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MORGANTOWN ENERGY TECHNOLOGY CENTER
TOPICAL REPORT

SURFACE COAL GASIFICATION

Gasification Development Section
Gasification Projects Branch
Coal Projects Management Division

This overview report, prepared by Morgantown Energy Technology Center staff, describes the historical development, current status, and technology crosscuts of the Surface Coal Gasification Program.

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1.0 INTRODUCTION

1.1 Program Perspective

Vast deposits across the United States make coal this nation's most abundant energy resource. Coal provides a valuable potential capability for offsetting anticipated petroleum and natural gas supply shortages through its conversion to alternate hydrocarbon liquids and gases. Coal gasification provides an easily transported, environmentally acceptable, and extremely versatile product. When fully developed, it will provide the means to convert American coals into clean, gaseous fuels for combustion, power generation, and cogeneration systems; synthesis gas for subsequent conversion into liquids ranging from chemical feedstocks to high-grade transportation fuels; and substitute natural gas (SNG) for pipeline distribution as shown in Figure 1.

The basic chemistry of coal gasification is simple and fairly well understood. Over the past century, simple gasifiers have been built and operated to yield a product suitable for fuel or chemical intermediary uses. However, existing "first generation" gasifiers (predominantly European, such a Lurgi, Koppers-Totzek, and Winkler) and "older generation" atmospheric pressure fixed-bed gasifiers (Wellman-Galusha, Wellman Incandescent, STOIC, et cetera) have limited throughputs, low conversion efficiencies, relatively high capital costs, and generally utilize carefully selected and prepared coals which do not cake or swell. Unfortunately, the coal resource base of the United States is characterized by a wide variety of coals. These range from lignite to anthracite and do not possess "select" characteristics which are ideal for coal gasification processes. These coals contain agglomerating as well as non-agglomerating species and vary in degree of associated volatile matter present, carbon content, sulfur content, ash content, reactivity, and propensity for swelling.

The United States Department of Energy (DOE) has recognized the technological deficiencies in existing gasifiers and associated process systems and the dilemma facing American industry in developing improved gasification systems for ill-defined markets. The DOE has, therefore, continued to sponsor development of advanced coal gasification processes, through the process development unit (PDU) stage, under the Surface Coal Gasification Program. Additionally, the DOE has initiated efforts to utilize these existing PDU's as test facilities for studying solutions to more generic gasification problems such as improving process efficiencies, economics, waste management, and coal fines handling. Private sector participation has been sought in individual projects to increase the impact of Government expenditures, to aid technology transfer, and to focus Government efforts toward activities which the private sector will ultimately support totally.

1.2 Program Objectives

The overall Surface Coal Gasification Program goal is to promote and assist in the development of an economically attractive and environmentally acceptable synthetic gaseous fuel and chemical feedstock technology. This goal is to be accomplished through research and development projects which will investigate potentially high-payoff areas that are too long term or high risk for private sector Research and Development (R&D) investments. The technical objectives of the Surface Coal Gasification Program will primarily center on novel process concepts. These concepts will be demonstrated and documented through the smallest necessary scale of experimentation.

The long-term goal of coal processing research is high overall thermal efficiency (at least a 5 percent improvement) and lower potential product cost (at least a 20 percent improvement) when compared with first and second-generation gasifier systems.

The three primary objectives of the program are as follows:

- Develop a strong engineering technology data base that could support activities leading to the design and/or optimization of gasifier systems and enhance private-sector commercialization.
- Evaluate the technological and economic status of advanced and novel processes or improvements over the state-of-the-art systems. Assess their suitability for meeting U.S. market needs and environmental requirements using both caking and non-caking domestic coals to produce (1) SNG; (2) gaseous fuels for power generation or industrial fuels; and (3) synthesis gas intermediate for chemical feedstocks, methanol, and gasoline.
- Establish availability, by supporting the development of cleanup equipment, components, and systems suitable for use in coal gasification processes to the extent that concepts can be proven.

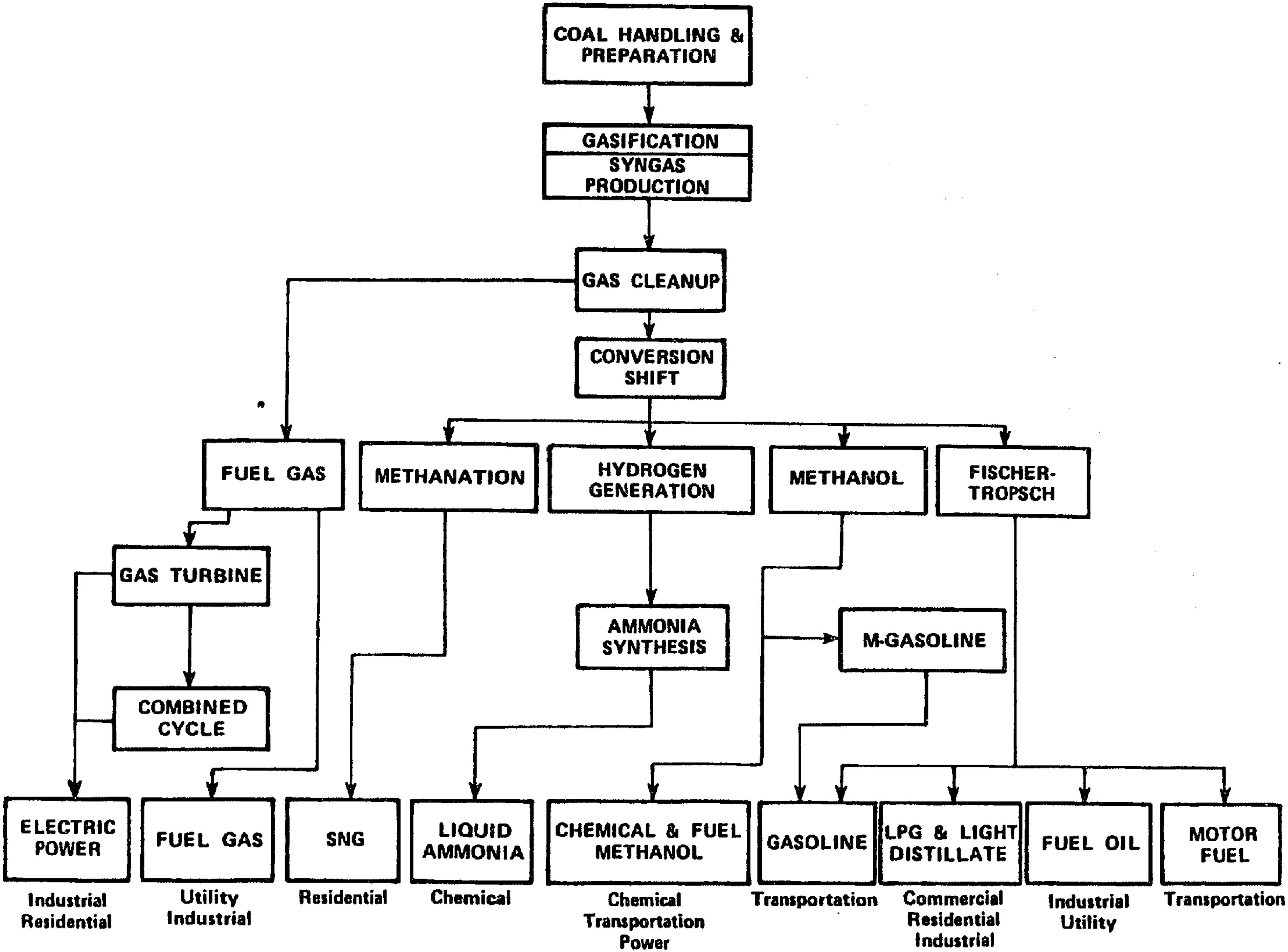

FIGURE 1. FLEXIBILITY OF COAL GASIFICATION

To meet these objectives, eight process development activities are being conducted under the Surface Coal Gasification Program. The following list of sections describe these development activities:

- 2.0 Bi-Gas, Two-Stage Entrained-Flow Gasification.
- 3.0 Westinghouse Ash-Agglomerating Fluid-Bed Gasification.
- 4.0 Mountain Fuel Resources Entrained-Flow Gasification.
- 5.0 METC Dry-Bottom Fixed-Bed Gasification.
- 6.0 GFPO Slagging Fixed-Bed Gasification.
- 7.0 General Electric Fixed-Bed Gasifier and Performance Evaluation Facility.
- 8.0 MIFGA Fixed-Bed Gasifier.
- 9.0 CAN-DO Fixed-Bed Gasifiers (Gasifiers-in-Industry Program).

1.3 Summary of Physical Facilities

The eight major DOE test facilities associated with the Surface Coal Gasification Program are intended to complement each other and provide the Government with proof-of-concept capabilities in a broad range of coal gasification, waste management, and product utilization technology areas. Detailed descriptions of the associated activities are presented in Sections 2.0 through 9.0. However, the test facilities, which are in place and operational, can be briefly summarized as follows:

- The Bi-Gas entrained-flow gasification pilot plant is located near Homer City, Pennsylvania. This plant features a 24 -inch inside diameter (ID), two-stage, upflow, high-pressure (to 1,500 pounds per square inch [psi]) gasifier with char recycle between the stages. The 120 tons per day (tpd) facility includes a rod mill for wet-grinding the feed coal, a slurry dryer and feed system, and a complete gas treatment and cleanup system including quench, shift, and methanation units along with Selexol H_2S and CO_2 removal and Claus sulfur recovery.
- The Westinghouse agglomerating-ash fluidized-bed PDU is located at the Westinghouse Waltz Mill Site near Madison, Pennsylvania. The gasifier is a nominal 24-inch ID, 24-tpd reactor designed to operate at up to 315 psi. Entrained fines are collected externally and recycled. The facility contains two water-quench scrubbers for contaminant removal and a thermal oxidizer for product gas disposal.
- The Mountain Fuel Resources (MFR) entrained-flow PDU is located in West Jordan, Utah. The gasifier is a 16-inch ID, downflow, oxygen-blown reactor which includes a reaction chamber and a primary radiant heat exchanger. It is designed to operate at 315 psi with a 36-tpd capacity. Product gas provides heat to a steam superheater prior to being cleaned via water quench scrubbing. Completed in late 1982, this is the newest of the DOE supported Surface Coal Gasification test facilities.
- The Morgantown Energy Technology Center (METC) pilot plant is located in Morgantown, West Virginia. This test facility includes a 24-tpd, 300 psi, fixed-bed, dry-bottom gasifier. This 42-inch ID reactor is a stirred-bed unit, and both the stirrer and gasifier vessel are water cooled. The gas cleanup system is a novel dry tar removal approach which is aimed at being universally applicable to all coals, minimizing waste-water treatment requirements and providing simpler and more reliable operational modes. Additionally, this facility features a Stretford sulfur removal system which will remove hydrogen sulfide in the cleaned gas stream to within a few parts per million (ppm).
- The Grand Forks Project Office (GFPO) pilot is located in Grand Forks, North Dakota, and features a 24-tpd, 400 psi, slagging, fixed-bed gasifier. The 22-inch ID unit is refractory lined with exterior water cooling and is equipped with a bed stirrer for operation with caking coals. The facility also contains provisions for washing and scrubbing the product gas.
- The General Electric (GE) air-blown, fixed-bed gasification system is located at GE's Research and Development Center in Schenectady, New York. This facility contains a 24-tpd, 36-inch ID, stirred, dry-bottom gasifier somewhat similar to that at METC. However, the gasifier is completely refractory lined with no water-cooling jacket. GE's gas cleaning system also differs considerably from the METC approach in

that it is similar to the more conventional Lurgi-type system and includes a Benfield H_2S absorber.

- The Mining Industrial Fuel Group (MIFGA) gasifier is located in Minneapolis, Minnesota, and is sponsored by a cooperative Government and MIFGA industry group made up of 22 industrial partners, the U.S. Bureau of Mines (BOM), and DOE. This facility contains a 6.5-foot ID, atmospheric pressure, air-blown Wellman-Galusha gasifier with a rotary kiln and combustor to evaluate the combustion characteristics of low-Btu fuel gas. A water quench unit, electrostatic precipitator, and Stretford desulfurization system are installed on a gas sidestream.
- The Community Area New Development Organization (CAN-DO) plant is comprised of two, 10-foot diameter, atmospheric pressure, air-blown Wellman-Galusha gasifiers. Each unit consumes 24-tpd, pea-sized anthracite coal to produce 1 billion British thermal units (Btu) per day of low-Btu gas which is sold to residents of the Humboldt Industrial Park in Hazelton, Pennsylvania.

1.4 Discussion Format

Detailed discussions of activities at each of the test facilities outlined above are presented in Sections 2.0 through 9.0 of this report according to the following format:

- Project History

  Outlines the origin, chronology, significant background events, and major achievements.

- Project Goals

  Defines specific short- and long-range goals in measurable terms and accomplishments to date.

- Process Description

  Defines basic project characteristics discriminating technology features/regimes, thrust, scope and ultimate applications, and data base relevance.

- FY82 Accomplishments

  Describes progress and specific achievements made toward meeting project goals during the 1982 fiscal year.

- Current Status and Projected Work

  Outlines present activities and near-term plans.

In addition, a technology crosscut discussion, which highlights the technical problems and issues common to the operating plants, is presented in Section 10.0.

2.0 BI-GAS TWO-STAGE ENTRAINED-FLOW GASIFICATION PILOT PLANT

2.1 Project History

Bi-Gas is a process for producing high-methane content synthesis gas by gasifying coal at high pressure and temperature in a two-stage entrained-bed reactor. This project was initiated in 1963 by Bituminous Coal Research, Inc. (BCR), under contract to the Office of Coal Research which was subsequently the U.S. Energy Research and Development Administration (ERDA). The current program is fully funded by DOE.

The development work was divided into three phases. In Phase I, state-of-the-art coal gasification was reviewed. The purpose of this review was to select a promising process which was worthy of further development and could be used in processing SNG from coal. It was concluded that a two-stage, entrained-bed, high-pressure, slagging gasification concept would be the best process concept. In Phase II of the program, process research and development activities provided information for designing pilot plant equipment. This work was conducted by BCR, and was successfully completed in late 1971. Phase III of the program involved the design, construction, and operation of the pilot plant which was carried out by Stearns-Roger, Inc. (SRI). SRI began construction of the 5 ton/h (120-tpd) plant in May 1973 and completed it in mid-1976. The pilot plant is located in Homer City, Pennsylvania, and is a complete, self-contained facility for processing and gasifying coal, purifying and enriching the product to pipeline quality gas, separating sulfur from the waste gas, and treating waste products to acceptable discharge levels.

Phillips Petroleum Company was chosen by BCR to manage the test program and SRI provided personnel and supervision for operation of the pilot plant. In October 1979, BCR relinquished its role as the prime contractor for the Bi-Gas program, and

Phillips Petroleum ceased responsibility for the administrative and technical management of the pilot plant. On November 1, 1979, SRI assumed BCR's responsibilities as the prime contractor to develop the Bi-Gas process. On July 1, 1982, after completing tests of highly caking Pittsburgh seam coal, SRI was directed by DOE to mothball the facility based on a three-phased facility mothballing plan.

Approximately 15 percent of the funds expended on the project were provided by the American Gas Association (AGA) and later by the Gas Research Institute (GRI). The remainder of these funds were provided by the Federal Government.

2.2 Project Goals

The three major objectives of the Bi-Gas Pilot Plant Development Program include:

- Evaluating (at pilot-plant scale) the viability and operability of the Bi-Gas process.
- Establishing a reliable data base from which to analyze the technical and economical potential for commercial-scale development of the Bi-Gas process to produce substitute natural gas.
- Evaluating components and process equipment.
- Developing process data on gas cleanup and conversion systems.

To accomplish these objectives, it is necessary to operate all phases of the pilot plant including coal preparation, coal feeding, gasification, and gas treating. The operational goal is to acquire meaningful, accurate, and reliable data on a range of process variables. This data will provide a foundation for optimum plant design and will help determine an operable range of conditions for a variety of feedstocks (including caking and non-caking coals).

2.3 Process Description

The Bi-Gas coal gasification process, which is illustrated in Figure 2, proceeds as follows:

Run-of-mine coal is wet-ground in a rod mill, screened to remove 100 mesh particles, and slurried with water. This coal-water slurry (35 percent solids) is pumped to high pressure (current operation is at 750 psi) and passed through a preheater into a slurry spray dryer where it is dried with recycled product gas. The resultant dry coal (1 percent moisture by weight) is separated from recycled product gas and moisture by a cyclone in the coal feed vessel. This coal, along with steam, is fed into the upper section or Stage II of the gasifier. Stage II is an entrained-bed section in which the coal is devolatilized as it is transported upward and out of the gasifier by hot synthesis gas from Stage I. Before entering the char vessel, this combined stream is water quenched to 800°F. In the char vessel, the char is separated from the gases by internal cyclones.

Char is recycled to the gasifier by steam eduction through char burners which mix and ignite the mixture of char, steam, and oxygen. Stage I temperatures are between 2,700° and 3,000°F, while temperatures in Stage II are between 1,600° and 1,800°F.

Quenched, raw product gas, as shown in Table 1, leaves the overhead of the char vessel and flows to the gas washer. In the gas washer, entrained char fines are removed and the gas is cooled to 400°F. The fines and water slurry from the gas washer are sent to the ammonia stripper, where steam and sodium hydroxide "strip" ammonia from the water. The fines and the wastewater are sent to a holding pond which is periodically dredged. Off-gas from the stripper is sent to the thermal oxidizer where it is flared with other waste gases.

TABLE 1. BI-GAS RAW PRODUCT GAS COMPOSITION (DRY BASIS)

CONSTITUENT	VOL. %
Hydrogen (H_2)	33
Carbon Monoxide (CO)	27
Carbon Dioxide (CO_2)	21
Methane (CH_4)	13
Nitrogen and other constituents (N_2, H_2S, et cetera)	6
TOTAL	100

The major advantages of the Bi-Gas process for coal gasification includes:

- Uses all types of coal, both caking and non-caking, without pretreatment.
- No net char production.
- High methane yield from gasifier.

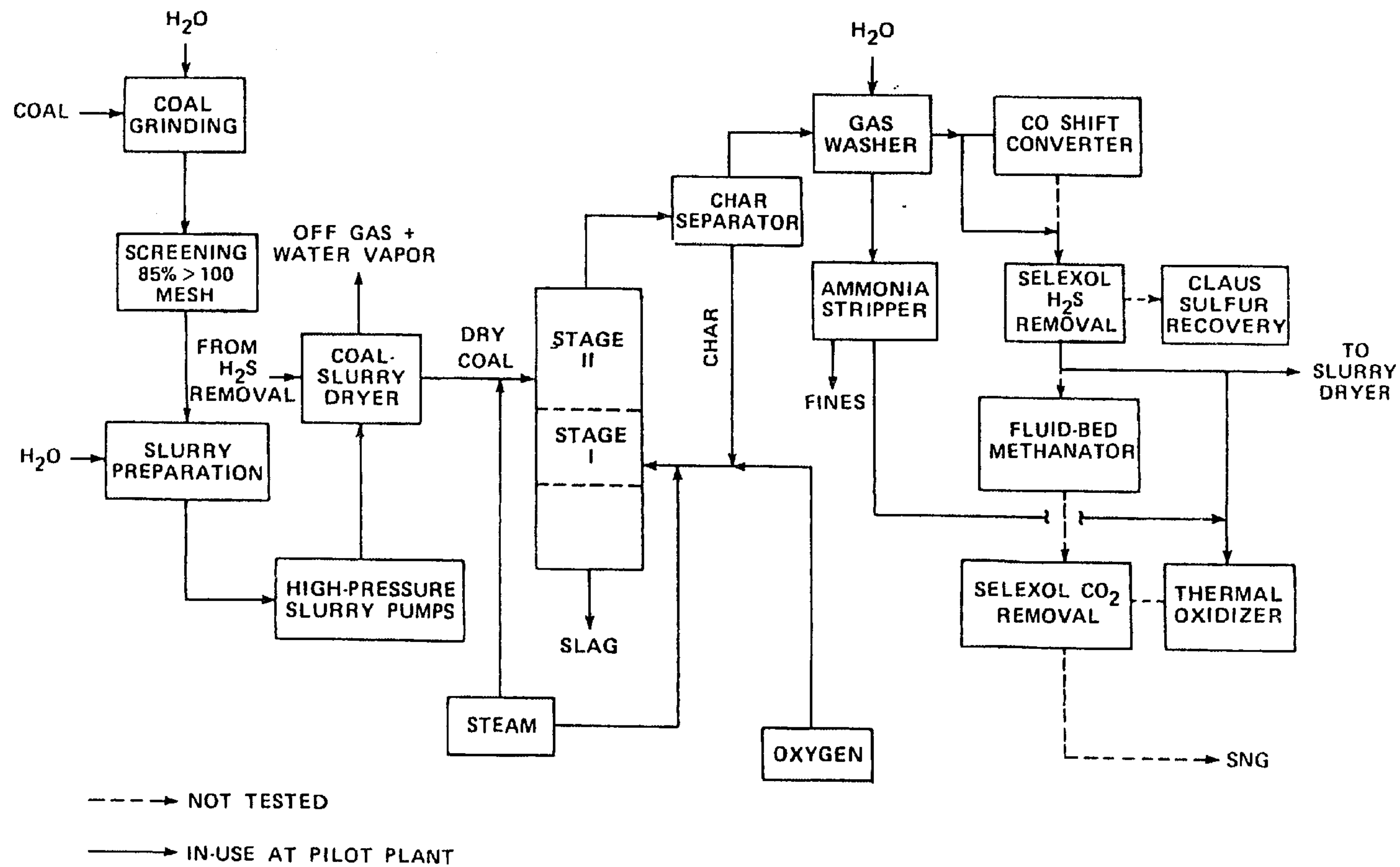

FIGURE 2. BI-GAS PILOT PLANT

- No tars or oils are produced.

- Operates at high pressure suitable for supplying an existing pipeline.

The major disadvantages of the Bi-Gas process for coal gasification include:

- High-temperature slagging environment makes temperature measurement difficult, resulting in difficult control of the two-stage reactor with char recycle.

- A high-pressure, dry coal feed system does not exist commercially; therefore, the process requires coal-water slurry pressurizing, and drying. (This disadvantage is not unique to the Bi-Gas process.)

- Naphthalene is produced.

2.4 FY82 Accomplishments

Six tests were conducted with Pittsburgh No. 8 seam coal for a total of 180 hours between February and May 1982. Testing was suspended in mid-1982 due to a shortage of funds. During this abbreviated testing period, Pittsburgh coal processing proved to be substantially different than Rosebud coal. The most important observations made during these tests were: (1) pulverized Pittsburgh seam coal had approximately the same size distribution as Montana Rosebud coal under the same grinding conditions, (2) Pittsburgh seam coal produced a lower density char than Montana Rosebud coal, and (3) Pittsburgh seam coal produced severe char feeding problems due to formation of larger size particles which were retained in the char system.

The major problems encountered in using Pittsburgh seam coal was the formation of agglomerated char in Stage II which was entrained into the char vessel and caused the recycle char legs to plug. As a result, steady-state operation was never achieved with a solids inventory in the coal and char vessels. The abbreviated tests were conducted with no char level in the char vessel and with supplemental fuel (natural gas) injected into Stage I of the gasifier.

Passive acoustic flow measurement systems developed by Argonne National Laboratory (ANL) were installed in the recycle char lines and proved to be an excellent means to detect stoppages in char feed. Unfortunately, these ANL devices do not measure the quantity of char flowing through the lines. An Auburn capacitance volume fraction monitor was tested and proved to be a potentially useful instrument for measuring the solids flow.

Improving solids feed is central in the development of the Bi-Gas process. Resolving the char line pluggage problem and attaining steadier feed rates will permit validated heat and material balances and will eliminate the use of supplemental fuels in Stage I of the gasifier.

2.5 Current Status and Projected Work

Pittsburgh coal testing was suspended in mid-1982. Mothballing of the facility was initiated and scheduled to be completed by the end of December 1982. In mid-November, however, Congress appropriated funds to the program to enhance the test data-data base of the process on an additional eastern bituminous coal. Therefore, a program redirection order was issued, mothballing activities were halted, and preparations for additional testing were begun. The plant is currently being reactivated and will be ready for testing in April 1983. After the Illinois No. 6 coal tests are completed, mothballing plans will be initiated once more. In addition to Congressional action toward further testing, direction was given to concurrently investigate future uses of the Homer City gasification facility. This effort is underway.

