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ENVIRONMENTAL ASSESSMENT DATA BASE FOR LOW/MEDIUM-BTU GASIFICATION TECHNOLOGY:
Volume I. Technical Discussion

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ABSTRACT

This report was prepared as part of an overall environmental assessment program for low/medium-Btu gasification. The program is being directed by the Fuel Process Branch of the Environmental Assessment and Control Division of the Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina. This document represents the current data base for the environmental assessment of low/medium-Btu gasification technology.

The purpose of this report is to determine the processes which can be used to produce low/medium-Btu gas from coal, the constraints imposed upon these processes by the intended end uses of the product gas, the multimedia discharge streams generated by these processes, and the technology required to control these discharge streams. Attention is focused on the processes which appear to have the greatest likelihood of near-term commercialization. This type of screening provides the preliminary basis for establishing the priorities for subsequent phases of the low/medium-Btu gasification environmental assessment program.

The processes required to produce low/medium-Btu gas from coal are divided into discrete units or operations. These operations are coal pretreatment, gasification, and gas purification. Each of these operations is then further divided into discrete modules, with each module having a defined function and identifiable raw materials, products and discharge streams.

This report is divided into two volumes. In Volume I, a discussion of the status, significant trends, major process operations, multimedia discharge stream control strategies, and recommendations for future program activities are presented. Volume II contains the appendices which consist of detailed process, environmental, and control technology data for the processes considered to have the greatest potential for near-term commercialization.

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SECTION 1.0
INTRODUCTION

1.1 BACKGROUND

The United States has been fortunate in the past to possess large reserves of the three major fossil-fuel energy sources: gas, oil and coal. However, in recent years the nation's energy picture has changed drastically due to increasingly severe shortages of oil and natural gas. Because of these shortages, there has been growing interest by government and industry in the technologies used to produce fuels from coal.

In response to this shift in our energy supply priorities, the Environmental Protection Agency has initiated a comprehensive assessment program to evaluate the environmental impacts of synthetic fuel processes having a high potential for eventual commercial application. This overall assessment program is being directed by the Fuel Process Branch of the Environmental Assessment and Control Division (EACD) of the Industrial Environmental Research Laboratory at Research Triangle Park (IERL-RTP).

The primary objectives of the EPA Synthetic Fuels Assessment Program are:

- To define the environmental effects of synthetic fuel technologies with respect to their multimedia discharge streams and their health and environmental effects

- To define control technology needs for an environmentally sound synthetic fuel industry.

The coal conversion technologies being studied in the total program include low/medium-Btu gasification, high-Btu gasification, and liquefaction. Radian Corporation is EPA's environmental assessment contractor for low/medium-Btu gasification technology.

1.2 PURPOSE OF THIS DOCUMENT

This document deals specifically with low/medium-Btu gasification and utilization technology; its purpose is to present a description of:

- the processes which can be used to produce low/medium-Btu gas from coal,
- the constraints imposed upon those processes by the intended end uses of the product gas,
- the air, water, and solid waste streams generated by those processes, and
- the pollution control techniques which appear to be applicable to the control of those multimedia discharge streams.

Throughout this report, attention is focused on those processes which appear to have the highest likelihood of near-term commercialization. This technology screening step is of considerable importance to the overall program because it provides the primary basis for establishing priorities for subsequent phases of program activity.

Both low/medium-Btu gasification and product gas utilization technologies are considered in this report. Gasification technology is assumed here to include the processes required both to produce low/medium-Btu gas and to control the resulting multimedia discharge streams. Utilization technology includes the processes that may use the product gas either for direct combustion (boilers, furnaces, gas turbines, etc.) or as a synthesis or reducing gas.

1.3 METHODOLOGY OF PRESENTING THE TECHNOLOGY

This environmental assessment program involves the study of a very complex technology composed of a large number of processes which can be arranged in many different combinations. In previous EPA sponsored programs involving technologies of this sort, it has been found useful to divide the technology into discrete units, with each unit having well defined functions and specific input and output streams. This effort considerably simplifies the task of analysis because it reduces a seemingly complex system to a series of manageable components.

In this report, low/medium-Btu gasification technology is assumed to consist of three general process operations: 1) coal pretreatment, 2) gasification, and 3) gas purification. Each of these operations is further divided into modules, with each module having a defined function and identifiable raw materials, products, and discharge streams.

1.4 CONTENTS OF THE REPORT

A general discussion on the status of and significant trends in low/medium-Btu gasification technology is presented in Section 2.0. The environmental impacts associated with this technology are also summarized.

In Section 3.0, the three major process operations are defined and their anticipated environmental impacts are described. Attention is focused upon processes which appear to have the highest probability of near-term commercialization. Consideration is given to all environmental impacts associated with each operation, but with emphasis on those that are unique to gasification technology. For example, the treatment of gasification process condensate is given much more attention than is the control of air emissions from on-site steam or power generation facilities.

In Section 4.0, environmental control strategies and problems associated with treating gasification plant air, water, and solid waste discharge streams are described. Recommendations for future program emphasis based upon the information presented in this report are discussed in Section 5.0.

In the appendices, data sheets are presented which provide detailed, yet orderly descriptions of the processes which are identified to be of primary concern to the low/medium-Btu gasification technology assessment program. This information supplements data contained in summary tables which are presented throughout this report. Data sheets for the processes in the gasification and gas purification operations are presented in

Appendices A and B. Processes used to treat air, water, and solid waste discharge streams from gasification plants are presented in Appendices C, D, and E.

SECTION 2.0
OVERALL TECHNOLOGY STATUS

The production of low/medium-Btu gas from coal has been practiced for many years both in the U.S. and in other countries where coal is an abundant resource. At one time a large number of coal gasifiers were in service in the U.S. Most of these were retired when cheap natural gas became available. Now, with gas supplies dwindling and petroleum prices escalating, there is an increasing interest by all energy-consuming sectors in evaluating the potential for gasification technology application.

Discussed in this section are the general factors that will determine which low/medium-Btu gasification processes will be applied in the U.S. More detailed descriptions of the processes and their environmental impacts are presented in Section 3.0.

2.1 GASIFICATION PROCESSES

On the order of 68 different gasification processes can be identified which either have been used commercially in the past or are currently under development. Twenty-five of the most prominent of these gasification processes are shown in Table 2-1. All involve partial oxidation of coal. Where the system is "air blown", low-Btu gas with a heating value in the neighborhood of 5.6×10^6 J/Nm^3 (150 Btu/scf) is produced. Where oxygen is used, medium-Btu gas with a heating value of about 13.1×10^6 J/Nm^3 (350 Btu/scf) is produced.

