from ASEA do not include power factor correction or filtering. These components depending on the application will add another $5-10/KW to the cost of the converter making the overall cost an average or some $27.50/KW for the first unit. Inquiries among many other manufacturers lead to the opinion that as soon as some experience is developed and pending increased ratings of the silicon-controlled rectifiers, the overall cost of converter equipment is likely to be $15/KW to $25/KW.

c. MHD Generator System Costs

The outstanding advantages of MHD for this application include high efficiency, low capital cost and direct current output with no requirement for short circuit protection. The estimated 1972 prices for an MHD unit are $165/KW with an inverter or $145/KW without an inverter. Assuming cost reduction after development the DC output MHD generator system is estimated to cost $135/KW.

d. System Costs

Table 3 gives estimated costs for coal electro-gasifier power supplies.

TABLE 2

CONVENTIONAL POWER PLANT COST

Plant Size MW_e	Cost 1970 $/KW	Cost 1975 $/KW	Cost 1980 $/KW	References
800	~200	~230	~350	Electrical World-July 1, 1971-p38
800	170.60			Electrical World-Feb. 2, 1971-p2
2600	188			AEP-Wall Street Journal March '
200	200			Electrical World-Jan. 12, 1970-p2
800	170			"
100	200			Amer. Power Corp. April 22, 1969 Maxwell Stanley*
500	152			"

* Transmission Costs $150/MW Mile

TABLE 3

OVERALL POWER SUPPLY COST

(Thousands of Dollars)

Option	MW	Generating Sources	Conventional Plant	Switch on Rectifier	MIID	TOTAL
1	110	Captive	23,320*	4,125**	-	27,445
2	110	Utility	-	4,125**	-	4,125
3	500	Captive	90,100***	12,500†	-	102,600
4	500	Captive	-	-	67,500††	67,500
5	500	Utility	-	12,500†	-	12,500

Note: Delivery Time for Options 1, 2, 3, 5 - Three years;
Delivery Time for Option 4 - Depends on Development Rate- Probably 6-10 years.

* Cost = $212/KW
** Cost = $ 37.50/KW
*** Cost = $180/KW
† Cost = $ 25/KW
†† Cost = $135/KW

6. SUMMARY AND CONCLUSIONS

The goal of this investigation was, in general, to investigate coal electrogasifier systems and their power supplies and, in particular, to establish the feasibility of operating a 110 MW system using a captive 110 MW power generating system. The results indicate that the feasibility of operating a 110 MW system is practically assured.

The matter of gathering further data from the 2 MW electrogasifier remains as an important milestone to achieve. Data of importance to the design of the 110 MW unit include:

a. Further data on the resistivity and resistance of electrogasifier beds

b. Further data relative to the aperiodic nature of electrogasifier bed resistance as a function of size

c. Time-performance data of the electrodes to establish optimum electrode performance

d. Time-performance data of the insulation to establish optimum insulation performance

and

e. Verification of the appropriateness of the presently engineered control system with data indicating what changes are necessary to improve the overall control function.

An itemized list of conclusions reached on the basis of this investigation follows:

1) Unknown technical factors of an AC system, in particular, the matters of unsymmetrical currents and the performance of electrogasifiers under AC operations decree against their use.

2) Operation of an electrogasifier from a three phase power source as a single phase unit is impractical and was ruled out from consideration.

3) Operation of three single phase electrogasifiers from a three phase power source suffers from the disadvantage that outage of one bed would probably lead to a shutdown of the whole system.

4) The 2 phase bed, although not tested, does offer an acceptable method of operating beds from three phase power supplies using concentric electrode configurations.

5) The cost of the AC and DC system, making some rather broad and unchecked assumptions, are essentially comparable.

6) The DC system offers advantages that the AC system does not possess, including:

(a) elimination of the major harmonics

(b) balanced operation even under part load conditions

7) Insulation of the bed appears to be a straightforward task. Probably the area most susceptible to breakdown is at the interfaces. Here, also, several simple solutions seem feasible.

8) As mentioned above, a captive system seems entirely practical. Tradeoff studies between capital and fuel costs for the captive unit as opposed to "over-the-fence" costs of electricity purchased from a utility must be made. Also, the matter of reliability requirements still needs to be investigated. It appears that auxiliary equipment demands such as for transformers, filters, capacitors may be considerably reduced for a captive system.

9) In the long run, advanced power supplies, such as MHD generator systems will undoubtedly be so attractive from all points of view that they will be used for all electrogasifier plants.

PROCESS DESCRIPTION AND FLOW DIAGRAMS

GENERAL COMMENTS

A. PROCESS UNITS

This section presents a brief written description covering the operation of the process unit, including a Utilities Summary, together with a process flow diagram for each of the major plant processing units. A tabulation of major equipment required is also included for each unit.

B. DEFINITION OF FUEL EQUIVALENT

On some of the following process flow diagrams, many of the flowstreams report, in addition to stream properties and component molal transfer, an additional value called "Fuel Equivalent". This is a measure of the potential methane content of the stream under consideration. It is a handy index to process efficiency through the many steps between the reactor and the product gas pipeline. Off-stream losses of high fuel equivalent deserve careful scrutiny; those of small fuel equivalent can be neglected at this stage of design.

The fuel equivalent is calculated as the sum of:

Mols	H_2	x	0.25
Mols	CO	x	0.25
Mols	CH_4	x	1.00
Mols	C_2H_6	x	1.75

In the stoichiometry of the shift reaction, one mol of carbon monoxide is equivalent to one mol of hydrogen. The methanation reaction requires four mols of H_2 equivalent to make one mol of CH_4. By similar logic, one mol of ethane is worth two mols of methane minus one mol of hydrogen.

The pertinent reactions are:

1. $CO + H_2O \longrightarrow CO_2 + H_2$

2. $CO + 3H_2 \longrightarrow CH_4 + H_2O$

3. $C_2H_6 + H_2 \longrightarrow 2\ CH_4$

C. <u>ACCURACY OF FIGURES</u>

1. There may be some mismatching of stream flow quantities from one flow sheet to another. These (if any) are minor and are believed to be well within acceptable limits for this study.

2. In most cases the numerical values for various data have been rounded off to practical significant figures. For this reason the values shown for the various constituents of stream flows may not add up to 100%.

UNITS 1100 & 1200 - COAL HANDLING & COAL PREPARATION

1. SCOPE

These two units cover the receipt of run-of-mine coal from a nearby mine and its storage, handling, and preparation, and subsequent delivery to the Coal Pretreatment facility. Unit 1100, Coal Handling, and Unit 1200, Coal Preparation, are considered together here because of their contiguity and the similarity of equipment involved.

Unit 1100 provides for receiving the coal and feeding it to a classifying breaker which will reduce the size of mine-run lump coal to 1½" x 0 size suitable for good conveying, storage and handling practice. Rock and other hard materials will be separated from the coal in the breaker and be discharged as refuse. This unit further provides for transfer of the coal from the breaker to live storage pile via feeders and belt conveyors for delivery to the Coal Preparation Unit. Dead storage will be created by bulldozing coal from the live storage pile; as required dead storage coal can be moved to the reclamation station via bulldozer.

Unit 1200 provides for receiving coal from the Coal Handling Unit and feeding the 1½" x 0 size coal to grinders which reduce the coal to #4M x 0 size and for transferring the size conditioned coal to the Coal Pretreatment Unit via belt conveyor. Incidental to receiving coal for grinding, the Coal Conditioning Unit will provide for transfer of 1½" x 0 size coal to the Power Plant.

2. DESIGN CONDITIONS

The sizing of equipment and the system arrangement in these units is based on the following design conditions, and assumptions:

a. Coal from the mine will be delivered to receiving hoppers by a belt conveyor equipped with weigh scale furnished by others.

b. Major equipment such as some of the hoppers and conveyors, breaker house, stacker reclamation facilities, and the coal conditioning house, etc. which would be impractical to expand later will be furnished initially for the 250 MM SCFD ultimate plant capacity.

c. Since the coal gasification plant process operates 24 hours a day, 7 days a week, those items of equipment associated with mine production and delivery will have higher hourly rates based on the following:

1. Demonstration Plant - 80 MM SCFD

Coal will be delivered from the mine at a rate of 1350 T/HR on a one-shift (7 hours operation) basis. This rate was established to supply sufficient coal for reclaiming from live storage during a normal 2-day weekend by gravity flow. To accommodate the several 3-day weekends sponsored on a national basis, coal from the live storage pile will be moved by bulldozer to the reclaim stations.

2. Ultimate Plant - 250 MM SCFD

Coal will be delivered from the mine at 2025 T/HR on a two-shift (7 hours per shift) basis. Similar arrangements can be provided for gravity flow of coal from storage for normal conditions and using a bulldozer on the pile for 3-day weekends.

d. Coal Live Storage

The above coal delivery rates will provide live storage capacity for 65 hours of plant operation based on gravity flow; total coal in live storage pile will provide for approximately 170 hours (7 days) of operation.

e. Coal Dead Storage

Coal dead storage will be provided for 30 days of plant operation which should cover most foreseeable temporary losses of supply, and the annual miner's holiday.

f. Coal Crushing and Grinding

A breaker has been provided for sizing run-of-mine lump coal to 1½" x 0 size for storage and handling. However, it appears to be industrial practice that coal companies provide in the order of 1½" x 0 size coal to utility companies (in Illinois). Accordingly, if sized coal can be obtained, the coal breaker and refuse handling could be deleted from the proposed HYGAS Demonstration Plant.

It has been specified that a coal size range of not more than 5% between #4M and #8M with a minimum of fines minus #100M is required for the process.

The coal grinding arrangement indicated utilizes primary crushers without screening. It is anticipated that the size range requirement can be met with a single crusher, with fines minus #100M amounting to 15%-17% of crushed product.

All the coal crushing and grinding equipment manufacturers contacted have advised that grinding and abrasion tests must be run on the actual coal to be used, before final recommendations and equipment can be offered. These tests must be run on the specific coal to be processed when a plant site is selected.

g. <u>Drying</u>

The surface moisture of the coal as delivered to the coal conditioning house has been assumed as 6%-8% for design, with a value of 15% for a temporary maximum. This moisture content is considered satisfactory for good grinding operations. A drying system for coal pretreatment is included in Unit 1300.

h. <u>Washing or Other Pretreatment</u>

For the purpose of this study, run-of-mine coal is considered suitable for processing and no provisions for washing or other treatment are included. However, depending on development of actual operating requirements, and composition of the particular run-of-mine coal, washing and/or other pretreatment may be required.

i. <u>Auxiliary Equipment</u>

All necessary hoppers, feeders, chutes, belt conveyor covers, belt cleaners, service walkways, controls, sequencing devices, etc. will be included, but have not been individually considered in this study.

j. <u>Coal for Power Plant</u>

The study to date indicates that coal will be required for fuel in the power plant, in addition to the spent char from the reactor. The quantity of coal required will depend on a final plant heat balance. A figure of 25 T/HR for the Demonstration Plant and 75 T/HR for the ultimate plant has been used in this report.

It should also be mentioned that reactor operation can be varied to produce more or less char, than the quantity used in this study. More spent char from the reactor would reduce, or eliminate, the need for supplemental coal required for fuel.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-11.00-1G attached. Following is a brief description of the operation:

Run-of-mine coal 6" x 0 is delivered to the receiving hoppers in the coal breaker house via the mine conveyor, or an extension thereof. The coal is fed from the hoppers to two rotary breakers, (one for the Demonstration Plant), which reduces the lump coal to 1½" x 0 size and removes the rock and other foreign matter larger than this size. Refuse is conveyed to a nearby refuse hopper.

The 1½" x 0 size was selected as it provides good characteristics for compacting in a coal dead storage pile and is also suitable for subsequent conveyor handling.

Crushed coal from the breakers is fed to a single 54" belt conveyor by vibrating feeders. This belt conveyor, sized for

2025 T/HR (ultimate plant requirements), delivers the coal to a traveling stacker which creates the live storage pile. A coal belt scale is located on the 54" belt to the stacker.

Coal from the live storage pile is either reclaimed for delivery to the Coal Preparation Unit, or via bulldozer can be moved to dead storage. Approximately 60% of the live storage pile is inactive and can be used for surge requirements by bulldozing the coal to the reclaim stations.

For reclamation the coal is fed through seven hoppers, for each reclaiming conveyor, located under the pile and above the reclaim tunnel. The hoppers, complete with vibrating feeders, feed two 42" reclaim belt conveyors, each of 900 T/HR capacity (ultimate plant requirements).

The reclaim belt conveyors move the coal from the tunnel to above grade receiving hoppers in the coal conditioning house. The head end of each conveyor will be provided with a magnet to remove tramp iron before discharging coal to the hopper.

At the coal conditioning house, belt weigh scales on the reclaim conveyors weigh the 1½" x 0 coal prior to discharging to the receiving hopper. This hopper receives the coal for both the power plant and process requirements.