3.0 WESTINGHOUSE ASH-AGGLOMERATING FLUID-BED GASIFICATION PDU

3.1 Project History

In the early 1970's, the Westinghouse Research and Development Center began to develop a fluidized-bed gasifier that withdrew ash through controlled growth of ash agglomerates for dry removal. The primary goal was to produce low-Btu gas production for electrical power generation. The initial two-stage configuration gave way to a simpler, single-stage operation. Subsequent use of oxygen in the system has resulted in broader applications such as SNG production and other medium-Btu gas uses. An integrated program, first funded by the Office of Coal Research and Westinghouse along with other industrial partners, continued during FY82. The program was broken down into the following phases:

- Development of an integrated program for a demonstration plant, construction of a 15- to 35-tpd PDU, and execution of fundamental R&D studies.

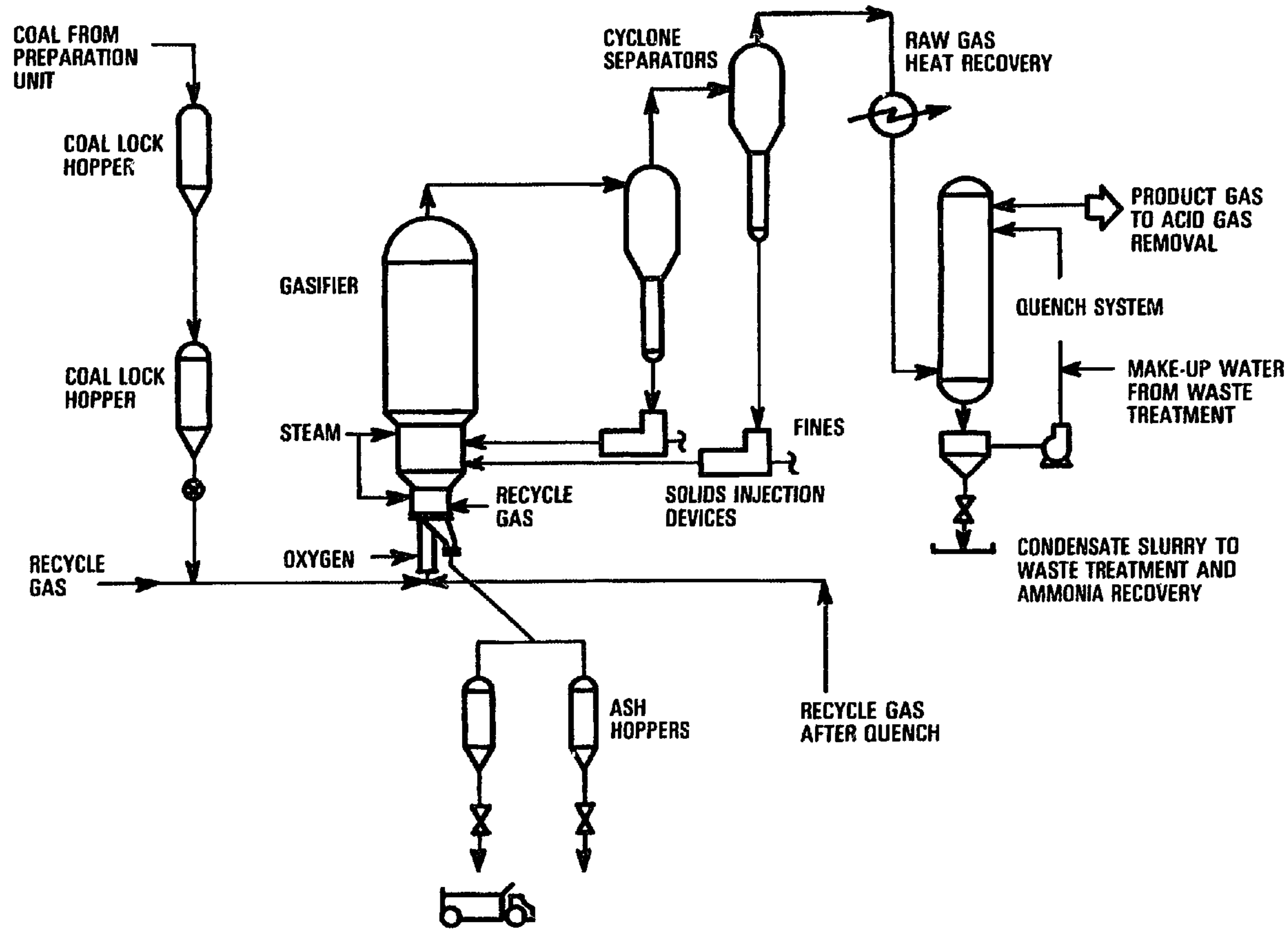

FIGURE 3. WESTINGHOUSE SINGLE-STAGE GASIFICATION PROCESS

- Redirection of the project to emphasize process development aspects rather than a demonstration plant.
- Verification of process design and balance of plant development/selection.

Through FY82, approximately 8 percent of the funds expended on the project were provided by Westinghouse, about 15 percent were provided by GRI, and the remainder were provided by the Federal Government.

3.2 Project Goals

The objectives of the Westinghouse project include:

- Develop and demonstrate the Westinghouse pressurized, ash-agglomerating, fluidized-bed, low-Btu gasification process for combined-cycle power generation.
- Develop and demonstrate the process for medium-Btu gasification for industrial fuel or synthetic gas production.

The Westinghouse development program has moved from the gasifier process feasibility stage to the process design verification and scale-up data base stage.

3.3 Process Description

3.3.1 Gasifier System

The heart of the gasification process is the fluidized-bed gasifier. This reactor, located in the process development unit, is a nominal 24-inch ID vessel consisting of a mild steel shell with 8 to 12 inches of Harbison-Walker Castolast G refractory lining. The gasifier operates at a pressure of 150 to 315 psi at temperatures of 1,500° to 2,000°F.

Run-of-mine washed coal, which has been crushed and top screened to a ¼-inch x 0-inch particle size, is fed pneumatically from pressurized lockhoppers using recycled product gas to the coaxial oxidant tube inside the gasifier. Coal, oxygen or air, steam, and recycled product gas are fed through the coaxial oxidant tube, and the coal is combusted in the resultant jet, providing heat to devolatize the coal particles and to react the carbon with the gasifying agent. Steam may be added through the conical grid section. The product gases flowing upward through the fluidized bed entrain some of the char fines from the bed. These are collected in two external cyclones and recycled directly to the gasifier by a non-mechanical valve from the first stage collection and a solids injection device from the second stage collection.

The raw gases from the cyclones, listed in Table 2, contain hydrogen sulfide and other contaminants, which are scrubbed in two water-quench scrubbers. No hydrocarbon tars are present since they are cracked to methane, hydrogen, and carbon monoxide at the high reaction temperature. The raw gas is sent to cooling towers and burned in a thermal oxidizer. The char/water slurry is separated in an Edens separator pit prior to disposal.

TABLE 2. TYPICAL WESTINGHOUSE PDU GAS COMPOSITION

CONSTITUENT, DRY GAS	AIR BLOWN, VOL. %	OXYGEN BLOWN, VOL. %
CO	20.1	39.6
H_2	5.1	23.1
CH_4	1.5	3.6
CO_2	11.9	31.8
N_2	61.2	Trace
Minor other gases	Trace	Trace
Heating Value HHV (Btu/scf)	96	240

The gasifier is unique in handling ash present in coal. As carbon is consumed in the char particles, which recirculate through the combustion jet, exposed ash particles reach a temperature at which partial melting takes place. Particles coalesce or agglomerate to form approximate spheroids of relatively pure ash which, after overcoming the minimum fluidization velocity, defluidize and fall to the bottom of the bed. In the char/ash separation zone, the lighter char particles are stripped from the ash agglomerates by the upward flow of recycled product gas, which also cools the agglomerates. The dry ash is continuously removed by a rotary valve on the bottom of the gasifier.

3.3.2 Cold Flow Scale-Up Facility

Fluid dynamic scale-up correlations of the fluidized-bed gasifier and a more complete understanding of fluidized-bed phenomena are achieved in the large-scale cold flow facility at Waltz Mill, Pennsylvania. It permits full front-face viewing of the fluidized-bed through a transparent plastic window, allowing a detailed study of jet behavior, solids circulations, bubble velocity and frequency, and related phenomena necessary to design a larger scale coal gasifier.

The test vessel is comprised of six identical, semicircular sections, each 10 feet in diameter. Transparent panels permit front face viewing. Curved face viewing is limited to individual circular windows whose location and number are dependent on the expected fluidized-bed location. An ash/char draw-off cone with a feed tube assembly is attached to the underside of the bottom viewing section. The draw-off cone fixes the feed tube laterally within the model and provides for vertical adjustment of the feed tube relative to the steam grid cone.

The simulated steam grid cone is located internally within the lower viewing sections where it forms a conical annulus around the feed tube. The conical surface is perforated and is subdivided into several annular regions, any or all of which may be supplied with pressurized air. Bed sample probes are positioned within the test section for direct withdrawal of materials from within the interior of the bed. Model design and process piping provide features that facilitate changes in feed tube size and configuration, draw-off cone configuration, and steam grid cone.

3.4 FY82 Accomplishments

3.4.1 Gasifier Tests

Over the past year, five single-stage, oxygen-blown PDU tests totaling 747 hours were conducted. Some 151 hours were conducted with Upper Freeport coal, 207 hours with Western Kentucky coal, 114 hours with Wyoming Sub-C coal, 104 hours with Indiana No. 7 coal, 103 hours with Brookville Seam A coal, and 68 hours with North Dakota lignite for feedstock characterization. To achieve campaign objectives for the year, (1) three tests supported gasifier development, (2) four tests supported gas utilization and component development, and (3) two tests supported system integration.

To accomplish the gasifier development objectives, four areas were explored. The first exploration expanded the operability and gasifier performance data base on Western Kentucky, Wyoming Sub-C, and Indiana No. 7 coals. Secondly, the operability and gasifier performance using Upper Freeport coal, Brookville Seam A coal, and North Dakota lignite were explored. Thirdly, the fines consumption through injection at various sites on the gasifier (i.e., upper annulus, radial injection, and axial injection) were explored. Lastly, the temperature profiles of the combustion zone using a non-slagging thermocouple were explored while feeding Western Kentucky and Wyoming Sub-C coals.

Within the gas utilization and component development objectives, the accomplishments during the year included:

- Installation and commissioning of the primary fines non-mechanical valve system, and successfully demonstrated control and transfer of coal fines in the valve.
- Installation and successful operation of the full cyclone cold wall with highly fouling coal feedstocks.
- Installation and successful operation of a solid injection device for hot secondary fines recycle.
- Installation and successful operation of the particle through-trap as an alternative to the full cyclone cold wall.
- Performing simultaneous isokinetic sampling of product gas upstream and downstream of the primary cyclone.
- Conducting tests with a hot gas alkali measurement system in the product gas stream.
- Installation and successful operation of a mini-scrubber system for product gas characterization of trace impurities, including Environmental Protection Agency (EPA) priority organic pollutants.
- Continued testing of the slipstream heat recovery evaporator, superheater, and feedwater units.

Two system integration objectives were achieved during the 1982 test programs. Closed-loop transient response tests of the gasifier were conducted, and an 8 percent/minute increase in calorific heat production from the gasifier and a total of 60 percent increase for a 40°F increase in freeboard temperature were demonstrated.

3.4.2 Cold Flow Scale-Up Facility

Development of a scale-up data base for the gasifier is an integral part of the fluidized-bed technology program. The primary objectives for the Cold Flow Scale-Up Facility (CFSF) are to study the effect of size on the critical fluid dynamic phenomena of solids flow behavior and gas-solids contacting in the gasifier, and to verify the similarity criteria developed from small cold flow units. Limitations of the CFSF 3-meter model are that temperature and pressure effects cannot be evaluated directly.

Seven programmed tests were performed to provide additional fluid dynamic and high-speed film data. The high-speed film data was taken from four angles through the transparent front of the 3-meter model. This data will be used to investigate jet penetration, bubble diameter, and bubble frequency over a wide range of operating velocities, grid distribution arrangement, and oxidant/feed tube heights and sizes. In three of the tests, a 16-inch air tube and an 8-inch feed tube (coaxial tube) were used to investigate pilot tube profiles for jet velocity, jet characteristics, and gas history with CO_2 injection. Detailed results of the 16-inch air tube tests will be contained in a topical report to be issued during 1983. In three other tests, a 10-inch air tube and a 4-inch feed tube were used. In the last test, gas/solids transport characteristics were investigated.

3.4.3 Process Development Unit Modifications

Modifications made to the PDU included the installation of (1) a full cyclone cold wall, (2) a particle through-trap as an alternative to the full cyclone cold wall, (3) a solids injection device for hot secondary fines recycle, (4) a primary fines non-mechanical valve, and (5) a mini-scrubber for hot product gas sampling.

3.4.4 Laboratory Support

Laboratory support provided by Westinghouse Corporate Research and Development Center, Churchill, Pennsylvania, during the past year included investigations in the following areas:

- Particle History

  Extended analysis of course particle history test results to develop correlations for solid mixing times and jet penetration; slug frequency and slug size; developed a model to project residence time of solids in jetting and slugging regions; modified test unit for fines history experiments; and performed initial fines particle history tests.

- Jet Phenomena

  Completed construction of a high-temperature unit, and initiated a test program to measure minimum fluidization velocity.

- Char/Ash Separation

  Completed particle separation rate tests, and experiments with smaller density and size ratios.

- Gasification Kinetics

  Performed reactivity tests on nine different coal feedstocks and experimental test programs to determine the effect of maximum temperature, heating rate, and pyrolysis atmosphere on reactivity; and initiated reactivity tests on recycle fines.

- Fines Particle Combustion

  Estimated combustion time for recycle fines.

- Ash Agglomeration

  Commissioned a hot-stage microscope for pressurized operation, and completed sintering tests on four different coal feedstocks using the hot-stage microscope.

- Deposit Control

  Analyzed PDU deposit experiences and correlated them with operating conditions; compiled PDU deposit analyses and characterization; designed, fabricated, and installed a deposit probe in the PDU; analyzed deposit experience from laboratory reactor tests; and initiated tests to determine binding material using the pressurized hot-stage microscope.

3.5 Current Status and Projected Work

3.5.1 Gasifier Tests

Five PDU tests have been scheduled in order to meet the objectives for the next year. Modifications to the PDU will be made as required to support individual test objectives. These objectives are to: (1) determine values of process parameters necessary to operate the single-stage gasifier, as shown in Figure 3, to produce medium-Btu gas and agglomerated ash at a high (>90 percent average) overall carbon utilization using at least one bituminous coal feedstock and one subbituminous coal or lignite feedstock and gasifying with oxygen or air and steam; (2) perform cold flow studies in the PDU at high pressures using solids circulation probes to measure and analyze pressure effects on solids history; (3) complete material and heat balances around the PDU for various operational modes, determine solids and gas composition at critical streams, and determine actual temperature and pressure drops across major system components; (4) determine the physical and chemical nature of PDU process effluent streams and contaminant levels in the product gas at various locations; and (5) complete design and performance evaluation of candidate particulate collections and recycle equipment, and evaluate the effectiveness of consuming fines in the gasifier and the PDU performance with advanced fines recycle system concepts.

3.5.2 Cold Flow Scale-Up Facility

Four test phases will be performed to meet CFSF program objectives for the next year. Two multiple test phases will be done for each air tube size (16-inch and 10-inch). CFSF program objectives include: (1) operation of the 3-meter cold flow model to evaluate operable geometries for the oxidant tube, ash withdrawal annulus, steam grid, and other critical areas of the gasifier, and (2) performing data reduction and analysis of CFSF test results to establish cold flow scale-up unit correlations and evaluation of available cold flow correlations for scale-up validation. The major CFSF modification required to achieve these objectives include lowering the internal grid section to provide increased bed depth, adding a section to the model to increase the freeboard height, and fabricating a multiple feed tube configuration.

3.5.3 Laboratory Support

Laboratory support for next year's program will include consultation and analytical and bench-scale studies by the Westinghouse Corporate Research and Development Center. Westinghouse will study coal, ash and fines behavior, ash agglomeration, gasification, devolatilization, ash deposition, cold flow phenomena, gas clean-up, and environmental analyses.

4.0 MOUNTAIN FUEL RESOURCES ENTRAINED-FLOW GASIFICATION PDU

4.1 Project History

The 0.5-tpd bench-scale test unit was designed and built for dry coal introduction directly into the reactor. The oxygen and steam were introduced around the coal feed injection nozzle to achieve a high degree of contact between the hot reactive gases and the finely ground coal. The reactor and the radiant heat exchanger located immediately below it were designed for (1) improved thermal efficiencies, (2) increased gasification rates, and (3) improved sensible heat recovery from the hot reactive gases. More than 20 different coal feed and gasifier configurations were tested to overcome the test unit design problems. In June 1977, a proposal for a PDU was submitted to DOE's predecessor, ERDA, MFR, and Ford, Beacon and Davis Utah (FBDU), Inc., both of Salt Lake City, Utah.

In April 1981, DOE awarded a cost-sharing contract to MFR to validate the commercial unit concept at a PDU scale. FBDU is the prime contractor.

Approximately 20 percent of the project funding is provided by the industrial partnership of MFR and FBDU. The DOE provides the remainder of the funding.

4.2 PROJECT GOALS

The major objective of the MFR gasification project is to develop further a pressurized, high-rate, entrained-downflow, medium-Btu gasification system. Advanced equipment designs will be tested for: (1) dry-feeding pulverized coal with recycle gas directly into the reactor, (2) introducing the oxygen and steam concentrically around the coal injection nozzle, and (3) recovering heat from the hot raw gasification products instead of quenching them. The objective is to use these designs in commercial coal gasification facilities to achieve higher coal conversion efficiency and lower synthetic fuel costs. Therefore, an ability to scale-up an existing 0.5 tpd design to a 30-ton/day PDU will be demonstrated and data will be provided for further scale-up to a 600-ton/day commercial unit.

Specific performance goals for the advanced components include a 5 percent increase in conversion efficiency over existing extrained-flow processes and a 5 percent decrease in the production cost of cooled, raw product gas suitable for medium-Btu fuel use or synthesis of liquid fuels synthesis. These goals translate into a 75 percent cold gas energy conversion efficiency and 70 percent calculated overall energy conversion efficiency.

Detailed engineering design studies conducted by

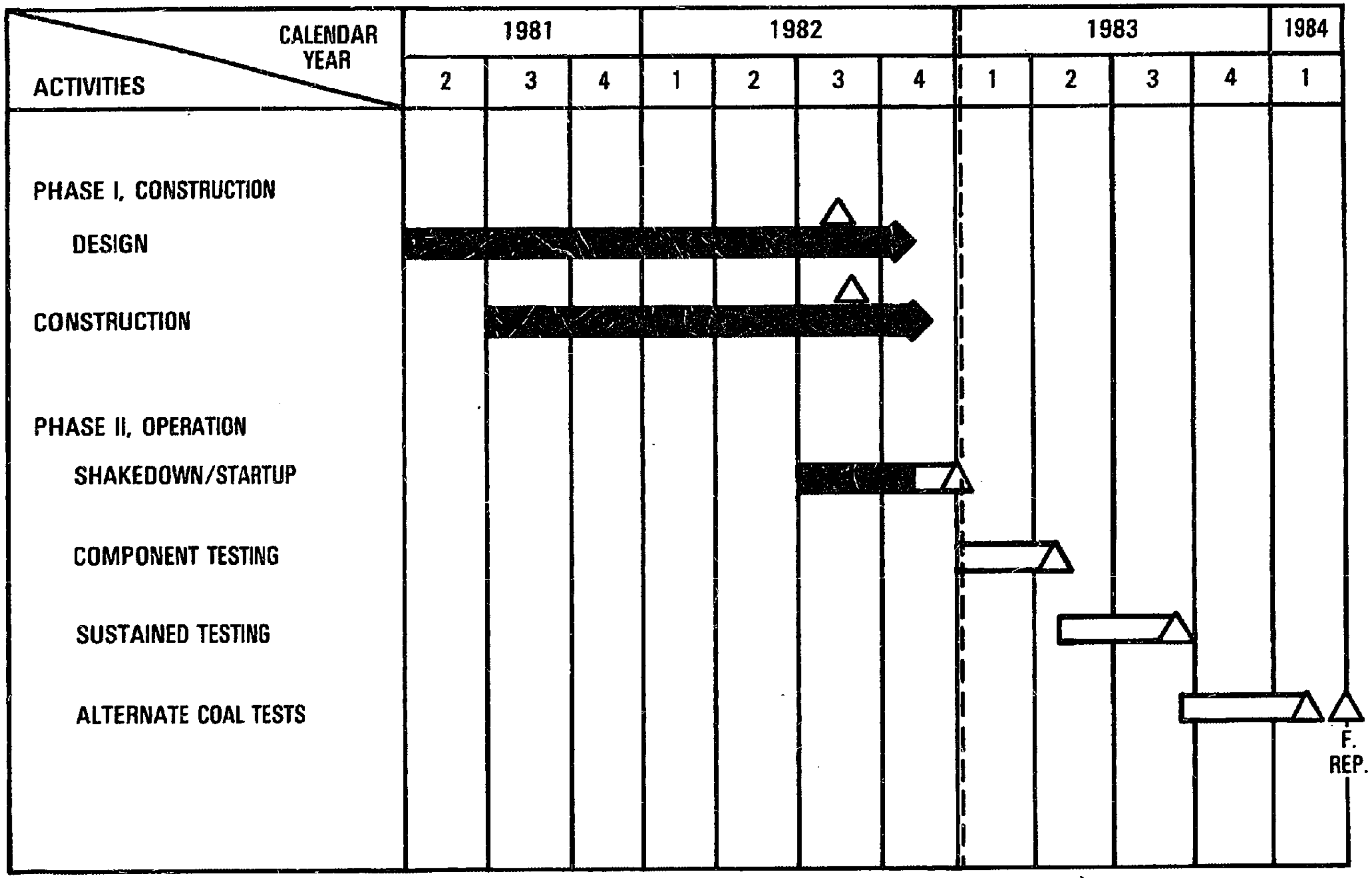

FIGURE 4. MOUNTAIN FUEL RESOURCES PDU PROJECT SCHEDULE

MFR and FBDU, which incorporate the gasification system and unique heat recovery system, indicate that the process potentially offers two significant advantages over current coal gasification technology. These advantages are lower costs and higher overall energy conversion efficiency.

The development of this gasifier and the associated direct, dirty gas heat exchanger will significantly improve coal gasification at efficiencies. Such systems will lead to state-of-the-art gasification combined-cycle systems operating at efficiencies equal to those anticipated for operation of advanced high-temperature turbines.

4.3 Process Description

The MFR coal gasification process is illustrated in Figure 5. Dry-pulverized coal (70 percent minus 200 mesh) is metered into the reactor feed line with a twin-auger feeder. Recycled product gas is the entraining medium for feeding the coal into the reactor. The gasification reactions are performed at pressures up to 20 atmospheres and at approximately 2,850°F in a 2.5-cubic foot, refractory-lined chamber. The reactor residence time is approximately 0.3 seconds. The reaction products are partially cooled by radiant heat transfer in a primary heat exchanger, located immediately below the reaction chamber where slag and large ash particles are separated from other reaction products. Approximately 50 percent of the ash, in the form of slag droplets, is collected at the base of this vessel. The slag is cooled by a water spray prior to passing into the ash lockhopper. After slag separation, the product gas is further cooled by a series of three convective heat exchangers. The first serves as an evaporator along with the radiative heat exchanger, in the reactor/radiant heat exchanger vessel, to produce high-pressure steam. The second serves as a steam super-heater, and the third serves to heat feed water supplied to the steam drum. The product gas is then passed from the final cooler into a scrubber where soot and fly ash are removed by contacting with rooter in a venturi and a packed tower. The final product is a cooled, clean, intermediate Btu fuel that is suitable, after sulfur removal, for firing industrial boilers and furnaces or use as a synthesis gas.

4.4 FY82 Accomplishments

By August 1982, as shown in Figure 4, major equipment components had been ordered and received. The design of the PDU was completed in September 1982, and construction was completed by November of that year. Individual component checkout and shakedown testing was approximately 50 percent complete by the end of FY82.

Various hazards analyses have been conducted to insure the safe design and operation of the MFR PDU. These analyses resulted in (1) upgrading the monitoring instrumentation, (2) designing a test program to ascertain the safety system operability and reliability, and (3) operating procedures that assist operators in identifying critical malfunctions.

4.5 Current Status and Projected Work

By spring 1983, the checkout/shakedown of the PDU components for operational readiness was completed. Minor equipment modifications were made and detailed operating procedures were written.

Approximately 30 2- to 6-hour component evaluation tests will be conducted at steady-state conditions using low-sulfur Utah bituminous coal to evaluate, as a minimum, feed hoppers and recycle gas equipment, feed nozzles, reactor refractory, radiant and convective heat exchangers, the slag discharge system, scrubber, and all related instrumentation and controls. Coupons of alternate construction materials for the heat recovery equipment will be placed into the radiant and convective heat recovery sections during these tests.

