EVALUATION OF POLLUTION CONTROL IN FOSSIL FUEL CONVERSION PROCESSES. GASIFICATION: SECTION 7. U-GAS PROCESS

EXXON RESEARCH AND ENGINEERING CO.,
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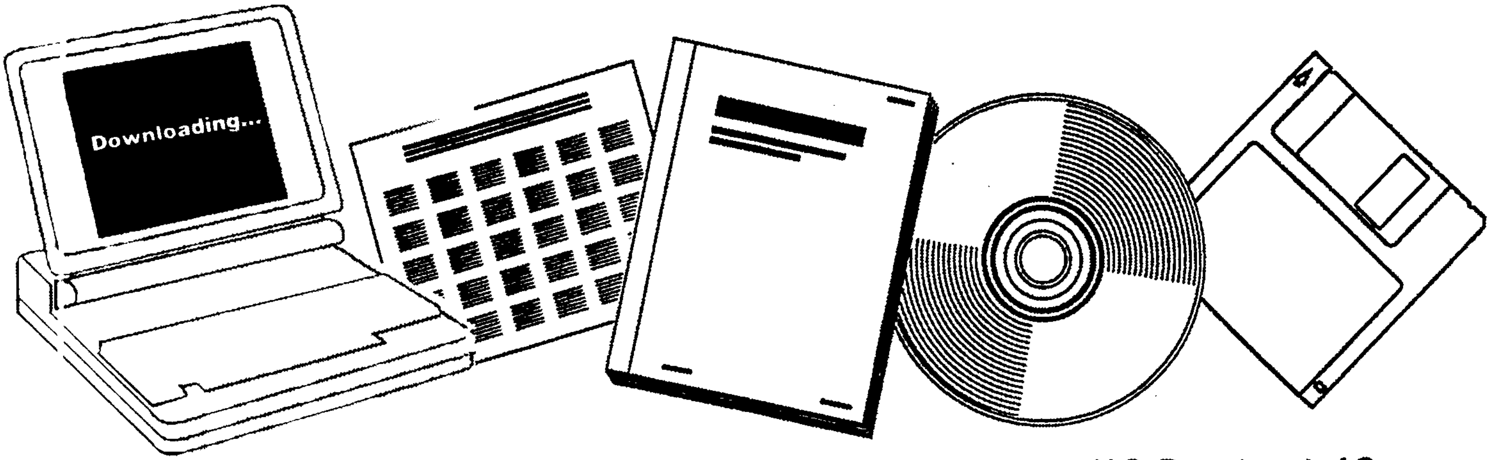

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EVALUATION OF POLLUTION CONTROL IN FOSSIL FUEL CONVERSION PROCESSES

GASIFICATION: SECTION 7. U-GAS PROCESS

by

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16. ABSTRACT
The report gives results of a review of the U-Gas Process being developed by the Institute of Gas Technology, from the standpoint of its effect on the environment. The quantities of solid, liquid, and gaseous effluents have been estimated, where possible, as well as the thermal efficiency of the process. For the purpose of reducing environmental impact, a number of possible alternatives are discussed, and technology needs are pointed out.

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To Convert From	To	Multiply By
Btu	Calories kg:	0.25198
Btu/pound	Calories, kg./kilogram	0.55552
Cubic feet/day	Cubic meters/day	0.028317
Feet	Meters	0.30480
Gallons/minute	Cubic meters/minute	0.0037854
Inches	Centimeters	2.5400
Pounds	Kilograms	0.45359
Pounds/Btu	Kilograms/calorie, kg	1.8001
Pounds/hour	Kilograms/hour	0.45359
Pounds/square inch	Kilograms/square centimeter	0.070307
Tons	Metric tons	0.90719
Tons/day	Metric tons/day	0.90719

1. SUMMARY

The U-Gas Process being developed by the Institute of Gas Technology has been reviewed from the standpoint of its effect on the environment. The quantities of solid, liquid and gaseous effluents have been estimated, where possible, as well as thermal efficiency of the process. For the purpose of reducing environmental impact, a number of possible alternatives are discussed, and technology needs are pointed out.

2. INTRODUCTION

Along with improved control of air and water pollution, the country is faced with urgent needs for energy sources. To improve the energy situation, intensive efforts are under way to upgrade coal, the most plentiful domestic fuel, to liquid and gaseous fuels which give less pollution. Other processes are intended to convert liquid fuels to gas. A few of the coal gasification processes are already commercially proven, and several others are being developed in large pilot plants. These programs are extensive and will cost millions of dollars, but this is warranted by the projected high cost for commercial gasification plants and the wide application expected in order to meet national needs. Coal conversion is faced with potential pollution problems that are common to coal-burning electric utility power plants in addition to pollution problems peculiar to the conversion process. It is thus important to examine alternative conversion processes from the standpoint of pollution and thermal efficiencies, and these should be compared with direct coal utilization when applicable. This type of examination is needed well before plans are initiated for commercial applications. Therefore, the Environmental Protection Agency arranged for such a study to be made by Exxon Research and Engineering Company under Contract No. EPA-68-02-0629, using all available nonproprietary information.

The present study under the contract involves preliminary design work to assure that the processes are free from pollution where pollution abatement techniques are available, to determine the overall efficiency of the processes, and to identify areas where present technology and information are insufficient to assure that the processes are nonpolluting. This is one of a series of reports on different fuel conversion processes.

All significant input streams to the processes must be defined, as well as all effluents and their compositions. This requires complete mass and energy balances to define all gas, liquid, and solid streams. With this information, facilities for control of pollution can be examined and modified as required to meet Environmental Protection Agency objectives. Thermal efficiency is also calculated, since it gives an indication of the amount of waste heat that must be rejected to ambient air and water and is related to the total pollution caused by the production of a given quantity of clean fuel.

Suggestions are included for filling technology gaps that exist for techniques to control pollution or conserve energy. Maximum use was made of the literature and information available from developers. Visits and/or contacts were made with the developers to update published information. Not included in the studies are such areas as cost, economics, operability, etc. Also coal mining and general offsite facilities are not within the scope of this work.

A number of reports have been issued on individual processes evaluated to date in the program (1,2,3,4,5,6). We wish to acknowledge the information and help provided by EPA in making this study.

3. BASIS AND BACKGROUND

The U-Gas Process for making clean gas fuel is based on gasifying coal with air plus steam, and has been referred to in the literature. Some information is given in Reference 7 on application to electric power generation using a combined cycle in which the gas is first burned for use in a gas turbine, and then goes to a boiler where additional power is generated using a steam cycle. Pretreating of coal feed is incorporated into the design to allow using caking type coal feed by first destroying the caking properties in a pretreating zone. Air is added to the pretreater to give partial oxidation at about 800°F. Composition of the combined gas, including that from pretreating, is given in Reference 8, while a general description of the system is given in Reference 9. More complete information is given in Reference 10 for a combined cycle application to generate electric power. Environmental controls are provided, together with a breakdown of the overall energy balance. Our environmental evaluation is based mainly on Reference 10, the others being used to arrive at a better understanding of the process in order to estimate utilities and auxiliary facilities where necessary, and to assess environmental and energy aspects of the process.

4. PROCESS DESCRIPTION

Coal feed amounts to 7346 tons/day containing 6% moisture. It is dried, then crushed, and sent to a pretreater where caking properties are destroyed by partial oxidation in the presence of air. The pretreated coal is gasified with steam and air in a fluidized solids system, at 1900°F and 300 psia to make low Btu clean gas fuel suitable for use in a combined cycle power plant.

As shown in Figure 1, dry coal crushed to 1/4 inch and smaller is fed to the pretreater by means of lock hoppers. Gases from the pretreater flow into the gasifier at a point above the fluid bed for the purpose of reacting and destroying all tar and oil vapors that are evolved in pretreating. A residence time of 10-15 seconds is provided on the vapors (8). Figure 2 shows the pretreater-gasifier system. Table 1 gives inputs to the plant, while Table 2 shows outputs. Additional process details are given in Section 10 of this report.

