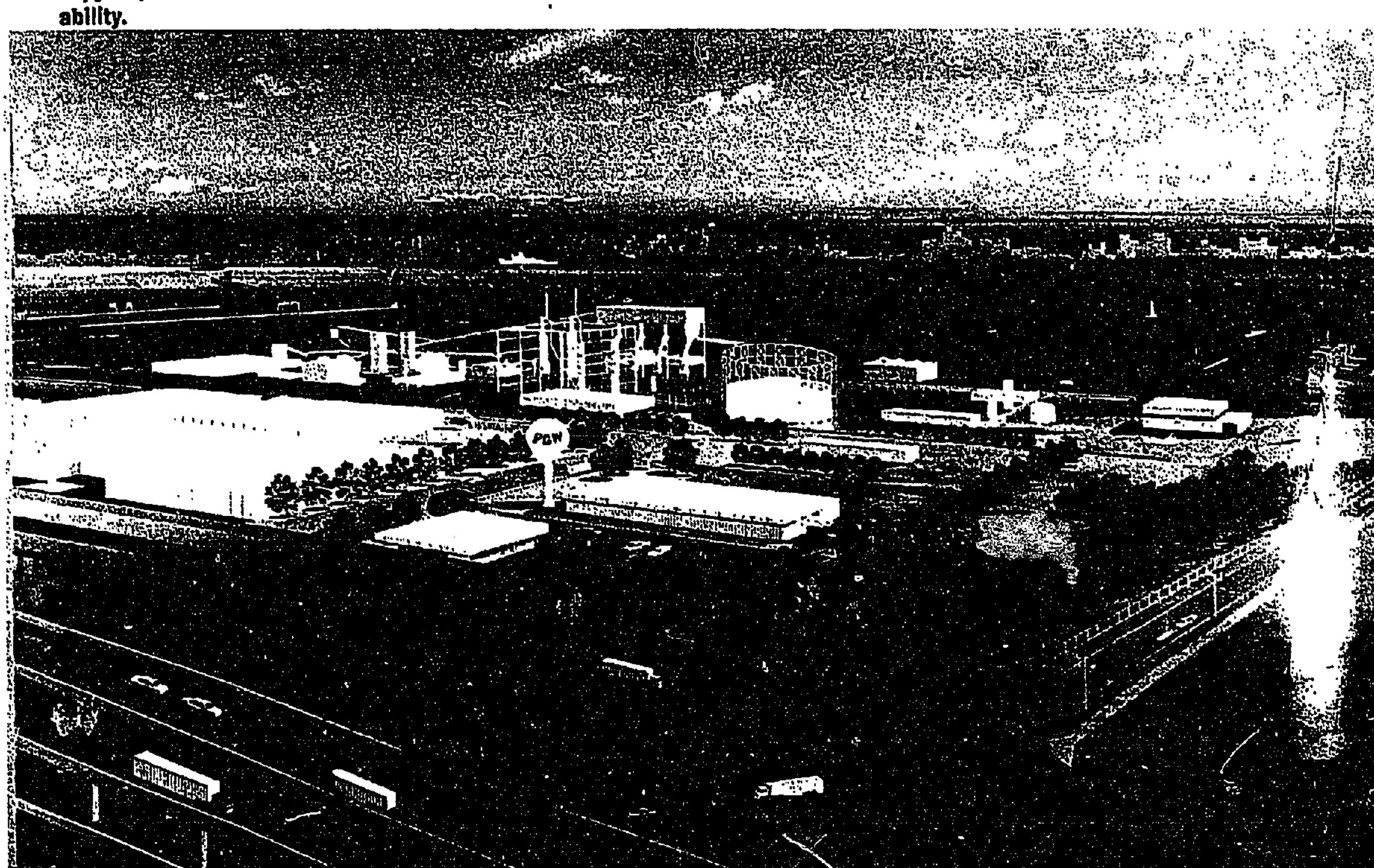
PLANT DESIGN

PHILADELPHIA GAS WORKS

MEDIUM Btu COAL GASIFICATION PROJECT

DECEMBER 1981



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PLANT DESIGN

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MEDIUM-BTU COAL GASIFICATION PROJECT

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Under

DOE GRANT NO. DE-FG01-80RA50371

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1.0 INTRODUCTION

The major objective of the feasibility study funded under DOE Grant No. DE-FG01-80RA50371 was to produce a definitive design and cost estimate for the PGW Coal Gasification Project, thereby producing design and economic information in sufficient detail to enable PGW to make a "go" or "no-go" decision on the project.

This report is a compilation of the design effort, beginning with a review of the previous feasibility study under NPI RA-21 with a discussion of the rationale leading to the overall plant design effort.

1.1 PROJECT BACKGROUND

The Philadelphia Gas Works (PGW), a municipally owned gas utility, distributes gas for residential, commercial, and industrial uses to about 540,000 customers within the limits of the City of Philadelphia.

Philadelphia Gas Works has experienced difficulties in securing a sufficient supply of natural gas to meet the requirements of all who would prefer to use this fuel. Restrictions have had to be placed on the acceptance of new industrial customers. This inability to project a reliable, sufficient, and moderately priced supply of natural gas for the future contributed to Philadelphia's difficulties in retaining the present industrial base as well as attracting new companies to the area.

At the same time, oil users are encountering rapidly escalating fuel costs, and uncertain about the future availability of low sulfur fuel oil. The situation is also complicated by legislation aimed at reducing oil consumption and by difficulties in assuring a long term supply of natural gas. The result is a threat to the continued well-being of industrial activity in Philadelphia.

In view of the potentially serious impact that the lack of a reliable competitive energy supply will have on the City of Philadelphia, PGW embarked on a search to develop alternate sources of fuel for industry within the city.

At the present time gas utility companies are not operating coal gasification plants in the United States. Although PGW can draw upon valuable past experience, technologies and economic conditions have changed significantly since coal gas was last distributed by PGW in Philadelphia. As a result, many issues had to be investigated prior to committing large amounts of capital to the implementation of a central coal gasification plant.

An assessment of a central coal gasification plant was initiated in November 1979 by PGW under a grant provided by the Department of Energy through NPI RA-21. The objective of that study was to assess the technical and economic feasibility of producing, distributing, selling, and using coal gas for industrial applications in Philadelphia.

The study, which was completed in October 1980, served as the basis for the PGW Coal Gasification Project. It resulted in the identification of: (1) users for the gas, (2) selection of a commercially proven gasification process, (3) a conceptual system design and cost estimate, and (4) a financial analysis. The specific tasks and their results are summarized on Table 1-1.

As a result of the Conceptual Design and Feasibility Study (or Phase I), PGW determined that the Coal Gasification Project can serve as a point of industrial growth and stability in Philadelphia. PGW looks upon this project as making a significant contribution to the energy supply of Philadelphia and has entered into Phase II of the project which is the definitive design stage.

TABLE 1-1

REVIEW OF PHASE I

o Market Analysis	Contacted 160 users throughout the city. Resulted in design basis concentrating on major users along Delaware River.
o Define Transmission Options	Computer analysis of various distribution systems demonstrated feasibility of isolated system for transmission of low-medium-Btu gas. A segregated system dedicated to industrial customers will ensure protection from interruption by residential market.
o Site Selection	Reviewed suitability of 16 sites throughout the city. Concluded that three sites on Delaware River are most suitable.
o Process Selection and Conceptual Design	Evaluated six different coal gasification processes. Selected the Koppers-Totzek for conceptual design for plant to produce 20 billion Btu per day of medium Btu gas.
o Retrofit Assessment	Evaluated the feasibility of producing LBG versus MBG. Concluded that LBG is feasible for large users with some derating, but MGB is most suitable for distribution to variety of users. Customer could take advantage of retrofit tax credits.
o Financial Analysis	Conducted detailed financial analysis for municipal and private ownership scenarios. Concluded that MBG is competitive with No. 6 fuel oil.

1.2 PROJECT OVERVIEW

The overall design and construction schedule for the PGW Coal Gasification Project is shown in Figure 1-1. It can be seen that the Conceptual Design and Feasibility Study was completed in October 1980 and the Definitive Study, or Phase II, was initiated immediately thereafter. The Phase II effort consists of a review of Phase I, a determination of the market for medium-Btu gas, a definitive engineering design and cost estimate, and a financial-risk analysis. Phase II also includes a determination of coal availability, an assessment of environmental impact, and an engineering/construction schedule. The result of Phase II is a Business Plan with which PGW can approach the financial community and users of the gas for support to proceed with the project.

If PGW proceeds with the project, detail design will begin in early 1982 with subsequent procurement and construction activity leading to plant start-up in early to mid-1985. Commercial operation and production of gas is planned for late 1985.

1.3 APPROACH TO DEFINITIVE DESIGN

The objective of this work is to develop a definitive design and cost estimate for the gasification system selected for conceptual design. The level of detail in this phase reflects the application of approximately 10 to 15 percent of the engineering for the project.

The objectives of this phase are accomplished by first establishing process criteria for the design. In transition from conceptual to definitive design, process suppliers in areas such as gasification and desulfurization will be requested to supply coal- and product gas-specific heat and material balances. The net result is a process description with process flow drawings to be used as the basis for design.

PHILADELPH GAS WORKS
COAL GASIFICATION PROJECT
OVERALL DESIGN/CONSTRUCTION SCHEDULE

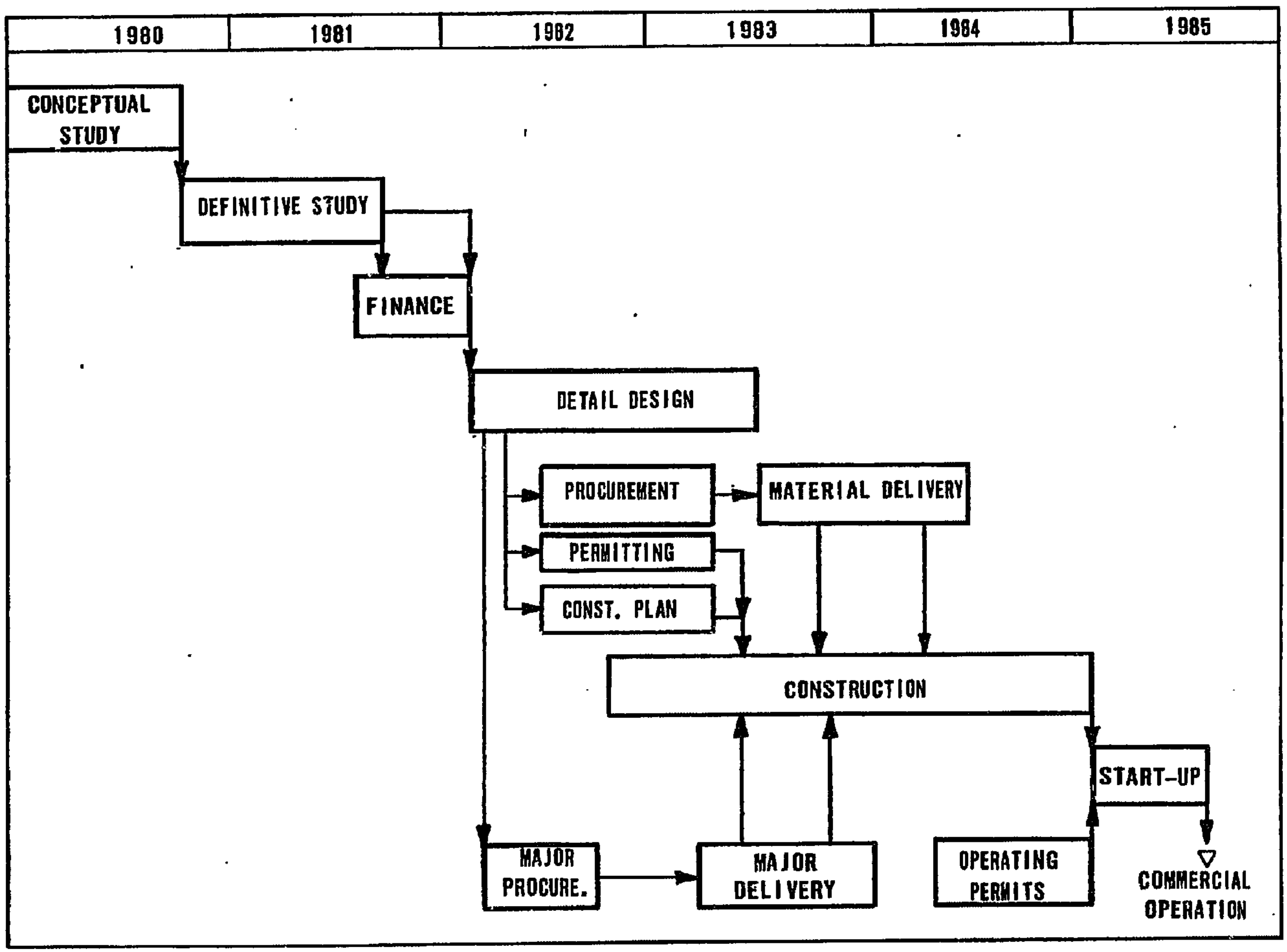


FIGURE 1-1

The definitive design entails developing a list of equipment and preparing specifications for the major items and evaluating the quotations received from vendors in sufficient detail to select the best offerings for estimating purposes. The cost estimate and the design then serves as the basis for the decision to enter into the detail plant design and construction phases.

Task 1.0 of Phase II was reserved to review Phase I and to establish criteria for definitive design. Included in this task were:

a. Review of projected fuel requirements,
b. Description of site,
c. Review market penetrations,
d. Review feedstock supply and byproduct disposition,
e. Review conceptual design of plant and distribution systems, and
f. Review overall conceptual design.

The result of Task 1.0 was an assessment of the project and an establishment of criteria for the definitive design.

1.3.1 Market and Fuel Use Considerations

The three major energy users that were identified in Phase I were contacted individually to review Phase I and to discuss the competitive position of MBG with alternative fuels.

Each of these companies was given a copy of the Phase I Draft Report and meetings were held with each on separate days during the week of November 17, 1980. The pertinent information discussed at these meetings was a review of the Phase I effort and the resultant economic analysis. Fuel price comparisons for Philadelphia were developed in current dollars and were compared with the projected costs for MBG. The gas users were advised of the effort involved in Phase II of the Project and that PGW intends to develop a negotiable cost figure for MBG by August 1981. The users were requested to indicate their interest and to provide further information with respect to load characteristics and future requirements.

Results of these meetings are summarized as follows:

- Rohm & Haas - Indicated that they are evaluating several options, one of which is MBG. They are the only company of the three that can economically consider conversion to direct firing of coal. They agreed to maintain interest in the MBG alternative as requested, and would advise immediately if it were removed from consideration.

- Allied Chemical - Indicated that direct firing of coal was still an option but it did not appear viable. Other offerers of fuel gas from coal had been notified by Allied that they were not being considered in deference to PGW. Allied agreed to maintain interest and would provide load information as requested.

- National Sugar - Stated that the results of PGW's coal gasification study would be evaluated in comparison with National's future alternatives. They did not consider direct firing of coal to be an alternate because of the large capital costs. They also agreed to maintain interest and would provide load information as requested.

A furcher penetration of the MBG market in Philadelphia was conducted by exploring the interest of the following companies and agency:

a. Publicker Industries,
b. Amstar Sugar,
c. Philadelphia Navy Yard, and
d. Newman Paper.

As with the three major users, copies of the Phase I Draft Report were distributed to each and a single meeting was held with each group represented. The results of that meeting indicated that insufficient interest in MBG exists to warrant distribution south of National Sugar. Newman Paper expressed considerable interest and was included as a point of distribution for the project.

Conclusions reached from the user analysis in these Subtasks are:

- Interest expressed by the three major users and Newman Paper is sufficient for the basis of a distribution system.
- The total connected load of these users is approximately 20 billion Btu per day.
- The number of gasifiers required to supply these customers is in excess of one, and considerably less than three. Therefore, the plant design will be based on two GKT gasifiers.
- Each user will be expected to maintain a dual fuel burner capability, probably using No. 6 fuel oil as the backup.

1.3.2 Site Considerations

The conceptual design of Phase I identified the former gasifier site of PGW as the site for definitive design. This selection was made after determining the feasibility of locating the plant at various sites within the city and along the Delaware River. Early in Phase II, the PGW site was precluded from consideration as a plant site in view of its potential use for future peak shaving facilities by PGW. It became necessary to identify and evaluate alternate sites for the gasification plant.

The following alternate sites were identified:

Eastern Gas	Not acceptable on the basis that siting would require purchase and demolition of the Philadelphia Coke Works.
Northern Metals	No longer available.
Kerr-McGee	No longer available.
Riverside	This site was the second choice in the conceptual study. At the time of Phase II evaluation, ownership and availability was not clear, which necessitated review of additional sites.
Port Richmond Coal Terminal	Two parcels of land available from Conrail on a long-term lease basis. Suitability of one parcel was determined.

1.3.2.1 Evaluation of the Port Richmond Site

The Port Richmond site, currently owned by Conrail, is located between Conrail's Port Richmond rail yard and Allegheny Avenue. The site would be available from Conrail on a 50-year lease basis.

The Port Richmond site essentially consists of four piers (A, B, C, and D) and a portion of the rail yard. The site is dissected by Shore Road, Conrail's private road. In addition, Conrail requires a right-of-way for two Philadelphia Belt Line railroad tracks which cross the property below Shore Road.

To implement the proposed plant layout it is recommended that the waterways between Piers A, B, C, and D be totally filled with an appropriate fill material. An attempt to partially fill the pier waterways would result in crowding of the process units which could lead to safety and layout problems in the detail design phase of the project.

The total volume of fill required between the piers (assuming an average depth of 30 feet) is approximately 400,000 yd^3. Assuming a very low cost of $10 per yd^3 for the fill operation, the total cost to fill the pier waterways is four million dollars.

From a technical viewpoint the only advantage of the Port Richmond site is the presence of the existing rail yard for coal unloading. The disadvantages of the site, however, are numerous and are listed as follows:

a. The pier waterway fill operation is not economically feasible compared to the cost of the alternative Riverside site.

b. The ability to obtain permits from the EPA, Department of Interior, and the U.S. Army Corps of Engineers for the fill operation is uncertain.

c. The right-of-way for the Philadelphia Belt Line railroad track and Conrail's Shore Road reduce the usability of the site. In addition, safety and insurance problems may result due to these rights-of-way.

d. The demolition of the warehouse on Pier B and the boat salvage increase the cost and time required for site preparation.

As a result of the above evaluation it was recommended that the Port Richmond site be dropped as a possible gasification plant site.

The second site in the Port Richmond yard was not considered because Conrail has entered into negotiations with a third party for lease of that site.

1.3.2.2 Evaluation of the Riverside Site

The site is located in the northeastern section of Philadelphia, south of Richmond Street and between Dyott and Cumberland Streets. The location has direct Delaware River frontage with a shipping berth on the eastern side of the site.

The site is located adjacent to the Conrail's Port Richmond rail yard. As a result, the site should have easy access to existing rail lines.

Based on the assumed rail yard configuration and the area requirements for the major process units, the site appeared to be feasible.

From a preliminary layout viewpoint, the site allows sufficient area for plant roads, conveyor systems, drainage ditches, pipe racks, and cable trays.

The owners of the Riverside Site were contacted to enter into negotiations for a one year option to purchase the site. In view of the limited availability of alternate sites for this project, the definitive design proceeded under the assumption that the Riverside Site is available.

1.3.3 Coal Considerations

In Phase I, a typical Pittsburgh No. 8 coal was used as the base coal in conceptual design. The base coal was only generic in that it was not identified with any specific coal suppliers and, as a consequence, some key data such as coal costs, availability, etc. were not firmly established.

In Phase II, a search for a design coal with identifiable coal suppliers was conducted to rectify these uncertainties.

The coal search was initiated by developing a design coal specification, followed by prescreening of coal companies in the five-state area, including Pennsylvania, West Virginia, Ohio, Kentucky, and Maryland. Letters of solicitation for coal data/information were sent to 15 potential coal suppliers, five of which responded. The coal data, as provided by the coal companies, were then analyzed and compared, and the impacts on the plant performance plant economics evaluated. A detailed description of the coal search and a summary of the evaluation is presented in Appendix A.

The results of the initial evaluation showed that the C&K coal is the preferred design coal in that it has the advantage of yielding relative potential savings compared to a somewhat arbitiary cost for Pittsburgh No. 8. It also has the advantage of abudant coal reserves and large production rate to meet the PGW gasification plant requirements.

In order to procede with the definitive design in a timely manner, the heat and material balances for the gasification process were based upon the analysis of Pittsburgh No. 8 which is very similar to the anlaysis of C&K and several other coals under evaluation. The supplier of the gasification process indicated that these similar coals would all produce essentially the same balances of this level of analysis, and that precise performance guarantees could not be determined without full commercial testing of the specific design coal.

1.3.4 Process Considerations

The process selection criteria for this project was based upon the requirement to use commercially proven processes. The commercial viability of this plant required that the level of technological risk identified with the process be minimal. Therefore, it was imperative that the processes making up the complete system be selected from those which are commercially proven and are guaranteed by a process supplier.

1.3.4.1 Gasification System

The Koppers-Totzek (KT) Entrained Bed gasification process was selected and Gessellschaft for Kohle-Technologie mbH (GKT) of West Germany is supplying process information. Since the start-up of the first KT plant in 1951, more than 50 gasifiers have been delivered to 14 different clients to produce synthesis gas, primarily for ammonia production. The daily ammonia capacity of KT plants in operation is in the range of 4,000 ton per day, which represents more than 90 percent of the world's coal-based ammonia production.

By experience gained in actual operation, the commercial capability of the KT process has been proven. A range of feedstocks can be gasified, from lignite to anthracite as well as petroleum coke, charcoal, tars, and heavy residues.

Feedstocks of high ash and/or sulfur content, which are not acceptable for conventional processes because of technical or environmental aspects, can be easily utilized by the KT process. Unlike fixed bed and fluidized bed processes, no limitation regarding size distribution exists with the KT process, and the entire mine output can be utilized. In general, critical design considerations with respect to ash or coking properties of the coal are not existent.

1.3.4.2 Desulfurization System

Other processes selected for this plant were also judged on proven commercial background. The most pertinent of these is the desulfurization plant, for which the Stretford process was selected.

The Stretford process uses reliable, rugged, simple technology for almost total removal of H_2S from gas streams. There are 31 successful Stretford units operating around the world. These involve a variety of applications: town-gas, coal gas, SNG, coke-oven gas, and natural-gas processing.

This proprietary process has been developed by W.C. Homes & Co. Ltd., England, a part of Peabody Galion Corporation of New York. This process is now available for wider use in the U.S. with four installations already operating successfully in St. Louis, Honolulu, Ontario, and York, Pennsylvania. The sulfur tonnage handled by individual Stretford plants has grown over the past 14 years from 200 lb per day to a capability of 30 long tons per day in a single-train. PGW is also using the Stretford process for desulfurization of gas produced in the 60 MMCFD synthetic gas plant.

1.3.4.3 Reliability Factors

Reliability and on-stream factors were considered in completion of the plant design. The plant will be operated as a baseload facility with a 50 percent turndown capability on weekends and a two or three week scheduled shutdown per year. It is anticipated that routine maintenance will be scheduled on dual train equipment for weekends. The stream factor of all equipment in this plant is rated above 90 percent. This is either stated by the process supplier or is specified in the design.

1.3.5 Critiera for Definitive Design

Having given due consideration to the information generated in the review of Phase I, an updated conceptual plant design was developed. This design is presented in a topical report entitled PGW Conceptual Plant Design Review, and is presented as Appendix I.

2.0 BASIS FOR PROCESS DESIGN

2.1 PLANT SITE

Riverside Industrial Park, the 43-arce site for the PGW coal gasification project is located in Northeast Philadelphia along the Delaware River, west of Conrail's Port Richmond rail yard and halfway between the Betsy Ross and the Benjamin Franklin Bridges. It is the only available site of this size in the city of Philadelphia which is designated as industrial zone and is near major industrial users of the medium-Btu gas to be generated by the gasification facility. The cleared and nearly level site consists of fill and rubble and remnants of piers and dry docks which existed during World War II when the site was known as the Camps Ship Yard. The L-shaped site is bordered to the northeast predominantly by water adjacent to Pier 20, to the southwest predominantly by water adjacent to Pier 75, to the northwest predominantly by Beach Street, and to the east by the Delaware River. Elevation of the site is 10.0 feet (USGS datum), the same as the 100 year flood level.

2.2 PLANT SIZE

The plant size of the coal gasification facility is nominally 20 billion Btu per day based on the higher heating value (HHV) of the product medium-Btu gas, which will be distributed to industrial users through a gas distrubition system at 35 psig. Based on the projected gas demand, the gasification facility is to operate at full load during the weekdays and at half load during the weekends (Saturday and Sunday). On a weekly basis, therefore, the expected on-stream factor is 6/7th or approximately 85.7 percent. However, the annual on-stream factor will be about 80 percent, taking scheduled and unscheduled shutdowns into account.

