with slag and gas and the development of a one-third scale plastic model for studying stream flow patterns. A mathematical analysis of the gasifier was carried out through the use of computer modeling of the unit. Plant metallurgical requirement studies and environmental studies were also conducted. Supporting studies consisted mainly of an analysis comparing the costs of producing electricity by various integrated gasification power plant systems. Two alternatives were selected for further study: a conventional steam plant with an atmospheric gasifier and a combined-cycle plant with a supplementary-fired boiler and atmospheric gasifier. In addition, specifications for an automated data-acquisition and reduction system were completed.

PROGRESS DURING JULY-SEPTEMBER 1977

Construction of the pilot plant was substantially completed by the end of the quarter. The remaining heat tracing, insulation, and nitrogen purge piping will not delay plant startup and should be completed by mid-November. The plant was accepted as complete from the major mechanical, electrical and instrument/control construction subcontractors.

Plant startup activities progressed well during September to the point where firing the gasifier with coal was expected during the last week of October or the first week of November.

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XII. LOW-BTU FUEL GAS (TRI-GAS PROCESS)

BITUMINOUS COAL RESEARCH, INC.
MONROEVILLE, PENNSYLVANIA

Plant Site: Monroeville, Pennsylvania
Contract No.: EF-77-C-01-1527
Contract Funding: \$2,690,000
(100% ERDA)

INTRODUCTION

Bituminous Coal Research (BCR) is developing a multiple fluidized-bed coal gasification process for producing low-Btu fuel gas from caking and noncaking coals. The project is being sponsored by ERDA. The low-Btu fuel gas product will be suitable primarily as boiler fuel gas for electricity generation, although alteration of operating conditions could yield medium-Btu gas suitable for other uses. The research task includes the design, construction, and testing of a process development unit, and laboratory investigations. The schedule for development of the low-Btu fuel gas system is shown in Figure XII-1.

PROCESS DESCRIPTION

The BCR low-Btu research effort is based on a three-stage fluidized-bed gasification process. Stage 1 of the three-stage system receives the raw coal and functions as the pretreatment step in which the coal is devolatilized. Stage 3 flue gas is used as the fluidizing medium for Stage 1. The coal then flows by gravity to Stage 2, where devolatilized coal is gasified with air and steam to generate the desired product gas. Stage 1 flue gas is fed to Stage 2 where the entrained tars and oils are gasified. The remaining char from Stage 2 is consumed in Stage

3 by fluidized combustion. The ash discharged will contain only a minimum amount of carbon.

The advantage of this process is that both caking and noncaking coals can be used. In addition, low-Btu fuel gas is the only product; no wastes or by-products such as tars and oils are produced. The end use of the gasification product dictates the operating conditions as well as the gasifying medium. For example, gasifying with air and steam will yield a low-Btu fuel gas, and gasifying with oxygen and steam will yield a medium-Btu gas.

HISTORY OF THE PROJECT

Initial development of the low-Btu fuel gas process involved laboratory investigations to obtain kinetic data for various chars, or devolatilized coal, that would be produced in the first step of a multiple fluidized-bed gasification process. A small fluidized-bed batch reactor system was then used to verify proposed rate equations, determine the reaction rate between steam and char, and provide physical data such as minimum fluidizing velocity, attrition rate, elutriation losses, etc. The successful laboratory studies led to the design of a process development unit with a capacity of 100 pounds of coal per hour. The design and definitive costs estimates were completed in December 1972. Responsibility for constructing the unit at BCR's Monroeville, Pennsylvania, laboratory

LEGEND:

- BEGIN MILESTONE
 COMPLETE MILESTONE

Figure XII-1. LOW-BTU FUEL GAS PROGRAM SCHEDULE

was awarded to Blaw-Knox Chemical Plants Division of Dravo Corporation, and construction was completed in September 1975.

Mechanical checkout and pressure testing of the system was completed during the fourth quarter of 1975, and operation of the unit was started. A variety of problems were encountered during the pressure testing and start-up operations, however, most of these have been resolved. Pretreatment testing of a Western noncaking coal (Montana Rosebud) was completed in the Stage 1 reactor. Correlations were developed for the properties of the product char as a function of Stage 1 operating temperature. Subsequently, testing of a caking coal (Illinois No. 6) was conducted in the Stage 1 reactor. A noncaking product char was obtained at pretreatment temperature of less than 800°F and in the presence of oxygen. Further testing at 900°F to 1000°F demonstrated the ability to devolatilize the coal while avoiding caking. The product char from this testing was free flowing and did not cake when subjected to laboratory testing at Stage 2 operating temperatures. A data-acquisition system was installed to sample selected test points, convert the data to engineering units, and store the values on magnetic tape.