Six of the gasifiers listed in Table 2-1 are currently being used to satisfy some commercial demand for low/medium-Btu gas. These are:

- Lurgi
- Wellman-Galusha
- Woodall-Duckham/Gas Integrale

Table 2-1. U.S. AND FOREIGN STATUS OF LOW/MEDIUM-BTU GASIFICATION TECHNOLOGY

Gasifier	Licensor/developer	No. of gasifiers currently operating (no. of gasifiers built) Low-Btu gas	Medium-Btu gas	Synthesis gas	Location	Scale
Lurgi	Lurgi Mineralöltechnik GmbH	5	(39)	(22)	Foreign	Commercial
Wellman-Galusha	McDowell Wellman Engineering Co.	8(150)	-	-	US/Foreign	Commercial
Woodall-Duckman/ Gas Integrale	Woodall-Duckham (USA) Ltd.	(72)	-	(8)	Foreign	Commercial
Koppers-Totzek	Koppers Company, Inc.	-	-	(39)	Foreign	Commercial
Winkler	Davy Powergas	-	(23)	6(14)	Foreign	Commercial
Chapman (Wilputte)	Wilputte Corp.	2(12)	-	-	US	Commercial
Riley Morgan	Riley Stoker Corp.	1	-	-	US	Commercial
BCG/Lurgi Slagging	British Gas Corp. and Lurgi Mineralöltechnik GmbH	-	1	-	Foreign	Demonstration
Bi-Gas	Bituminous Coal Research, Inc.	-	1	-	US	Demonstration
Foster Wheeler/Stoic	Foster Wheeler/Stoic Corp.	1*(2)	-	-	US/Foreign	Demonstration/Commercial
Pressurized Wellman-Galusha (MERC)	ERDA	1*	-	-	US	Demonstration
GFERC Slagging	ERDA	-	1*	-	US	Demonstration
Texaco	Texaco Development Corp.	-	-	1*	US	Demonstration
BCR Low-Btu	Bituminous Coal Research, Inc.	1*	-	-	US	Demonstration
Combustion Engineering	Combustion Engineering Corp.	1*	-	-	US	Demonstration
Hygas	Institute of Gas Technology	-	1	-	US	Demonstration (High-Btu)
Synthane	ERDA	-	1	-	US	Demonstration (High-Btu)
CO_2 Acceptor	ERDA	-	1	-	US	Demonstration (High-Btu)
Cogas	COGAS Development Co.	-	1	-	US	Demonstration (High-Btu)
Foster Wheeler	Foster Wheeler Energy Corp.	1	-	-	US	Pilot
Babcock & Wilcox	The Babcock & Wilcox Co.	1	-	-	US	Pilot
U-Gas	Institute of Gas Technology, Phillips Petroleum Corp. Sterns-Roger	1	-	-	US	Pilot
Westinghouse	Westinghouse Electric Corp.	1	-	-	US	Pilot
Coalex	Inex Resources, Inc.	1 (1*)	-	-	US	Pilot Commercial
Wellman Incandescent	Applied Technology Corp.	(2*)**	-	-	US/Foreign	Commercial/Demonstration

*Under construction.
Demonstration scale indicates 2000 to 10,000 lb/hr coal feed.
Pilot scale indicates 400 to 1500 lb/hr coal feed.
**Undetermined number overseas

- Koppers-Totzek
- Winkler
- Chapman (Wilputte)

A number of the remaining gasifiers listed in Table 2-1 appear to have significant commercialization potential. For example, a commercial-scale Riley-Morgan system has been operated as a development/test unit and a commercial-scale Coalex plant is under construction.

Gasification systems can be considered to consist of three basic operations: coal pretreatment, coal gasification, and gas purification. Each of these operations can, in turn, be assumed to consist of process modules which are employed to satisfy the functions of the operations. These modules and their interrelationships are depicted in Figure 2-1.

From Figure 2-1, it can be seen that the coal pretreatment processes used will vary depending upon the coal type and the gasifier design. Coals having excess moisture may be dried while caking bituminous coals may be partially oxidized to reduce their caking tendencies. The feed coal must be crushed and sized for fixed-bed gasifiers or pulverized for fluid-bed or entrained-bed gasifiers. Fines from crushing processes which cannot be fed directly to a fixed-bed gasifier can either be sold as a by-product, consumed to supply on-site fuel needs, or briquetted and fed to the gasifier.

The six gasification systems listed previously, together with eight others which are currently under development make up a population of fourteen systems which, on the basis of a screening analysis presented in Section 3.2, have been identified as the most promising candidates for satisfying near-term commercial needs for low/medium-Btu gas. These systems are listed in Table 2-2.

The fourteen gasification processes which are considered to be members of this "most promising" group all fall into one of six classes of processes which have unique environmental impacts. These six classes and the proprietary processes which comprise each class are as follows:

