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ENTRAINED FLOW, SLAGGING GASIFICATION OF COAL

UPDATE OF BI-GAS PILOT PLANT OPERATIONS

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## Background

The BI-GAS coal gasification program was initiated in 1963 under contract with the Office of Coal Research; subsequently the U.S. Energy Research and Development Administration and the American Gas Association. The program is currently fully sponsored by the U.S. Department of Energy.

The original scope of work covered two phases; with Phase I being a review of the state-of-the-art in coal gasification[1]. The purpose of the review was to determine what processes would be reasonable candidates for further development. It was concluded from this evaluation that the concept of two-stage, entrained, high-pressure, slagging gasification offered considerable promise for production of substitute natural gas (SNG) from coal. Phase II of the program involved certain process research and development activities which were to provide information for design of pilot-scale equipment[2]. This work was conducted by Bituminous Coal Research, Inc. and was successfully completed in late 1971.

Stearns-Roger Inc. was subsequently selected by competitive bid to design and construct a five-ton-per-hour BI-GAS Coal Gasification Pilot Plant. Construction of the plant was started in May 1973; and completed in mid-1976, with checkout and start-up operations initiated immediately thereafter.

The pilot plant is located on a thirty-five acre site near U.S. Route 119 in Homer City, Pennsylvania, which is approximately sixty-five miles northeast of Pittsburgh. This facility contains all equipment for complete handling and processing of coal to produce substitute natural gas (SNG). Stearns-Roger is currently the prime contractor for this project and is responsible for detailed research program planning, operation, and maintenance of the facility. Stearns-Roger is aided by its principal process subcontractors, Bituminous Coal Research, Inc. and CONOCO Coal Development Co. The U.S. Department of Energy is responsible for overall planning and assists Stearns-Roger in evaluating pilot plant operations.

## BI-GAS Process Description

The BI-GAS coal gasification process illustrated in the block flow diagram (Figure 1) proceeds as follows:

Coal from various sources can be transported to the plant via either railroad hopper car or by truck. The as received coal, usually 1-1/2" x 0" in size, is then ground to the desired consist and a coal/water slurry containing approximately 35% solids is prepared. This slurry is pumped to operating pressure then spray dried and injected into the upper section (Stage 2) of the gasifier.

In Stage 2, the coal comes in contact with a stream of hot synthesis gas produced in the lower section or Stage 1 of the gasifier and is partially converted into methane and additional synthesis gas.[3] Approximately 50% of the methane in the final product gas results from this direct coal methanation.

Residual char from Stage 2 is swept from the vessel and quenched along with the gas and is then separated by cyclone from the gas stream for recycle to Stage 1. The char is gasified under slagging conditions by reaction with oxygen and steam, thereby producing the synthesis gas and heat required for Stage 2 operation.

Process gas from the gasifier is directed to a carbon monoxide shift converter where its hydrogen to carbon monoxide ratio is altered prior to the methanation step. Slag produced in Stage 1 flows into the quench section at the bottom of the gasifier for removal as a slurry. Hydrogen sulfide and carbon dioxide are then removed from the process gas; with carbon dioxide being discharged and the sulfur bearing gas sent to a Claus unit for conversion to elemental sulfur. The clean process gas is then heated and sent to a fluidized-bed methanator where its calorific value is upgraded to yield pipeline quality substitute natural gas (SNG).

## BI-GAS Gasifier

The BI-GAS Pilot Plant gasifier is a cylinder with a shell diameter of five feet, a reaction zone diameter of two feet, and an overall length approximately fifty-four feet (Figure 2). The main sections of the gasifier are the bottom slag quench zone, the Stage 1 char slagging section, and Stage 2 where coal is injected. The throat area between Stage 1 and 2 aids in the separation of molten slag and produces gas velocities high enough to prevent direct return of coal or char particles from Stage 2.

As mentioned earlier, the feed coal is prepared as a water slurry, then pumped to pressure, and spray dried. The coal is subsequently separated by cyclone and injected with steam into Stage 2 of the gasifier. There it contacts hot synthesis gas from Stage 1 which converts the coal to methane, additional synthesis gas, and char. The gas and char are quenched; the raw gas undergoes further processing and char is recycled to Stage 1. The char plus oxygen and steam are admitted to Stage 1 via three injectors arranged to fire cyclonically, thus promoting slag separation and a swirl effect. Molten slag flows down Stage 1 walls into the quench zone where it is removed by sequencing two slag lockhoppers.