Concurrent with the construction effort, BCR is conducting laboratory research in an effort to further refine the low-Btu fuel gas process. During 1975, laboratory research included using a cold flow model of the gasifier bed to study bed fluidization. Fluidization was improved when a 45-degree conical, rather than flat, distributor was installed in conjunction with special nozzles that

direct the fluidizing gas downward toward the distributor base and horizontally toward adjacent nozzles. Among other fluidization studies were those to observe the behavior of char in a fluidized bed, determine whether the purge flows on the pressure taps were necessary, and study the effect of purge flows on pressure drop in the unit. A computer model to predict the conversion in the fluidized-bed gasifier was also developed. The results showed the effects of mass diffusion and bubble diameter on conversion and product gas concentration.

PROGRESS DURING JULY-SEPTEMBER 1977

During July, two tests were completed in the PEDU. The first of these, Test No. 3S-6, was a carbon burnup test in the Stage 3 reactor. Test 3S-7, a three-stage test, was the first test in which the Stage 1 preheater was used. About 800 pounds of coal were treated in Stage 1 and partially gasified in Stage 2. The test was terminated when tar condensed in the Stage 1 gas exit line.

Two tests were conducted in the PEDU during August. Test 3S-8 was conducted in Stage 3 alone. The purpose of the test was to see if the elutriation rate from Stage 3 could be reduced by reducing the fluidizing velocity. Elutriation was successfully reduced, but some agglomeration of the ash was evident at the lower flow rates.

In an integrated three-stage test, Test 3S-9, about 300 pounds of coal were fed and treated in Stage 1. After a blockage occurred in the Stage 1 gas exit line, Stage 1

was isolated from the rest of the system. The tests continued in the gasification (Stage 2) and carbon burnup (Stage 3) reactors until reactions could no longer be supported. Following the test, all three reactors were completely inspected. A slight amount of ash agglomeration

was evident in Stage 1 reactor. No agglomeration was evident in either Stage 2 or Stage 3 reactor. Extensive equipment modification was performed on the PEDU during the remainder of the quarter to eliminate the plugging problems encountered in the last test.

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XIII. THE COAL CONVERSION SYSTEMS TECHNICAL DATA BOOK

INSTITUTE OF GAS TECHNOLOGY
CHICAGO, ILLINOIS

Contract No.: E(49-18)-2286
Contract Funding: \$840,000
(100% ERDA)

INTRODUCTION

The Coal Conversion Systems Technical Data Book is being prepared by the Institute of Gas Technology (IGT) under ERDA sponsorship. The overall objective of this project, initiated in October 1974, is to provide a single, comprehensive source of data on coal conversion systems. IGT is to provide up-to-date information for the research, development, design, and engineering of coal conversion processes and/or plants. In addition, IGT is to identify those areas where data are required and to suggest research programs that will provide the necessary data not available otherwise. The data book will be published with a loose-leaf binding, and loose-leaf sheets will be published periodically for the timely distribution of new and revised data.

PROGRAM DESCRIPTION

IGT's tasks involve collecting information from published literature and reports submitted by ERDA's contractors. The data are then surveyed, compiled, evaluated, correlated, and prepared in a form most useful to scientists, designers, and engineers involved in coal conversion activities. Initially, IGT is concentrating on publishing critical data that are not readily available. As the need for the more urgent and unique material is fulfilled, previously published material will be updated and added to the book.