Sustained operation testing will consist of at least three 4-week test runs. These tests will be conducted to assess the operational reliability of system component designs and to evaluate coupons of alternate materials in the PDU heat recovery sections.

Coal variation tests will be conducted to study the effects of coal properties on various system components. These tests will include a high-sulfur caking bituminous coal, a low-sulfur subbituminous coal, a lignite, and a coal char or coal residual. Differences in coal ash properties, refractory material effects, and radiant and convective heat exchanger materials will be closely examined.

5.0 METC DRY-BOTTOM FIXED-BED GASIFICATION PILOT PLANT

5.1 Project History

The most highly developed gasification technology is the fixed-bed process. This process also offers the highest potential efficiency but, unfortunately, presents the greatest environmental problems. These

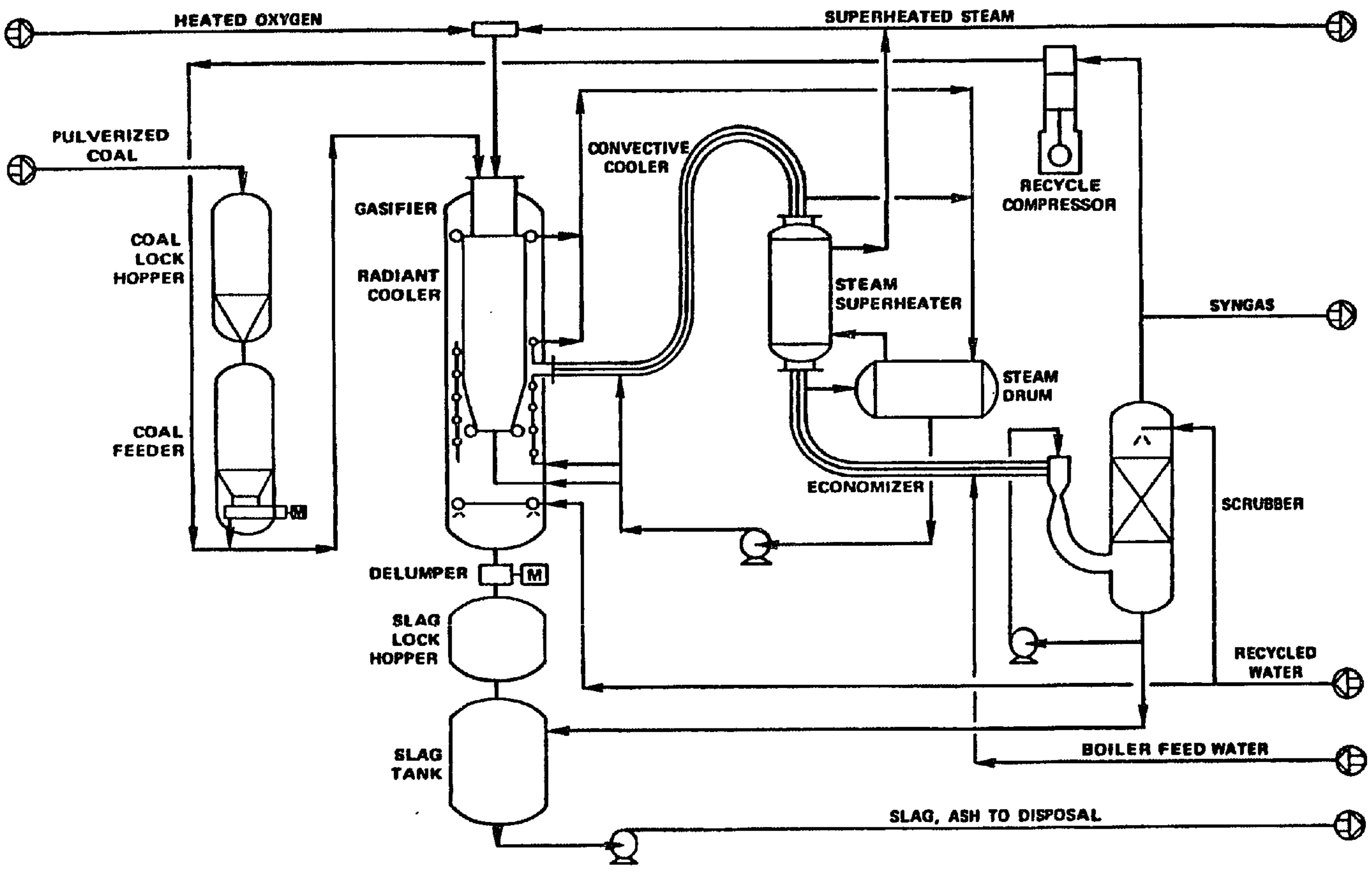

FIGURE 5. MOUNTAIN FUEL RESOURCES PDU

problems were recognized by the predecessor agency of METC 17 years ago and, in 1963, plans were made to construct a fixed-bed gasification pilot-plant test facility. The heart of this facility is a 3.5-foot diameter pressurized gasifier, which is capable of gasifying and evaluating all ranks of U.S. coals including the highly caking eastern coals. The lack of demonstrated ability to process highly caking coals is probably the major drawback of the European fixed-bed gasifier technology.

Since the completion of construction in 1967, the METC Gasifier Pilot Plant has produced data on and demonstrated operation with all major ranks of U.S. coals. In 1976, METC began an expansion program to include a novel gas-cleanup facility to evaluate the environmental problems associated with gasification plants and to develop improved cleanup systems. The construction and checkout of this full-scale cleanup system were completed within the past year, and the pilot plant facility now has the capability of gasifying all U.S. coals and producing a relatively tar-, oil-, particulate-, and sulfur-free fuel gas.

5.2 Project Goals

The METC project goals have been divided into primary and secondary categories. Emphasis is being placed on achievement of the primary goals with subsequent completion of as many secondary goals as possible. These primary goals include:

- Characterizing and determining the applicability/treatability of product gases.
- Developing and verifying improved process models for gasification and gas cleanup.
- Demonstrating that tar can be collected and utilized by proper separation and recycle.
- Demonstrating that fines can be utilized without excessive carryover.
- Demonstrating and comparing alternatives to lockhopper feeding.
- Determining the treatability of waste effluents for environmental acceptance.

The secondary goals include:

- Demonstrating physical cleanup system at full-flow capacity.
- Demonstrating Stretford system performance.
- Establishing a base case with respect to fines carryover and tar production with lockhopper feeding.
- Evaluating the effect of tar recycle on effluents and humidifier operation.
- Developing a steady-state characterization test matrix which is aimed at quantifying effluents and wastewater.
- Developing a coordinated plan and approach to wastewater treatability that embraces the entire fixed bed.
- Continuing development and testing of instrumentation for system control/automation and for stream characterization.
- Instituting a review of control/automation activities and pursuing a course consistent with the primary goals.

5.3 Process Description

5.3.1 Gasifier System

The METC gasifier is 3½ feet ID and 24 feet high, and it can process coal at feed rates up to 1.25 tpd. As shown in Figure 6, the lower portion of the steel shell is water jacketed while the upper section is expanded and lined with refractory to the same inner diameter as the lower portion. The fuel bed, normally 5 to 7 feet deep, is supported on a rotating grate that can be varied in speed from 1.8 to 8.4 revolutions per hour (rph). The gasifier is equipped with an adjustable, rotating, mechanical stirrer that moves vertically through the bed in a spiral pattern. The entire length of the stirrer shaft as well as the two horizontal arms, which penetrate the incandescent zones of the bed, are cooled by circulating water. The bottom arm can reach to within 2 inches of the grate top. When bituminous coals are used, the stirrer is typically rotated at about 30 rph and set to vertically cycle through the bed in about 20 minutes. The vessel is also equipped with nuclear density gages which provide a means for detecting bed level and bed voids. Coal (minus 1 inch) is fed from two feed hoppers by a combination of rotary feed valves and screw feeders. The rotary valves perform a metering or feed rate control function, and the screw feeder provides a rapid coal transition from ambient to gasifier temperatures to prevent feed system pluggage. An independently controlled air and superheated steam blast, pre-mixed to a temperature of about 500°F, is injected below the grate. This mixture cools the grate discharges ash to a lockhopper arrangement. The blast is preheated as it passes upward through the ash zone above the grate.

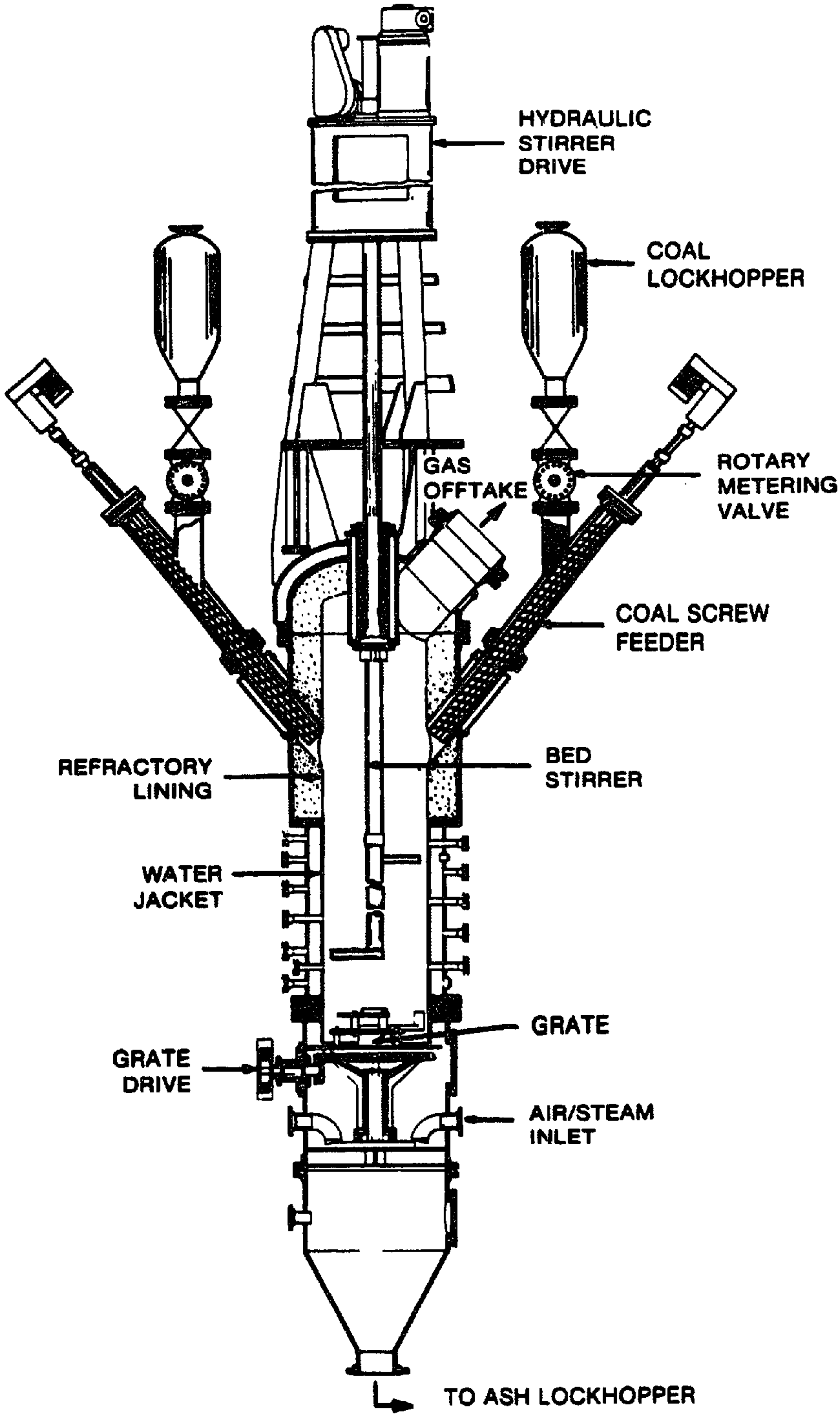

FIGURE 6. METC FIXED-BED GASIFIER

5.3.2 Gas Cleanup System

The low-Btu gas exits the gasifier at approximately 1,000°F and contains large quantities of entrained dust, tar/oil vapors, sulfur-bearing gas constituents, alkali-metal compounds, and water vapor.

The METC gas cleanup and cooling system shown in Figure 7 contain several developmental components. In this system, raw gas from the gasifier, at approximately 1,000°F and up to 300 psig, enters a low-velocity dust cyclone in which approximately 85 to 90 percent of the dust is removed. Currently, recovered dust is collected separately in drums and, if agglomerated, is available for recycling to the gasifier. The overhead flow from the dust cyclone flows to the humidifier. Because problems have been anticipated with deluge-type water quenching such as operability of pumps, formation and accommodation of tar-water emulsions, and three-layer separation needs, a decision was made to utilize a developmental humidifier to condense and remove heavy tars from the gas stream in a "dry" and more manageable state. This is accomplished in the humidifier by atomization and evaporation of recycle water (liquor) which reduces the gas-stream temperature to 25° to 50°F above its dew point (300° to 400°F) and causes tar to condensate. Because of the small droplet size of the condensed tars, another developmental unit, a tar separator, is needed to prevent reentrainment droplets into the gas stream. The gas then flows to a venturi scrubber in which the very fine tar mist, which is not removed in either the humidifier or the tar trap, is separated from the raw gas. After leaving the venturi scrubber, the gas stream flows to a direct cooler which is operated with recycled water and is cooled to approximately 100°F. This is the only non-adiabatic step in the process.

This cooling step condenses and removes unconverted steam fed to the gasifier, water atomized in the humidifier, and condensable light oils from the gasification process. Next, the gas flows through an electrostatic precipitator (ESP) to reduce any remaining hydrocarbon mists prior to entering a Holmes-Stretford Desulfurization Unit (HSDU). This unit is sensitive to contamination buildup by hydrocarbons. The desulfurization unit removes hydrogen sulfide (H_2S), the major sulfur-containing constituent in the gas stream. Following desulfurization, the gas passes to a water-scrub column to remove any trace alkali metals from the gas stream. These metals can be introduced during desulfurization and can produce severe corrosion and erosion damage in gas turbines.

5.4 FY82 Accomplishments

Mechanical and instrumentation improvements were incorporated during FY82. These improvements included developing an electronic system to control grate rotation automatically for maintaining constant ash level. Parallelling this development was testing of abrasion resistant stirrer arm coatings to extend the stirrer life by eliminating stirrer abrasion.

Tar/fines utilization capability was successfully demonstrated in a 300-hour test using briquettes made from coal fines and high-molecular weight tars extracted from the tar separator. The quantity of extracted tars was adequate to bind 50 percent of coal fines (¼-inch size) associated with run-of-mine coal.

The HSDU was tested using enlarged sieve tray holes in the absorber. Performance testing indicated H_2S removal to be 400-600 ppm with acceptable carryover at design flow rates. Indications are that the gas-liquid content in the scrubber is low by a larger factor.

Due to excessive gas leakage in the producer dome bearing, testing time was shortened and the bearing and new stirrer were redesigned.

5.5 Current Status and Projected Work

Major refurbishment activities to be completed in the spring of 1983 include fabrication of a hardened stirrer and dome bearing. Additionally, the tar mini-cyclone separator will be redesigned. An improved stirrer/dome bearing seal will eliminate noxious gas and tar emissions. The tar separator has been redesigned to include a vortex breaker to eliminate erosion.

An oxygen system has been installed and includes; a 9,000-gal, 400-psi storage tank, evaporator, piping, and controls. A safety system has been designed to ensure an adequate steam/oxygen ratio.

Work planned for FY83 includes the following tests:

- Completing incorporation of O_2-blowing capability.
- Conducting process and effluent characterization tests with lignite (oxygen-blown) in support of the Great Plains Gasification project and with Pittsburgh No. 8 bituminous coal (both air- and oxygen-blown) to verify system operability, validate gasifier and cleanup models, extend models

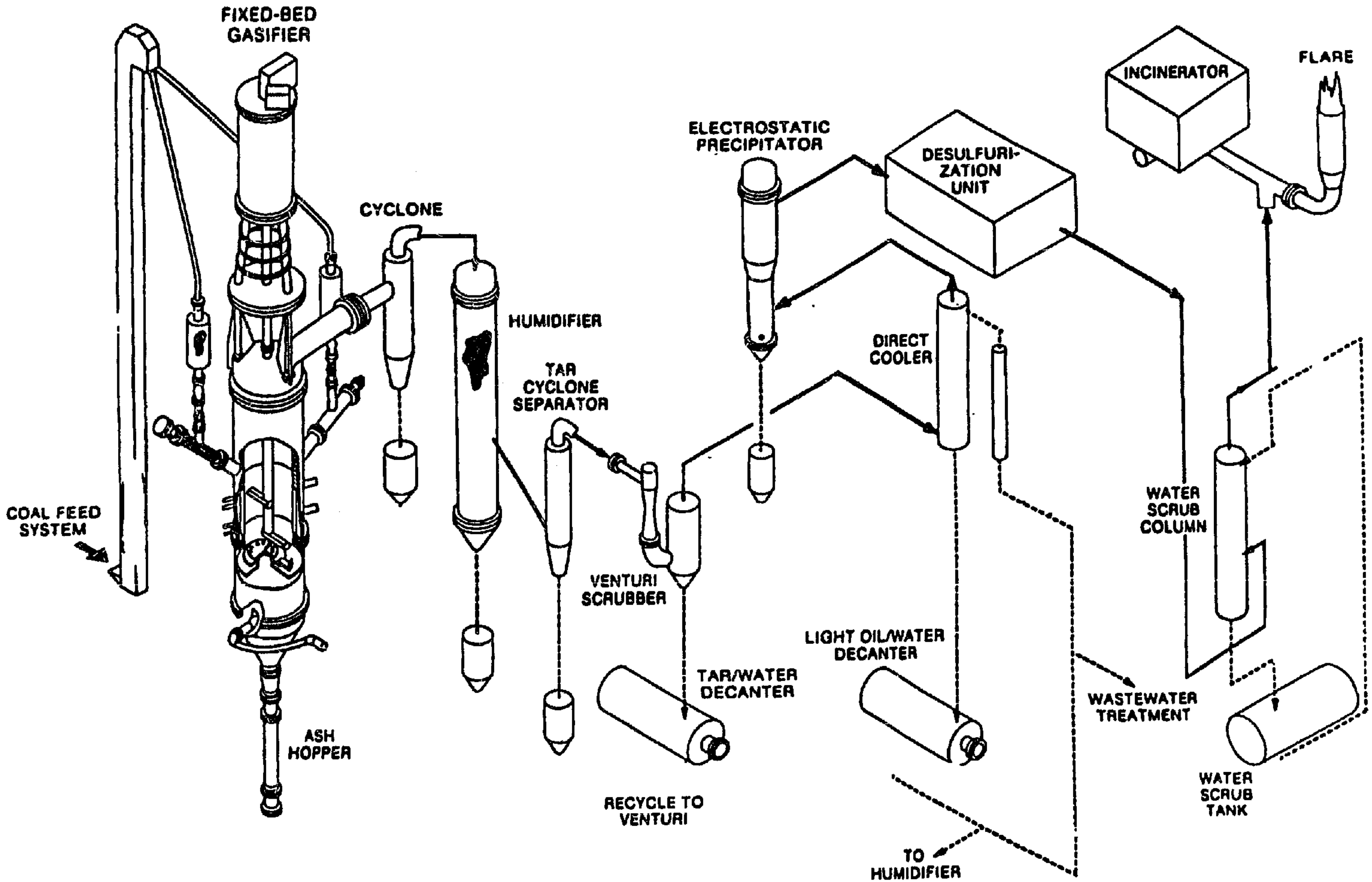

FIGURE 7. METC GASIFIER/GAS CLEANUP SYSTEM

to include transients, and obtain environmental, emission, and wastewater data.

- Investigating the use of briquettes and direct tar reinjection as methods for improving tar/fines utilization.
- Supporting health, safety, and environmental programs through sampling/analysis activities and wastewater treatment programs.

6.0 GFPO SLAGGING FIXED-BED GASIFICATION PILOT PLANT

6.1 Project History

The University of North Dakota Energy Research Center or GFPO operates the only slagging fixed-bed gasifier (SFBG) in the United States. The pilot plant gasifier was designed, constructed, and operated under the BOM during 1958 to 1965 to demonstrate slagging operation feasibility. In 1976, the program was renewed to investigate environmental concerns associated with commercial-scale facilities. In September 1978, gasifier operation was suspended for modifications to accomodate using eastern bituminous caking coals.

The gasifier is a pilot plant-scale modification of the commercial dry ash, fixed-bed process and represents a second generation gasifier which has been proposed for commercialization. In a dry ash process, temperatures are maintained sufficiently low by using excess steam to remove ash in the dry state. An SFBG differs in that no excess steam is required and the operating temperatures are maintained high enough to discharge ash as molten slag. As a consequence, there are three important SFBG advantages. In units with an equivalent internal diameter, the steam requirement per pound of coal is about one-fourth that of a dry-ash gasifier. Consequently, wastewater production per pound of coal fed is greatly reduced, while the gas production rate or throughput is nearly four times greater than for a dry ash gasifier. This difference had been demonstrated many times in the 16-inch ID GFPO SFBG where, in a typical run at 300 psig, 5,600 scf/h O_2, and an O_2/steam molar ratio of 0.94, the throughput is over 1,100 lbs/hr/ft^2 of gasifier cross section for as-received coal, producing over 31,000 scf/h of 330-Btu gas.

6.2 Project Goals

The major goals of the GFPO program include:

- Developing environmental data on effluent characteristics needed to satisfy permitting and siting requirements and proof of concept for advanced control technologies in the treatment and reuse of gas liquor from fixed-bed gasification of low-rank coals.
- Validating the adequacy of various combinations of alternative physical, chemical, and biological wastewater treatment methods to meet criteria for reusing wastewater and disposing contaminants.
- Developing or improving select aspects of downstream treatment technology.
- Characterizing slag and waste treatment sludges and their leachates to ensure safe disposal under Resource Conservation and Recovery Act (RCRA) guidelines.
- Assessing occupational health issues starting with biomedical assessment of all primary and secondary effluent streams that could involve worker exposure.

6.3 Process Description

Figure 8 illustrates a cross sectional view of the GFPO gasifier. This unit can convert approximately 1 ton of coal per hour into medium-Btu gas. Coal is charged to the lockhoppers, and rotary feeders are used to meter it as it is gravity fed into the gasifier. Moisture is removed from the coal as it enters the devolatilization zone where tars and oils are vaporized. The devolatilized coal then enters the gasification/combustion zones where hot char reacts with the oxygen-steam mixture which is introduced through four tuyeres positioned circumferentially at 90° intervals just above the hearth. The oxygen/steam ratio must be great enough to provide sufficiently high temperatures to consume carbon in the char and transform the ash to a molten liquid. The molten ash drains through a centrally located taphole into a water-quench bath. A critical heat balance must be maintained at the hearth and taphole area to maintain slag flow.

Recently, the internal diameter of the gasifier was increased from 16 inches to 22 inches, which reduces bed hang-ups and permits smoother operation on subbituminous and lignite coals. A stirrer was also installed, but bituminous coal runs were not made before the facility was shut down in May 1982. A schematic of the modified pilot plant system is shown in Figure 9.