TABLE 2-1

COAL CHARACTERISTICS

Rank Classification	Bituminous	
State, County	PA, Greene	
Bed Name & Number	Pittsburgh No. 8	
Proximate Analysis, Wt. %, A.R.		
Mositure (seam)	4.58	
Volatile Matter	37.33	
Fixed Carbon	50.26	
Ash	7.83	
TOTAL	100.00	
High Heating Value, Btu/lb		
As Received	13,442	
Moisture & Ash Free (MAF)	15,330	
Ultimate Analysis, Wt %, Dry		
Hydrogen	5.28	
Carbon	77.71	
Nitrogen	1.42	
Oyxgen	4.74	
Sulfur	2.64	
Ash	8.21	
TOTAL	100.00	
Free Swelling Index (FSI)	7.5	
Ash Fusibility Temp., ° F		
	Reducing	Oxidizing
Initial Deformation	2093	2444
Softening	2138	2480
Fluid	2156	2516
Hardgrove Grindability Index	64	

2.3 COAL FEED

The design coal for the facility is a typical Pittsburgh NO. 8 coal, the characteristics of which are shown in Table 2-1. Although the generic properties of this coal were used for the basic process design and performance calculations, many other coals can also be used as feed, since the gasifier can handle a wide range of coal types (see Appendix A). The feed coal (2-inches by 0-inch) will be brought into the plant site by unit trains via Conrail's Port Richmond rail yard. An approximately 60-day supply of coal will be stored on-site.

2.4 GASIFICATION PROCESS

The GKT process as offered by Gesellschaft für Kohle-Technologie of Essen, West Germany, is used as the gasification process in the present design. The GKT process, which was previously known as the Koppers-Totzek process, was selected during Phase I (Conceptual Design) of the current project.

The GKT gasifier is an entrained-bed, oxygen blown unit. It is flexible in coal feed types and does not reject coal fines nor generate tars, oils, and phenols. When fed with an Eastern bituminous coal, the carbon conversion efficiency of the gasifier is in the range of 88 to 95 percent. For the present design, a conservative figure of 88 percent has been recommended by GKT (in conjunction with the Pittsburgh No. 8 design coal) to provide a margin of flexibility to account for variations in coal feed. Furthermore, a scheme of recycling fly ash (containing unburned carbon) to the gasifier is also included in the present design which will provide an additional degree of carbon conversion efficiency.

For the present design basis of a nominal 20 billion Btu per day plant, two four-headed gasifiers have been proposed by GKT. The GKT battery limits will include two trains of gasifier with ancillary equipment, waste heat recovery boilers, gas clean-up equipment, and a common gas holder, electrostatic precipitator, and wash water treatment unit. All other units interfacing with the GKT units are made compatible with the gasification process as offered by GKT.

2.5 SULFUR REMOVAL AND RECOVERY

The raw gas from the GKT plant will be desulfurized in a Stretford process, which was also selected during the Conceptual Design Phase. The Stretford plant is designed to remove the bulk of sulfur compounds in the raw gas such that, when the final clean gas is burned in industrial boilers, the emission will comply with the limit (500 ppmv SO_2 or 0.86 lb SO_2 per 10^6 Btu) set by the City of Philadelphia.

The Stretford process is a direct conversion process which is capable of removing H_2S present in the raw gas and subsequently converting it to a recoverable elementary sulfur. In the present design, 27.2 tons per day of sulfur is recovered as high quality molten sulfur, which is salable at about $110 to 125 per ton at the plant gate. Purge liquor associated with molten sulfur production will be treated on-site so that there will be no hazardous discharge from the sulfur removal and recovery units.

2.6 MAKEUP WATER SUPPLY

Approximately 1.4 million gallons per day of plant makeup water is required for process system uses. Economics favor providing an on-site river water treatment system to supply process system uses, in lieu of purchasing treated water from the City of Philadelphia Water Department (approaching $0.75 per 1,000 gallons). For potable water supply and sanitary purposes, City of Philadelphia water is the exclusive source.

2.7 SOLID WASTE DISPOSAL

The coal gasification facility will produce two types of solid wastes - granular slag and fine fly ash mixed with unburned carbon. Approximately 30 percent of the coal ash is recovered as quenched molten slag from the gasifier bottom and the remaining 70 percent (entrained in the raw gas) is recovered in the form of a wet filter cake from a downstream gas cleanup system. The high temperature oxidation process results in these materials being stabilized and free of organics. They are suitable for disposal in a land fill.

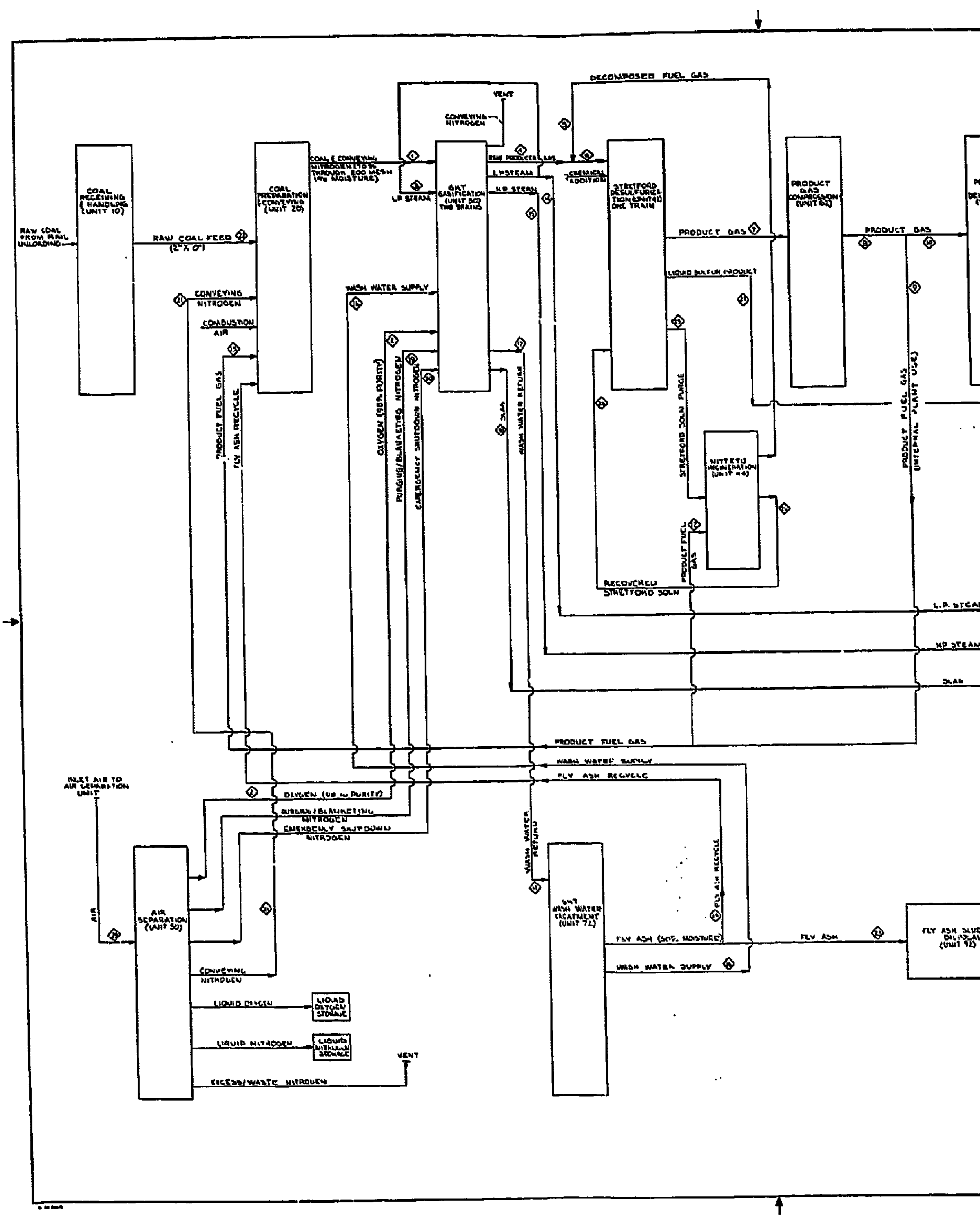
In order to alleviate solid waste disposal problems, and also to reutilize some of the carbon contained in the fly ash filter cake, recycling of up to 50 percent of the fly ash cake to the gasifier is incorporated in the present design. The quantity of net solid wastes that must be disposed of varies with the recycling rate - at 0 percent recyle, it is 378 tpd (33 tpd of slag and 345 tpd of fly ash) and at 50 percent recycle, it is 250 tpd (48 tpd of slag and 202 tpd and fly ash), or only two-third of the non-recycle case.

3.0 PROCESS DESCRIPTION

3.1 OVERALL PROCESS DESCRIPTION

The preliminary design completed during Phase II of the PGW Coal Gasification Project is based on the gasification process offered by GKT. The GKT Gasification Unit consists of two parallel gasification and clean-up trains. No spare trains are provided in the present design. An overall process block diagram of the PGW gasification plant is shown in Figure 3-1. The gasification plant basically consists of the following units:

Unit No.		
10		Coal Receiving and Handling
	15	Coal Dust Supression
20		Coal Preparation and Conveying
30		GKT Gasification
40		Sulfur Removal and Recovery
	42	Stretford Desulfurization
	44	Nittetu Incineration
50		Air Separation
60		Product Gas Handling
	62	Gas Compression
	64	Gas Dehydration
70		Water Treatment
	72	GKT Wash Water
	74	Waste Water
80		Utilities
	81	Cooling Water
	82	Steam, BFW, and Condensate Return
	83	Firewater
	84	Plant & Potable Water
	85	Plant and Instrument Air
	86	Sewer and Sanitary Drain
	87	Boiler


RAW COAL FROM RAIL UNLOADING
COAL RECEIVING & HANDLING (UNIT 10)
RAW COAL FEED (2" X 0")
COAL PREPARATION & CONVEYING (UNIT 20)
CONVEYING NITROGEN
COMBUSTION AIR
PRODUCT FUEL GAS
FLY ASH RECYCLE
COAL & CONVEYING NITROGEN (70% THROUGH 200 MESH 1% MOISTURE)
VENT
CONVEYING NITROGEN
L.P. STEAM
RAW PRODUCT GAS
HP STEAM
WASH WATER SUPPLY
OXYGEN (98% PURITY)
PURGING/BLANKETING NITROGEN
EMERGENCY SHUTDOWN NITROGEN
SLAG
WASH WATER RETURN
DECOMPOSED FUEL GAS
CHEMICAL ADDITION
STRETFORD DESULFURIZATION (UNIT 42) ONE TRAIN
PRODUCT GAS
LIQUID SULFUR PRODUCT
STRETFORD SOLN PURGE
NITTETU INCINERATION (UNIT 44)
PRODUCT FUEL GAS
RECOVERED STRETFORD SOLN
PRODUCT GAS COMPRESSION (UNIT 62)
PRODUCT FUEL GAS (INTERNAL PLANT USE)
L.P. STEAM
HP STEAM
SLAG
PRODUCT FUEL GAS
WASH WATER SUPPLY
FLY ASH RECYCLE
OXYGEN (98% PURITY)
PURGING/BLANKETING NITROGEN
EMERGENCY SHUTDOWN NITROGEN
INLET AIR TO AIR SEPARATION UNIT
AIR
AIR SEPARATION (UNIT 50)
CONVEYING NITROGEN
LIQUID OXYGEN
LIQUID OXYGEN STORAGE
LIQUID NITROGEN
LIQUID NITROGEN STORAGE
EXCESS/WASTE NITROGEN
VENT
WASH WATER RETURN
FLY ASH RECYCLE
WASH WATER TREATMENT (UNIT 72)
FLY ASH (50% MOISTURE)
WASH WATER SUPPLY
FLY ASH
FLY ASH SLUDGE DISPOSAL (UNIT 92)

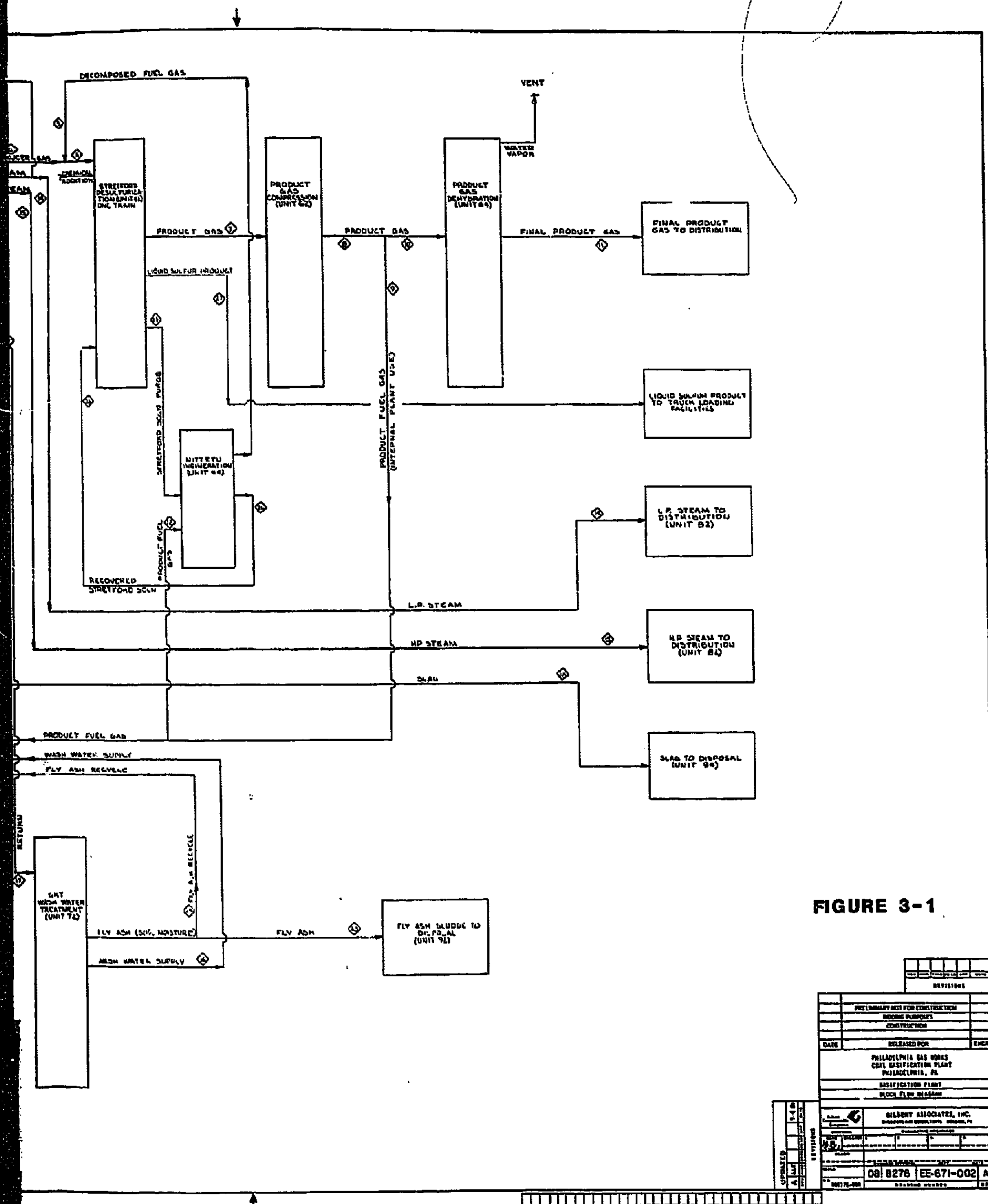

DECOMPOSED FUEL GAS
VENT
WATER VAPOR
STRETFORD DESULFURIZATION (UNIT 61) ONE TRAIN
PRODUCT GAS COMPRESSION (UNIT 62)
PRODUCT GAS DEHYDRATION (UNIT 64)
PRODUCT GAS
FINAL PRODUCT GAS
FINAL PRODUCT GAS TO DISTRIBUTION
LIQUID SULFUR PRODUCT
STRETFORD SOLN PURGE
NITTETU INCINERATION (UNIT 64)
PRODUCT FUEL GAS (INTERNAL PLANT USE)
LIQUID SULFUR PRODUCT TO TRUCK LOADING FACILITIES
PRODUCT FUEL GAS
RECOVERED STRETFORD SOLN
L.P. STEAM
L.P. STEAM TO DISTRIBUTION (UNIT 82)
HP STEAM
H.P. STEAM TO DISTRIBUTION (UNIT 81)
SLAG
SLAG TO DISPOSAL (UNIT 94)
PRODUCT FUEL GAS
WASH WATER SUPPLY
FLY ASH RECYCLE
RETURN
GKT WASH WATER TREATMENT (UNIT 72)
FLY ASH (50% MOISTURE)
FLY ASH
WASH WATER SUPPLY
FLY ASH SLUDGE TO DISPOSAL (UNIT 91)
REVISIONS
DATE
RELEASED FOR
ENGR.
CONSTRUCTION
PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA
GASIFICATION PLANT
BLOCK FLOW DIAGRAM
GILBERT ASSOCIATES, INC.
UPDATED
08 8276
EE-671-002
A

FIGURE 3-1

Unit No.	
90	Offsites
91	Main Process Flare & Relief
92	Fly Ash Removal and Storage
94	Slag Removal and Storage

For the GKT gasification plant 2-inches by 0-inch sized coal is delivered by unit train via in-plant tracks to the Coal Receiving and Handling Unit. In this unit the coal is unloaded from the unit train to the storage area, where a stock pile is formed by a lowering well. From the storage area, belt conveyors deliver the coal to bunkers for coal preparation at the rate of approximately 1,200 tons per day (as received, without loss).

In the Coal Preparation and Conveying Unit the coal is fed from the bunkers to pulverizers where the coal is dried and pulverized to the following GKT gasifier feed requirements:

- Size - 90 percent through 170 mesh and 70 percent through 200 mesh
- Moisture Content - one percent

An air heater which uses medium-Btu product gas is used to heat air for the purpose of reducing the coal inlet moisture to one percent in the pulverizer. The heated air pneumatically carries the coal from the pulverizer to a particulate removal system. Coal dust (pulverized coal) from the removal system is collected and pneumatically conveyed via by-product nitrogen from an air separation plant to service bins within the GKT Gasification Unit battery limits.

In the entrained bed gasifiers, the coal dust is oxidized by oxygen in the presence of steam. Coal, oxygen, and steam are brought together and distributed to four gasifier burner heads which are 90° apart. Reaction temperature at the burner head discharge is 3300 to

3500°F and the operating pressure is slightly above atmospheric. The coal is gasified almost completely and immediately. Under the process conditions prevailing in the gasifer, carbon and hydrocarbons contained in the coal are converted to carbon monoxide, hydrogen, and carbon dioxide.

The gasifier is a refractory lined steel shell equipped with a water jacket for producing low-pressure process steam at 28 psig. The low pressure steam from the jacket is more than enough to meet the gasifier's needs.

Oxygen for the gasification reaction is provided by an air separation plant. The air separation plant will be a turnkey facility, and engineering and design services will be furnished by a contractor experienced in this field. The oxygen purity for the plant is 98 volume percent with two percent inerts (mostly argon). By-product nitrogen (98 volume percent purity) from the plant is used for coal dust conveying and gasification system purging and blanketing.

In the gasifier, approximately 30 percent of the coal ash particles coalesce and drop out as slag into a slag quench and removal system. The slag is removed by belt conveyor to temporary slag storage facilities (Unit 94) prior to rail loading for disposal.

The remaining 70 percent of the fine ash particulates are carried overhead out of the gasifier as fly ash entrained with unburned carbon and are removed downstream by the gas clean-up train.

The medium-Btu product exits the gasifier at approximately 2700°F. The gas passes through a waste heat boiler which produces 925 psig saturated steam. At the exit of the waste heat boiler the gas temperature is reduced to 600°F. The gas then passes through a clean-up train where the temperature of the gas is subsequently reduced to 95°F and the majority of the entrained fly ash and carbon particulates are removed.

In the clean-up train the fly ash is removed via a circulating wash water system which scrubs the gas. The wash water stream ladden with fly ash and unburned carbon is sent to the GKT Wash Water Treatment Unit (72). In the wash water treatment the entering wash water stream is sent to two rectangular settling ponds. The fly ash sludge from the settling ponds is sent to a common thickener. The underflow of the thickener is pumped to rotary vacuum filter where the moisture is reduced to 50 percent. The fly ash filter cake is then sent via belt conveyor to temporary storage facilities (Unit 92) prior to disposal by rail or truck. The amount of fly ash to disposal for a typical Pittsburgh No. 8 coal at the plant design production rate is 345 tpd.

To reduce the sludge disposal problems, and also to reutilize some of the carbon in the fly ash cake, recycling of up to 50 percent of the sludge cake to the gasifiers is incorporated in the present design. Recycle of 50 percent of the fly ash cake will increase the gasifier carbon conversion from 88.0 to 93.6 percent while reducing the raw coal feed by six percent. The recycle of sludge to the gasifier is limited to 50 percent, since the pulverizer and air heater design is currently limited to a maximum of 12 percent moisture. Recycle of 50 percent of the sludge cake to the gasifier will not significantly affect the gasifier gas production or composition, since the hydrogen, oxygen, nitrogen, and sulfur to carbon ratios in the mixed feed are essentially the same as the raw coal feed.

Summarized in Table 3-1 is the material balance for the recycle of sludge cake cases. The material balance represents a product gas production rate of 20.58 billion Btu per day at the plant battery limits (high heating value, no sensible heat credit basis).

Downstream of the gas clean-up train the two gasification trains join together to form a single train. The gas then passes through a

TABLE 3-1

PCW GASIFICATION PLANT OVERALL MATERIAL BALANCE
DESIGN PRODUCT GAS PRODUCTION (20.58 x 10^9 BTU/DAY), ASH RECYCLE CASE

STREAM NO.(1)	1		2		3	4		5		6	
STREAM DESCRIPTION	DRIED COAL FEED TO GKT UNIT		OXYGEN FEED TO GKT UNIT		L.P.STEAM INPUT TO GKT GASIFIERS	PRODUCT GAS OUTLET GKT BATTERY LIMITS		DECOMPOSED FUEL GAS FROM NITTETU INCINERATION		PRODUCT GAS INLET STRETFORD UNIT	
TOTAL FLOW, LB/HR	99,137 (1189.6 TPD)		94,910 (1139 TPD)		8843	179,794		7,420		186,069	
VAPOR FLOW, SCFM	-		18,662		-	52,781		1,581		53,958	
LIQUID FLOW, GPM	-		-		-	-		-		-	
VAPOR MOLECULAR WT.	-		32.16		-	21.54		29.69		21.81	
TEMPERATURE, °F	60		100		274	95		120		101	
PRESSURE, PSIG (IN W.C.)	ATM		0.4 (12)		28	0.8 (22)		0.8 (22)		5.8	
COMPONENTS	LB/HR	WT %	LB/HR	MOLE %	LB/HR	LB/HR	MOLE %	LB/HR	MOLE %	LB/HR	MOLE %
S	2,370	2.39	-	-	-	-	-	-	-	-	-
C	74,180	74.83	-	-	-	-	-	-	-	-	-
H_2	4,739	4.78	-	-	-	4,556	27.29	22	4.45	4,578	26.82
O_2	4,250	4.29	92,556	98.00	-	-	-	-	-	-	-
N_2	1,279	1.39	-	-	-	2,150	0.92	3,392	48.38	5,538	2.32
Ar	-	-	2,354	2.00	-	1,900	0.57	-	-	1,900	0.56
CO_2	-	-	-	-	-	23,358	6.36	2,677	24.33	26,035	6.93
CO	-	-	-	-	-	136,980	58.61	672	9.59	137,652	57.62
CH_4	-	-	-	-	-	13	0.01	-	-	13	0.01
H_2S	-	-	-	-	-	2,417	0.85	137	1.61	2,554	0.88
COS	-	-	-	-	-	451	0.09	-	-	451	0.09
HCN	-	-	-	-	-	17	75 PPMV	-	-	17	74 PPMV
H_2O	995	1.00	-	-	8843	7,952	5.30	524	11.64	7,331	4.77
STRETFORD SOLN.	-	-	-	-	-	-	-	-	-	-	-
ASH	11,324	11.42	-	-	-	-	-	-	-	-	-
SLAG	-	-	-	-	-	-	-	-	-	-	-
TOTAL	99,137	100.00	94,910	100.00	8843	179,794	100.00	7,420	100.00	186,069	100.00

(1) Stream numbers correspond to those shown on Gasification Block Flow Diagram, Figure 3-1.