In the fluid bed gasifier operating at about 2 ft/sec, char is reacted to give a carbon level of about 20% in the ash. Agglomeration of ash particles is accomplished in a "spouting" zone or venturi throat at the bottom of the gasifier maintained at sintering temperature by adding air and steam. Ash agglomerates of perhaps 1/8 inch diameter pass down through this throat, to be quenched and removed from the system. Dust recovered by cyclones from the raw gas product is also passed through the agglomerating zone. Further description of this type of agglomeration is given in Reference (11).

Raw gas is cooled in a waste heat boiler to make high pressure steam, following by additional heat recovery to preheat boiler feed water. Air cooling is then used to bring the gas down to scrubbing temperature. The water scrubber removes dust and ammonia primarily, together with unreacted steam. Gas liquor from the scrubber is processed in a sour water stripper to recover ammonia and remove H_2S (12). The treated water is recycled to the cooling tower or used to slurry the ash being returned to the mine for disposal.

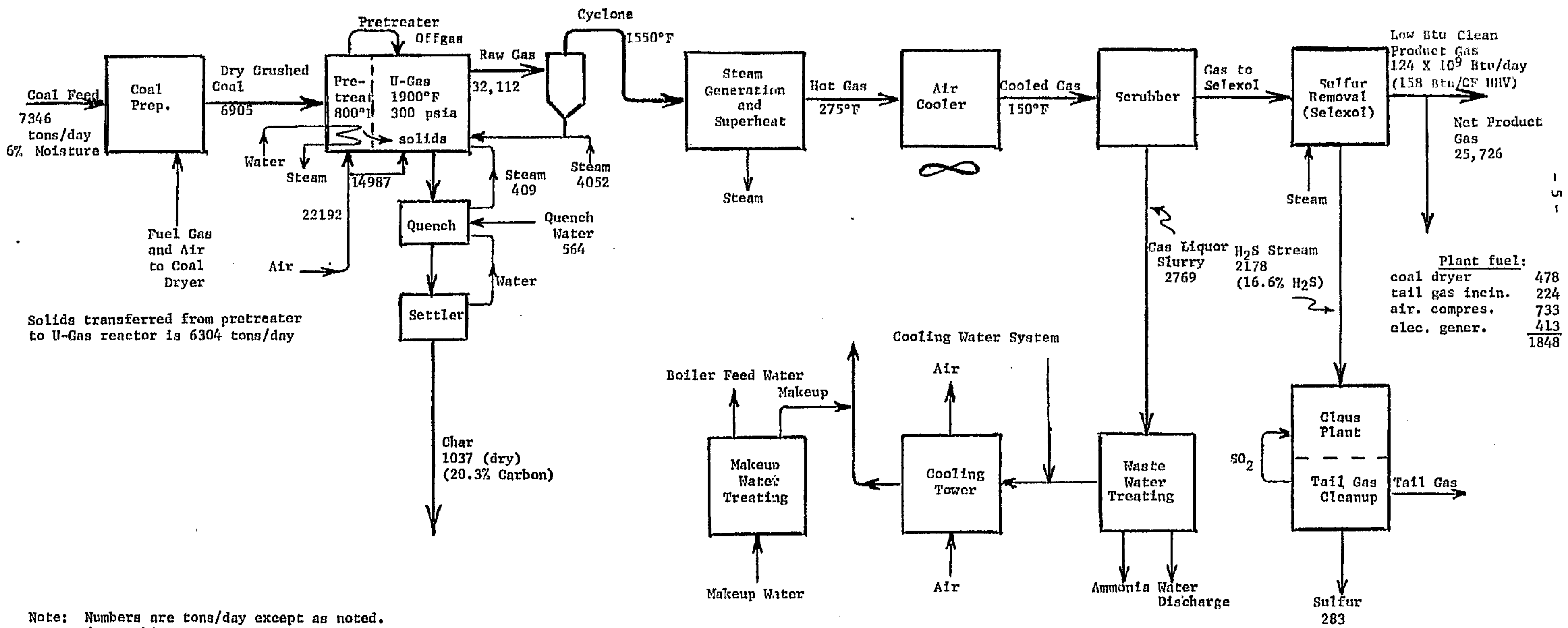
In this particular design, water is indicated to be recycled to extinction within the process, in which case there would be no net water discharge that might cause environmental concern. However, there will be soluble salts (e.g., sodium chloride and sulfate) introduced with the makeup water, plus volatile elements from gasification (chlorine, fluorine, boron, etc.) that will accumulate and must be purged from the system. It is obvious that some water must be discharged.

Sulfur is removed from the cooled gas using the Selexol process (13) based on a glycol type solvent, which can remove H_2S and COS from the gas. About 60% of the CO_2 is left in the gas, but the solvent does dehydrate the gas.

FIGURE 1

U-GAS PROCESS

Flowplan and Flowrates for Plant Processing
7346 Tons/Day of Pittsburgh Type Coal (6.0% Moisture)



Note: Numbers are tons/day except as noted.
(See Table 7 for details on stream compositions.)

FIGURE 2

U-GAS PROCESS WITH COMBINED CYCLE FOR POWER GENERATION

(From Reference 8)

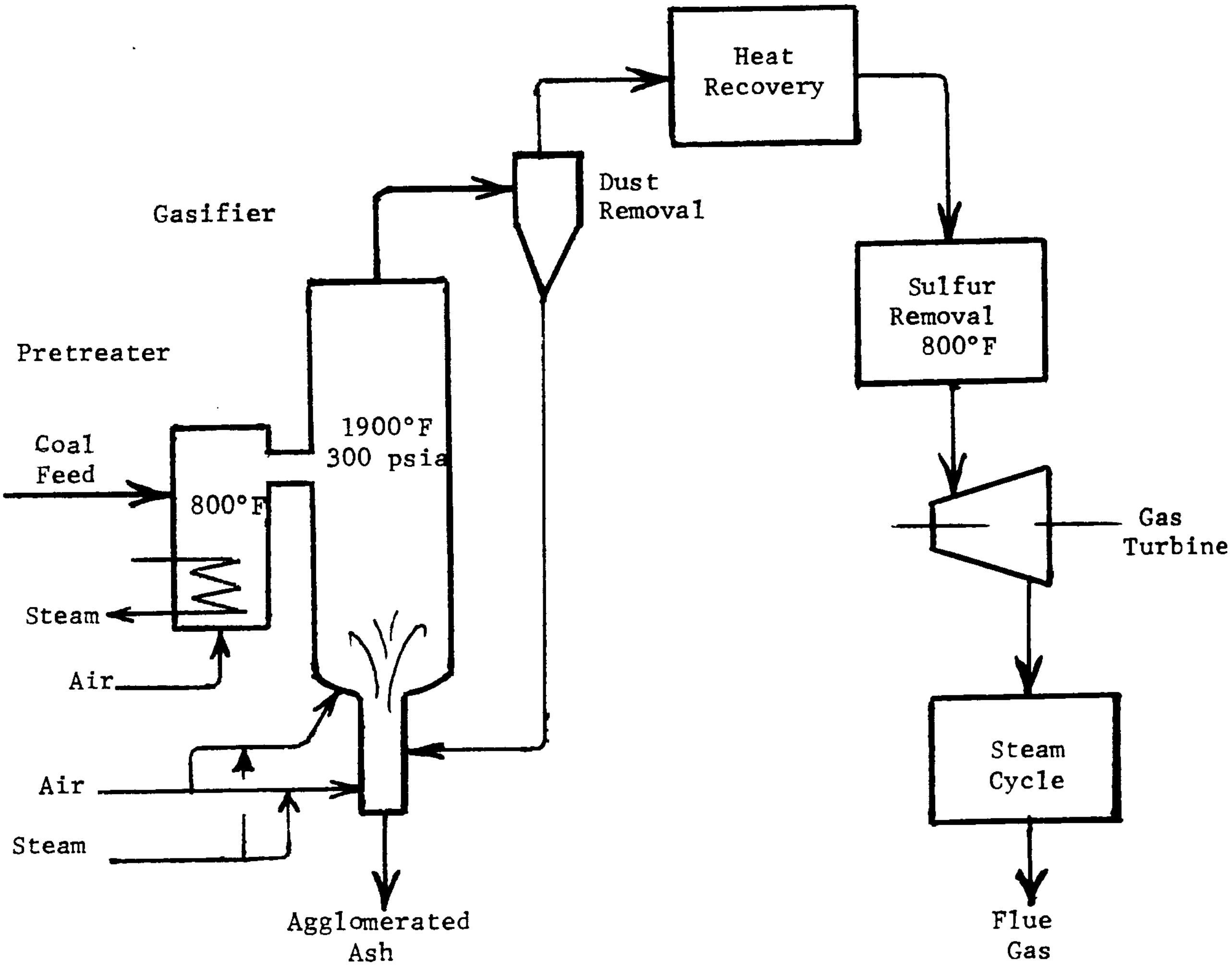


TABLE 1

RAW MATERIALS USED, U-GAS PROCESS

Coal: Pittsburgh Seam (Cleaned)