The 1½" x 0 coal <u>for the power plant</u> (Unit 5100) is fed from the hopper, via a vibrating feeder to a 24" belt of 75 T/HR capacity (225 T/HR ultimate plant). This belt is sized to fill the powerhouse bunkers in an 8-hour shift.

Coal <u>for processing</u> is fed, via vibrating feeders, from the hopper to three coal crushers (1-initial and 2-future). The discharge from the crusher is fed to a single 30" belt conveyor of 225 T/HR capacity which will receive the #4M x 0 coal, via a vibrating feeder, and deliver the coal to the Coal Pretreatment Unit for the Demonstration Plant. Additional 30" belts, one for each additional pretreater, will be added for the ultimate plant.

4. <u>UTILITIES SUMMARY</u>

Cooling Water	-	None
Boiler Feedwater	-	None
Steam Generator	-	None
Steam Consumption	-	None
Motor Horsepower	-	1460 HP (Operating)
Air Cooler Fan Power	-	None

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT/#	REMARKS
11.04-01A		14 RECLAIM HOPPERS	10'SQ.W/45° SLOPED WALLS	REIN. CONCRETE				
11.04-01B		30 RECLAIM HOPPERS	10'SQ.W/45° SLOPED WALLS	REIN. CONCRETE				(FUTURE)
11.04-02		RECLAIM TUNNEL	300'LONG x 30'WIDE x 10'DEEP	REIN. CONCRETE				FOR 2 RECLAIM CONVEYO[RS] ON CONVERGING CENTER LINES
11.10-01		COAL BREAKER HOUSE						
11.17-01		36" REFUSE CONVEYOR	200 TPH					75'LONG, 20'RISE
		& MOTOR	7½ HP					460V/3 PH/60 CY
11.17-02A		54" COAL COLLECTING CONVEYOR	1350 T/HR					35'LONG, 2'RISE
		& MOTOR	15 HP					460V/3 PH/60 CY
11.17-02B		54" COAL COLLECTING CONVEYOR	1350 T/HR					35'LONG, 2'RISE (FUTU[RE])
		& MOTOR	15 HP					(FUTURE)
11.17-03		54" COAL STACKER CONVEYOR	2025 T/HR					1100'LONG, NO RISE
		& MOTOR	200 HP					460V/3 PH/60 CY

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11.17-04		BELT SCALE						
11.17-05		54" BELT STACKER WITH BOOM, & TROLLERY ASSEMBLY	125 HP 25 HP 60 HP	Boom Hoist Travel (4@ 15HP)				POWER COLLECTOR RAILS NOT INCL. IN L-B QUOTE
11.17-05A		TRAILING TRIPPER						TRIPPER PROPELLED BY STACKER
11.17-06A,B		2-42" COAL RECLAIM CONVEYORS	900 T/HR EA.					800' LONG, 90'RISE
		& MOTORS	125 HP EA.					460V/3 PH/60 CY
11.17-07A,B		2 MAGNET SEPARATORS						
11.17-08A,B		2 BULLDOZERS						FOR DEAD COAL STORAGE PILE
11.31-01		REFUSE HOPPER						
11.31-02		RECEIVING HOPPERS						
11.32-01A		COAL BREAKER	1350 T/HR					REDUCES R.O.M. COAL TO 1½" x 0
		& MOTOR	250 HP					460V/3 PH/60 CY

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
11.32-01B		COAL BREAKER	1350 T/HR					(FUTURE)
		& MOTOR	250 HP					(FUTURE)
11.33-01A		VIBRATING FEEDER FOR BREAKER	1350 T/HR					
		& MOTOR	20 HP					460V/3 PH/60 CY
11.33-01B		VIBRATING FEEDER FOR BREAKER	1350 T/HR					(FUTURE)
		& MOTOR	20 HP					(FUTURE)
11.33-02A		TRANSFER CHUTE						COLLECTOR BELT/ STACK CONVEYOR
11.33-02B		TRANSFER CHUTE						(FUTURE)
11.33-03A		14 VIBRATING FEEDERS FOR RECLAIM CONVEYORS	225 T/HR EA					
		& MOTORS	7½ HP EA.					460V/3 PH/60 CY.
11.33-03B		30 VIBRATING FEEDERS FOR RECLAIM CONVEYOR	225 T/HR EA					(FUTURE)
		& MOTORS	7½ HP EA.					(FUTURE)
11.33-04A		(DELETED)						

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
11.33-04B		(DELETED)						
12.10-01		COAL CONDITIONING HOUSE						
12.17-01		24" BELT CONVEYOR, COAL TO POWER PLANT	75 T/HR					TO POWER PLANT (225 T/HR FUTURE) 1000'LONG, 100' RISE
		& MOTOR	30 HP					460V/3 PH/60 CY
12.17-02A		30" BELT CONVEYOR, COAL TO PRETREATER	225 T/HR					300'LONG, 50'RISE
		& MOTOR	20 HP					460V/3 PH/60 CY
12.17-02B,C		2 30" BELT CONVEYORS, COAL TO PRETREATER	225 T/HR EA.					300'LONG, 50'RISE (FUTURE
		& MOTORS	20 HP EA.					(FUTURE)
12.17-03A,B		2 42" BELT TRANSFER CONVEYORS	300 T/HR EA.					60'LONG, NO RISE 900 T/HR (FUTURE)
		& MOTORS	15 HP EA.					460V/3 PH/60 CY
12.17-04		BELT SCALE						FOR COAL TO POWER PLANT

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
12.17-05A		BELT SCALE						FOR COAL TO PRETREATER
12.17-05B,C		2 BELT SCALES						FOR COAL TO PRETREATER (FUTURE)
12.17-06		1 SET FLIP-FLOP GATES & TRANSFER CONVEYOR						40'LONG, NO RISE (FUTURE)
12.17-07A,B		(DELETED)						
12.17-07 C,D,E,F		(DELETED)						
12.17-08A,B		2 TRIPPERS						
12.31-01A,B		2 RECEIVING HOPPERS WITH DUAL OUTLETS						
12.31-02A		1 SET CHUTES, & DUCTS FOR COAL CONDITIONING HOUSE						
12.31-02B,C		2 SETS CHUTES, & DUCTS FOR COAL CONDITIONING HOUSE						(FUTURE)

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
12.31-03A,B		2 SURGE HOPPERS						
12.31-03C,D		2 SURGE HOPPERS						(FUTURE)
12.32-01A		COAL CONDITIONER (CRUSHER)	225 T/HR					
		& MOTOR	500 HP					460V/3 PH/60 CY
12.32-01B,C		2 COAL CONDITIONERS (CRUSHER)	225 T/HR EA.					(FUTURE)
		& MOTORS	500 HP EA.					(FUTURE)
12.33-01A		VIBRATING FEEDER FOR COAL CONDITIONER	225 T/HR					
		& MOTOR	10 HP					460V/3 PH/60 CY
12.33-01B,C		2 VIBRATING FEEDERS FOR COAL CONDITIONERS	225 T/HR EA.					(FUTURE)
		& MOTORS	10 HP EA.					(FUTURE)
12.33-02		VIBRATING FEEDER FOR POWER PLANT	75 T/HR					(225 T/HR FUTURE)
		& MOTOR	10 HP					460V/3 PH/60 CY

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
12.33-03A,B		2 VIBRATING FEEDERS FOR TRANSFER CONVEYORS	225 T/HR EA.					
		& MOTORS	7½ HP EA.					
12.33-03C,D		2-VIBRATING FEEDERS FOR TRANSFER CONVEYORS	225 T/HR Ea.					(FUTURE)
		& MOTORS	7½ HP EA					(FUTURE)

UNIT 1300 - COAL PRETREATMENT

1. SCOPE

This unit performs several functions:

1. Removal of the moisture from the minus #4M crushed coal or lignite.
2. If the coal is of an agglomerating bituminous type, pretreatment by controlled combustion with air at 800^{o}F & 20 PSIG destroys its caking characteristics.
3. Quenching of the pretreatment "off-gases" to permit recovery of the tars and light oils in the gas scrubbing system.
4. Cool the char to permit storage in the Char Feed Hopper in Unit 1400.

The major equipment items required in the coal pretreatment unit consist of the pretreater feed storage hopper and weigh belt feeders, flash driers with auxiliaries, dried feed surge drum, pretreater reactor, air blower, char cooler, char cooler-stripper, aeration inert gas compressor with aftercooler and knockout pot, and recycle inert gas compressor with aftercooler and knockout pot. Heat is removed from the pretreater reactor by both generating and superheating steam. Additional heat is removed from the char by vaporizing water and stripping with inert gas. A fin fan air cooler and a shell and tube exchanger also remove heat in the "off-gas" quench system.

2. DESIGN CONDITIONS

The Coal Pretreatment Unit is designed to treat a coal feed of about 204 tons per hour containing 8% moisture as received from the coal grinding facility. About 183 tons per hour of dried pretreated char are required as feed to the hydrogasification reactor.

The use of mechanical materials handling equipment is reduced to an absolute minimum, and where it cannot be avoided, essentially 100% sparing is provided. Conventional, but advanced, commercially demonstrated fluidized solids design principles are used exclusively. The design of the most critical item in this system, the Pretreater Reactor, is based on commercial fluidized solids design and operating experience of the regenerators of fluid catalytic cracking plants and the burners of fluid coking plants. Thus, the particular bed superficial gas velocities, bed height-to-diameter ratios, inlet distribution systems for both air and solids, method of promoting the desired reaction kinetics, etc., as proposed in this Pretreater Reactor design are all supported by years of actual operating experience and plant data.

3. PROCESS FLOW DESCRIPTION

The Coal Pretreatment Unit is shown on Process Flow Diagrams #1843-13.00-1-G and #1843-13.00-2-G. The system consists of the feed drying system, the pretreatment system, the inert gas system, and the off-gas quench system. These will be discussed separately.

The feed drying system contacts the entire wet sized coal as received from Unit 1200 with hot air to reduce the moisture content from 8% to 1%. The coal is delivered to the pretreater feed storage hoppers by conveyor and is withdrawn by constant weigh feeders to the flash drying circuits. Primary cyclones separate the bulk of the dried coal from the drying gases which are handled by the exhaust fans. The gases pass through bag filters to further reduce the dust loading prior to being sent to the boilers in the power plant. All equipment thus far is provided with complete parallel spares to maximize reliability of this system. The primary cyclones discharge the dried coal into the Dried Feed Surge Drum.

The pretreatment system contacts the dried coal with air at 20 PSIG and 800°F to destroy the caking characteristics of bituminous coal. The pretreated coal or "char" is then cooled prior to being sent to storage in Unit 1400. The dried coal is elevated in pressure by the use of a conventional downflowing aerated fluidized solids standpipe with intermediate storage in the Pressurized Feed Hopper. All standpipes and laterial transfer lines are aerated and fluidized by means of the inert gas. The coal remains in the pretreater reactor for 30 minutes and about 10% of the coal feed is consumed. Air is provided by the pretreater air blower and part is admitted (33%) with the feed coal via a "bird cage" in the bottome cone of the reactor and the balance is introduced via two combustion air rings located higher up in the cone.

The 800°F char is moved from the reactor to the Char-Cooler via a transfer pipe and then cooled to 250°F by injection and vaporization of sour water from the gas quenching system. Inert gas strips the water vapor from the char and the steam and inert gas join the "off-gas" from the reactor. This vessel also operates at 20 PSIG. The pressure on the char is reduced in a fluidized solids standpipe that transports the partially cooled char to the Atmospheric Char Cooler-Stripper. Additional cooling is achieved by vaporizing injected water followed by inert gas stripping. The char is then sent to the Char-Feed Hoppers in Unit 1400.

The inert gas system provides the aeration and fluidizing gas needed in the various lines and other equipment in the Coal Pretreatment Unit. The inert gas source is the CO_2 Rich Vent Gas from Unit 3600. This gas is mostly carbon dioxide and about 2% ethane and would normally be vented. However, approximately half of this gas is used in this section and is ultimately consumed as fuel in the boilers of the power plant. It is very desirable to have a low, or zero, oxygen content gas in contact with the coal or char throughout the system. The appropriate aftercoolers and knock-out pots are installed on the discharge lines of the two compressors.

The off-gas quench system removes the tar and oil from the pretreater off-gas, reduces its temperature, and then sends this low BTU gas to the boilers of the power plant. The initial quench is accomplished with a mixture of oil and water to reduce the temperature and absorb the tar and oil in sufficient oil to render them manageable. This mixture joins oil from the second quench and is then returned to the char-oil slurry mix tank in Unit 1400. The water to be recycled is cooled in a fin fan air cooler and the excess water joins that from the second quench to be either recycled to the char coolers elsewhere in Unit 1300 or sent to Unit 4400 as makeup water for limestone slurrying. The second quench uses water only and reduces the oil losses (benzene) to a minimum. The cooled "off-gases" are used in the power plant boilers to recover the heat value and to combine the sulfur dioxide present with that formed in the boilers.