Operating conditions for the pilot plant gasifier vary as follows depending upon the type of coal being processed: Temperatures in Stage 1 range from 2600F to 3000F with estimated mixing temperature in Stage 2 of

2200F. The temperature of gas and char exiting Stage 2 ranges from 1600F to 1800F and operating pressure may vary from 750 to 1150 psi.

## Advantages-BI-GAS Process

The main advantages of the BI-GAS coal gasification process as perceived by the original developers and sponsors may be found by referring to Table 1. The principal assumption of this process concept was that high yields of methane could be obtained directly in Stage 2 of the gasifier via devolatilization and direct coal methanation. These original assumptions have been confirmed through several years of bench scale and process development scale research on Stage 2 reactions, utilizing a variety of coal feed stocks.

Currently at the BI-GAS Pilot Plant, the gasifier is being routinely operated in a two-stage, integrated slagging mode for periods of five to seven days. The main purpose of the following sections is to describe in some detail the operations history of the BI-GAS Pilot Plant, with emphasis on the period from mid-1980 to mid-1981. With this objective in mind, we will discuss the most recent improvements in plant systems which have enabled sustained operation of the gasifier in controlled commercial mode - that is, with minimum supplemental fuel.

## Operations History - 1977 to mid-1980

The purpose of this section is to recap briefly the period beginning with plant checkout in early 1977 and continuing with operations of the gasifier and other process units through mid-1980. After preliminary checkout of all plant hardware, grinding and slurry preparation tests were conducted with Montana Rosebud coal, which was to be the initial feed stock for the BI-GAS Plant. Upon successful completion of those grinding tests, operation of the slurry spray drying system was initiated and successfully completed.

Initial operations of the two-stage entrained gasifier were planned in three phases beginning with natural gas firing of Stage 1 and steam injection to Stage 2.[4] The next phase involved gas firing of Stage 1 with coal and steam being injected into Stage 2 of the gasifier. Phase 3 involved recycle of char plus oxygen and steam into Stage 1 of the gasifier with coal and steam introduction to Stage 2.

During these initial operations in 1977, numerous problems were encountered with cooling water leaks and material failures in the slag tap and slag heating burners as well as the three char burners. Slagging operations in Stage 1 were hampered by low feed rates into the gasifier, which resulted in excessive heat loss and inconsistencies in the quantity and quality of slag produced. Temperature measurements were also a continual problem, primarily because of the severe operating conditions in the slagging section of the gasifier. Some initial difficulties were also experienced with the triethylaluminum burner ignition system, but these problems were essentially solved during 1978.

Early in 1978, a rupture of a line in one of the three char burner systems caused a rapid depressurization of the gasifier and subsequently a fire, which resulted in an extended shutdown from mid-February until approximately mid-year.

During the latter part of 1978, problems were still encountered with erratic coal and char feed and with durability of Stage 1 thermocouple systems; however, several operational milestones were achieved. Although most of the runs were of short duration, there were two gasifier tests where coal and char feed were continuous for more than fifty hours. These tests resulted in a generation of good quality slag with low carbon content, which was reasonably easy to remove from the gasifier quench section. During the latter part of 1978, some revisions were attempted on the char burners, specifically, changes in both the location and in materials for the expansion bellows. Unfortunately in early 1979, another rupture in one of the char burner bellows resulted in a fire which required repairs for a period of approximately five months. During this extended shutdown, investigations were made regarding better materials of construction for Stage 1 temperature measuring systems, and acoustic flow/no flow meters developed by Argonne National Laboratories were also installed in the three char feed lines. Subsequently, problems in plant start-up were experienced with the compressors, pumps, and valves that had not been in service for a period of several months. In addition, problems still existed with the char feed system; however, during the latter part of the year, better coal and char feed were maintained; and consequently, more realistic material balances were then possible. Also during 1979, our attempts at measuring Stage 1 temperatures with a portable radiometer were hampered by inability to maintain a clear site path into Stage 1 of the gasifier.

