FINAL 119-19

CONTROL TECHNOLOGY ASSESSMENT

FOR

COAL GASIFICATION AND LIQUEFACTION PROCESSES

Slagging Fixed-Bed Gasification Pilot Plant
Lignite Liquefaction Facility
Grand Forks Energy Technology Center
Grand Forks, North Dakota

Report for the Site Visit of
March 1980

Contract No. 210-78-0084

March 1982

Submitted to:

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Foreword

On March 3 and 4, 1980, the Enviro Control, Inc. (ECI) Control Technology Assessment (CTA) team met with representatives of the Grand Forks Energy Technology Center (GFETC), Grand Forks, North Dakota. Attending this meeting were:

Grand Forks Energy Technology Center

Philip Freeman, Industrial Hygienist
Gale Mayer, Chemist

Enviro Control, Inc.

James Evans, Project Manager
Donato Telesca, Principal Investigator
Russell Tanita, Senior Industrial Hygienist

The CTA assessment included detailed inspection of the plant and the equipment, review of engineering drawings, and interviews with personnel in maintenance, operations, safety and engineering. In addition, Mr. Freeman collected and forwarded for ECI use, reports detailing the various studies at GFETC.

This report would not have been possible without the excellent cooperation of the personnel at the GFETC facility.

Those interviewed at the GFETC were:

Philip Freeman, Industrial Hygienist
Gale Mayer, Chemist
Curtis Knudson, Supervisor - Liquefaction Unit
Raymond Majkrzak, Mechanical Engineer
Benny Kwang, Engineer Sterns-Roger

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I. INTRODUCTION

A. Contract Background

The objective of the "Control Technology Assessment for Coal Gasification and Liquefaction Processes" program is to study the control technology that is available to prevent occupational exposure to hazardous agents in coal conversion plants. This report details the control technology and industrial hygiene information gathered at the (1) Slagging Fixed-Bed Gasification Pilot Plant and the (2) Liquefaction Facility located at the Grand Forks Energy Technology Center (GFETC), Grand Forks, North Dakota, during the site visit of March 3 and 4, 1980.

Both the Slagging Fixed-Bed Gasification Pilot Plant and the Liquefaction Facility are being operated by GFETC for the Department of Energy. The overall objective of the gasification project is to develop data to support commercial and demonstration applications of slagging fixed-bed gasification (a second generation process). The objective of the liquefaction project is to develop the chemical and engineering data base required to liquefy lignites and subbituminous coals using techniques common to the SRC-II, H-Coal, and Donor Solvent processes.

B. History of the GFETC Gasification and Liquefaction Projects

Interest in slagging fixed-bed technology has intensified over the past several years because of the attractive economics plus reliance on existing commercial technology. The British Gas Corporation, Conoco Coal Development Corporation, and a consortium of approximately 15 other companies have developed this technology at the commercial facilities in Westfield, Scotland and have been awarded a contract with DOE to construct and operate a large demonstration plant in Noble County, Ohio.[1] This technology is not unfamiliar in the United States. The Bureau of Mines built and operated the first slagging fixed-bed gasifier with lignite in 1958 and continued the program until 1965.[2,3,4] The effort was based on earlier work in lignite gasification conducted at Grand Forks in the mid-1940s.[5,6] This gasifier was designed to compare the performance of slagging operation with non-caking coals to dry-bottom, fixed-bed gasification.[7] This objective was reached, and from 1965 until 1974, the pilot plant was essentially maintained in a mothball status. Operation of the gasifier was reestablished in April of 1976 to investigate the production of synthetic natural gas and evaluate environmental concerns associated with commercial scale fixed-bed coal gasification facilities. In September 1978 gasifier operations were temporarily suspended for extensive modifications to the pilot plant.[7] Operation of the plant had resumed just prior to the control technology study team visit in March 1980. The goal of the present GFETC gasification program is to develop data to support commercial and demonstration applications of fixed-bed gasification.

Liquefaction research at GFETC was initiated in 1975 to support the development of the CO-Steam process. This process was named for the reaction of carbon monoxide and steam with coal to provide in situ hydrogen; CO also reacts with coal oxygen to form CO_2 (no catalyst is added). The process was developed principally at the Pittsburgh Energy Technology Center of DOE using cold-charge autoclaves and a continuous processing unit. It was found that conversion was particularly high for lignite. The goal of the process was to produce a high yield of environmentally acceptable liquid boiler fuel in a process involving a one-step reaction and using filtration or centrifugation for solids separation.

The liquefaction research facilities established at GFETC since 1975 have included a unique hot-charge and time-sampled batch autoclave system for studying reaction kinetics, a 5-lb coal/hr continuous process unit for studying lined-out operation in various reactor flow configurations, and an array of analytical instrumentation for determining elemental and molecular compositions.

The emphasis in work on CO-Steam had been to reduce product viscosity while maintaining high liquid yield and reducing reaction time. Recently, emphasis has been shifted away from viscosity control toward greater interest in distillate products as a means of avoiding the problem of ash-solids separation. Because of the emphasis on recycling and on raising temperature, which requires a good hydrogen donor solvent, the work at GFETC supports the application of the SRC-II and Exxon Donor Solvent processes to lignite.

The present objective of liquefaction research on lignite performed by DOE through the Grand Forks Energy Technology Center is to develop the chemical and engineering data base required to liquefy lignites and subbituminous coals using techniques common to the SRC-II, H-Coal, and Donor Solvent processes.

C. Description of the Facilities

1. Slagging Fixed-Bed Gasification Pilot Plant Facility

As a part of the modifications, the gasifier was moved to a newly constructed wing of an existing GFETC building. This wing had been specially constructed to house the gasifier, the gasifier control room, a simple laboratory for operating-control analyses, gasifier auxiliary equipment, and a stairwell.

The stairwell, which is the only access to all gasifier levels, is relatively broad, heated, and well lighted by natural and electric lighting. The building enclosing the gasifier is built of concrete block on the stairwell side and a light transite-like siding on the second side. The roof over the gasifier is light-weight and is designed to yield in the event of an explosion. Each floor of the six levels of the gasifier building above the ground floor level is constructed of metal grating. The ground floor where the steam boilers, tar storage tanks, gas-liquid separation tanks, pumps, and ash removal equipment are located is concrete.

The first three levels above ground level contain ancillary facilities for the gasifier so the gasifier enclosure acts as a hub for this portion of the building. The waste treatment study area occupies the first floor, the control room and further waste treatment study areas are located on the second floor, and the analytical laboratories are on the third floor.

2. Liquefaction Facility

The equipment for the continuous process unit was housed in one wing of the laboratory building. The structure was modified by installing the outside wall as a blow-out wall behind the high-pressure area. The inside wall of the test area was 1/2" steel plate, with tubing and/or piping passing through the wall to required instrument and control valves.

D. Process Description

1. Fixed-Bed Gasification Pilot Plant (Figure 1.)

In the GFETC gasifier, batches of coal are gravity fed to the unit from dual lockhoppers mounted on top of the main body of the gasifier. The coal is dried as soon as it falls into the gasifier and it is carbonized by the upward countercurrent flow of hot gases. The coal slowly descends the gasifier shaft, and when the hearth is reached, only char material remains. Combustion and gasification occur when the char is mixed with steam and oxygen. The resulting temperatures cause the ash to melt. The molten slag flows out of the gasifier where it is water quenched, forming a sand-like slag. The slag settles out and is removed through a lockhopper.