4. UTILITIES SUMMARY

Cooling Water	-	6800 GPM
Boiler Feedwater	-	610 GPM
Steam Generated	-	290,240 Lbs/Hr @ 250 PSIG, Sat. (327,400 Lbs/Hr, superheated from 406°F to 456°F)
Steam Consumption	-	65,600 Lbs/Hr @ 250 PSIG, 456°F.
	-	180,400 Lbs/Hr @ 50 PSIG, Sat.
Motor Horsepower	-	3325 HP (Operating)
Air Cooler Fan Power	-	150 HP

5. COAL AND CHAR FEEDS

The coal feed and pretreated char product (Streams 1301 and 1304, respectively) have the following analysis (dry basis):

	Coal Feed		Pretreated Char	
	Wt %	Lb/Hr	Wt %	Lb/Hr
Carbon	71.50	291,257	71.34	261,545
Hydrogen	5.02	20,449	4.02	14,738
Sulfur	4.42	18,005	3.83	14,041
Nitrogen	1.23	5,010	1.00	3,666
Oxygen	6.53	26,600	7.51	27,533
Ash	11.30	46,031	12.30	45,094
Total	100.00	407,352	100.00	366,617

6. SPECIAL NOTE

It was originally planned to vent the excess inert gas from Unit 3600 directly to atmosphere, as is now done in seven operating plants. (By "excess inert gas" is meant the surplus of CO_2 not needed for fluidization, transport, and aeration in Unit 1300.) However, it has recently been pointed out that the two percent ethane content violates proposed emission standards in Illinois and perhaps other states. This information was received too late to incorporate corrective measures in this report or the accompanying cost estimate. The proper corrective measures have not been decided, but this gas could also be sent to the power plant for boiler fuel, or activated carbon bed absorbers could be used prior to venting of the gas.

MASTER ITEM INDEX
UNIT 1300
COAL PRETREATMENT

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

PROJECT W-1843
DATE 3/1/72
DATE ______

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
13.05-01		START-UP AIR HEATER (GAS FIRED)	5'0" ID X 8'0" TT					
13.06-01		PRETREATER FEED STORAGE HOPPER	30'0" ID X 90'0" TT	VERTICAL				
13.06-02		PRETREATED PRESSURIZED FEED HOPPER	8'-6" ID X 36'0" TT	VERTICAL				W/INTERNAL CYCLONES
13.06-03		PRETREATER REACTOR	35'6" ID X 45'0" TT	VERTICAL				W/STEAM COIL & INTERNAL CYCLONES
13.06-04		PRETREATER CHAR COOLER VESSEL	17'6" ID X 39'0" TT	VERTICAL				W/INTERNAL CYCLONES
			STRIPPER: 4'0" ID X 20'0" TT					
13.06-05		ATMOSPHERIC CHAR COOLER-STRIPPER VESSEL	9'6" ID X 30'0" TT	VERTICAL				W/INTERNAL CYCLONES
			STRIPPER: 4'0" ID X 10'0" TT					
13.06-06		VENTURI SCRUBBER SEPARATOR	16' 0" ID X 30' 0" TT	VERTICAL				316 SS W/DEMISTER
13.06-07		PRETREATER QUENCH TOWER	15' 6" ID X 60' 0" TT	VERTICAL				25 BAFFLE TRAYS 316 SS
13.06-41		INERT GAS QUENCH DRUM	3' 6" ID X 8' 0" TT	VERTICAL				

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

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UNIT 1300
COAL PRETREATMENT

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
13.06-42		DRIED FEED SURGE DRUM	8' 6" ID X 18' 0" TT	VERTICAL				W/EXTERNAL CYCLONES
13.06-43		HIGH PRESSURE AERATION INERT GAS COMPRESSOR DISCHARGE	3' 0" ID X 6' 0" TT	VERTICAL				W/DEMISTER
13.06-44		LOW PRESSURE AERATION INERT GAS COMPRESSOR DISCHARGE K. O. POT	3' 6" ID X 8' 0" TT	VERTICAL				W/DEMISTER
13.06-45		PRETREATER TAR OIL MIX DRUM WITH TAR OIL MIX DRUM MIXER	12' 0" ID X 12' 0" TT 10 HP EST.	VERTICAL				316 SS
13.06-46		STEAM DRUM	12' 0" ID X 48' 0" TT	HORIZONTAL				
13.06-47		TAR-OIL DECANTER	16' 0"ID X 56' 0" TT	HORIZONTAL				316 SS
13.06-48		PRETREATER QUENCH SEPARATOR	12' 0" ID X 48' 0"	HORIZONTAL				316 SS
13.07-1		VENTURI SCRUBBER RECYCLE OIL TAR FIN COOLER	148.0 MM BTU/HR					
13.07-51		DELETED						
13.07-52		HIGH PRESSURE AERATION INERT GAS COMPRESSOR AFTER COOLER	1.1 MM BTU/HR					

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COAL PRETREATMENT

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
13.07-53		LOW PRESSURE AERATION INERT GAS COMPRESSOR AFTER COOLER	0.8 MM BTU/HR					
13.07-54		QUENCH TOWER RECYCLE WATER COOLER	33.0 MM BTU/HR					316 SS
13.08-01A,B		4-VENTURI SCRUBBER RECYCLE OIL PUMP	10,000 GPM EA					316 SS 1 SPARE
		3 MOTOR DRIVE &	300 HP EA					
		1 STEAM TURBINE DRIVE						250 PSIG, 456°F ST 50 PSIG EXH. STM.
13.08-02A,B		2-TAR OIL TRANSFER PUMP	500 GPM EA.					316 SS 1 SPARE
		& MOTOR	30 HP EA.					
13.08-03A,B,C		3-QUENCH TOWER RECYCLE WATER PUMP	7000 GPM EA.					316 SS 1 SPARE
		& MOTOR	250 HP EA					
13.08-04A,B,C		3-BOILER CIRCULATING PUMP	2200 GPM EA.					1 SPARE
		2 MOTOR DRIVE &	75 HP EA					
		1 STEAM TURBINE DRIVE						250 PSIG,456°F STM 50 PSIG EXH. PRES

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UNIT 1300
COAL PRETREATMENT

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
13.08-05A,B		2-BOILER FEED WATER PUMP	875 GPM EA					1 SPARE
		1 MOTOR DRIVE &	200 HP EA					
		1 STEAM TURBINE DRIVE						250 PSIG,456°F STM 50 PSIG EXH. PRESS.
13.08-06A,B		2-CONDENSATE PUMPS	360 GPM ΔP = 65 PSI					1 SPARE
		& MOTOR	25 HP					
13.09-01		PRETREATER AIR BLOWER WITH STEAM TURBINE DRIVE &	82,500 SCFM 10,350 HP					50 PSIG, SAT. STM FOR TURBINE & AUX.
		AIR COOLED CONDENSER						CONDENSING OPERATION TO 8" HG. ABS.
13.09-02A,B		2-AERATION INERT GAS COMPRESSOR	3500 SCFM					1 SPARE
		& MOTOR	600 HP					
13.09-03		RECYCLE INERT GAS COMPRESSOR	18,800 SCFM					
		WITH STEAM TURBINE DRIVE	1700 HP					250 PSIG,456°F STM FOR TURBINE & AUX.-
								50 PSIG EXH. PRESS.
13.17-01A-D		4-PRETREATER FEED WEIGH BELT	220 TPH EA					55 TPH - NORMAL FEED RATE
		& MOTOR	32 HP					

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MASTER ITEM INDEX
UNIT 1300
COAL PRETREATMENT

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. / $	REMARKS
13.22-01A,B		2-FLASH DRYING SYSTEMS INCLUDING EXHAUST VENT FAN WITH 500 HP MOTOR, PRIMARY CYCLONE, MIXER WITH 15 HP MOTOR, ROTARY AIR LOCK WITH 2 HP MOTOR & (1) COAL FIRED FURNACE WITH 1 HP FEEDER DRIVE, 2 HP GRATE DRIVE, 15 HP OVER-FIRE AIR FAN, & 30 HP FORCED DRAFT FAN, WITH STACK, DUCTS, & INSTRUMENTATION						
13.35-01		PRETREATER VENTURI						316 SS
13.36-01A,B		2-BAG FILTER W/ACCESSORIES						

UNIT 1400 - CHAR FEED PREPARATION

1. SCOPE

This unit performs three major functions:

1. Prepares the char oil slurry for introduction into the hydrogasification reactor.
2. Provides facilities for recovering all sulfurous gases from both the Pretreatment and Char Feed Sections.
3. Provides seal flush oil for all pumps handling any slurry in oil within the Demonstration Plant.

The major equipment required in the char feed preparation unit consists of char feed hoppers and weigh feeders for storing and metering the pretreated char; char-oil mix tanks for mixing or slurrying the char and oil, pumps for circulating and bringing the char-oil slurry up to reactor pressure, and heat exchange equipment for heating the char oil slurry to the proper temperature for introduction into the gasification reactor.

2. DESIGN CONDITIONS

The Char Feed Preparation Unit is designed to mix 366,000 pounds per hour of pretreated char with 735,000 pounds per hour of slurry oil. The resultant slurry is then heated from 155°F to 360°F after pressurization in the slurry feed pumps. The effluent gases from the mix tanks and the vent gases from the Tar Oil Mix Drum, Unit 1300, are combined, compressed and sent to Incineration and Tail Gas Treatment, Unit 4300, after being cooled to 100°F.

Careful attention is required in the design of the slurry system to minimize potential problems such as erosion and slurry settling. The heat exchangers and all piping are designed with these criteria in mind.

3. PROCESS FLOW DESCRIPTION

The Char Feed Preparation Unit is illustrated on Process Flow Diagram #1843-14.00-1G. The system consists basically of mixing char and oil and then heating the resultant slurry. Auxiliary facilities for handling the sulfurous vent gases and for providing seal flush oil are also provided.

Pretreated char from Unit 1300 is stored at 200°F under an inert gas atmosphere in the char feed hoppers. The hoppers are sized to provide a ten hour storage period. The char is metered and conveyed to the mix tanks where it is thoroughly mixed with slurry oil, entering at 140°F. The resultant slurry consisting of 33-1/3% by weight char, leaves the mix tank at 155°F. Transfer pumps circulate the slurry through the feed pumps which then increase the pressure to 1450 PSIG. Excess flow is recycled back to the mix tank.

The temperature of the char-oil slurry is increased in two heat exchangers operating in series using 100 and 250 PSIG steam, respectively. Condensate is returned to the plant boiler feedwater system. These exchangers consist of multi-pass large diameter pipes enclosed in single shells. The main slurry flow is split by geometrically designed piping prior to entering the heat exchangers.

The flash gases from the mix tank and from the mix drum in Unit 1300 are mixed, compressed and cooled to minimize loss of oils. Any condensed oil is returned to the mix tank. The remaining gases are sent to Unit 4300 for incineration.

The benzene fraction from Unit 3600 and oil condensate from Unit 2500 are collected and stored in the clean oil storage tank. This oil is then pumped as seal flush oil to all pumps handling oil that contains char or dust. The major portion of flush oil sent to Unit 2100 is returned, cooled, depressurized and recycled to the clean oil storage tank.

UTILITIES SUMMARY

Cooling Water	-	None
Boiler Feed Water	-	None
Steam Generated	-	7,790 lbs/hr. @ 50 PSIG, SAT.
Steam Consumed	-	24,150 lbs/hr. @ 250 PSIG, SAT.
		93,100 lbs/hr. @ 100 PSIG, SAT.
Motor Horsepower	-	3,512 HP (Operating)
Air Cooler Fan Power	-	None

MASTER ITEM INDEX
UNIT 1400
CHAR FEED PREPARATION

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

PROJECT W-1843
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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
14.06-01A,B		2-PRETREATED CHAR FEED HOPPERS	30' 0" ID X 90' 0" TT	VERTICAL				
14.06-41A,B		2-CHAR OIL MIX TANKS WITH MOTOR DRIVEN MIXERS	15' 0" ID X 20' 0" TT	VERTICAL				
			30 HP EST					
14.06-42		MIX TANK VENT CONDENSATE DRUM	2' 0" ID X 6' 0" TT	VERTICAL				
14.07-51		RECYCLE SEAL FLUSH OIL COOLER	3.1 MM BTU/HR 700 FT^2					
14.07-52		1-CHAR OIL SLURRY HEATER	82.0 MM BTU/HR (TOTAL) 13' 0" ID X					USE 100 PSIG SAT.STM.
			70' 0" TT					
14.07-53		1-CHAR OIL SLURRY HEATER	19.8 MM BTU/HR (TOTAL) 9' 0" ID X					USE 250 PSIG SAT. STM
			50' 0" TT					
14.07-54		MIX TANK VENT COOLER	0.4 MM BTU/HR 520 FT^2	DOUBLE PIPE				
14.08-01A,B,C		3-SLURRY TRANSFER PUMPS	1380 GPM EA. ΔP=60 PSI	CENTRIFUGAL				1 SPARE
		& MOTORS	75 HP					
14.08-02A,B,C		3-SLURRY FEED PUMPS	1200 GPM EA ΔP=1250 PSI	RECIPROCATING				1 SPARE
		& MOTORS	1250 HP					

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MASTER ITEM INDEX
UNIT 1400
CHAR FEED PREPARATION

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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
14.08-03A,B,C		3-SEAL OIL CHARGE PUMPS	108 GPM EA ΔP=1450 PSI	CENTRIFUGAL				1 SPARE
		& MOTORS	250 HP					
14.09-01A,B		2-MIX TANK VENT BLOWER	917 SCFM	ROTARY				
		WITH MOTOR	125 HP					
14.17-01A,B		2-WEIGH FEEDERS WITH ACCESSORIES	180 TPH EA 20 HP					90 TPH - NORMAL FEED RATE
14.17-02A,B		2-TRANSFER CONVEYORS	180 TPH EA					
		& MOTORS	50 HP					
14.17-03A-D		4-ROTARY FEEDERS	30" DIA.					
		& MOTORS	3 HP					
14.27-01		CLEAN OIL STORAGE TANK	20'0"x24'0" TT	VERTICAL				12 HR CAPACITY

UNIT 1500 - REACTOR SECTION

1. SCOPE

This unit produces the major portion of the methane product by the reaction of char, steam and hydrogen in the reaction vessel. This product stream is sent to the Raw Gas Quench system (Unit 2100). Spent char is removed from the reaction vessel for further use as fuel in the power plant.