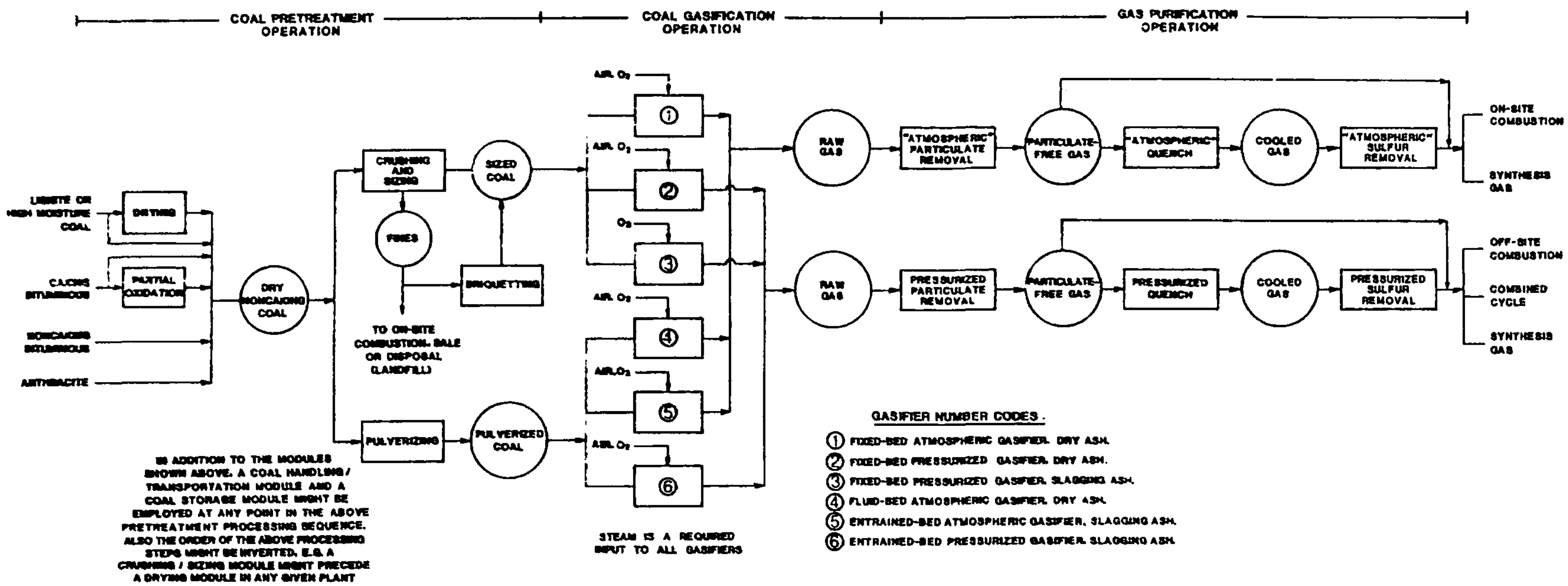


Figure 2-1. Coal gasification system process modules

Table 2-2. PROMISING LOW/MEDIUM-BTU GASIFICATION SYSTEMS

First Group[1]	Second Group[2]	Third Group[3]
• Wellman-Galusha	• Chapman (Wilputte)	• Pressurized Wellman-Galusha (MERC)
• Lurgi	• Riley Morgan	• GFERC Slagging Gasifier
• Woodall Duckham/Gas Integrale		• BGC/Lurgi Slagging Gasifier
• Koppers-Totzek		• Texaco
• Winkler		• Bi-Gas
• Wellman Incandescent and Foster Wheeler/Stoic		• Coalex

[1]Commercially available; significant number of units currently operating in the U.S. or in foreign countries.

[2]Commercially demonstrated in limited applications.

[3]Commercial or demonstration-scale units operating or being constructed; technology is promising and should be monitored.

- Fixed-bed atmospheric dry ash gasifier;
  - Wellman-Galusha
  - Woodall-Duckham/Gas Integrale
  - Chapman (Wilputte)
  - Riley-Morgan
  - FW/Stoic and Wellman Incandescent
- Fixed-bed pressurized dry ash gasifier;
  - Lurgi
  - Pressurized Wellman-Galusha (MERC)
- Fixed-bed pressurized slagging ash gasifier;
  - BGC/Lurgi Slagging Gasifier
  - GFERC Slagging Gasifier
- Fluid-bed atmospheric dry ash gasifier;
  - Winkler
- Entrained-bed atmospheric slagging ash gasifier;
  - Koppers-Totzek
  - Coalex
- Entrained-bed pressurized slagging ash gasifier;
  - Bi-Gas
  - Texaco

The low-Btu product gas purification scheme will vary depending upon the desired end use of the ultimate product fuel. Gases used for on-site boiler firing or for on-site industrial process heat may need only particulate collection if sulfur compounds are not present in objectionable quantities. Where sulfur compounds must be removed for either environmental or product quality reasons, two additional gas cleaning steps are necessary. Gas quenching and scrubbing are needed to cool the gas and remove condensable tars and oils so that any one of several commercially available low-temperature acid gas removal processes can be used. Sulfur removal processes are needed to remove the reduced sulfur compounds present in the product gas.

2.2 RAW MATERIALS

In general, any type of coal can be gasified if appropriate coal pretreatment and gas cleaning processes are employed. However, the type of gasifier design and the intended end use of the product gas will affect the selection of suitable coals for gasification. The properties which are important in determining the suitability of a given coal feedstock are:

- Particle size and friability
- Caking properties
- Moisture content
- Ash content and fusion temperature
- Sulfur content

Particle size, friability, and caking properties are probably the most critical factors as far as the operability of fixed-bed gasifiers is concerned. Since "fixed-bed" gasifiers actually have slowly gravitating beds where coal is added and ash is withdrawn regularly, proper bed composition and uniform gas-solid contact can be maintained only if these coal feedstock properties are within the limits required for the gasifier.

For most fixed-bed gasifiers, coal fines (<3 mm in diameter) will have to be separated from the gasifier feedstock. These coal fines can be sold as a by-product, burned in a boiler, or briquetted for re-use as gasifier feedstock. Fluidized- and entrained-bed gasifiers generally require pulverized feedstock; therefore, coal fines are not a raw material limitation.

Caking coals may cause operating problems for fixed-bed and some fluidized-bed gasifiers. Fixed-bed gasifiers may require bed agitators in order to gasify caking coals. Partial oxidation can make caking coals suitable for gasification. Caking properties are not a limitation for entrained-bed gasifiers.

Coal feedstocks with a high moisture content can cause operational problems for coal feeding devices. The high moisture content may also result in low gas outlet temperature (<420°K; 300°F) which can result in condensation of tars and oils in the gas outlet or hot cyclone. If the coal feedstock must be dried, the energy requirement for drying the coal will result in lower thermal efficiency of the overall process. Even if drying is not required, coals with higher moisture content will result in lower gasification efficiency because of the energy which must be supplied to evaporate the moisture in the gasifier.

Ash content and fusion temperature are important factors for gasifiers which operate above the ash fusion (slagging) temperature. Slagging fixed- and entrained-bed gasifiers may require the addition of fluxing agents to the coal feedstock in order to lower the fusion temperature of the coal ash. Slagging fixed-bed gasifiers may also require the addition of slag to the coal feedstock for coals with a very low ash content in order to maintain adequate slag withdrawal rates.

Sulfur content can be a factor in selecting acceptable coal feedstock if no acid gas removal operations are to be used. If the product gas is to be used as a synthesis gas, fuel for combined-cycle turbines, or as an off-site combustion fuel transported by pipeline, acid gas removal will always be required. For on-site combustion of the product gas, acid gas removal may not be required if the coal sulfur content is sufficiently low. The acceptable sulfur level will be determined by the federal, state, and local sulfur dioxide emission regulations.

2.3 PRODUCTS

The four potential end-use alternatives for coal gasifier product gas are the following:

- On-site combustion fuel
- Off-site combustion fuel
- Combined-cycle fuel
- Synthesis or reducing gas

On-site combustion refers to a direct combustion process which consumes the product gas within a relatively short distance of the coal gasification plant. Although any of the fourteen gasifiers just discussed could be used to produce on-site combustion fuel, the atmospheric pressure systems appear to be the best suited to this end use.

Off-site combustion refers to a direct combustion process which consumes the product gas at a site that is not near the coal gasification plant. Pressurized gasifiers are well suited to this end-use option, since it is cheaper to compress the air or oxygen and steam feed to the gasifier than it is to compress the product low/medium-Btu fuel gas. Also, air-blown gasifiers do not appear to be well suited to the production of off-site combustion fuel because of the excessive costs of transporting a gas with a low heating value.

The first step in a combined-cycle operation is the combustion of a pressurized fuel gas and the expansion of the combustion gases through a gas turbine to provide shaft work. Then, the sensible heat of the gas turbine exit gas stream is recovered in a conventional steam turbine cycle to provide additional shaft work. Combined cycles are primarily used in the generation of electricity. Pressurized gasifiers are most applicable to this end-use option, since combined-cycle gas turbines are designed to operate at high turbine inlet gas pressures. Either air-blown or oxygen-blown gasifiers can be used to produce a combined-cycle fuel.