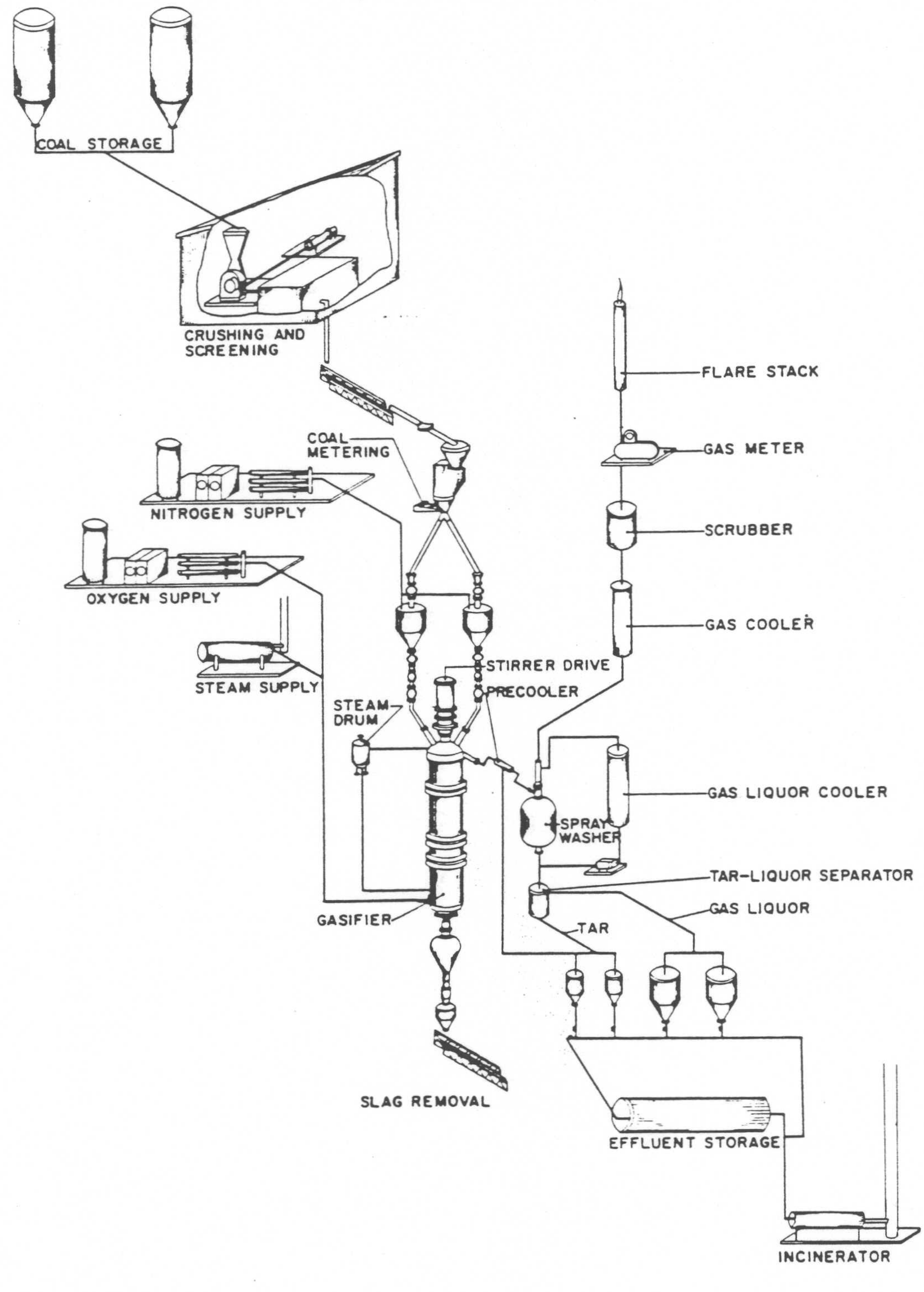

FIGURE 1. Schematic of the GFETC Slagging Fixed-Bed Gasification Process. (Adapted from reference 7 .)

The product gas consists of the reaction gas rising from the fuel bed and the tar, light oil, water vapors, and other gases which result from the carbonization of the coal. The undesired oil, tar vapors, and dust particles are removed from the gas mixture by means of a condensing process which uses the recycled gas liquor as a cooling agent. The gas is further cooled and scrubbed and the final gas product can then be metered and flared.[7]

Fixed-bed gasification is a thoroughly commercialized process with the Lurgi process being one of the better known examples. Fixed-bed gasification, when compared with other gasification processes, offers advantages in high thermal efficiency, high carbon conversion, and favorable oxygen consumption. However, fixed-bed gasification is limited to weakly caking coals and requires a sized fuel with a limited percentage of fine material.[3]

The chief disadvantage of the conventional Lurgi gasifier, which operates under nonclinkering conditions, is the large quantities of excess steam that must be supplied with the oxygen-steam mixture to reduce temperatures in the fuel bed below the fusion temperature of ash. Most of the steam leaves the bed undecomposed with the product gas, and, after cooling, produces large amounts of dilute gas-liquor. Operation of a gasifier at ash slagging conditions would reduce the steam requirements and the volume of waste liquor obtained. Overall thermal efficiency of the fixed-bed gasification process would also be increased as would be the gasifier capacity per unit cross-sectional area. Other advantages of a slagging gasifier are its ability to use coals having low ash-fusion temperatures and to operate without a mechanical grate.[3,4]

In dry-ash, fixed-bed gasification the material resting on the mechanical grate consists of 15 to 24 inches of ash which forms a counter-current heat exchange medium for incoming gas. The high temperature combustion zone is located on top of the ash. In slagging fixed-bed gasification the combustion zone is essentially at the hearth level as illustrated in Figure 2. The temperature profile, illustrated in Figure 3 is typical as opposed to the more graded temperature increase observed in the lower bed of dry-ash fixed-bed gasifiers.

2. Liquefaction Facility

The 5-lb coal/hr continuous process unit in use at the GFETC Liquefaction Facility, is shown in Figure 4. A slurry of minus 60 mesh lignite containing about 30% moisture is preblended with solvent or recycle product slurry and pumped to a slurry hold tank. A high-pressure piston pump delivering up to 25-lb/hr of slurry at pressures up to 6000 psi is used to charge the slurry into the system. A single-stage diaphragm compressor compresses the reaction gas to 6300 psi, and meters it into the system. Slurry and gas are heated independently and mixed at the entrance of the continuous stirred-tank reactor. Reacted slurry and gas leaving the reactor enter a high-pressure separation vessel maintained at about 572 F (300 C).

The product recovery vessel acts as a low pressure flash tower, followed by a water-cooled, light oil and water condenser. Noncondensable gases are vented through a positive displacement meter. Light oils/water are removed from the flash tower through a manual valve. Gases and vapors from the primary separator pass to a condensate accumulator where the light oils and water are condensed by a water-cooled coil. Light oils are removed from the system through a series of two manually operated valves. Tail gas at about 73 F (23 C) is let down through a back-pressure regulator, metered and flared.

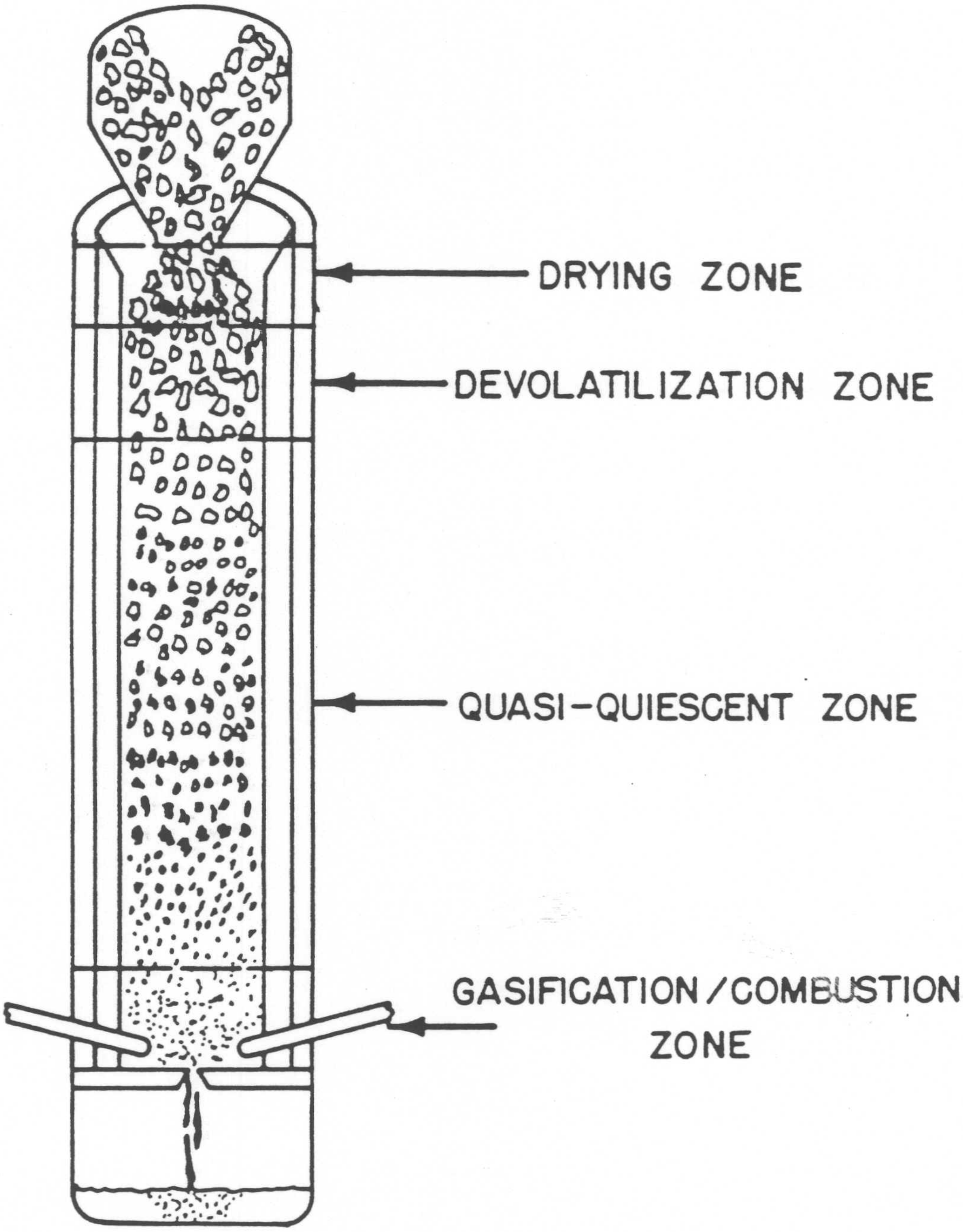

FIGURE 2. Conceptual View of Reaction Zones in Slagging Fixed-Bed Gasifier. (Adapted from reference 7.)