The major equipment in this unit includes the Hydrogasification Reactor vessel, reactor steam separator, and steam-spent char cyclone separator.

2. DESIGN CONDITIONS

The design of this unit is based on the amount of char required to produce a final plant capacity of 80 MM SCFD of pipeline gas. This requires about 183 T/HR of char to the reactor. The heat and material balance used for the process design are shown in Figures 1 and 2, attached.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-15.00-1G. The following is a brief description of the operation:

Char slurry as received from the Char Feed Preparation section (Unit 1400) at 1250 PSIG and 360°F enters the top section of the reaction vessel. Here the hot product gases dry the char by evaporating the slurry oil and heat the dry char to about 600°F. The gas stream containing the vaporized light oil and the product gases leave the system at 1200 PSIG and 600°F to enter the Raw Gas Quench system (Unit 2100).

The char passes down through the first and second stages of the hydrogasification section of the reaction vessel where reaction with hydrogen-rich synthesis gas and steam occurs to produce the product gases. These reaction zones operate at about 1200°F and 1750°F respectively. The char enters the bottom or electrothermal gasification section of the reaction vessel where it reacts with the steam feed to produce the hydrogen-rich synthesis gas used in the upper sections of the vessel. The high temperature level required (1900°F) is maintained by resistance heating of the char particles with the 110 MW input of power from the Power Conditioning system (Unit 5500).

The steam feed enters the system at 1250 PSIG and 1000°F from the Power Plant (Unit 5100) and is split into two streams. The smaller stream (25%) enters the reaction vessel above the electrothermal gasification beds and mixes with the hydrogen-rich synthesis gases entering the second stage of hydrogasification. The major portion (75%) of the steam is used to lift the spent char leaving the bottom bed to the steam-spent char cyclone separator. This reduces the char temperature from 1900°F to 1230°F and increases the steam temperature from 1000°F to 1230°F. This results in a power input savings as well as reducing the char temperature to a level where more conventional materials of construction can be utilized.

The cyclone separator divides the steam and spent char into their respective streams. The steam then enters the electrothermal gasification section to react with the char to produce the synthesis gas. The spent char leaves the system to enter the Char Recovery system (Unit 1600).

The reactor steam separator is used to separate the steam and water from the reaction vessel water jacket. Water is circulated in the jacket to keep the outer pressure wall of the vessel cool and to absorb the heat losses from the hot reaction zones. This is done by vaporizing a portion of the water to steam at system pressure (1250 PSIG and 574°F). The steam leaves the separator and enters the plant 1250 PSIG saturated steam system. Make-up water of boiler feedwater quality enters the separator as required.

4. UTILITIES SUMMARY

Cooling Water	- None
Boiler Feedwater	- 406 GPM
Steam Generated	- 99,200 Lbs/Hr @ 1250 PSIG, Sat.
Steam Consumption	- 289, 210 Lbs/Hr @ 1250 PSIG, 1000°F
Motor Horsepower	- 350 HP (Operating)
Air Cooler Fan Power	- None
"EG" Unit Electric Supply	- 110 MW

	WT %
C	71.36
H_2	4.03
O_2	7.51
N_2	0.99
S	3.81
Ash	12.30
Total	371,547 Lb/Hr
L.Oil	735,000 Lb/Hr

	WT %
C	71.36
H_2	4.03
O_2	7.51
N_2	0.99
S	3.81
Ash	12.30
Total	371,547 Lb/Hr

	WT %
C	80.89
H_2	0.94
O_2	--
N_2	0.42
S	1.59
Ash	16.16
Total	282,875 Lb/Hr

	WT %
C	75.04
H_2	0.87
O_2	--
N_2	0.56
S	2.11
Ash	21.42
Total	213,466 Lb/Hr

	WT %
C	57.76
H_2	0.67
O_2	--
N_2	0.99
S	2.75
Ash	37.83
Total	119,249 Lb/Hr

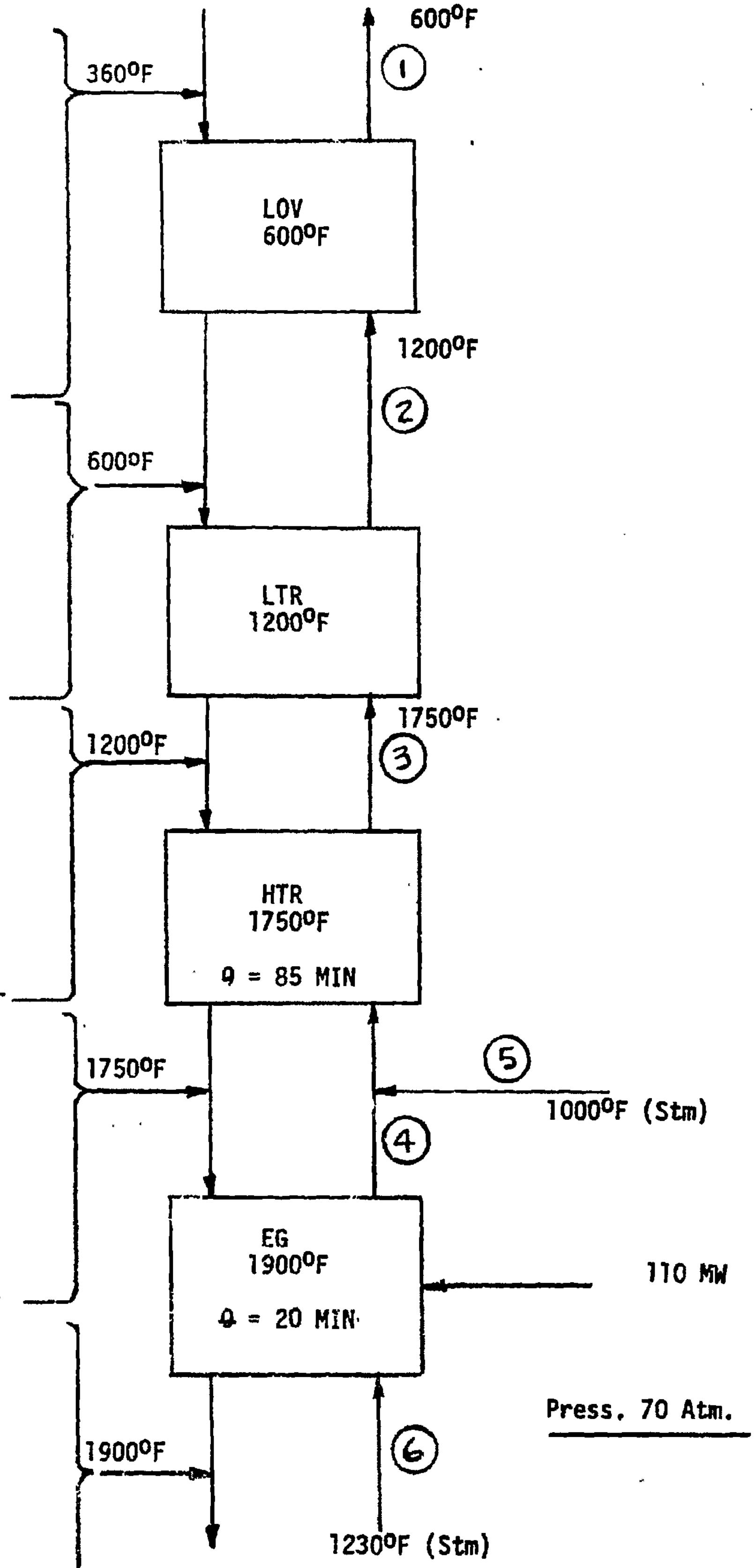

Figure 1 of 2
Process Design Material Balance

	(1)		(2)		(3)		(4)		(5)	(6)
TEMP, °F PRESS, PSI	600°F 1200 PSI		1200°F 1210 PSI		1750°F 1230 PSI		1900°F 1250 PSI		1000°F 1250 PSI	1230 1250
	MOL/HR	MOL %	MOL/HR	MOL %	MOL/HR	MOL %	MOL/HR	MOL %	MOL/HR	MOL/HI
CO	5621	17.80	5621	21.35	5053	24.19	4805	26.79	--	--
CO_2	3793	12.01	3793	14.41	3446	16.49	1570	8.75	--	--
H_2	6340	20.07	6340	24.09	3718	17.80	6335	35.31	--	--
H_2O	4500	14.25	4500	17.09	4087	19.56	4147	23.12	4008	12,041
CH_4	5250	16.62	5250	19.94	4553	21.79	1046	5.83	--	--
C_2H_6	197	0.62	197	0.75	--	--	--	--	--	--
C_6H_6	65	0.21	65	0.25	--	--	--	--	--	--
NH_3	166	0.53	166	0.63	--	--	--	--	--	--
H_2S	333	1.05	333	1.27	36	0.17	36	0.20	--	--
L. Oil	5319	16.84	59	0.22	--	--	--	--	--	--
Total	31,584	100.00	26,324	100.00	20,893	100.00	17,939	100.00	4008	12,041
SCF/Hr.	11,970,340		9,976,800		7,918,450		6,798,880		1,519,030	4,563,5
ACF/Hr.	296,560		382,040		397,200		358,430		49,430	176,4
ACF/Sec.	82		106		110		100		14	

Total Coal Req'd = 371,547 Lb/Hr = 4460 Ton/Day

Total Slurry Oil = 735,000 Lb/Hr

Total Steam = 289,200 Lb/Hr = 6.94 MM Lb/Day

Total Power = 110 MW

Figure 2 of 2
Process Design Material Balance

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 1500
REACTOR SECTION

PROJECT W-1843
DATE 3/1/72
DATE ______

ITEM NO.	PROC. DWG. NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT.	REMARKS
15.06-01		HYDROGASIFICATION REACTOR VESSEL WITH ELECTROTHERMAL GASIFIER	24' 0" O.D. x 203' TT	VERTICAL				
15.06-02		REACTOR STEAM SEPARATOR	8' 0" I.D. x 24' 0" TT	VERTICAL				
15.06-03		STEAM CHAR CYCLONE SEPARATOR	8' 0" I.D. x 16' 0" TT	VERTICAL				
15.08-01A,B		2-REACTOR STEAM SEPARATOR FEED PUMPS	210 GPM EA.	CENTRIFUGAL				1 SPARE
		1-MOTOR DRIVE &	350 HP EA					
		1-STEAM TURBINE DRIVE						250 PSIG,456°F.STM 50 PSIG EXH.PRESS
15.17-01A,B		2-METERING HOPPER WITH ACCESSORIES	5' 0" I.D. 15'0" TT	VERTICAL				5-MINUTE CYCLE

UNIT 1600 - CHAR RECOVERY

1. SCOPE

This unit reduces the temperature of the spent char and prepares it to be used as fuel in the boilers of the power plant.

Since the spent char has good adsorption characteristics, strong phenolic water streams from Units 2400 and 3500 are mixed with the spent char-water slurry so that the mass concentration of phenol in the foul water stream can be reduced to 10 PPM.

The major equipment in this unit includes the spent char-water slurry mix tank, three slurry pressure letdown tanks, centrifuge feed tank, centrifuges, char fines settler, weak phenolic water surge tank, mixed phenolic water-feed tank, pulverizer-dryer and associated pumps.

2. DESIGN CONDITIONS

The design of this unit is based on the amount of spent char available from the Reactor section. This is approximately 60 tons per hour.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-16.00-1G. The following is a brief description of the operation:

The spent char as received from the Reactor system (Unit 1500) at 1240 PSIG and 1230°F is blown into the spent char-water slurry mix tank with a small stream of saturated steam at 1250 PSIG and 574°F. Here the char temperature is reduced to 573°F and most of the steam condensed. The tank is vented back to the steam feed line to the hydrogasification section of the reactor in order to pressure balance the system.

The pressure is then reduced to atmospheric in four stages in order to minimize wear and erosion on the pressure letdown system.