TABLE 3-1 (Cont'd)

STREAM NO.	7		8		9		10		11		12	
STREAM DESCRIPTION	PRODUCT GAS OUTLET STRETFORD UNIT		PRODUCT GAS OUTLET GAS COMPRESSION UNIT		PLANT PRODUCT FUEL GAS USAGE		PRODUCT GAS DEHYDRATION UNIT INLET		PRODUCT GAS PLANT BATTERY LIMITS OUTLET		PRODUCT FUEL GAS TO NITTETU INCINERATION	
TOTAL FLOW, LB/HR	186,150		178,188		5,147		173,041		170,683		2,935	
VAPOR FLOW, SCFM	54,517		51,719		1,485		50,234		49,385		852	
LIQUID FLOW, GPM	-		-		-		-		-		-	
VAPOR MOLECULAR WT.	21.60		21.79		21.78		21.78		21.85		21.78	
TEMPERATURE, °F	105		100		100		100		160		100	
PRESSURE, PSIG (IN W.C.)	1.5 (41.6)		40.3		40.3		40.3		35.3		40.3	
COMPONENTS	LB/HR	MOLE %	LB/HR	MOLE %	LB/HR	MOLE %	LB/HR	MOLE %	LB/HR	MOLE %	LB/HR	MOLE %
S	-	-	-	-	-	-	-	-	-	-	-	-
C	-	-	-	-	-	-	-	-	-	-	-	-
H_2	4,575	26.53	4,575	27.98	129	27.98	4,446	27.98	4,446	28.45	74	27.98
O_2	-	-	-	-	-	-	-	-	-	-	-	-
N_2	5,538	2.29	5,538	2.41	177	2.41	5,361	2.41	5,361	2.45	101	2.41
Ar	1,900	0.55	1,900	0.58	58	0.58	1,842	0.58	1,842	0.59	33	0.58
CO_2	25,549	6.74	25,549	7.10	733	7.10	24,816	7.10	24,816	7.22	418	7.10
CO	137,565	56.99	137,565	60.07	3,949	60.07	133,616	60.07	133,616	61.08	2,251	60.07
CH_4	13	0.01	13	0.01	-	0.01	13	0.01	13	0.01	-	0.01
H_2S	-	-	-	-	-	-	-	-	-	-	-	-
COS	451	0.09	451	0.09	25	0.09	426	0.09	426	0.09	14	0.09
HCN	6	27 PPMV	6	28 PPMV	1	28 PPMV	5	28 PPMV	5	26 PPMV	0.6	28 PPMV
H_2O	10,553	6.80	2,591	1.76	75	1.76	2,516	1.76	158	0.11	43	1.76
STRETFORD SOLN.	-	-	-	-	-	-	-	-	-	-	-	-
ASH	-	-	-	-	-	-	-	-	-	-	-	-
SLAG	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	186,150	100.00	178,188	100.00	5,147	100.00	173,041	100.00	170,683	100.00	2,934.6	100.00

TABLE 3-1 (Cont'd)

STREAM NO.	13		14	15	16	17	18		19
STREAM DESCRIPTION	PRODUCT FUEL GAS TO COAL PREPARATION		GKT GASIFICATION L.P. STEAM TO DISTRIBUTION	GKT GASIFICATION H.P. STEAM TO DISTRIBUTION	GKT UNIT WASH WATER SUPPLY	GKT UNIT WASH WATER RETURN	GKT UNIT SLAG TO DISPOSAL		PURGING/BLANKETING NITROGEN TO GKT UNIT
TOTAL FLOW, LB/HR	2,212		101,062	111,093	2,088,407	2,090,143	3,997 (48 TPD)		10,990
VAPOR FLOW, SCFH	642		-	-	-	-	-		2,482
LIQUID FLOW, GPM	-		-	-	4,178	4,182	-		-
VAPOR MOLECULAR WT.	21.78		-	-	-	-	-		28
TEMPERATURE, °F	100		274	453	113	158	70		100
PRESSURE, PSIG (IN W.C.)	40.3		28	925	100	10	ATM		10
COMPONENTS	LB/HR	MOLE %	LB/HR	LB/HR	LB/HR	LB/HR	LB/HR	WT%	LB/HR
S	-	-	-	-	-	-	-	-	-
C	-	-	-	-	-	-	-	-	-
H_2	55	27.98	-	-	-	-	-	-	-
O_2	-	-	-	-	-	-	-	-	-
N_2	76	2.41	-	-	-	-	-	-	-
Ar	25	0.58	-	-	-	-	-	-	-
CO_2	315	7.10	-	-	-	-	-	-	-
CO	1,698	60.07	-	-	-	-	-	-	-
CH_4	-	0.01	-	-	-	-	-	-	-
H_2S	-	-	-	-	-	-	-	-	-
COS	11	0.09	-	-	-	-	-	-	-
HCN	0.4	28 PPMV	-	-	-	-	-	-	-
H_2O	32	1.76	101,062	111,093	2,088,407	2,090,143	600	15.00	-
STRETFORD SOLN.	-	-	-	-	-	-	-	-	-
ASH	-	-	-	-	-	-	3,397	85.00	-
SLAG	-	-	-	-	-	-	-	-	-
TOTAL	2,212.4	100.00	101,062	111,093	2,088,407	2,090,143	3,997	100.00	10,990

TABLE 3-1 (Cont'd)

STREAM NO.	20	21	22		23		24	
STREAM DESCRIPTION	EMERGENCY SHUTDOWN NITROGEN TO GKT UNIT	CONVEYING NITROGEN TO COAL PREPARATION UNIT	RAW COAL FEED TO COAL PREPARATION UNIT		FLY ASH TO DISPOSAL		FLY ASH RECYCLE TO COAL PREPARATION UNIT	
TOTAL FLOW, LB/HR	65,940	13,736	2,000,000 (1000 TPH)(1)		16,826 (201.9 TPD)		16,826 (201.9 TPD)	
VAPOR FLOW, SCFM	14,891	3,102	-		-		-	
LIQUID FLOW, GPM	-	-	-		-		-	
VAPOR MOLECULAR WT.	28	28	-		-		-	
TEMPERATURE, °F	100	100	60		70		70	
PRESSURE, PSIG (IN W.C.)	15	35	ATM		ATM		ATM	
COMPONENTS			LB/HR	WT %	LB/HR	WT %	LB/HR	WT %
S	-	-	50,400	2.52	-	-	-	-
C	-	-	1,483,000	74.15	4,452	26.46	4,452	26.46
H_2	-	-	100,800	5.04	-	-	-	-
O_2	-	-	90,400	4.52	-	-	-	-
N_2	-	-	27,200	1.36	-	-	-	-
Ar	-	-	-	-	-	-	-	-
CO_2	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-
CH_4	-	-	-	-	-	-	-	-
H_2S	-	-	-	-	-	-	-	-
COS	-	-	-	-	-	-	-	-
HCN	-	-	-	-	-	-	-	-
H_2O	-	-	91,600	4.58	8,413	50.00	8,413	50.00
STRETFORD SOLN.	-	-	-	-	-	-	-	-
ASH	-	-	156,600	7.83	3,961	23.54	3,961	23.54
SLAG	-	-	-	-	-	-	-	-
TOTAL	65,940	13,736	2,000,000	100.00	16,826	100.00	16,826	100.00

(1) Maximum 1 shift per day operation

TABLE 3-1 (Cont'd)

STREAM NO.	25		26		27
STREAM DESCRIPTION	STRETFORD SOLN. PURGE TO NITTETU INCINERATION		RECOVERED STRETFORD SOLUTION FROM NITTETU INCINERATION		LIQUID PRODUCT SULFUR FROM DESULFURIZATION UNIT
TOTAL FLOW, LB/HR	3,500		3,540		2279 (27.3 TPD)
VAPOR FLOW, SCFM	-		-		-
LIQUID FLOW, GPM	6.17		6.1		-
VAPOR MOLECULAR, WT.	-		-		-
TEMPERATURE, °F	105		195		280
PRESSURE, PSIG (IN W.C.)	110		30		ATM
COMPONENTS	LB/HR	WT %	LB/HR	WT %	LB/HR
S	-	-	-	-	2,279
C	-	-	-	-	-
H_2	-	-	-	-	-
O_2	-	-	-	-	-
N_2	-	-	-	-	-
Ar	-	-	-	-	-
CO_2	-	-	-	-	-
CO	-	-	-	-	-
CH_4	-	-	-	-	-
H_2S	-	-	-	-	-
COS	-	-	-	-	-
HCN	-	-	-	-	-
H_2O	2,484	70.97	2,775	78.38	-
STRETFORD SOLN.	1,016	29.03	765	21.62	-
ASH	-	-	-	-	-
SLAG	-	-	-	-	-
TOTAL	3,500	100.00	3,540	100.00	2,279

gas holder and an electrostatic precipitator for final particulate removal before exiting the GKT battery limits. The composition and conditions of the product gas exiting the GKT battery limits are shown below:

Component	Mole%
H_2	27.29
N_2	0.92
Ar	0.57
CO_2	6.36
CO	58.61
CH_4	0.01
H_2S	0.85
COS	0.09
HCN	75 PPMV
H_2O	5.30
TOTAL	100.00
Temperature, ^oF	95
Pressure, in. W.C.	22

From the GKT Gasification Unit the gas is compressed to approximately 6 psig prior to entering the Desulfurization Unit. The desulfurization unit is a Stretford process which removes H_2S present in the raw gas by converting it to recoverable elemental sulfur. The Stretford process is a low temperature absorption-direct oxidation desulfurization process. The raw gas from the GKT gasifier contains about 0.90 and 0.09 percent of H_2S and COS, respectively, on a dry gas volume basis. To comply with the EPA environmental regulations set by the City of Philadelphia (500 PPMV or 0.86 lb SO_2 per 10^6 Btu input), the raw gas must be cleaned before being utilized in the boilers. The Stretford desulfurization process removes almost all H_2S from the gas. COS in the gas is not removed; however, its content is low and burning the gas will produce only 350 PPMV SO_2.

The Stretford process basically consists of an absorber, oxidizers, a sulfur removal system, an incineration unit for handling Stretford purge solution, and associated pumps, air blowers, and solution makeup equipment. Removal of H_2S occurs in the Stretford absorber mixer and reaction vessel where the product gas stream contacts the lean Stretford solution. The clean gas exiting the reaction vessel is delivered to the Gas Compression and Dehydration Units at 105°F and 2 psig.

The sulfur removal system employed for the Stretford process produces a saleable molten sulfur product. The molten sulfur is stored in a storage pit prior to rail loading. The molten sulfur produced at design gasification plant capacity for a typical Pittsburgh No. 8 coal is 27.3 tpd.

In the Stretford process, salts (Na_2SO_4, $Na_2S_2O_3$, and NaSCN) are produced during the absorption and oxidation steps. The salts accumulate in the Stretford solution and the free alkali portion of the working solution is suppressed. To remedy this, a purge stream from the Stretford solution containing salts formed during the process is sent to a Nittetu Incineration Plant (Unit 44) to decompose the salts via reductive incineration. In the Nittetu unit the purge solution is vaporized and the salts decomposed in a furnace. Reformed molten salts are then quenched and the solution returned to the Stretford process. Decomposed gases (containing H_2S) formed during the quench operation are sent to the inlet of the Stretford absorber where they are mixed with the raw product gas from the GKT plant.

From the Desulfurization Unit the desulfurized product gas is compressed to 35 psig in a set of parallel compressors. The two compressors are centrifugal machines with aftercoolers and are driven by condensing steam turbines using excess low pressure steam from the gasifier jacket. A third compressor driven by electric motor will provide a 50 percent standby capability for startup and emergency situations.

From the Gas Compression Unit (Unit 62) the product gas enters the Gas Dehydration Unit. In the gas dehydration unit, excess water from the compressed gas (40 psig) is removed to meet the selected product gas water content. Most natural gas pipelines specifications require a water content not to exceed 7.0 lb H_2O per MM SCF because of long pipeline distances and pressures up to 1000 psia. The PGW application requires transmission distances of only five miles and a discharge pressure of 35 psig. Therefore, a low gas water content specification is not necessary and economic considerations have led to the selection of 53.3 lbs H_2O per MM SCF (or 20°F dew point). The wet compressed gas at 40 psig and dew point of 100°F has a water content of 851.1 lb per MM SCF. The dehydration unit will remove the excess water (797.8 lb per MM SCF) to prevent gas freeze-ups and gas transmission problems such as pipe line corrosion. A standard triethylene glycol system is employed for the Dehydration Unit (Unit 64).

From the gas dehydration unit the product gas is metered prior to exiting the plant battery limits and entering the product gas distribution system. The composition and conditions of the product gas exiting the plant battery limits are shown below:

Component	Mole%
H_2	28.45
N_2	2.45
Ar	0.59
CO_2	7.22
CO	61.08
CH_4	0.01
H_2S	-
COS	0.09
HCN	26 PPMV
H_2O	0.11
	100.00
Temperature, °F	160

Pressure, psig	35
HHV, Btu/SCF	289.5

The design heat duty of the medium Btu gas delivered from the gasification battery limits to the users is 20.58 billion Btu/day (HHV basis). The cold gas efficiency is 66.7 percent based on the following definition:

$$\text{Cold Gas Efficiency } \% = \frac{\text{(HHV of Product Gas at 60°F at GKT battery limits)}}{\text{(HHV of A.R. Coal Feed)}} \times 100$$

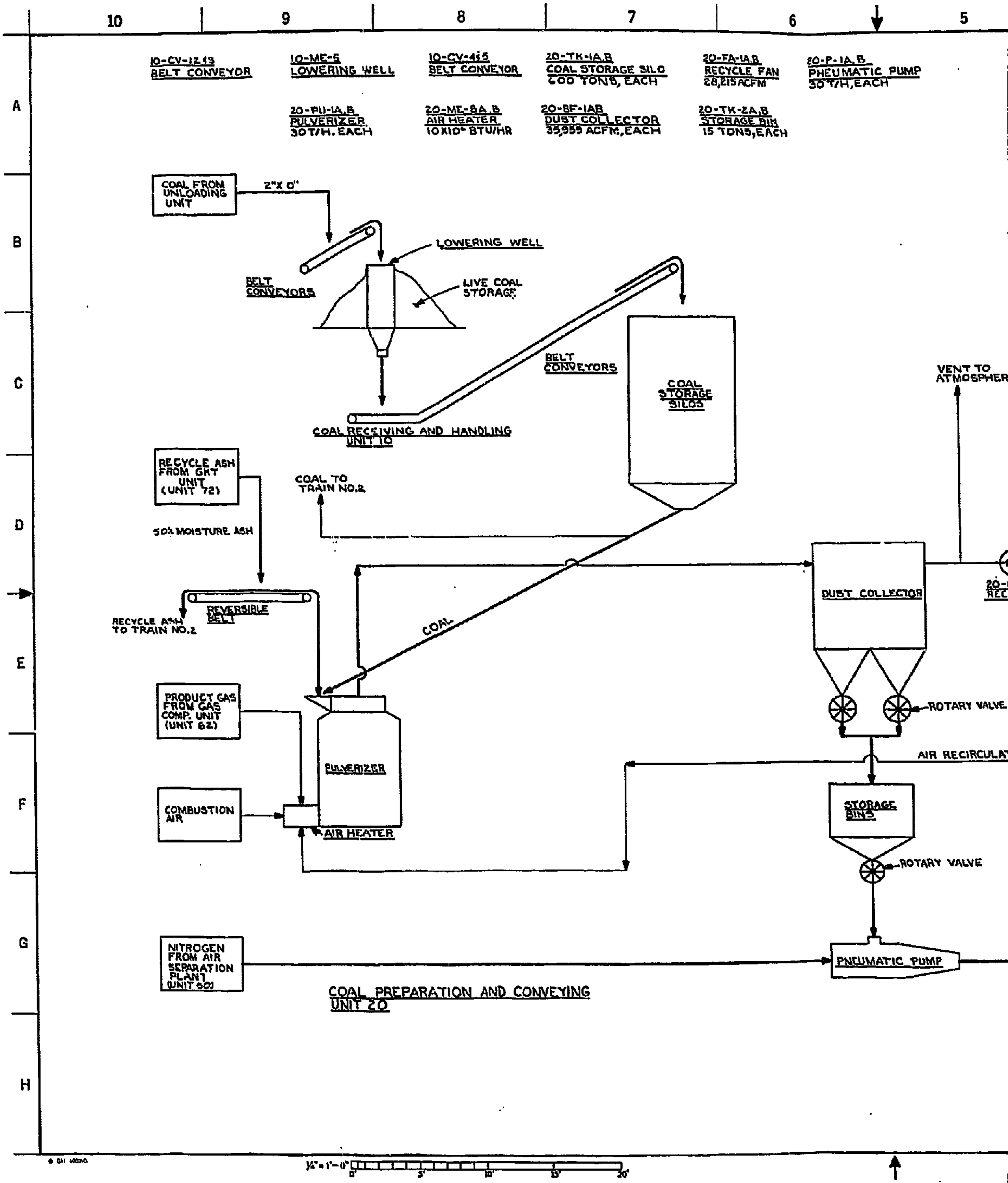
3.2 COAL RECEIVING AND HANDLING

Complete coal handling facilities are provided for receiving and storing coal delivered by rail and transferring the coal to the plant. Two trains are provided for coal unloading, and one train for stacking, reclaiming and conveying equipment. A process flow diagram for the Coal Receiving and Handling Unit (Unit 10) is shown in Figure 3-2. Although the receiving and handling facilities are designed for Pittsburgh No. 8, the storage and conveying facilities are capable of handling other eastern bituminous coals selected as possible candidates (see Appendix A).

3.2.1 Coal Receiving

Washed coal is delivered to the plant by unit trains consisting of seventy 100-ton bottom dump cars (or their equivalent). The design coal has a nominal size of 2-inches by 0-inch, weighs 50 pounds per cubic foot, and has an angle of repose of 38 degrees. Allowance is made, however, for accepting reasonable variations in these parameters.

Coal is received at two parallel track unloading hoppers. An enclosure is provided over each hopper, incorporating thaw shed and a manually operated car shaker to assist in unloading wet or frozen



10-CV-12,13
BELT CONVEYOR
10-ME-5
LOWERING WELL
10-CV-4,5
BELT CONVEYOR
20-TK-1A,B
COAL STORAGE SILO
600 TONS, EACH
20-FA-1A,B
RECYCLE FAN
28,215 ACFM
20-P-1A,B
PHEUMATIC PUMP
30 T/H, EACH
20-PU-1A,B
PULVERIZER
30 T/H, EACH
20-ME-8A,B
AIR HEATER
10 X10⁶ BTU/HR
20-BF-1AB
DUST COLLECTOR
35,959 ACFM, EACH
20-TK-2A,B
STORAGE BIN
15 TONS, EACH
COAL FROM UNLOADING UNIT
2"X 0"
LOWERING WELL
BELT CONVEYORS
LIVE COAL STORAGE
BELT CONVEYORS
COAL STORAGE SILOS
VENT TO ATMOSPHER
COAL RECEIVING AND HANDLING
UNIT 10
RECYCLE ASH FROM GKT UNIT (UNIT 72)
COAL TO TRAIN NO.2
50% MOISTURE ASH
DUST COLLECTOR
REVERSIBLE BELT
RECYCLE ASH TO TRAIN NO.2
COAL
ROTARY VALVE
PRODUCT GAS FROM GAS COMP. UNIT (UNIT 62)
PULVERIZER
AIR RECIRCULAT
COMBUSTION AIR
AIR HEATER
STORAGE BINS
ROTARY VALVE
NITROGEN FROM AIR SEPARATION PLANT (UNIT 50)
PNEUMATIC PUMP
COAL PREPARATION AND CONVEYING
UNIT 20
¼"=1'-0"
0'
5'
10'
15'
20'

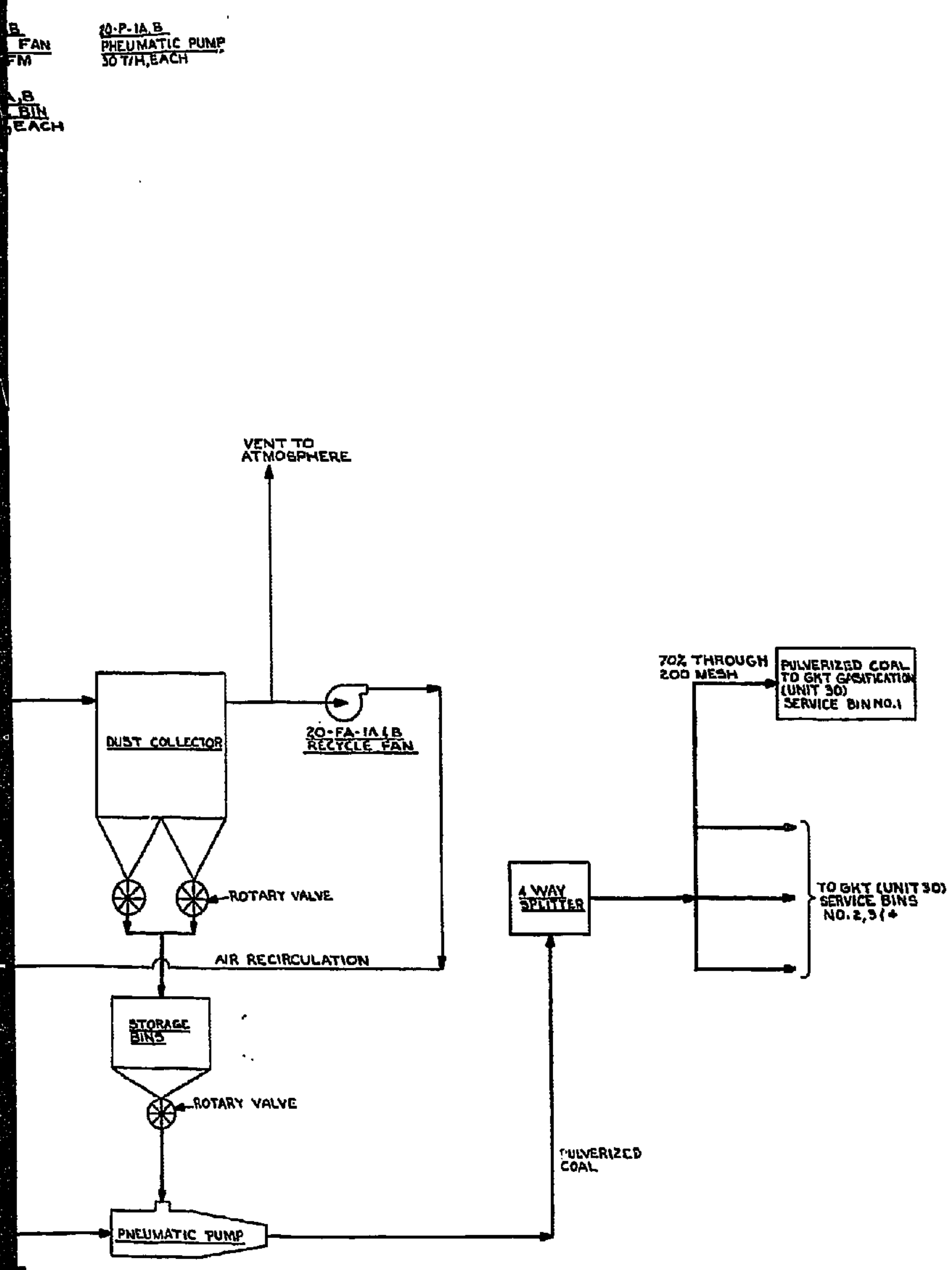


FIGURE 3-2

PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA

PROCESS FLOW DIAGRAM
COAL HANDLING (UNIT 10) &
COAL RECEIVING (UNIT 20)

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

RELEASED FOR: CONSTRUCTION / PRELIMINARY NOT FOR CONSTRUCTION / BIDDING PURPOSES

REVISIONS: A — UPDATED — ALK — 9-11-81

SCALE: NONE

DRAWING NUMBER: 08 8276 C-671-003 REV A

coal. Dust suppression and collection systems are provided to control the fugitive dust emissions generated by the unloading operation (Unit 15).

Each unloading hopper with a capacity of 100 tons has manually operated shutoff gate and four vibrating feeders. The vibrating feeders discharge to the two parallel unloading conveyors, each 48 inches wide. Coal unloading from the unit train is completed in two days, based on one shift (eight hours) per day.

3.2.2 Conveying To Storage, Weighing, and Sampling

The hooded coal unloading transfer conveyor is 48 inches wide and has a capacity of 1,000 tph. It conveys coal from the hopper unloading conveyors to a live storage pile (10,000 tons) via a lowering well (stacking tube).

As the conveyor leaves the unloading hopper tunnel, at a point just above grade elevation, a self-contained weigh scale is provided. The weigh scale is capable of determining flow rate and total integrated accumulated flow, and has provisions for periodic calibration.

The unloading transfer conveyor head pulley is located in the sampling system enclosure. A magnetic separator is provided to remove tramp iron from the coal stream. The rejects are chuted outside of the sampling enclosure to a tote box at grade. Periodic truck removal of tramp iron is made.

A sampling system is installed to collect coal samples for laboratory analysis and coal supplier's use. The system enclosure is ventilated, and dust supression and collection systems are also installed (Unit 15).

3.2.3 Coal Storage

The coal is stored as a long pile, which is capable of storing 66,000 tons of coal. The coal storage area is sized for approxiatmely 60 day supply of coal. About 10,000 tons of coal or 10 days supply is placed in "live storage." The live storage pile is formed by a lowering well at one end of the pile, fed by the transfer conveyor.

Underneath the live pile are three reclaim hoppers, from which a belt conveyor of 200 tph capacity and 30 inches wide conveys the coal to the two coal storage silos. Each storage silo is 25 feet diameter and has a live capacity of 600 tons. The top of each silo is at an elevation of approximately 123 feet above grade. The bottom of each silo has a power operated shutoff gate and a vibrating feeder with a variable capacity up to 50 tph. The vibrating feeders discharge directly into the pulverizer assemblies.