During the latter part of 1979 and early 1980, significant improvements were made in the coal and char feed systems by substantially reducing the diameter of these lines; therefore, it was possible to routinely feed coal to the gasifier at rates of 5000 or 6000 pounds per hour compared to earlier limitations of 2000 to 3000 pounds. Also, during this time frame, new type char burner tips and different expansion bellows were installed. These factors coupled with installation of new type valves substantially improved the control and reliability of char feed to the gasifier.

For complete details of plant revisions and operations of the various process units through mid-1980, reference is made to a recent Stearns-Roger paper entitled "Operation of the BI-GAS Coal Gasification Pilot Plant".[5]

## Current Operations - mid-1980 to Present

Continuing problems during 1980 with failures of the char burners prompted Stearns-Roger Engineering to completely redesign the system. After fabrication and checkout, one of the newly designed burners was installed in the gasifier. At this time, all the four-inch diameter coal and char feed legs were replaced with one-and-one-half inch diameter and one-inch diameter feed lines respectively. These improvements had a significant impact on plant operations; in fact, shortly thereafter, the first five-day run with continuous coal and char feed to the gasifier was completed. By fall of 1980, investigations of new thermocouple and thermowell systems had considerably improved the reliability of Stage 1 temperature measurements.

Also, by this time, the newly designed char burners had been installed in all three char feed systems; subsequently, the second gasifier run of over one-hundred hours coal and char feed was completed. Another significant operational goal was achieved by reducing supplemental fuel gas flow to the char burners; in fact, the char burners were at times operated on an individual basis with no supplemental fuel gas.

Testing was also begun with a solids fraction meter developed by Auburn International, Inc. This unit was installed in one of the char feed lines and promises to aid in the measurement of char flow. With regard to temperature measuring devices, an optical pyrometer developed by Capintec Instruments, Inc. has been installed in one of the thermocouple positions in Stage 1 of the gasifier and is currently being evaluated.

Since January 1981, several hundred hours of slagging operation have been achieved at the BI-GAS Pilot Plant. During recent runs, we have also experienced much better continuous slag removal than at previous times. This work has been exemplified by exceptional control over start-up, operation, and shutdown of the various process units.

Another milestone was achieved in April 1981 by the first seven-day test with continuous coal and char feed to the gasifier. Numerous validated material and energy balances were obtained during these early 1981 tests and subsequent tests as well.

## Major Improvements in Plant Systems and Operations

During 1979 and 1980 several process unit areas underwent revisions which contributed significantly to the most recent operational achievements at the BI-GAS Pilot Plant.

As mentioned earlier, major improvements were made in both the coal and char feeding systems, with the principal change being reduction in line sizes from four inch to one-and-one-half inch diameter for coal feed and from four inch to one inch for the char feed lines. The smaller leg diameters immediately enabled better temperature control of the coal and char feed systems, with much less tendency for plugging, and in turn, significantly reduced the amounts of purge gas required. It was also readily apparent that solids flow could be more easily controlled with smaller size valves.

Due to difficulties in directly measuring solids feed, particularly the char, to a high pressure, high temperature gasifier, the normal mode of operation for the BI-GAS unit has until recently incorporated supplemental fuel gas to prevent any violent reactions. In recent months, Stearns-Roger has designed, installed, and thoroughly checked out a redundant char feed and fuel gas safety interlock system (see Figure 3). Detection of low char flow by one or more of several differential pressure devices, or by any of the Argonne flow/no flow meters causes supplemental fuel gas to be automatically added to Stage 1. In addition, trip switches cause fuel gas to be added to all three char burners if the Stage 1 temperature goes beyond a predetermined set point. As a further backup, an on-line oxygen analyzer continuously monitors the environment in Stage 2 of the gasifier.

Another major modification which has already been discussed briefly involved the char burners themselves. As can be seen in the original char burner design (Figure 4), the burner tips were prone to deterioration because of the geometry and inefficient cooling water flow to temperature sensitive surfaces. Materials of construction have also been a continuing problem with these burners. In the Stearns-Roger modified char burner (Figure 5), several improvements have been made with regard to cooling water circuitry, elimination of expansion bellows, physical geometry of the burner face, and number of oxygen ports required. These design changes plus improvements in materials of construction have enabled several hundreds of hours of operation with no significant deterioration of the burners.