At every stage both pressure and temperature are decreased because of the flashing of water at the control valve. The steam generated is then totally condensed and the condensate flows back to the pressure letdown tank.

At the last stage, phenolic foul water from Unit 2400 is sprayed inside the centrifuge feed tank. From this tank the slurry (25% weight solids) is pumped to three centrifuges operating in parallel.

The effluent water from the centrifuge contains about 6% fines and flows by gravity to the settler. Here the fines settle to the bottom and a thickened fines slurry (25% by weight) is pumped back into the centrifuge for recovery of the fines. Treatment in the form of chemical flocculants may be required to settle the fines. Any chemicals added must be capable of going through the boiler burners with no detrimental effects.

The overflow from the settler (weak phenolic water) goes to a water surge tank. The outlet of this tank is divided into two flows; the first one is going to Unit 4500 Foul Water Disposal for further treatment and the second one is sent to the water feed tank where it is mixed with strong phenolic water from Unit 3500. The phenolic water in this tank is then pumped back to the spent char slurry mix tank.

The main char solids flow from the centrifuge is fed directly to a pulverizer dryer. Since the char contains 25% by weight water, air at 680°F is required to dry the char during the pulverizing operation. This air then conveys the char to the boiler burners for use as fuel.

4. UTILITIES SUMMARY

Cooling Water	-	None
Boiler Feedwater	-	None
Steam Generated	-	None
Steam Consumption	-	23,850 Lbs/Hr @ 1250 PSIG, Sat.
Motor Horsepower	-	1030 HP (Operating)
Air Cooler Fan Power	-	210 HP

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 1600
CHAR RECOVERY

PROJECT n-1343
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
16.05-01	A,B	2-PULVERIZER-DRYER	70 T/HR-TOTAL					
16.06-01		SPENT CHAR-WATER SLURRY MIX TANK	12' 0" ID X 25' 0" TT	VERTICAL				
16.06-02		CENTRIFUGE FEED TANK	10' 0" ID X 25' 0" TT	VERTICAL				
16.06-41		FIRST STAGE SLURRY PRESSURE LETDOWN TANK	8' 0' ID X 18' 0" TT	VERTICAL				
16.06-42		SECOND STAGE SLURRY PRESSURE LETDOWN TANK	8' 0" ID X 18' 0" TT	VERTICAL				
16.06-43		THIRD STAGE SLURRY PRESSURE LETDOWN TANK	10' 0" ID X 20' 0" TT	VERTICAL				
16.06-44		CENTRIFUGE FEED TANK CONDENSATE DRUM	3' 0" ID X 8' 0" TT	VERTICAL				
16.07-01		AIR FIN COOLER - THIRD STAGE LETDOWN TANK	32.3 MM BTU/HR 33,000 FT^2	AIR COOLER				
		& 2 MOTORS	30 HP EA					60 HP TOTAL
16.07-02		AIR FIN COOLER - CENTRIFUGE FEED TANK - LIQUID FEED	13.0 MM BTU/HR 33,000 FT^2	AIR COOLER				
		& 2 MOTORS	25 HP EA					50 HP TOTAL

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 1600
CHAR RECOVERY

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
16.07-03		AIR FIN COOLER - CENTRIFUGE FEED TANK - VENT	47.3 MM BTU/HR 114,000 FT^2	AIR COOLER				
		& 4 MOTORS	25 HP EA					100 HP TOTAL
16.07-51		FIRST STAGE SLURRY PRESSURE LETDOWN TANK CONDENSER	17.3 MM BTU/HR 664 FT^2					
16.07-52		SECOND STAGE SLURRY PRESSURE LETDOWN TANK CONDENSER	37.7 MM BTU/HR 1933 FT^2					
16.07-53		THIRD STAGE SLURRY PRESSURE LETDOWN TANK CONDENSER	30.5 MM BTU/HR 2358 FT^2					
16.07-54		PHENOLIC FOUL WATER COOLER	4.7 MM BTU/HR 659 FT^2					
16.08-01A,B,C		3-PHENOLIC WATER FEED PUMPS	335 GPM EA ΔP=1294 PSI	CENTRIFUGAL				1 SPARE
		2-MOTOR DRIVE &	400 HP					
		1-STEAM TURBINE DRIVE						250 PSIG, 456°F, STM 50 PSIG EXH. PRESS.
16.08-02A,B		2-SPENT CHAR SLURRY CIRCULATION PUMPS	1250 GPM EA ΔP=30 PSI	CENTRIFUGAL				1 SPARE
		& MOTORS	30 HP					
16.08-03A,B		2-CENTRIFUGE FEED PUMPS	1490 GPM EA. ΔP=39 PSI	CENTRIFUGAL				1 SPARE
		& MOTORS	60 HP					

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX

UNIT 1600
CHAR RECOVERY

PROJECT W-1843
DATE 3/1/72
DATE ______

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT #	REMARKS
16.08-04A,B		2-FINES SLURRY RECYCLE PUMPS	60 GPM EA $\triangle$P=38 PSI	CENTRIFUGAL				1 SPARE
		& MOTORS	5 HP					
16.08-05A,B		2-SEAL FLUSH WATER CHARGE PUMPS	10 GPM EA $\triangle$P=1220 PSI	CENTRIFUGAL				1 SPARE
		& MOTORS	35 HP					
16.08-06A,B		2-WEAK PHENOLIC WATER TRANSFER PUMPS	850 GPM EA. $\triangle$P=39 PSI	CENTRIFUGAL				1 SPARE
		& MOTORS	35 HP					
16-08-07A,B		2-CENTRIFUGE FEED TANK CONDENSATE RECYCLE PUMPS	95 GPM EA $\triangle$P=20 PSI	CENTRIFUGAL				1 SPARE
		& MOTORS	5 HP					
16.27-01		MIXED PHENOLIC WATER FEED TANK	70' 0" ID X 32' 0" TT	VERTICAL				24 HR CAPACITY
16.27-02		WEAK PHENOLIC WATER SURGE TANK	45' 0" ID X 8' 0" TT	VERTICAL				24 HR CAPACITY
16.28-01A-D		4-CENTRIFUGE	25 T/HR EA					1 SPARE
		& MOTORS	150 HP					

CUSTOMER : INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 1600
CHAR RECOVERY

PROJECT W-1843
DATE 3/1/72
DATE ____

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
16.28-02		CHAR FINES SETTLER	200' ID x 10' HIGH	CONCRETE				48 HR CAPACITY
		2-MOTOR	10 HP					

UNIT 2100 - RAW GAS QUENCH

1. SCOPE

This unit performs three major functions:

1) Cools reactor effluent from 600°F to 400°F, and a major fraction further to 175°F.
2) Recovers heat from the reactor effluent stream to improve the heat efficiency of the process.
3) Reduces the oil content of the gaseous feed for the Shift Conversion unit to a tolerable minimum.

These functions are carried out in two steps of cooling and subsequent separation of liquid and vapor phases. Tars, dust, and water carried over in the raw gas are removed from the gas phase in the quenching operations. Condensed water is discharged to waste disposal and also utilized in the Shift Conversion, Unit 2400.

The major equipment items required in the raw gas quench operation consist of an ejector type quench nozzle for contacting of quench oil with hot gas; a primary quench separating drum for separating cooled liquid and vapor phases; a main gas condenser for further cooling and condensing of primary quenched gases; and a final phase separating drum for separation of oil and aqueous condensates in two liquid streams apart from the remaining gas.

Heat is removed from the system with a quench oil circulation loop. Heat is recovered from the hot circulating quench oil in a steam generation system. A shell and tube unit is used for the hot quench/steam heat exchange. Additional heat is removed from the circulating quench oil with a fin fan air cooler.

2. DESIGN CONDITIONS

This Raw Gas Quench unit is designed to treat 26,100 mols per hour of reactor products along with 735,000 pounds per hour of vaporized slurry oil. About one-fourth of the gas is discharged at 400°F; the remaining three-quarters is cooled to 175°F to reduce the oil content to 0.6 mol percent, dry gas basis. This oil-free fraction is destined for shift conversion.

Careful attention must be paid to avoid the potential problems of tar buildup and dust carry-over. No cooled metal surface may be exposed to the hot raw gas until after it is quenched with substantial volumes of lower-temperature oil condensate. Small-diameter gas passages must be avoided in the design.

3. PROCESS FLOW DESCRIPTION

This Raw Gas Quench unit is illustrated on Process Flow Diagram #1843-21.00-1G. The system consists basically of two stages of cooling and partial condensation. The two stages will be discussed separately.

The first stage contacts the entire reactor effluent gas stream with a large flow (12,800 gpm) of recirculated sub-cooled (290^{o}F) oil condensate. This contact is done as close as possible to the reactor outlet, 230 feet above grade, in an ejector type mixing nozzle which bears a silhouette similar to a venturi. In the co-current flow free-draining line down from the quench nozzle to the first quench drum the gas-liquid mixture comes to adiabatic thermal equilibrium at 400^{o}F. Entry into the drum is through a submerged sparger which gives good gas distribution, maximum dust entrainment into the liquid phase, and maximum opportunity for tars to be absorbed into the oily condensate. The ports in the sparger have replaceable grommets to cope with erosive wear.

The temperature of the first quench is kept fairly high, 400^{o}F, to permit economical recovery of heat, and to reduce corrosion by staying above the dew point of water as a separate liquid phase.

Gas and oil condensate are separated in the first quench drum. The gas, after passing through a single tray to be discussed later, is divided into two streams. Three-quarters of the gas goes to the second stage cooling system of this unit; one-quarter is by-passed downstream of the shift converter to Unit 2500. The oil is pumped back to quench nozzle through a pair of waste heat steam generators and a group of air-cooled fin fan exchangers. The net make of oil condensate, which corresponds roughly to the amount of oil used to slurry the char in Unit 1400, is discharged to Unit 3100.

The second stage of gas cooling is accomplished in air-cooled fin fan exchangers. Since water as well as oil is condensed over the temperature range 390° to 175°F, corrosion-resistant alloys such as 304L are employed here. The cooled mixture is separated into three phases, gas, oil, and water, in a vessel serving as flash drum and decanter. The gas goes to shift conversion, Unit 2400. Part of the water condensate goes to Unit 2400 also, but since Unit 2400 can only accommodate a limited amount of water, the remainder is diverted through Unit 3500 for stripping and eventually winds up in Foul Water Disposal, Unit 4500. Second stage oil condensate is pumped back to the single gas contacting tray in the first quench drum, mentioned in the preceding paragraph.

4. UTILITIES SUMMARY

Cooling Water	- None
Boiler Feedwater	- 200 GPM
Steam Generated	- 93,100 LBS/HR @ 105 PSIG
Steam Consumption	- 64,000 LBS/HR @ 250 PSIG, 456°F
Motor Horsepower	- 317.5 HP (Operating)
Air Cooler Fan Power	- 340 HP

MASTER ITEM INDEX
UNIT 2100
RAW GAS QUENCH

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
21.06-41		FIRST QUENCH DRUM	11' 0" ID X 15' 0" TT	CARBON STEEL				
21.06-42		SECOND QUENCH DRUM	11' 0" ID X 20' 0" TT	CARBON STEEL				LOWER ½ TANK TO BE CONCRETE LINED
21.07-01		MAIN GAS CONDENSER	74.3 MM BTU/HR 114,000 FT^2	AIR COOLER				TYPE 304 SS CONST.
		& 4 MOTORS	25 HP. EA.					100 HP TOTAL
21.07-02A,B		2-QUENCH COOLERS	151.8 MM BTU/HR 232,000 FT^2	AIR COOLER				TYPE 304 SS CONST.
		& 8 MOTORS	30 HP EA.					240 HP TOTAL
21.07-51A,B		2-STEAM GENERATOR	48.4 MM BTU/HR 15,580 FT^2	KETTLE TYPE				
21.08-01A,B,C		3-QUENCH CIRCULATING PUMP	6400 GPM EA. Δ P=127 PSI	CENTRIFUGAL				1-50% SPARE
		3-STEAM TURBINE DRIVE	800 HP					250 PSIG, 456°F, STM. 50 PSIG EXH. PRESS.
21.08-02A,B		2-RECYCLE OIL PUMPS	152 GPM EA Δ P=60 PSI	CENTRIFUGAL				1 SPARE
		1-MOTOR DRIVE &	10 HP					
		1-STEAM TURBINE DRIVE						250 PSIG 456°F STM. 50 PSIG EXH. PRESS.

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 2100
RAW GAS QUENCH

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
21.08-03A,B		2-QUENCH WATER PUMPS	129 GPM EA. ΔP=45 PSI	CENTRIFUGAL				1 SPARE
		1-MOTOR DRIVE &	7½ HP					
		1-STEAM TURBINE DRIVE						250 PSIG,456°F.STM. 50 PSIG EXH.PRESS
21.08-04A,B		2-HOT WATER CIRCULATING PUMP	1680 GPM EA. ΔP=227					1 SPARE
		1-MOTOR DRIVE &	300 HP					
		1-STEAM TURBINE DRIVE						250 PSIG,456°F.STM. 50 PSIG EXH.PRESS.
21.35-01		QUENCH NOZZLE						

UNIT 2400 - SHIFT CONVERSION

1. SCOPE

This unit converts 2840 mols per hour of carbon monoxide to hydrogen by the well-known water gas reaction:

$$CO + H_2O \longrightarrow CO_2 + H_2$$

This is for the purpose of adjusting the CO/H_2 ratio so that the methanator downstream can produce pipeline gas virtually free of carbon monoxide.