The "dead storage" section of the pile (56,000 tons) is formed by moving the coal with a bulldozer. This coal is used only in case of supply interruptions. The pile is compacted and sprayed with an organic polymer crusting agent to minimize both dusting and rain erosion problems. The entire coal pile is diked and lined with a clay base to prevent seepage. Contaminated rainfall runoff is collected in a lined settling pond. Settled particles are periodically removed and sent back to the coal pile. The water from the pond is pumped to a waste treatment facility and neutralized before being discharged to the river.

3.3 COAL PREPARATION AND CONVEYING

In the coal preparation unit the bunker coal or a mixture of the bunker coal and recycled fly ash sludge cake (50 percent moisture from the GKT coal gasification plant) is dried and pulverized to the following GKT gasifier feed requirements:

- Size - 90 percent through 170 mesh and 70 percent through 200 mesh
- Moisture content - One percent

Pneumatic conveyors transport the dried and pulverized coal from the pulverized coal storage bin to the gasifier service bins. Compressed nitrogen from the air separation plant is used as the conveying medium.

It should be noted that the fly ash has a high carbon content and the recycle approach is selected for a higher carbon utilization. For the design coal (Pittsburgh No. 8) 50 percent of the filter cake recovered in the GKT gasification plant is recycled. However, depending upon the coal being processed, overall moisture removal and heat duty required in the pulverizer, the recycle rate can be varied. The equipment is designed to provide this flexibility. More discussion of the recycle of the filter cake and its effect on overall carbon utilization is given in Appendix B.

The complete system as shown in Figure 3-2 is designed to provide maximum in safety, reliability, and flexibility. Each train is designed to process 25 tph (600 tpd) of puliverized coal/filter cake mixture (dry basis).

The coal preparation unit consists of two 50 percent roller mills, and two 50 percent trains of associated ancilliary equipment such as bag collector, recycle fan and air heater. The pulverized coal conveying unit has two trains, each consisting of a storage silo, pneumatic pump, and a conveying line feeding to the gasifier service bins.

The roller mills are designed to process coal with a Hardgrove Grindability Index of 50, and a maximum moisture content of 12.0 percent. Provisions are made to recycle up to 50 percent of the fly ash cake from the GKT unit with the base coal. For higher ash coals a smaller recycle percentage is recommended. For the design coal (4.6 percent moisture) with 50 percent filter cake recycle, the heating load required for the pulverizer heater is about 20.5 MM Btu per hour. For a 12 percent moisture raw coal feed the heating load increases to about 34.4 MM Btu per hour. A small portion of the clean product gas from the gasification unit will be utilized in a heater for producing the hot air for the pulverizers.

Each mill and its associated equipment, with the exception of the bag collector, are designed for 50 psig in accordance with the NFPA code. The bag type dust collector is suitably equipped with an explosion door which reseals, to prevent the infiltration of ambient air into the system after relieving. In addition, partial recirculation of gases from the clean side of the collector back to the roller mill further increases the safety and reliability of the pulverizing circuit. This recycle loop, containing less than 0.02 grains of particulate per actual cubic foot, insures a sufficiently low oxygen content in the system gases, which minimizes the hazardous nature of the finely pulverized coal. Each baghouse is sized for 36,000 ACFM and has an air/cloth ratio of 4.5 to 1.0.

Pulverized coal from each baghouse goes to a 15-ton capacity pulverized coal storage bin, which is 10 feet in diameter. The top of the bin is at an elevatin of approximately 28 feet above grade. The bottom of the bin has rotary air lock and discharges directly into the pneumatic pump inlet hopper. Compressed nitrogen (98 percent purity) at 35 psig is supplied from the air separation plant. The coal is conveyed via a carbon steel conveying pipe to the gasifier service bins through a four-way splitter.

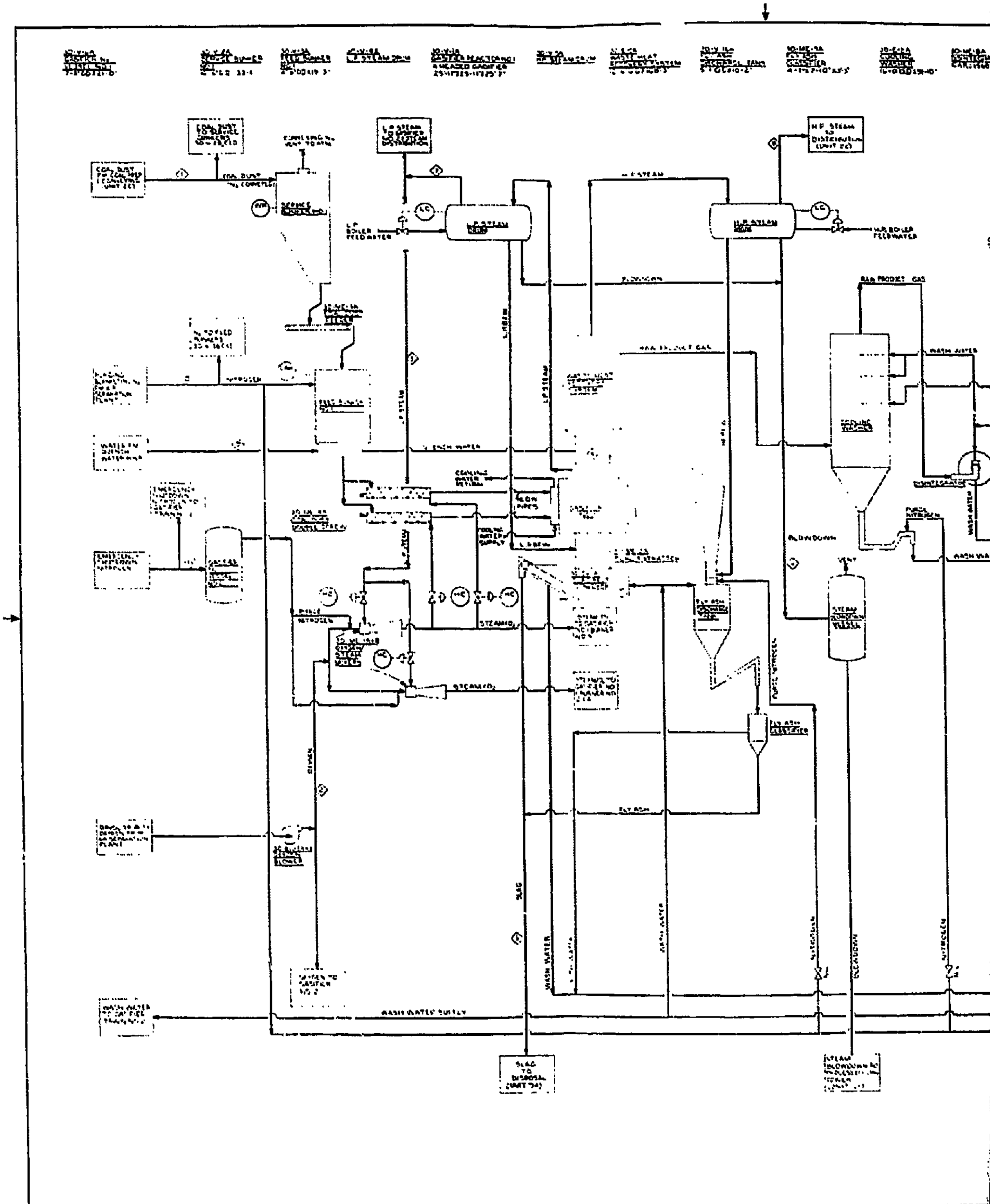
3.4 GKT COAL GASIFICATION AND WASH WATER TREATMENT

For the production of medium-Btu gas from coal, GKT's entrained bed coal gasification process has been selected for the PWG plant. Coal dust pulverized and conditioned to 70 percent through 200 mesh size and one percent water content from the Coal Preparation and Conveying Unit is processed through the gasifier and partially oxidized under exothermic conditions at pressures slightly above atmospheric. Process flow diagrams for the GKT Unit (Unit 30) are shown in Figures 3-3 and 3-4. The GKT Wash Water Treatment Unit (Unit 72) is shown in Figure 3-5.

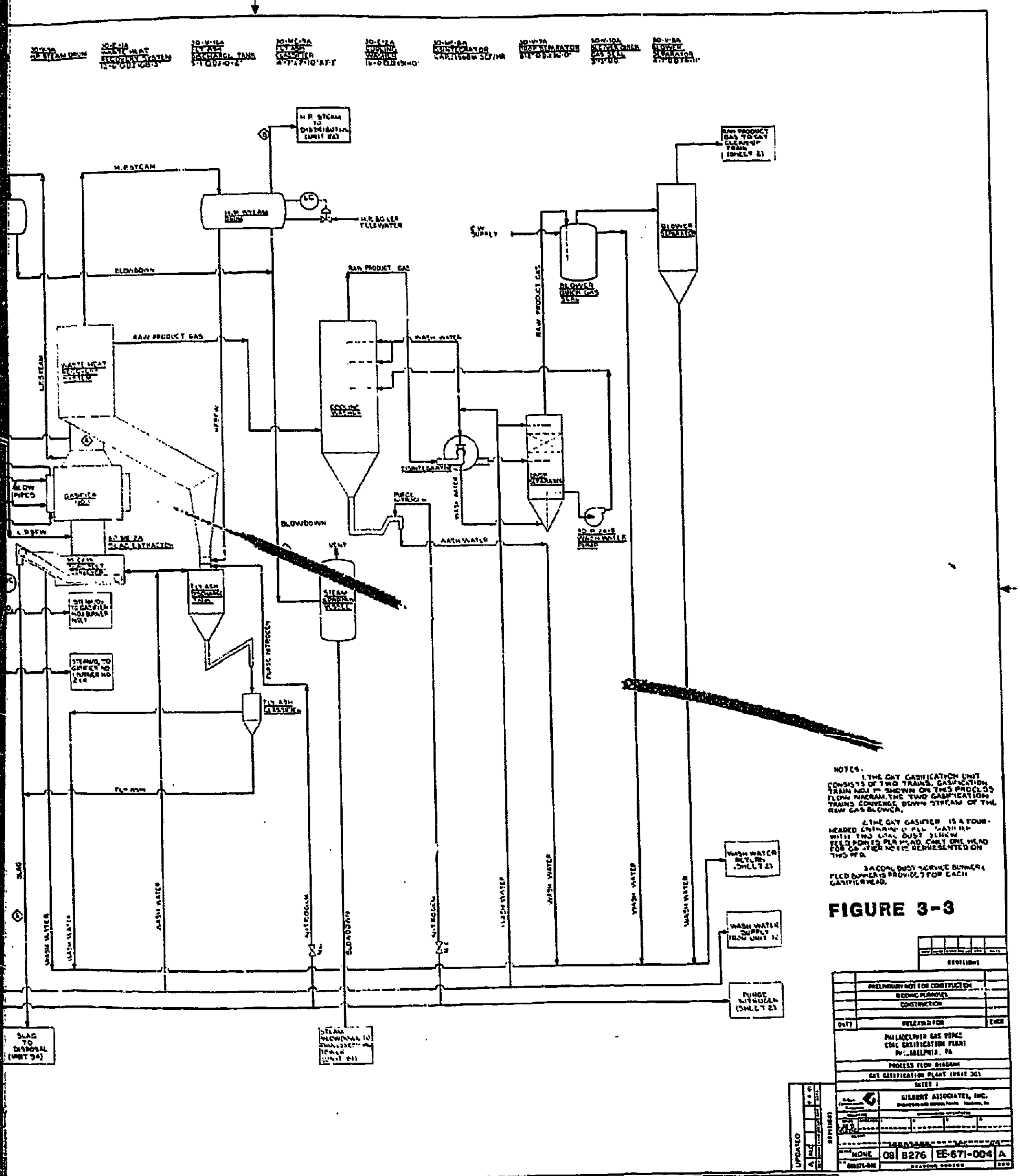
Note that a single gasification train is shown on Figure 3-3 for clarity. This is reflected in Table 3-2, GKT Gasification Unit Material Balance. This balance is independent of ash recycle, as it is restricted to the gasification process and wash water treatment.

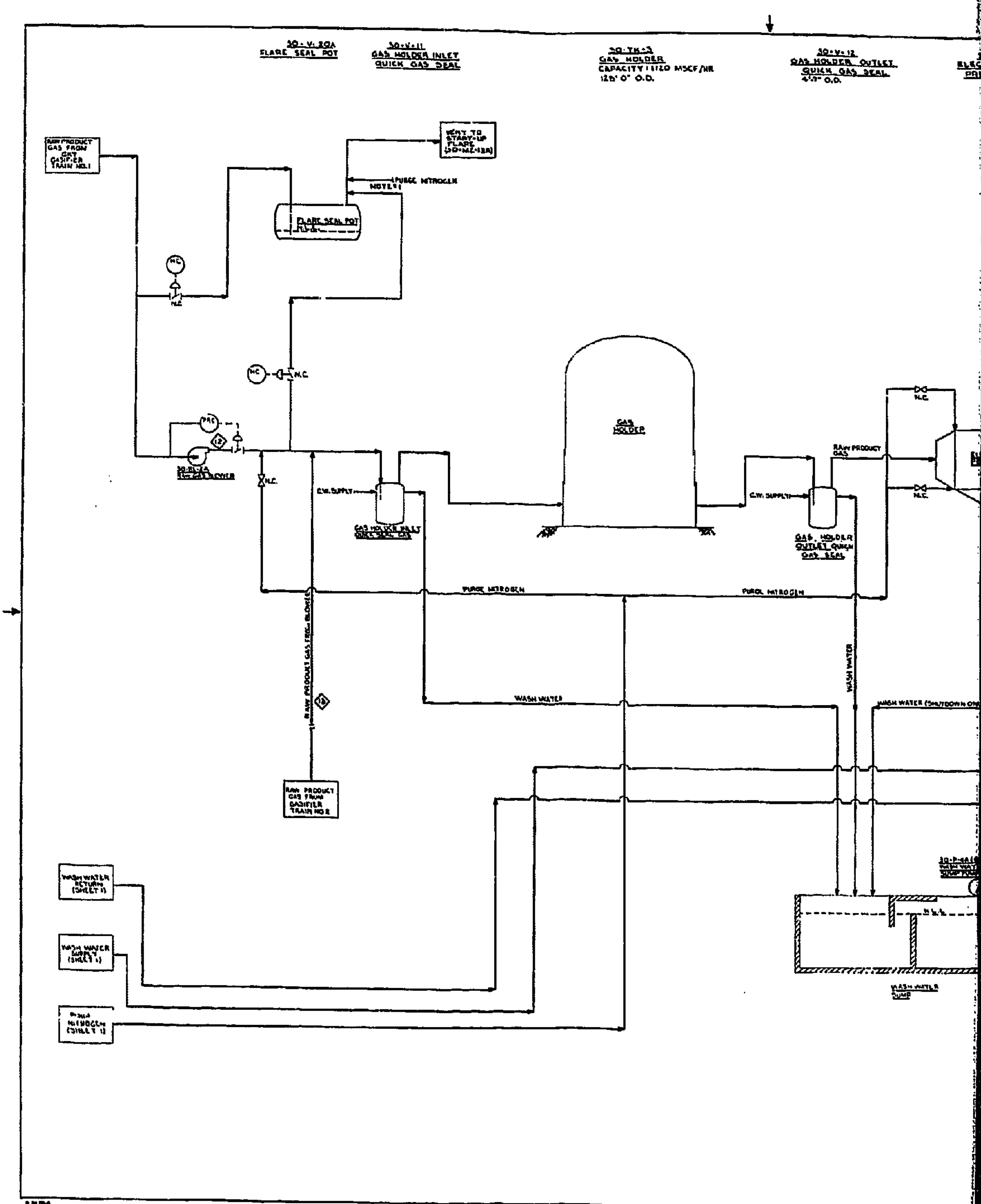
To produce approximately 20 billion Btu per day of medium Btu gas from a typical bituminous coal, two four-headed GKT gasifiers are required. As feedstock to the gasifier, in principle, any kind of coal can be used. The efficiency, however, defined by the overall carbon conversion and the output of useful gas (carbon monoxide plus hydrogen) is to a certain degree dependent on the type and quality of the feedstock. For the PGW plant, a typical Pittsburgh No. 8 coal has been used as the design coal for the plant design. Enough flexibility, however, has been added to the gasification plant design to accommodate a variety of eastern bituminous coals.

The gasification plant is designed to handle 1,200 tpd as-received coal (2-inches by 0-inch). Raw coal is dried and ground to the required size in the Coal Preparation Unit. Pulverized coal is then pneumatically transported from the Coal Preparation Unit to the GKT gasifier trains via conveying nitrogen supplied from the Air Separation Unit. The pulverized coal is routed via a flow splitter to service bins within the GKT battery limits. The conveying nitrogen is vented to the atmosphere through filters at the service bins. Pulverized coal flows by gravity from the service bind to the feed bins. Four service bins and four feed bins are provided for each gasifier. The service bins and feed bins provide a guaranteed supply of coal to the gasifiers in the event of an upstream



RAW PRODUCT GAS
WASH WATER
BLOWDOWN
FLY ASH
SLAG
WASH WATER
WASH WATER SUPPLY
NITROGEN
VENT
STEAM


H.P. STEAM TO DISTRIBUTION
RAW PRODUCT GAS TO GAT CLEANUP TRAIN (SHEET 2)
H.P. STEAM
H.P. STEAM DRUM
H.P. BOILER FEEDWATER
BLOWDOWN
RAW PRODUCT GAS
COOLING WASHER
C.W. SUPPLY
BLOWER QUICK GAS SEAL
BLOWER SEPARATOR
WASH WATER
PURGE NITROGEN
BLOWDOWN
VENT
STEAM BLOWDOWN TANK
FLY ASH
WASH WATER RETURN (SHEET 2)
WASH WATER SUPPLY
PURGE NITROGEN (SHEET 2)
SLAG TO DISPOSAL
NITROGEN
WASH WATER
ASH WATER
SLAG
NOTES:
1. THE GAT GASIFICATION UNIT CONSISTS OF TWO TRAINS. GASIFICATION TRAIN NO. 1 IS SHOWN ON THIS PROCESS FLOW DIAGRAM. THE TWO GASIFICATION TRAINS CONVERGE DOWN STREAM OF THE RAW GAS BLOWER.
FIGURE 3-3
REVISIONS
PRELIMINARY NOT FOR CONSTRUCTION
CONSTRUCTION
RELEASED FOR
PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA
PROCESS FLOW DIAGRAM
GAT GASIFICATION PLANT
GILBERT ASSOCIATES, INC.
NONE
08 B276
EE-671-004
A
UPDATED



30-V-20A
FLARE SEAL POT
30-V-11
GAS HOLDER INLET
QUICK GAS SEAL
30-TK-3
GAS HOLDER
CAPACITY 1120 MSCF/HR
126' 0" O.D.
30-V-12
GAS HOLDER OUTLET
QUICK GAS SEAL
VENT TO START-UP FLARE
RAW PRODUCT GAS FROM GASIFIER TRAIN NO.1
PURGE NITROGEN
FLARE SEAL POT
N.C.
GAS HOLDER
C.W. SUPPLY
RAW PRODUCT GAS
PURGE NITROGEN
WASH WATER
RAW PRODUCT GAS FROM BLOWER
RAW PRODUCT GAS FROM GASIFIER TRAIN NO.2
WASH WATER RETURN (SHEET 1)
WASH WATER SUPPLY (SHEET 1)
NITROGEN (SHEET 1)
WASH WATER SUMP

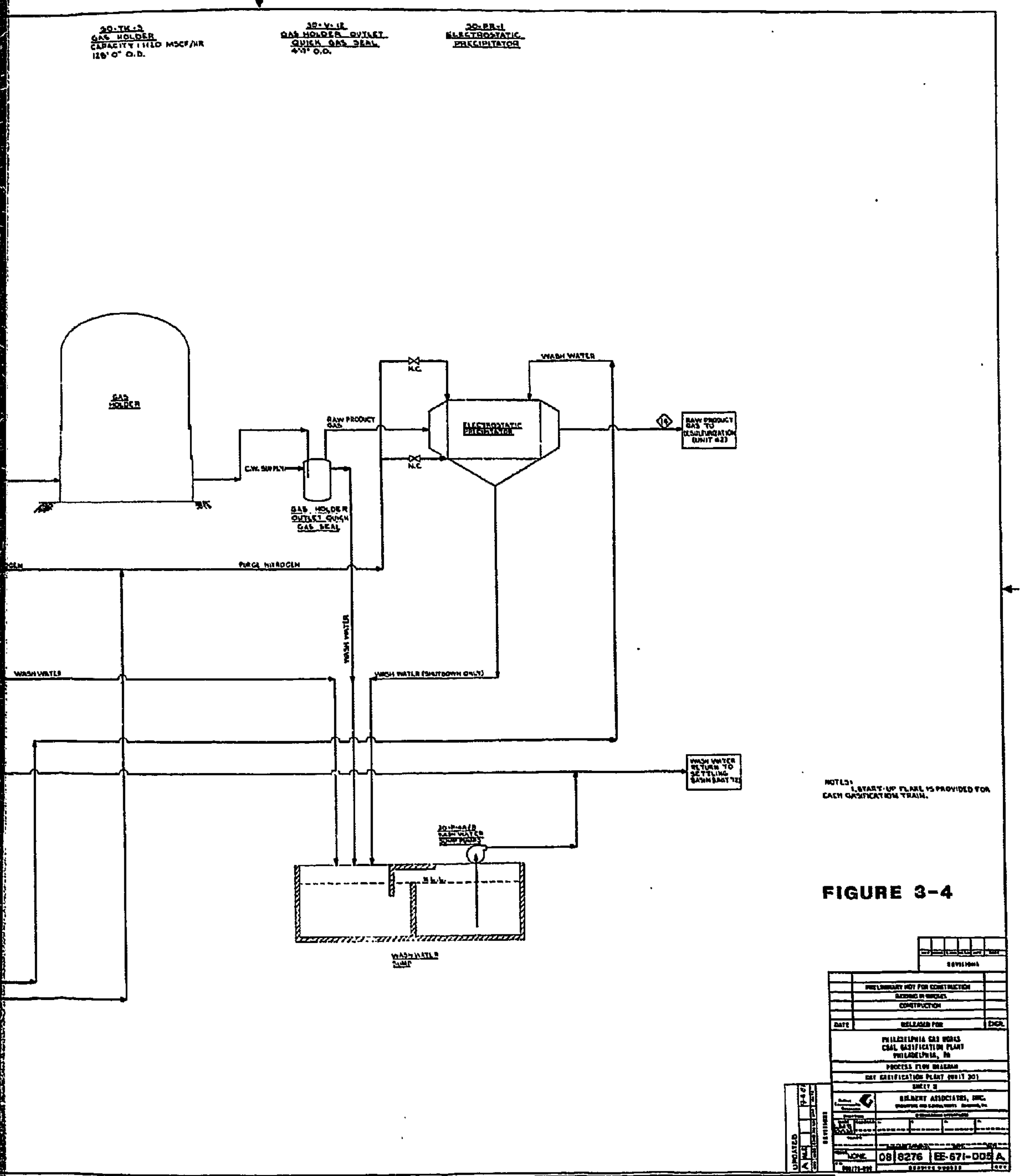
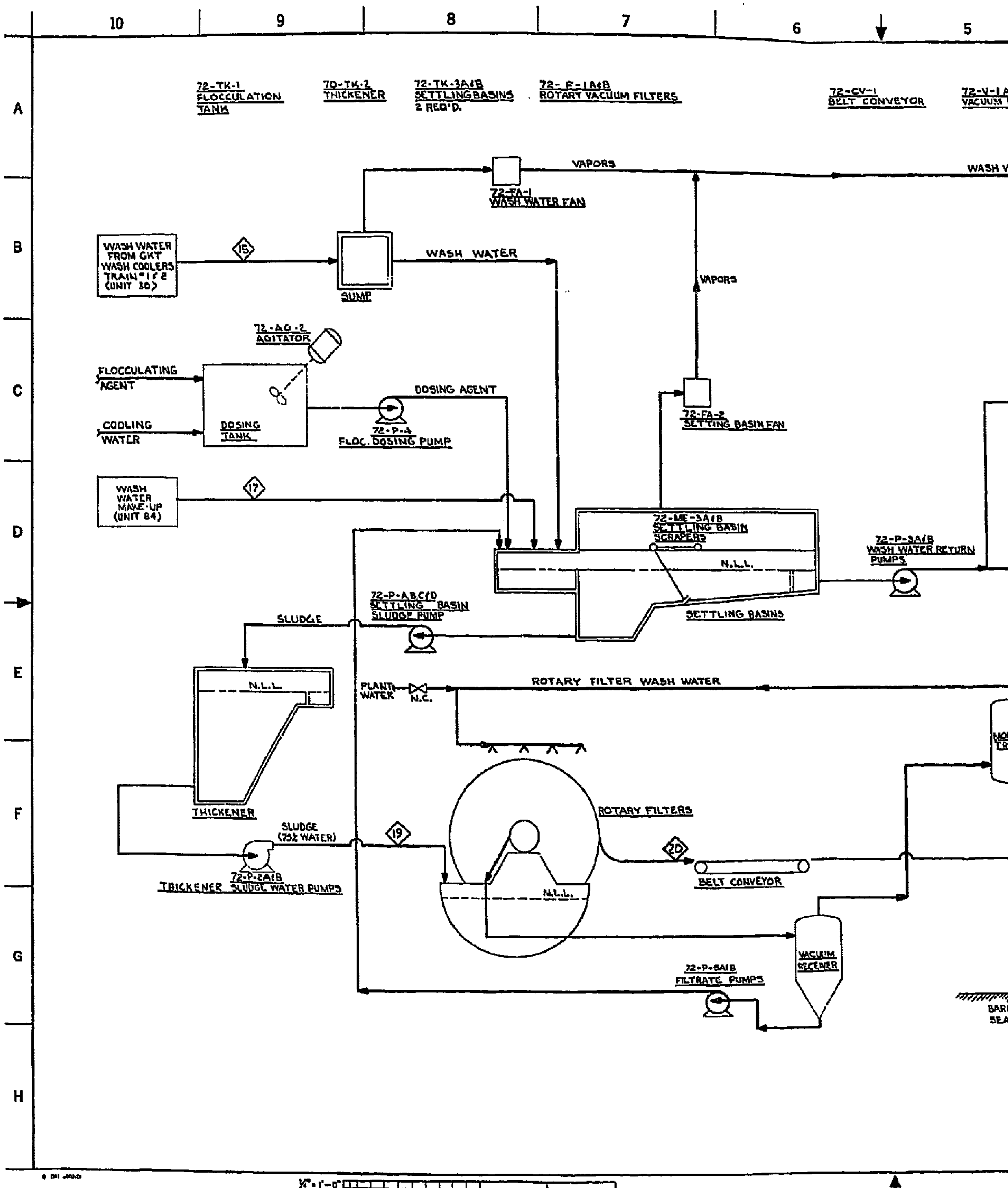
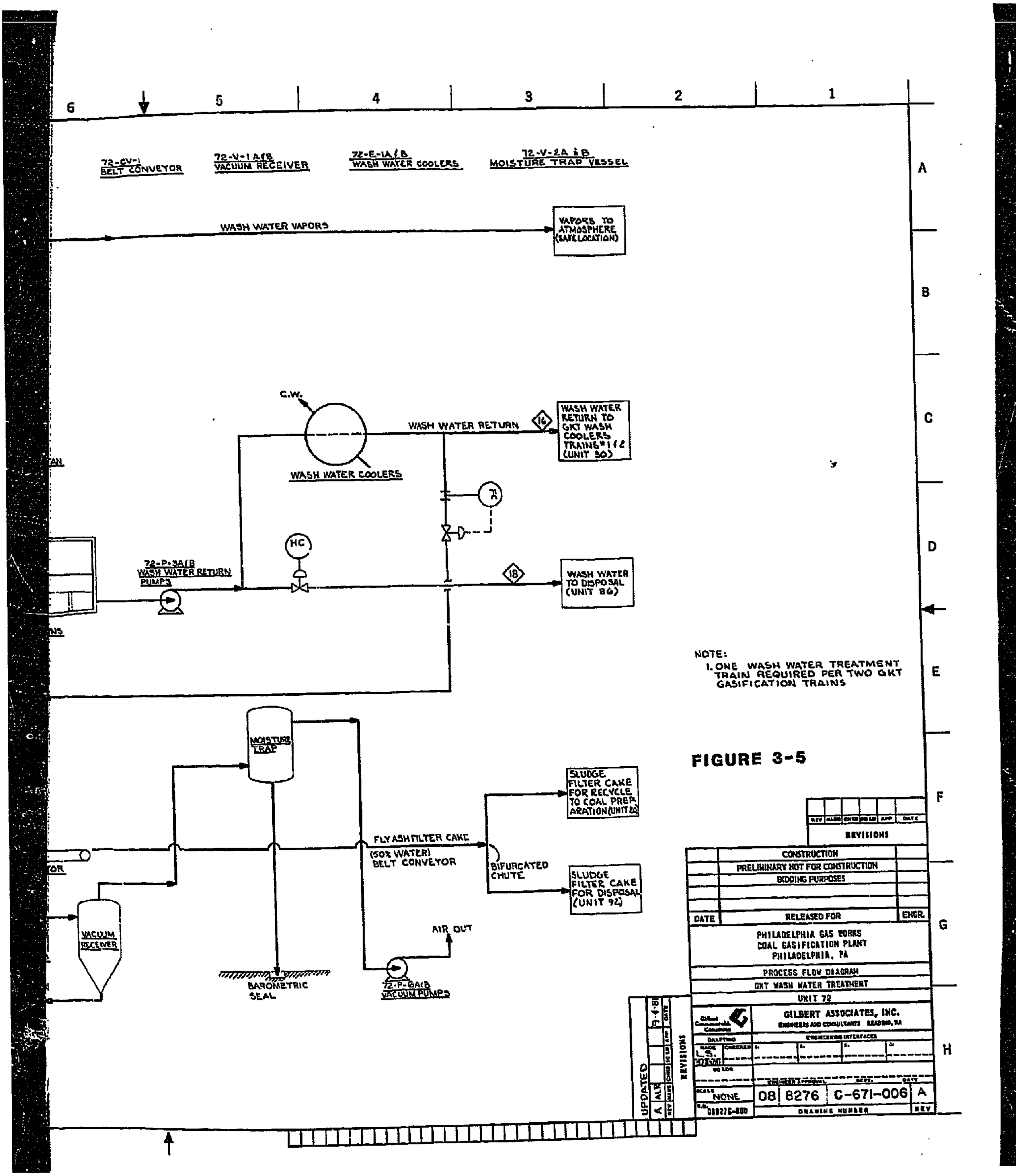