6% Moisture .... 7346 tons/day

Analysis, Wt. % (dry basis)

	Coal	Pretreated Coal
C	71.5	71.25
H	5.0	4.02
O	6.5	7.50
N	1.2	1.00
S	4.4	3.74
Ash	11.4	12.49
	100.0	100.00

High Heat Value, dry coal .... 13,178 Btu/lb

Water Makeup.................................... 2122 gpm

TABLE 2

STREAMS LEAVING PLANT, U-GAS PROCESS

Net Product Gas	25,726 tons/day (784 MM SCFD)

Composition, Vol. %	
CO	20.16
CO_2	6.72
H_2	13.75
CH_4	4.89
N_2	54.47
H_2S	.005
COS	.01
	100.00

High Heating Value : 158 Btu/SCF

Char from gasifier (dry basis)	1037 tons/day (plus 156 tons/day of water)

Composition	Wt %
C	20.33
H	1.43
N	1.78
S	0.58
Ash	75.88
	100.00

	tons/day
Waste water discharge	2000 (334 gpm)
Sulfur byproduct	283
Ammonia byproduct	2

If it were possible to remove sulfur and particulates at high temperature, the gas cleanup system might be simplified and overall efficiency improved. However, the potential NO_x emissions would then have to be evaluated carefully, since the raw gas will contain ammonia which if not removed increases the NO_x formation in subsequent combustion. By way of illustration, a modification of the U-Gas Process has been proposed (8), in which sulfur is removed by contact with a suitable metal at 800°F. A practical process for removing large amounts of sulfur at high temperature is not yet commercially available, although trace amounts can be removed using guard beds of zinc oxide for example. Exploratory work has been done on using iron or nickel base materials which can be regenerated (14), making it practical to remove large amounts of sulfur from a gas stream.

The sulfur acceptor may be regenerated by contacting it with air to form SO_2, which is sent to a Claus unit and reacted with H_2S from other sources for sulfur recovery. Instead of using a metal as the sulfur acceptor, half calcined dolomite might be used as has been mentioned in the literature (4). The sulfur acceptor is then regenerated by reacting with CO_2 and water at about 200°F to form H_2S which can be converted to free sulfur via a liquid phase Claus type operation.

Returning to a discussion of acid gas treatment, clean low Btu gas from the Selexol unit is available to use as fuel, in conventional systems or in a combined cycle system. The H_2S stream from solvent regeneration is indicated to contain 16.6% H_2S and is sent to a Claus unit for sulfur recovery. Tail gas cleanup by the Wellman-Lord process (15) is included to give 250 ppm SO_2 in the final gas released to the atmosphere.

High heating value of the total gas produced is 5533 MM Btu/hr, but part of the gas is needed to supply requirements of the process. Net gas available from the process is 5162 MM Btu/hr, equivalent to a potential power generation of 600,000 KW at a nominal 40% efficiency. Of the total gas produced, 6.7% is consumed in the process to supply fuel to the coal dryer and tail gas incinerator, on the sulfur plant, plus a combined cycle system supplying plant electricty and power for air compression. In addition, steam is generated from waste heat in the process, but all of this is used within the plant, partly to drive the air compressor.

Auxiliary facilities are required in addition to the basic process, such as coal handling and storage. Coal preparation will include drying and crushing, as well as coal cleaning unless this is provided elsewhere. Ash handling and disposal are also needed, with means to drain the ash slurry, recover the water for reuse, and transport the drained ash to the mine or to a landfill area. The Claus plant for sulfur recovery includes tail gas cleanup by scrubbing with sodium sulfite using the Wellman-Lord process, but sulfur storage and shipping facilities are also needed.

Waste water treatment employs the Chevron process to recover by-product ammonia, and makes it feasible to reuse the water (12). While not included in the original design, a biological oxidation system (biox) is needed to give adequate cleanup of the water for return to the cooling water circuit. In addition, to prevent buildup of sodium salts etc., some water will have to be discharged from the plant, although no net water discharge was shown in the original design (10).

The plant may be self sufficient in steam and power during normal operation, but in order to start it up a furnace or other method for heating is required, together with startup steam and power. Fuel for startup probably should be oil rather than gas or coal, so as to avoid the storage problem with gas, or the environmental problems with coal due to sulfur and ash.

Makeup water must be brought in and treated to make it suitable for use in the cooling water circuit, while further treatment and demineralization are required to supply boiler feedwater makeup. Cooling towers are used and are a major area of environmental concern.

Other facilities required are maintenance shops, fire protection, warehouses, control laboratory, offices, cafeteria, roads, trucks, etc., all of which must be taken into account in assessing total environmental impact.

5. EMISSIONS TO THE ENVIRONMENT

Overall flow rates for the process were shown in Figure 1. Figure 3 and Table 3 show all of the streams entering and leaving specific units, some of which are returned to other units within the plant. All streams which are actually discharged to the environment are indicated by heavy dashed lines in Figure 3 and by asterisks in Table 3. Emissions to the environment are discussed in the following subsections, in the order of process sequence shown in Figure 1.

5.1 Coal Preparation and Drying

The first effluent is to the air from the coal handling and preparation area. Coal is delivered and crushed to 1/4 inch and smaller. Such operations will normally have a dust problem, and careful consideration and planning is required for control. Covered conveyers should be provided wherever possible; even so, there may be vent streams or leaks that could release dust. A dust collection system should be used operating at slightly below atmospheric pressure to collect vent gas and pass it through bag filters. Since spills from conveyers and leaks can also create dust, facilities such as clean-up equipment and water sprays may be needed.

The coal storage pile is also of concern in that wind can pick up and disperse fine particles. Evaluation is needed for each specific situation in order to provide proper control measures. Proposals for dust control have been made such as spraying oil or asphalt on the surface of the pile, or convering it with plastic. The amount of coal handled is so large that a loss of even a small fraction of a percent could be excessive.