Operating data and test results for GFPO fixed-bed,

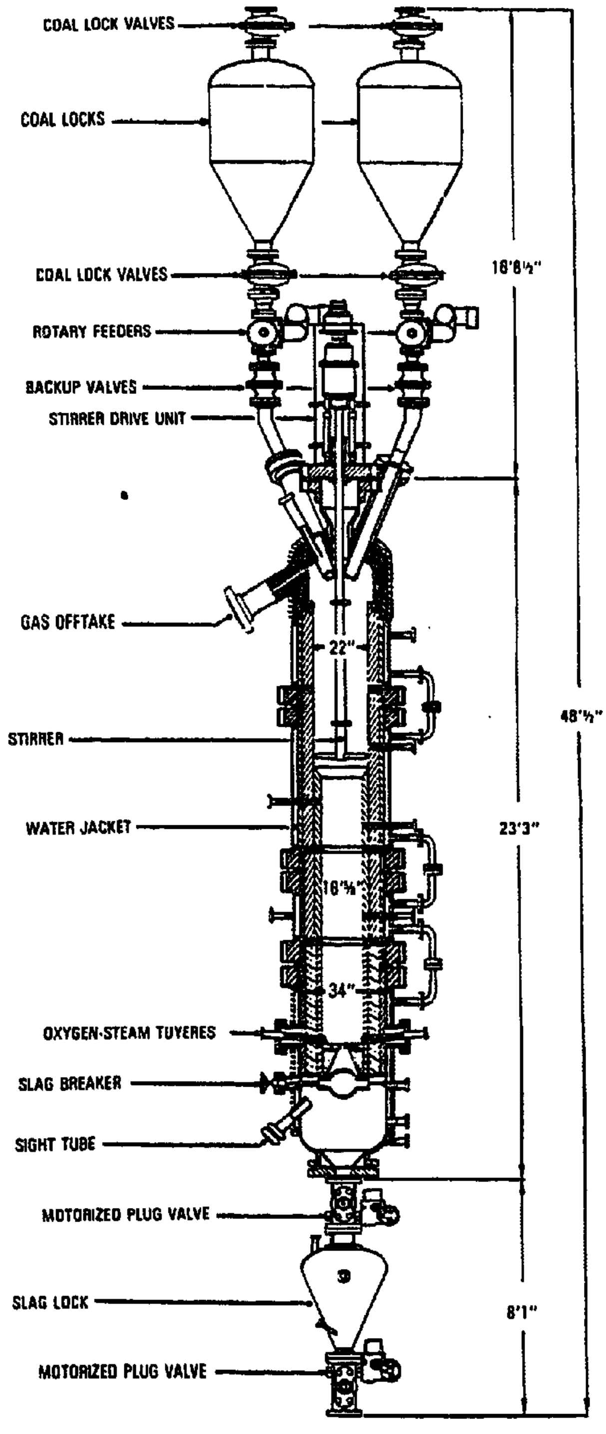

FIGURE 8. CROSS SECTION OF MODIFIED GFPO GASIFIER

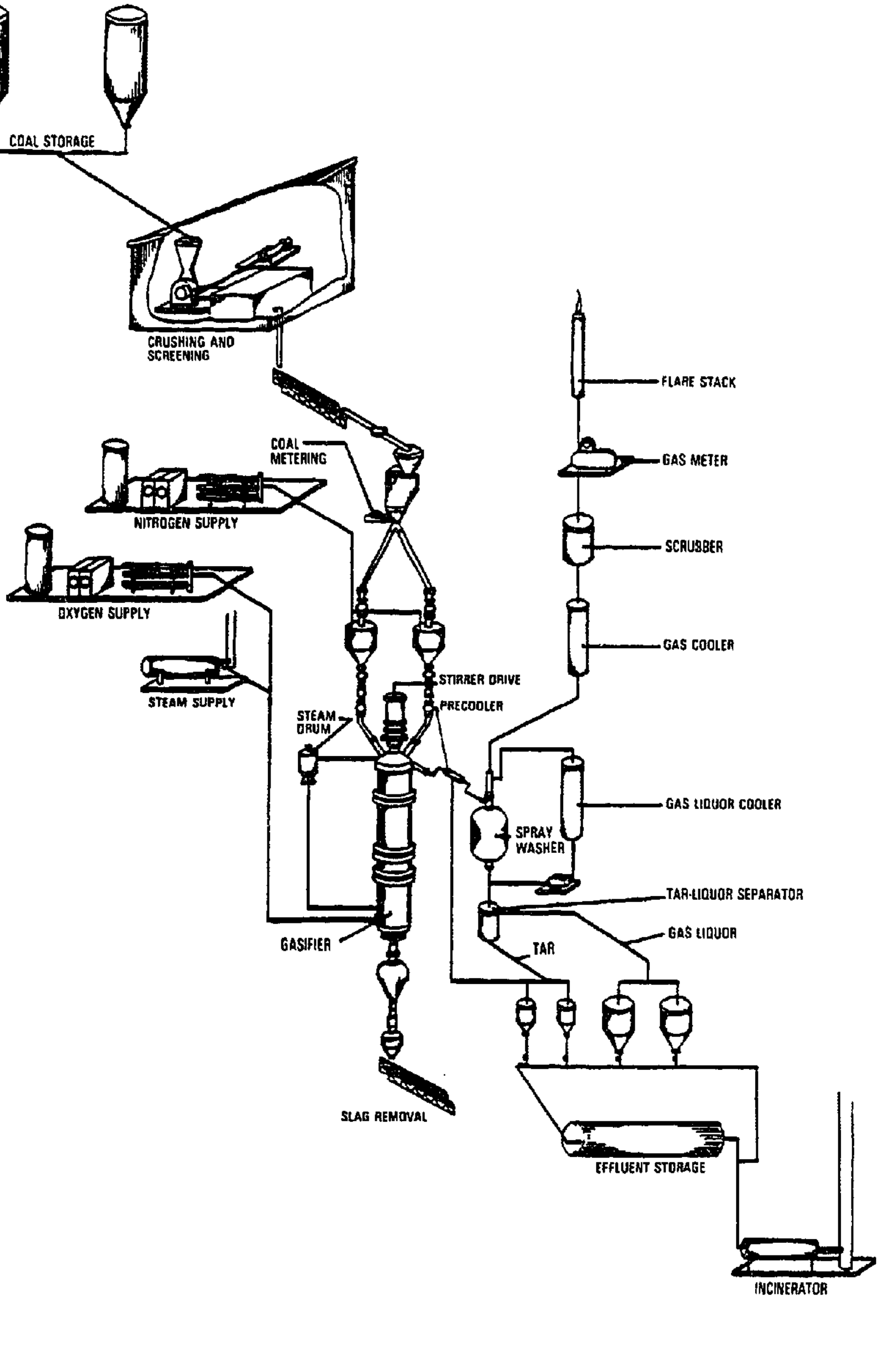

FIGURE 9. MODIFIED GFPO GASIFIER SYSTEM

TABLE 3. OPERATING DATA AND TEST RESULTS FOR GFPO GASIFIER

RUN NO.:	116	117	118	119	120	121
Coal	Indian Head Lignite	Indian Head Lignite	Indian Head Lignite	Indian Head Lignite	Indian Head Lignite	Indian Head Lignite
Pressure (psig)	300	300	300	300	300	300
Input, lb/hr (maf)						
Coal	1358	1311	1287	1272	1239	1270
Oxygen	568	574	551	554	554	555
Steam	340	354	347	343	347	394
Input Ratios, lb/lb						
Steam: Coal	0.3	0.3	0.3	0.3	0.3	0.3
O_2: Coal	0.4	0.4	0.4	[illegible]	0.4	0.4
Output, lb/hr						
Ash (Slag)	68	87	81	56	71	60
Cyclone Dust	0	0	0	0	0	0
Gas	1584	1444	1412	1445	1419	1476
Tar	32	31	31	50	36	31
Water	630	589	553	638	616	539
Gas Yield						
mscfh	40.4	31.9	27.8	30.7	35.4	30.5
sdf/lb Coal, (maf) basis	29.7	24.3	22.5	24.1	28.6	24.0
Gas Analysis						
CO	53.2	52.5	52.4	54.6	50.6	51.9
CO_2	9.0	9.0	10.1	8.5	11.3	10.1
N_2	0.0	0.0	0.0	0.0	0.0	0.0
H_2	30.9	31.8	30.5	30.3	30.8	31.1
CH_4	6.0	5.9	6.1	5.8	6.3	6.0
C_2H_6	0.7	0.7	0.8	0.7	0.8	0.7
H_2S	0.2	0.1	0.1	0.1	0.2	0.2
O_2	0.0	0.0	0.0	0.0	0.0	0.0
Heating Value						
Btu/sfc	344	343	344	345	342	342
Cold Gas Efficiency	88	86	80	85	83	86
Throughput						
lb/hr/ft^2 grate	514	497	488	482	469	481
mscf/ft^2 grate	15.3	12.1	10.5	11.6	13.4	11.6

slagging gasifier runs are given in Table 3.

6.4 FY82 Accomplishments

Recent modifications to the gasifier, which consisted of enlarging the diameter to its maximum and inclusion of taphole burners in the hearth plate, have greatly enhanced the operability of the fixed-bed gasifier. Since these modifications were completed, eight tests were made with Indian Head lignite, four of which were concluded with voluntary shutdown, including a record 5-day test with continuous slagging. Since termination of the other four tests was due to problems associated with auxiliary equipment, the SFBG was considered operational with Indian Head lignite, which is similar to the feed to the Great Plains Gasification Plant.

Slag obtained from a North Dakota lignite was shown in laboratory studies to be suitable for disposal in a landfill in compliance with current RCRA guidelines. Heavy metals analysis of the leachate indicated that only iron levels are excessive, even if secondary drinking water standards are adopted at a later date. Ames testing for potential mutagenicity showed no biological activity.

Phenolic distribution coefficients for raw wastewater and a variety of solvents, including the two that apparently are used in commercial processes, were determined. Of these solvents, methyl isobutyl ketone (MIBK) showed the largest distribution coefficient for wastewater phenolics and was selected for use in subsequent laboratory studies.

SFBG wastewater, pretreated by solvent extraction and ammonia stripping, was tested in laboratory-scale activated sludge (AS) systems at full strength with and without addition of powdered activated carbon (PAC). The effluent from PAC/AS treatment was somewhat lower in total organic carbon (TOC), chemical oxygen demand (COD), phenolics, organic nitrogen, and color than that treated by AS alone. However, both AS and PAC/AS-treated wastewater showed excellent reduction in extractable/chromatographable organics with effluents containing only low levels of relatively few compounds.

The key to wastewater processing apparently lies in solvent extraction for phenol recovery, since it was shown that when phenolics were reduced to the range of a few mg/l by solvent extraction, most wastewater organic contaminants, both aqueous and suspended phase, were reduced to detection limits. Solvent-extracted wastewater did not require dilution prior to biological treatment, and it had less tendency to foam and a lower COD, TOC, and color than did a similar sample diluted to the same phenolic level.

Based on a new gas chromatographic procedure developed by the Analytical Research Division at GFPO, the bulk of the previously undetermined COD remaining in wastewater after solvent extraction is not long-chain humic acids, as believed by most investigators. It is composed predominantly of hydantoins, which are extremely water soluble and, therefore, resistant to solvent extraction. Hydantoins may have further impact on processing lignitic wastewater in that they are probably refractory toward biological degradation and, as a class of compounds, are mild sedatives.

6.5 Current Status and Projected Work

The SFBG system is fully operational and can be used for generating lignitic wastewaters in support of the Great Plains Gasification Project.

The projected work includes:

- Determining the efficacy of a minimal treatment scheme, such as proposed by Great Plains, in preparing makeup for a cooling tower. Wastewater will be solvent-extracted with de-isopropyl ether and ammonia-stripped to levels representative of those anticipated at Great Plains as agreed upon by the American Natural Gas (ANG) engineers. Stripped gas liquor (SGL) will then be used as the principal source of makeup for a 2-month cooling tower assessment in an attempt to evaluate the consequences of high COD levels in the drift as well as fouling and corrosion tendencies. Coincidental work will include operating the gasifier for over 200 hours to produce wastewater which will be processed in the activated sludge unit for the second phase of cooling tower tests.
- Assessing environmental and process consequences for using SGL that has undergone biological oxidation treatment as a cooling tower makeup. In addition to extraction and stripping, wastewater will be processed in an aerated, AS reactor to simulate the treatment employed at South African Coal Oil Company, Ltd. (SASOL).
- Planned operating parameters for the AS unit include flow rates of nominally 1 gpm, a 1- to 2-day hydraulic detention time, and a 2- to 5-day sludge age. In addition to preparing wastewater for further cooling tower assessments, a detailed evaluation will be made of the AS treatability of SGL from lignite, including such factors as sludge settling.
- Identifying and quantifying highly water-soluble organics, which remain after solvent extraction and are refractory to bio-oxidation. In addition, the organics in the drift will be determined. Coincident work will be devoted to the characterization of the highly polar, phenolic tar fraction, which has been largely unidentified and makes up to about 60 percent of the tar. In addition, an effort will be made to develop a laboratory-scale devolatilization apparatus to simulate gasifier atmospheres in order to correlate primary devolatilization products with organic effluents.
- Continuing to develop predictive models for waste-water unit operations with Carnegie-Mellon University, Pittsburgh, Pennsylvania, such as the model developed for solvent extraction. The work will focus on modeling a laboratory-scale cooling tower which will be validated later at the PDU and commercial levels. An attempt will also be made to model

organics degradation in the soil to be used as a predictor for spills.

- Investigating advanced treatment processes at a laboratory scale. This work will include studies such as those on anaerobic digestion, in conjunction with activated sludge processing and as a less energy-intensive substitute for biological oxidation, being performed at the Georgia Institute of Technology. Recovery and regeneration of activated carbon from biological treatment systems will be pursued.
- Evaluating the disposal of biological and physical/chemical sludges employing RCRA guidelines at the University of Pittsburgh, Pennsylvania. Sludges will initially be simulated from laboratory-scale units and then will be compared with those from the wastewater PDU's. Leachate will be examined for potential mutagenicity using Ames testing and acute toxicity using bioassay procedures.
- Evaluating all effluent streams, including those from various treatment steps, for biological activity using Ames tests. The more active streams will be chemically characterized and further tested to determine their effects on mammalian cells.

7.0 GENERAL ELECTRIC FIXED-BED GASIFIER AND PERFORMANCE EVALUATION FACILITY

7.1 Project History

A Performance Evaluation Facility (PEF) scale fuels plant simulation is in operation at the General Electric Research and Development Center in Schenectady, New York. Its key components are a gasifier and both physical gas cleanup system, and chemical gas cleanup systems, which are common to many synthetic fuel processes. This fuels plant configuration can be coupled with a pressurized combustion system and gas turbine airfoil cascade in a direct simulation of a gasification/gas cleanup/power generation coal-conversion process. The complete PEF has been operated under conditions typical of such end-use application.

In earlier programs, performance information was obtained on the advanced fixed-bed gasifier with highly swelling coal. Technical data from the chemical cleanup demonstrated that this type of coal conversion plant can meet a 90 percent sulfur capture criterion. The power generation simulator and its control system proved that a steady combustor exit temperature can be maintained using gas from this fuels plant.

Since the primary objective is to develop a technique which will predict the operational performance of a commercial-size integrated coal conversion system, a key program activity is to project full-scale performance from PEF experimental results. The task of providing an analytical simulation of the full-scale and PEF-scale system is, therefore, critical to defining PEF dynamic experiments and interpreting results. System simulation models that are available for analyzing integrated gasification gas turbine/steam turbine combined cycles are being modified to reflect the geometry and operational characteristics of the PEF-scale system. Data generated by these models are used to define both system and component tests on the PEF system. The experimental tests results from these tests are then evaluated and used to modify the analytical system simulation model.

This project is totally funded by DOE and was initiated in 1980. It is scheduled to be completed by the end of 1983. During the first year, fired operation of the PEF concentrated on steady-state system and component performance. During the second year, operation concentrated on characterizing the dynamic behavior of the system components and determining the environmental intrusion of the system. The third year of the program is focused on characterization of integrated system dynamics and validation of the system dynamic model. By the end of the third year, a data base will be established to ensure that the simulation model is adequately verified experimentally.

7.2 Project Goals

Coal gasification/gas cleanup fuels plants for synthetic fuel applications must be developed within two sets of constraints: one is imposed by dynamic load response to variations in end-use demand and the other by the need to comply with environmental regulations. The overall objective of this program is to establish the technology base required to operate within those constraints. In order to establish this base, system and component fuels plant performance is being characterized in both steady-state and dynamic operation. Additionally, the information required to establish system control logic is being developed.

The PEF, an integrated coal gasification system composed of proven process units, is being used to perform tests for establishing an information base. This information base will:

- Establish performance parameters for each process unit.
- Define dynamic interactions of process units operating under variable loads.
- Characterize effluent flow streams from the process.
- Develop an experimentally verified simulation model for integrated system operations.

The employment of a combined experimental-analytical approach will yield empirically verified performance projections for full-scale systems.

7.3 **Process Description**

The PEF system includes an advanced fixed-bed gasifier, a low-temperature gas cleanup system, and a gas turbine simulator. Auxiliary facilities include a high-pressure air and steam supply system and a computer-based data acquisition and control system which provides sophisticated data monitoring, analysis, and control. The integrated gasification system is shown in Figure 10.

7.3.1 Gasification Subsystem

The gasifier shown in Figure 11 is an advanced, pressurized , fixed-bed unit with a 1-ton/hr coal capacity. The reactor is refractory lined and incorporates an upper bed stirrer and a lower grate paddle. Both of these mechanical devices are water-cooled and can be raised and lowered in the bed, as well as rotated. Two lockhoppers feed coal into the vessel by using a variable-speed auger. Another lockhopper is used to remove ash.

The gasifier blast feed is a mixture of heated air and steam. The air is supplied by three compressors capable of producing up to 18 lbm/sec of air at pressures up to 30 atm. Preheaters can heat the air to 540°C. Steam is generated by an auxiliary boiler which can supply up to 2.8 lbm/sec of saturated steam at 30 atmosphere (of pressure) (atm). Automatically controlled valves meter the blast quantity and quality.

7.3.2 Gas Cleanup Subsystem

Uncracked hydrocarbons, particulates, ammonia, and sulfur-bearing gases are removed from the raw gas in a low-temperature cleanup system. A reheat/resaturator reintroduces the condensate and recovers the thermal energy. The cleanup system is shown in Figure 12.

The gas leaving the gasifier is adiabatically quenched to lower its temperature and to remove tars and the bulk of the fine particulates. The quenched gas then passes through a venturi fume scrubber in which circulating water provides the scrubbing energy. The scrubber is operated isothermally to prevent further condensation thus ensuring maximum particulate and mist scrubbing efficiency.

In the first gas cooler/condenser, the gas is cooled from 165° to 146°C by indirect heat exchange with the scrubbed gas. The heat exchanger can reduce the gas temperature further if other temperature splits are desired. The condensate formed during this gas cooling is sent to a pressurized condensate decanter. The gas then enters a second gas cooler where it is further cooled to 82°C. This temperature is required by the H_2S scrubbing system. The condensate from this cooler is sent to a second pressurized decanter.

H_2S removal is accomplished in a Benfield hot potassium carbonate system, in which the H_2S reacts with an aqueous K_2CO_3 solution. The solution is steam regenerated to strip the acid gas. A gas wash column is located directly down-stream of the H_2S absorber. In the gas washer, the scrubbed fuel gas contacts a recirculating flow of demineralized water. It is then passed to the reheat/resaturator column where the decanted condensate, having been heated to approximately 170°C, is evaporated into the scrubbed gas. The scrubbed gas enters the resaturator at a temperature of 80°-90°C and is subsequently reheated to approximately 160°C and saturated with steam and light hydrocarbons. The product gas is then superheated to 200°C to ensure that no condensation takes place in the piping run to the turbine simulator.

7.3.3 Turbine Simulator Subsystem

The gas turbine simulator consists of a combustor and first-stage nozzle airfoil cascade. It operates on the total output of the fuels plant. The pressure and temperature conditions are representative of those which would be found in gas turbines employed in an integrated gasification combined cycle (IGCC) end-use application. The air supply for the turbine simulator is drawn from the same compressors that feed the gasifier via computer-controlled valves. This configuration is designed to simulate the power generation cycle interactions in an IGCC application.