30-TK-3
GAS HOLDER
128' 0" O.D.
ELECTROSTATIC PRECIPITATOR
GAS HOLDER
RAW PRODUCT GAS
C.W. SUPPLY
N.C.
WASH WATER
RAW PRODUCT GAS TO DESULFURIZATION
PURGE NITROGEN
WASH WATER
WASH WATER (SHUTDOWN ONLY)
WASH WATER RETURN TO SETTLING
WASH WATER SUMP
PRELIMINARY NOT FOR CONSTRUCTION
CONSTRUCTION
DATE
RELEASED FOR
PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA
PROCESS FLOW DIAGRAM
SHEET 2
GILBERT ASSOCIATES, INC.
UPDATED
NONE
08 8276
EE-671-005 A

FIGURE 3-4



72-TK-1
FLOCCULATION TANK
70-TK-2
THICKENER
72-TK-3A/B
SETTLING BASINS
2 REQ'D.
72-F-1A/B
ROTARY VACUUM FILTERS
72-CV-1
BELT CONVEYOR
VAPORS
72-FA-1
WASH WATER FAN
WASH WATER FROM GKT WASH COOLERS TRAIN #1 & 2 (UNIT 30)
15
SUMP
WASH WATER
VAPORS
72-AG-2
AGITATOR
FLOCCULATING AGENT
COOLING WATER
DOSING TANK
DOSING AGENT
72-P-4
FLOC. DOSING PUMP
72-FA-2
SETTING BASIN FAN
WASH WATER MAKE-UP (UNIT 84)
17
72-ME-3A/B
SETTLING BASIN SCRAPERS
N.L.L.
72-P-3A/B
WASH WATER RETURN PUMPS
72-P-A,B,C/D
SETTLING BASIN SLUDGE PUMP
SLUDGE
SETTLING BASINS
N.L.L.
PLANT WATER
N.C.
ROTARY FILTER WASH WATER
THICKENER
SLUDGE (75% WATER)
19
ROTARY FILTERS
20
BELT CONVEYOR
72-P-2A/B
THICKENER SLUDGE WATER PUMPS
N.L.L.
VACUUM RECEIVER
72-P-8A/B
FILTRATE PUMPS
¼" = 1'-0"



72-CV-1
BELT CONVEYOR
72-V-1 A&B
VACUUM RECEIVER
72-E-1A&B
WASH WATER COOLERS
72-V-2A & B
MOISTURE TRAP VESSEL
WASH WATER VAPORS
VAPORS TO ATMOSPHERE (SAFE LOCATION)
C.W.
WASH WATER RETURN
WASH WATER RETURN TO GKT WASH COOLERS TRAINS #1 & 2 (UNIT 30)
WASH WATER COOLERS
HC
72-P-3A/B
WASH WATER RETURN PUMPS
WASH WATER TO DISPOSAL (UNIT 86)
NOTE:
1. ONE WASH WATER TREATMENT TRAIN REQUIRED PER TWO GKT GASIFICATION TRAINS
MOISTURE TRAP
SLUDGE FILTER CAKE FOR RECYCLE TO COAL PREPARATION (UNIT 26)
FLY ASH FILTER CAKE
(50% WATER)
BELT CONVEYOR
BIFURCATED CHUTE
SLUDGE FILTER CAKE FOR DISPOSAL (UNIT 92)
VACUUM RECEIVER
AIR OUT
BAROMETRIC SEAL
72-P-6A/B
VACUUM PUMPS
REVISIONS
CONSTRUCTION
PRELIMINARY NOT FOR CONSTRUCTION
BIDDING PURPOSES
DATE
RELEASED FOR
ENGR.
PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA
PROCESS FLOW DIAGRAM
GKT WASH WATER TREATMENT
UNIT 72
GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA
UPDATED
A
ALR
9-4-81
REVISIONS
NONE
08
8276
C-671-006
A
DRAWING NUMBER
REV

FIGURE 3-5

TABLE 3-2

GKT GASIFICATION UNIT MATERIAL BALANCE
DESIGN PRODUCT GAS PRODUCTION (20.58×10^9 BTU/DAY)
NON-ASH RECYCLE CASE

STREAM NO.	1		2		3	4		5	6
	COAL FEED TO GKT GASIFIER NO. 1		OXYGEN FEED TO GASIFIER NO. 1		L.P. STEAM TO GASIFIER NO. 1	PRODUCT GAS EXITING GASIFIER NO. 1		SLAG FM GASIFIER NO. 1 TO DISPOSAL	GASIFIER NO. 1 H.P. & L.P. STEAM DRUM BLOWDOWN
TOTAL FLOW, LB/HR	48,230 (578.8 TPD)		47,455 (569.5 TPD)		4,422	91,584		1,383	1,100
VAPOR FLOW, SCFM	-		9,331		-	26,918		-	-
LIQUID FLOW, GPM	-		-		-	-		-	-
VAPOR MOLECULAR	-		32.16		-	21.52		-	-
TEMPERATURE, °F	60		100		274	2230		100	-
PRESSURE, PSIG (IN W.C.)	-		0.4 (12)		28	1.0		-	-
COMPONENTS	LB/HR	WT %	LB/HR	MOLE %	LB/HR	LB/HR	MOLE %	LB/HR	
S	1,259	2.61	-	-	-	-	-	-	-
C	37,103	76.93	-	-	-	-	-	-	-
H_2	2,523	5.23	-	-	-	2,272	26.69	-	-
O_2	2,262	4.69	46,278	98.00	-	-	-	-	-
N_2	680	1.41	-	-	-	1,075	0.90	-	-
Ar	-	-	1,777	2.00	-	950	0.37	-	-
CO_2	-	-	-	-	-	11,679	6.24	-	-
CO	-	-	-	-	-	68,490	57.46	-	-
CH_4	-	-	-	-	-	7	0.01	-	-
H_2S	-	-	-	-	-	1,208	0.83	-	-
COS	-	-	-	-	-	226	0.09	-	-
HCN	-	-	-	-	-	8	70PPMV	-	-
H_2O	482	1.00	-	-	4,422	5,669	7.40	207	1,100
STRETFORD SOLN.	-	-	-	-	-	-	-	-	-
ASH	3,921	8.13	-	-	-	-	-	-	-
SLAG	-	-	-	-	-	-	-	1,176	-
TOTAL	48,230	100.00	47,455	100.00	4,422	91,584	100.00	1,383	1,100

TABLE 3-2 (Cont'd.)

STREAM NO.	7	8	9	10	11	12	
STREAM DESCRIPTION	L.P. STEAM GENERATION FM GASIFIER NO. 1	H.P. STEAM GENERATION FM GASIFIER NO. 1	QUENCH WATER TO GASIFIER NO. 1	PURGING/ BLANKETING NITROGEN TO GASIFIER NO. 1	EMERGENCY SHUTDOWN NITROGEN TO GASIFIER NO. 1	PRODUCT GAS FM RAW GAS BLOWER NO. 1	
TOTAL FLOW, LB/HR	54,953	55,546	23,320	5,495	32,970	89,897	
VAPOR FLOW, SCFM	-	-	-	1,241	7,446	26,391	
LIQUID FLOW, GPM	-	-	46.6	-	-	-	
VAPOR MOLECULAR	-	-	-	28	28	21.54	
TEMPERATURE °F	274	453	70	100	100	95	
PRESSURE, PSIG (IN W.C.)	28	925	40	10	15	1.5 (42)	
COMPONENTS	LB/HR	LB/HR	LB/HR	LB/HR	LB/HR	LB/HR	MOLE %
S	-	-	-	-	-	-	-
C	-	-	-	-	-	-	-
H_2	-	-	-	-	-	2,278	27.29
O_2	-	-	-	-	-	-	-
N_2	-	-	-	-	-	1,075	0.92
Ar	-	-	-	-	-	950	0.57
CO_2	-	-	-	-	-	11,679	6.36
CO	-	-	-	-	-	68,490	58.61
CH_4	-	-	-	-	-	7	0.01
H_2S	-	-	-	-	-	1,208	0.85
COS	-	-	-	-	-	226	0.09
HCN	-	-	-	-	-	8	75 PPMV
H_2O	54,953	55,546	23,320	-	-	3,976	5.30
STRETFORD SOLN.	-	-	-	-	-	-	-
ASH	-	-	-	-	-	-	-
SLAG	-	-	-	-	-	-	-
TOTAL	54,953	55,546	23,320	5,495	32,970	89,897	100.00

TABLE 3-2 (Cont'd.)

STREAM NO.	13		14		15	16	17	18
STREAM DESCRIPTION	PRODUCT GAS FM RAW GAS BLOWER NO. 2		PRODUCT GAS FM GKT UNIT-TRAINS 1 & 2		WASH WATER FM GKT WASH COOLERS - TRAINS 1 & 2	WASH WATER RETURN TO GKT WASH COOLERS - TRAINS 1 & 2	WASH WATER MAKE-UP TO SETTLING BASINS	EXCESS WASH WATER TO DISPOSAL
TOTAL FLOW, LB/HR	89,897		179,794		2,090,143	2,088,407	NORMALLY 0	5,470
VAPOR FLOW, SCFH	26,391		52,781		-	-	-	-
LIQUID FLOW, GPH	-		-		4,182	4,178	-	10.9
VAPOR MOLECULAR	21.54		21.54		-	-	-	-
TEMPERATURE, °F	95		95		158	113	-	158
PRESSURE, PSIG (IN. W.C.)	1.5 (42)		0.8 (22)		10	100	-	-
COMPONENTS	LB/HR	MOLE %	LB/HR	MOLE %	LB/HR	LB/HR	LB/HR	LB/HR
S	-	-	-	-	-	-	-	-
C	-	-	-	-	-	-	-	-
H_2	2,278	27.29	4,556	27.29	-	-	-	-
O_2	-	-	-	-	-	-	-	-
N_2	1,075	0.92	2,150	0.92	-	-	-	-
Ar	950	0.57	1,900	0.57	-	-	-	-
CO_2	11,679	6.36	23,358	6.36	-	-	-	-
CO	68,490	58.61	136,980	58.61	-	-	-	-
CH_4	7	0.01	13	0.01	-	-	-	-
H_2S	1,208	0.85	2,417	0.85	-	-	-	-
COS	226	0.09	451	0.09	-	-	-	-
HCN	8	75 PPMV	17	75 PPMV	-	-	-	-
H_2O	3,976	5.30	7,952	5.30	2,090,143	2,088,407	-	5,470
STRETFORD SOLN.	-	-	-	-	-	-	-	-
ASH	-	-	-	-	-	-	-	-
SLAG	-	-	-	-	-	-	-	-
TOTAL	89,897	100.00	179,794	100.00	2,090,143	2,088,407	0	5,470

TABLE 3-2 (Cont'd.)

STREAM NO.	19		20	
STREAM DESCRIPTION	FLY ASH SLUDGE TO ROTARY FILTERS		FLY ASH SLUDGE TO DISPOSAL	
TOTAL FLOW, LB/HR	56,816		28,750 (345 TPD)	
VAPOR FLOW, SCFH	-		-	
LIQUID FLOW, GPH	-		-	
VAPOR MOLECULAR	-		-	
TEMPERATURE, °F	70		70	
PRESSURE, PSIG (IN W.C.)	-		-	
COMPONENTS	LB/HR	WT %	LB/HR	WT %
S	-	-	-	-
C	8,721	15.35	8,892	30.93
H_2	-	-	-	-
O_2	-	-	-	-
N_2	-	-	-	-
Ar	-	-	-	-
CO_2	-	-	-	-
CO	-	-	-	-
CH_4	-	-	-	-
H_2S	-	-	-	-
COS	-	-	-	-
HCN	-	-	-	-
H_2O	42,612	75.00	14,375	50.00
STRETFORD SOLN.	-	-	-	-
ASH	5,483	9.65	5,483	19.07
SLAG	-	-	-	-
TOTAL	56,816	100.00	28,750	100.00

emergency shut-down. The service and feed bins provide a total of approximately 15 minutes of storage for the gasifiers at design usage rates.

Controls regulate the intermittent feeding of coal from the service bins to the feed bins which are connected to twin variable-speed coal screw feeders. Four double coal screw feeders are provided per gasifier to supply pulverized coal to each burner head. The pulverized coal is continuously discharged from the twin screws into mixing nozzles where it is entrained in oxygen and low pressure steam. For each gasifier 48,230 lbs per hour (579 tpd) of Pittsburgh No. 8 coal react with 47,455 lbs per hour (569.5 tpd) of oxygen and 4,422 lbs per hour of steam for the production of 10 billion Btu per day of medium-Btu gas (lower heating value basis). The mixture is then delivered through twin blow pipes to each burner head. Moderate temperature and high burner velocity prevents the reaction of coal and oxygen until they enter the gasification zone.

Oxygen/steam mixers are provided to insure complete mixing before injection into the blow pipes. Two oxygen/steam mixers are provided per gasifier. The normal oxygen/ coal ratio for a typical Pittsburgh No. 8 coal is 0.98 lb/lb and the normal steam/coal ratio is 0.09 lb/lb. The oxygen required for the partial oxidation reaction is provided at 98 volume percent purity from an air separation plant. Approximately 54,950 lbs per hour of low pressure steam at 28 psig is generated from each gasifier jacket.

In the gasifier, the coal dust is oxidized by oxygen in presence of steam. Under the process conditions prevailing in the gasifier, carbon and hydrocarbons contained in the coal are converted to carbon monoxide, hydrogen, and carbon dioxide. Besides these components, sulfur compounds in accordance with the sulfur content of the feedstock, and nitrogen resulting from the impurity of the oxygen and the feedstock, are contained in the generated gas.

Traces of methane, not exceeding 0.01 percent by volume, are also produced. However, no hydrocarbons, phenols, aromatics, or any other organic compounds are generated in the GKT gasification process.

The gasification reaction (partial oxidation) of the coal is carried out in two four-headed gasifiers, each of which is connected to a waste heat recovery system for generation of high pressure steam (925 psig). The gasifier itself is a double-shell reactor, lined with refractory, and generates low-pressure steam (28 psig) within its shell. Endothermic reactions, occuring in the gasifier between carbon and steam, and radiation to the refractory walls substantially reduce the flame temperature from 3500°F to 2700°F.

Ash in the coal feed is liquified in the gasifier high temperature zone. Approximately 30 percent of the ash is dropped out of the gasifier as molten slag and is quenched and collected in a water seal type slag quench tank and recovery system at the bottom of the gasifier. The recovered granular slag is transported from the bottom of the slag recovery system, via a slag extractor (drag chain conveyor), where the slag is dewatered and delivered to a belt conveyor. Belt conveyors, in turn, deliver the slag to an on-site storage area prior to disposal.

The remainder of the ash and the unreacted carbon are entrained in the gas exiting the gasifier. Water sprays quench the gas to reduce the temperature below the ash fusion temperature to prevent slag particules from adhering to the tubes of the waste heat boiler mounted over the gasifier.

The raw gas from the gasifier passes through the waste heat boiler where 55,550 lbs per hour of high pressure, saturated steam (925 psig) is generated per gasifier. After leaving the waste heat boiler, the gas at 600°F is cleaned and cooled in a gas clean-up system. The system consists of a cooling washer which removes the largest particulates and cools the gas to 170°F, followed by a "disintegrator" type scrubber which reduces the particulate content of the gas to approximately 0.004 grains per standard cubic feet.

To reduce the water droplets carried with the raw gas, a separator is linked downstream to the disintegrator by which the majority of the water is recovered. The collected water is recycled to the cooling washer. After leaving the separator, the gas passes through a second separator for final treatment and is routed to the raw gas blower which feeds a gas holder and an electrostatic precipitator. The gas blower pressurizes the raw product gas to a delivery pressure at the GKT Gasification Unit battery limits (downstream of electrostatic precipitator) to approximately 22 inches of water.

Downstream of the raw gas blowers the two gasification trains join together to form a single train. The combined pressurized raw product gas passes into a single gas holder. The capacity of the gas holder is approximately 1.117 MM SCF of raw product gas. The gas holder provides approximately 20 minutes of storage capacity at the design usage rate in the event of a short term upstream gasification system failure. The gas holder also helps to smooth out the product gas user demand fluctuations. From the gas holder the gas is discharged to an electrostatic precipitator which removes the remaining fine particles before the gas enters the Desulfurization Unit for final clean-up.

Particulate-laden water from the GKT gas cleaning and cooling system is channeled to settling basins in the GKT Wash Water Treatment Unit (Unit 72). A portion of the fly ash carried over from the gasifier will be collected at the fly ash sump and pumped as slurry to the waste water treatment settling basins. The major portion of the particles, however, are channeled with the circulating waste water which, after leaving the wash cooler, flows to settling basins for particulate removal.

In the Wash Water Treament Unit, two 33 ft by 197 ft settling basins are provided to separate the ash and carbon particles entrained in the wash water from the GKT Gasification Unit. The settling basins are designed with adequate residence time to allow the settling of particles to the bottom of the settling basins, from which they are pushed by scrapers to a collecting sump adjacent to the settling basins. The ash slurry from the collection sump is pumped to a thickener. From the underflow of the thickener, a slurry pump transports the ash sludge to rotary vacuum filters for water removal. Two rotary vacuum filters are provided to reduce the sludge water content to 50 percent.

The fly ash sludge from the rotary filters is transported to the ash storage area via belt conveyors for temporary on-site storage. For Pittsburgh No. 8 coal with an ash content of 7.83 percent this would result in an ash sludge production rate of 345 tpd at design capacity. To reduce the ash disposal problem the GKT gasification plant has been designed with the capability of recycling a maximum of 50 percent of the ash sludge to the pulverizers. (The recycled sludge cake is transported to the pulverizers in the Coal Preparation Unit via belt conveyors). The sludge, at 50 percent recycle, contains approximately 26 percent unused carbon and will increase the gasifier carbon conversion from 88.0 to 93.6 percent while reducing the raw coal feed by 6 percent. The mixed feed would contain approximately 11.5 percent moisture compared to 4.6 percent for the Pittsburgh No. 8 fresh feed coal. The pulverizer and the pulverizer air heater are sized to handle the ash recycle operation.

During start-up of the gasifiers, the off-spec product gas will be routed to start-up flares provided within the GKT battery limits. A start-up flare is provided for each GKT gasifier train. Product gas is diverted upstream of the raw gas blowers to each flare. The start-up of a gasifier from ambient to design conditions takes a maximum of ten hours. Restart of the gasifier after a short shut-down period (about one hour), however, takes only 30 minutes.

A single GKT gasifier can be turned down to approximately 70 percent of its full load capacity within a few minutes. By shutting down one gasifier completely and turning the remaining gasifier down to 70 percent, the plant production is reduced to 35 percent. Therefore, the product gas output from the two-gasifier GKT plant can be adjusted in the range of 35 to 100 percent.

3.5 SULFUR REMOVAL AND RECOVERY

The sulfur removal and recovery system consists of two units. The first unit consists of a Stretford desulfurization plant (Unit 42) which removes H_2S present in the raw gas by converting it to recoverable elemental sulfur. The Stretford plant generates a purge liquor stream containing insoluble Na_2SO_4, $Na_2S_2O_3$, and NaSCN salts. The purge stream has a high COD value and is decomposed in the second unit, the Nittetu reductive incineration plant (Unit 44). Part of the clean product gas from the Stretford plant is burned with substoichiometric air in the Nittetu plant to produce the hot reduced gas necessary for the decomposition of the salts. Sodium vanadate, a component of Stretford Solution, is recovered with caustic alkali in the Nittetu plant and is recycled to the Stretford plant. The decomposed gas produced in the Nittetu plant contains H_2S and is recycled to the Stretford plant to combine with the raw gas from GKT gasification plant for sulfur removal.