Through consultation with commercial vendors and with various experts in materials and components, improved reliability and durability of temperature measuring systems, particularly the thermocouple and thermowell systems in Stage 1 of the BI-GAS gasifier, have been achieved. Currently, the tungsten-rhenium thermocouples and molybdenum thermowells have been in service routinely for five to seven day runs; however, normal procedure is to replace these systems after each run. The BI-GAS technical program also involves the checkout of selected optical pyrometers for use in Stage 1 of the gasifier. A dual range unit which is currently being tested and shows good promise is manufactured by Capintec Instruments, Inc.

Recognizing the responsibility to obtain optimum data for commercial plant design, Stearns-Roger staff has also expended considerable effort to improve both the hardware and procedures for obtaining solids and gas samples from various process units. In fact, multiple sampling at specified time intervals is a mandatory requirement for obtaining validated material and energy balances. As an example of this concept, refer to Table 2 which lists typical gasifier products from a recent test with Montana Rosebud coal. This information represents an average of seven separate samples taken at specified times and conditions in the overhead of the gas washer.

## Summary and Future Plans

In summary, BI-GAS Plant operations, particularly the several tests conducted from mid-1980 to the present, have involved long-term runs under slagging conditions with minimum supplemental fuel gas. This represents a significant achievement - namely, operation of the BI-GAS gasifier in a commercial mode.

Extensive and repeated checks of redundant plant safety systems, particularly those involving gasifier Stage 1 operations, have further increased confidence in the BI-GAS process.

Durability of hardware, particularly regarding the char burners, refractory in Stage 2 of the gasifier, maintenance of the protective slag layer in Stage 1 of the gasifier, plus performance of cooling water tube material and thermocouple systems amplify the confidence in future commercial development of this type gasification system.

It is anticipated that developmental work on the BI-GAS process per se will be completed by the end of Fiscal Year 1982. We recognize that prior to that time, however, several additional objectives must be achieved to further enhance the commercial appeal of the BI-GAS process. (Refer to Table 3.) A principal near-term milestone will be gasification of an Eastern Pittsburgh seam coal initially at low pressure (750 psi) and then at higher pressure (1150 psi), and at design coal feed rates. Present plans are to continue operating the gasifier with minimum or zero supplemental fuel to Stage 1.

During the latter part of Fiscal Year 1982, plans include operation of the following downstream process units in an integrated fashion: the carbon monoxide shift unit, complete acid gas removal system, the fluidized-bed methanation system and the Claus sulfur plant.

To further aid in the evaluation of future operations, we have installed a new computer-based data acquisition and process analytical system; an important tool which will be used for dynamic evaluation of all process units and for on-line computation of steady-state material and energy balances.

Anticipating that the major hardware and process difficulties have been overcome, our intention is to optimize plant operations in the relatively near future so that a data base for the design of a commercial-scale BI-GAS facility can be firmly established. In addition, Stearns-Roger and the sponsor, the Department of Energy, intend to make available all BI-GAS process information as a contribution to the general data bank on coal conversion technology.