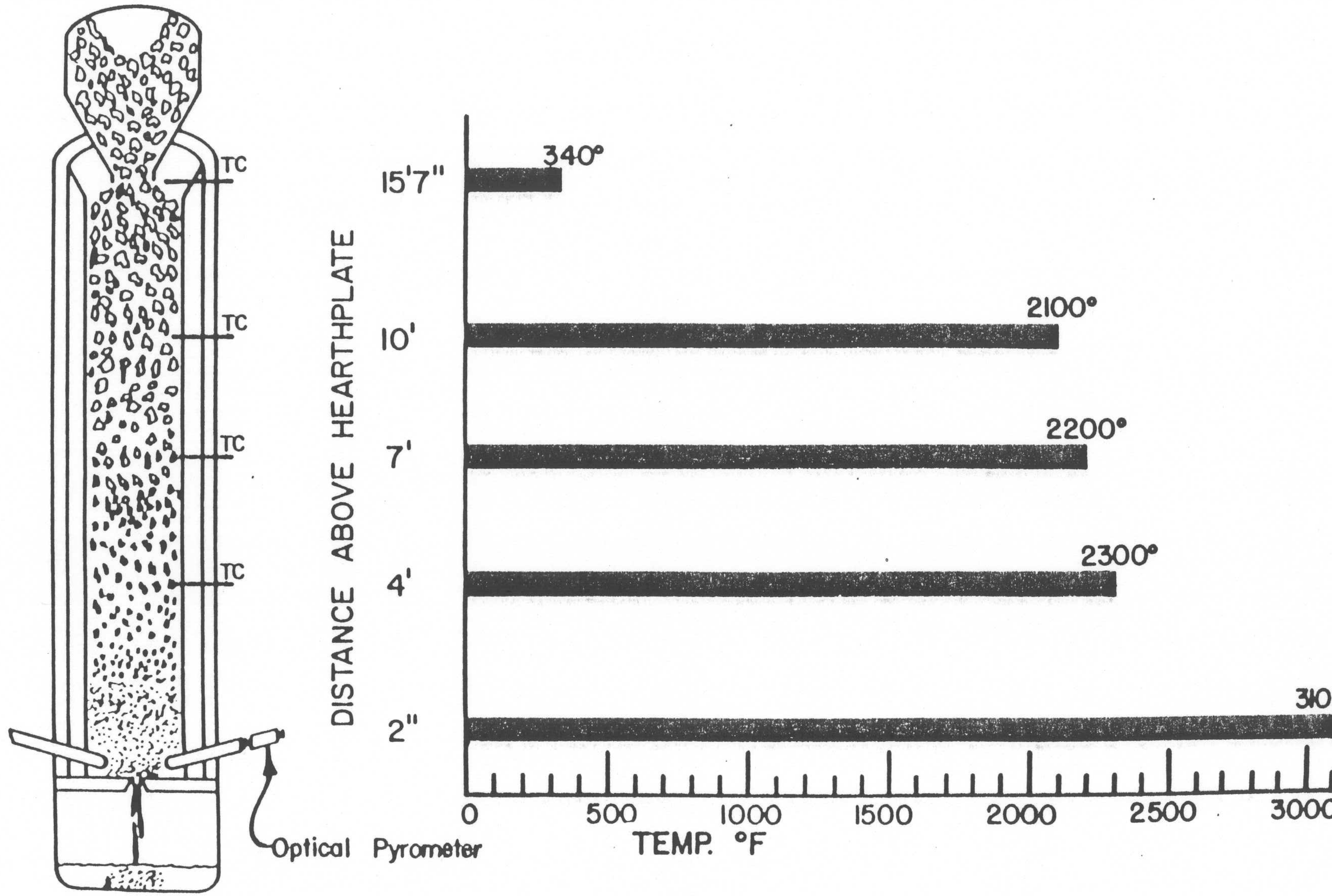

FIGURE 3. Typical Temperature Profile as Function of Bed Height for the Slagging Fixed-Bed Gasifier. (Adapted from reference 7.)

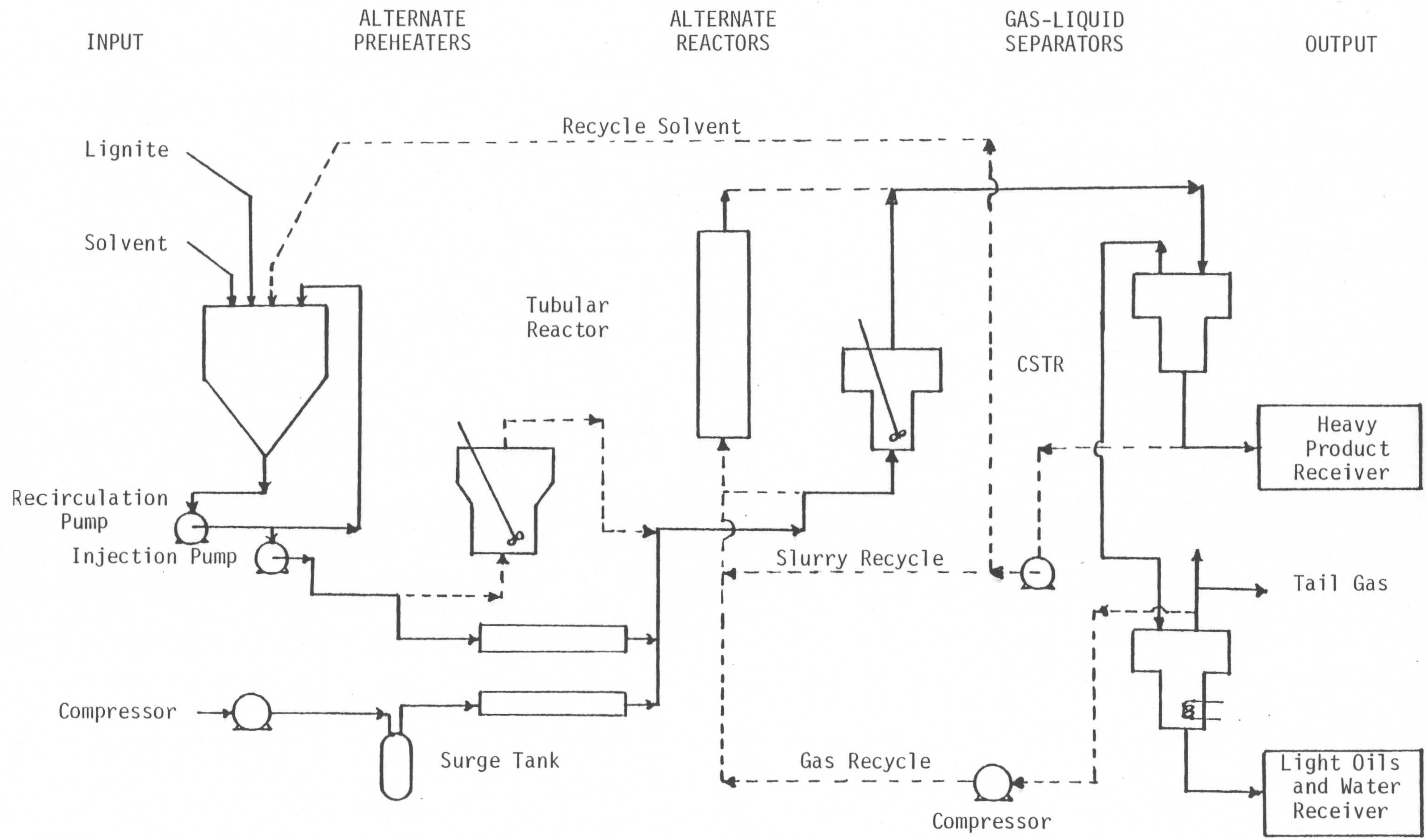

FIGURE 4. Schematic Flow Diagram of the Continuous Process Unit (5-lb coal/hr). (Adapted from reference 15.)

E. Potential Hazards

The principle hazard associated with the liquefaction and gasification facilities at GFETC is explosion. The reactor/ separator section is the major area for the liquefaction facility in which explosions can occur because of the high operating pressure. The gasifier is the primary site of a potential explosion in the gasification facility.

The major health problem is exposure to the PNA-containing materials. At the liquefaction facility, the product has a low vapor pressure, so concern is mainly one of skin contact rather than inhalation. The principle process areas where skin contact could occur are in the slurry mix and product collection areas. These rooms are open rooms located adjacent to and at opposite ends of the enclosed main process area.

The recycled product used in the slurry mix has as its initial composition 70% aromatics, primarily two- and three-ring aromatic compounds, and 30% paraffins. Under continuous running condition, this anthracene oil product is reduced to lower molecular weight constituents with a relatively higher vapor pressure. Because the recycle product is manually poured into the slurry mix vessel, the potential of inhalation exposure exists through the volatilization of the high vapor pressure components of the recycle product. The nature of the volatile components is dependent upon the amount of recycling or passes the product has undergone, but is believed to be simple aromatics such as benzene and the phenolics.