The major equipment is centered around an adiabatic catalytic converter. The catalyst bed is divided into two zones, so that the fore-bed can be by-passed whenever it clogs. Other major equipment includes a gas-fired start-up heater, two feed-product exchangers, a steam economizer, (combination of feed gas preheater and saturator), a waste heat steam generator, a condensate collection drum, and a start-up charge pump.

2. DESIGN CONDITIONS

Approximately 70% of the main gas stream is passed through the shift conversion. Complete conversion and resultant elimination of all carbon monoxide is not an objective of this process application. Quite the contrary; sufficient carbon monoxide must remain in the gas to feed the methanator.

Since only partial conversion is desired, relatively high-temperature operation can be employed. Furthermore, there is no need to eliminate carbon dioxide prior to shift conversion, and the presence of large quantities of carbon dioxide suppresses the Boudouard reaction.*

Using the Badische Anilin & Soda-Fabrik AG Catalyst K8-11, the feed gas should contain a minimum of 1400 PPM of sulfur compounds. Lower concentration of sulfur should be avoided. This catalyst also has a tolerance for oil of one to two percent. All of these features permit shifting a very crude gas stream; raw gas which has only been scrubbed free of particulate solids and exposed to a temperature of 175°F to reduce oil content.

The fore-bed is sacrificial and may be by-passed if clogged. The catalyst is a cobalt-molybdenum oxysulfide, deposited on a steam-resistant spinel ($MgO.Al_2O_3$). It is available from Badische Anilin & Soda-Fabrik AG on a strictly purchase basis, without process license or performance guarantees.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-24.00-1G. The feed gas stream from Unit 2100 passes first through a steam economizer, where it is preheated to 348°F

* The Boudouard reaction is: $2\,CO \rightleftharpoons CO_2 + C$

and saturated with water vapor from a foul water stream from Unit 2100. This saturated stream is passed through a superheater exchanger where it is superheated to 380°F. Addition of steam is then required to bring the steam/dry gas ratio to 0.67. This mixture then goes through the feed-effluent exchanger which brings its temperature to 650°F and then through the catalytic shift reaction beds.

Effluent from the reactor passes counterflow to the feed through the two exchangers, the steam economizer, a waste heat steam generator, and a condensate collection drum.

The aqueous condensate from the collection drum is sent to the Foul Water Disposal Unit 4500 by way of Unit 1600 for phenol reduction by adsorption on spent char. Shifted gas from the condensate collection drum flows to the next gas treatment in sequence, Unit 2500.

4. IN SITU CATALYST REGENERATION

Conventional iron oxide high-temperature shift catalysts are inexpensive enough to discard frequently. It may be more economical to regenerate the BASF catalyst in situ rather than replace fresh catalyst every year or two. Details of the regeneration procedure are not available from BASF. A dollar contingency allowance will be added to provide for extra equipment necessary to conduct the regeneration.

5. UTILITIES SUMMARY

Cooling Water	-	None
Boiler Feedwater	-	140 GPM
Steam Generated	-	69,730 Lbs/Hr @ 50 PSIG, Sat.
Steam Consumption	-	146,540 Lbs/Hr @ 1250 PSIG, Sat.
Motor Horsepower	-	25 HP (Start-up Only)
Air Cooler Fan Power	-	None

MASTER ITEM INDEX
UNIT 2400
SHIFT CONVERSION

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
24.05-01		START-UP HEATER, GAS FIRED	40 MM BTU/HR					
24.06-01		CATALYTIC SHIFT CONVERTER (FORE-BED & AFTER-BED)	10' 6" ID X 49' 0" TT	HORIZONTAL				BOTH BEDS IN ONE VESSE CONNECTED EXTERNALLY
24.06-41		CONDENSATE COLLECTION DRUM	8' 6" ID X 10' 0" TT	VERTICAL				W/DEMISTER
24.07-51		STEAM ECONOMIZER	55.4 MM BTU/HR 2520 SQ. FT.	KETTLE				
24.07-52		ECONOMIZER SUPERHEATER	24.8 MM BTU/HR 2100 SQ. FT.					
24.07-53		FEED-EFFLUENT HEAT EXCHANGER	41.2 MM BTU/HR 4950 SQ. FT.					
24.07-54		WASTE HEAT STEAM GENERATOR	71.9 MM BTU/HR 5250 SQ. FT.	KETTLE				
24.08-01		START-UP CHARGE PUMP	50 GPM ΔP=1035 PSI	CENTRIFUGAL				
		& MOTOR	25 HP					

UNIT 2500 - AMMONIA SCRUB AND GAS PRECONDITIONING

1. SCOPE

The equipment in Unit 2500 serves to precondition the gas before contact with the acid gas removal step in Unit 2600. The gas is cooled to remove oil as a condensate, scrubbed to remove the ammonia, and finally chilled to 70°F to knock out still more oil.

The major equipment in this unit is a set of fin fan exchangers, a flash drum and decanter, a water cooler, a scrubbing tower, a refrigerated cooler, an oil knockout drum and three sets of booster pumps.

2. DESIGN CONDITIONS

This unit is designed to recover 118 mols/hr of ammonia from 27,700 mols/hr of shifted gas. In the scrubbing tower, carbon dioxide and hydrogen sulfide are dissolved to form a slightly acidic solution. This enables the ammonia to leave in a foul water stream in ion form. Residual ammonia in the product gas is specified as no more than 15 PPM. Residual oil (benzene and heavier) should be less than 0.3 percent.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-25.00-1G. Shifted Gas from Unit 2400, Scavenged Gas from Unit 3100, and Bypass Gas from Unit 2100 combine and go through a set of fin fan exchangers which reduce the temperature of the stream from 360°F to 180°F. Condensate is separated and decanted. The vapors go to another exchanger, cooled by water, which reduces the temperature to 120°F. The stream continues to a scrubbing tower where the ammonia is washed out by a scrub water stream from Unit 2800. The overhead vapors from the scrubbing tower are cooled to 70°F by refrigeration; condensate is separated in an oil knockout drum. The vapors leave the unit free of ammonia and go to Unit 2600. The liquid stream from the ammonia scrubber and from the oil knockout drum are returned to the decanter. The decanter separates the oil from the aqueous phase. Aqueous condensate goes to Unit 3500 for further treating and ammonia removal. Oil condensate is sent to Unit 1400 for use as slurry pump seal flush medium.

4. UTILITIES SUMMARY

Cooling Water	-	1065 GPM
Boiler Feedwater	-	None
Steam Generated	-	None
Steam Consumption	-	None
Motor Horsepower	-	17 HP (Operating)
Air Cooler Fan Power	-	100 HP
Refrigeration	-	900 Tons @ + 60°F

MASTER ITEM INDEX
UNIT 2500
AMMONIA SCRUB & GAS PRECONDITIONING

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
25.06-01		AMMONIA SCRUBBER	10' 0" ID X 27' 0" TT	VERTICAL				12 TRAYS
25.06-41		FLASH DRUM & DECANTER	10' 0" ID X 21' 0" TT	HORIZONTAL				W/DEMISTER
25.06-42		OIL KNOCKOUT DRUM	9' 0" ID X 11' 0" TT	VERTICAL				W/DEMISTER PAD
25.07-01A-D		4-MAIN COOLER CONDENSER	99.17 MM BTU/HR 127,400 FT^2					
		& 4-MOTORS	25 HP EA.					100 HP TOTAL
25.07-51		WATER COOLER	16.3 MM BTU/HR 3220 FT^2	SHELL & TUBE				
25.07-52		REFRIGERATED COOLER	12.2 MM BTU/HR 3790 FT^2	KETTLE TYPE				
25.08-01A,B		2-SCRUB WATER BOOSTER PUMP	100 GPM ΔP=140 PSI	CENTRIFUGAL				1 SPARE
		& MOTOR	10 HP					
25.08-02A,B		2-AMMONIA SCRUB BOOSTER PUMP	141 GPM ΔP=50 PSI	CENTRIFUGAL				
		& MOTOR	5 HP					

MASTER ITEM INDEX
UNIT 2500
AMMONIA SCRUB & GAS PRECONDITIONING

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
25.08-03A,B		2-OIL KNOCKOUT DRUM BOOSTER PUMP	18 GPM Δ P=60 PSI	CENTRIFUGAL				1 SPARE
		& MOTOR	2 HP					

UNIT 2600 - METHANOL SCRUB (RECTISOL)

1. SCOPE

The sour gas from Unit 2500 is purified in this unit. Benzene and acid gases, carbon dioxide and hydrogen sulfide, are removed by a physical absorption process, using methanol as the solvent and operating at temperatures well below zero. The unit consists of three high pressure wash towers with associated pumps and exchangers.

2. DESIGN CONDITION

This unit is designed to scrub 220 MM SCFD of sour gas. This is equivalent to 80 MM SCFD of final product gas. It is designed to remove all of the benzene and heavier oils, and to remove sufficient amounts of acid gases to meet the sweetened gas specifications of 0.15 percent carbon dioxide and 0.1 PPM hydrogen sulfide. The unit operates at high pressure (1000 PSI range) and at low temperatures, minus 40° to minus 70°F.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-26.00-3G. Sour gas from Unit 2500 enters the benzene wash tower where it is scrubbed with sweet methanol from Unit 3600 to remove the benzene and heavier oils and any water in the gas. The benzene-rich methanol is sent to Unit 3600 for recovery of the benzene. The benzene-free sour gas is cooled down by exchange against the sweet product gas and CO_2 rich gas and then fed to the H_2S wash tower. Here the H_2S is removed by scrubbing the gas with methanol from the CO_2 wash tower. The H_2S-free product gas is combined with a recycle stream from Unit 3600 and fed to the CO_2 wash tower where it is again washed with methanol to reduce the CO_2 content of the product gas to the desired level. The methanol used in the top portion is free of CO_2 while that added in the middle of the column has had the major portion of the CO_2 removed. Some of the heat solution is removed by intermediate cooling of the methanol with refrigerant. A portion of the CO_2-rich methanol from the wash tower is pumped to the H_2S wash tower; the remainder is sent to Unit 3600. The sweet product gas is heated up and sent to Unit 2700.

The refrigeration recuperation scheme is quite elaborate, and includes many process gas exchangers and a power-generating turbine expander. Either ammonia or Freon 22 could be used as the refrigerant, with the German process licensors preferring ammonia because of a slight edge in horsepower requirements.

4. UTILITIES SUMMARY

Cooling Water	-	None
Boiler Feedwater	-	None
Steam Generated	-	None
Steam Consumption	-	None
Motor Horsepower	-	100 HP (Operating)
Air Cooler Fan Power	-	None
Refrigeration	-	360 T/HR @ (-) 50°F
Methanol Loss	-	75 LBS/HR

5. SPECIAL NOTE

This design is part of LINDE AG'S RECTISOL process. Due to the proprietary nature of this process, the Process Flow Diagram and the descriptive writeup in this report have been simplified and condensed. The cost estimate is based on a complete confidential design disclosure by LINDE AG.

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 2600
METHANOL SCRUB (RECTISOL)
*(SIMPLIFIED)

* CENSORED VERSION FOR PUBLICATION

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. / *	REMARKS
26.06-01		BENZENE WASHTOWER						
26.06-02		H_2S WASHTOWER						
26.06-03		CO_2 WASHTOWER						
26.07-51		FEED GAS PRECOOLER						
26.07-52		FEED GAS PRECOOLER						
26.08-01A,B		2-SOUR METHANOL PUMP						
		& MOTOR						

* DUE TO THE PROPRIETARY NATURE OF THIS PROCESS, NOT ALL EQUIPMENT IS LISTED.

UNIT 2700 - SULFUR CLEANUP GUARD BEDS

1. SCOPE

At this point in the process the gas must be passed through a fixed bed of chemically reactive material to trap out the last traces of sulfur. No volatile sulfur compounds may be permitted to leak through to the methanation step, where sulfur would deactivate the catalyst.

The major equipment in this unit consists simply of two large pressure vessels to contain the reagent. The reagent material to be placed in these vessels can be chosen later. Prime candidates are:

1. Zinc Oxide (unsupported or impregnated on activated carbon)
2. Iron Oxide (supported on activated carbon or, as in antique gas technology, supported on wood chips)
3. Copper Oxide (on activated carbon)
4. Nickel Oxide (spent methanation catalyst)
5. A secret metal oxide on activated carbon alleged by the vendor to be more effective than any of the other possible choices.

At the date of publication of this report zinc oxide has been selected for this design.