Synthesis or reducing gas is used as a raw material for the production of a wide range of chemicals and metals. In most applications, a gas having high concentrations of hydrogen and carbon monoxide and low concentrations of methane and other hydrocarbons is desired. Because of this composition requirement, an entrained-bed, slagging ash gasifier is probably best suited to this end-use option.

2.4 ENVIRONMENTAL IMPACTS

The environmental impacts associated with coal gasification operations range from conventional pollution problems such as coal dust emissions to such ill-defined problems as fugitive emissions which, because of their probable noxious character, will require the design of special systems for their control. Emissions from coal preparation processes generally fall in the category of problems which appear to be solvable with available technology. Wastes from coal storage, handling, size reduction, and classification processes can be handled using available techniques for controlling coal dust emissions, disposing of mineral wastes, and handling runoff waters from storage piles. However, less costly or, in some cases, more efficient controls are needed.

The control of air emissions from coal dryers, briquetting and partial oxidation processes may present more difficult problems because of the volatile hydrocarbons which can be liberated as the coal is heated. The exact character of these materials has not been determined as far as their potential toxicities are concerned. Hence, the limit to which they must be controlled and the adequacy of available control technology have not been determined.

The coal gasification operation appears to be the most serious source of potential gasification system pollution problems. For all systems, the feeding of coal and the withdrawal of ash provide opportunities for the escape of coal or ash dust and hydrocarbons which, being products of the thermal processing of coal, must be considered to be potentially toxic. These problems are similar for all gasifiers even though emissions from some types of equipment may be limited to coal or ash dust. Also, it is certain that gasifiers and associated equipment will be sources of fugitive leaks from pump seals, flanges and the like. This leakage, unless controlled to adequate levels, can be hazardous.

The gas cleaning modules also appear to present difficult control problems. The particulate removal and gas cooling steps will produce ash and water contaminated with condensable hydrocarbons, many of which are toxic. The sulfur removal processes will produce fugitive emissions which are similar to those generated during gasification. Pollution control needs for the gas cleaning area are poorly defined and more work is needed to support judgments on the adequacy of available control technology. EPA's current scope of activities includes assessment of these pollution control needs.

2.5 STATUS OF DEVELOPMENT

Low- and medium-Btu gasification technologies are in varying stages of development. A number of systems are now being offered commercially. A second group of processes which are expected to introduce substantial improvements are currently under development. However, neither the older systems, such as those offered commercially, nor the new processes, have been proven to be satisfactory solutions to today's clean fuel supply problems.

While some six different gasification units are in operation in industrial plants in the U.S., publicly available information on their cost, fuel efficiency, applicability to various markets, and environmental impacts is lacking. Further, it is not known whether they are representative of the best systems (from both process efficiency and an environmental impact point of view) which could be built today. Hence, much more information is needed to determine the commercialization potentials of the various candidate systems. At present, it is difficult to predict how the different systems will fare in competition with each other or how low-Btu gasification will fare in competition with other technologies such as direct coal combustion/flue gas desulfurization, coal liquefaction, etc.

It is possible, however, to comment on some of the factors for judging the status of development, the most important of these being:

- The cost of the fuel gas produced.
- The applicability of the technology to different end-use requirements.
- The energy efficiency of the process.
- The extent of ongoing work to develop and commercialize the technology.

- The rate at which systems can be commercialized.

These factors are discussed in the following pages.

2.5.1 Cost

Projecting the costs of low/medium-Btu fuel gas produced from coal is difficult because of uncertainties in the limited cost data available and because costs are sensitive to the type and location of application. It appears, however, that simple atmospheric systems can produce low-Btu gas for about $\$2.50/10^9$ J (10^9 Joule $\approx 10^6$ Btu) if particulate collection in a hot cyclone is the only product gas cleaning step needed. If additional treatment steps are necessary (e.g., gas quenching, sulfur removal, by-product recovery, water treatment, etc.), this could easily add at least an estimated $\$1.00/10^9$ J to the cost of the gas.

These figures represent large increases over costs estimated when low-Btu systems again received serious consideration in the U.S. in the early 1970's. Even two years ago, costs in the general range of \$1.00 to \$2.00 per 10^9 J were considered reasonable. This continuing escalation is attributable to rising construction costs, rising coal costs, and a better understanding of problems associated with commercialization of the technology. Despite this apparent high cost, it appears that low- and medium-Btu gasification systems may be competitive in numerous critical applications where clean fuels are required but are not available from other sources.

2.5.2 Applicability of Low/Medium-Btu Gasification Technology

Low- and medium-Btu fuel gases from coal appear to be reasonable alternatives to natural gas or distillate fuels in certain critical applications where clean fuels are required. These applications include synthesis gas/chemical feedstock and combustion gas used to supply direct heat in processes such as brick ovens, lime kilns, glass furnaces, paint drying ovens, and food processing equipment as well as a variety of other processes where direct coal firing may not be a viable alternative. When the fuels which currently supply those uses become prohibitively expensive or are reserved for other uses by legislative mandate, a significant demand for low/medium-Btu gasification systems could result. The quantities of gas and oil used for these purposes in the industrial sector in 1972 are shown in Table 2-3.

Table 2-3. ESTIMATED CONSUMPTION OF GAS AND OIL TO SUPPLY DIRECT PROCESS HEAT OR CHEMICAL FEEDSTOCK NEEDS IN THE INDUSTRIAL SECTOR IN 1972

End Use	Fuel energy (10^{18} Joules) Gas	Oil	Total
Direct heat	3.4	.9	4.3
Feedstock	.5	2.5	3.0
	3.9	3.4	7.3
Total Energy Consumption, Industrial sector All End Uses	11.2	6.0	17.2

Source: Ref. 1 (References are listed at the end of Vol. I and Vol. II.)

Although all of the end uses represented by the energy consumption figures shown in Table 2-3 cannot realistically be satisfied by low/medium-Btu gas (for either technical or economic reasons), the energy use figures shown give some indication of the significance of one potential market for low/medium-Btu gasification systems. Small gas and oil-fired industrial boilers of less than a 10 MWe equivalent capacity appear to represent another potential market for low/medium-Btu gas. Data published by Battelle (Ref. 2) indicate that these systems consume approximately 6.5 x 10^{18} Joules of gas and oil per year. In many of these systems, the use of low/medium-Btu gas may be a viable alternative to the replacement of existing units with coal-fired systems. This indicates a potential need for several thousand gasifiers having annual outputs of 0.5 to 30 x 10^{15} J to satisfy these energy requirements.

Another application being considered as an important market for low-Btu gas is in combined cycle systems for electricity generation. It is not clear, however, whether overall cycle efficiencies will be high enough to make this approach attractive. As discussed in the following section, gasification process efficiencies are low and difficult to define precisely.

The capabilities of gas turbines which could be used in combined cycles are also poorly defined. Manufacturers' claims are generally more optimistic than the reported experience of users. It is clear, however, that present day gasifiers and turbines would not be as efficient as a modern conventional coal-fired power boiler. Improved efficiencies of gasifiers and turbines could, however, reverse this situation.