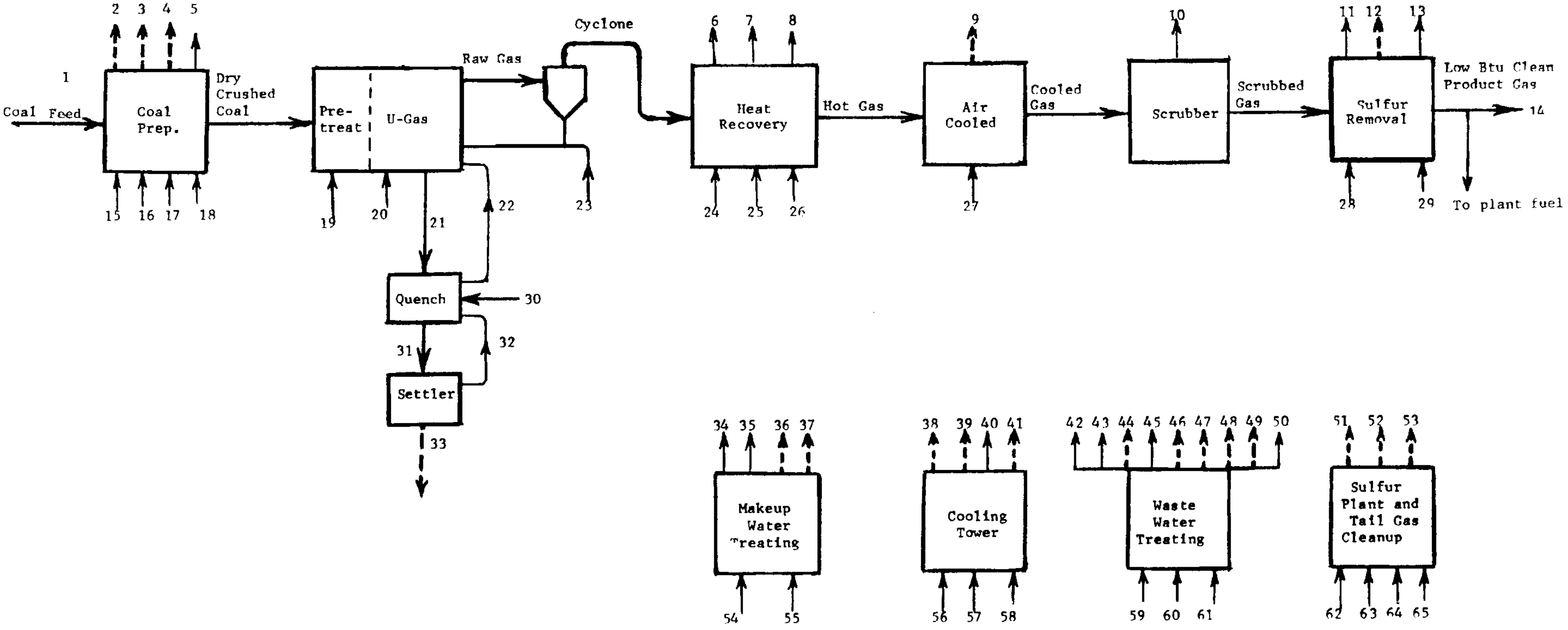
A further consideration on any coal storage pile is the possibility of fires and spontaneous combustion which would result in evolution of odors, fumes, and volatiles. One control measure is to compact the pile in layers as it is being formed. In any event, plans and facilities should be available for extinguishing fires if they occur.

The coal storage and preparation area may also contribute to water pollution. If 30 days' storage is provided, it amounts to over 200,000 tons; so the coal storage pile will cover a large area. Rain runoff can lead to undesirable effluents. A large part of the rain can run off quickly and carry suspended particles, while the remainder will have a long contact time with the coal and can pick up acids and organics. Therefore, rain runoff from the storage area should be collected in storm sewers and sent to a separate storm pond. With a certain amount of treatment, this water can then be used as makeup for the process. Control of seepage may be desirable on the pond, and particularly on the coal storage area, using for example, a layer of concrete, plastic or clay.

FIGURE 3

U-GAS PROCESS

Block Diagram Showing Streams In and Out of Specific Sections of Plant



Note: Emission to the environment are shown by heavy dashed line -- other are returned to the process. See Table 3 for details.

TABLE 3

Stream	Identification	Flow Rate tons/day	Comments
1	Coal Feed	7346	6% moisture, cleaned
*2	Wind	--	Wind may blow dust from coal storage and handling area.
*3	Rain	e.g. 6" in 24 hrs.	Rain can wash fines from coal preparation and storage area, and leach organics, sulfur, iron, trace elements etc.
*4	Dryer vent gas	1700 (51.4 MM SCFD)	Combustion gases from coal dryer - contain dust. Part of product gas is burned with 10% excess air.
5	Dust	--	Coal fines entrained in drying gas, recovered in bag filters and returned to gasifier.
6	Steam	7,752	High pressure steam made from waste heat on process.
7	Superheated steam	4,052	Superheated steam fed to gasifier.
8	Steam	6,190	Low pressure steam made from waste heat used for Selexol unit and sour water stripping.
*9	Air	227,000	Air cooling on raw gas before Selexol unit.
10	Gas liquor	2,769	Water layer condensed from raw gas and sent to waste water treating.
11	H_2S stream	2,178	Sulfur compounds removed by Selexol unit and sent to sulfur plant.
*12	Chemicals	--	Makeup glycol and chemicals are added to Selexol unit and will appear in effluents.
13	Condensate	6,190	Recovered from steam used for heating - return to boiler feed water.
14	Net product gas	25,015	Clean fuel gas, produced by process
15	Wind	--	Wind action on coal storage and preparation area.
16	Rain	e.g. 6" in 24 hrs.	Rain onto coal storage pile
17	Flue gas	480	Part of clean product gas use as fuel in coal dryer.
18	Air	779	Combustion air to coal dryer
19	Air	7,205	Process air used in pretreater

TABLE 3 (Cont'd)

Stream	Identification	Flow Rate tons/day	Comments
20	Air	14,987	Process air added to gasifier
21	Char	1,037 (dry)	Char rejected from gasifier (20.3 wt. % carbon).
22	Steam	408	Steam formed in quenching hot char - returned to gasifier.
23	Steam	4,052	Steam to gasifier
24	Boiler feed water	7,752	To make high pressure steam from waste heat.
25	Steam	4,052	Superheating of steam fed to gasifier.
26	Boiler feed water	6,190	To make low pressure steam from waste heat.
27	Air	227,000	Air cooling on raw gas.
28	Chemicals	--	Glycol and other chemicals used in Selexol unit.
29	Steam	6,190	Low pressure steam used for heating in Selexol unit.
30	Water	564	Makeup to char quench.
31	Slurry	2,074	Slurry of char (50% water) to settler.
32	Water	881	Water recovered in settler.
*33	Char	1,193	Char returned to mine (15% moisture on dry char).
34	Makeup water	10,692	Makeup to cooling water circuit.
35	Boiler feed water	4,244	Makeup to boiler feed water supply.
*36	Sludge	See Table 11	From treating makeup water.
*37	Chemicals	See Table 11	Waste chemicals from water treating.
*38	Air	600,000	Air from cooling tower (plus 8688 tons/day of evaporated water).
*39	Drift loss	--	Loss of water mist from cooling tower - not included in water balance. May provide blowdown (see stream 41).
40	Cooling water	300,240 (50,000 gpm)	Circulating cooling water
*41	Blow down	2,004	Blowdown from cooling water system to control buildup of dissolved solids, etc.
42	Treated water	564	From waste water treating. Returned to ash quench.

TABLE 3 (Cont'd)

Stream	Identification	Flow Rate tons/day	Comments
43	Treated water	2,205	Treated waste water used as makeup water.
*44	Ammonia	2	Recovered from sour water stripping system; may be sold or incinerated.
45	H_2S	--	Sour gas stripped from gas liquor - returned to Claus unit.
*46	Oil	--	Some oil, tar, phenols, etc. may be removed from raw gas.
*47	Sludge	--	Cellular material from biox unit.
*48	Sludge	--	Sludge from chemical treatment of waste water, if used e.g., to precipitate fluoride
*49	Solids	--	Ash, coal fines, etc. removed from raw gas in scrubber - may contain trace elements.
50	Condensate	830	Condensed steam used on sour water stripper - returned to boiler feed water.
*51	Sulfur	283	From sulfur plant.
*52	Tail gas	3,171	After incineration and tail gas cleanup.
*53	Chemical purge	See Table 4	From tail gas cleanup system, may contain 2 ton/day sulfur.
54	Makeup water	14,936	To makeup water treating (includes 2205 tons/day from waste water).
55	Chemicals	See Table 11	For water treating.
56	Air	600,000	Air to cooling tower.
57	Cooling water	308,928	Cooling water to cooling tower
58	Chemicals	See Table 11	Additives to cooling water circuit to control fouling and corrosion.
59	Gas liquor	2,769	Water layer from scrubber sent to waste water treating.
60	Chemicals	--	As may be used in waste water treatment.
61	Steam	830	To reboiler on sour water stripper.
62	H_2S stream	2,178	Sulfur compounds from Selexol unit.
63	Air	1,075	For oxidation of sulfur compounds in sulfur plant (includes 382 tons/day to incinerate tail gas for cleanup).
64	Fuel gas	205	Part of product gas is used as fuel on sulfur plant incinerator.
65	Chemicals	--	Make up sodium sulfite etc., to replace chemicals purged on tail gas cleanup.