The outline of the data book is shown below:

- Section I: **PROPERTIES OF PROCESS MATERIALS**
 - A. Properties of Gasification Products
 - B. Properties of Intermediates and Conversion Products
 - C. Properties of Related Processing Products
- Section II: **SOLIDS STORAGE, PREPARATION, HANDLING AND PRETREATMENT**
 - A. Coal Storage and Handling
 - B. Coal Preparation
 - C. Weighing and Metering of Solids Flow
 - D. Feeding of Solids
 - E. Chemical Treatment of Coal
- Section III: **CONVERSION FUNDAMENTALS**
 - A. Gasification
 - B. Pyrolysis
 - C. Liquefaction
 - D. Fluidized-Bed Combustion
 - E. Advanced Power Generation
 - F. Chemical Equilibrium and Heats of Reaction
- Section IV: **DESIGN PROCEDURES**
 - A. Conversion Tables and Constants
 - B. Fluidization
 - C. Fluid Flow
 - D. Heat Transfer
 - E. Phase Separations
 - F. Integrated Reactor Design

Section V: SUPPORTING PROCESSES

- A. Gas Treating
- B. Gas Purification
- C. Shift Conversion
- D. Methanation
- E. Environmental Control

Section VI: MISCELLANEOUS PRODUCTS

- A. Methanol
- B. Acetylene
- C. Ammonia
- D. Plastics

Section VII: MATERIALS OF CONSTRUCTION

- A. Refractories
- B. Ceramics
- C. Metals and Alloys
- D. Plastics

Section VIII: EQUIPMENT SPECIFICATIONS

Section IX: PROCESS ECONOMICS

- A. Cost Data
- B. Costing Procedures

Section X: PROCESS FLOW SHEETS

- A. Liquefaction
- B. High-Btu Gasification
- C. Low-Btu Gasification
- D. Fluidized-Bed Combustion
- E. Advanced Power Generation

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

Work on the Properties of Process Materials included various correlations for estimating the calorific value of coal from its elemental composition. Conversion Funda-

mentals dealt with characterization of products of pyrolysis. Design procedures investigated gas-solids transport and heat-transfer correlations.

Properties of Process Materials

Various correlations for estimating the calorific value of coal from its elemental composition were evaluated using an extended data base of American coals.

Conversion Fundamentals

Tar and light oils produced by pyrolysis were characterized and a summary of Fischer Assay data for various coal types was presented. A correlation between tar-plus-light oil yield and total conversion for pyrolysis of Western coals and lignites was also presented. Equilibrium constants for various reactions encountered in coal conversion processes were discussed as was the fate of trace elements in coal gasification.

Design Procedures

Gas-solids flow in horizontal pipes was reviewed and various saltation velocity correlations described. The work in heat transfer to coal-solvent slurries continued with experimental and calculated fluid temperature profiles in coal-slurry heaters compared for a low solvent/coal ratio. Heat transfer coefficient curves as functions of temperature for various solvent/coal ratios and fluid velocities were presented.

Materials of Construction

Results of tests to evaluate performance of insulating materials in coal conversion reactors were presented.

XIV. COMPUTER MODELING OF COAL GASIFICATION REACTORS

SYSTEMS, SCIENCE, AND SOFTWARE
LaJOLLA, CALIFORNIA

Contract No.: E(49-18)-1770

Contract Funding: \$1,270,000
(100% ERDA)

INTRODUCTION

Under the terms of this ERDA contract, Systems, Science, and Software (S³) is to develop a general computer model of coal gasification reactors. The model will combine theoretical descriptions of the thermomechanical interactions between the solid and gas phases with a kinetic model of chemical reactions based on the best experimental data available at the time of program development. The model will be used to expedite the development, aid in optimization, and assist in the scale-up of coal gasification reactors. The model will first be applied to high-Btu fluidized-bed gasification processes and later expanded to include low-Btu fluidized-bed reactors, entrained-flow reactors, and fluidized-bed combustors.

PROGRAM DESCRIPTION

This project began in June 1975 and will require three years to complete. Work during the first year dealt with multiphase fluid flow without chemical reactions and heterogeneous chemical reaction without fluid flow. The objective of these studies was to establish a firm theoretical description of the thermodynamics, hydrodynamics, and chemical behavior of high-Btu gasification reactors through the development of computer models of the essential features of the processes. The results of the studies will then be compared with experimental meas-

urements and the optimum mathematical formulations will be used in the model. The specific goals of the first year's research are:

- Problem formulation, documentation, and information gathering.
- Development of a one-dimensional fluidized-bed model and computer program.
- Development of a two-dimensional fluidized-bed model and computer program.
- Development of a boundary layer model and computer program.
- Development of a chemical reaction model and computer program.