3.5.1 Stretford Desulfurization

The Stretford desulfurization process developed by the British Gas Board is a direct oxidation process. The Stretford Plant is designed to remove 90 percent of the sulfur contained in the product gas produced from the gasification of Pittsburgh No. 8 coal, which contains 2.64 percent sulfur by weight (dry basis). The product gas from the GKT gasification plant contains 0.90 percent H_2S and 0.09 percent COS on a dry volume basis. The Stretford plant removes almost all H_2S. COS is not removed from the gas; however, when burned it will produce only 350 ppmv SO_2 or 0.60 lb SO_2 per 10^6 Btu heat input which is well below the 500 ppmv or 0.86 lb SO_2 per 10^6 Btu limit set by the City of Philadelphia.

The Stretford plant can be designed to produce either filter cake or molten sulfur. The selection depends on the plant capacity, environmental restrictions, by-product sulfur credit and the filter cake disposal costs. The molten sulfur configuration generates a purge liquor stream which requires either on-site treatment by reductive incineration or disposal by hauling it to a hazardous waste treatment facility. Again the selection between the two depends on the size of the plant and economics. An economic evaluation of the above options was performed (see Appendix C) and the results favored the selection of the molten sulfur option with on-site reductive incineration.

3.5.1.1 Process Chemistry

The Stretford solution is an aqueous mixture of anthraquinonedisulfonic acid (ADA), sodium metavanadate, and sodium carbonate. The removal of H_2S and its conversion to elemental sulfur are represented by the following idealized reactions:

$$2H_2S + 2Na_2CO_3 \rightarrow 2NaHS + 2NaHCO_3$$
$$2NaHS + 4NaVO_3 + H_2O \rightarrow Na_2V_4O_9 + 4NaOH + 2S$$
$$Na_2V_4O_9 + 2\ NaOH + H_2O + 2ADA \rightarrow 4NAVO_3 + 2ADA(H_2)$$
$$2NaHCO_3 + 2NaOH \rightarrow 2Na_2CO_3 + 2H_2O$$
$$2ADA(H_2) + O_2 \rightarrow 2ADA + 2H_2O$$

where $ADA(H_2)$ represents the reduced form of ADA. Ionized forms of the reactants in aqueous solution are usually involved. The sum of the foregoing reactions gives the overall reaction

$$2H_2S + O_2 \rightarrow 2H_2O + 2S.$$

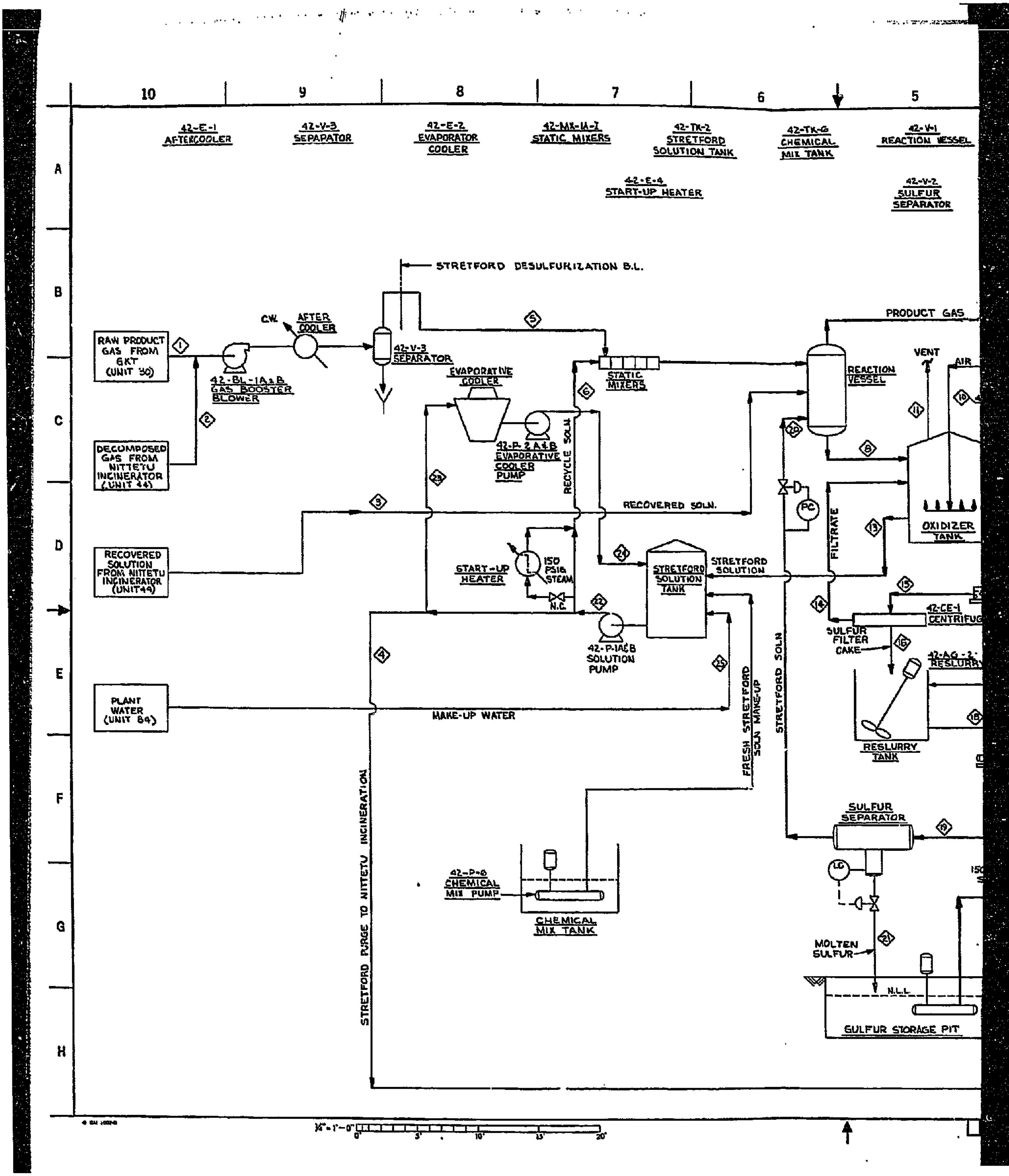
In this sequence of reactions, the hydrosulfide reaction product is oxidized to free elemental sulfur by reduction of vanadium from the pentavalent to the quadrivalent oxidation state, and the reduced vanadium is reoxidized by reduction of ADA. Air is blown through the solution in the oxidizer vessel to reoxidize the reduced ADA. Although the rate of H_2S absorption increases with the alkalinity of the solution, pH values above 9.5 are unfavorable for conversion to elemental sulfur.

3.5.1.2 Process Description

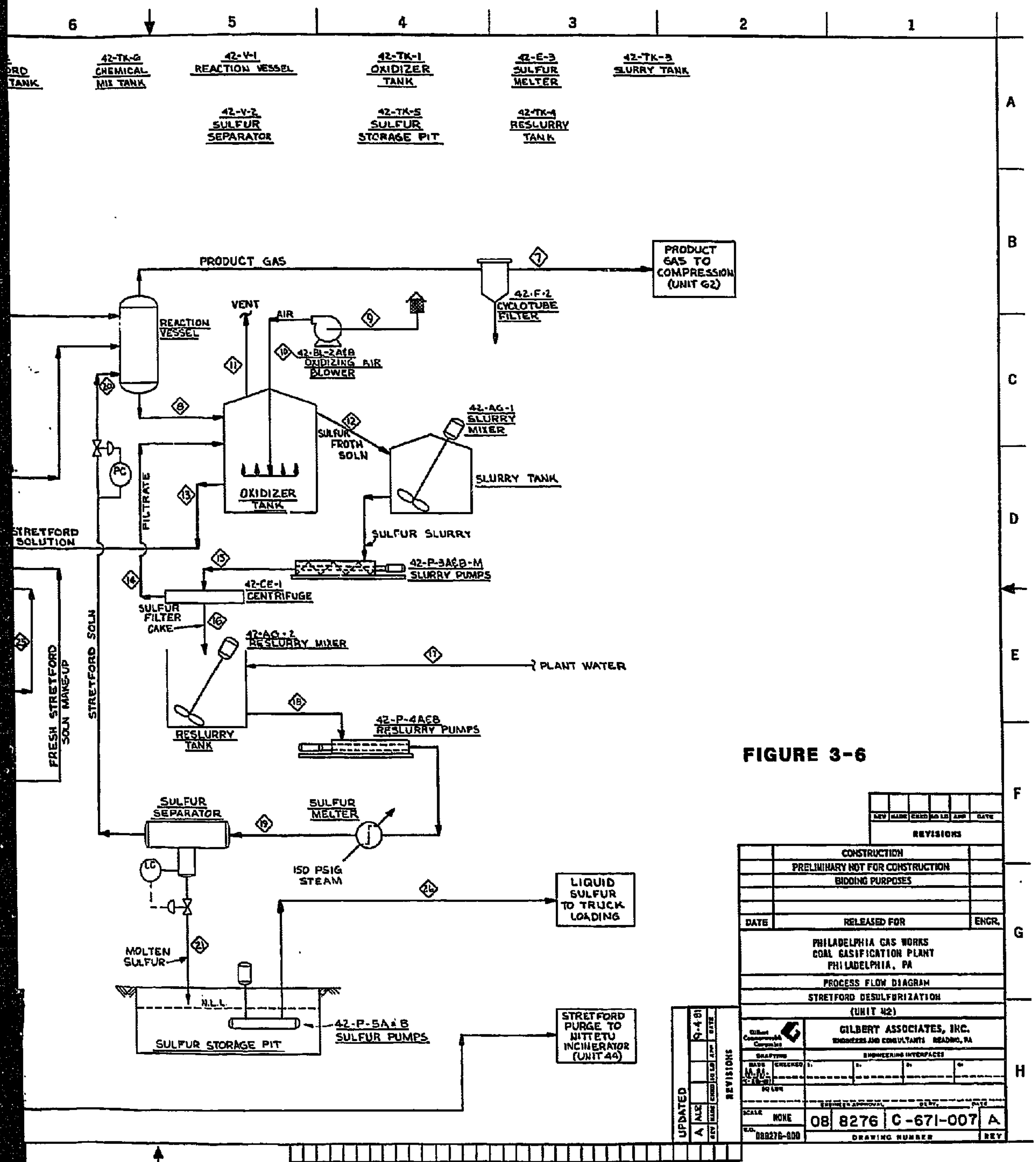
For the design coal (2.64 percent S, dry basis) the Stretford plant capacity is 27.3 tpd sulfur. Equipment sizing for the process is governed by the total quantity of sulfur in the fuel gas from the GKT gasification plant. The present design conservatively assumes that all the sulfur present in the coal appears in the gas. However, in the actual operation, some sulfur is retained in the ash. This allows a margin for using a higher sulfur coal.

Figure 3-6 shows the process flow and Table 3-3 gives the material balance for the Stretford plant. The raw gas from the GKT gasification plant at 95°F and 15.5 psia, and the decomposed gas from the Nittetu plant at 120°F and 15.5 psia are combined and compressed in the blower. The combined gas is cooled and washed in static mixers with the oxidized Stretford solution. The gas and the solution from the static mixers discharge into the reaction vessel which is sized to allow sufficient residence time for the sulfur forming reaction mechanism to go to completion.

The treated gas exits the top of the reaction vessel and enters the gas compression and dehydration units. The solution from the reaction zone in the reaction vessel flows to an oxidizer tank where an aerator disperses air supplied by the air blower. Sulfur slurry overflows from the oxidizer tank into the sulfur slurry tank by gravity. The oxidized solution is recycled from the pump tank to



10
9
8
7
6
5
A
B
C
D
E
F
G
H
42-E-1
AFTERCOOLER
42-V-3
SEPARATOR
42-E-2
EVAPORATOR COOLER
42-MX-1A-J
STATIC MIXERS
42-TK-2
STRETFORD SOLUTION TANK
42-TK-6
CHEMICAL MIX TANK
42-V-1
REACTION VESSEL
42-E-4
START-UP HEATER
42-V-2
SULFUR SEPARATOR
STRETFORD DESULFURIZATION B.L.
RAW PRODUCT GAS FROM GKT (UNIT 30)
C.W.
AFTER COOLER
42-V-3 SEPARATOR
42-BL-1A & B GAS BOOSTER BLOWER
PRODUCT GAS
VENT
AIR
STATIC MIXERS
REACTION VESSEL
EVAPORATIVE COOLER
DECOMPOSED GAS FROM NITTETU INCINERATOR (UNIT 44)
42-P-2 A & B EVAPORATIVE COOLER PUMP
RECYCLE SOLN
RECOVERED SOLN.
OXIDIZER TANK
FILTRATE
RECOVERED SOLUTION FROM NITTETU INCINERATOR (UNIT 44)
START-UP HEATER
150 PSIG STEAM
N.C.
STRETFORD SOLUTION TANK
STRETFORD SOLUTION
PC
42-CE-1 CENTRIFUG
SULFUR FILTER CAKE
42-P-1A & B SOLUTION PUMP
42-AG-2 RESLURRY
PLANT WATER (UNIT 84)
MAKE-UP WATER
RESLURRY TANK
FRESH STRETFORD SOLN MAKE-UP
STRETFORD SOLN
STRETFORD PURGE TO NITTETU INCINERATION
SULFUR SEPARATOR
LC
42-P-6 CHEMICAL MIX PUMP
CHEMICAL MIX TANK
MOLTEN SULFUR
N.L.L.
SULFUR STORAGE PIT
¼" = 1'-0"
0'
5'
10'
15'
20'



42-TK-6 CHEMICAL MIX TANK
42-V-1 REACTION VESSEL
42-TK-1 OXIDIZER TANK
42-E-3 SULFUR MELTER
42-TK-3 SLURRY TANK
42-V-2 SULFUR SEPARATOR
42-TK-5 SULFUR STORAGE PIT
42-TK-4 RESLURRY TANK
PRODUCT GAS
PRODUCT GAS TO COMPRESSION (UNIT G2)
42-F-2 CYCLOTUBE FILTER
REACTION VESSEL
VENT
AIR
42-BL-2A&B OXIDIZING AIR BLOWER
SULFUR FROTH SOLN
42-AG-1 SLURRY MIXER
SLURRY TANK
OXIDIZER TANK
FILTRATE
STRETFORD SOLUTION
SULFUR SLURRY
42-P-3A&B-M SLURRY PUMPS
42-CE-1 CENTRIFUGE
SULFUR FILTER CAKE
42-AG-2 RESLURRY MIXER
PLANT WATER
RESLURRY TANK
42-P-4A&B RESLURRY PUMPS
STRETFORD SOLN
FRESH STRETFORD SOLN MAKE-UP
SULFUR SEPARATOR
SULFUR MELTER
150 PSIG STEAM
LIQUID SULFUR TO TRUCK LOADING
MOLTEN SULFUR
N.L.L.
42-P-5A&B SULFUR PUMPS
SULFUR STORAGE PIT
STRETFORD PURGE TO NITTETU INCINERATOR (UNIT 44)
REVISIONS
CONSTRUCTION
PRELIMINARY NOT FOR CONSTRUCTION
BIDDING PURPOSES
DATE
RELEASED FOR
ENGR.
PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA
PROCESS FLOW DIAGRAM
STRETFORD DESULFURIZATION
(UNIT 42)
GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA
UPDATED
SCALE NONE
08 8276 C-671-007 A
DRAWING NUMBER

FIGURE 3-6

TABLE 3-3

PGW GASIFICATION PROJECT
STRETFORD PLANT PROCESS
MATERIAL AND ENERGY BALANCE

STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13
Temp, °F	95.0	120.0	195.0	105.2	101.0	105.2	105.2	105.2	91.0	304.1	105.2	105.2	105.2
Press, psia	15.5	15.5	44.7	124.7	20.5	46.7	16.2	16.7	14.7	35.86	14.7	14.7	14.7
Total Flow, lbs/hr	179794	7424	3540	3500	186069	6574634	186224	6583454	37974	37974	38542	31626	6578417
Liquid, gpm		0.0594	6.1	6.17		10117		10132				47.49	10124
Flowing, lbs/gal		8.25	9.67	9.45		10.831		10.83				11.10	10.83
Vapor Flow, ACFS	889.69	27.75			694.83		895.20		151.3	84.28	157.12		
Flowing, lbs/ft³	0.0561	0.0743			0.0744		0.0578		0.070	0.125	0.068		
Vapor Mol. Wt	21.54	26.69			21.81		21.60		28.55	28.55	28.05		
ADA Soln (lbs/hr)			3540	3500		6574634		6580669				29347	6578417
Sulfur (lbs/hr)								2279				2279	
Composition, Moles/hr: CO_2	530.87	60.84			591.71		580.66	11.05			11.05		
CO	4892.16	23.99			4916.15		4913.04	3.11			3.11		
H_2	2277.89	11.13			2289.02		2287.61	1.41			1.41		
H_2S	70.95	4.02			47.97		-						
COS	7.51				7.51		7.51						
HCN	0.63				0.63		0.23	0.40					
N_2	76.79	120.99			197.78		197.78		1023.04	1023.04	1023.04		
Ar	47.57				47.57		47.57						
CH_4	0.83				0.83		0.83						
H_2O	441.77	29.10	154.15	138.0	407.03	346995	586.26	347331	34.8	34.8	103.56	1547.74	347159
Sulfur								71.22				71.22	
O_2									271.95	271.95	231.88		
NaHS			4.30										
TOTAL	8346.97	250.07	158.45	138.0	8533.20	346995	8621.49	347418	1329.79	1329.79	1374.05	1618.66	347159

TABLE 3-3 (Cont'd.)

STREAM NO.	14	15	16	17	18	19	20	21	22	23	24	25	26
Temp, °F	105.2	105.2	105.2	86.0	105.2	280	280	280	105.2	105.2	95.4	86.0	
Press, psia	30.0	64.7	30.0	64.7	79.7	74.7	16.7	14.7	124.7	100.0	30.0	64.7	
Total Flow, lbs/hr	27118.3	31644.9	4507.7		7450.7	7450.7	5171.7	2279	8527174	1949040	1936210	12542	
Liquid, gpm	41.73	47.3	5.71	5.9	11.49	12.13		2.55	13123	3000	2974	25.1	
Flowing, lbs/gal	10.83	11.1	13.15		10.65	10.08		14.9	10.83	10.83	10.85	8.33	
Vapor Flow, ACFS													
Flowing, lbs/ft^3													
Vapor Mol. Wt													
ADA Soln (lbs/hr)	21778.3	29365.9	2207.3		5171.7	5171.7	5171.7						
Sulfur (lbs/hr)		2279	2279		2279	2279		2279					91160
Composition, Moles/hr: CO_2													
CO													
H_2													
H_2S													
COS													
HCN													
N_2													
Ar													
CH_4													
H_2O	1431.24	1548.74	116.50	163.5	281.16	281.16	281.16		450043	102910	102197	696.8	
Sulfur		71.22	71.22		71.22	71.22		71.22					2848.8
O_2													
NaHS													
TOTAL	1431.24	1619.96	187.72	163.5	352.38	352.38	281.16	71.22	450043	102910	102197	696.8	2848.8

the static mixers. A cooling tower and circulating pump are provided with the pump tank to maintain the heat and water balance in the unit.

The sulfur slurry which flows to the slurry tank is agitated and, thus, deaerated. Slurry from the slurry tank is then pumped to a centrifuge. The recovered solution in the centrifuge goes back to the oxidizer tank and the 50 percent concentrated sulfur cake passes to the reslurry tank. The concentrated sulfur slurry is mixed with water to a 30 percent slurry, which is pumped to the sulfur melter by a reslurry pump. The sulfur melter consists of a steam-heated exhanger where the temperature of the slurry is raised above the melting point of the sulfur at a pressure sufficiently high to prevent the solution from boiling. Separation of the molten sulfur and the hot solution occurs in the sulfur separator because of a large difference in specific gravity. The molten sulfur passes to the sulfur storage pit with the hot solution being returned to the reaction vessel. A chemical mix tank is required for preparing fresh Stretford solution and adding makeup chemicals.

A purge stream from the recirculating Stretford solution stream is sent to the Nittetu incineration plant.

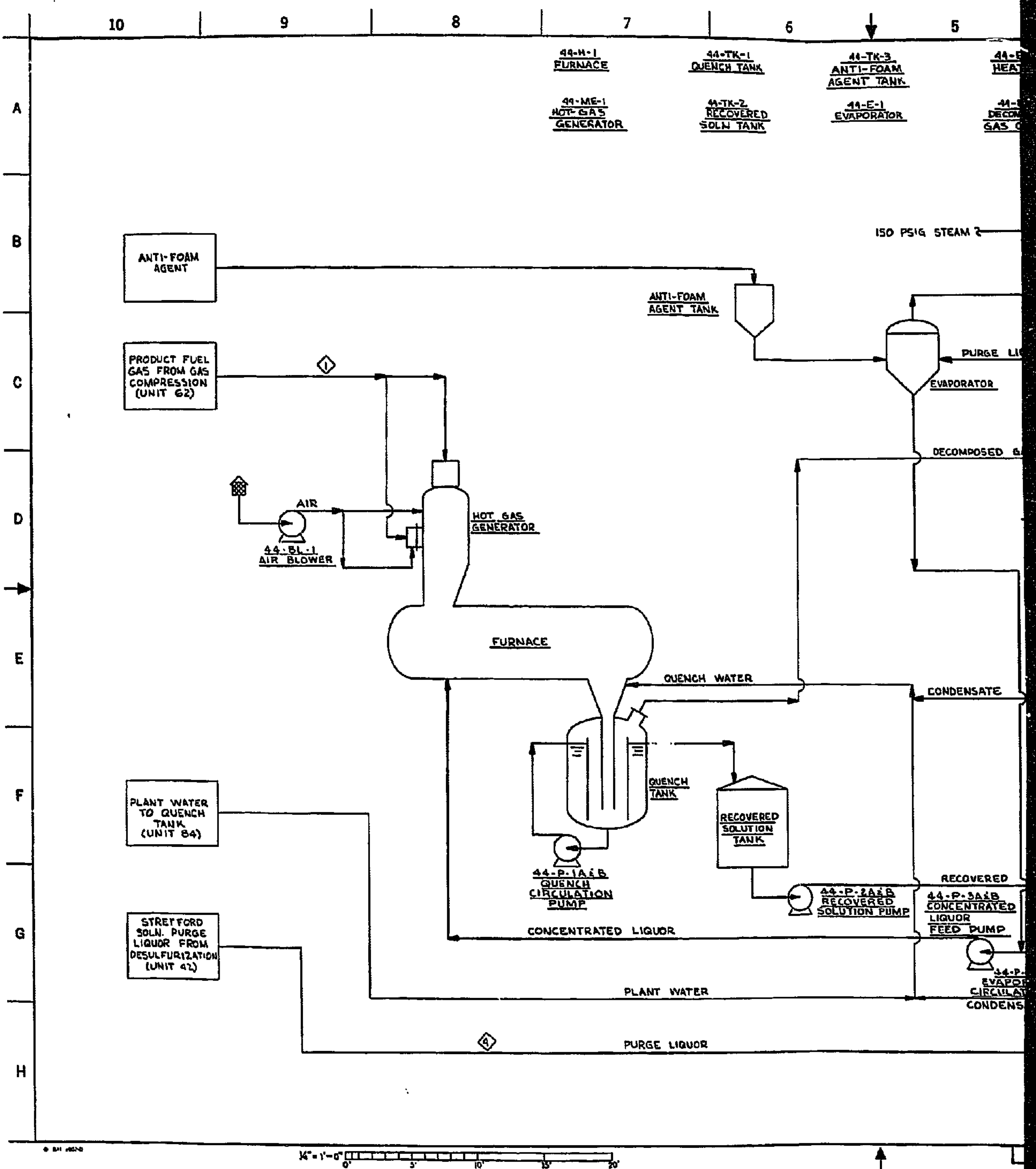
3.5.2 Nittetu Incineration

The stretford plant purge liquor (containing sodium salts) has high COD value and cannot be biodegraded. The Nittetu reductive incineration process is designed to decompose the purge liquor under high temperature and reducing atmosphere in which accumulated inert compounds such as Na_2SO_4, $Na_2S_2O_3$, and NaSCN in the solution are converted to the active components Na_2CO_3, $NaHCO_3$, and NaHS. Also, sodium vanadate is recovered with caustic alkali. Decomposed gas containing H_2S is recycled back to the Stretford plant.

The Nittetu process is shown in Figure 3-7, and Table 3-4 gives the material balance. The purge liquor from the Stretford process, containing about 70 percent water, is fed to an evaporator at the operating conditions of about 140°F and 100 to 200 mm Hg abs, where it is concentrated by use of decomposed gas as a heat source. Vaporized water from the evaporator is sent to a surface condenser, where it is condensed and recycled to the quench tank. The concentrated waste, with a total solid content of 40 to 45 wt percent, is fed to a furnace using spray nozzles. At the upper section of the furnace, a hot gas generator burns the product fuel-gas with substoichiometric air to produce hot reducing gas. In the furnace, water is vaporized from the waste liquor and the inactive salts are decomposed under the reducing atmosphere. These salts are in molten state. Some are carried over by hot decomposed gases and some flow along the refractory-lined wall to the quench tank located below the furnace. Here the gases are cooled quickly and the salts are collected and dissolved in the liquid. Hot decomposed gases are injected into the liquid through a downcomer tube and rise through an annular section between tube and weir where they are contacted intimately with water. The recovered solution is collected in the recovered solution tank and pumped back to the Stretford plant. The decomposed gas leaving the quench tank is first sent to the evaporator heat exchanger for heat recovery and finally to a gas cooler. The decomposed gas containing H_2S is sent back to the Stretford plant to be mixed with the raw gas from the GKT gasification plant.