2. DESIGN CONDITIONS

The following statistics, some of them arbritarily selected from conflicting educated opinions, are of interest in the design of this unit:

Feed gas inlet sulfur content:	0.1 PPM vol. as H_2S
Exit gas sulfur content:	0.02 PPM
Space velocity:	2000 reciprocal hours, S.C.
Temperature:	Ambient
Pressure:	1045 PSIG

Regeneration cycle:

None with zinc oxide. Manufacturer will reclaim spent catalyst at his plantsite.

Three to four months of operation with reagent number five, followed by a week-long cycle of steaming with 1000 PPM oxygen, then cooling under inert gas. In situ, sulfur will be oxidized from the sulfide form to the elemental form.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-27.00-1G.

The main gas stream from the Methanol Scrub system (Unit 2600) passes through the adsorption beds and is sent on to the Methanation step (Unit 2800).

4. UTILITIES SUMMARY

None Required.

MASTER ITEM INDEX
UNIT 2700
SULFUR CLEAN-UP GUARD BEDS

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

PROJECT W-1843
DATE 3/1/72
DATE ____

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
27.06-41A		ZINC OXIDE BED ABSORBER	10'6"ID x 25'0"TT	HORIZONTAL DRUM			185,000	A.S.M.E. CODE SEC. VIII DIV. 2
27.06-41B		ZINC OXIDE BED ABSORBER	10'6"ID x 25'0"TT	HORIZONTAL DRUM			185,000	A.S.M.E. CODE SEC. VIII DIV. 2

UNIT 2800 - METHANATION SECTION

1. SCOPE

This unit is for conversion of carbon monoxide to methane by reaction with hydrogen according to the reaction:

$$CO + 3H_2 \rightarrow CH_4 + H_2O$$

This reaction raises combustion heat content of the product gas to 954 Btu/cu. ft. (HHV) which approaches that of natural gas, and reduces the carbon monoxide content to less than 1000 PPM. This specification is the tolerance permitted for fuel gas for domestic appliances, as specified by the American Gas Association.*

The reaction is highly exothermic, generating about 52,700 cal/gm mol, or about 260 MM Btu/hr (LHV) for this HYGAS® project. (By way of comparison the LHV of hydrogen combustion is 58,000 cal/gm mol). The reaction is carried out over beds of nickel catalyst in adiabatic vessels. Heat of reaction is dissipated by recycling large quantities of cold product gas. Ultimately the heat of reaction is removed as sensible heat of the effluent gas stream and used to generate steam at two pressure levels.

* Gas Engineers Handbook, McGraw-Hill Book Co. First Edition, 1934, pp. 528-531. Later editions do not devote as much text to this subject.

There are four reactors operating in parallel enclosed in a single horizontal pressure vessel. (The mode of operation is not exactly parallel, as explained below, but each bed of catalyst performs the same function on gas of the same inlet composition). The rest of the major equipment consists of a series of very large heat exchangers and the recycle gas compressor.

2. <u>DESIGN CONDITIONS</u>

This unit is designed to methanate 17,000 pound mols per hour of sulfur-free gas containing 16% carbon monoxide. After dilution with recycled product gas the feed to the reactors contains only four percent carbon monoxide. The volume of catalyst used corresponds to a space velocity of 8000 reciprocal hours. The product gas must contain not more than one-tenth percent carbon monoxide (1000 PPM) dry basis and, of course, minimum residual excess hydrogen.

Catalyst stability and vessel metallurgy limit the exit gas temperature to 905°F. This in turn determines the minimum hydrogen concentration of the effluent by reaction equilibrium, and the minimum recycled diluent gas volume by heat balance.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-28.00-1G.

The reaction is divided into four stages, but the stages can be considered to be parallel in function, rather than consecutive. The feed gas to each stage is of the same composition as the feed to the other stages; effluent gas compositions are alike; feed temperatures are identical, 550°F; and effluent temperatures differ by only 5°F.

Each stage receives as feed a blend of three gas streams:

(1) A quota of fresh CO-rich gas from Unit 2700.

(2) A quota of cold, inert, dry product recycle gas.

(3) All the hot, inert, wet reactor effluent from the preceding stage.

Only the first stage must be preheated by exchange to reaction temperature. The feed to the first stage is preheated by surface exchange.

Sensible heat in the effluent heat of each stage is sufficient to raise to reaction temperature about double the amount of gas feeding the following stage. Hence, the fresh CO-rich gas is distributed in the ratio 1:2:4:8 to the consecutive stages. The successive catalyst volumes are also in approximately the same ratio.

Effluent gas from the final stage reactor passes through a feed-effluent exchanger, a 250 PSIG steam boiler, a 50 PSIG steam boiler and an air-cooled partial condenser. At a temperature of 150°F it is then compressed in the recycle gas compressor to a pressure (1050 PSIG) sufficient to be fed to the first stage reactor. Approximately one-third is diverted as product gas, further cooled, and sent to the Drying system (Unit 2900).

The seemingly complex flow pattern around the reactor is the result of selecting the most economical arrangement. A much simpler flow pattern would be to combine all the reactor beds into one, put all the fresh feed into the recycle compressor suction, and preheat the recycle gas by surface exchange with reactor effluent. This simpler alternative arrangement would increase the recycle compressor circulation volume by roughly two-fold and the feed-effluent heat exchanger duty by roughly fifteen-fold. It would decrease the recycle compressor pressure differential by one-fourth, and the horsepower by one-half.

4. UTILITIES SUMMARY

Cooling Water	-	440 GPM
Boiler Feedwater	-	388 GPM
Steam Generated	-	147,700 LBS/HR @ 250 PSIG, Sat.
	-	31,000 LBS/HR @ 50 PSIG, Sat.
Steam Consumption	-	32,000 LBS/HR @ 1250 PSIG, Sat. (Start-up)
	-	60,000 LBS/HR @ 250 PSIG, 456°F
Motor Horsepower	-	100 HP (Operating)
Air Cooler Fan Power	-	240 HP

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 2800
METHANATION SECTION

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
28.06-01		STAGE I METHANATION REACTOR	11'0" ID X 11'8" OD X 4'0" BED LENGTH	HORIZONTAL	200			STAGES 1 THRU IV
								CONTAINED IN SINGLE
28.06-02		STAGE II METHANATION REACTOR	11'0" ID X 11'8" OD X 8'0" BED LENGTH	HORIZONTAL	400			SHELL
								11'0" ID X 11'8" OD
28.06-03		STAGE III METHANATION REACTOR	11'0" ID X 11'8" OD X	HORIZONTAL	800			61' 3½" TT
28.06-04		STAGE IV METHANATION REACTOR	11'0" ID X 11'8" OD X 30'0" BED LENGTH	HORIZONTAL	1500		536,000	TOTAL, 4 STAGES
28.06-41		CONDENSATE COLLECTION DRUM	7'0" ID X 15'0" TT	HORIZONTAL				W/DEMISTER
28.06-42		PRODUCT GAS WATER K.O. DRUM	6'0" ID X 10'0" TT	VERTICAL				W/DEMISTER
28.07-01A-D		4-RECYCLE GAS COOLER-CONDENSER	112 MM BTU/HR 250,000 FT^2	AIR-COOLED				6 SECTIONS
		& 8 MOTORS	30 HP					240 HP TOTAL
28.07-51		FEED-EFFLUENT EXCHANGER	17.0 MM BTU/HR 476 FT^2	U-TUBE				
28.07-52		PRODUCT GAS COOLER	4.8 MM BTU/HR 965 FT^2	U-TUBE				

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX

UNIT 2800
METHANATION SECTION

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
28.07-53		START-UP HEATER	19 MM BTU/HR 900 FT^2	U-TUBE				
28.07-54		WASTE HEAT BOILER 250 PSIG STEAM	156.1 MM BTU/HR 10,552 FT^2	U-TUBE KETTLE				
28.07-55		WASTE HEAT BOILER 50 PSIG STEAM	32.6 MM BTU/HR 2637 FT^2	U-TUBE KETTLE				
28.08-01A,B		2-BOILER FEEDWATER PUMPS	320 GPM Δ P=195 PSI	CENTRIFUGAL				1 SPARE
		1-MOTOR DRIVE &	100 HP					
		1-STEAM TURBINE DRIVE						250 PSIG,456°F.STM. 50 PSIG,EXH.PRESS.
28.09-01		METHANATION RECYCLE GAS COMPRESSOR	3182 ACFM @ 993 PSIG SUCTION 1065 PSIA DISCHARGE					
		WITH STEAM TURBINE DRIVE	1610 HP					250 PSIG,456°F.STM 50 PSIG EXH.PRESS.

UNIT 2900 - PRODUCT GAS DRYING

1. SCOPE

This system is a packaged glycol drying unit designed to remove water from the product gas prior to discharge into the pipeline system. The major pieces of equipment are a seven tray glycol absorber with an internal heat exchange coil, and a skid mounted glycol regenerator consisting of a reboiler with steam coil, a storage tank with an external heat exchanger, a still column with reflux coil, pumps, and a filter.

2. DESIGN CONDITIONS

The unit is designed to dehydrate 80 MM SCFD of product gas from a dew point of 110°F to a water content of 6 Lb/MM SCF while circulating 13 GPM of glycol. The glycol concentration will swing between 99.9 and 94.9 percent by weight. The dew point of the product gas is minus 40°F.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-29.00-1G. Water saturated product gas from Unit 2800 enters the bottom of the absorber and is contacted with triethylene glycol. The dehydrated product gas stream leaves the top tray and exchanges heat with the incoming water-lean glycol which is circulated through the coil. The dehydrated product gas passes out the top of the absorber as pipeline-quality product gas. Water-laden glycol is discharged to the regenerator. It enters the reflux coil in the top of the still column to condense glycol vapors and preheat the rich glycol.

It passes through the heat exchanger coil in the storage tank, through the filter, then into the still column. Here it is contacted with the vapors from the reboiler. Water vaporized in the regenerator is discharged to the atmosphere. The glycol is reconcentrated by boiling it at 400°F using 600 lb. steam in the reboiler coil. The glycol is then additionally stripped with inert gas in the packed column between the reboiler and storage tank. Reconcentrated glycol is cooled by exchange with the incoming water-laden glycol and stored. From the storage tank it is pumped to another absorber.

4. UTILITIES SUMMARY

Cooling Water	-	None
Boiler Feedwater	-	None
Steam Generated	-	540 Lbs/Hr
Steam Consumption	-	2400 Lbs/Hr @ 600 PSIG, Sat.
Motor Horsepower	-	15 HP (Operating)
Air Cooler Fan Power	-	None
Glycol Loss	-	3 Lbs/Hr.

5. SPECIAL NOTE

This design incorporates features patented by Black, Sivalls & Bryson, Incorporated.

FINAL - 3/1/72

MASTER ITEM INDEX

UNIT 2900
PRODUCT GAS DRYING SECTION

CUSTOMER : INSTITUTE OF GAS TECHNOLOGY

PROJECT W-[illegible]
DATE 3/1 [illegible]
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT #	REMARKS
29.22-01		PACKAGED GLYCOL DEHYDRATOR UNIT						
		INCLUDING ABSORBER, REGENERATOR,						
		STORAGE TANK, PUMP, EXCHANGERS,						
		FILTER, PIPING, & INSTRUMENTATION.						
29.27-01		GLYCOL STORAGE TANK	2,000 GAL.					ATMOSPHERIC

1. SCOPE

The purpose of this unit is to remove and recover dissolved gas contained in the oil condensate stream (gassy oil) leaving the first quench drum of the Raw Gas Quench, Unit 2100. This is accomplished by cooling the condensate and successively flashing the liquid through three de-pressuring stages. Resulting flashed vapor from successive pressure reductions is compressed and cooled for recovery of heavy hydrocarbons. Liquid water is removed in the first flashing and cooling step. The liquid product (stabilized oil) from the third flashing step is essentially free of dissolved gas and transferred to Unit 7100 for storage.

2. DESIGN CONDITIONS

The oil stabilization unit was designed to process the design flow quantity of gassy oil from the Raw Gas Quench operation in Unit 2100. Three stages of flashing and compression were selected to optimize product separation and recovery, and compression costs. The design provides for reduction to 0.1 weight percent gas in the stabilized oil and a benzene recovery of 99.6 weight percent. Stripped gas (scavenged gas) is compressed for delivery to Unit 2500 for preparation of methanation unit feed.