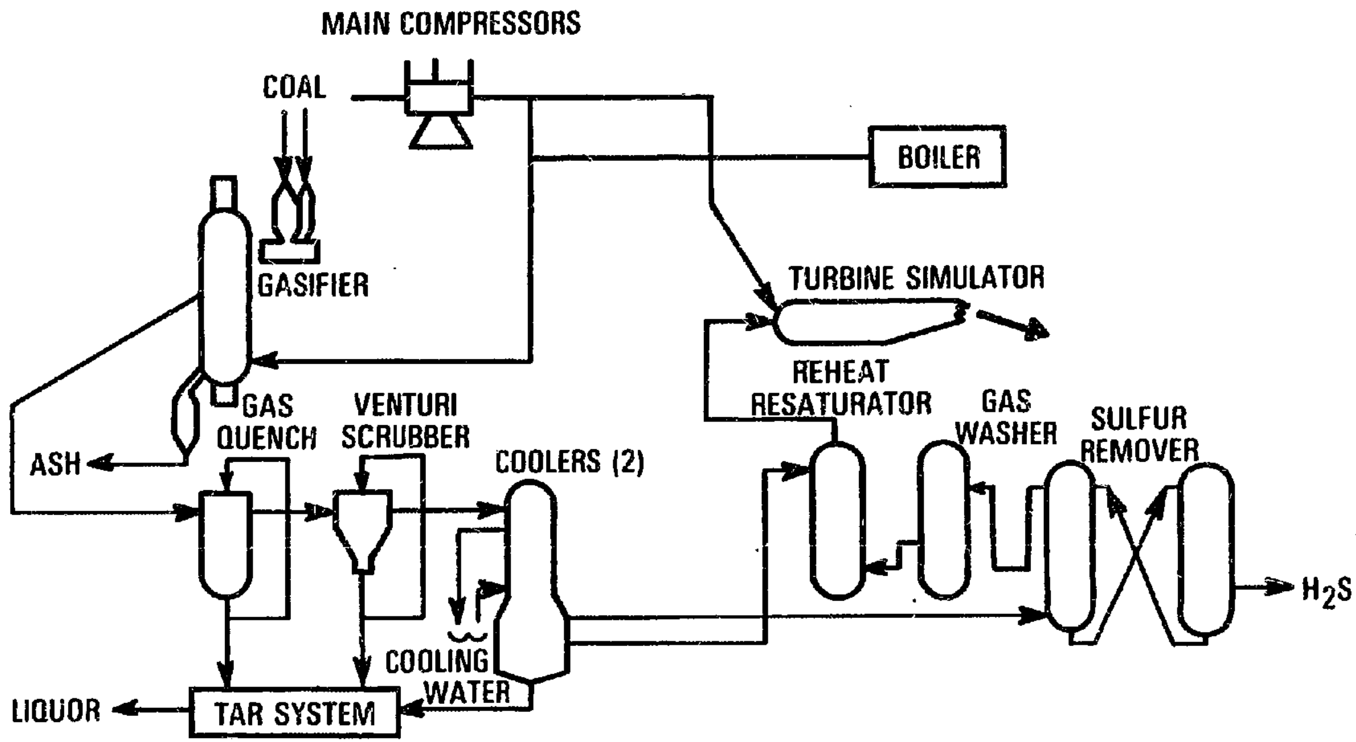

FIGURE 10. GE INTEGRATED PROCESS EVALUATION FACILITY

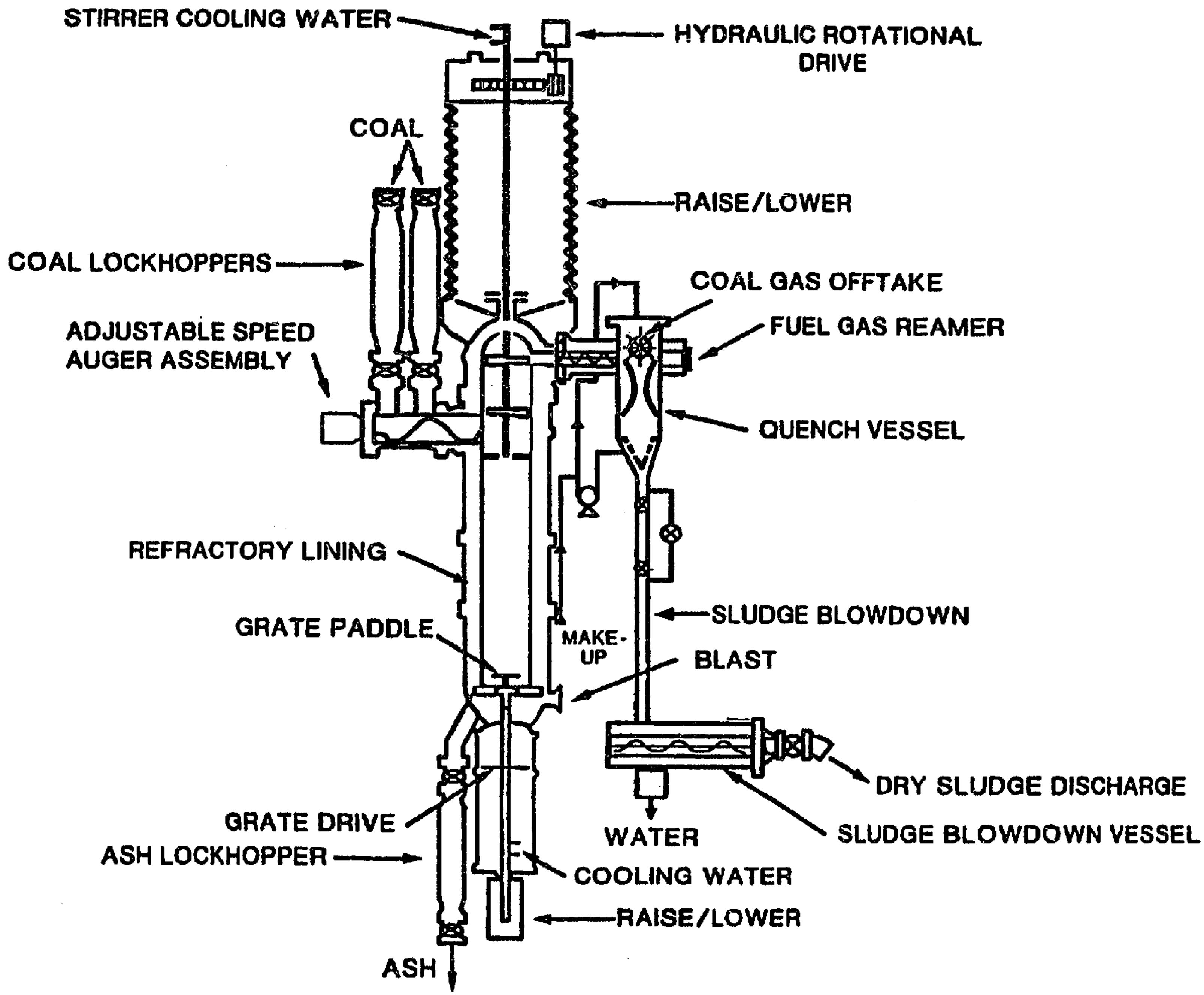

FIGURE 11. GE GASIFIER SYSTEM

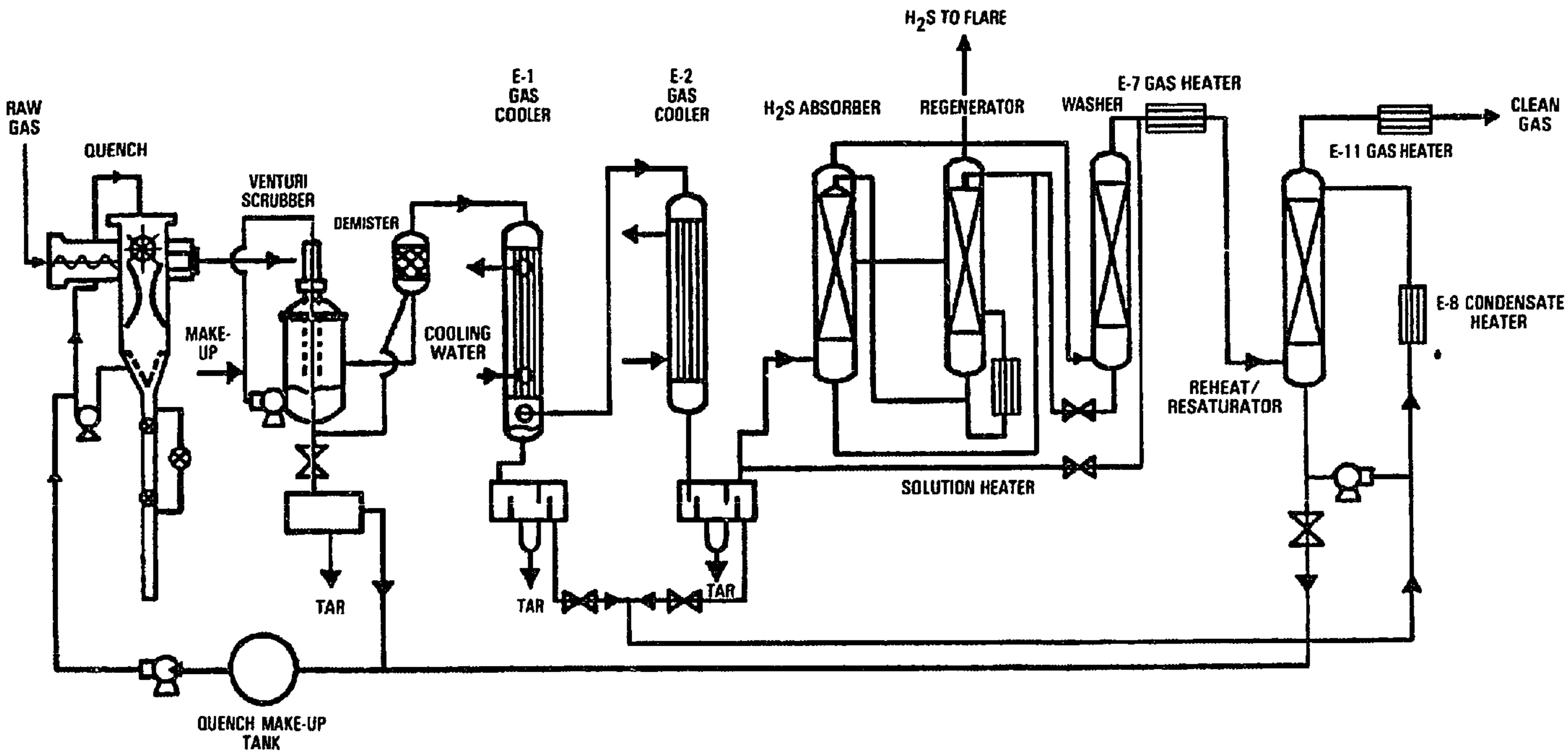

FIGURE 12. GE GAS CLEANUP SYSTEM

7.3.4 Computer-Based Data Acquisition and Control System

A hierarchial, multilevel, distributed, real-time, computer-based data acquisition and control system supports the PEF. This system provides experimental data acquisition, real-time data analysis, system control, data and calculational result display, test data archiving, post-test data analysis, and real-time and post-test system simulation.

Operator interfaces and displays are provided by multiple cathode ray tube (CRT) display terminals. Displays are updated with new information as it becomes available in the system; variable up date rates range from 1 to 20 seconds depending on data acquistion frequency. Over 70 on-line data displays are available to operators and engineers during PEF operations.

7.4 FY82 Accomplishments

During 1982, the PEF was operated under various steady-state and transient conditions to characterize both the integrated system and individual components of the system. The facility was operated on Illinois No. 6 coal which had a nominal sulfur content of 1.5 percent and a heating value of 13,286 Btu/lb (dry basis).

7.4.1 Dynamic Characterization and System Simulation

Controlled transient tests, covering a range of step and ramp input changes, were conducted on several major system components such as the gas cooler, resaturator, steam heaters, Benfield system, and gasifier. Output responses from these components were recorded throughout the tests by the data acquisition system and analyzed in detail later. This unique data base not only describes the dynamic behavior characteristics of gasification fuels plant components, but also provides insight into phenomena which are critical in governing component response. For example, in the case of the resaturator, a rapid change in the exit gas temperature was observed after a step change in the heat input to the liquid recirculation loop. For steam heaters, a nonlinear response in the exit gas temperature was observed when a step change was introduced to the steam flow.

Simulation models were developed for all major components. Most of these models have been verified by using the dynamic testing data base described above and show excellent agreement.

The verification has included modification of the models to incorporate the critical phenomena revealed as critical by the dynamic testing. The computer simulation model was extended to enable the component models to be interconnected in an overall system model.

7.4.2 Process Stream Characterization and Environmental Compatibility

All major gaseous and liquid streams within the PEF system have been characterized with respect to composition, pressure, temperature, and flow rate. As a result, the potential environmental intrusion of the system discharge streams can be assessed and environmental performance improvement areas have been identified.

To simulate a commercial configuration, the PEF system was operated with full condensate recycle. Such operation produces results in the lowest feasible liquid effluent discharge. The relationship between liquid effluent discharge rate and effluent stream composition was investigated and a technique was developed for projecting long-term, steady-state discharge stream composition at various discharge rates, based on short-term transient test data. A typical result for the PEF system using this technique is shown in Figure 13. This projection technique permits selection of a discharge rate that is compatible with waste treatment, gas quality, and system integrity requirements.

Material balances were developed for several important species. For example, Figure 14 shows the sulfur-bearing species balance. Some 21 g/min of sulfur, carried in the condensate streams from the condensing gas coolers E-1 and E-2, is returned to the resaturator, bypassing the Benfield acid gas removal system, while 12 g/min of sulfur is recycled via the quench stream. This flow, equivalent to about 100 ppm leakage into the clean gas stream, means that condensate stream treatment is required to substantially reduce the clean gas sulfur content.

7.4.3 Component Performance

The steady-state performance of each PEF system component was characterized by using a comprehensive series of tests that covered a wide range of conditions.

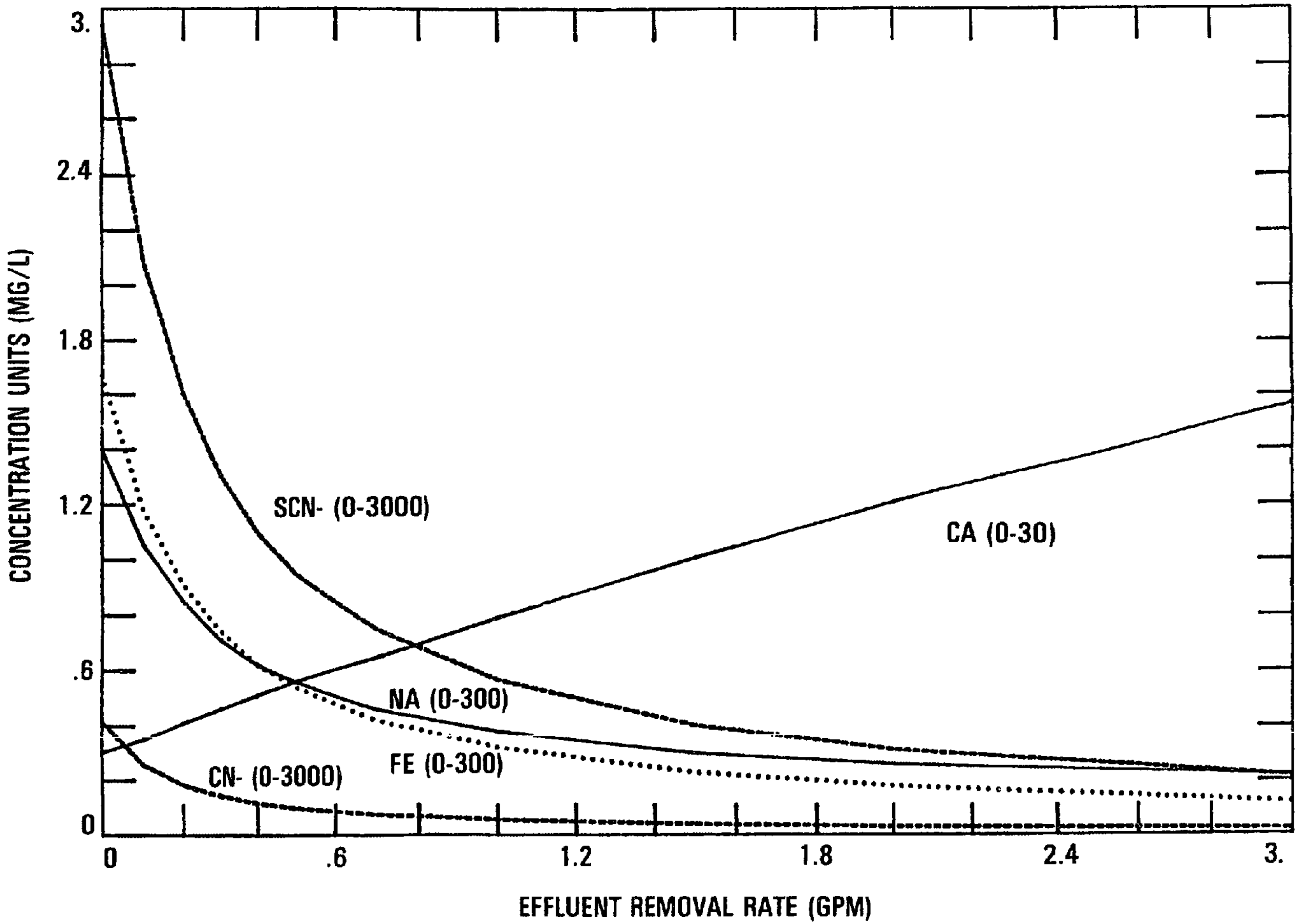

FIGURE 13. GE PREDICTED CONCENTRATION VERSUS EFFLUENT RATE

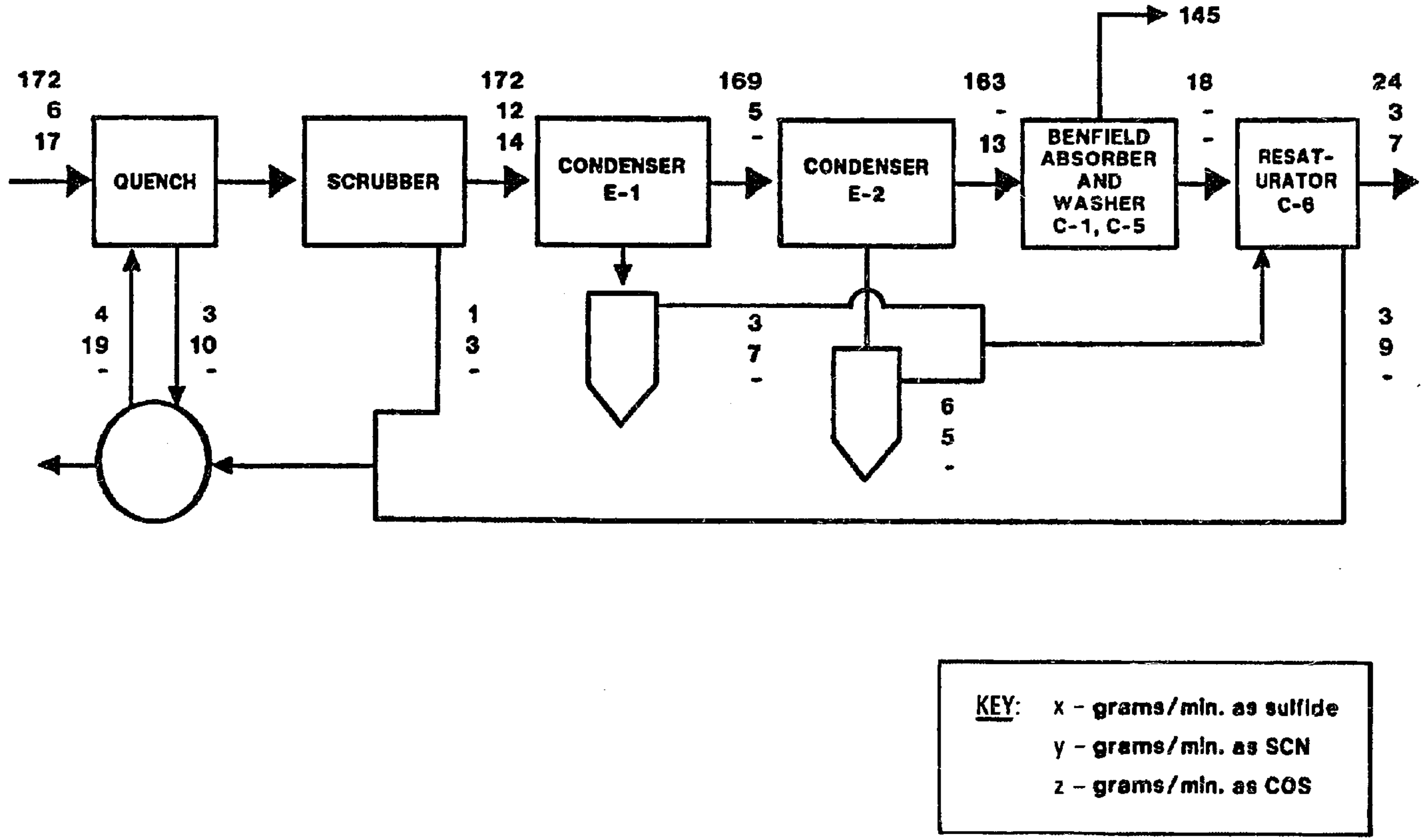

FIGURE 14. GE SULFUR DISTRIBUTION

The Benfield acid gas removal system was characterized over a wide range of system parameter variations with gas produced from coals having 1.5 and 2 percent sulfur content. As shown in Figure 15, over 90 percent of the sulfur was captured while less than 30 percent of the CO_2 was removed.

The steady-state performance of the gasifier during the 1982 testing period is shown in Table 4. A comparison of the gasifier operating results for 1981 and 1982 at base case conditions is shown in Table 5. The results obtained during these two years were consistent with each other. Key material balances were developed through system stream sampling to characterize integrated component performance and to identify approaches that will achieve system performance improvements and reduce environmental intrusion.

TABLE 4. BASE CASE GASIFIER OPERATION DATA

Raw Coal (lbm/hr)	1,960
Dry Fines Carryover (%)	3
Hot Gas Temperature (°F)	1,094
Quench Exit Temperature (°F)	341
Raw Gas Flow (lbm/hr)	6,691
Tar Yield (wt% Dry Coal)	4.7
Gas Higher Heating Value (Btu/scf)	169
Raw Gas Water Content (vol% wet)	17.1

7.4.4 Process Development

Ammonia from coal-bound nitrogen is passed from the raw gas to the clean gas via the condensate streams and the resaturator. This ammonia flow would cause unacceptable NO_x emissions in a combustion end-use application. Removal of ammonia in the condensate by stripping it with part of the gasifier blast feed was investigated.

Theoretical and laboratory-scale evaluations of the stripping process effectiveness have shown that using 25 percent of the gasifier blast feed, with the condensate at 138°F, will remove 50 percent of the ammonia. This degree of removal would satisfy current environmental requirements. Operation with the condensate at 160°F removed 80 percent of the ammonia, which is a sufficient reduction to satisfy anticipated future requirements.

An experiment was conducted in which ammonia was injected into the PEF gasifier blast feed line to simulate the effect of the stripping step described above. Table 6 shows the results of this experiment. The composition of the raw gas exiting the gasifier appears not to have been affected by the ammonia injection. The 109 g/min flow rate corresponds to the 50 percent ammonia stripping level discussed earlier. This result confirms a preliminary theoretical study which indicated that the injected ammonia would be oxidized to elemental nitrogen when passing through the gasifier bed.

TABLE 5. GASIFIER OPERATION RESULTS

	1981 BASE CASE	1982 OPERATION
Raw Gas Water Content (vol%)	18.4	17.1
Dry Gas Higher Heating Value (Btu/scf)	162	169
Cold Gas Efficiency (%)	73.2	74.1
Steam Utilization (%)	56.5	56.1
Enthalpy Conversion Efficiency (%)	66.1	67.5

7.5 Current Status and Projected Work

To date, program activities have been directed toward evaluating the environmental compatibility of the system, characterizing the steady-state performance of the system and components,

TABLE 6. RESULTS OF NH_3 INJECTION TEST

NH_3 INJECTION RATE (g/min)	CONCENTRATION (ppm)	
	NH_3	NO_x
0 (Baseline)	3,000-4,300	1,170-1,570
64	3,400	1,300
109	4,030	1,480
133	—	1,200

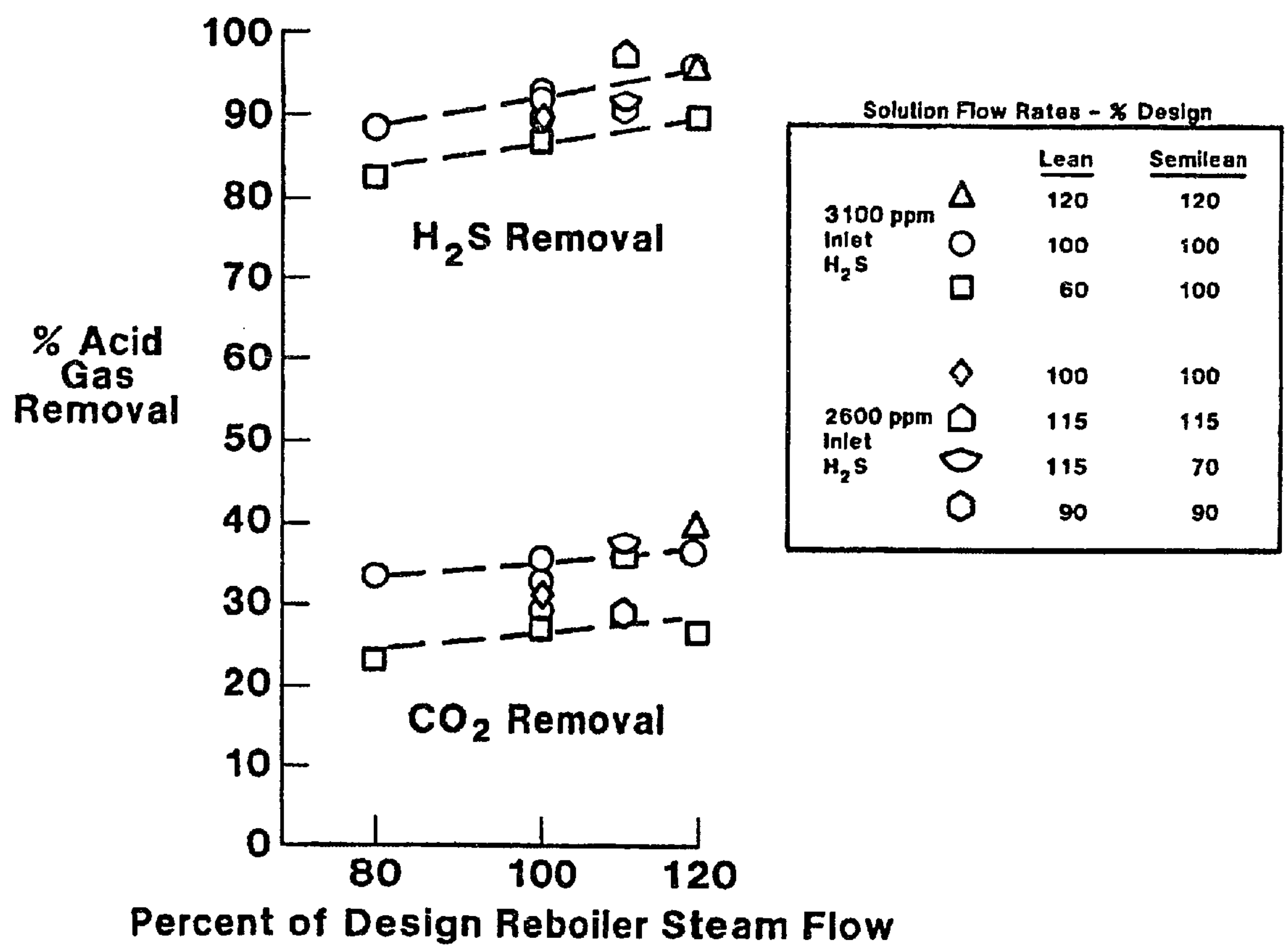

FIGURE 15. GE BENFIELD PERFORMANCE RESULTS

characterizing the dynamic behavior of the components, and developing verified analytical models of the dynamic behavior of the components.

A wide range of transient tests conducted in 1982 established a unique data base that describes the dynamic behavior of each component in a coal gasification fuels plant. This data base has been used to verify those dynamic analytical models previously developed for each major component in the system. The verification process has led to analytical model enhancement which includes predicting phenomena not previously recognized as being critical.

A detailed operational test plan has been developed to address the remaining program objectives for 1983. Tests to complete the characterization of the gaseous effluent streams will be conducted. Transient tests will be performed on the entire system rather than on individual components. The data generated from the system transient tests will be used to validate the existing system model.

8.0 MIFGA FIXED-BED GASIFIER

8.1 Project History

MIFGA is a cooperative, cost-sharing organization comprised of both Governmental and industrial participants. It succeeded the Pellet Energy Group (PEG) which was formed in 1975 to respond to gas supply interruptions. These interruptions led to tripled gas prices for U.S. iron ore mining and pelletizing operations. PEG consisted of a consortium of 18 companies who were interested in iron ore, coal, gas, engineering, and construction. DOE and BOM had the same interests.

This industry supplies about 70 to 75 percent of the Nation's iron ore and had relied heavily on natural gas to roast iron ore pellets.

To limit their reliance on uncertain fuel supplies and to seek more economical process heat, the pelletizing industry examined direct coal utilization as an alternative energy source.

After the BOM feasibility study, low-Btu gas was thought to be suitable for use in iron ore pellet innovation. At this point, PEG developed and implemented plans to validate this concept in a pilot plant. The plant was constructed by the BOM at the Twin Cities Research Center in Minneapolis, Minnesota. For 2 years, performance tests were conducted with a 6.5-foot ID Wellman-Galusha fixed-bed gasifier using various coals, some of which had never been used as a gasifier feedstock. During this time, the gas was burned in an experimental rotary kiln to indurate iron ore pellets for blast furnace feedstock as well as to test low-pressure, low-Btu gas burners in a 22-foot combustion chamber.

After PEG had essentially completed its original objectives by 1979, the program was expanded to provide a broadened outlook for the gasification of other essentially untested fuels and end-use applications. MIFGA was formed in 1980 to include these new users.

The organization now includes three Federal Government agencies; DOE, BOM, and the EPA; two major industrial groups; Electric Power Research Institute (EPRI) and (GRI); seven vendors of gasification equipment; major architect and engineering firms; coal companies; natural gas companies; railroads; state agencies, and others.