3.6 AIR SEPARATION

A 1,200 tpd air separation plant is required to provide oxygen for the GKT Gasification Unit. The by-product nitrogen from the air separation plant is utilized for pneumatic conveying of pulverized coal from the coal preparation area to the gasification unit and for gasifier unit purging and blanketing.



44-H-1 FURNACE
44-ME-1 HOT GAS GENERATOR
44-TK-1 QUENCH TANK
44-TK-2 RECOVERED SOLN TANK
44-TK-3 ANTI-FOAM AGENT TANK
44-E-1 EVAPORATOR
150 PSIG STEAM
ANTI-FOAM AGENT
ANTI-FOAM AGENT TANK
PRODUCT FUEL GAS FROM GAS COMPRESSION (UNIT 62)
PURGE LI
EVAPORATOR
DECOMPOSED
AIR
HOT GAS GENERATOR
44-BL-1 AIR BLOWER
FURNACE
QUENCH WATER
CONDENSATE
QUENCH TANK
RECOVERED SOLUTION TANK
PLANT WATER TO QUENCH TANK (UNIT 84)
44-P-1A&B QUENCH CIRCULATION PUMP
44-P-2A&B RECOVERED SOLUTION PUMP
RECOVERED
44-P-3A&B CONCENTRATED LIQUOR FEED PUMP
STRETFORD SOLN. PURGE LIQUOR FROM DESULFURIZATION (UNIT 42)
CONCENTRATED LIQUOR
PLANT WATER
CONDENS
PURGE LIQUOR
1/4" = 1'-0"

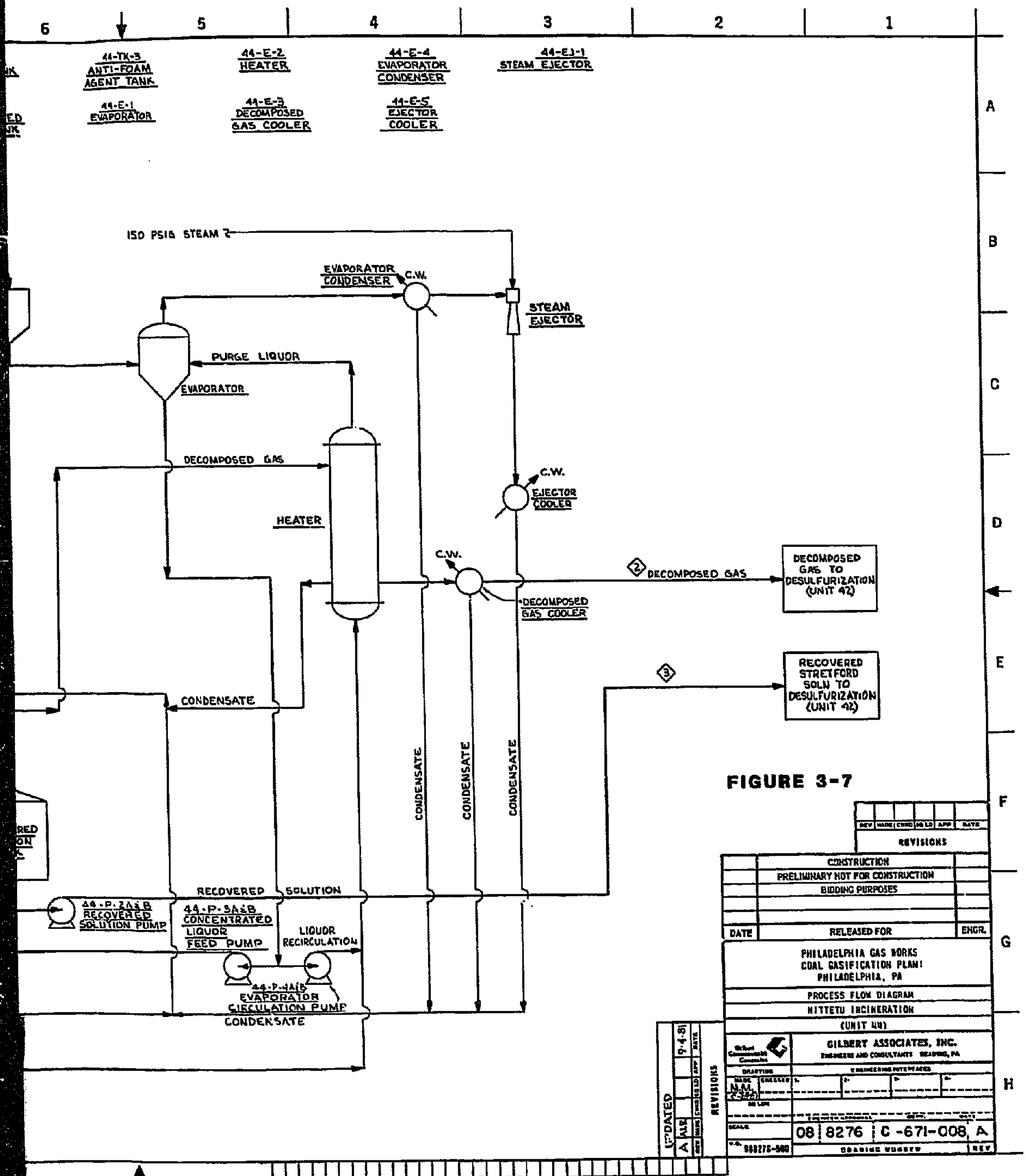

44-TK-3 ANTI-FOAM AGENT TANK
44-E-1 EVAPORATOR
44-E-2 HEATER
44-E-3 DECOMPOSED GAS COOLER
44-E-4 EVAPORATOR CONDENSER
44-E-5 EJECTOR COOLER
44-EJ-1 STEAM EJECTOR
150 PSIG STEAM
EVAPORATOR CONDENSER
C.W.
STEAM EJECTOR
PURGE LIQUOR
EVAPORATOR
DECOMPOSED GAS
EJECTOR COOLER
HEATER
DECOMPOSED GAS
DECOMPOSED GAS COOLER
DECOMPOSED GAS TO DESULFURIZATION (UNIT 42)
RECOVERED STRETFORD SOLN TO DESULFURIZATION (UNIT 42)
CONDENSATE
RECOVERED SOLUTION
44-P-2A&B RECOVERED SOLUTION PUMP
44-P-3A&B CONCENTRATED LIQUOR FEED PUMP
LIQUOR RECIRCULATION
44-P-4A&B EVAPORATOR CIRCULATION PUMP
REVISIONS
CONSTRUCTION
PRELIMINARY NOT FOR CONSTRUCTION
BIDDING PURPOSES
DATE
RELEASED FOR
ENGR.
PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA
PROCESS FLOW DIAGRAM
NITTETU INCINERATION
(UNIT 44)
GILBERT ASSOCIATES, INC.
UPDATED
9-4-81
08 8276 C-671-008 A

FIGURE 3-7

TABLE 3-4
MATERIAL BALANCE FOR NITTETU INCINERATION PLANT

STREAM NUMBER		1	2	3	4
Temperature, °F		105	120	195	105.2
Pressure, psia		16.2	15.5	44.7	124.7
Total Flow, lbs/hr		1892	7424	3540	3500
Liquid, gpm		-	.0594	6.1	6.17
Flowing, lbs/gal		-	8.25	9.67	9.45
Vapor Flow, ACFS		13.6	27.70	-	-
Flowing, lbs/ft^3		0.0591	0.0743	-	-
Vapor Mol. Wt.		21.6	29.77	-	-
ADA Solution, lb/hr				3540	3500
	CO_2	9.02	60.84	-	-
	CO	76.33	23.99	-	-
	H_2	35.53	11.13	-	-
	COS	0.12	-	-	-
	N_2	3.07	120.99	-	-
	Ar	0.74	-	-	-
	CH_4	0.01	-	-	-
	H_2O	9.11	29.10	154.15	138.0
	H_2S	-	4.02	-	-
	NaHS	-	-	4.30	-
TOTAL		133.93	250.07	158.45	138.0

The oxygen purity specified for the plant is 98 volume percent with two percent inerts (mostly argon). The by-product nitrogen contains a maximum of two percent oxygen and is bone-dry. The required pressures for the oxygen and by-product nitrogen at the air separation plant battery limits are 1 psig and 40 psig, respectively. The oxygen product piped from the air separation plant is compressed to approximately 15 psig by a compressor within the GKT battery limits. The by-product nitrogen available at 40 psig from the air separation cold box will be adequate for the GKT gasification unit conveying and purging requirements.

The total normal nitrogen requirement for GKT gasification plant conveying and purging is shown below. The conveying nitrogen estimate is based on 7.0 lbs of coal conveyed per lb of nitrogen. In addition to the normal nitrogen requirements, the nitrogen requirement for gasifier system emergency shutdown purging is also shown.

Conveying	186,140 Scf/hr (35 psig)
Purging & Blanketing	148,900 Scf/hr (25 psig)
Total Normal	335,040 Scf/hr
Emergency Shutdown Purging	893,470 Scf/hr (15 psig)

The air separation plant (Unit 50) is a turnkey facility. Engineering and design will be furnished by a contractor experienced in this field.

The basic process for separating oxygen from air is a distillation operation that takes place at low temperatures under moderate pressure in which air is reduced to the liquid state and the components are separated by fractionation. The cryogenic temperatures are achieved by special heat exchange equipment and expansion turbines that efficiently transfer heat and energy between feed and products to make the operation economically practical.

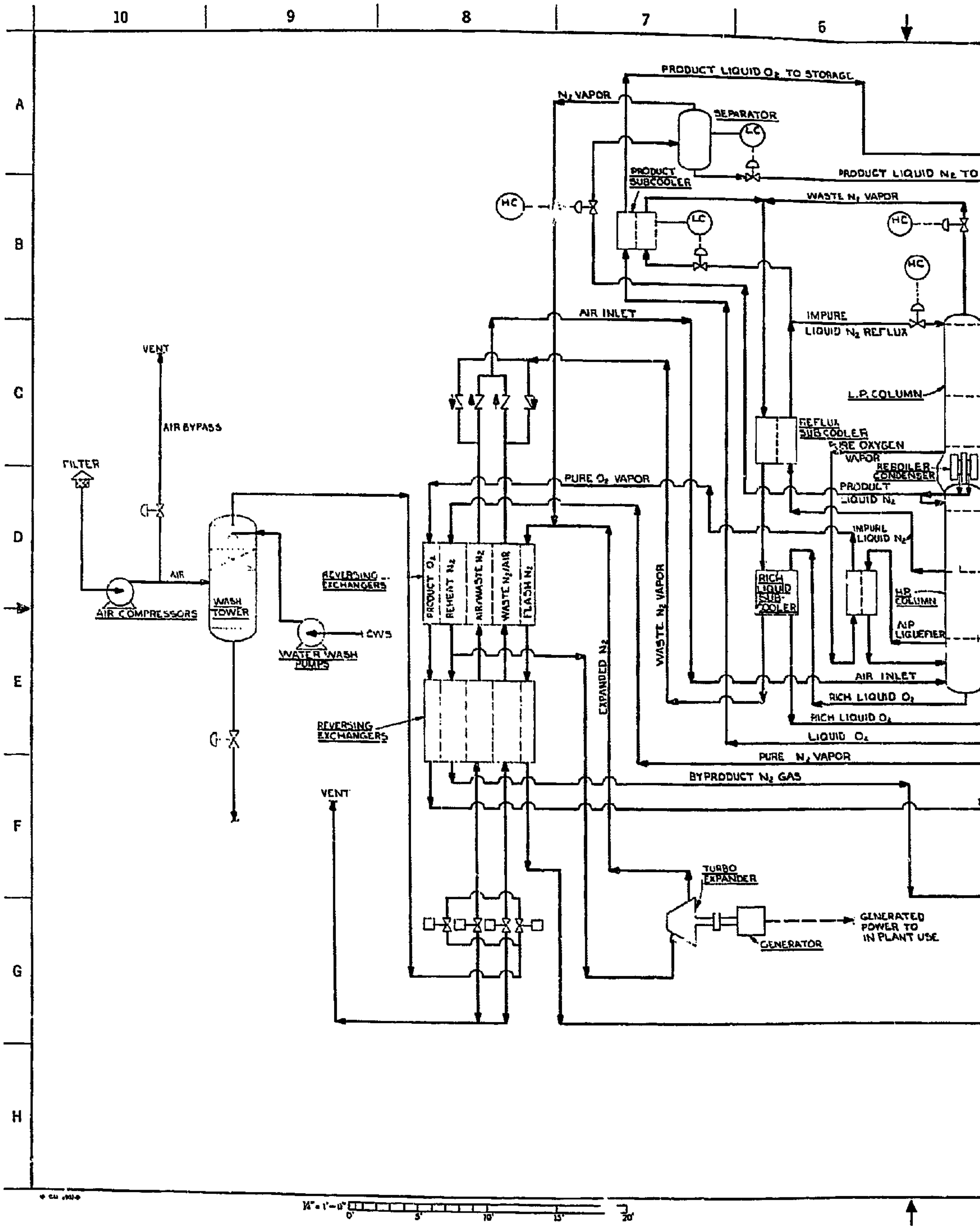
In a simplified form, the main process steps to produce oxygen and by-product nitrogen in an air separation plant include: air compression, water and carbon dioxide removal, cooling to liquid air temperature, gas expansion to produce refrigeration, separation of air by distillation, product heating by heat exchange with the incoming air, and compression of oxygen to the required pressure. Figure 3-8 depicts a typical low pressure cycle oxygen plant with liquid oxygen and nitrogen storage.

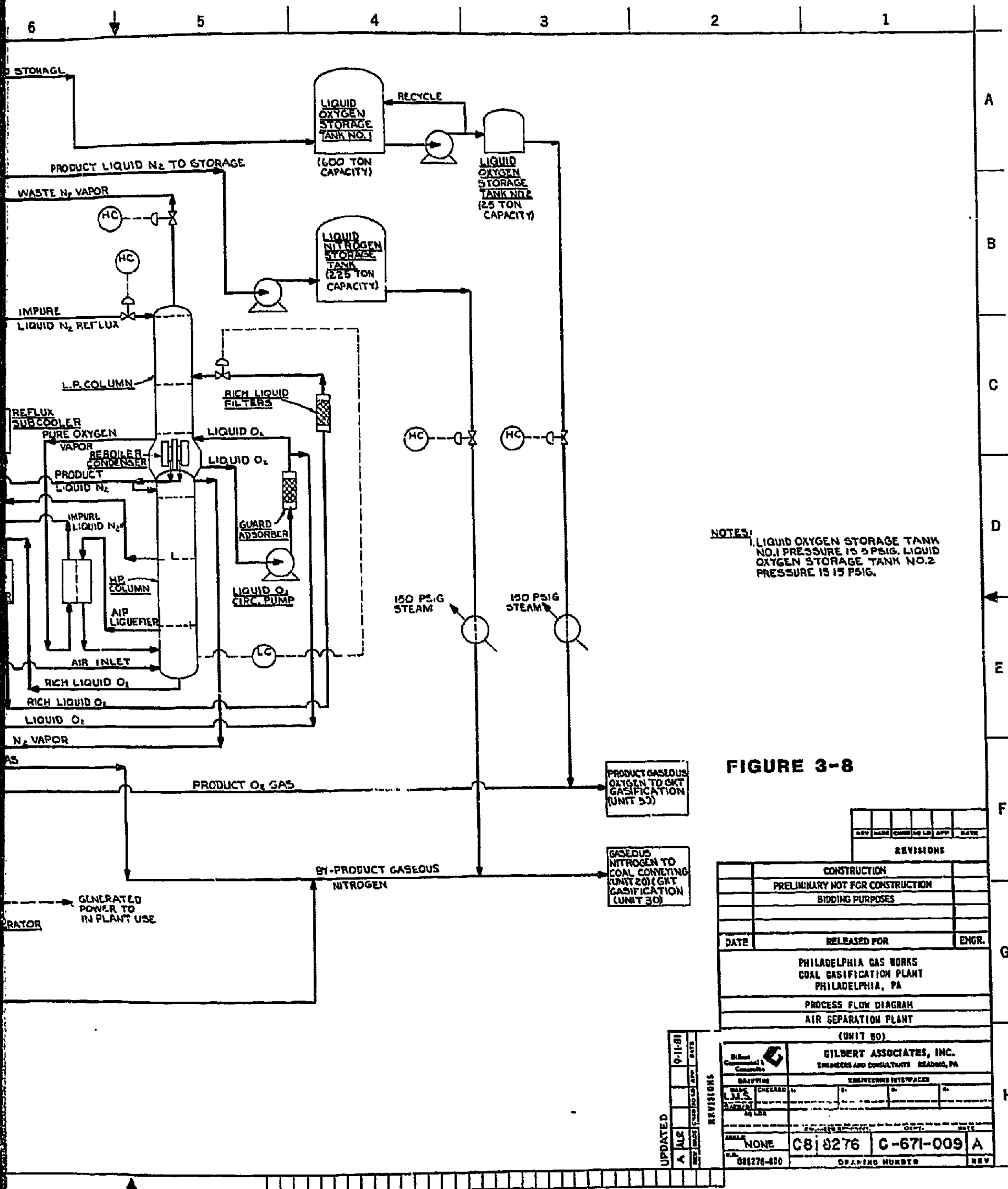
In the air separation plant the refrigeration process used to reach liquid air temperatures is regenerative. Warm process air entering the plant is cooled by the separated products as they leave in a reversing heat exchanger. The heat recovery is incomplete, however, so refrigeration must continuously be added.

Air also contains variable quantities of dust, water, carbon dioxide and hydrocarbons. These impurities must be removed from the system to insure a safe, efficient operation. In the process, dust is removed by a filter on the inlet of the main air compressors. The dust that goes by, along with other contaminants, is removed in a water wash tower.

For reliability and flexibility in turndown, two 50 percent air separation trains (600 tpd each) will be provided. In addition, there will be two main air compressors - one driven by an electric motor, the other by a steam turbine. Approximately 93,000 lbs per hour of saturated steam at 925 psig is available for use by the air compressor steam turbine. This is approximately 65 percent of the total compressor power requirement. The electric driven compressor is sized to provide 50 percent of the air compressor requirement.

Compressed air from the main air compressors enters the base of water wash tower and is cooled by a countercurrent direct contact with water sprayed into the top of the tower. The warmer water is returned to the cooling water system by process air pressure. Air


PRODUCT LIQUID O2 TO STORAGE
N2 VAPOR
SEPARATOR
LC
PRODUCT SUBCOOLER
PRODUCT LIQUID N2 TO S
HC
WASTE N2 VAPOR
AIR INLET
IMPURE LIQUID N2 REFLUX
L.P. COLUMN
REFLUX SUBCOOLER
PURE OXYGEN VAPOR
REBOILER-CONDENSER
PRODUCT LIQUID N2
IMPURE LIQUID N2
VENT
AIR BYPASS
FILTER
PURE O2 VAPOR
AIR
AIR COMPRESSORS
WASH TOWER
REVERSING EXCHANGERS
PRODUCT O2
REHEAT N2
AIR/WASTE N2
WASTE N2/AIR
FLASH N2
CWS
WATER WASH PUMPS
WASTE N2 VAPOR
EXPANDED N2
RICH LIQUID SUB-COOLER
HP COLUMN
AIR LIQUEFIER
AIR INLET
RICH LIQUID O2
RICH LIQUID O2
LIQUID O2
PURE N2 VAPOR
BYPRODUCT N2 GAS
TURBO EXPANDER
GENERATOR
GENERATED POWER TO IN PLANT USE
1/4" = 1'-0"
0'
5'
10'
15'
20'



STORAGE
LIQUID OXYGEN STORAGE TANK NO.1
(600 TON CAPACITY)
RECYCLE
LIQUID OXYGEN STORAGE TANK NO.2
(25 TON CAPACITY)
PRODUCT LIQUID N₂ TO STORAGE
WASTE N₂ VAPOR
HC
LIQUID NITROGEN STORAGE TANK
(225 TON CAPACITY)
IMPURE LIQUID N₂ REFLUX
L.P. COLUMN
RICH LIQUID FILTERS
REFLUX SUBCOOLER
PURE OXYGEN VAPOR
LIQUID O₂
REBOILER-CONDENSER
PRODUCT LIQUID N₂
IMPURE LIQUID N₂
GUARD ADSORBER
HP COLUMN
AIR LIQUEFIER
LIQUID O₂ CIRC. PUMP
LC
AIR INLET
RICH LIQUID O₂
N₂ VAPOR
150 PSIG STEAM
NOTES:
1. LIQUID OXYGEN STORAGE TANK NO.1 PRESSURE IS 5 PSIG. LIQUID OXYGEN STORAGE TANK NO.2 PRESSURE IS 15 PSIG.
PRODUCT O₂ GAS
PRODUCT GASEOUS OXYGEN TO GKT GASIFICATION (UNIT 30)
BY-PRODUCT GASEOUS NITROGEN
GASEOUS NITROGEN TO COAL CONVEYING (UNIT 20) (GKT GASIFICATION (UNIT 30)
GENERATED POWER TO IN PLANT USE
RATOR
REVISIONS
CONSTRUCTION
PRELIMINARY NOT FOR CONSTRUCTION
BIDDING PURPOSES
DATE
RELEASED FOR
ENGR.
PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA
PROCESS FLOW DIAGRAM
AIR SEPARATION PLANT
(UNIT 80)
GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA
UPDATED
A
9-11-81
NONE
C81 8276
C-671-009
A

FIGURE 3-8

leaves at the top of the tower at near ambient temperature and flows to the reversing heat exchangers.

Compressed process air is cooled to liquid air temperatures in reversing heat exchangers by the outgoing streams. During this process, contained water and carbon dioxide are frozen and deposited as solids inside the exchanger.

At regular intervals, the air and the waste nitrogen stream, which is the largest effluent stream, are interchanged. Both continue to flow in the same direction, across the same temperature gradient, but the passages through which they flow are switched. As a result, the water and carbon dioxide deposited by the air before reversal is evaporated completely and removed from the plant by waste nitrogen. Switching is accomplished by an automatic system of timers, warm-end reversing valves, and cold-end check valves.

Slightly superheated air leaves the reversing exchanger, enter the high pressure column and is separated into an oxygen rich liquid at the bottom, pure liquid nitrogen at the top, and impure liquid nitrogen part way up the column.

Pure nitrogen gas from the top of the high pressure column is condensed in the reboiler by boiling pure liquid oxygen in the low pressure column. The returning liquid nitrogen serves as reflux for the high pressure column.

Further down the high pressure column, impure liquid nitrogen is withdrawn and subcooled, part of it providing reflux for the low pressure column and part of it acting as a subcooling medium for liquid oxygen product in the product subcooler, if required. Waste nitrogen vapor is withdrawn from the top of the low pressure column.

Rich liquid oxygen is taken from the base of the high pressure column, subcooled via the waste nitrogen stream, purified in the rich liquid filter, and passed to the feed entry tray of the low pressure column.

Provisions for nitrogen drawn off the top of the high pressure column will be made in two places. First is the pure liquid nitrogen stream sent to a nitrogen flash separator where resulting liquid is sent to nitrogen storage. The flash from the separator is combined with the effluent gas of the turbo expander and sent through the reversing exchangers for recovery of its refrigeration, then on to product usage, otherwise it goes out as waste nitrogen through the silencer. The operator will control just how much liquid nitrogen is withdrawn, from the high pressure column.

The other stream, cold pure nitrogen gas, is sent to the reversing exchanger. Part of this gas is drawn off at the midpoint and sent to the expander. Expander exhaust along with the possible flash from the separator is sent back to the reversing exchanger as described above.

Final separation of oxygen takes place in the low pressure column. Provisions for liquid oxygen to be taken from the base of low pressure column, passed through liquid oxygen guard absorber, subcooled in product subcooler, and then sent to storage will be made. The subcooling medium would be impure nitrogen from the high pressure column.

Product oxygen gas is taken off just above the bottom of the low pressure column and sent through air liquefier exchanger, where it may be superheated by a slipstream of condensing air, and then to the reversing exchangers for the recovery of the rest of its refrigeration, and finally to delivery to the GKT Gasification Unit battery limits.

Liquid oxygen and nitrogen storage facilities are required to provide 24 hours of back-up product oxygen and nitrogen during an emergency shutdown. Since the oxygen plant is dual train and has the capability of operating one train on either steam or electricity, it is expected that a shut-down would only reduce oxygen production by 50 percent. For this reason, the liquid storage requirement is 50 percent of design capacity for 24 hours, i.e., 600 tons.