During the second and third years, the computer model will be expanded to apply to high-Btu gasification, low-Btu gasification, and entrained-flow processes. The computer programs developed during the first year will be combined and the resulting prototype programs will be used to verify the accuracy of the formulations and provide preliminary results relevant to coal gasification. A boundary layer formulation will be incorporated into the model and tested on configurations of various dimensions. A method to describe particle size distributions will be developed and integrated into the two-dimensional thermomechanical-chemical model, with heterogeneous chemistry coupled directly to the heat and mass transfer processes. The model will be verified using pilot plant data and applied to specific problems of interest to ERDA. The computer model will then be developed further to include three-dimensional effects, internal heat transfer surfaces, and combustion chemis-

try, so that it can be applied to the broad spectrum of fluidized-bed and entrained-flow processes being considered for coal conversion and utilization.

HISTORY OF THE PROJECT

Work during 1975 was primarily directed toward formulation programming of the one (spatial) dimension (axial distance and time) model for the fluidized bed. This model was completed in 1976 and consisted of a set of differential equations for the conservation of solid mass, conservation of gas mass, conservation of solid momentum, conservation of gas momentum, and conservation of energy.

A 5000 Fortran statement program was written for the two-dimensional model. A program was also written for the model of chemical reactions in the fluidized bed, allowing for a variety of gas and solid feeds to the bed and including the kinetic equations for the reactions.

In April 1976, the basic structure of the chemistry code for the carbon dioxide acceptor process was com-

pleted. When tested against data from the carbon dioxide acceptor plant in Rapid City, South Dakota, the steady state calculated results were in good agreement.

PROGRESS DURING JULY-SEPTEMBER 1977

The programming of the chemistry and transport for steam-oxygen gasification was completed during the quarter. Kinetics and heterogeneous reaction models for the combustion reactions have been incorporated into the code. In addition, the numerical structure for the slower gasification reactions was finished.

A fundamental study of heterogeneous and homogeneous reactions for char particles in an oxidizing environment was continued with the major goal of the investigation to determine the nature of reaction rate control.

A three dimensional version of the entrained flow model was completed and test calculations of individual subroutines in that code were initiated. The formulation of a model for devolatilization of coal was continued during the quarter.

XV. MODIFICATION AND OPERATION OF AN ATMOSPHERIC PRESSURE ASH-AGGLOMERATING GASIFIER

INSTITUTE OF GAS TECHNOLOGY
CHICAGO, ILLINOIS

Project Site: Chicago, Illinois
Contract No.: E(49-18)-2336
Contract Funding: \$2,484,318
(100% ERDA)

INTRODUCTION

A seven-ton-per-day process development unit, previously operated by IGT under the HYGAS program, demonstrated the operability of the ash-agglomerating process on coke feedstock. Under the current program, the gasifier will be modified to process coal feed. The specific objectives of the contract are to:

- Demonstrate the use of the ash-agglomerating gasification process in the production of low-Btu gas from coal at high carbon utilization rates for extended periods of time.
- Provide design and cost estimates for both a commercial-scale atmospheric pressure gasifier and a pilot-scale pressurized gasifier.

The 22-month program is divided into the following four tasks:

- Modification and shakedown of the existing gasifier, including the addition of a thermal oxidizer.
- Operation of the process development unit for up to 30-day test periods.
- Preparation of design and cost estimates for a commercial-size atmospheric pressure gasifier.
- Preparation of design and cost estimates for a pressurized test gasifier capable of operating in the 100-350 psi range.

Figure XV-1 provides a schedule for the ash-agglomerating gasification development.

Figure XV-1. ASH-AGGLOMERATING GASIFICATION
PROJECT SCHEDULE

PROCESS DESCRIPTION

The ash agglomerating gasification process uses a single-stage fluidized-bed reactor which incorporates an ash-agglomerating technique to achieve high carbon utilization and simple residue handling. The process has been previously tested at atmospheric pressure with coke breeze and char as feedstocks. A flow diagram of the process is shown in Figure XV-2.

Figure XV-2. ASH-AGGLOMERATING GASIFICATION PROCESS SCHEMATIC

Coal is first crushed to $\frac{1}{4}$ -inch. Coal of any rank may be used, but caking coals may require pretreatment by contacting with air in a fluidized bed at temperatures in the range of 700-800°F. The coal is introduced into the gasifier, where it is reacted with steam and air (or oxygen) in a single-stage fluidized bed at a temperature of approximately 1900°F. Residence time in the reactor is on the order of 45 minutes with a fluidizing velocity of 1.0-2.5 feet per second. While in the gasifier, the ash is agglomerated into progressively larger and heavier particles, thus facilitating selective separation from the bed. Fines which are elutriated from the bed are returned to the gasifier through both internal and external cyclones. The low-Btu gas generated in the gasifier is subsequently combusted in a thermal oxidizer.

capacity coincident with an allowable maximum inert conveying gas requirement. As a result of the test program, it was decided to install a two-foot-long horizontal section of L-valve as part of the modifications to the reactor feed system.