8.2 Project Goals

MIFGA was formed to promote the development and demonstration of low-Btu gas production and its usefulness in industrial applications. Currently, the basic objective is to identify and fill data gaps as perceived by the 24 members of the organization and the various agencies involved. Tests are designed and conducted to provide an accurate scientific and engineering data base which the private sector can use to deploy this form of coal gasification expeditiously when and where it is economically feasible.

8.3 Process Description

The MIFGA gasifier shown in Figure 16 is a 6½-foot diameter, fixed-bed, atmospheric pressure unit with a water-cooled agitator arm and a rotating ash grate. It has a nominal bituminous coal consumption rate of 3,000 lb/hr, and is fed from above by a 10-ton storage hopper. Moist, warm air is generated for the gasification process by passing air over water heated in the gasifier cooling jacket. The air and steam react with heated coal to form the low-Btu gas, often called "producer gas" or "coal gas".

From the gasifier, the low-Btu gas flows through a refractory-lined cyclone to a combustor chamber via a 24-inch ID duct or to the pelletizing kiln via an 8-inch ID duct. The combustion chamber is designed to match the full gas producer output (about 30 million Btu/hr). The original scroll-type gas burner

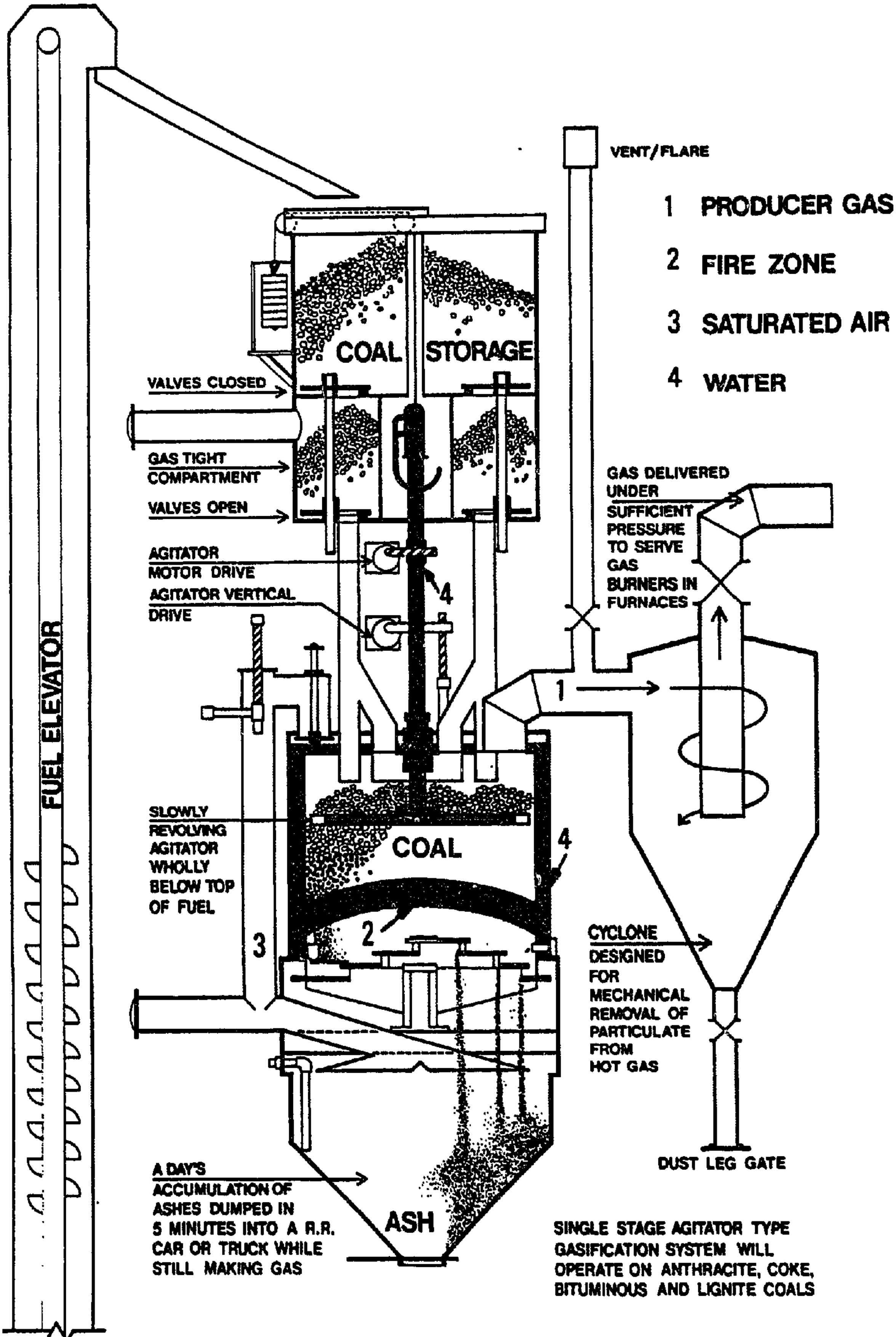

FIGURE 16. MIFGA FIXED-BED GASIFIER

with register vanes to control flame shape has now been replaced by an axial-type burner.

Exhaust gases from the combustion chamber are cleaned with an impingement tray-type scrubber with pH control. A combination ignitor-incinerator is installed on the gasifier vent stack to ignite gases during flaring or to completely burn the small amount of gas generated during banking.

In 1982 joint plans were made with EPA and EPRI to install a wet scrubbing system to remove tars and oils, and to install a Stretford desulfurization system to investigate desulfurization and the characteristics of the cleaned fuel gas. Installation of these systems was completed during autumn of that year.

8.4 FY82 Accomplishments

During FY82, the operating contractor, Black, Sivalls, and Bryson, Inc., made numerous minor modifications to the gasification system, but the major accomplishment was the installation of a computerized data acquisition system. In addition, a side stream tar quench/electrostatic precipitator (ESP) system designed by the Fluid Ionic Division of Dresser Industries was installed along with an EPA-owned Stretford Sulfur Removal System designed by the Pritchard Company. Both of these units are designed for 1,000 scfm gas flows.

During FY82, two operational runs were made. One, with Montana Rosebud (colstrip) subbituminous coal and another with Eastern Kentucky Jetson (low free-swelling index) bituminous coal. The colstrip subbituminous coal provided relatively poor throughputs because thermal shock apparently broke up the lumps causing bed packing and large amounts of fines carryover. The Jetson coal, on the other hand, ran very well in all respects.

The tar quench/ESP system experienced a series of electrical failures but, after the repairs, it operated well, and provided greater than 99 percent tar removal efficiency.

Initially, the Stretford Sulfur Removal System operated at about a 66 percent efficiency and increased to a 99.8 percent efficiency as the operational parameters were established.

8.5 Current Status and Projected Work

The MIFGA gasifier is undergoing minor modifications in preparation for seven operational tests that will total 145 days of operation during FY83. The following tests were begun in April:

BOM/FGT — 003	
Lucite Hills SB-Wyoming	20 Days
BOM/FGT — 004	
DOE Briquettes SB-Rosebud Montana	10 Days
BOM/FGT — 005	
E&K Bituminous (Central Pennsylvania)	30 Days
BOM/FGT — 006	
Petroleum Coke (Minnesota-High Sulfur)	20 Days
BOM/FGT — 007	
Bituminous (Eastern Kentucky)	35 Days
BOM/FGT — 008	
Peat Pellets-Minnesota	10 Days
BOM/FGT — 009	
Lignite-Texas	20 Days

The tar quench/electrostatic precipitator will be run during all tests and the Stretford System will be operated for 30 to 45 days.

9.0 CAN-DO FIXED-BED GASIFIERS (GASIFIERS-IN-INDUSTRY PROGRAM)

9.1 Project History

A severe decline in anthracite coal mining in the mid-fifties caused the Hazelton, Pennsylvania, Chamber of Commerce to assemble a group of local people and form a group called CAN-DO. A charter was established to bring in new industries that would provide jobs for Hazelton area residents. Under its guidance, two new industrial parks were built on the outskirts of Hazelton. With funding help from the Appalachian Regional Commission (ARC) and the U.S. Economic Development Administration (EDA), the group built a gasification facility in the Humboldt Industrial Park to supply up to 1 billion Btu per day of clean low-Btu industrial fuel gas to park residents. At this time, oil and gas prices were escalating and many gas customers were suffering from interruptions in supplies.

Gas plant operation began in late 1981, and it was discovered that there was a series of design deficiencies which had to be overcome before steady-state, long-term operation could begin. Concurrently, oil prices stopped escalating, natural gas became plentiful, and anthracite coal prices almost doubled. By late 1982, the design problems were overcome and the plant began to supply low-Btu gas to the Inland Container Corporation (ICC), one of the park residents.

During 1981, DOE contributed funds to the program on a cost-sharing basis to characterize operating parameters. DOE contributed 60 percent and CAN-DO contributed 40 percent under the Gasifiers-in-Industry Program. The data from parametric studies will fill a gap in the DOE gasification data base with regard to the use of anthracite fuels in fixed-bed gasifiers.

9.2 Project Goals

DOE funding has been targeted toward obtaining comprehensive operating data from the gasification of anthracite fuels of various sizes and qualities in the CAN-DO fixed-bed gasifier systems. Efforts have been made to specifically study lower-cost anthracite fuels, because premium coal was costing $35.00 per ton when the project started and had escalated to $74.00 per ton by late 1982.

The parametric test program was designed to obtain the maximum throughput, minimum steam requirements, effects of bed agitation, cleanup system requirements, environmental control requirements, and optimum operating characteristics for each fuel and fuel size.

9.3 Process Description

The CAN-DO gasification facility shown in Figure 17 includes two 10-ft diameter, wet-wall, stirred, dry-bottom, single-stage, air-blown, atmospheric pressure, Wellman-Galusha fixed-bed gasifiers. Each gasifier has a throughput capacity of 24-tpd of pea-sized anthracite coal and produces approximately ½-billion Btu's per day (about 22 MMBtu/hr) of low-Btu gas.

Large particulates are removed directly downstream of the gasifier in cyclones, after which the gas is partially cooled in a waste heat boiler and passed through a water scrubber/cooler. The gas is then pressurized in turbo compressors to about 6 psig, passed through a venturi scrubber, and chilled to lower its temperature below the dewpoint which will remove any remaining traces of moisture. From the chiller, the gas is partially reheated before entering the underground distribution line. Excess product gas is automatically flared to the atmosphere.

Neither tar removal nor sulfur removal equipment is required because of the low-volatile matter content and low-sulfur content of the anthracite coal.

9.4 FY82 Accomplishments

During FY82, the plant gas cleanup system and gas distribution system underwent several modifications to prevent toxic gases from leaking into the building and to prevent water condensation and particulate carryover in the gas distribution system. One of the two gasifiers was operated under partial load and low-Btu fuel gas was supplied to ICC. A test plan was completed for parametric tests scheduled to begin in March 1983.

9.5 Current Status and Projected Work

The CAN-DO operation will be shut down once the parametric tests are completed in the Spring of 1983. CAN-DO applied for price and loan guarantees from the Synthetic Fuels Corporation (SFC) during the third SFC solicitation but their operation did not meet the SFC objectives.

10.0 COAL GASIFICATION TECHNOLOGY CROSSCUT

10.1 Introduction

Technology crosscut was addressed in METC's first two reports on Surface Coal Gasification (DOE/METC/SP-110, October 1980 and SP-192, February 1982). The information and data presented in those reports are, to some degree, still valid and progress has been made in some areas. The Combustion Engineering atmospheric entrained-bed gasifier project has been dropped from the crosscut discussions. Development efforts were completed prior to the past year. Discussion of several other gasifier development efforts has been incorporated and significantly expanded in this report. In comparison to previous formats, a modified approach has been taken, wherein, more information is provided in a tabular form. As a result, the technical information provided for all eight gasifiers concerning their similarities, differences, achievements, and problem areas can be readily compared. A "crosscut" review of the technologies is, therefore, quickly and easily provided to the reader and available at several levels of detail.

One should realize that the Surface Coal Gasification program has been directed under changing policies over the last several years. All projects

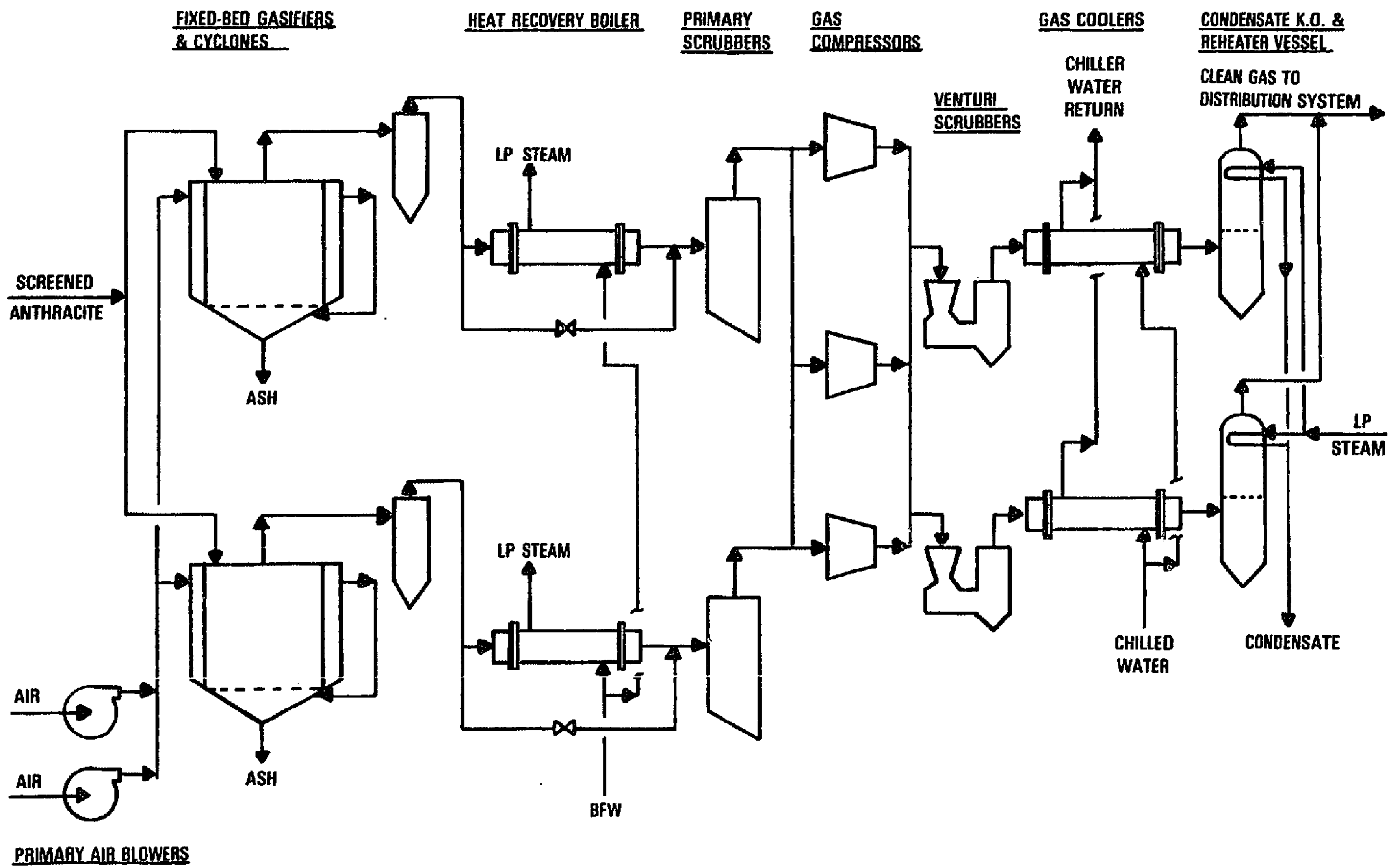

FIGURE 17. CAN-DO GASIFICATION FACILITY

discussed have different major goals and objectives, and direct comparisons are not easily achieved, nor was that the intent of the program. However, limited discussion of common problems generic to the eight gasification process development projects is provided and conclusions may be drawn from studying any of the five tables presented. These tables illustrate the eight gasifier projects: one involving a fluidized-bed unit, two entrained-bed units, and five fixed-bed gasifiers. The information provided is of a subjective nature. For example, "contractor/agency assessment of greatest system inefficiencies," represents statements given by the respective contractor or agency. The five tables include:

- General Information

  Relates to the status as of December 1982 and overview information of project objectives, problem areas, and generalized assessment of the efforts to date.

- Gasifier Data

  Provides the gasifier structural specifics, design parameters, and achieved performances.

- Operational Parameters

  Presents achieved operational parameters critical to assessing the capabilities of various gasifiers in efficient coal conversion.

- Particulate Removal/Recycle/Tar Removal

  Reviews the unit operations employed in various facilities for handling particulates and, where applicable, for recycling carbon or tar fines and tar removal.

- Acid Gas Cleanup/Instrumentation

  Provides a look at those systems which possess acid gas removal devices and a brief overview of instrumentation achievements and difficulties experienced.

10.2 Overview of Generic Gasification Systems Problems

This section will attempt to provide a limited discussion of the commonality of problems exhibited by the several projects and present conclusions which may be drawn from examination of the crosscut tables and knowledge of the projects' status. The following eight areas are discussed: (a) coal feeding systems, (b) char recycle, (c) residence times, (d) slagging versus non-slagging operation, (e) gasifier design specificity to feedstock, (f) system integration, and (g) environmental activities. The conclusions drawn are not intended to be all-inclusive nor to reflect all that can be extracted from the crosscut tabular information provided.

10.2.1 Coal Feeding

An economical feeding system that will adequately process all types of coal remains a major problem area for gasifiers which are operated at pressure and at higher temperatures. Additionally, reinjection of char fines to improve the overall economics for low-pressure gasifiers has proven to be a problem. The only commercially proven dry coal feed system is the Lurgi lockhopper approach, in which multiple-staged lockhoppers are employed in conjunction with a rotating coal distributor located at the top of the gasifier. Even this system is limited by the integrity of the lockhopper valves and the incapability to process coal fines, which are generated by mining, transport, and gasification site coal handling. A two-stage lockhopper train is used in an attempt to decrease the costs of compressing the pressurizing gas. The higher pressure lockhopper is vented to the lower pressure lockhopper in a continual sequence. Alternate means of feeding coal and coal fines have been explored to improve efficiency and reduce costs.

In fixed-bed gasifiers, adequate utilization of coal fines generally less than ¼ inch would provide much improved cost effectiveness. A system which can successfully agglomerate fine coal, typically rejected at a rate as high as 80 percent of the total delivered coal, would be immeasurably useful. A variance from 20 to 80 percent in the rejection rate exists depending on the coal rank and handling method employed. Investigation of such a system was conducted during 1982 through a program designed to review agglomeration methods such as pelletizing and briquetting and to estimate the cost of these processes. Dry coal feeder research using piston and screw-type devices was also performed by DOE/METC; however, these feeders were designed to reconstitute (agglomerate) the fine coal to sizes useable in the fixed-bed gasifier system. Previous work with extrusion-type feeders involved reconstituting coal fines to a useful feed size. For further information, refer to the Bibliography.

As shown in Table 8, a choke feed system was used by MIFGA and CAN-DO on the Wellman-Galusha gasifiers. This system does not allow any adjustments to fuel bed height and, therefore, does not permit optimization of the gas off-take temperatures. The Bi-Gas system uses a steam-dried coal slurry as feed to the reactor. This approach provides good control of size consistency with few operational difficulties. However, it has proven to be highly energy intensive. The MFR gasifier utilizes a dry coal feed system in which two-stage lockhoppers act to pressurize the coal and a single screw meters the coal into a pneumatic feed line using recycle gas to transport coal to the single gasifier nozzle. This unique system may provide sustained, highly controllable, dense-phase coal feed to the entrained-bed gasifier and improve overall system thermal efficiency. The unit is now undergoing shakedown trials. Westinghouse employs a similar system except that it feeds larger coal sizes (¼ inch x 0) and rotary star-wheel feeders are used as metering devices. The system has proven to be satisfactorily reliable, but problems associated with recompression of dirty recycle gas have been a nuisance.

10.2.2 Char Recycle

Both Bi-Gas (an entrained unit) and Westinghouse (fluid bed) require recycling char back to the gasification zone to achieve acceptable carbon conversion efficiency. This is a major problem because some 30 to 48 percent of the char produced in the gasifiers and elutriated out must be recycled in multiple passes to be fully converted to gaseous product. High-efficiency particulate separation devices (cyclones) must be used and made operationally reliable. Additionally, positive pressure created by energy-consuming pneumatic systems must be applied to transport the char back to the reactor over a significantly high pressure differential. These recycle flows must be accurately measured and precisely controlled so that the correct (minimal) oxygen-to-coal ratios can be provided. Total carbon losses from the systems are accentuated if the cyclones do not continuously function with high efficiency. Both developers have investigated this problem intensely. Recently, Westinghouse successfully recycled char for 15 continuous days by employing an L-valve with a fluidic control using recycle gas under one cyclone and an eductor using CO_2 under the second cyclone. Utilization of all available carbon has been significantly improved in both processes; however, a penalty has been assessed to the overall system due to increased energy requirements and reduced operability and reliability caused by the added mechanical devices.

10.2.3 Residence Times

In Table 8, the trend in advanced gasifiers is toward decreasing fuel residence times in the reactor. The MFR gasifier is designed for an estimated gasification zone residence time of 0.3 to 0.5 seconds in the gasification zone. Although not addressed in this topical report, the AVCO steam pyrolysis two-stage bench-scale gasifier has been designed for residence times as low as 0.03 seconds. Ultra-fast rate coal conversion studies in hydropyrolysis have shown that up to 86 percent of the coal can be converted to gaseous products within residence times of 3 to 5 milliseconds.

The shorter and shorter residence times have required much higher reaction temperatures and, therefore, slagging gasifier operations. In addition, because of limited reactor carbon inventories, they have required constant and uniform coal feed rates to prevent oxygen breakthrough. Slagging operation in all cases has created many problems which have resulted in unreliable gasifier performance, requirements for more exotic and expensive formulations of refractories, and severe environments for critically needed control instrumentation. In all cases, some form of slag breaking devices have been required and in some cases, extra burners have been necessary to maintain the molten slag at a viscosity low enough to flow readily. Slag removal has thus assumed a major role in establishing the operational reliability of the advanced short residence time gasifiers. A great amount of sensible heat is available in gas exiting these advanced reactors and this factor strains the design limits for high-temperature heat exchangers. Thus, with the added advantages of advanced gasifier concepts also come the creation of major problems (primarily mechanical) for which there are no immediate state-of-the-art solutions.

10.2.4 Non-Slagging and Slagging Gasifiers

Table 8 shows that three of the eight gasifiers remove ash via slagging operation, whereas the others remove ash from the system using a non-slagging condition in the gasifier.