Coal gasifiers are also being considered as sources of replacement fuel supplies for natural-gas-fired power boilers. It does not appear however, that these systems will be competitive with replacement coal-fired boilers for base load generation. It is possible that gasification could be competitive when producing a fuel for peaking units, but this would require continuous operation of the gasifier and storage of the fuel when the boiler was not being used. Even though this approach appears attractive, the extent of the potential market is probably very limited.

2.5.3 Energy Efficiency

Like costs, the energy efficiencies of the various gasification systems being studied are difficult to determine with certainty. This is a significant problem. Low efficiencies will tend to make the technology non-competitive with alternative technologies serving the same need, e.g., the energy efficiency of a low-Btu gasification/combined-cycle system may be too low to make it competitive with coal-fired power plants equipped with sulfur and particulate emission control hardware.

At this point, many questions relating to the efficiency of gasification systems still exist. The confusion associated with efficiencies which have been quoted in the literature can be illustrated by considering some of the variables involved. In one study (Ref. 3) it was reported that no more than 65 percent of the heat content of the coal supplied to an entrained-bed, slagging ash gasification system and the associated boiler supplying electrical power could appear as product heating value. Also, a 4 percent penalty was associated with the fuel used for coal drying which reduced the net process efficiency to 61 percent. If the boiler was assumed to be fired with product gas instead of coal, the overall plant efficiency dropped to 53 percent. If the process operating pressure was assumed to be 15 psig instead of 150 psig, the savings in compression energy increased the base efficiency of 61 percent to 69 percent.

It would appear from these figures that the efficiencies which have been cited for some gasification systems are probably optimistic. However, it is important to realize that the efficiency of a gasification process is affected by many process- and site-specific factors. (These factors are discussed further in Section 3.2).

2.5.4 Extent of Development Work

Gasifier operating experience, as indicated earlier, is quite extensive. The applicability of some of this experience to current U.S. needs, however, is questionable. This is particularly true of the environmental aspects of gasification technology since many of the systems which were utilized in the past would not be environmentally acceptable by today's standards.

Government agencies such as the EPA and ERDA, as well as a significant number of industrial organizations, are sponsoring research aimed at improving the capabilities of gasification systems which are currently available or under development. Work in this connection is being concentrated in the following areas:

- Evaluations of advanced gasification system designs which utilize features enhancing the efficiency and/or the operability of systems which are representative of currently available technology. In many cases, these measures will also enhance the environmental acceptability of the gasification processes involved. This research has been directed toward developing improved:
    - Reactor designs
    - Materials of construction
    - Coal feeding and ash removal devices (particularly for pressurized systems)
    - High temperature product gas cleanup processes

- Fundamental studies aimed at developing a better understanding of the reaction mechanisms involved in gasification processes.

- Development and use of improved analytical techniques for characterizing the components present in process and emission streams.

Control technology applicability and development will also be given more attention. Many of the potential environmental problems associated with coal gasification can be handled using techniques developed to solve similar problems in related industries. However, many other emission problems will be unique. As gasification process research continues and as these problem areas are identified, there will be an increasing emphasis on control technology assessment and development studies.

2.5.5 Rate of Commercialization

The rate at which coal gasification (or any other major energy technology) can be applied will depend primarily on the rate at which process suppliers can respond to demands for new units. Up until just recently, there was a fairly small group of process vendors who were actively marketing their gasification systems. Generally, these systems were based on designs which were widely used in the past.

Awareness of the potential for the application of gasification systems has over the past several years led to an increase in the number of groups that are actively developing and marketing gasification systems. It is therefore expected that the growth of the coal gasification industry during the next few years will tend to be limited by the availability of the specialized equipment required in those plants. For this reason, it will probably be several years before there will be a significant increase in the number of operating gasifiers in this country. The number of operating gasification systems may increase substantially, however, during the 1980-1990 time-frame.

2.5.6 Status Summary

The major factors affecting the development status of low-Btu gas producers are given in Table 2-4. These factors are

Table 2-4. SUMMARY OF THE MAJOR FACTORS AFFECTING THE STATUS OF LOW-BTU GAS PRODUCERS

Gasifier Type/Name	Gasifier Efficiency(1) Cold Gas (%)	Overall Thermal (%)	Applicability to Various End Uses(2) Most Suitable End Use	Least Suitable End Use	Summary of Ongoing Efforts to Develop and Commercialize the Technology
Fixed-Bed (Dry Ash)					
Wellman-Galusha	~79	—	On-site combustion	Off-site combustion Combined-cycle units	This gasifier has been in commercial use for many years. Current designs are essentially the same as a 20-year old unit. Work on improved process instrumentation is being done.
Lurgi	63–80	~75	Off-site combustion Combined-cycle units	Synthesis/reductant gas	This gasifier has been in commercial use for many years. Recent design improvements include recycle tar injection nozzles.
Woodall-Duckham/ Gas Integrale	~77	~88	On-site combustion	Off-site combustion Combined-cycle units	This gasifier has been in commercial use for many years. Major improvements in tar collection techniques have been made.
Chapman (Wilputte)	—	—	On-site combustion	Off-site combustion Combined-cycle units	This gasifier has been in commercial use for many years.
Riley Morgan	64–68	71–78	On-site combustion	Off-site combustion Combined-cycle units	A commercial-size gasifier is being evaluated at Riley Stoker's pilot plant facility in Worchester, Massachusetts.
Foster Wheeler/Stoic Wellman-Incandescent	—	~89	On-site combustion	Off-site combustion Combined-cycle units	The design of this gasifier is similar to the Woodall-Duckham/Gas Integrale gasifier. The improvements that have been made include automated pokers and a water-sealed ash pan.
Pressurized Wellman-Galusha (MERC)	~79	—	Off-site combustion Combined-cycle units	Synthesis/reductant gas	Gasifier design is being evaluated at ERDA's Morgantown Energy Research Center (MERC).
Fixed-Bed (Slagging Ash)					
GFERC Slagging	~85	—	Off-site combustion Combined-cycle units	Synthesis/reductant gas	Gasifier design is being evaluated at ERDA's Grand Forks Energy Research Center (GFERC).
BGC/Lurgi Slagging	~83	—	Off-site combustion Combined-cycle units	Synthesis/reductant gas	This gasifier has been tested on a pilot plant scale. A commercial scale gasifier is being evaluated at Westfield, Scotland.