The gasification facility produces a lighter tar relative to the liquefaction process containing PNAs of 3-rings or less. Worker exposure is considered to be minimal during the operation of the gasification facility. Major exposure is expected to occur among the maintenance crew during nonoperational periods when the gasifier is dismantled, cleaned, and repaired. Because the hazard of exposure to these light tars is not known, the gasification facility is considered to have the same degree of hazard as the liquefaction facility.

Other potentially hazardous areas include the coal handling area, the feed from the coal bin to the gasifier lockhopper, and the water sprayer. Because of recurring leakage of the seals, the latter two are potential problem areas for coal dust and phenolic and cresylic compounds, respectively. The coal handling area is open and is reported to have high coal dust levels. A summary of the potential hazards associated with these two facilities is given in Tables I and II.

II. ENGINEERING CONTROL TECHNOLOGY

A. Introduction

Control technology for the Grand Forks Energy Technology Center liquefaction and slagging fixed-bed gasification facilities is presented in the following sections. A two part discussion of each process area in the slagging gasification facility is presented first. This section consists of a process area description followed by a discussion of the potential hazards associated with that process along with the engineering controls used to mitigate those hazards. This is followed by a similar two part discussion of the liquefaction facility; however, because the facility is of bench-scale size, the process description and engineering control technology sections are not divided by process area.

B. Slagging Fixed-Bed Gasification Pilot Plant

1. Coal Storage and Preparation

(a) Process Description

Coal is brought to GFETC by truck to the storage and crushing building. After crushing, the coal is conveyed by bucket elevator to the

TABLE I

LIGNITE LIQUEFACTION
GFETC

Process	Potential Hazards
Slurry Mix	Coal Dust Organic Solvents Coal Tars
Reactor/Separators*	Coal Tars Gas Explosion
Product Collection	Coal Tars Light Oils

*No exposure - area off-limits to personnel during runs.

TABLE II

GASIFICATION FACILITY
GFETC

Process	Potential Hazard
Coal Preparation	Coal Dust Noise
Gasifier (including lockhopper)	Gas Explosion Tar (PNA) CO H_2S
Cleanup System (includes all equipment after gasifier)	Tar (PNA) CO H_2S Phenols Cresols

top of the screening building. The coal storage facilities and the crushing and screening facilities were used in earlier gasification and other coal related studies.

A 1200 ton bin provides a coal reservoir for continuously charging the coal lockhopper for the 40-70 minute operating time of the one-ton-per-hour gasifier. The bin is located above a weigh-belt metering device and is attached to it with a cloth or canvas covering. The covering is clamped in place on the outlet ducts of the bin and weight-belt inlet ducts. Light metal piping is used to direct the weighed coal to an open funnel placed above the upper lockhopper valves. The valves are one level below the coal bin.

(b) Control Technology Assessment

The use of both the old and new raw coal preparation and conveying systems has resulted in seven transfer points where coal dust could be generated. Only one transfer point, the funnel on top of the coal feed bin, is located within the enclosure.* A filter cloth cover prevents dust leakage from the end of the gravity-flow, coal-feed pipe or funnel.

At the time of the visit there were 30 air changes per hour (100 per cent make-up air) in the coal preparation area. There were plans to increase the air flow to 60 changes per hour in order to reduce the dust exposure problem. Ventilation is required to maintain CO concentrations below the threshold limit value.

2. Gasification

(a) Process Description

Coal, introduced into the gasifier through a lockhopper, is heated by the countercurrent flow of hot gases coming from the reaction

*The dust control system has since been changed to a closed system.

zone. Drying, devolatilization and gasification occur in distinct zones in the coal bed. The coal reacts with the steam-oxygen mixture that is injected into the hearth section. Gasification occurs at temperatures of approximately 3100 F (1700 C), completely consuming the coal and leaving only molten slag. The slag drops down into a water bath in the lower lockhopper, producing a frit resembling coarse sand. The slag is periodically removed. The product gas leaves the top of the gasifier and enters a recycle liquor spray washer where water vapors, tar, oil and dust are removed. Figure 5 shows the cross section of the modified GFETC slagging gasifier; Figure 6 shows the cross section of the original gasifier.

The inside diameter of the gasifier is 16-5/8 inches, with a fuel bed area of 1-1/2 square feet. The total height of the gasifier available-fuel-bed-depth is 15 feet, giving heat exchange time and gas residence time similar to commercial Lurgi units.

The gasifier consists of a head section, a slagging section, and intermediate 3- and 6-foot sections, with the various sections joined by large flanges. By removing either or both of the intermediate sections, the fuel bed depth may be varied in 3-foot increments from 6 feet to 15 feet. This flexible design permits future determination of the optimum fuel bed height, which may vary for different process conditions and type of fuel gasified.

The gasifier is suspended from mounting pads attached to the head section. The total weight of the gasifier is about 25 tons; no section weighs more than 5 tons, and each section can be readily handled. Except for the slagging section, the gasifier has design and working pressure ratings of 700 and 600 psig, respectively.

(b) Control Technology Assessment

Lockhoppers

The present design of the SFBG uses parallel lockhoppers located above rotary feeders (See Figure 5). In this way the gasifier may be fed continuously to maintain a constant bed level.

Before modification, one lockhopper was used with the GFETC gasifier. This unit was filled with coal then opened to flood-fill the gasifier (see Figure 6). This coal hopper, followed the Lurgi design technology and uses the Lurgi lockhopper valving technique.*

The original coal lock was flanged to the top of the gasifier, and had a capacity of about 1,200 pounds. The bottom closure was a manually operated cone valve, whereas the top closure was a quick-opening type using a self-energizing rubber gasket seal. The present parallel seal lockhoppers have been attached to openings previously used for thermocouples or gas samplers. The stirrer will be flange mounted in the position originally occupied by the single lockhopper.

The lockhoppers are nitrogen purged and pressurized. During operation the lockhopper valves are interlocked with the lockhopper pressure system so that the lockhopper cannot be pressurized if the upper valve does not seat properly; and cannot be depressurized or opened if the bottom valve does not seat properly. Lockhoppers are positively pressurized above the gasifier pressure to reduce the potential for migration of product gas into the lockhopper during coal discharge. Lockhopper pressurizing gas is discharged to the flare system.

* None of the GFETC reports studied discuss any problems identified with this type of lockhopper valves. This emphasizes the reliability of the Lurgi design.

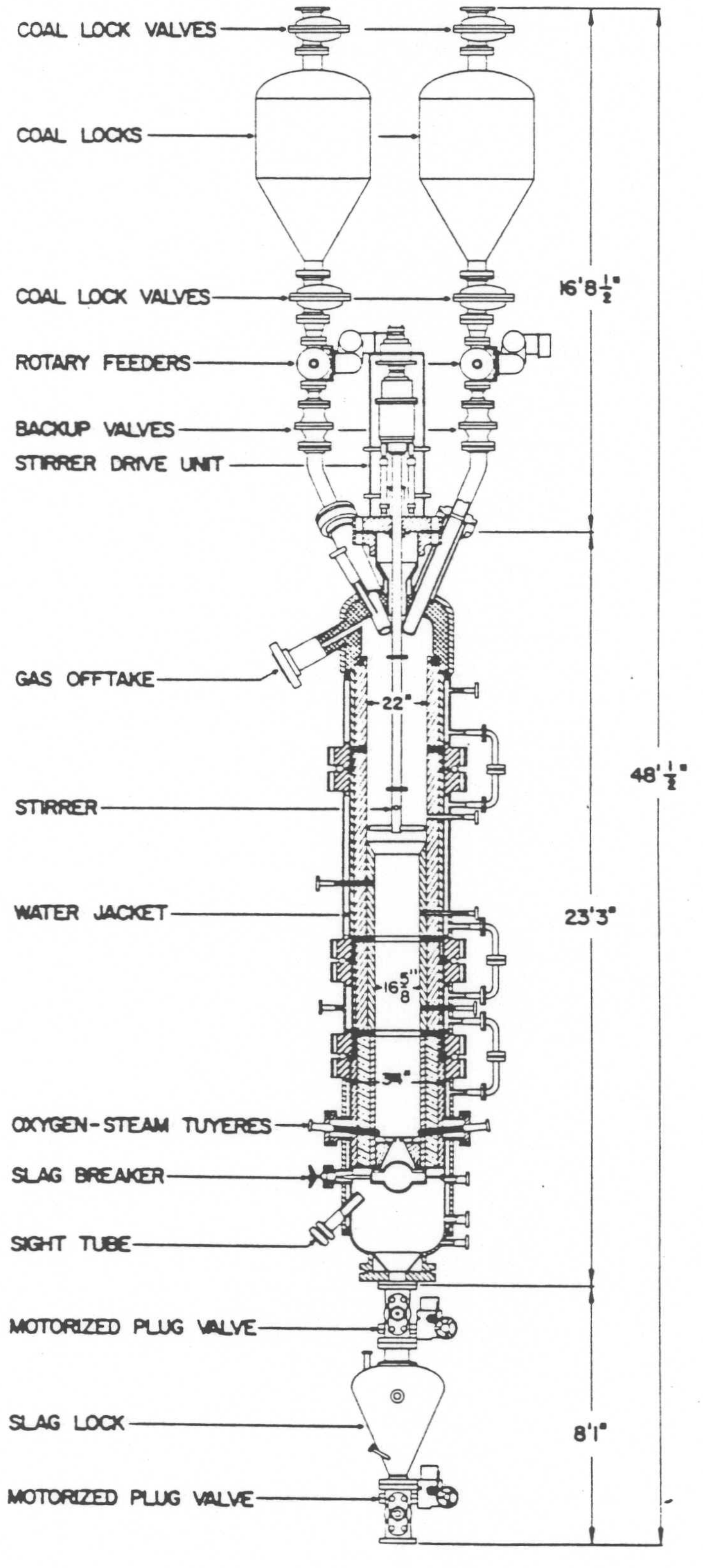

FIGURE 5. Cross Section of Modified GFETC Slagging Gasifier. (Adapted from reference 7.)