In non-slagging operation, the gasifier temperature is limited by the ash fusion point. To control the temperature below the fusion point, steam in excess of that required to gasify the carbon is injected into the gasifier. For any given size gasifier, the production throughput is limited by the volumetric flow rate of gaseous vapors and unreacted steam leaving the

TABLE 7. TECHNOLOGY CROSSCUT-GENERAL INFORMATION

	WESTINGHOUSE FLUID BED	BI-GAS ENTRAINED BED	MOUNTAIN FUELS ENTRAINED	GENERAL ELECTRIC FIXED BED
GENERAL INFORMATION 1983 CURRENT STATUS	OPERATIONAL	OPERATIONAL	OPERATIONAL NEW UNIT - UNDERGOING SHAKEDOWN	OPERATIONAL
MAJOR THRUST OF PROGRAM	1 ENVIRONMENTAL STREAM CHARACTERIZATION 2. SOLVING RECYCLE PROBLEM 3. IMPROVED CARBON CONVERSION < 90%	DEMONSTRATE OPERABILITY ON ILLINOIS NO. 6 HIGH SULFUR COAL	1. DEMONSTRATE DRY COAL FEEDING 2. IMPROVE OVERALL THERMAL EFFICIENCY	OBTAINING DATA ON THE DYNAMICS AND TRANSIENTS WITH LOAD CHANGE IN THE INTEGRATED SYSTEM
NEAREST COMMERCIAL TECHNOLOGY	60 PSIG WINKLER FLUID BED	TEXACO ENTRAINED	TEXACO ENTRAINED	LURGI-DRY BOTTOM FIXED BED
MAJOR DIFFERENCE WITH COMMERCIAL UNIT	1. HIGHER PRESSURE OPERATION 2. RECYCLE SYSTEM FOR CHAR	BI GAS DESIGN UP FLOW AT 1500 PSIG TEXACO DOWN FLOW AT 450 PSIG BI-GAS USES DRIED SLURRY	TEXACO USES SLURRY. MOUNTAIN FUEL USES DRY COAL FEED TO LOWER O_2 CONSUMPTION MOUNTAIN FUEL 300 PSIG TEXACO 450 PSIG	LURGI NON-STIRRED DESIGNED FOR 550 PSIG G. E. DESIGN FOR 300 PSIG DEEP BED STIRRING
CONTRACTOR/AGENCY RATIONALE FOR CHOICE OF DESIGN	1. USES ALL COAL RANKS 2. SIMPLICITY OF DESIGN 3. PRODUCES NO TARS 4. MINIMIZES ENVIRONMENTAL IMPACTS 5. LOW O_2 - STEAM REQUIREMENTS 6. CONTROLLABLE 7. LARGE CARBON INVENTORY NO O_2 BREAKTHROUGH	1. EXPECT HIGH YIELDS OF METHANE 2. SYSTEM WILL USE ALL RANKS OF COAL 3. SIMPLICITY OF DESIGN 4. NO NEED FOR GAS COMPRESSION DOWNSTREAM	1. SIMPLE COMPACT REACTOR 2. USES ALL COAL RANKS 3. USES FINES 4. PRODUCES NO TARS-OILS 5. SLAGS ASH 6. EXPORTS STEAM 7. SINGLE NOZZLE DESIGN 8. CLAIMED HIGHER EFFICIENCY 9. NO FURTHER COMPRESSION REQUIREMENTS FOR MOST USES	1. ONLY SUCCESSFUL REACTOR WITH PRESSURIZED OPERATIONAL HISTORY 2. NO O_2 BREAKTHROUGH-LARGE CARBON INVENTORY 3. MODIFICATIONS WOULD PERMIT: A. HANDLE CAKING COAL B. BUILT IN CLINKER BREAKER C. OPERATE AT REDUCED AIR TO STREAM RATIOS 4. FIXED BED VERY CONTROLLABLE
DESIGN - SPECIFIC END USES FOR GAS	1. COMBINED CYCLE OPERATION 2. SYNTHESIS GAS 3. INDUSTRIAL FUEL GAS	PIPELINE QUALITY SNG - 300 BTU/SCF	MEDIUM BTU GAS FOR ALL USES	1. COMBINED CYCLE OPERATION 2. INDUSTRIAL FUEL GAS
ORIGINAL GO - NO - GO DESIGN PARAMETERS	1. USE COALS OF ALL RANKS 2. CHAR MUST NOT SINTER IN FEED TUBE 3. ASH AGGLOMERATION MUST BE CONTROLLABLE	NOT KNOWN	1. THROUGHPUTS OF 2000#/HR/FT^2 2. OPERABLE AT 300 PSIG 3. MAXIMUM STEAM PRES. - 450 PSIG 4. COLD GAS CONVERSION EFFICIENCY OF 75% 5. OVERALL ENERGY CONVERSION OF 70%	1. USE OF CAKING COALS 2. MAINTAIN STEAM TO AIR RATIOS OF 0.2 TO 0.4 3. RECYCLE OF TAR/FINES
MAJOR PROBLEM AREAS	1. ASH DEPOSITION IN CYCLONE 2. FINES RECYCLE 3. SINTERING ON OXIDANT FEED TUBE 4. DEPOSITION ON GASIFIER WALLS 5. RELIABILITY OF COAL FEED	1. BACKFLOW OF GAS INTO BURNERS AND PIPING CAUSING EXPLOSIONS 2. NEED FOR SUPPLEMENTAL FUEL GAS 3. COAL AND CHAR FEEDING 4. MEASUREMENT OF TEMPERATURE/FLOWS 5. MAINTENANCE OF SLAG TAPPING 6. STRESS CORROSION CRACKING 7. CAKING COAL CAUSING CHAR FEED PROBLEMS 8. DURABILITY OF CHAR BURNERS	1. CORRECTING PIPING AND INSTRUMENTATION DESIGN DEFICIENCIES 2. DESIGNING FAST RESPONSE EMERGENCY SHUTDOWN SYSTEM	1. SOLIDS HANDLING - COAL AND ASH 2. UNDERSTANDING PLANT DYNAMICS TO PERMIT ADEQUATE CONTROL AND DYNAMIC RESPONSE
CONTRACTOR/AGENCY ASSESSMENT OF GREATEST SYSTEM INEFFICIENCIES	1. RECYCLE OF 30 TO 40% OF CHAR 2. PROVIDING HIGH PRESSURE GAS TO LOCKHOPPER SYSTEM 3. HEAT LOSSES ASSOCIATED WITH GAS CLEANING	1. STEAM DRIED COAL SLURRY FEED SYSTEM 2. QUENCH OF STAGE II EFFLUENT WOULD BE REPLACED BY A HEAT RECOVERY SYSTEM 3. HEAT LOSSES IN STAGE I WOULD BE REDUCED BY STEAM GENERATION OR BETTER REFRACTORIES	EXPECT INCOMPLETE GASIFICATION WITH SOME COALS	1. INABILITY TO RECYCLE HEAVY HYDROCARBONS AND CONVERT TO TURBINE FUEL 2. INABILITY TO USE COAL FINES 3. NEED TO INCREASE GAS CLEANUP TEMPERATURES 4. IN COMBINED CYCLE OPERATION TURBINE INLET TEMPERATURES NEED INCREASED FROM 2600°F TO 3000 °F
WHAT WOULD CONTRACTOR/ AGENCY CHANGE IN NEW DESIGN	1. MAX. SYSTEM PRESSURE WOULD INCREASED TO 600 PSIG FOR SNG OR LIQUID FUELS OR 340 PSIG FOR COMBINED CYCLE WITH COLD GAS CLEANUP	1. A DRY COAL FEED SYSTEM WOULD BE USED 2. THE QUENCHING OF STAGE II EFFLUENCT GAS WOULD BE REPLACED BY A HEAT RECOVERY SYSTEM 3. THE HEAT LOSSES IN STAGE I COOLING WATER WOULD BE REDUCED BY STEAM GENERATION OR BETTER REFRACTORIES 4. SECOND STAGE SIZE WOULD BE REDUCED	1. MAXIMUM STEAM PRESSURE WOULD BE INCREASED TO 600 PSIG TO BE NEARER TO COMMERCIAL NEED 2. CAPABILITY FOR DUAL FEED SYSTEMS	1. WOULD DESIGN FOR STEAM/ AIR RATIO OF 0.4 2. A SEPARATE COS HYDROLYSIS UNIT WOULD BE ADDED

TABLE 7. TECHNOLOGY CROSSCUT-GENERAL INFORMATION
(Continued)

GFETC FIXED BED	METC FIXED BED	MIFGA FIXED BED	CAN-DO FIXED BED
OPERATIONAL	OPERATIONAL	OPERATIONAL	OPERATION TERMINATED 4-30-83
WASTEWATER COOLING TOWER CHARACTERIZATION AND STUDIES IN SUPPORT OF GREAT PLAINS PROJECT	1. STRETFORD TESTING 2. INTEGRATED SYSTEM CHARACTERIZATION 3. O_2 OPERATION WITH N. D. LIGNITE SUPPORTING GREAT PLAINS	1. FUELS TESTING TO BROADEN BASE OF ACCEPTABLE FUELS 2. QUANTIFYING COMBUSTION CHARACTERISTICS OF FUEL GAS 3. CHARACTERIZING NEW TAR REMOVAL SYSTEM 4. QUANTIFYING STRETFORD CHEMICAL CONSUMPTION	1. PARAMETRIC TESTS WITH ANTHRACITE FUEL 2. SUPPLYING FUEL GAS TO AN INDUSTRIAL PARK
LURGI-BGB SLAGGING FIXED BED	LURGI-DAY BOTTOM FIXED BED	UNIT IS A COMMERCIAL GASIFIER (6 FT 6 IN. DIAM.)	(7 UNITS) COMMERCIAL GASIFIERS - (10 FT DIAM)
GFETC DEEP BED STIRRING GREATER L OVER D	LURGI NON-STIRRED DESIGNED FOR 650 PSIG METC FOR 300 PSIG DEEP BED STIRRING	INCLUDES 1000 SCFM SIDESTREAM TAR AND SULFUR REMOVAL SYSTEMS AND FULL FLOW COMBUSTION TEST FACILITY	UNITS HAVE DOWN STREAM PARTICULATE REMOVAL SYSTEM OTHER THAN CYCLONE
1. TWO TO THREE TIMES AS EFFICIENT AS NON SLAGGER 2. GENERATES LESS WASTEWATER 3. USES LESS STEAM 4. DEMONSTRATE SLAGGING OPERATIONS WITH LOW RANK COALS	1. ONLY SUCCESSFUL REACTOR WITH PRESSURIZED OPERATIONAL HISTORY 2. NO-O_2 BREAKTHROUGH LARGE CARBON INVENTORY 3. MODIFICATIONS WOULD PERMIT USE OF CAKING COAL 4. WOULD SERVE AS TEST VEHICLE FOR: A. COMPONENTS B. ENVIRONMENTAL CONTROL ELEMENTS C. END USE APPLICATIONS D. FUELS	1. LOW CAPITAL COST OF EQUIPMENT 2. PROVEN RELIABILITY 3. NEED FOR CHEAPER FUEL SUPPLY IN MIDWEST AREA 4. NEEDED DATA BASE FOR COMBUSTION CHARACTERISTICS OF FUEL 5. NEED FOR ACTUAL FUEL GAS TO APPLY TO END USE APPLICATION EXPERIMENTATION	1. LOW CAPITAL INVESTMENT 2. PROVEN TECHNOLOGY 3. IDEAL LOW SULFUR FUEL AVAILABLE 4. MINIMUM OF GAS CLEANUP REQUIRED 5. EFFICIENCY
EXPERIMENTAL VEHICLE PROJECT OBJECTIVE - TO CONTINUOUSLY SLAG LOW RANK COALS	EXPERIMENTAL VEHICLE FOR ALL END USES	INDUSTRIAL FUEL GAS FOR BOILER AND KILN FIRING	SUPPLY OF ECONOMIC 150 BTU/SCF FUEL GAS TO AN INDUSTRIAL PARK
MAINTAIN CONTINUOUS SLAGGING OPERATION WITH LOW RANK COALS	1. OPERATE AT 300 PSIG 2. USE CAKING COALS 3. INTERCHANGEABLE COMPONENTS	1. LOW COST 2. INDUSTRY MUST CONTRIBUTE TO OPERATION 3. ADAPTABLE TO PROPOSED END USES	1. LOW CAPITAL INVESTMENT 2. EFFICIENT 3. MEET ENVIRONMENTAL REQUIREMENTS 4. RELIABLE
1. LOSS OF SLAG FLOW 2. REFRACTORY DAMAGE 3. HEARTH PLATE DESIGN 4. IMPEDED FUEL BED SETTLING	1. VESSEL PENETRATION SEALS 2. STIRRER AND GRATE DRIVE 3. FEED SYSTEM 4. STRETFORD UNDERDESIGN 5. PARTICULATE REMOVAL 6. INSTRUMENTS AND CONTROLS 7. GAS QUENCH SYSTEM 8. STIRRER INTEGRITY	1. CHOKE FEED SYSTEM LIMITS BED HEIGHT CONTROL 2. STEAM CONTROL NEEDS MODERNIZATION 3. CANNOT USE FINES OR HIGHLY CAKING COAL 4. MECHANICAL COMPONENTS NOT STATE OF ART	1. FUEL CHOICE LIMITED EVEN WITH ANTHRACITE 2. HIGH COST OF FUEL 3. DESIGN DEFICIENCIES IN PARTICULATE REMOVAL SYSTEM 4. DESIGN DEFICIENCIES IN GAS TRANSMISSION SYSTEM
WASTEWATER PRODUCTION	1. INABILITY TO RECYCLE TAR 2. MECHANICAL NON-RELIABILITY OF COMPONENTS 3. COMPONENT DESIGN DEFICIENCIES	1. ABILITY TO VARY BED HEIGHT 2. PARTICULATE REMOVAL POOR 3. AUTOMATION LACKING 4. INABILITY TO USE HIGHLY CAKING COALS 5. INABILITY TO USE FINES 6. INABILITY TO RECYCLE TAR 7. NON-PRESSURE CAPABILITY ESPECIALLY IN DOWNSTREAM SYSTEMS	1. FUEL CHOICE LIMITED EVEN WITH ANTHRACITE 2. HIGH COST OF FUEL 3. PARTICULATE REMOVAL VERY INEFFICIENT 4. MANY DESIGN DEFICIENCIES IN GAS CLEAN UP - TRANS - MISSION SYSTEM
NOT KNOWN	CHANGES HAVE BEEN CONTINUOUS	1. WOULD DESIGN FOR 1-5 PSIG 2. WOULD AUTOMATE 3. REFINE EQUIPMENT	1. TOTAL REDESIGN OF GAS COMPRESSION/ CLEANUP SYSTEM 2. REDESIGN GASIFIER TO OPERATE ABOVE 10" W. G. 3. SET UP TEST SERIES TO SCREEN FUELS TO FIND A CHEAPER FUEL

TABLE 8. TECHNOLOGY CROSSCUT-GASIFIER DATA

	WESTINGHOUSE EXPERIMENTAL	BI-GAS EXPERIMENTAL	MOUNTAIN FUELS EXPERIMENTAL	GENERAL ELECTRIC EXPERIMENTAL
GASIFIER	FLUID BED	HIGH RATE ENTRAINED BED	HIGH RATE ENTRAINED BED	DEEP STIRRED FIXED BED
NUMBER OF STAGES	SINGLE STAGE	TWO STAGE	SINGLE STAGE	SINGLE STAGE
VESSEL I.D. AND LGTH.	24 IN. X 35 FT	24 IN. x 54 FT	18 IN. x 28 IN.	36 IN. x 14.5 FT
GASIFIER CROSS SEC. AREA	3.14 SQ. FT	3.14 SQ. FT	1.40 SQ FT	7.07 SQ. FT
VESSEL L OVER D	17.5	27.0	1.63	4.83
NORMAL OPERATING BED DEPTH	12 FT BED DENSITY = 10 TO 15 LBS/FT³	NONE	NONE	8 FT
DESIGN RESIDENCE TIME	100 SECONDS 3100 SECONDS (SLUG FLOW) @ 1250 LBS/HR @ 230 PSIG	6 SECONDS @ 750 PSIG @ 1900 LBS/HR	0.3 TO 0.5 SECONDS @ 3000 LBS/HR @ 300 PSIG	5600 SECONDS @ 2000 LBS/HR @ 300 PSIG
VESSEL DESIGN PRESSURE	0-800 PSIG	0 TO 1500 PSIG	300 PSIG	300 PSIG
NOMINAL OPER. PRES.	230 PSIG	750 PSIG	150 PSIG DURING SHAKEDOWN	300 PSIG
VESSEL WALL TYPE	REFRACTORY	STAGE I - WATER WALL STAGE II - REFRACTORY	REFRACTORY	REFRACTORY
DESIGN THROUGHPUT RAW COAL	1250 TO 2500 LBS/HR	10,000 LBS/HR	3000 LBS/HR	2000 LBS/HR
ACHIEVED THROUGHPUT	1200 LBS/HR WITH AIR 2400 LBS/HR WITH O_2 WITH BITUMINOUS COAL	8000 LBS/HR @ 750 PSIG WITH SUBBITUMINOUS COAL	750 LBS/HR @ 150 PSIG WITH UTAH BITUMINOUS COAL	1837 LBS/HR @ 300 PSIG WITH ILL. NO. 6 COAL
THROUGHOUT PER SQ. FT OF CROSS SECTIONAL AREA PER HOUR	400 LBS/HR/FT² WITH AIR @ 230 PSIG 800 LBS/HR/FT² WITH O_2 @ 230 PSIG	1910 LBS/HR/FT² @ 750 PSIG WITH MONTANA SUBBITUMINOUS W/O_2	536 LBS/HR/FT² @ 150 PSIG WITH UTAH BITUMINOUS W/O_2	260 LBS/HR/FT² @ 300 PSIG WITH ILL. NO. 6 BITUMINOUS w/AIR
DESIGN COAL FEED SIZE	¼" x 0"	70% - 200 MESH	70% - 200 MESH	2" x 1¼"
ACTUAL FEED SIZE	3/16" x 0"	70% - 100 MESH	70% - 200 MESH	2" x 1¼"
LOCATION AND NO. OF FEED NOZZLES	BOTTOM CENTER - UP - 1	LOWER 1/3 - SIDE 2 COAL NOZZLES - 3 CHAR NOZZLES	TOP CENTER DOWN 1	TOP-SIDE 1 HORIZONTAL SCREW
ASH CONDITION	AGGLOMERATED ASH	SLAG	SLAG	DRY ASH
OXIDANT	AIR AND O_2	O_2	O_2	AIR
FEED SYSTEM USED	(TWO STAGE) DUAL LOCKHOPPERS FUEL METERED BY ROTARY VALVE TRANSPORTED BY RECYCLE GAS CHAR RECYCLE BY L VALVE AND EDUCTOR FROM TWO CYCLONES	PUMPED SLURRY - (35% SOLIDS) - TO FLASH DRYER LIQUID SEPARATED IN CYCLONE - TRANSPORTED BY STEAM. - CHAR RECYCLE BY STEAM EDUCTOR	SINGLE TWO STAGE LOCKHOPPERS TO A METERING SCREW - FUEL TRANSPORTED BY RECYCLE GAS TO SINGLE NOZZLE	SINGLE STAGE LOCKHOPPER TO METERING SCREW - GRAVITY DROP TO TOP OF FUEL BED SINGLE NOZZLE
ASH REMOVAL SYSTEM	DRY GRANULAR ASH DISCHARGE IS METERED BY A ROTARY FEEDER TO TWO PARALLEL LOCKHOPPERS, AUTOMATIC CONTROL HAS BEEN DEVELOPED	BOTTOM PART OF GASIFIER SERVES AS SLAG QUENCH SECTION AND IS EQUIPPED WITH AN AGITATOR. SLAG DISCHARGES THROUGH TWO NOZZLES TO TWO LOCKHOPPERS IN PARALLEL	SLAG FALLS THROUGH MECHANICAL SLAG BREAKER TO LOCKHOPPER. LOCKHOPPER DISCHARGES TO SLURRY TANK	ROTATING CLINKER BREAKER/ADJUSTABLE VERTICALLY ECCENTRIC, TIERED VARIABLE SPEED GRATE
MAJOR PROBLEM AREA	1. COAL INJECTION RELIABILITY RELATIVE TO NOZZLE SCALEUP. 2. RECYCLE OF CHAR	1. EXCESSIVE ENERGY CONSUMPTION OF FEED SYSTEM AND CHAR RECYCLE SYSTEM 2. EXPLOSIONS AT CHAR RECYCLE NOZZLES - O_2 BREAKTHROUGH 3. HIGH TEMP. THERMOCOUPLES IN CONTROL FUNCTIONS	1. SPALLED REFRACTORY 2. LIQUID SLAG SAMPLING	1. THROUGHPUT IS COAL SPECIFIC 2. INABILITY TO RECYCLE TAR 3. INABILITY TO USE COAL FINES 4. TRANSIENT CONTROL OF INTEGRATED SYSTEM 5. SOLIDS HANDLING IN GENERAL 6. COAL BRIDGING IN HOPPERS

TABLE 8. TECHNOLOGY CROSSCUT-GASIFIER DATA
(Continued)

GFETC EXPERIMENTAL	METC EXPERIMENTAL	MIFGA COMMERCIAL	CAN-DO COMMERCIAL
DEEP STIRRED FIXED BED	DEEP STIRRED FIXED BED	STIRRED FIXED BED	STIRRED FIXED BED
SINGLE STAGE	SINGLE STAGE	SINGLE STAGE	SINGLE STAGE
TOP 8 FT. x 22 IN. 16.5 IN. x 21 FT	42 IN. x 18 FT	78 IN. x 9 FT	120 IN. x 10 FT
1.48 SQ. FT	9.62 SQ. FT	33.18 SQ FT	78.5 SQ FT
15.27	4.57	1.38	1.0
10 FT	6.58 FT	5.0 FT	7 FT
2250 SECONDS @ 1290 LBS/HR @ 300 PSIG	6267. SECONDS @ 2000 LBS/HR @ 150 PSIG	16,425 SECONDS @ 2000 LBS/HR @ ATM PRES.	54,408 SECONDS @ 2000 LBS/HR @ ATM PRES.
600 PSIG	300 PSIG	10 IN. WATER GAUGE	10 IN. WATER GAUGE
300 PSIG	125 TO 214 PSIG	6 IN. WATER GAUGE	13 IN. WATER GAUGE
REFRACTORY	LOWER PORTION-WATER WALL UPPER PORTION - REFRACTORY	WATER WALL	WATER WALL
2000 LBS/HR	2000 LBS/HR	2000 LBS/HR	2000 LBS/HR ANTHRACITE 6000 LBS/HR BITUMINOUS 8000 LBS/HR SUBBITUMINOUS
720 LBS/HR @ 300 WITH N. D. LIGNITE FUEL ON MAF BASIS	2138 LBS/HR @ 214 PSIG WITH PITTS NO. 8 BITUMINOUS	4000 LBS/HR @ ATM. PRES. WITH LUCITE HILLS SUBBITUMINOUS	2600 LBS/HR @ ATM. PRES. WITH BUCKWHEAT SIZE ANTHRACITE
514 LBS/HR/FT² @ 300 PSIG WITH LIGNITE w/O_2 FUEL ON MAF BASIS	222 LBS/HR/FT² @ 214 PSIG WITH PITTS NO. 8 COAL w/AIR	130 LBS/HR/FT² @ ATMOS. WITH SUBBITUMINOUS COAL w/AIR	[illegible]3 LBS/HR/FT² @ ATMOS. WITH ANTHRACITE w/AIR
¼ x ⅛ - ¼ x ½	2" x ¼"	2" x ½"	2" x ¼"
¾" x ¼"	1" x ⅛"	¾" x ¼"	ANTHRACITE NUT AND BUCKWHEAT SIZE
TOP DOWN 2	TOP SIDE 2 @ 180°	TOP - DOWN (CHOKE) 2	TOP - DOWN (CHOKE) 6
SLAG	DRY ASH	DRY ASH	DRY ASH
O_2	AIR AND O_2 O_2 NOT YET TRIED	AIR	AIR
DUAL, SINGLE STAGE LOCKHOPPER, METERING BY ROTARY FEEDER GRAVITY TO TOP OF FUEL BED, TWO NOZZLES	DUAL SINGLE STAGE LOCKHOPPER METERING BY ROTARY DEEDER-SCREWS IN FEED TUBES TO PREVENT COKING. GRAVITY DROP TO TOP OF FUEL BED TWO NOZZLES AT 180° ON SIDE OF GASIFIER	SINGLE LOCKHOPPER GRAVITY TO CHOKE FEED IN TOP OF GASIFIER 2 FEED NOZZLES	SINGLE LOCKHOPPER GRAVITY TO CHOKE FEED IN TOP OF GASIFIER 6 FEED NOZZLES TO PROVIDE UNIFORM BED HEIGHT
SLAG FALLS THROUGH MECHANICAL SLAG BREAKER INTO LOCKHOPPER WHERE IT IS QUENCHED	ROTATING ECCENTRIC CLINKER BREAKING VARIABLE SPEED GRATE. DRY ASH DISCHARGES TO LOCKHOPPER EQUIPPED WITH AUTOMATIC CONTROL	ROTATING ECCENTRIC CLINKER BREAKING, VARIABLE SPEED GRATE. DRY ASH DISCHARGES TO LOCKHOPPER EQUIPPED WITH QUENCH SYSTEM	ROTATING ECCENTRIC CLINKER BREAKING, VARIABLE SPEED GRATE, DRY ASH DISCHARGES TO LOCKHOPPER EQUIPPED WITH QUENCH SYSTEM
1. MAINTAINING DOWNWARD BED MOVEMENT 2. MAINTAINING SLAG FLOW 3. HEARTH PLATE IS CRITICAL ELEMENT	1. NO WAY TO BREAK CLINKER LODGED AROUND GRATE TIERS 2. RABBLE ARM INTEGRITY	1. GASIFIER THROUGHPUT PROVEN TO BE VERY COAL SPECIFIC 2. INABILITY TO USE FINES 3. STIRRER TORQUE CAPACITY LIMITS COAL USE TO LOW FSI COALS 4. BLOWER CAPACITY	1. DOWNSTREAM PARTICULATE REMOVAL IS LIMITING GASIFIER CAPACITY 2 INABILITY TO USE FINES AND SOME ANTHRACITES