(continued)

Table 2-4. SUMMARY OF THE MAJOR FACTORS AFFECTING THE STATUS OF LOW-BTU GAS PRODUCERS (continued)

Gasifier Type/Name	Gasifier Efficiency[1] Cold Gas (%)	Gasifier Efficiency[1] Overall Thermal (%)	Applicability to Various End Uses[2] Most Suitable End Use	Applicability to Various End Uses[2] Least Suitable End Use	Summary of Ongoing Efforts to Develop and Commercialize the Technology
Fluidized-Bed (Dry Ash)					
Winkler	55-72	~69	On-site combustion	Off-site combustion Combined-cycle units	This gasifier has been in commercial use for many years.
Entrained-Bed (Slagging Ash)					
Koppers-Totzek	~75	~68	Synthesis/ reductant gas	On-site combustion Combined-cycle units	This gasifier has been in commercial use for many years. Significant improvements in process control have been made. A pressurized gasifier is currently being developed.
Texaco	~77	—	Synthesis/ reductant gas Combined-cycle units	On-site combustion	The design of this gasifier has been applied to heavy oils. Development work using coal is being done at Texaco's Montebello, California Research Center.
Coalex	—	88-93	On-site combustion	Off-site combustion Combined-cycle units	This gasifier has been successfully operated on a pilot plant scale. A recent improvement includes the use of a hot mobile bed to remove particulates from the product gas.
Bi-Gas	~69	~65	Off-site combustion Combined-cycle units	Synthesis/reductant gas	A pilot plant is being operated by Bituminous Coal Research Co. at Homer City, Pennsylvania.

(1) Cold gas efficiency = $\frac{\text{(Product gas energy output)}}{\text{(Coal energy input)}} \times 100$

Overall thermal efficiency = $\frac{\text{[Total energy output (product gas, hydrocarbons, and steam)]}}{\text{[Total energy input (coal, electric power, and steam)]}} \times 100$

The useful overall thermal efficiency of a gasifier may vary from the ranges given depending upon the ability of the integrated system to use the energy contained in by-product hydrocarbons and waste steam.

(2) Bases for evaluating utilization technology:

Atmospheric gasifiers are limited to on-site combustion applications.

Pressurized, oxygen-blown gasifiers are best suited to off-site combustion applications.

Pressurized gasifiers, both air- and oxygen-blown, are suitable for combined-cycle applications.

Product gases which are high in CO and H_2 content, and low in CH_4 and hydrocarbon content are suitable for use as synthesis/reductant gases.

process efficiency and applicability to various end uses. A brief summary of the ongoing efforts to develop and commercialize low-Btu gasification systems is also presented in this table.

SECTION 3.0

LOW/MEDIUM-BTU COAL GASIFICATION-PROCESS OPERATIONS

As indicated in the previous section, the production of low/medium-Btu gas from coal involves three basic process operations: coal pretreatment, coal gasification and product gas purification. In this section, the optional processing steps that may be used to accomplish the functions of these three operations and the associated environmental impacts are described in detail. The objectives of this discussion are:

1) To identify the potential sources of emission from coal gasification plants

2) To identify the components of environmental concern which might be present in those streams.

3) To define how feedstock and process variable changes affect the production rates and fates of those components.

Although all three of the processing operations just mentioned are discussed to some extent in this section, the depth of treatment given to each varies considerably. In the discussion of the coal pretreatment operation, for example, emission stream sources and compositions are described in qualitative terms only. This operation is included here because it is important to consider how the emission streams generated by coal pretreatment processes would be handled in a low/medium-Btu coal gasification plant. On the other hand, an in-depth discussion of this operation is not attempted since a detailed environmental assessment of coal pretreatment processes is being conducted as part of EPA's Coal Cleaning Technology Assessment program. Pertinent results from that program will be integrated into future low/medium-Btu program reports as appropriate.

Coal gasification and gas purification are the process operations which are given major attention in this section. Detailed consideration of these operations is justified for several reasons. From an environmental viewpoint, these operations generally will be the sources of the most significant waste streams generated in a coal gasification plant. These two operations deserve detailed treatment also because of the large choice of processes which can be used to accomplish the functions of these operations. In the case of the coal gasification operation, for example, 68 mechanically different gasifier designs were identified in the literature screening study which provided most of the background information for this document.

Because of the large number of candidate processes which appear to be suited to the requirements of the coal gasification and gas purification operations, it was necessary to limit the list of processes given detailed consideration to those that have the greatest likelihood of near-term commercial application. These processes were identified on the basis of the following criteria:

- Applicability to low/medium-Btu gasification and utilization technology requirements,
- Development status,
- Energy efficiency,
- Limitations (unusual raw material needs, sensitivity to various feedstocks and operating parameters, utilization processes, etc.),
- Environmental impacts, and
- Costs.

In this section, processes are compared with respect to the above criteria in a series of summary tables. In order to understand the conclusions reached as a result of these comparisons, the reader must have some knowledge of the technical details of the various processes. To satisfy this need, detailed process "fact sheets" have been prepared for most of the important processes described here. These fact sheets, which contain process descriptions, flow diagrams and summaries of available process and discharge stream information, are included in Appendices A through E.

It should be emphasized that the processes which are given detailed consideration in this section have been selected on the basis of currently available information. Additions to and deletions from this list of processes are anticipated as new information is obtained from ongoing development programs.