*Further Modifications to the gasifier have been made.

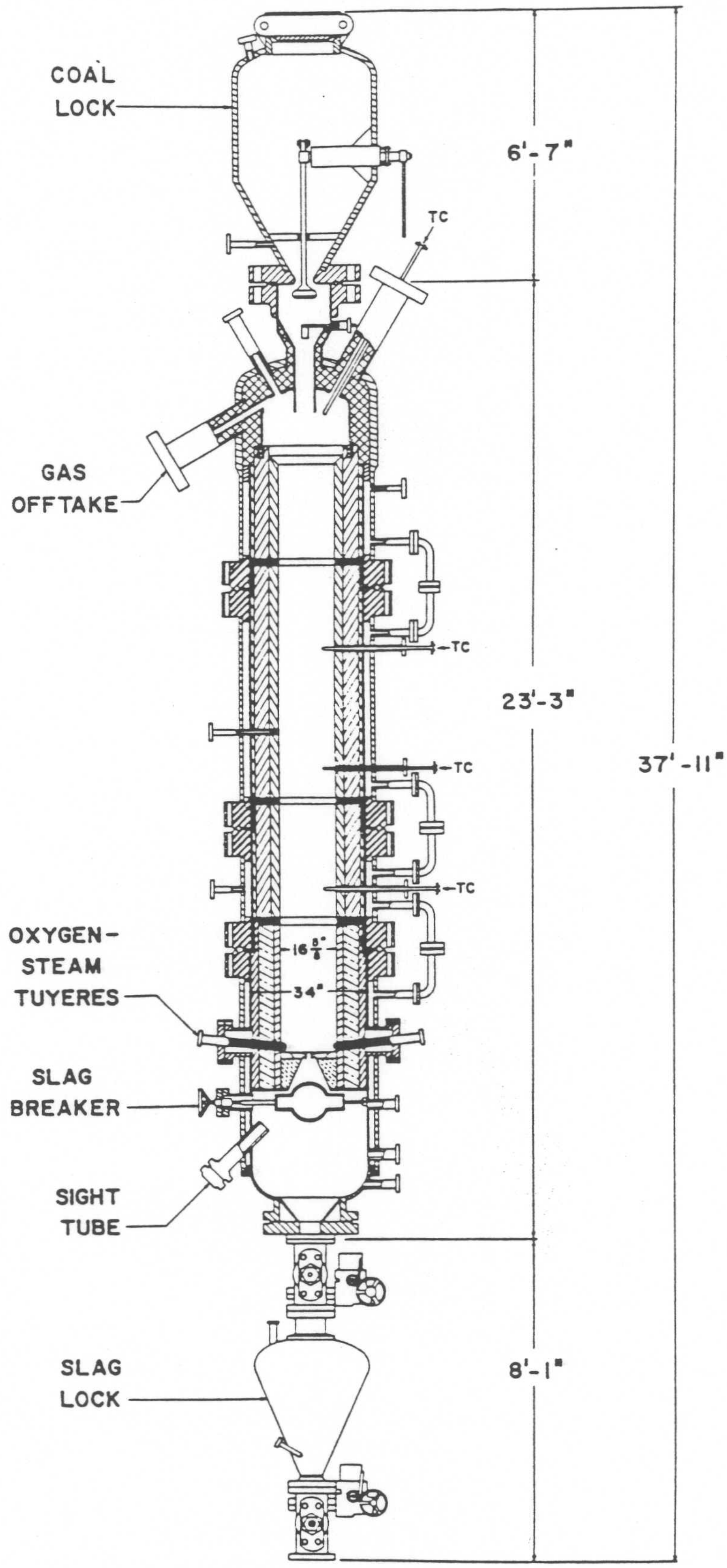

FIGURE 6. - Cross Section of Original GFETC Slagging Gasifier.
Configuraton used until September 1978.

(Adapted from reference 7.)

The CTA study team anticipates emission problems around the lockhopper system. Coal dust emissions are likely to occur when the lockhoppers are filled. In addition, sealing and wear problems may occur in the lockhopper valves and in the rotary feeders. This is the first site visit where a rotary feeder has been used in a high pressure gasifier.* From experience at other gasification plants, rotary feeders used in low pressure service have been a source of gasifier emissions. Further experience is needed to determine the ability of this valve to avoid excessive emissions in high-pressure operations. However, if emissions do occur, the high air change-rate, intended to maintain CO concentrations below the threshold limit value, would substantially dilute any emissions thereby reducing the potential for worker exposure to gasifier gases or vapors.

The block (coal lock) valves installed both above and below the two lockhoppers are knife gate valves manufactured by the Everlasting Valve Company. At the time of the CTA site visit these valves were not purged for removal of particulate matter from the valve seats before closing. However, nitrogen purges were added to the valves(9) after sealing problems were encountered. Drawings of the valve internals are proprietary.(9)

Gasifier(7)

Unlike the modern, high-capacity Lurgi gasifiers which use unlined metal walls, refractory lining is incorporated in the small experimental unit to reduce heat losses per unit of gas production. The refractory lining in the upper three sections before modification is 8-11/16 inches thick. A 2-11/16 inch layer of high-grade mullite tile with a service temperature in excess of 3,000 F (1,650 C) forms the inner lining. This is followed by a 4-1/2 inch layer of insulating firebrick having a 2,800 F (1,538 C) service temperature and

*Use of the rotary feeder has been discontinued.

is backed by 1-1/2 inches of insulating castable refractory having a service temperature of 2,000 F (1,093 C).

The inner lining of the slagging section and hearth is made of 2-inch thick silicon carbide tile. This silicon carbide is backed by 4-1/2 inches of high-grade alumina brick and 5-1/2 inches of insulating brick. The top head and attached nozzles are insulated from the hot gases with an alumina-silicate liner supported by 1/8-inch thick metal liners. The service temperature of the liner is 2,300 F (1,260C). This liner is also used as a compression joint between various sections of the gasifier.

The high-temperature sections of the gasifier are water jacketed.

The outer shell of the 3- and 6-foot straight sections are fabricated from 1-3/16 inch carbon steel plate. The entire top section, with the exception of the connecting flange, is made of type 310 stainless steel. Wall thicknesses are 1-7/8 inch for the head piece and 7/8-inch for the straight portion.

Several nozzles are attached to the gasifier top and the straight sections to provide outlets for measuring temperature and pressure, collecting gas samples, adding purge gas, or accommodating rupture disks. Nozzles in the wall of the straight sections are used for temperature and pressure elements.

The gasifier has been modified for the addition of a stirrer by removal of 2.69 inches of refractory from the upper or devolatilization (Figure 5) portion of the bed. Rotation of the stirrer can be controlled up to 4 RPM; and to a vertical motion of 48 inches. Incorporation of the stirrer should permit the use of agglomerating coal in the gasifier.

The stirrer had not been installed in the gasifier head at the time of the CTA site visit. GFETC plans were to delay installation of the unit until the proposed lignite and subbituminous coal tests had been completed. However, it was understood that the mounting to be used would be similar to that used with GEGAS gasifier described previously.[10] If so, a hand-tightened packed seal will be used around the stirrer shaft. Intermittent gasifier product gas leakage and significant shaft scoring in the sealing area can be anticipated.

Hearth & Taphole

The principal problem areas in the slagging gasifier identified in the 1958-1965 period were sustained discharge of molten slag in high pressure operation and severe refractory erosion of hearth materials.[8] The operations program from 1976 through September of 1978 was designed, in part, to concentrate on the development of solutions to the hearth and taphole problems.

Many of the items developed to aid slag flow through the taphole in the 1958 to 1965 period, such as the taphole burner and slag breaker are incorpoorated into the modified gasifier. During the 1976 to 1978 period various types of hearth plate materials were tested in combination with different types of cooling coils and taphole inserts (see Figure 7). Refractory hearth plate materials tested include two compositions of silicon carbide, two compositions of aluminum oxide-chromium oxide, and an alumina-zirconia-silica material. Cooling coil materials tested include a Hasteloy-C & G at the taphole lip, a copper coil buried approximately 1/2" below the taphole lip and a copper coil imbedded in the bottom of the plate. Erosion occurred on all of the refractory hearth plates in areas that were not cooled sufficiently. A silicon carbide taphole insert installed in the "Jade" (aluminum oxide-chromium oxide) hearth delayed erosion of the taphole in one run, but after 12 hours of slagging the insert was gone and the plate severely eroded. A zirconium oxide insert in an "AZS" (aluminazirconium-silica) hearth plate failed after only one hour slagging time and the run was terminated because of high fuel bed loss.