The liquid oxygen storage consists of a main 600 ton liquid oxygen storage tank at 5 psig and a 25 ton liquid oxygen tank at 15 psig. Two 100 percent liquid oxygen pumps are provided to pump liquid oxygen from the 600 ton tank to the 25 ton tank. A vaporizer at the discharge of the 25 ton tank vaporizes the liquid oxygen for delivery to the GKT battery limits. The minimum delivery pressure of gaseous oxygen to the GKT battery limits is 1 psig. This system will insure that fluctuation of the oxygen pressure does not occur in the event that response time of the air separation unit is slow relative to the oxygen demand rate of the gasifiers.

The liquid nitrogen storage system consists of a 275 ton storage tank at 40 psig and a vaporizer which provides the normal nitrogen required for conveying and purging in the event of an air separation plant shutdown. The storage system will be capable of supplying nitrogen gas at 40 psig at a design withdrawal rate of 6000 SCFM. For gasification system emergency shutdown purging, a high pressure nitrogen tube trailer (rental) is provided. The high pressure tube trailer will provide an instantaneous supply of nitrogen for gasifier system purging. The tube trailer will be designed for a maximum withdrawal rate of 15,000 SCFM for 15 minutes, i.e., 225,000 SCF storage capacity.

3.7 PRODUCT GAS HANDLING

3.7.1 Gas Compression

The clean fuel gas from the Stretford plant is compressed to 40 psig and cooled to 100°F prior to dehydration and distribution. The product gas leaves the Stretford absorber at 105°F and 1.5 psig saturated with water vapor. The gas is compressed in a set of parallel compressors. The compressors are centrifugal machines with aftercoolers.

The compressors will be driven by condensing steam turbines using excess low pressure steam from the gasifier jackets. The steam is superheated prior to entering the turbines at 25 psig and 322°F (55°F superheat). There is sufficient steam to provide 100 percent of the compression duty. Because of the high specific volume of the steam, two turbines will be needed to handle the steam available. A third compressor driven by electric motor will provide 50 percent of the plant output and will be used for startup and standby duty.

The outlet gas from the compressor will be cooled in a shell and tube heat exchanger to 100°F with cooling water in order to condense as much water as possible. It is intended to minimize the load on the dehydration unit. The condensate from the compressor aftercoolers will be used as make-up to the plant main cooling tower.

3.7.2 Gas Dehydration

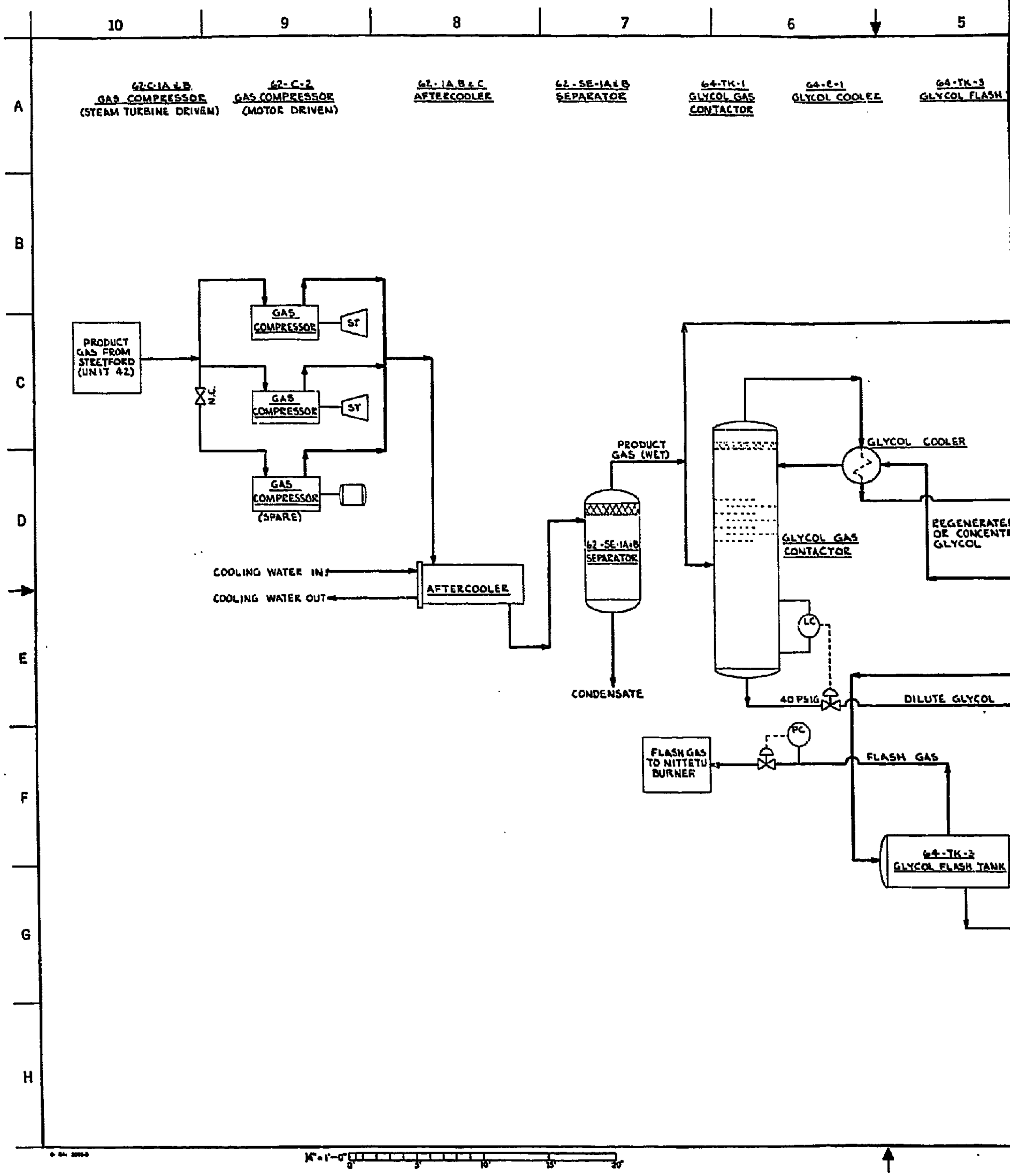
In the gas dehydration unit (Unit 64), excess water from the desulfurized and compressed gas (40 psig) is removed to meet the selected medium-Btu pipeline gas specifications of water content not to exceed 53.3 lb H_2O per MM SCF. Most natural gas pipelines specifications require a water content specification not to exceed 7.0 lb H_2O per MM SCF because of long distances and pipeline pressures up to 1000 psig. However, the PGW application requires only short distance transmission and a relatively low pressure of 35 psig. Therefore, very low water content specification is not necessary and economic considerations led to the selection of 53.3 lb H_2O per MM SCF (or 20°F dew point) limit. The wet compressed gas at 40 psig and dew point of 100°F has a water content of 851.1 lbs per MM SCF. Dehydration unit will remove the excess water (797.8 lbs per MM SCF) to prevent gas freeze-ups and gas transmission problems such as pipe line corrosion. In most newer plants triethylene glycol (TEG) system has been utilized, as in the present design.

A process flow diagram of a typical gas dehydration plant is shown in Figure 3-9. The wet inlet gas enters the bottom of the absorber and flows upward through trays countercurrent to the concentrated (99.7 percent) glycol flowing downward through the column. 97.8 percent of the water in the gas is absorbed by glycol flowing at a rate of 1.55 gallons per lb H_2O removed. The dry gas with a water content of 53.3 lbs per MM SCF leaves the top of the absorber through mist eliminator which aids in removing any entrained glycol droplets. It then flows through a glycol cooler and is heated from 100 to 160°F by the incoming regenerated hot glycol which is cooled from 250 to 110°F.

The dilute glycol (93.6 percent) leaves the bottom of the absorber and enters a heat exchanger coil (in the glycol still) where it is preheated before being flashed in the flash tank. The diluted glycol stream then passes through a glycol filter which removes any foreign solid particles. The clean glycol is further heated in the accumulator/heat exchanger to about 260°F and enters the glycol still (stripper) for regeneration, which is mounted on the top of a reboiler operating at 400°F.

The dilute glycol passing downward through the stripper is contacted by hot rising water vapors passing upward through the column. The water vapor released in the reboiler and stripped from the glycol in the stripper is discharged to the atmosphere.

In the reboiler, glycol is concentrated to 99.7 percent by adding 1 ft^3 per gallon of stripping gas (nitrogen) through a sparger. The nitrogen aids in removing any water vapor pockets which might



62-C-1A & B
GAS COMPRESSOR
(STEAM TURBINE DRIVEN)
62-C-2
GAS COMPRESSOR
(MOTOR DRIVEN)
62-1A,B & C
AFTERCOOLER
62-SE-1A & B
SEPARATOR
64-TK-1
GLYCOL GAS CONTACTOR
64-E-1
GLYCOL COOLER
64-TK-3
GLYCOL FLASH
PRODUCT GAS FROM STEETFORD (UNIT 42)
GAS COMPRESSOR
ST
GAS COMPRESSOR
ST
GAS COMPRESSOR
(SPARE)
N.C.
COOLING WATER IN
COOLING WATER OUT
AFTERCOOLER
62-SE-1A & B SEPARATOR
CONDENSATE
PRODUCT GAS (WET)
GLYCOL GAS CONTACTOR
GLYCOL COOLER
REGENERATED OR CONCENTR
GLYCOL
LC
40 PSIG
DILUTE GLYCOL
FC
FLASH GAS TO NITTETU BURNER
FLASH GAS
64-TK-3
GLYCOL FLASH TANK

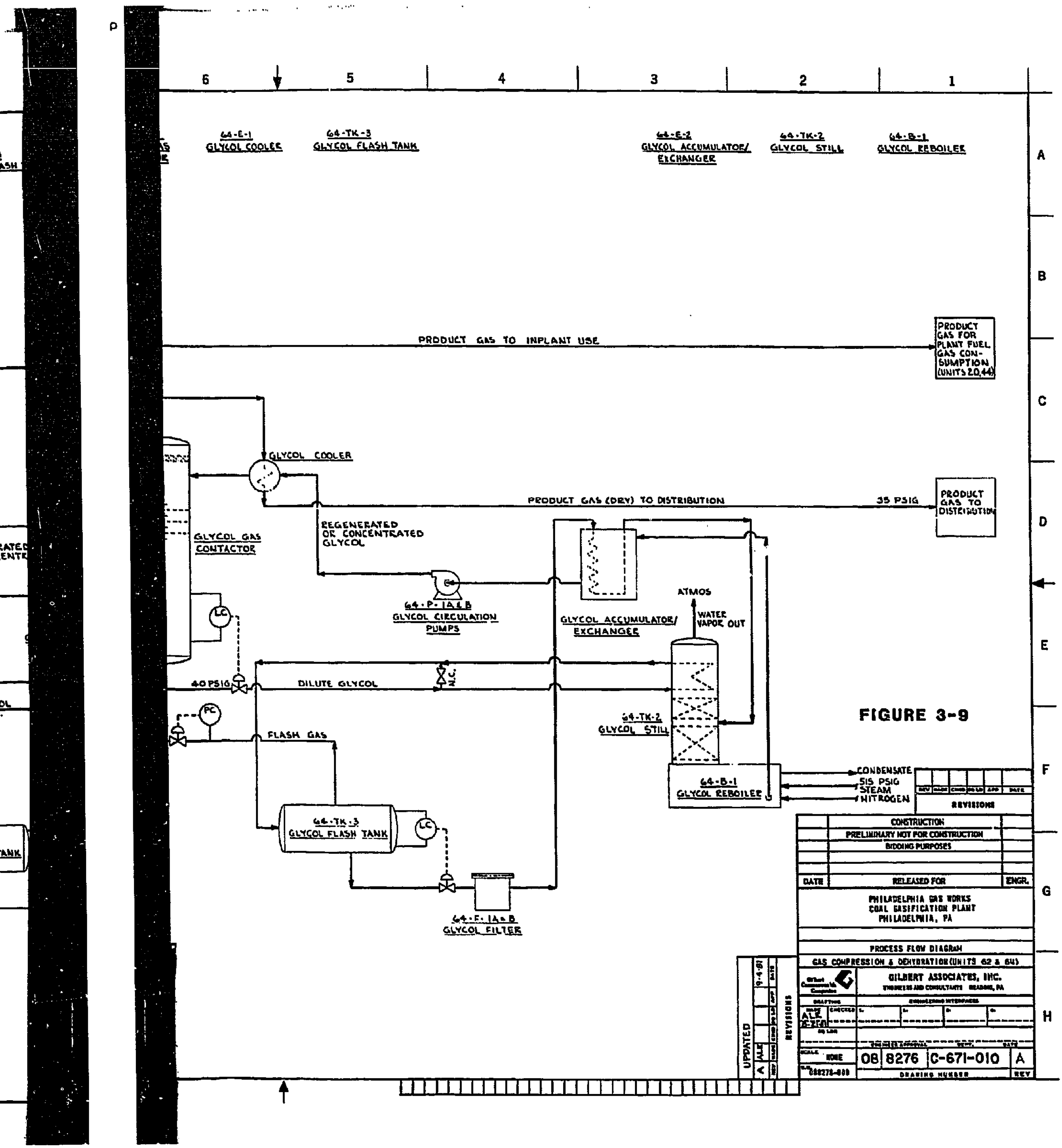

64-E-1
GLYCOL COOLER
64-TK-3
GLYCOL FLASH TANK
64-E-2
GLYCOL ACCUMULATOR/ EXCHANGER
64-TK-2
GLYCOL STILL
64-B-1
GLYCOL REBOILER
PRODUCT GAS TO INPLANT USE
PRODUCT GAS FOR PLANT FUEL GAS CONSUMPTION (UNITS 20,44)
GLYCOL COOLER
PRODUCT GAS (DRY) TO DISTRIBUTION
35 PSIG
PRODUCT GAS TO DISTRIBUTION
REGENERATED OR CONCENTRATED GLYCOL
GLYCOL GAS CONTACTOR
64-P-1A & B
GLYCOL CIRCULATION PUMPS
GLYCOL ACCUMULATOR/ EXCHANGER
ATMOS
WATER VAPOR OUT
40 PSIG
DILUTE GLYCOL
N.C.
FLASH GAS
64-TK-2
GLYCOL STILL
64-B-1
GLYCOL REBOILER
CONDENSATE
515 PSIG
STEAM
NITROGEN
64-TK-3
GLYCOL FLASH TANK
64-F-1A & B
GLYCOL FILTER
REVISIONS
CONSTRUCTION
PRELIMINARY NOT FOR CONSTRUCTION
BIDDING PURPOSES
DATE
RELEASED FOR
ENGR.
PHILADELPHIA GAS WORKS
COAL GASIFICATION PLANT
PHILADELPHIA, PA
PROCESS FLOW DIAGRAM
GAS COMPRESSION & DEHYDRATION (UNITS 62 & 64)
GILBERT ASSOCIATES, INC.
UPDATED
9-4-81
NONE
08 8276 C-671-010 A
DRAWING NUMBER
REV

FIGURE 3-9

otherwise remain in the glycol solution. The concentrated glycol from the reboiler flows to the glycol accumulator/heat exchanger, passes through the glycol cooler, and returns to the absorber to complete the cycle. A glycol makeup of seven gallons per day is required.

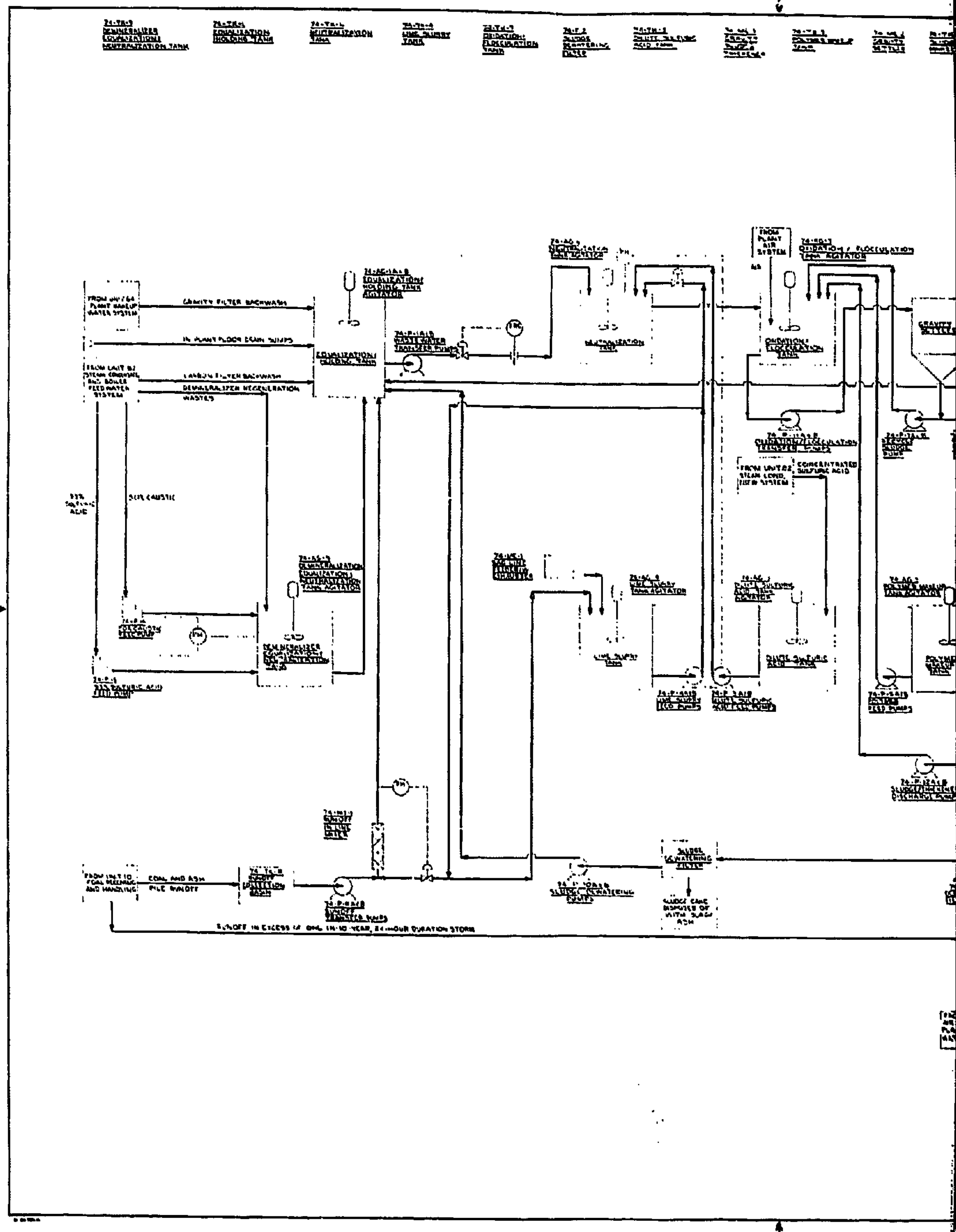
3.8 WASTEWATER TREATMENT

Plant industrial wastewaters are collected and treated before discharge to the Delaware River so that the effluent meets applicable discharge regulations of the U.S. Environmental Protection Agency, Pennsylvania Department of Environmental Resources, Delaware River Basin Commission and City of Philadelphia. The process flow diagram shown in Figure 3-10 schematically represents the wastewater treatment system (Unit 74). Plant industrial waste sources are as follows:

a. Travelling water screen backwash,
b. In-plant floor drains,
c. Gravity filter backwash,
d. Carbon filter backwash,
e. Demineralizer regeneration wastes,
f. Coal and ash pile runoff,
g. River water clarifier sludge, and
h. Cooling towers blowdown.

Travelling water screens are backwashed to an adjacent dewatering chamber where solids are separated and the water allowed to drain back to the intake structure. Solids are collected in a dumpster for haulaway.

Wastes from the in-plant floor sumps, gravity filter backwash and carbon filter backwash are directed to an equalization and holding tank. Demineralizer regeneration wastewater is collected in a separate tank, where the acid and alkaline wastes are allowed to



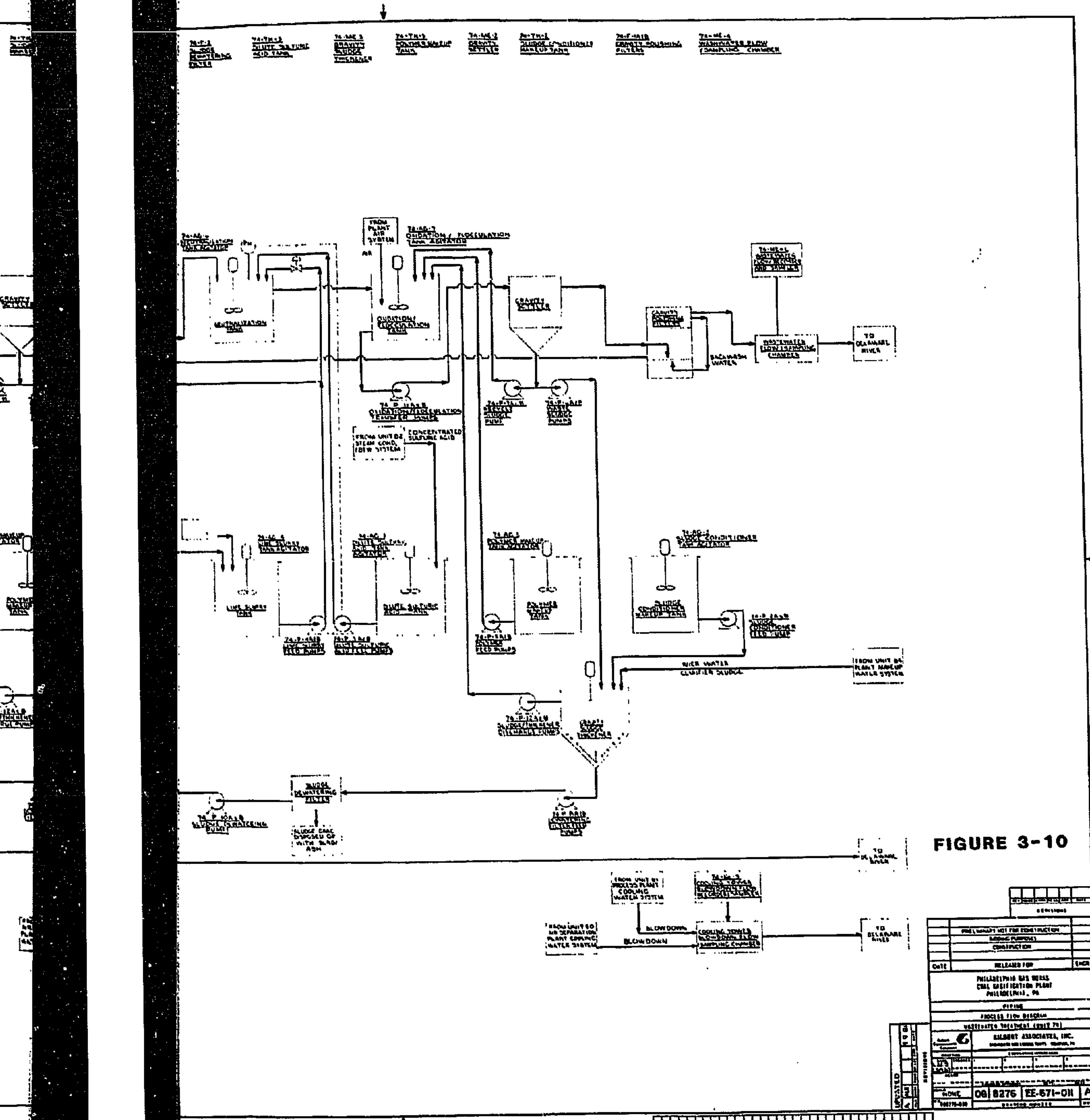

FROM PLANT AIR SYSTEM
AIR
BLOWDOWN
BLOWDOWN
CONSTRUCTION
08
8276
A

FIGURE 3-10

self-equalize before being "rough" neutralized and conveyed to the equalization and holding tank. Coal and ash pile runoff are collected and pumped at a controlled rate to the equalization and holding tank. An in-line mixer and pH monitor are provided in the pump discharge line. A pH controller adjusts the feed of lime slurry to neutralize the runoff to a minimum pH of 6.0, before it enters the equalization and holding tank. Rainfall in excess of the once-in-ten-year, 24-hour storm overflows directly to the outfall.

Wastewaters collected in the equalization and holding tank are mixed and pumped at a flow-controlled rate to the neutralization tank. A pH control system feeds either lime slurry or sulfuric acid solution, as required, to adjust the pH within 8.0 to 9.0 range. Neutralization tank overflow enters the oxidation/flocculation tank where polymer is added to the wastewater to aid in floc formation and air supplied to oxidize any iron. Overflow from the oxidation/flocculation tank enters a Lamella type gravity settler where suspended solids are separated from the wastewater. Settler overflow enters the gravity polishing filters and is then directed to the effluent flow and sampling chamber, prior to discharge to the Delaware River.

The settler sludge is periodically blown down to the sludge thickener where it combines with the river water clarifier sludge. Thickened sludge is pumped to the dewatering filter. The sludge cake is disposed of with the gasifier slag/ash in an approved landfill.

Cooling tower blowdown is generally acceptable for discharge without treatment due to the high degree of treatment provided for tower makeup water. In the final design phase, cooling tower blowdown may be used for gasifier quench or coal dust suppression, thereby eliminating the need for a direct blowdown discharge.