Cleaning and washing of run of mine coal is not included in the present design, assuming that this will be done elsewhere. However, it should be pointed out that some applications of the process may include cleaning and washing, which employ large amounts of water, and generate large volumes of solid refuse to dispose of.

Noise control should be carefully considered since it is often a serious problem in solids handling and size reduction. If the grinding equipment is within a building, the process area may be shielded from undue noise, but additional precautions are needed for personnel inside the building.

Crushed coal next goes to a dryer where essentially all of the moisture is removed. To make the plant complete and self-sufficient, we have included coal preparation and drying in the balances. Fuel for the dryer is supplied by using part of the clean gas product, so that sulfur removal is not needed on the vent gas. However, dust recovery must be provided, using for example bag filters, scrubbing, or electrostatic precipitation. Recovered fines can be returned to the process, possibly to the "agglomerating" zone of the gasifier to minimize entrainment. One other concern on the dryer vent gas is possible odors, which calls for careful evaluation with specific coals and drying facilities that will be used.

Regulations on coal dryers may call for a maximum dust loading in the vent gas of .07 to .10 grains per standard cubic foot of gas, as legislated by the State of West Virginia (Chapter 16-20 Series V, 1968). Smoke emission must not be darker than No. 1 on the Ringelman Smoke Chart.

In the drying operation a large volume of hot gas is contacted with the coal. Oxygen content is normally limited to about 10 Vol. % by safety considerations. Also the maximum temperature should be limited to avoid heating the coal above 500°F, so as not to release volatile matter. It is common practice to use a large amount of excess air, such as 100%, in order to minimize moisture content of the drying gas and thereby facilitate drying. In some cases effluent gas may be recycled or inert gas added to control gas temperature and oxygen content.

With the present high price of fuel, the design of drying facilities should be optimized to minimize fuel consumption. This subject is discussed more fully in a previous study (4). In brief, it is desirable to operate the dryer with minimum excess air, for example 10% excess, and to recycle vent gas as needed to control temperature of the hot gas. This gives minimum fuel consumption as well as minimum volume of vent gas to be cleaned up. Of course, the moisture content of the drying gas will be higher than when a large amount of excess air is used, making it more difficult to achieve the same degree of drying, although the moisture content of the dried coal could be allowed to increase slightly. Further details on flue gas from the dryer are given in Table 3.

In general, it will be desirable to preserve the sensible heat in the dried coal, so as to maximize heat recovery on the pretreater. Coal preheat temperatures as high as 500°F have been used without substantial evolution of volatile matter from coal. This temperature has also been considered practical from the standpoint of using lock hoppers.

The coal feeding system for pressurizing the coal in this specific design uses lock hoppers. Vent gas from depressuring the lock hoppers should be cleaned up and returned to the process. Normally there will be no effluent to the air from this system. Coal feeding may involve pneumatic transport of coal, in which case recovery and cleanup of the conveying gas is needed.

5.2 Pretreatment and Gasification

In the pretreatment reactor, coal is contacted with air and partially decomposed, releasing tar as well as lighter hydrocarbons. Gases from pretreating pass to the upper zone of the gasifier above the fluidized bed, with the intention of completely destroying all tar and hydrocarbons. However, the temperature in this zone varies from 1900°F leaving the bed, to 1550°F outlet temperature on the combined gas stream, and it is unlikely that refractory aromatic type compounds will be destroyed completely. There is also a possibility that some soot may be formed by cracking at high temperature. If these problems occur, they would complicate considerably the cleanup and waste disposal facilities for the plant, beyond the simple system shown.

Pretreated coal, amounting to 91.3 wt. % on dry coal, is transferred to the gasification reactor as a separate stream, to be reacted with air and steam. All overhead gases are contained and processed for cleanup. The only direct effluent to the environment from this section of the plant is the char or ash removed from the bottom of the gasifier. It is dropped into an enclosed hopper filled with water - the resulting steam flowing back up into the gasifier - and the ash slurry is depressured for removal via a settler. Water recovered in the settler is returned to the quench hopper. Wet ash is then disposed of as landfill, or returned to the mine.

A desirable feature in this design is the agglomeration of ash provided by a sintering zone in the bottom of the gasifier. Benefits obtained are:

- Lower carbon in ash
- Large ash particles, and less dust
- Higher density particles

Sintering to give increased ash density may be particularly desirable so as to minimize disposal problems. If there is no sintering, particle density of the ash may be very low, for example 5-10 lb./cu. ft. As previously pointed out (6), when coal is gasified without change in particle size. density of the char or ash must decrease correspondingly. The particles also become much more friable tending to aggravate problems of dust separation on the raw gas, and in disposing of the ash.

A potential problem is leaching of chemicals or toxic elements from the ash. Thus, potential contamination of natural water must be evaluated, and data needed for this purpose should be obtained when developing the process.

Hopefully, the sintered nature of the ash will minimize ash disposal problems such as leaching. It should be recognized that makeup water supplied to quenching will normally contain dissolved solids, and that these have no way to leave except with the ash. Consequently, a thorough evaluation of potential leaching will be needed.

5.3 Gas Cooling and Dust Removal

Raw gas leaving the gasifier passes through a cyclone to recover dust, which is returned to the gasifier agglomerating zone. Next the gas goes to waste heat boilers and a steam superheating exchanger to recover useful heat. Air cooling is then used to bring the gas down to scrubbing temperature. Normally all process streams are confined within the equipment and there are no intentional emissions to the environment. However, leaks are common, especially on exchangers, and if leaks occur on air coolers, the emissions will be dispersed in the large volume of air used for cooling. Consideration of this problem is needed in design, possibly with some monitoring of operations.

Water scrubbing removes dust, soluble compounds such as ammonia, and phenol that may also be present. This scrubber water will be saturated with H_2S and other gases. It is sent to waste water treating to clean it for reuse in the process, as will be discussed further in Subsection 5.5 on Auxiliary Facilities. This gas liquor is expected to contain fine dust, as well as tar, cyanides, phenols and other oxygenated compounds, etc. to be removed in the waste water treating operations.

5.4 Sulfur Removal

The final step in cleaning up the raw gas is sulfur removal. The product gas is then suitable for use in a gas turbine, without requiring stack gas cleanup to remove sulfur or particulates. It is not necessary to remove CO_2 for this use, therefore the base design uses the Selexol process which scrubs the gas with a glycol type solvent. A concentrated H_2S stream is sent to the sulfur plant, along with moisture removed by the dehydrating effect of the solvent. Steam used to regenerate the solvent is supplied from waste heat recovery on the hot raw gas. Some makeup of glycol, and possibly other chemicals such as inhibitors, may be added to the system, in which case they must also appear in one of the effluent streams and should be considered in any detailed specific design. If any such materials are carried out in the product gas, they could affect operation of turbines, etc.

5.5 Auxiliary Facilities

In addition to the basic plant, auxiliary facilities are needed to make the plant self-sufficient, including sulfur recovery, cooling water, water treating, and electric power. A Claus plant is used to recover sulfur. In a typical Claus plant the acid gas is first burned with air to form free sulfur which is condensed and recovered. This is followed by additional stages using a catalyst to allow operating at lower temperature so as to give more complete reaction between H_2S and SO_2, and increase the sulfur recovery. In this case having a Claus plant feed containing 16.6 vol. % H_2S, sulfur recovery may be about 95% in a 3 stage operation. Since the resulting 15 tons/day sulfur emission would be excessive, tail gas cleanup is provided using the Wellman-Lord process based on incineration plus scrubbing with a sodium sulfite solution.