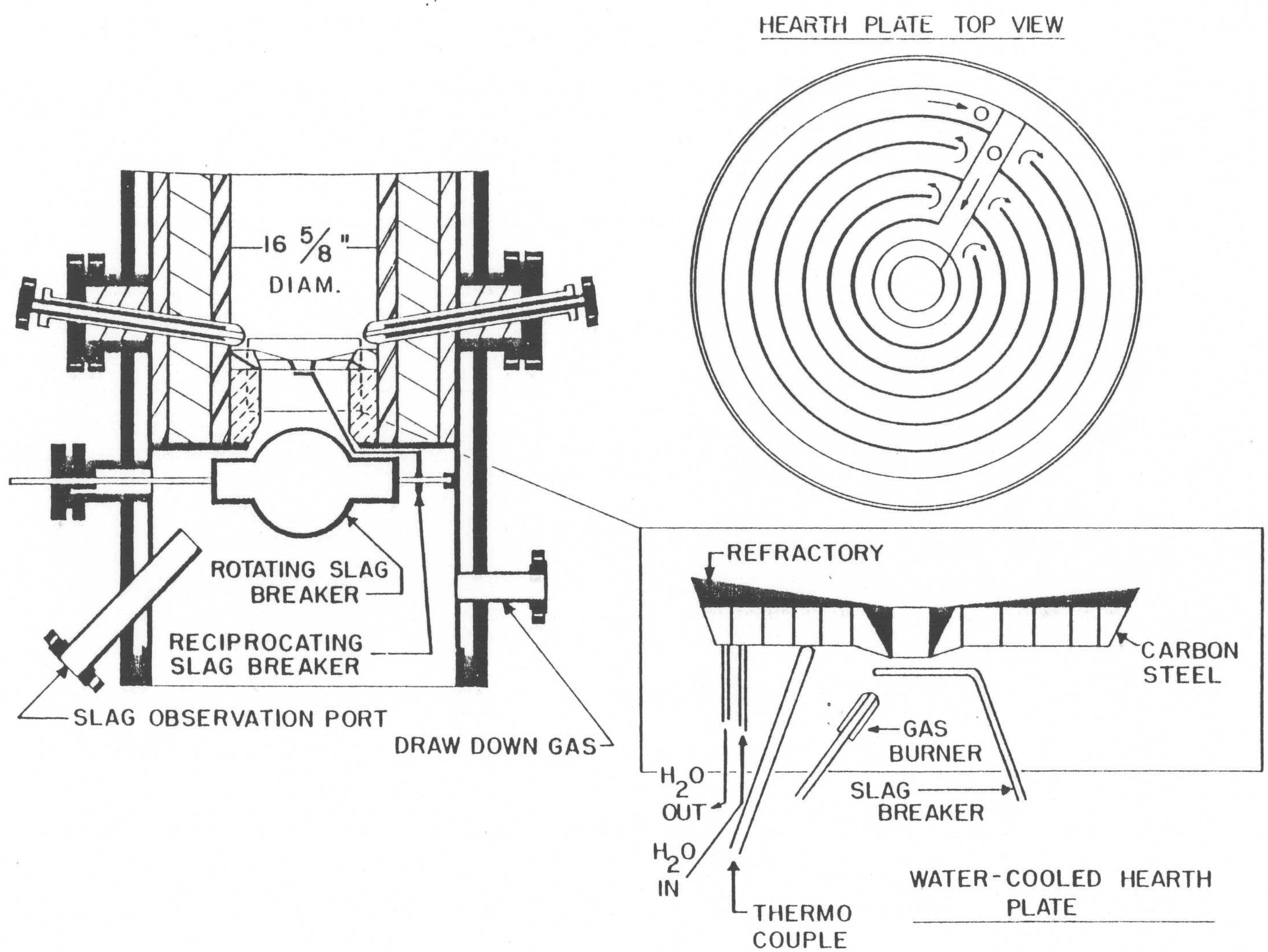

FIGURE 7. Hearth Design and Slag Flow Control System.
Source: Reference 2

Taphole Burner

The location of the burner, which is used to provide additional heat in the taphole area for initiating and maintaining slag flow, was shown in Figure 7. Past experience has shown that the use of the burner is very important for operation with refractory type hearth plates and essential for operation with water-cooled hearth plates. If heat is not provided at the taphole, the opening cannot be maintained and flow stops.

The major problem with the burner has been molten slag dropping on the burner tip which either destroys the burner or causes misalignment of the burner flame. A number of modifications to protect the burner from slag were tested with varying degrees of success. The present design delivers the methane-oxygen mixture to the tip through individual concentric tubes with mixing taking place at the burner tip. A high gas velocity was maintained to prevent the methane oxygen mixture from preigniting before reaching the burner tip. Development of moveable and multiple burners are planned to improve the operation of this critical device.

Slag Quench

The slag flows through the taphole into the water bath where it is quenched and granulated. The upper plug valve of the slag lock is normally open and is closed only during the slag discharging period. The water bath is fitted with a sight glass to observe the flow of slag from the taphole to the water bath. If stalactites form below the taphole, they can be broken off with a rotary slag breaker. Hot gases can be drawn from the gasifier through the taphole and released through the standpipe along with the quench water overflow.

General

AISI type 304 stainless steel is used for vessels, pipelines, valves, and heat exchanger tubing in contact with gas, condensate, and preheated oxygen and steam under pressure. After pressure release, carbon steel is used.[4] All gasifier flanges and piping flanges are either of the D-ring or Lens-ring type. It was reported that these had given little trouble either in the past or during the shake down operations. However, extreme care has to be used in handling either the D- or Lens-rings and thus, torquing procedures are highly important.

Emergency breathing apparatus and first aid materials are located at several landings in stairwells to facilitate access. The stairwell is separated from the gasifier by a concrete block wall. Heavy metal doors give access to the gasifier area at each level. However, the stairwell did not have a ventilation system at the time of our visit. Ventilation for the gasifier enclosure provided at each floor by an air discharge duct located at ceiling level across the length of the building and opposite the intake duct so that air flow would be across the gasifier and toward the corner of the room where access is most difficult (Figure 8). The system is designed to provide 25 air changes per hour. Discharged air is water-scrubbed and vented through a special heat recovery system designed to conserve energy.

3. Product Gas Quench and Scrubbing Train

(a) Process Description

Product gas is taken off the gasifier by a 1 to 1-1/2-inch I.D. horizontal line at floor level. To facilitate gasifying bituminous coals, a precooler has been installed in this line to reduce gas temperatures, before the gas enters the spray washer. Gas liquor from the spray washer is pumped through a gas liquor cooler and used as the liquor supply for the spray washer. Excess gas liquor flows by gravity to the tar-liquor separator located on the ground floor. Decanted tar and tar from the precooler can be stored in tankage or pumped with a Moyno pump to an incinerator. There are five 1000 gallon stainless steel sealed tanks vented through the roof. The