Acknowledgement

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## LITERATURE REFERENCES


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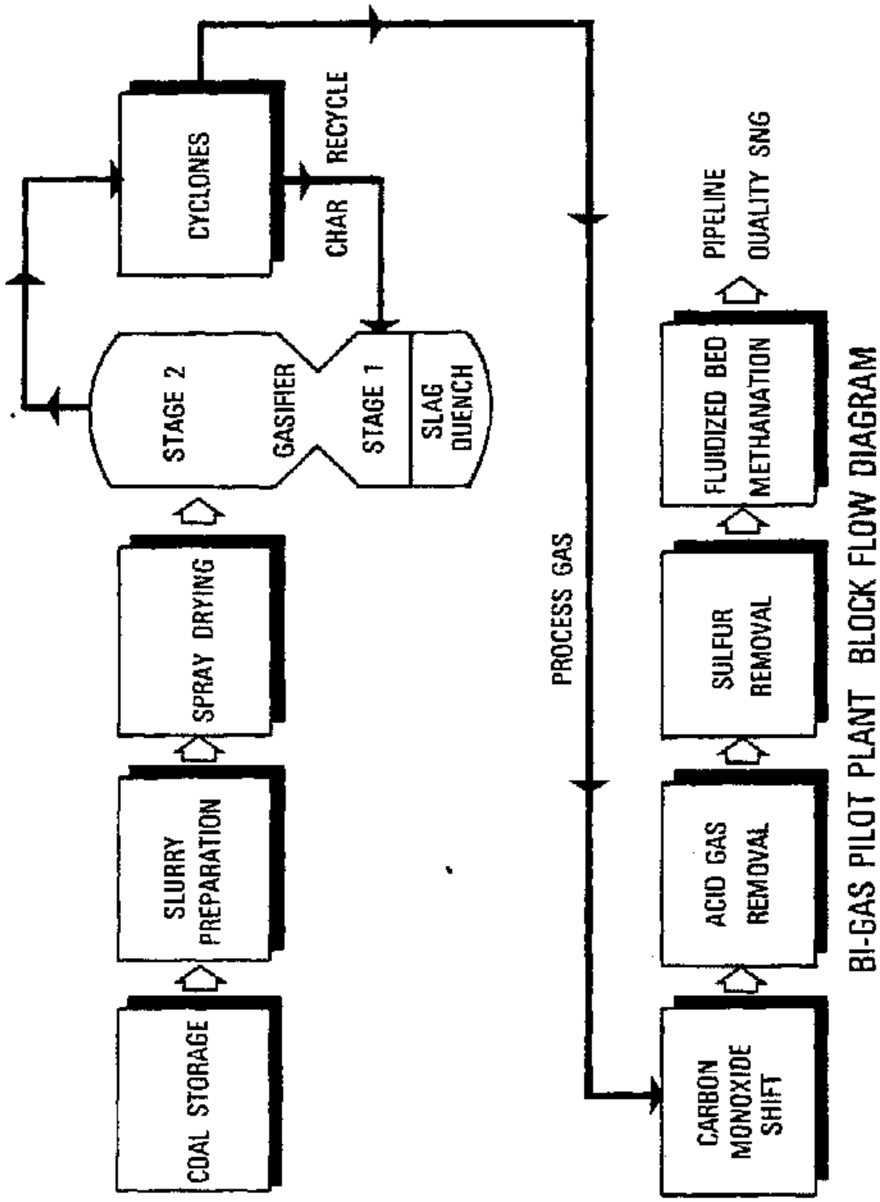