A modification of the U-Gas process was mentioned earlier based on removing sulfur from the raw gas at high temperature, for example with molten metal. The sulfur acceptor would then be regenerated with air to form SO_2. With this modification, a conventional Claus plant could not be used for sulfur recovery. Instead, it would be necessary to reduce SO_2 to sulfur, for example using carbon as the reducing agent. Of course if sufficient H_2S were available from some other source, it could be reacted with the SO_2 in a Claus plant, in which case the environmental effects of sulfur would be similar to the present study case. However, high temperature cleanup of the gas may not remove ammonia, in which case the contribution of ammonia to NO_x formation in subsequent combustion would have to be carefully evaluated.

One other consideration on the sulfur plant is to control odor emissions due to leaks or associated with handling the product sulfur. There is an appreciable solubility of H_2S in molten sulfur, and it may escape during handling or storage; however, there are well established techniques for controlling this and other possible sources of contamination such as sulfur dust.

The utility cooling tower, which has by far the largest emission to the atmosphere of any part of the plant, is of particular concern regarding environmental considerations. Since a very large volume of air is contacted efficiently with cooling water, any contaminants in it such as ammonia, H_2S, phenol, cyanide, etc. can be stripped out. It might be thought that the cooling water is perfectly clean, however, experience shows that there will be leaks in exchangers such as those in sour water service and on acid gas treatment. Since the process operates at elevated pressure, any leakage is into the cooling water circuit. This source of contamination has been of concern in petroleum refineries and on chemical plants. If the problem is severe, monitoring for leaks may be warranted.

The volume of air passing through the cooling tower is so large that every precaution should be taken to see that it does not inadvertently become contaminated. On any cooling tower there are also potential problems associated with drift loss or mist and the formation of a plume or fog. If the cooling tower is near public highways, these may be of concern, especially in the winter when icing may occur and condensation to form a plume is likely. In designing the plant, careful consideration should be given to this in placing equipment, in order to minimize or avoid potential problems.

Some blowdown is needed from the cooling water system to purge soluble salts that become concentrated by evaporation, and chemicals that are added to control algae and corrosion. The blowdown goes to waste water treating before leaving the plant as an effluent.

Waste water to be treated includes the cooling tower blowdown, gas liquor from scrubbing the raw gas, and chemical purge from tail gas cleanup on the sulfur plant. Boiler blowdown is relatively clean so it is used as makeup to the cooling water system. The gas liquor may contain considerable ammonia, as 60-70% of the nitrogen in the coal feed often shows up in this form on gasification operations. It is also saturated with H_2S and other gases from contacting in the scrubber at elevated pressure. When the sour water is depressured, gases which flash off must be collected and returned to the system, for example to the Claus plant. As in other gasification processes, the gas liquor is expected to contain various other contaminants, such as cyanides, thiocyanates, phenols, fatty acids, oil, possibly some tar, and particulates. In any event, there will be startup conditions and plant upsets that produce a full range of contaminants, so provision to handle them should be provided, including such facilities as oil separators, settlers or filters for solids, and biological oxidation (biox) for cleanup.

In addition to the above, trace elements are of concern in that some of them are known to be partly or highly volatile at gasification conditions, and will be removed in the gas cleanup system. Consequently they can appear in the gas liquor. Many of these trace elements are known to be toxic, and the amounts involved are large, giving cause for real concern on their satisfactory disposal. Considerable volatility has been shown for arsenic, lead, cadmium, mercury, fluorine, chlorine, etc. The particular subject of trace elements is discussed more completely in Section 8.

Solid residue will be separated from the gas liquor, representing fines and ash that remain in the raw gas and are separated in the scrubber. Depending upon the amount and the combustible content, it may be desirable to return them to the gasifier, or they might be included with the ash stream for disposal. Again, the question of trace elements appears, since some of these may be recovered as particulates and present special disposal problems.

Other solid residues will include sludge from biox treatment, where contaminants are removed by incorporating into cellular material. This sludge can be an odor problem and might be incinerated, buried, or sent to the gasifier. There may also be solid wastes from treating waste water with lime for example, to release ammonia, or to deactivate fluorides, etc. In any case, there will be sludge from treating makeup water, which is innocuous and can be disposed of along with ash from the gasifier.

While not shown in the original design, there will have to be a significant discharge of water from the process in order to purge soluble salts and maintain an operable system. Such salts enter in the plant makeup water and become concentrated by evaporation in the cooling tower. Additional amounts are contributed by chemicals used in water treating, demineralization to prepare boiler feed water, cooling water additives, etc. In addition, sodium sulfate is purged from the tail gas cleanup system, while chlorides in the coal feed appear to be volatile in which case they will appear in the gas liquor. Depending upon these factors and the quality of makeup water, the minimum amount of waste water may amount to 20-25% of the net makeup water used. The latter is set primarily by the amount evaporated in the cooling tower.

6. SULFUR BALANCE

Sulfur in the coal feed is mostly removed by gasification, appearing as H_2S in the raw gas. Some 10% of it may be as carbonyl sulfide rather than H_2S, due to reaction with carbon monoxide. A small amount of sulfur remains in the ash leaving the bottom of the gasifier.

Raw gas treatment in the Selexol unit separates 99% of the H_2S entering, and about one-half of the COS, into a stream which is sent to the Claus plant. With tail gas cleanup, the sulfur plant gives 99+% removal of sulfur, leaving 1 ton/day of sulfur or 250 ppm of SO_2 in the tail gas. Details on sulfur balance are shown in Table 4.

TABLE 4

SULFUR BALANCE, U-GAS PROCESS

	tons/day	Wt. %
Sulfur in Coal	303	100
Sulfur in ash	6	2.0
Sulfur in product gas	7	2.3
Sulfur to Claus plant	290	95.7
		100.0
Balance on sulfur plant		
Sulfur in acid gas feed	290	95.7
Sulfur product	287	94.7
Sulfur in chemical purge	2 (est.)	0.7
Sulfur in tail gas	1	0.3
	290	95.7

7. THERMAL EFFICIENCY

Thermal efficiency relates the useful heating value of the net clean product gas from the process to the heating value of coal consumed, after making full allowance for all process requirements such as fuel for coal drying, power for compressors, and utilities such as steam, electric power, and water. Literature values for thermal efficiency do not always include these effects, but to be realistic, our studies give thermal efficiency for a complete plant that is self-sufficient. On this basis, the heating value of net available product gas from the U-Gas process is 68.1% of the heating value of coal consumed.

Details on thermal efficiency are given in Table 5, showing that part of the clean gas product is needed within the process to supply fuel for coal drying, for part of the power on air compression, and as fuel in the Claus plant incinerator prior to tail gas cleanup. Combined, these use 6.7% of the total gas made.

The air compressor requires 132,000 BHP most of which can be supplied by using byproduct steam. In addition, about 10,000 KW of electric power is needed in coal preparation, for cooling tower pumps and fans, etc. Incremental power beyond that available from byproduct steam is supplied by a combined cycle consuming part of the product gas, at a nominal 40% efficiency based on heating value of the gas. Thermal efficiency from coal to electric power is less, of course.

The losses that occur are itemized in the lower part of the table. Unused carbon in the ash accounts for 4.4% of the heating value in the coal feed. Perhaps this could be consumed in a final "cleanup zone" to improve thermal efficiency. The Selexol unit and sour water stripper consume considerable steam for stripping. If this requirement could be decreased, possibly by using some type of sulfur removal at high temperature, thermal efficiency would be improved. Heat dissipated to the atmosphere is 13.1% of the input, representing waste heat that is at too low a temperature level for eonomical recovery.

It should be recognized that the product gas is available at about 280 psig, so credit should be allowed for the compression power that would have been required if the gas were produced at lower pressure. This compression power is 130,000 theoretical horsepower from atmospheric pressure, corresponding to 6.0% on thermal efficiency.