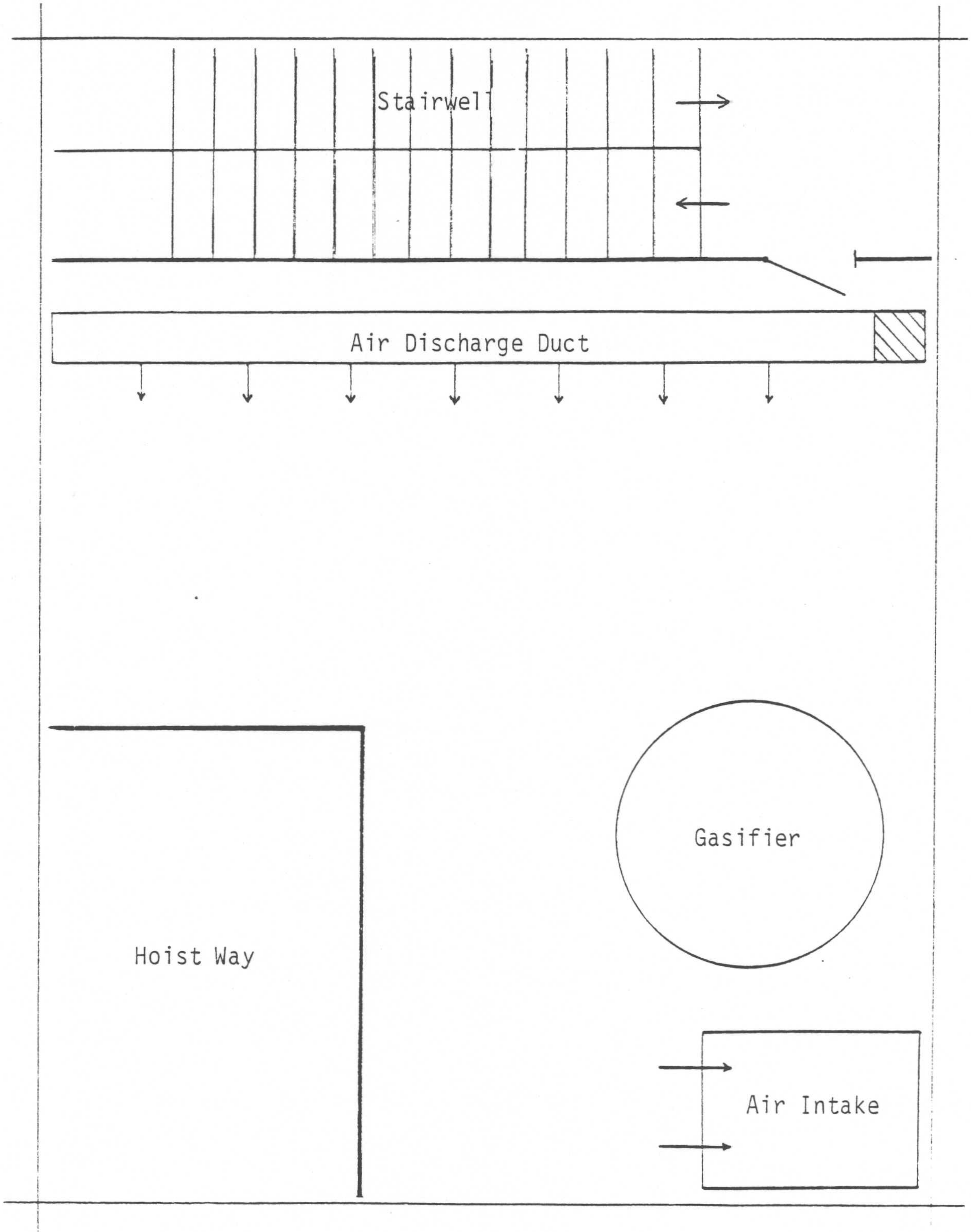

FIGURE 8. Schematic of Gasifier Ventilation System

incinerator is a Brulé, two-stage, gas-fired unit with steam injection and can be operated on fuel oil as an alternate fuel.

(b) Control Technology Assessment

The CTA study team anticipates that plugging problems will occur in the gasifier gas offtake line upstream from the precooler. Historically, when operating on lignite or coke, this line has not been a source of problems. However, off-gas temperatures have been low and lignite tars tend to be very light and fluid. Off-gas temperatures when operating on bituminous coal operations will be high and the tar is much heavier than lignite tar. The two conditions when linked are conducive to plugging.

Washed product gas is further cooled, scrubbed, then passed through a gas meter and flared. In a commercial facility, the flare would be used only for process upsets and normal venting of gases. The gas liquor circulation pump was a part of the original SFBG installation and has a good operating history. The pump shaft is sealed with packing to prevent process fluid leakage.

C. Lignite Liquefaction Facility

1. Process Description[15]

The 5-lb coal/hr continuous process unit in use at the GFETC liquefaction facility is designed for changing reactor modules and recycle flow patterns to control residence time distribution and turbulence. A slurry of minus 60 mesh lignite which contains about 30% moisture, is preblended by hand with solvent or recycle product slurry and pumped to a slurry hold tank. This tank is stirred by recirculation and suspended from a load cell for accurate feed rate determinations. A high-pressure piston pump delivering up to 25-lb/hr of slurry at pressures up to 6000 psi is used to charge the slurry into the system. A single-stage diaphragm compressor is used to compress the reaction gas to 6300 psi, after which it is regulated and metered into the system. Slurry and gas are heated independently and mixed at the entrance of the reactor.

The continuous stirred-tank reactor currently installed is a 1 gallon magnetically-stirred autoclave with two marine-type propellor stirrers circulating downward. The autoclave has a total volume of 231 in^3, but a dip tube limits slurry volume to about 150 in^3. At a normal flow rate of 10 lb slurry/hr the mean residence time of the liquid is approximately 30 minutes. The reactor, constructed of type 316 stainless steel, is designed for 5000 psig at 932 F (500 C). Normal operating pressure is 4000 psi. The slurry can be sampled directly from the reactor through a two-valve system which removes 3 ml per cycle.

Reacted slurry and gas leaving the reactor enter a high-pressure separation vessel maintained at about 572 F (300 C). The liquid level in this pressure vessel is controlled by a nuclear level detector which actuates the sequential operation of two valves. Since these pressure letdown valves release only 25 ml of slurry every 25 seconds, the sampling system works very reliably. The small volume removed during each cycle of valve operation results in only a slight fluctuation in pressure and gas flow.

The product recovery vessel acts as a low pressure flash tower, followed by a water-cooled light oil and water condenser. Noncondensable gases are vented through a positive displacement meter. Light oils and water are removed from the flash tower through a manually operated valve. A gas sampling port allows on-line analyses of the dissolved gas.

Gases and vapors from the primary separator pass to a condensate accumulator where the light oils and water are condensed by a water-cooled coil. The liquid level in this pressure vessel is monitored by a second nuclear level detector. Light oils are removed from the system through a series of two valves which are operated manually.

Tail gas at about 73 F (23 C) is let down through a back-pressure regulator and metered, and a fraction is analyzed by an on-line gas chromatograph. A flare has been installed to burn the off-gas.

2. Control Technology Assessment

The major concern at the GFETC liquefaction facility involves the potential of a gas explosion within the process units. Accordingly, all high-pressure equipment is installed in a barricade constructed of 1/2-inch steel boiler plate. The barricade is equipped with blowout windows and an independent ventilation system. The gas supply bottles, compressor, and high pressure accumulators are in a second barricade separate from the main building.[15] In the liquefaction facility ventilation is provided to maintain CO concentrations at acceptable levels and additionally to remove any hydrogen which may originate in small leaks. In addition, efforts are made to minimize exposure of operating personnel to coal liquids and vapors through the use of high rates of ventilation. The use of workplace monitoring, work practices, and personal protective equipment such as protective clothing, solvent-resistant gloves, and respirators, is discussed in the following sections of this report.

III. WORK PRACTICES

At the GFETC liquefaction and gasification facilities, the major hazard is safety related and involves the potential of a gas explosion within the process units. At the liquefaction facility, the danger of gas explosion is associated with the high-pressure units (main process area), such as the reactor and separators. Workers are protected by isolating the high-pressure units on three sides with 1/2-inch steel boiler plate and on the fourth side with a blowout wall. No fitting is tightened when there is pressure in the system. During leak detection, all electrical power to the heaters is cut off.[15] As added protection, the enclosure is off-limits to all personnel during process runs.

An additional benefit of these precautions is the isolation of potential emissions within the enclosure. These precautions are believed to be most effective in controlling the danger of gas explosions and potential exposures to process contaminants. However, the liquefaction facility is a bench scale operation and the practice of keeping workers out of the high-pressure area may not be feasible in a larger scale operation.

At the gasification facility the danger of gas explosion is adequately controlled through the use of engineering controls such as dilution ventilation and the lockhopper interlock system, etc. Details on these controls can be found in the Engineering Controls section of this report. As an additional safeguard, no worker is permanently stationed in the gasifier area, although entry is allowed for monitoring the process. These precautions also provide an effective means of controlling gas explosions and potential exposures to process contaminants.

The primary health concern at the two GFETC facilities is worker exposure to PNAs found in coal-derived material. The PNA hazard is considered to be relatively more critical at the lignite facility because of the higher molecular weight PNAs produced at this facility and because of the laboratory nature of this bench scale operation which requires more handling of the process stream. The health program at GFETC liquefaction facility was designed primarily to control skin contact with these PNA-containing materials. The GFETC Safety and Environment Office has the responsibility for the health program, which has been fully implemented at the liquefaction facility and is in the process of being integrated at the gasification facility. Good worker acceptance has been reported at the liquefaction facility and at the gasification facility for existing work practices such as the use of protective equipment.

The basis of the health program is the division of the process facilities into clean (uncontaminated) and dirty (contaminated) areas.

The clean areas are free of coal-derived material and include the offices, lunchroom, locker room, and restroom; the dirty areas delineate sections where coal-derived material is handled or stored and include the laboratory, operating areas, and connecting corridors.

The clean areas are maintained in an uncontaminated condition by a set of work practice guidelines which are designed to keep contaminated material out of the clean areas. These guidelines include:

- Removing contaminated lab coats or overalls before entering clean areas;
- Prohibiting the removal of contaminated articles or tools, and product material from the dirty areas;
- Disposing of waste materials properly and under the supervision of the Safety Office;
- Washing hands and face before proceeding to lunchroom, offices, or restroom; phosphate soap is recommended; and
- Changing to uncontaminated shoes before proceeding to clean areas or wearing disposable shoe covers while in contaminated areas; shoe covers are removed prior to leaving contaminated areas.
- In addition, the lunchroom is checked monthly with long wavelength ultraviolet light for PNA contamination and any contaminated areas are cleaned with tetrahydrofuran (THF) followed by detergent and water. Results of these inspections are dated and posted within the lunchroom.
- Guidelines for the dirty areas are designed to restrict access or to control worker skin contact with PNA-containing materials. Access to the dirty areas is restricted to authorized personnel only. A daily roster is maintained of workers entering the contaminated areas.