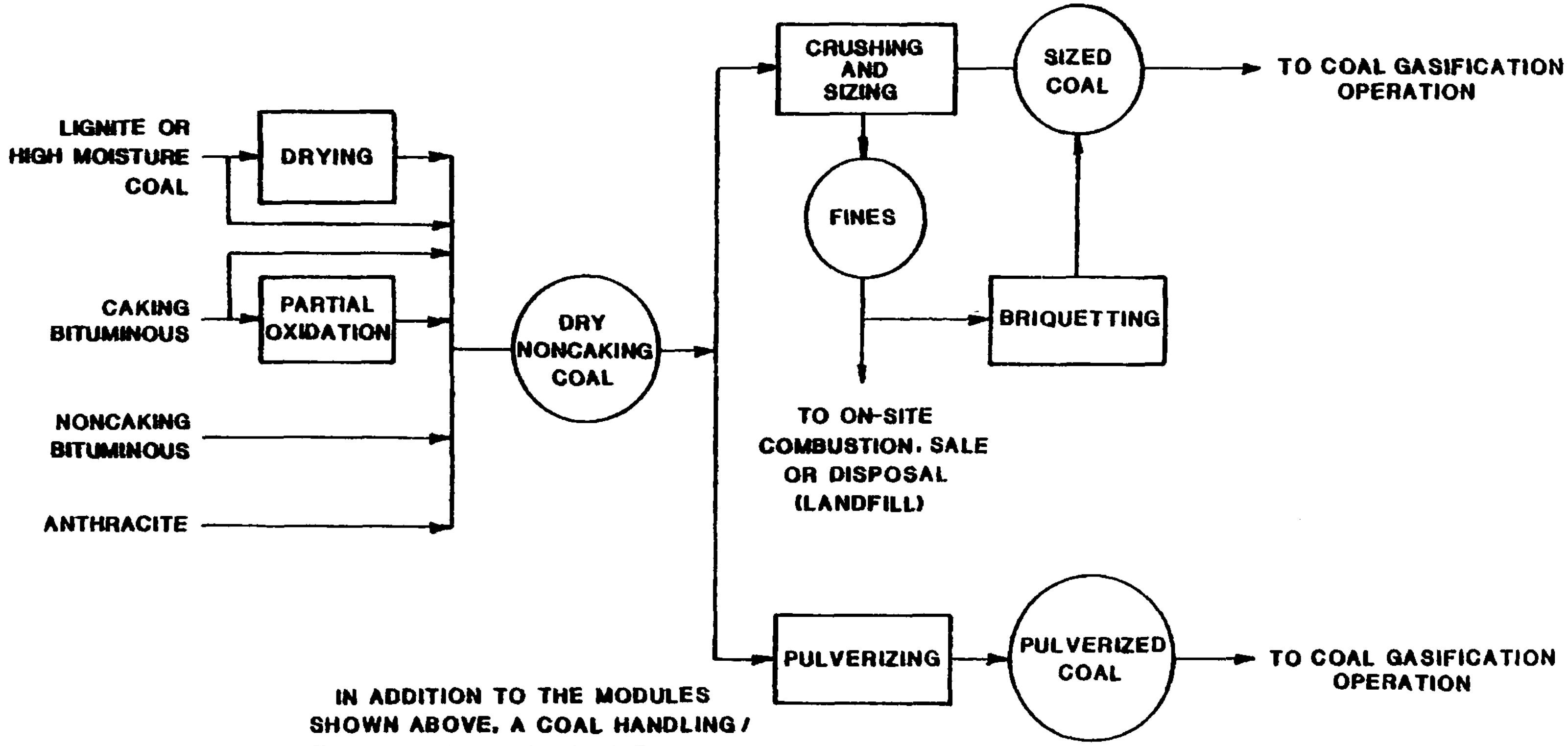
3.1 COAL PRETREATMENT OPERATION

The primary function of the coal pretreatment operation is to supply a coal feedstock which satisfies the physical specifications of the gasification operation. Coal handling and storage modules are almost always required in this operation. The need for other processing modules such as grinding and screening depends on the nature of the run-of-mine coal feedstock and the requirements of downstream processing operations.

Figure 3-1 is a flow diagram showing the modules which comprise the coal pretreatment operation. The functions of these modules are summarized in Table 3-1. In the following text, these optional pretreatment modules are described and the bases for their use are discussed.

3.1.1 Crushing/Sizing Module

Crushing and sizing steps are needed to produce a coal feedstock which is suitable for charging to a coal gasifier. Particle sizes for coal feed to fixed-bed gasifiers are generally in the range of 2-50 mm (about 0.1-2.0 inches) in diameter. Excessive quantities of fines cannot be tolerated in fixed-bed systems because they can cause excessive bed pressure drop, poor gas distribution or, in extreme cases, severe channeling. Oversized coal particles can reduce the maximum throughput of fixed-bed gasifiers because of their lower reactivity (low surface area/volume ratio). Oversized coal particles rejected from the sizing step are a minor problem because they can be easily recycled to the crushers. On the other hand, the fines produced from this operation must either be burned on site (e.g., in utility boilers), sold as a by-product, disposed of as a solid waste (landfill) or briquetted and fed to the gasifier.



IN ADDITION TO THE MODULES SHOWN ABOVE, A COAL HANDLING/ TRANSPORTATION MODULE AND A COAL STORAGE MODULE MIGHT BE EMPLOYED AT ANY POINT IN THE ABOVE PROCESSING SEQUENCE. ALSO THE ORDER OF THE ABOVE PROCESSING STEPS MIGHT BE INVERTED, E.G. A CRUSHING/ SIZING MODULE MIGHT PRECEDE A DRYING MODULE IN ANY GIVEN PLANT.

Figure 3-1. Coal pretreatment operation

Table 3-1. FUNCTIONS OF MODULES IN COAL PRETREATMENT OPERATION

Module	Function	Equipment Used
Handling/ Transportation	Movement of coal to and from other pretreatment modules and to the gasification operation.	Belt conveyors Bucket elevators
Storage	Provides adequate reserves to allow for supply/demand surges (mine or gasification plant downtime) and possibly blending capability to provide a uniform feed to the gasification operation.	Covered/uncovered bins - up to about 1.8 x 10^6 kg (2000 short tons) per bin; uncovered piles on ground for greater than 2.3 x 10^8 kg (250,000 short tons) (Ref. 4)
Crushing/ Sizing	Size reduction and elimination of over- and undersize coal particles from a fixed-bed gasifier feed stream. Size specifications dictated by mechanical characteristics of gasifier.	Crushing - double and single roll crushers, rotary breakers, impactors, cage mills Sizing - Coarse (>50 mm [2 in.] particles) - grizzly screens Medium (>13 mm [½ in.] particles) - revolving, shaking or vibrating screens Fine (>2 mm [0.08 in.] particles) - oscillating screens
Briquetting	Compaction of coal fines to produce a briquette of a size suitable for feed to a fixed-bed gasifier. Certain binders, such as asphalt or tar, may be required, along with a baking or curing step, to give the briquette the required structural strength.	Coal fines hopper, feeder and either a rotating or a plate-type press along with provisions for adding a binder. A baking oven may also be required.
Pulverizing	Size reduction to provide a feedstock for a fluid- or entrained-bed gasifier.	Hammer mills Cage mills Impactors Ball mills
Drying	Mechanical dewatering or heat treatment to remove excess moisture from coal feed.	Mechanical: centrifugal; filtration Thermal: fixed- or fluid-bed driers.
Partial Oxidation	Method of achieving a reduction in the caking tendencies of a feed coal by contacting the coal with hot air or combustion gases under controlled conditions (temperature; time) in a suitable reactor.	Same as thermal driers

3.1.2 Pulverizing Module

A pulverized coal feed is needed for fluid- or entrained-bed gasifiers. This step would normally be performed on site in contrast to the crushing and sizing steps which could just as easily be performed at the mine as at the site of the gasification unit.

3.1.3 Drying/Partial Oxidation Modules

These processes are lumped here because both generally involve contacting the coal with hot gases. Coal drying is desirable when the moisture content of the coal is so high that the efficiency of the gasification process would be adversely affected if the coal were fed directly to the gasifier. Partial oxidation can be used to reduce the caking tendency and increase the softening temperature of a coal gasifier feedstock. This process may be needed to prepare coal for certain fixed- and fluid-bed gasifiers that are unable to gasify caking coals. Usually, this oxidation is performed under controlled conditions such that most of the volatile matter in the coal is retained.

The effects of partial oxidation on the caking properties of coal vary greatly with the type of coal. Some coals oxidize spontaneously when held at room temperature for a few days. Other coals may be stored for months without any change in caking properties. In most cases, lower rank coals (lignite, subbituminous) are more readily oxidized than higher rank coals (anthracite). By contacting coal with air or oxygen at regulated temperatures, it is usually possible to reduce its caking tendencies to any desired level (Ref. 5).