TABLE 5

THERMAL EFFICIENCY, U-GAS PROCESS

	MM Btu/hr	%
Coal feed	7,583	100
Net available clean product gas	5,162	68.1
Plant fuel gas		
To coal dryer	96	1.3
For air compression	147	1.9
To make electric power consumed	83	1.1
To tail gas incinerator	45	0.6
	371	4.9
Losses		
Sulfur byproduct	96	1.3
Ammonia byproduct	2	--
Ash from gasifier	335	4.4
Steam to Selexol and sour water stripper	620	8.2
Air cooling	237	3.1
Cooling tower and other	760	10.0
	2,050	27.0

Note: Expansion energy available from product gas at 280 psig corresponds to a credit of 6.0% on thermal efficiency. Although this effect should be recognized, it may not be a realistic credit and has not been included in previous reports of this series.

8. TRACE ELEMENTS

Coal contains many trace elements present in less than 1% concentration that need to be carefully considered from the standpoint of potential impact on the environment. Many of these may volatilize to a small or large extent during processing, and many of the volatile components can be highly toxic. This is especially true for mercury, selenium, arsenic, molybdenum, lead, cadmium, beryllium and fluorine. The fate of trace elements in coal conversion operations, such as gasification or liquefaction, can be very different than experienced in conventional coal fired furnaces. One reason is that the conversion operations take place in a reducing atmosphere, whereas in combustion the conditions are always oxidizing. This maintains the trace elements in an oxidized condition such that they may have more tendency to combine or dissolve in the major ash components such as silica and alumina. On the other hand, the reducing atmosphere present in coal conversion may form compounds such as hydrides, carbonyls or sulfides which may be more volatile. Studies on coal fired furnaces have indicated that smaller particles in fly ash contain a higher concentration of trace elements, presumably due to volatilization of these elements in the combustion zone and their subsequent condensation and collection on the fly ash particles (16). Other studies on coal fired furnaces are pertinent (17, 18, 19) and some of these report mass balances on trace elements around the furnaces (20).

Considerable information is available on the analyses of coal, including trace constituents, and these data have been assembled and evaluated (21,22,23). A few studies have been made to determine what happens. to various trace elements during gasification (24,25). As expected, these show a very appreciable amount of volatilization on certain elements. As an order of magnitude, using these factors for this specific U-Gas design would result in 147 lbs. per day carryover for each 10 ppm of trace element in the coal that is volatilized.

In order to make the picture on trace metals more meaningful, the approximate degree of volatilization shown for various elements has been combined with their corresponding concentration in a hypothethical coal (as typical), giving an estimate of the pounds per day of each element that might be carried out with the hot gases leaving the gasifier. Results are shown in Table 6 in the order of decreasing volatility. Looking at the estimated amounts that may be carried overhead, it becomes immediately apparent that there can be a very real problem. For each element an evaluation must be made to determine the net amount carried overhead and the potential problem. Where a problem exists, the constituent must be collected, removed from the system, and disposed of in an acceptable manner. In the case of zinc, boron and fluorine the degree of volatilization has not yet been determined, but they would be expected to be rather volatile. Even if only 10% of the total amount is volatile, there will be large quantities to remove in the gas cleaning operation and to dispose of.

TABLE 6

EXAMPLE OF TRACE ELEMENTS THAT MAY APPEAR IN RAW GAS FROM GASIFIER

Element	Possible ppm in Coal (a)	Possible % Volatile (b)	Estimated In Gas lb/day
Cl	1,500	90+	<19,800
Hg	0.2	90+	3
Se	2.2	74	24
As	31	65	296
Pb	7.7	63	71
Cd	0.14	62	1
Sb	0.15	33	1
V	35	30	154
Ni	14	24	49
Be	2	18	5
Zn	44	(10)	65
B	165	(10)	243
F	85	(10)	125
Ti	340	(10)	500
Cr	22	nil	nil

(a) Mainly based on Pittsburgh Seam Coal (2).

(b) Mainly based on reference 24, and indicated at 10% for Zn, B, and F, in absence of data.

The preceding discussion has been directed primarily at trace elements that are partially volatilized during gasification and that may have to be recovered and diposed of in the gas cleaning section. Consideration must also be given to trace elements that are not volatilized and leave in the solid effluents from the plant, particularly the char from gasification. Undesirable elements might be leached out of this char, since it is slurried in water and handled as a wet solid, and will ultimately be exposed to leaching by ground water when it is disposed of as land fill or to the mine.

Sufficient information is not now available to adequately evaluate the potential problems of trace elements, and the necessary information needs to be developed in future programs so as to assure environmentally sound planning on large scale operations.

9. TECHNOLOGY NEEDS

From this review and examination of environmental aspects of the U-Gas process, a number of areas have been defined where further information is needed in order to evaluate the situation, or where additional studies or experimental work could lead to a significant improvement from the standpoint of environmental controls, energy consumption, or thermal efficiency of the process. Items of this nature will be discussed in this section of the report.

Any coal conversion operation has solid refuse to be disposed of. Although not included in this specific design, coal cleaning must be provided at some location. The cleaning operation will generate solid refuse that could amount to over 2000 tons/day, for example. In addition char is rejected from gasification at a rate of over 1000 tons/day. Other solid residues include fines removed during gas cleanup, plus sludges from biox and water treating. More work is needed in order to define methods of disposal that do not create problems due to leaching of acids,metals, organics, or sulfur which could contaminate natural water. In addition, adequate controls are needed with regard to the potential dust nuisance and washing away of particulates. In many cases the material may be suitable for land fill with revegetation. Although there is already a lot of background on this subject, specific information is needed on each coal and for each specific location in order to allow thorough planning to be sure that the disposal will be environmentally sound.

Coal drying is used on most coal conversion processes; consequently, considerable effort is warranted to optimize the operation from the standpoints of fuel consumption, dust recovery, and volume of vent gas to be handled. It will often be attractive to burn high sulfur coal rather than clean gas fuel for inplant use, and to include facilities for cleaning up the vent gas.

The need for a simple, efficienct means of feeding coal to the high pressure gasifier has been apparent and has received considerable study. For pressure levels of 300-500 psig, lock hoppers have been used satisfactorily although they are expensive.

One potential improvement would be to develop a way to efficiently remove dust from gas at high temperature. An important advantage is that particulates are then kept out of the sour water stream, and consequently it is easier to clean up. Sand bed filters are promising for dust removal from hot gases although they have not been fully demonstrated commercially.

In the area of acid gas removal, conventional systems based on amine or hot carbonate leave room for improvement. Amine scrubbing is not effective on carbonyl sulfide, while contaminants such as cyanide interfere with regeneration of the scrubbing liquid. Hot carbonate systems partially remove carbonyl sulfide, but it is often difficult to provide a highly concentrated stream of H_2S to send to the sulfur plant. Adsorption/oxidation systems are often not effective on carbonyl sulfide, and its presence may require increase liquid circulation. The Selexol process is used in the U-Gas case. The design indicates a reasonably high H_2S concentration in the stream to the Claus plant, although steam requirement and pumping rates for the operation are sizeable.

Available systems for acid gas removal have high utility requirements, causing a significant loss in thermal efficiency for conversion of coal to clean fuel products. In addition there is often a waste stream of chemical scrubbing medium which may be difficult and expensive to dispose of.

Desirable objectives for an acid gas removal process can be summarized as follows: (a) good clean up of all forms of sulfur to give a stream high in sulfur concentration for processing in a Claus sulfur plant, (b) low utility and energy consumption, (c) no waste streams that present a disposal problem.

The need for a process to remove sulfur at high temperature was mentioned earlier. Systems based on half calcined dolomite or iron appear promising; however, they may give less complete sulfur removal than conventional scrubbing systems and do not remove ammonia or other nitrogen compounds. If filtering techniques could be incorporated to remove particulates at the same time that sulfur is removed, such systems could be quite attractive. A further need is to destroy or remove undesirable contaminants such as carbonyl sulfide, cyanides, and possibly phenol and ammonia. This function might also be provided by a high temperature gas cleanup system.