TABLE 9. TECHNOLOGY CROSSCUT-OPERATIONAL PARAMETERS

OPERATIONAL PARAMETERS	WESTINGHOUSE	BI-GAS	MOUNTAIN FUELS	GENERAL ELECTRIC
FUELS TRIED	PRACTICALLY ALL TYPES INCLUDING PETROLEUM COKE	MONT. ROSEBUD-SUBBITUMINOUS	UTAH BITUMINOUS	ILL. NO. 6 AND PITTSBURGH NO. 8
COLD GAS EFFICIENCY	COAL SPECIFIC 86.0%	71%	DESIGN 70 TO 75%	COAL SPECIFIC 75% NO TAR CREDIT
HOT GAS EFFIECIENCY	95.0%	75%	NOT KNOWN	92% NO TAR OR OIL CREDIT
GAS YIELD-SCF/LB C	58.0 SCF/LB C	49 SCF/LB C	NOT KNOWN	82 SCF/LB c
TOTAL SYSTEM CARBON LOSS	10%	1% TO 6%	NOT KNOWN	1% TO 3%
GAS HEAT VALUE BTU/SCF	COAL SPECIFIC 70 TO 99 (AIR BLOWN) 248 (O_2 BLOWN)	COAL SPECIFIC 306 TO 350 (O_2 BLOWN)	NOT KNOWN	COAL SPECIFIC ~ 150 (AIR BLOWN)
AIR/OXYGEN/COAL RATIO	0.629 TO 0.763 LB/LB (O_2)	0.780 LB/LB (O_2)	NOT KNOWN	2.31 LBS/LB (AIR)
STEAM/COAL RATIO	0.290 TO 0.356 LBS/LB (O_2)	0.580 LBS/LB	NOT KNOWN	0.93 LBS/LB
LB STEAM/LB AIR/O_2	0.426 (O_2)	0.75	NOT KNOWN	0.4 (AIR)
TURN DOWN RATIO	60%	40%	~ 40%	75%

TABLE 9. TECHNOLOGY CROSSCUT-OPERATIONAL PARAMETERS
(Continued)

GFETC	METC	MIFGA	CAN-DO
SEVERAL TYPES OF LIGNITE	PRACTICALLY ALL TYPES AND BRIQUETTES	PRACTICALLY ALL TYPES, BRIQUETTES, AND PETROLEUM COKE	SEVERAL TYPES AND SIZES OF ANTRACITE PLUS ANTHRACITE BRIQUETTES
84% WITH TAR CREDIT	COAL SPECIFIC 85% W/TAR CREDIT	COAL SPECIFIC 64 TO 75% WITHOUT TAR 85% WITH TAR	COAL SPECIFIC 85% (NO TAR)
90% WITH TAR CREDIT	73% WITHOUT TAR 93% WITH TAR	93% WITH TAR	93% (NO TAR)
26 SCF/LB C	51 SCF/LB C	51 TO 110 SCF/LB C	102 SCF/LB C
1% TO 5%	1% TO 3%	3%	1.5% TO 2%
COAL SPECIFIC 344 (O_2 BLOWN)	COAL SPECIFIC 155 (AIR BLOWN)	COAL SPECIFIC 145 (AIR BLOWN)	COAL SPECIFIC 145 (AIR BLOWN)
0.47 LBS/LB	AIR 2.57 LBS/LB (AIR)	2.55 LBS/LB (AIR)	3.91 LBS/LB (AIR)
0.23 LBS/LB	0.5 LBS/LB	0.44 LBS/LB	0.610 LBS/LB
1.0 (O_2)	0.20 (AIR)	0.17 (AIR)	0.156 LBS/LB
NOT KNOWN	75%	75%	75%

TABLE 10. TECHNOLOGY CROSSCUT-PARTICULATE REMOVAL/RECYCLE/TAR REMOVAL

UNIT OPERATION PARTICULATE REMOVAL/RECYCLE	WESTINGHOUSE	BI-GAS	MOUNTAIN FUELS	GENERAL ELECTRIC
GASIFIER EXIT TEMP.	1600°F TO 1920°F	785°F TO 800°F	2200°F TO 2800°F	1100°F
GAS PARTICULATE LOAD.	800 TO 900 LBS/HR AVE. 40% OF COAL FEED RATE	2600 LBS/HR OUT OF GASIFIER 0.15 LBS SOLIDS/LB OF GAS	NOT YET KNOWN	3% OF COAL FEED 7% OF RAW GAS WT.
PARTICULATE SIZE	AVE 120 um	ROSEBUD SUBB. = 0-12 MESH PITT. NO. 8 = 0-8 MESH	NOT YET KNOWN	0-120 u.m. AVE. 70 u.m.
PARTICULATE CARBON	50% TO 75%	74% TO 78%	NOT YET KNOWN	69% - SAME AS COAL
VARIANCE OF PARTICULATE AMOUNT WITH FUEL	PITTS. NO. 8 BIT: 0.35 LBS/LB TEXAS LIG - 0.48 LBS/LB	NO SIGNIFICANT DIFFERENCE	NOT YET KNOWN	NOT KNOWN
COMPONENTS USED	1. WATER SPRAY IN TOP OF GASIFIER 2. TWO CYCLONES IN TANDEM FOLLOWED BY QUENCH SCRUBBER. 3. WATER SPRAY IN TOP OF GASIFIER TO CONTROL TEMP. 4. MOLTEN PARTICLE TRAP	CHAR VESSEL WITH INTERNAL CYCLONE FOLLOWED BY GAS WASHER	COMBINED VENTURI AND PACKED TOWER SCRUBBER	DELUGE WATER SPRAY QUENCH VENTURI SCRUBBER FILTERED WATER RECYCLED
SYSTEM ΔT INLET/OUTLET TEMP.	1900°F/400°F	800°F/400°F		1100°F/335°F
EFFICIENCY OF SYSTEM	76 TO 98% WITH LATEST MODS.	CYCLONE-95%/GAS WASHER HIGH.	NOT YET KNOWN	QUENCH REMOVES 95% VENTURI REMOVES 75% OF REMAINDER 98% OVERALL
ΔP ACROSS CYCLONES	1 TO 2 PSIG		NA	NA
RECYCLE REQUIREMENTS	~40% OF COAL FEED = 800 LBS/HR	~43% OF COAL FEED= 2600 LBS/HR	NONE	HAVE RECYCLED TAR WITH FINE COAL VIA EXTRUDER
COMPONENTS MAKING UP RECYCLE SYSTEM	2-CYCLONES, L VALVE WITH FLUIDIC CONTROL, EDUCTOR (CO_2 POWERED)	CHAR VESSEL, STEAM EDUCTOR	NONE	NONE
TOTAL ΔP REQUIREMENT	10 PSIG FOR L VALVE 70 PSIG FOR EDUCTOR		NONE	TAR & FINES EXTRUDER WAS TRIED TO 110 PSIG ΔP
PARTICULATE TEMP. FOR RECYCLE	~800°F	~800°F	NONE	TAR HEATED TO 300°F
PROBLEMS	FORCING HOT FINES ACROSS ΔP	1. PRESSURE UPSETS IN GASIFIER LEADS TO POOR CYCLONE PERFORMANCE 2. LINES MUST BE HEATED TO PREVENT CONDENSATION (>500°F) 3. EXPLOSIONS BECAUSE OF NON UNIFORM FEED	NOT KNOWN	NOT ENOUGH FUNDING TO CONTINUE WORK ON RECYCLE
RECYCLE H.P.	151 HP/T/HR	737 HP/TON/HR	NONE	EXTRUDER 7 HP/T/HR
TOTAL CARBON-LOSS TO SYSTEM	10%	1. TO 6%	NOT KNOWN	1 TO 3%
TAR REMOVAL				
TYPE SYSTEM	NA	SMALL QUANTITIES OF TAR ARE PRODUCED. SHELL AND TUBE HEAT EXCHANGES UP STREAM OF SELEXOL UNIT WILL EVENTUALLY PLUG	NA	DELUGE QUENCH
TAR REMOVAL EFFICIENCY	NA		NA	~100%
COMPONENTS IN SYSTEM	NA	NONE	NA	QUENCH VESSEL-VENTURI SCRUBBER - GAS COOLER - SETTLING VESSEL - RESATURATOR
GAS TEMP.-IN/OUT	NA	200/300°F TO 70/100°F OUT	NA	1100°F/335°F
MAJOR PROBLEM AREAS	NA	TARS HAVE CAUSED PROBLEMS IN LINE FROM HEAT EXCHANGERS	NA	MEASUREMENT OF TAR LEVELS IN SETTLING TANKS-HEAT TRACING EVERYTHING
RECOMMENDATIONS	NA	NA	NA	PHENOLS AND OILS SHOULD BE RETAINED IN GAS FOR EFFICIENCY IN COMBINED CYCLE OPERATIONS
WASTEWATER TREATMENT	NA	AMMONIA STRIPPER, THICKENER CENTRIFUGE AND SETTLING POND	NA	NONE USED EFFLUENT TRUCKED TO DISPOSAL
RECOMMENDATIONS FOR W. W. TREATMENT	NA	SYSTEM ADEQUATE	NA	

TABLE 10. TECHNOLOGY CROSSCUT-PARTICULATE REMOVAL/RECYCLE/TAR REMOVAL (Continued)

GFETC	METC	MIFGA	CAN-DO
300°F TO 700°F	100°F TO 1200°F	212°F TO 932°F	650°F
NOT KNOWN	1.5% OF COAL FEED	0.2 TO 0.5% OF RAW GAS WT	VARIES WIDELY WITH FUEL
NOT KNOWN	0-128 u.m. - AVE. 40 u.m.	0-1000 u.m.	0-1000 u.m.
SAME AS COAL	SAME AS COAL	SAME AS COAL	SAME AS COAL
HIGH WITH LIGNITES 3% LOW WITH BIT. COAL - 1%	NOT KNOWN	COAL SPECIFIC VARIANCE OF 5 TIMES	VARIES WIDELY WITH FUEL SIZE AND QUALITY
SPRAY WASHER WITH RECYCLE CONDENSATE LIQUOR	STD. CYCLONE (40 TO 60 FPS)	LARGE DIAM. CYCLONE	LARGE DIAM CYCLONE VENTURI SCRUBBER, SECONDARY SCRUBBER, CHILLER
700°F/90°F	1000/1200°F IN AND OUT CYCLONE ONLY	TYPICALLY 572°F TO 842°F	650 TO 60°F
	86%	VERY LOW-MAY REACH 60%	CYCLONE VERY INEFFICIENT REMAINDER OF SYSTEM UNDER-SIZED TO HANDLE FULL LOAD
		1 IN. W.G.	1 IN. W.G.
NONE	NONE	NONE	NONE
NONE	NONE	NONE	NONE
NONE	NA	NONE	NONE
NONE	NA	NONE	NONE
NONE	NA	NONE	NONE
NONE	NA	NONE	NONE
	1-6%	3.0%	1.5-2.0%
COOLER TO QUENCH SYSTEM	CYCLONE FOLLOWED BY 3 STAGES OF QUENCH FOLLOWED BY COOLER AND ESP	1000 SCFM PILOT SIDESTREAM QUENCH & ESP	NO TAR - ANTHRACITE FUEL
NOT KNOWN	96 TO 98%	99%	NONE
PRECOOLER SPRAY WASHER, GAS LIQUOR COOLER, TAR LIQUOR SEPARATOR		DELUGE QUENCH SCRUBBER SYSTEM FOLLOWED BY ESP	NONE
300 TO 700°F IN/?	950°F/100°F	300°F/500°F IN - 130°F OUT	NA
TAR IS VERY STICKY-ENDS UP WHERE NOT EXPECTED	LOW TEMP. OPERATIONS-EROSION OF TAR SEPARATOR-PUMP FAILURES SPRAY NOZZLE PLUGGING	ESP-ELECTRODES TAR WATER SEPARATION	PHENOL IN BLOWDOWN
	ADDITIONAL TAR REINJECTION STUDIES UTILIZATION OF LIGHT OIL THROUGH REINJECTION WITH AIR	MODIFYING TO RECYCLE H_2O	NONE
SOLVENT EXTRACTION-NH_3 STRIPPING (ACTIVATED SLUDGE)	PONDED-FILTERED THROUGH ACTIVATED CARBON	NONE-IT IS INCINERATED	NH_3/STRIPPER
WOULD OMIT ACTIVATED SLUDGE	NONE	NA	NA

TABLE 11. TECHNOLOGY CROSSCUT-ACID GAS CLEANUP/INSTRUMENTATION

ACID GAS CLEAN UP SYSTEM	WESTINGHOUSE	BI-GAS	MOUNTAIN FUELS	GENERAL ELECTRIC
SYSTEM USED	NOT USED	HIGH PRESSURE SYSTEM TWO SELEXOL SYSTEMS ONE FOR H_2S-ONE FOR CO_2	ACID GAS ABSORBED IN PARTICULATE SCRUBBER WATER-NEUTRALIZED WITH CAUSTIC	BENFIELD
CHEMISTRY	NA	DIMETHYL ETHER OF POLYETHELENE GLYCOL	NA	HOT POTASSIUM CARBONATE
GAS TEMP. IN/OUT	NA	76°F/76°F	NA	180°F/180°F
DESIGN GAS FLOW RATE	NA	7715 SCFM	NA	2 LBS/SEC
EFFICIENCY OBTAINED	NA	99.9% FOR H_2S	NA	98% SULFUR REMOVAL BUT EXCESSIVE CO_2 REMOVAL
CHANGES TO SYSTEM	NA	IMPROVED FILTER ADDED UPSTREAM OF SELEXOL PUMPS. CORROSION OF PALL RINGS CAUSED DAMAGE TO STAINLESS STEEL RINGS	NA	CHANGED TO 92% SULFUR REMOVAL TO REDUCE CO_2 REMOVAL TO 30% LEVEL CO_2 IS DESIREABLE FOR MASS
ALKALINE METAL REMOVAL	NA	NO PROBLEMS IN THIS AREA	NA	1. MOST CONTAINED IN PARTICULATES. 2. SULFUR ABSORPTION TOWER PROVIDES REMAINING REMOVAL UP TO 99%. 3. A DEMINERALIZED WATER WASH SYSTEM REMOVES CARRYOVER K_2CO_3
RECOMMENDATIONS	NA	PRESSURE IN SYSTEM HAS TO BE MAINTAINED ABOVE 300 PSIG SELEXOL FOR CO_2 REMOVAL NOT YET USED	NA	1. ADVANCED CONTROL TECHNIQUES ARE NEEDED TO PREVENT INTEGRATED SYSTEM UPSETS 2. AMMONIA STRIPPING IN THE CONDENSATE STREAMS 3. COS REMOVAL PRIOR TO SULFUR REMOVAL
INSTRUMENTATION	1. NO MAJOR PROBLEMS 2. AUTOMATIC ASH WITHDRAWAL HAS BEEN ACHIEVED VIA TEMP. CONTROL 3. AUTOMATIC BED LEVEL CONTROL HAS BEEN ACHIEVED VIA ΔP	THERMOCOUPLES ARE A SERIOUS PROBLEM SOME PYROMETERS WORK-OTHERS DO NOT STD TRANSMITTERS WORK WELL 1. PURGES MUST BE HEATED 2. FLOW MUST BE TURBULENT 3. SENSING LINES SLOPE AWAY FROM TRANSMITTERS THERMAL FLOW METERS DO NOT WORK DENSITY GAUGES WOULD WORK OK IF SIZED PROPERLY	PROBLEMS NOT YET KNOWN	1. NON INTRUSION DEVICES HAVE WORKED WELL 2. MECHANICAL LEVEL SENSORS HAVE PROVED TROUBLESOME 3. PRESSURE TRANSDUCERS AND ΔP TRANSDUCERS HAVE BEEN ADEQUATE GE BELIEVES THAT IT WILL BE DIFFICULT TO FULLFIL RESPONSE REQUIREMENTS IMPOSED BY INTEGRATED COAL GASIFICATION/POWER PLANT

TABLE 11. TECHNOLOGY CROSSCUT-ACID GAS CLEANUP/INSTRUMENTATION
(Continued)

GFETC	METC	MIFGA	CAN-DO
FLARING GAS	PRESSURIZED HOLMES STRETFORD	HOLMES STRETFORD ON SIDESTREAM	NOT REQUIRED
NA	SODIUM VANADATE	SODIUM VANADATE	NA
NA	100 TO 110°F IN /100°F OUT	120°F /100°F	NA
NA	180,000 SCFH - @ 300 PSIG	1000 SCFH/SIDE STREAM	NA
NA	99.9% SULFUR 4000 ppm IN 10 ppm OUT	99.6% SULFUR REMOVAL 1700 ppm IN 6 ppm OUT	NA
NA	HAD TO ENLARGE HOLES IN TRAYS IN SCRUBBER COLUMN	ADDED TAR QUENCH-ESP TO PERMIT STRETFORD TRIALS	NA
NA	RECYCLED WATER THROUGH A PACKED COLUMN IS UTILIZED REMOVAL-50 TO 100 PPB DOWN TO 1-15 ppB	NONE	NA
NA	VALIDATION OF MODIFICATIONS TO SYSTEM DURING NEXT RUN	FURTHER VALIDATION RUNS REQUIRED TO QUANTIFY CHEMICAL CONSUMPTION	NA
NOT KNOWN	VERY MODERN-HAVE LOWERED MANPOWER REQUIREMENTS BY 50% AND DRAMATICALLY IMPROVED DATA QUALITY. HAVE AUTOMATED COAL HANDLING BED HEIGHT CONTROL SYSTEM, PRESSURE AIR STEAM RATIOS, ASH LEVEL/REMOVAL	ORIGINAL INSTRUMENTS ADEQUATE BUT NEED REPLACEMENT. MODERN DATA ACQUISITION SYSTEM HAS BEEN INSTALLED	NO MAJOR PROBLEMS MODERN INSTRUMENTATION WAS USED ON THIS SYSTEM

fuel bed; therefore, if the amount of excess steam injected into the gasifier is reduced, a higher throughput of product gas could be achieved. The major disadvantages of non-slagging gasifiers are the high steam of steam-to-oxygen requirements discussed above and the limited range of coal types which can be processed. These factors have led to the development of gasifiers.

A gasifier, under slagging conditions, operates at a much higher temperature to melt the ash, which is then withdrawn from the gasifier as a liquid slag. The major problems of a slagging gasifier lie in high temperature operations. The gasifier operates several hundred degrees higher than the ash fusion temperature. Almost every unit has experienced the problems of short refractory lining life and temperature measurement and slag tapping difficulties. One of the primary problems of this mode of operation is the maintenance of a sufficiently high temperature at the slag discharge port. To maintain this temperature, carbon from the coal must be available to burn at this point. In the fixed-bed unit at Grand Forks, North Dakota, the carbon tended to burn higher in the reactor, permitting slag to freeze up in the area around the discharge port. Auxiliary burners were, therefore, required to maintain the slag at a temperature high enough to allow it to readily flow through the port. Slag flow, refractory life, and temperature measurement are all problems which must be resolved if a reliable slagging gasifier is to be successfully developed.

10.2.5 Gasifier Design Specificity to Feedstock

One of the major goals of the Surface Coal Gasification program has been to develop a gasifier which would readily gasify all types of U. S. coals. However, to a great extent, efforts to accomplish this goal have been thwarted by the multiplicity of coal properties between types and even between amounts of similar coal from the same source. Throughout the gasification development efforts it has become evident that certain types of coal gasify and perform better in a fixed-bed type gasifier than in an entrained- or fluidized-bed type. This can be attributed to properties such as reactivity, free-swelling, index, ash content, et cetera, of the coal being used. There is such a wide range of properties from (bituminous) coal to another (lignite), that one gasifier type should not be expected to perform equally well with all coals. A gasifier must be tailored to a particular type of coal. For example, a fixed-bed gasifier having a stirrer will perform better, in regard to limiting fines carry-over, with bituminous coal than with a subbituminous or lignite. The agglomeration properties of the bituminous coal cause the coal fines to stick together, forming larger particles that stay in the bed for longer times and are not entrained with the raw product gas. On the other hand, coal fines from lignite are not agglomerated as they enter a gasifier but are elutriated with the off-gas. In fluid-bed and entrained flow gasifiers, the more reactive coals such as lignite and subbituminous seem to perform much better than the less reactive bituminous coals. In slagging gasifiers, the quantity and composition of ash in the coal play an important part in allowing continual removal of ash.

10.2.6 System Integration

A gasification system is considered integrated when all process components are in place and are being used to generate a gas which is tailored to a particular end use application and is capable of meeting all environmental requirements. In developing a process, the data generated from a fully integrated system, which is similar to the process being developed, can be utilized directly in the design and scale-up to a larger size plant. System economic studies can also be based on data generated through process optimization. From a process controllability standpoint, information can be obtained about the interaction between the various components in the system, especially during start-up, shut-down, and system upsets. Such information is necessary to design system control and can only be obtained from an integrated system.

Of the eight projects discussed in this report, only the systems at GE, Bi-Gas, and METC can be classified as fully integrated. Both GE and METC have operated their systems in an integrated mode. The system at Bi-Gas contains all components but has never operated in the integrated mode. In the case of Westinghouse, MFR, GFPO, MIFGA, and CAN-DO, components in the gas clean-up system such as H_2S and sulfur removal are missing. The MIFGA system does employ a Stretford desulfurization unit but only in a sidestream mode.

The GE facility represents an IGCC system for producing electric power. The integrated PDU has been operated in both the steady-state mode to generate component characterization and optimization data and in the dynamic or transient mode to generate transient data for determining component interaction and system controllability. The METC system has essentially been operating only in the steady-state mode to generate system and component characterization data.

10.2.7 Environmental Activities

Although not specifically addressed in the accompanying technology crosscut tables, significant environmental activities have been conducted or are planned for most of the major gasification test facilities. This work is primarily centered around process stream and effluent characterization studies related to gasifiers and to downstream particle removal and gas cooling. The characterization of gasifier ash and/or slag, product gas, particulates recovered during downstream gas cleanup, process byproducts, and tars, oils, and aqueous condensates resulting from particle scrubbing and gas cooling steps has been emphasized.

Regarding the fixed-bed systems, comprehensive wastewater and solid waste sampling and characterization programs are underway for the METC dry-bottom gasifier and the GFPO slagging gasifier. In addition, during FY82, a sampling and analysis effort was completed for GE gasifier wastewater. The METC gasifier data collected to date are associated with air gasification. Similar environmental characterization, focused on METC's new oxygen-blown capability, is planned for a lignite and a bituminous coal during FY83. Concerning acid gas removal systems, a Benfield unit has been characterized at GE while study of the pressurized Stretford at METC continues. The METC unit is the only pressurized Stretford in the country that treats a coal gasification product gas.

Some characterization of an atmospheric pressure Stretford sidestream unit has been conducted at MIFGA. In general, however, effluent streams from these desulfurization systems have not been greatly studied to date.

Environmental characterization of the Bi-Gas entrained-flow pilot plant was conducted by Radian Corporation, Austin, Texas, in FY82 under the joint sponsorship of EPRI and DOE. This effort included developing sampling procedures and generating data for scale-up purposes. Of particular interest was the Selexol acid gas removal process and the Claus sulfur recovery unit. This entrained-flow environmental data will be augmented by charaterization studies of the MFR gasifier system, once that facility is operational.

In the fluidized-bed technology area, a preliminary gas stream sampling project was initiated for the Westinghouse PDU. Test plan development for a more comprehensive characterization program was initiated in FY82. Execution of this program, jointly sponsored with the GRI, will be completed in FY83. The results will also provide information for process scale-up.

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APPENDIX A: GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AGA	American Gas Association
ANG	American Natural Gas
ANL	Argonne National Laboratory
ARC	Appalachian Regional Commission
AS	Activated Sludge
atm	atmospheres (of pressure)
BCR	Bituminous Coal Research, Inc.
BOM	U.S. Bureau of Mines
Btu	British thermal unit
CAN-DO	Community Area New Development Organization
CFSF	Cold Flow Scale-Up Facility
COD	Chemical Oxygen Demand
CRT	Cathode Ray Tube
DOE	U.S. Department of Energy
EDA	U.S. Economic Development Administration
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ERDA	U.S. Energy Research and Development Administration
ESP	Electrostatic Precipitator
FBDU	Ford, Beacon, and Davis Utah
GE	General Electric
GFPO	Grand Forks Project Office
gpm	gallons per minute
GRI	Gas Research Institute
HSDU	Holmes-Stretford Desulfurization Unit
ICC	Inland Container Corporation
ID	Inside Diameter
IGCC	Integrated Gasification Combined Cycle
lb	pound
METC	Morgantown Energy Technology Center
MFC	Mountain Fuel Resources, Inc.
mg	milligrams
MIBK	Methyl Isobutyl Ketone
MIFGA	Mining Industrial Fuel Group
PAC	Powdered Activated Carbon
PDU	Process Development Unit
PEF	Performance Evaluation Facility
PEG	Pellet Energy Group
ppm	parts per million
psi	pounds per square inch
psig	pounds per square inch, gauges
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
rph	revolutions per hour
SASOL	South African Coal Oil Gas Company, Ltd.
scf/h	standard cubic feet per hour
SFBG	Slagging Fixed-Bed Gasifier
SFC	U.S. Synthetic Fuels Corporation
SGL	Stripped Gas Liquor
SNG	Substitute Natural Gas
SRI	Stearns-Roger, Inc.
TOC	Total Organic Carbon
tpd	tons per day

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