The shop-fabricated four foot-diameter cold model of the ash-agglomerating gasifier reactor was erected and modifications completed in November. The model will be used to study the fluidization and agglomerating zone dynamics at ambient temperatures.

The design of the 85 foot-high 100-ton silo was completed, and the silo fabrication started with delivery anticipated in January of 1977.

HISTORY OF THE PROJECT

The Institute of Gas Technology was awarded the contract in June 1976 and began modification of the existing gasifier equipment.

An L-valve type feeder system with no mechanical parts that could be damaged by the high-temperature fluidized bed was chosen to feed coal directly into the high-heat content bed. A study was conducted to ascertain whether the L-valve had a sufficient range and

PROGRESS DURING JULY-SEPTEMBER 1977

Summary

Work continued during the quarter using successively coarser fractions of subbituminous coal; fractions up to one inch in size, to determine if size requirements govern ash agglomerating conditions. Complete gasification of coal was accomplished using a 100 percent air gasification medium as well as air-steam mixtures.

Discussion of Activities

The first coal test run, Run 105, was completed in July. The run was conducted in the steam oxygen mode and produced a 222 Btu per cubic feet gas at approximately 1500°F. No ash agglomerates were produced due to the difficulty of sustaining steady-state operation because controllability of the L-valve feeder was undependable. Numerous feed interruptions occurred, but no tars or condensables were evolved, as fuel gas was produced from the direct feeding of subbituminous coal to the gasifier. All feeding was undertaken through the L-valve leading directly into the bed. Condensable free fuel gas production was verified by an examination of the downstream fines collectors and by analysis of the fines.

Test work was suspended during the last half of July because of the annual IGT Pilot Plant facilities turn-around. During that period cold test work was conducted on the L-valve to achieve flow controllability.

Run 106 was conducted continuously for 30 hours in August, with the L-valve feeding coal directly into the fluidized bed. The test was terminated by a blockage in the L-valve line. It showed that reactor operation could be sustained even though air alone was the gasification medium. The use of air produced bed temperatures near 1700°F. The additional gas produced due to the higher feed rates caused the internal cyclone to develop a hole in

its shell by erosion. The shell was replaced and the inlet redesigned before starting Run 107.

The procedure planned for Run 107 was essentially the same as for Run 106 with the exception that start-up coke feeding was to be continued until ash agglomerates formed. When ash agglomerates were produced using coke, the process was switched to coal feed. Rocks and foreign material created numerous L-valve feed interruptions, and the feed was diverted to the freeboard feed chute to maintain gasification. Though feeding in this manner for eight hours, no evidence of tars or condensibles was found either in the dust collected or on the surfaces of the downstream equipment.

Three tests were started during September, but only during one, Run 108, was subbituminous coal fed to the reactor. In both of the other two runs, 109 and 110, the tests had to be terminated due to defluidization because the start-up coke received from the supplier contained excessive amounts of oversize particles and thereby exceeded the reactor's fluidization velocity capabilities. Run 108 was a 58-hour gasifier test run, operated entirely by air gasification. The 1650°F operating temperature of Run 106 was duplicated. The run verified previous data that the elutriated fines contained most of the ash feed. There were no accumulations of ash or tar in any section of the reactor, quencher, or dust collection equipment.

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GLOSSARY

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

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

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

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

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

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

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

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

API — American Petroleum Institute.

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

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

ash — solid residue remaining after the combustion of coal.

ASTM — American Society for Testing Materials.

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

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

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

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

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

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

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

BTX — benzene, toluene, xylene; aromatic hydrocarbons.

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

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

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

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

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

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

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

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

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

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

coalification — metamorphosis of vegetable debris into coal.

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

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

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

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

combustor — a vessel in which combustion takes place.

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

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

crude gas — impure gas produced in a gasifier.

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

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

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

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

deminerallization — 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.