The need for a simple, effective method to clean up sour water for reuse is another item that is common to most fossil fuel conversion operations. Sour water generally contains sulfur compounds, ammonia, H_2S, phenol, thicyanates, cyanides, traces of oil, etc. These are generally present in too high a concentration to allow going directly to biological oxidation, but their concentration is often too low to make recovery attractive. Particulates, if present, further complicate the processing of sour water. Usual techniques for clean up include sour water stripping to remove H_2S and ammonia, and in addition, extraction may be required to remove phenols and similar compounds. Such operations are large consumers of utilities and have a large effect on overall thermal efficiency.

One possible approach is to vaporize sour water to make steam which can be used in the gasifier. In this case, compounds such as phenol should be destroyed and reach equilibrium concentration in the circulating sour water. It may not be practical to vaporize sour water in conventional equipment such as exchangers, due to severe fouling and corrosion problems. Therefore, new techniques may be required, and one possibility would be to vaporize the sour water by injecting it into a hot bed of fluidized solids.

In a large scale application there will be a water effluent from the plant, therefore, detailed study of the facilities for clean up will be needed. In any event, the water make-up that is brought to the plant will contain dissolved solids including sodium and calcium salts. Calcium salts may be precipitated during the water treating operation to form a sludge which can be disposed of with the other waste solids, but the fate of the sodium salts in the make-up water calls for further study. These will leave with the blowdown from the cooling tower. If the concentration of dissolved solids is too high in this blowdown water to allow discharging it to the river, then some suitable method of disposal will have to be worked out. On one proposed commercial plant, this has been handled by using an evaporation pond where the water is evaporated to dryness. The salts accumulate and will ultimately have to be disposed of. If they cannot be used or sold then it would seem logical to dispose of them in the ocean.

On trace elements information is needed on the amount vaporized in the gasifier, what happens to them, where they separate out and in what form, so that techniques can be worked out for recovering or disposing of the materials. Again specific information is needed for each coal and for each coal conversion process since operating conditions differ. In many cases, the trace elements may tend to recycle within the system and build up in concentration. This offers an interesting opportunity to perhaps recover some of them as useful by-products. The toxic nature of many of the volatile elements should be given careful consideration from the standpoint of emissions to the environment, as well as protection of personnel during operation and maintenance of the plant. Carcinogenicity of coal tar and other compounds present in trace amounts or formed during start up or upsets must also be evaluated.

Protection of personnel, especially during maintenance operations should be given careful attention, which will require that additional information be obtained. Thus, toxic elements that vaporize in the gasifier may condense in equipment such as piping and exchangers where they could create hazards during cleaning operations.

10. PROCESS DETAILS

Additional details on the process and information on potential problems are given in Tables 7 through 13.

TABLE 7

STREAM COMPOSITIONS, U-GAS PROCESS

(See Figure 1 for identification)

lb mol/hr	Pretreater Offgas	Raw Gas	Gas to Selexol	Selexol Effluent	H_2S to Claus
CO	735	18,595	18,593	18,593	--
CO_2	2,011	9,609	9,601	6,198	3,403
H_2	--	12,686	12,681	12,681	--
H_2O	5,806	13,148	328	--	328
CH_4	115	4,516	4,514	4,513	1
N_2	16,311	50,246	50,246	50,246	--
H_2S	--	750	748	5	743
COS	--	24	24	12	12
SO_2	176	--	--	--	--
C_2H_6	63	--	--	--	--
Tar	8	--	--	--	--
	25,225	109,574	96,735	92,248	4,487

Note: Value reported for COS is based on calculation in absence of data - data for some other processes show much higher proportion of sulfur in form of COS, for example, 10% of the total sulfur in the gas may be as COS. Amount of ammonia in raw gas is unknown but some processes show 60-70% of the nitrogen in coal appears as ammonia in the raw gas.

TABLE 8

STEAM BALANCE, U-GAS PROCESS

	lb/hr
High Pressure Steam, 600 psig	
From waste heat on pretreater and raw gas, preheated to 800°F. Used in gasifier	338,000
From waste heat on pretreater, raw gas, and intercooler on air compressor, preheated to 900°F. Used to supply 108,000 shaft HP on air compressor	646,000
Low Pressure Steam, 125 psig and 15 psig.	
From waste heat on cooling raw gas. Used in Selexol unit and sour water stripper	516,000
Ash Quenching	
Steam from quenching ash - returned to gasifier	34,000
Sulfur Plant	
By product steam from waste heat recovery. Used to supply utility requirements of Claus plant and tail gas cleanup	50,000

TABLE 9

ELECTRIC POWER CONSUMED, U-GAS PROCESS

	KW
Coal preparation and handling	4,000
Cooling water pumps	1,500
Cooling tower fans	1,000
Air cooler fans	500
Other plant uses	3,000
	10,000

TABLE 10

WATER BALANCE, U-GAS PROCESS

	gpm
Net consumed in gasifier	202
In wet ash to mine	26
Evaporated in cooling tower	1,448
Waste water discharged from plant	334
In H_2S stream to Claus plant	12
Losses on steam and condensate	100
Total water makeup required	2,122

TABLE 11

MAKE UP CHEMICALS AND CATALYST REQUIREMENTS

Chemicals

Acid Gas Removal:

- scrubbing solution
- additives

Sulfur Plant tail gas cleanup

Cooling Tower Additives

Anticorrosion, e.g., chromate
Antifouling, e.g., chlorine

Water Treating

Lime
Alum
Caustic
Sulfuric acid

Catalysts, etc.

Sulfur plant catalyst

Ion exchange resin for water treating

TABLE 12

POTENTIAL ODOR EMISSIONS

Coal storage and handling.
Coal drying - vent gas.
Vent gas from lock hoppers.
Wet ash handling and disposal.
Sour water stripping and handling.
Sulfur plant and tail gas.
Biox pond and other ponds.
Leaks: ammonia, H_2S, phenols, etc.

TABLE 13

POTENTIAL NOISE PROBLEMS

Coal handling and conveyors.
Coal crushing, drying and grinding.
Air compressor.

In utilities area:

- Burners on furnaces.
- Stacks emitting flue gases.
- Turbo-generator etc.

11. QUALIFICATIONS

As pointed out, this study does not consider costs or economics. Also, areas such as coal mining and general offsites are excluded, as well as miscellaneous small utility consumers such as instruments, lighting etc. These will be similar and common to all coal conversion operations.

The study is based on the specific process design and coal type cited, with modifications as discussed. Plant location is an important item of the basis and is not always specified in detail. It will affect items such as the air and water conditions available, and the type of pollution control needed. For example, this U-Gas study uses high sulfur Pittsburgh seam coal. Because of variations in coal feed, moisture content, and other basic items, great caution is needed in making comparisons between coal gasification processes as they may not be on a completely comparable basis.

The design for this study did not include coal cleaning and washing, which therefore must be provided elsewhere, together with associated energy and water requirements. Related environmental impacts must be included to give a complete overall assessment.

Other gasification processes may make large amounts of various by-products such as tar, naphtha, phenols, and ammonia. The disposition and value of these must be taken into account relative to the increased coal consumption that results and the corresponding improvement in overall thermal efficiency. Such variability further increases the difficulty of making meaningful comparisons between processes.

The U-Gas process as described in publications makes no appreciable amounts of tar, naphtha, or phenols; although there is a small yield of ammonia, amounting to about 2 tons/day which might be disposed of by incineration. It is possible, at least under some conditions such as startup or plant upsets that ammonia yield might be very much higher, and that some tar, oil, and/or soot may be formed in the gasification system. These would complicate the gas cleanup facilities and require provision for disposal, therefore such possibilities should be evaluated thoroughly in process development and in planning commercial applications. Provision will definitely be needed for separating trace elements and disposing of them in a satisfactory manner, especially the portions volatilized in gasification, but additional information is needed in order to define the problem and to develop suitable control systems.

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16. ABSTRACT The report gives results of a review of the U-Gas Process being developed by the Institute of Gas Technology, from the standpoint of its effect on the environment. The quantities of solid, liquid, and gaseous effluents have been estimated, where possible, as well as the thermal efficiency of the process. For the purpose of reducing environmental impact, a number of possible alternatives are discussed, and technology needs are pointed out.

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