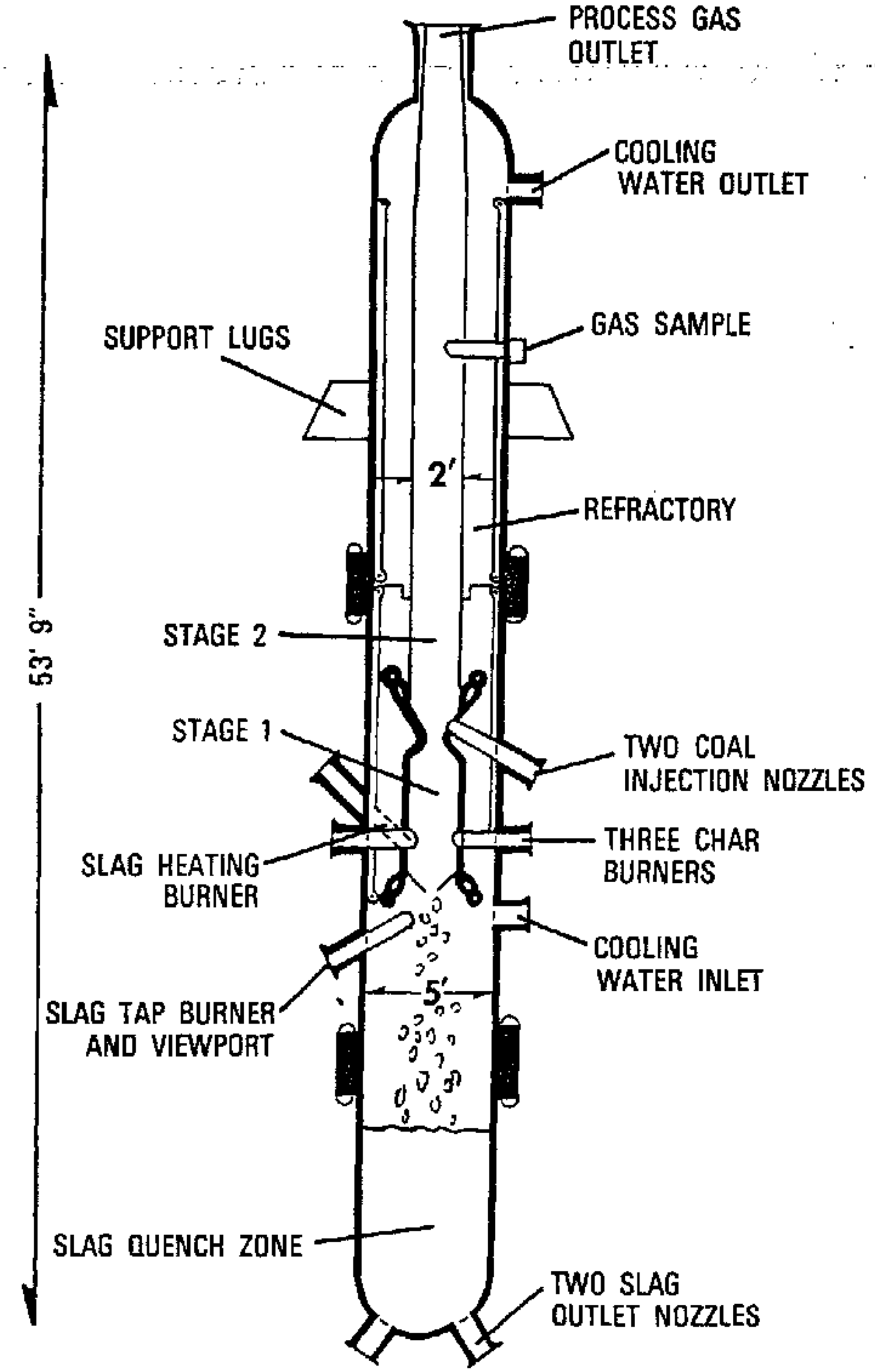
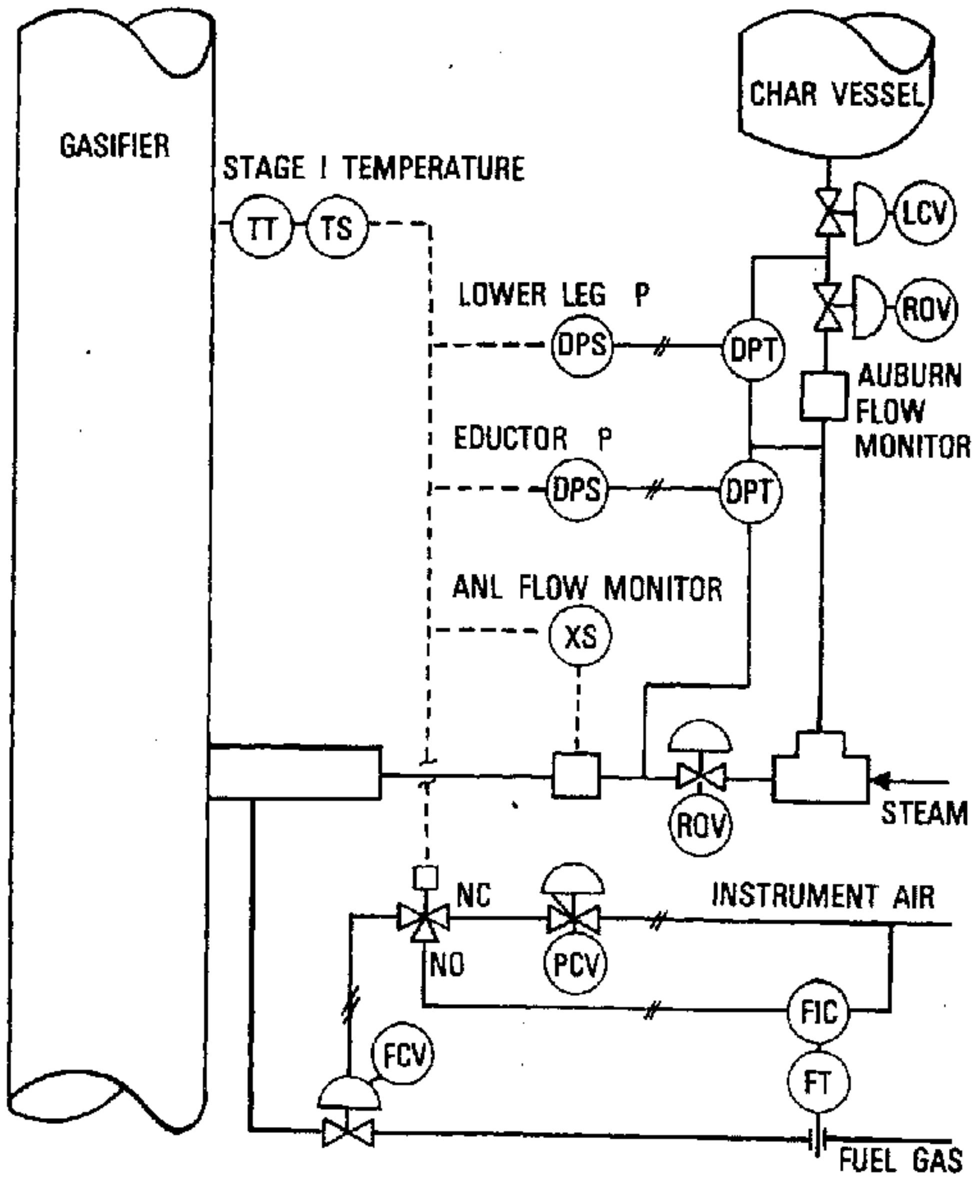