3. PROCESS FLOW DESCRIPTION

The oil stabilization system is shown on Process Flow Diagram #1843-31.00-1G. Gassy oil at a temperature of 175°F is stepped down in pressure from 1175 PSIG to 340 PSIG upstream of the gassy oil air cooler. Cooled effluent, at 150°F, is combined with the compressed gas stream flowing from the second stage blowdown drum and is further cooled in a water cooled shell and tube exchanger to 120°F. Upon cooling the oil, dissolved water separates. This combined stream is then transferred to the first stage blowdown drum for phase separation. The first blowdown drum water phase is transferred to Unit 3500 for ammonia removal. First stage gas phase at 295 PSIG is compressed to 1145 PSIG and transferred to Unit 2500 for ammonia removal and subsequent use as methanation unit feed. First blowdown drum liquid hydrocarbon phase is transferred to the second stage blowdown drum after a pressure reduction to 60 PSIG. Vapor separated in the second stage drum is compressed to 330 PSIG and combined with gassy oil and processed as outlined above. Second stage liquid hydrocarbon is heated to a temperature of 155°F and then stepped down to atmospheric pressure before transfer to the third stage blowdown drum for vapor-liquid separation. The gas phase leaving the third stage drum is compressed to 75 PSIG, partially condensed in a water cooled heat exchanger, and transferred to the second stage blowdown drum for phase separation. The liquid (stabilized oil) leaving the third stage blowdown drum is essentially free of gas and is pumped to Unit 7100 for storage.

4. UTILITIES SUMMARY

Cooling Water	-	1750 GPM
Boiler Feedwater	-	None
Steam Generated	-	None
Steam Consumption	-	17,560 Lbs/Hr @ 50 PSIG, Sat.
Motor Horsepower	-	1725 HP (Operating)
Air Cooler Fan Power	-	100 HP

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 3100
OIL STABILIZATION AND
SCAVENGE GAS COMPRESSION

PROJECT W-1843
DATE 3/1/72
DATE ______

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
31.06-41		FIRST STAGE BLOWDOWN DRUM	12' 0" ID X 25' 0" TT	CARBON STEEL				LOWER ½ TANK TO BE CONCRETE LINED
31.06-42		SECOND STAGE BLOWDOWN DRUM	8' 0" ID X 20' 0" TT	CARBON STEEL				LOWER ½ TANK TO BE CONCRETE LINED
31.06-43		THIRD STAGE BLOWDOWN DRUM	8' 0" ID X 20' 0" TT	CARBON STEEL				
31.07-01		GASSY OIL COOLER	88.3 MM BTU/HR 200,000 FT^2	AIR COOLER				
		& 4 MOTORS	25 HP EA					100 HP TOTAL
31.07-51		COMBINED FEED COOLER	13.3 MM BTU/HR 4880 FT^2	SHELL & TUBE				
31.07-52		FLASHED VAPOR CONDENSER	4.42 MM BTU/HR 800 FT^2	SHELL & TUBE				
31.07-53		THIRD STAGE BLOWDOWN PREHEATER	16.01 MM BTU/HR 850 FT^2	SHELL & TUBE				
31.08-01A,B		2-STABILIZED OIL PUMPS	1955 GPM EA Δ P=65	CENTRIFUGAL				1 SPARE
		1-MOTOR DRIVE &	125 HP					
		1-STEAM TURBINE DRIVE						250 PSIG, 456°F.STM 50 PSIG EXH.PRESS.

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 3100
OIL STABILIZATION AND
SCAVENGE GAS COMPRESSION

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
31.09-01		SCAVENGE GAS COMPRESSOR	5.399 MM CFD @ 14.7 PSIA, 60°F	RECIPROCATING				
		FIRST STAGE						
		& MOTOR	600 HP					
31.09-02		SCAVENGE GAS COMPRESSOR	5.323 MM CFD @ 14.7 PSIA, 60°F	RECIPROCATING				
		SECOND STAGE						
		& MOTOR	600 HP					
31.09-03		SCAVENGE GAS COMPRESSOR	2.613 MM CFD @ 14.7 PSIA	RECIPROCATING				
		THIRD STAGE						
		& MOTOR	400 HP					

UNIT 3200 - SULFUR RECOVERY (CLAUS SULFUR PLANT)

1. SCOPE

This unit converts hydrogen sulfide to molten elemental sulfur, a marketable by-product. The hydrogen sulfide is contained in two acid gas streams coming from different points of the HYGAS® plant. The reactions are:

(1) $H_2S + 1\frac{1}{2}O_2 \longrightarrow SO_2 + H_2O$

(2) $2H_2S + SO_2 \longrightarrow 3S^o + 2H_2O$

Reaction 1 is carried out in a specially-designed furnace; reaction 2, the Claus reaction, is conducted catalytically in two adiabatic stages.

The major equipment consists of an air compressor, the furnace, a waste heat boiler, the catalytic converters, and the product condensers. Many pieces of equipment shown as separate items on the flow sheet can be mechanically assembled within a single shell.

2. DESIGN CONDITIONS

This unit will be designed for a feed of at least 300 pound mols per hour of H_2S contained in acid gas mixtures at a concentration of 30% or higher. At least two-thirds of the H_2S must be free of ammonia (200 PPM max.). The overall efficiency of sulfur recovered will be better than 93%. The unit will produce slightly less than one hundred long tons per day of bright sulfur.

3. PROCESS FLOW DESCRIPTION

The system is shown on Process Flow Diagram #1843-32.00-1G.

The system is called, in the jargon of the sulfur industry, a "split flow" or "bypass" arrangement. Only about one-third of the acid gas is fed to the non-catalytic flame furnace.

Furnace effluent passes through a waste-heat boiler, generating 250 PSIG steam, and is mixed with bypass gas to arrive at a proper Claus reactor feed. Both the stoichiometric ratio of H_2S to SO_2 and the temperature of the feed to the catalytic reactor must be carefully controlled.

From the catalytic first-stage reactor, the gas passes through a recuperative heat exchanger to preheat second-stage feed, then through a condenser generating 50 PSIG steam, and a sulfur collection drum. The flow pattern through the second-stage reactor is similar to the first-stage.

4. UTILITIES SUMMARY

Cooling Water	-	None
Boiler Feedwater	-	53 GPM
Steam Generated	-	15,840 Lbs/Hr @ 250 PSIG, Sat.
	-	7,000 Lbs/Hr @ 50 PSIG, Sat.
Steam Consumption	-	14,000 Lbs/Hr @ 250 PSIG
Motor Horsepower	-	25 HP (Operating)
Air Cooler Fan Power	-	None

5. SPECIAL NOTE

The process on which this sulfur plant will be designed is the property of the AMOCO PRODUCTION COMPANY - Tulsa, Oklahoma. It is available under license. More than 110 sulfur recovery plants have been designed and constructed under Amoco license.

Because of the proprietary nature of this design the complete material balance is not presented nor are some of the mechanical design details.

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 3200
SULFUR RECOVERY
*(SIMPLIFIED)

* CENSORED VERSION FOR PUBLICATION

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. *	REMARKS
32.05-01		FURNACE						
32.06-01		REACTOR						
32.06-41		ACID GAS K. O. DRUM						
32.06-42		ACID GAS K. O. DRUM						
32.06-43		SULFUR K. O. DRUM						
32.06-44		SULFUR K. O. DRUM						
32.07-51		FIRST SULFUR CONDENSER						
32.07-52		RECUPERATIVE HEAT EXCHANGER						
32.07-53		SECOND SULFUR CONDENSER						

CUSTOMER : INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 3200
SULFUR RECOVERY
*(SIMPLIFIED)

*CENSORED VERSION
FOR PUBLICATION

PROJECT W-1843
DATE 3/1/72
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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. $	REMARKS
32.08-01A,B		2-SULFUR PRODUCT PUMPS		VERTICAL				1 SPARE
		& MOTOR						
32.08-03A,B		2-BOILER FEEDWATER PUMP						
		1 MOTOR DRIVE &						
		1 STEAM TURBINE DRIVE						
32.09-01		AIR BLOWER						
		WITH STEAM TURBINE DRIVE						
32.19-01		WASTE HEAT BOILER						

UNIT 3500 - AMMONIA SEPARATION (PHOSAM PROCESS)

1. SCOPE

This unit is designed to strip volatile contaminants from the foul water stream which originates in Unit 2500, before the foul water is discharged to the disposal facility, Unit 4500, and to separate the volatile contaminants into the basic component, ammonia, and the acidic components, carbon dioxide and hydrogen sulfide. The ammonia is recovered in anhydrous liquid form of commercial purity. The acid gases are recovered as an ammonia-free gas mixture suitable for feed to a Claus Sulfur Recovery Plant, Unit 3200.

The following four basic process steps are involved in this unit:

1. Stripping of foul water.
2. Selective absorption of stripped gases.
   2a. Partial condensation of water and overhead acid gases from the selective absorber.
3. Desorption of ammonia.
4. Dehydration and refining of ammonia.

2. DESIGN CONDITIONS

The contaminated water feed stream is first steam stripped to separate out the volatile components. The gas stream is sent to the absorber which yields an acid gas stream of 2.3 MM SCFD to the sulfur recovery unit. This acid gas contains approximately 17 mol % H_2S, 9 mol % water vapor and less than 200 PPM NH_3. The balance is predominantly carbon dioxide.

Product ammonia, approximately 30 tons/day, is delivered to battery limits. The ammonia is of commercial quality, perhaps of refrigerant grade.

3. PROCESS FLOW DESCRIPTION

Foul water containing dissolved phenols, acid gases, and ammonia is fed to the sour water stripper where the volatile components are separated and fed to the absorber. This gas contains NH_3, CO_2, H_2S and H_2O as principal components, with light hydrocarbons as minor components, and will be free of entrained coal tar or other nonvolatile materials. Ammonia removal from this gas is accomplished by counter-current scrubbing of the gas with an ammonium phosphate solution which absorbs the ammonia, and counter-current direct steam stripping of the solution to remove the absorbed ammonia. In the stripping operation the ammonia is obtained as an aqueous vapor and the phosphate solution is regenerated for recycling to the absorber. The wet ammonia vapor is condensed and fractionated to produce anhydrous ammonia and a waste water stream.

The sour overhead gas from the ammonia absorber must be suitable for the Claus process sulfur plant. A partial condenser serves to dehydrate the gas and simultaneously eliminate the last traces of ammonia. The condensate is sent to the sour water stripper, item number 35.06-04.

The result of the total process is the removal of ammonia from the foul water, its conversion to anhydrous liquid ammonia, and removal of volatile acid gases from the foul water and delivery in a gas stream suitable for Claus-type sulfur recovery.

4. UTILITIES SUMMARY

Cooling Water	-	2740 GPM
Boiler Feedwater	-	None
Steam Generated	-	None
Steam Consumption	-	25,640 Lbs/Hr @ 250 PSIG, Sat.
	-	30,000 Lbs/Hr @ 50 PSIG, Sat.
Motor Horsepower	-	65 HP (Operating)
Air Cooler Fan Power	-	None

5. SPECIAL NOTE

The PHOSAM process outlined on this flow sheet was designed by United States Steel Corporation's subsidiary USS Engineers and Consultants, Inc. Vessel sizes, flow rates, and exchanger duties were determined by preliminary methods suitable for cost estimation purposes.

The USS PHOSAM process has been in successful operation since 1968. Six plants are in operation or under construction in the United States, Japan, and Canada.

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 3500
AMMONIA SEPARATION
(PHOSAM)
* Simplified

* CENSORED VERSION FOR PUBLICATION

PROJECT W-1843
DATE 3/1/72
DATE

ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT #	REMARKS
35.06-01		ABSORBER						
35.06-02		AMMONIA STRIPPER						
35.06-03		AMMONIA DEHYDRATOR						
35.06-04		SOUR WATER STRIPPER						
35.06-05		PARTIAL CONDENSER						
35.06-41		PHOSPHORIC ACID TANK						
35.06-42		CONTACTOR						
35.06-43		FRACTIONATOR FEED TANK						
35.06-44		CAUSTIC TANK						
35.06-45		ACTIVATED CARBON BED						

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 3500
AMMONIA SEPARATION
(PHOSAM)
* Simplified

* CENSORED VERSION
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PROJECT W-1843
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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. / *	REMARKS
35.07-51		LEAN SOLUTION COOLER						
35.07-52		SOLUTION HEAT EXCHANGER						
35.07-53		AMMONIA STRIPPER CONDENSER (1)						
35.07-54		AMMONIA STRIPPER CONDENSER (2)						
35.07-55		FRACTIONATOR CONDENSER						
35.07-57A,B		2-PARTIAL CONDENSER RECYCLE COOLER						
35.08-10A,B		2-ABSORBER BOTTOMS PUMP						
		& MOTOR						
35.08-11A,B		2-AMMONIA STRIPPER FEED PUMP						
		& MOTOR						
35.08-12A,B		2-FRACTIONATOR FEED PUMP						
		& MOTOR						

CUSTOMER: INSTITUTE OF GAS TECHNOLOGY

MASTER ITEM INDEX
UNIT 3500
AMMONIA SEPARATION
(PHOSAM)
* Simplified

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PROJECT W-1843
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ITEM NO.	PROCON NO.	DESCRIPTION	SIZE	TYPE	CU. FT.		WT. #	REMARKS
35.08-13A,B		2-FRACTIONATOR REFLUX PUMP						
		& MOTOR						
35.08-14		PHOSPHORIC ACID MAKEUP PUMP						
		& MOTOR						
35.08-15A,B		2-CAUSTIC METERING PUMP						
		& MOTOR						
35.08-16A,B		3-PARTIAL CONDENSER RECYCLE PUMP						
		& MOTOR						