Housekeeping guidelines are also used to control skin contact with PNA-containing materials. The guidelines call for each worker within the restricted area to clean his own spills with tetrahydrofuran. At the liquefaction facility work surfaces were covered with disposable absorbent, plastic-backed paper to facilitate cleanup operations. These guidelines minimize work surface contamination by coal derived materials and thereby reduce worker contact. An inspection and decontamination procedure was being developed for the restricted area to identify and remove coal tar residues.

The Safety Office encourages daily showers at the end of the work shift during nonoperational periods. However, showers are required during process runs and in the event of spills or splashes which could lead to possible contamination of the worker with PNA-containing materials. In the latter case contaminated clothing is set aside for disposal.

Long wavelength ultraviolet light is available in the shower area for the inspection of hands for possible coal tar residues. These light sources are wall-mounted and designed to prevent their use in facial examination because of possible eye damage that may occur through misuse.

Additional provisions have been taken by the Safety Office:

- To minimize the accidental ingestion of PNA-containing materials; storage, consumption, or use of food, beverages, cosmetics, chewing material, and smoking material is prohibited in the dirty areas; and

- To reduce the level of PNA aerosols and solvent vapors in the laboratories, all procedures which may lead to the production of airborne contaminants are conducted in laboratory-type hoods.

IV. PERSONAL PROTECTIVE EQUIPMENT

Skin contact with PNA materials in the dirty areas is controlled through the use of protective clothing and equipment, housekeeping, and daily showers. Protective clothing and equipment requirements differ at the two facilities.

The liquefaction facility is a bench scale operation and requires the use of safety glasses and a lab coat or smock within the dirty areas. The gasification pilot plant guidelines require hardhats, safety shoes, and safety glasses in these areas. All items are supplied by GFETC.

Gloves are not required at either facility, but their use is encouraged. The Safety Office has reported better worker acceptance with this policy rather than with a mandatory policy. Two types of gloves are available with use being dictated by the material being handled. Rubber gloves are used as all-purpose gloves in the handling of most materials at these facilities; however, these gloves are penetrated by tetrahydrofuran. Polyvinyl acetate gloves are used with coal tar and tetrahydrofuran; but, because these gloves dissolve in water, their use is limited to the handling of water free materials.

Other protective equipment available to the workers includes ear plugs and ear muffs, disposable dust masks, respirators for organic solvents, and face shields. The use of any of this equipment is left to the discretion of the worker. Ear plugs and muffs and disposable dust masks are used principally in the coal preparation and boiler areas of the gasification facility. The respirators are used primarily as protection against solvents in the enclosed slurry mix area of the liquefaction facility. A respirator program including maintenance and storage is operated for the two facilities, under the supervision of the Safety Office.

Barrier creams have been used as a substitute for gloves at the liquefaction facility. However, these protective agents are not as effective as gloves in providing the necessary protection. It was found that workers using the barrier creams were not as careful as other workers in the handling of the coal tars thereby increasing the chance of skin contact. In addition, the barrier creams were believed to act as a carrier of the coal tar material.

V. MONITORING

A. Worker Exposure

There are about 80 employees in the GFETC programs; however, only a minority of these workers are potentially exposed to process contaminants at these two facilities. Since the liquefaction facility is a bench-scale, laboratory research facility, the number of workers in the facility fluctuates depending on need. During the site visit there were six personnel within the process area monitoring the equipment and conducting laboratory analyses.

The gasification facility has a more stable workforce. There are two shifts with 12 workers per shift at all times. Of the 12 shift workers only 6 are in the gasifier and coal handling areas and thereby potentially exposed to the process contaminants. The other workers are stationed in the control room or utility areas which are separate from the process area.

The monitoring of worker exposure by GFETC to process contaminants is in the development stage. Current work was limited to the liquefaction facility and included direct-reading instrumentation and sampling for benzene-solubles. Direct-reading instrumentation included Draeger tubes for sulfur dioxide, carbon monoxide, and chlorinated solvents; carbon monoxide badges; Kitagawa detector tubes for carbon monoxide, hydrocarbons, hydrogen sulfide, methane, and ammonia; and long-term Kitagawa detector tubes for carbon monoxide, hydrogen sulfide, and ammonia. Actual data were not available. However, results for the direct-reading instruments were reported to indicate low levels within the facilities suggesting that these compounds were being adequately controlled. Benzene-soluble results showed non-detectable levels but results are considered inconclusive because of inadequate sample volumes.

Noise and ionizing radiation surveys were also conducted within the last three years at the two GFETC facilities. The noise survey indicated that the gasifier boiler room with a level of 92 dBA and the gasifier with a level of 85 dBA to 90 dBA may be potential problem areas. The coal handling facility for the gasification plant was not surveyed but is considered to be another area of concern. Since workers are in these areas for short periods of time, ear plugs and muffs were used to control exposure. However, poor worker acceptance of these protective devices have led the Safety Office to consider the installation of insulation and baffles, especially in the boiler area.

Gamma exposure from the 11 nuclear level gauges present at these facilities were tested using geiger counters and dosimeters. Results indicate that workers were exposed only to background levels of gamma radiation.

B. <u>Medical Program</u>

GFETC has a detailed program designed to establish a baseline for workers at the two facilities. The pre-employment physical is conducted by an outside physician but is similar to the annual physicals given in-house. The annual physicals are provided to everyone over the age of 45 or to those who are exposed to coal tar. For others the physical is given every two years.

The physical consists of:

- audiometry
- visual acuity
- pulmonary function tests (FEV-1, PVC, % FEV/FVC)
- chest x-rays
- resting electrocardiogram
- complete blood count
- serology
- urinalysis

Other tests are provided under the directive of the physician.

The program has been in progress for 3 years. No occupational related abnormalities were reported with the exception of an ear infection caused by dust irritation. The program is too new to draw conclusions with regard to possible adverse effects caused by working in these facilities.

VI. CONCLUSIONS AND RECOMMENDATIONS

- The major hazard at both the Liquefaction and Slagging Fixed-Bed Gasification Facilities involves the potential of a gas explosion. At the liquefaction facility, workers are protected by isolating the high-pressure units on three sides with 1/2-inch steel boiler plate and on the fourth side with a blow-out wall. In addition to providing high dilution ventilation rates, the enclosure is off-limits to all personnel during process runs. These precautions are believed to be most effective in controlling the danger of gas explosions and potential exposures to process constituents.

- The danger of gas explosion at the Slagging Fixed-Bed Gasification Facility is controlled primarily through the use of dilution ventilation of the gasifier building at 25 air changes per hour. The CTA team anticipates emission problems around the lockhopper system. Coal dust emissions are likely to occur when the lockhoppers are filled. In addition, sealing and wear problems may occur in the lockhopper valves and in the rotary feeders. Rotary feeders in low pressure service have been a source of gasifier emissions.

- A nitrogen sweep (purge) used to remove particulate matter from the valve seats in the knife gate valve is an important feature in valve designs of this type.

- If the mounting for the installation of a stirrer into the gasifier uses a hand-tightened packed seal around the stirrer shaft, the potential for intermittent gasifier product gas leakage and significant shaft scoring in the sealing area, should be anticipated. Regardless of the type of mounting and seal, the area should be monitored to determine emissions, if any.

- The modified coal storage and handling system has resulted in seven transfer points where coal dust could be generated. While only one transfer point is located within the coal preparation enclosure area, there were plans to increase the air flow from 30 to 60 air changes per hour to reduce exposure to dust. A grass-roots coal conversion facility would be better able to control dust generation through proper design of the handling system. However, the potential exists for reclaiming old handling systems for incorporation into a new handling system. Unless properly designed, this interface could result in loss of fines, dust generation, and erratic coal movement characteristics.

- The potential for coal dust explosions exists when finely ground coal is handled. Means to prevent explosions, such as inert atmospheres in storage and grinding equipment and avoiding dust accumulations on surfaces, should be considered.

- Two procedures used in the bench and pilot scale operation to prevent worker exposure to hazards are high ventilation rates to remove fugitive emissions and exclusion of personnel from certain areas. While these are suitable for small scale operation, they cannot be readily applied to commercial facilities. Alternatives to these procedures are needed.

- Barrier creams as substitutes for gloves may have application with respect to specific chemicals, however, the wide range of compounds found in coal-derived materials makes their usefulness questionable. Gloves resistant to penetration by coal liquids should be required.

- Flare design specification should be established. For a commercial facility the flare or flares will not only handle normal vented proces materials, but in the event of catastrophic failure of plant equiment may need the capability of handling full process stream flows for short times.

- A leak detection program to evaluate the performace of shaft seals, particularly those exposed to extreme conditions of temperature, pressure, or corrosive or abrasive materials, should be considered.

- Ventilation is provided to maintain CO concentrations below the threshold limit value in both facilities. In addition, it is to remove H_2 escaping from small leaks in the liquefaction facility. Values reported are design rates.

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