BI-GAS PILOT PLANT BLOCK FLOW DIAGRAM
COAL STORAGE
SLURRY PREPARATION
SPRAY DRYING
STAGE 2
GASIFIER
STAGE 1
SLAG QUENCH
CYCLONES
CHAR RECYCLE
PROCESS GAS
CARBON MONOXIDE SHIFT
ACID GAS REMOVAL
SULFUR REMOVAL
FLUIDIZED BED METHANATION
PIPELINE QUALITY SNG

FIGURE I



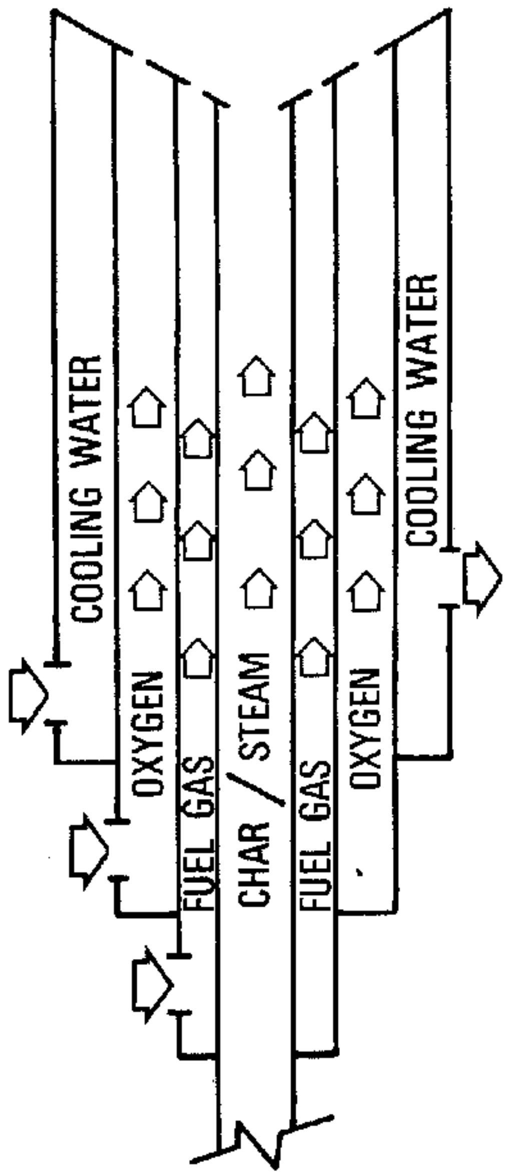

BI-GAS PILOT PLANT GASIFIER

FIGURE II




CHAR FEED SAFETY INTERLOCK SYSTEM

FIGURE III




ORIGINAL CHAR BURNER DESIGN

FIGURE IV

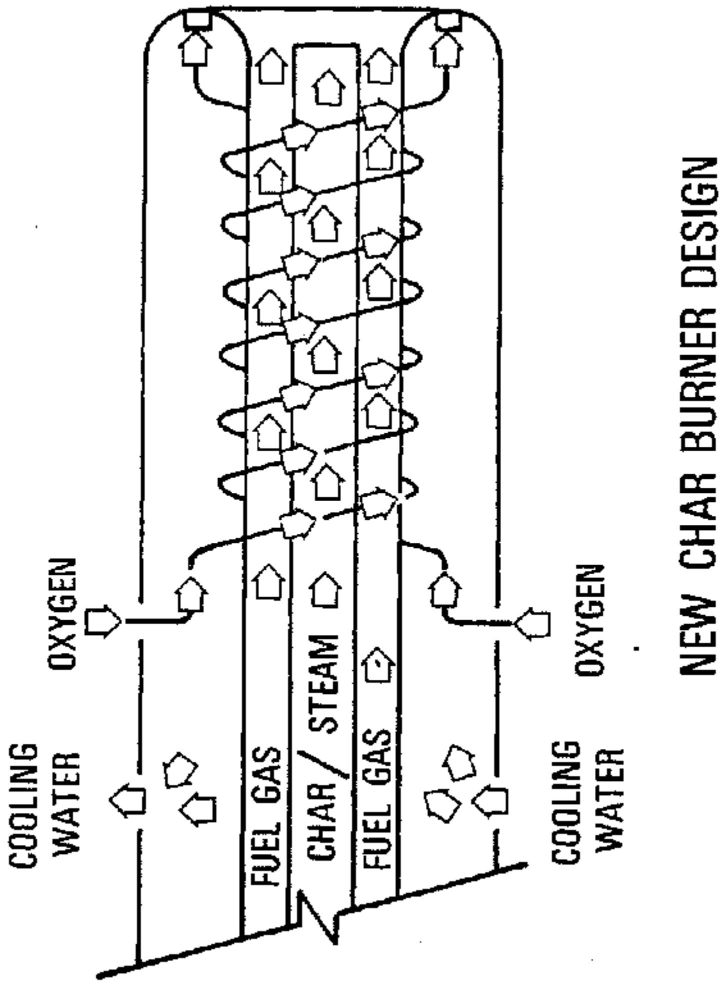

COOLING WATER
OXYGEN
FUEL GAS
CHAR / STEAM
FUEL GAS
OXYGEN
COOLING WATER
NEW CHAR BURNER DESIGN

FIGURE V

# ADVANTAGES OF BI-GAS PROCESS

COMPARATIVELY SIMPLE TWO-STAGE GASIFIER

NO COAL PRETREATMENT REQUIRED

PRODUCTS INCLUDE ONLY GAS, SULFUR, AND SLAG

HIGH YIELDS OF METHANE OBTAINED IN GASIFIER

OPERATING CONDITIONS ELIMINATE DOWNSTREAM GAS CLEANUP AND COMPRESSION

TABLE I

# TYPICAL GASIFIER PRODUCTS

(Montana Rosebud Coal)

| | |
|---|---|
| METHANE | 10.0% |
| HYDROGEN | 32.2% |
| CARBON MONOXIDE | 29.0% |
| CARBON DIOXIDE | 14.2% |
| WATER | 13.3% |
| NITROGEN | 1.0% |
| HYDROGEN SULFIDE | 0.3% |
| | 100.0% |

TABLE II

# BI-GAS PROGRAM OBJECTIVES

GASIFICATION OF EASTERN COAL(s)

OPERATION AT HIGHER PRESSURE

ELIMINATION OF SUPPLEMENTAL FUEL

OPERATION OF ALL DOWNSTREAM UNITS

OPTIMIZATION OF PLANT OPERATIONS

ESTABLISHMENT OF DATA BASE FOR COMMERCIAL DESIGN

CONTRIBUTIONS TO DATA BANK ON COAL CONVERSION TECHNOLOGY

TABLE III