3.1.4 Briquetting Module

In this module, coal fines are compacted into briquettes of sizes which are suitable for feed to a fixed-bed gasifier. To produce briquettes, coal fines would usually be fed between a pair of mated rolls with recessed surfaces. The fines are compacted in these recessed areas as the rolls come together. A binder such as asphalt or tar may be required in order to give the briquette sufficient structural strength. In some cases, the briquette may also need to be baked to provide additional structural strength.

3.1.5 Discharge Stream and Control Technology Summary - Coal Pretreatment Operation

Several of the process modules in the coal pretreatment operation are potential sources of air emissions, liquid effluents, and/or solid wastes. The sources and compositions of these discharge streams and the associated control technology requirements are summarized in Table 3-2.

Air Emissions -

Air emissions may be generated by all of the modules in the coal pretreatment operation. From conveying, crushing, pulverizing, sizing and briquetting equipment may come significant quantities of coal dust produced by mechanical agitation and windblown transport. The storage module may also be a source of windblown coal dust. Minor amounts of volatile components in the coal may be emitted from coal storage piles or bins, due to the effects of solar or spontaneous heating. Coal dust may be emitted from mechanical dewatering processes. Coal dust, volatile components, and combustion products are also possible emissions from thermal drying processes. Air emissions from the partial oxidation and briquetting modules may contain coal dust and/or volatile coal components.

Liquid Effluents -

Liquid effluents from the coal storage module may contain a wide range of organic and inorganic constituents leached by rainfall or water spray runoff from storage piles. Water sprays for controlling coal dust emissions will also produce a liquid effluent.

Solid Wastes -

The solid wastes generated in the crushing and pulverizing steps may consist of rock or other mineral matter rejected by the equipment. The solid waste from the sizing step may include rock or other mineral matter as well as undersize coal particles (fines).

Table 3-2. EMISSION STREAM AND CONTROL TECHNOLOGY - COAL PREPARATION OPERATION

	Handling/ transportation module	Storage module		Crushing/sizing and pulverizing modules	Drying and partial oxidation modules	Briquetting module
		Storage piles	Storage bins			
AIR EMISSIONS	Coal dust	Coal dust; volatile matter	Coal dust; volatile matter	Coal dust	Coal dust; volatile matter; combustion products	Coal Dust; volatile organics; combustion products
Control Technologies						
• Suppression techniques	Water sprays	Water sprays; polymer coatings	Covered bins		Proper temperature control	Proper control of operating conditions
• Collection and treatment techniques	Covered conveyors; collection ducts; transfer to air pollution control process		Collection hoods and ducts; transfer to air pollution control process	Collection hoods and ducts; transfer to air pollution control process	Collection ducts; transfer to air pollution control process	Collection ducts; transfer to air pollution control process
LIQUID EFFLUENTS	None	Runoff/leachate from rainfall and/ or water sprays	None if covered; same as storage piles if not	None	None	None
Control Technologies						
• Suppression techniques		Polymer coatings				
• Collection and treatment techniques		Collection ditches; reuse as spray water for dust suppression; transport to water pollution control process				
SOLID WASTES	None	None	None	Rejected rock and mineral matter; coal fines	None	None
Control Technologies				Landfill for rejected wastes; on-site consumption, sale, or landfill for coal fines		

Control Technology Requirements -

There are two basic types of control technologies which can be used to treat discharge streams from the coal pretreatment operation; suppression techniques and collection and treatment techniques. Suppression techniques are used to reduce the magnitude of a discharge stream. Collection and treatment techniques are used to contain a discharge stream and to remove or convert its hazardous components. These techniques may include direct sale or disposal, or transfer of the discharge stream to a pollution control process.

All of the modules in the coal pretreatment operation may emit coal dust. Control of this emission is one of the most important control technology requirements associated with this operation. Water sprays can be used to suppress coal dust from conveying and storage processes. Covered bins or polymer spray coatings can be used to suppress coal dust emissions from storage bins and ground storage piles. Hoods and ducts can be used to collect and transport coal dust from any module. Particulate control equipment items such as cyclones, baghouse filters, scrubbers, and electrostatic precipitators can be used to recover the coal dust collected from these sources.

Air emissions containing coal dust, volatile matter and combustion products from the drying, partial oxidation and briquetting modules, can be minimized by maintaining proper control of process operating conditions. Hoods and ducts can be used to collect and transport these emissions to appropriate air pollution control processes (particulate, hydrocarbon, and/or sulfur emission control processes).

Rainfall runoff and leachate from the storage module can be suppressed with polymer spray coatings. These liquid effluents can be collected in ditches and then either reused as spray water for dust suppression or transported to a suitable water pollution control process for further treatment.

Solid wastes consisting of rejected rock and mineral matter from crushing, pulverizing and sizing processes would usually be disposed of in a landfill. Undersize coal fines from the sizing module can be sold, disposed of by landfill, consumed on site as a fuel or briquetted for use as a gasifier feedstock.

3.2 COAL GASIFICATION OPERATION

The function of the coal gasification operation is to produce raw low/medium-Btu gas by reacting coal with a steam/air or steam/oxygen mixture. Additionally, some gasification processes may use certain additives such as dolomite or fluxing agents in the gasifier.

Air is used for the production of low-Btu gas while oxygen is required to produce medium-Btu gas. Higher heating values of low-Btu gas are approximately 3.7×10^6 to 9.3×10^6 Joules/Nm^3 (100 to 250 Btu/scf). Medium-Btu gas has a higher heating value of approximately 9.3×10^6 to 18.6×10^6 Joule/Nm^3 (250 to 500 Btu/scf). In addition to steam and perhaps oxygen production facilities, any one of several other modules may be required for the coal gasification operation.

Numerous reactions occur during coal gasification. Among the more important ones for product gas specifications are (Ref. 6):

1) $C + \frac{1}{2}O_2 \rightarrow CO$

2) $C + O_2 \rightarrow CO_2$

3) $H_2O + C \rightarrow CO + H_2$

4) $CO + H_2O \rightarrow CO_2 + H_2$

5) $2H_2 + C \rightarrow CH_4$

6) $CO_2 + C \rightarrow 2CO$

From an environmental viewpoint, coal devolatilization and reactions involving the sulfur and nitrogen species as well as the trace elements in coal are probably of greater significance than the reactions listed above because these can result in the formation of a variety of hazardous compounds which must be handled in downstream processing steps. Reactions involving additives may also be important in some gasification processes.

Many types of gasifiers have been developed to produce low/medium-Btu gas from coal; each has characteristics that make it unique, both from a process and an environmental viewpoint. These differences must be taken into account in the environmental assessment of coal gasification technology.

The production rates and compositions of coal gasifier effluent streams are affected by:

- the mechanical features of the gasifier,

- coal feedstock properties, and
- gasifier operating conditions.

The following discussion of these factors is broken down into six major sections. The distinguishing mechanical features of coal gasifiers are discussed in the first section. The bases used to identify the gasifiers which appear to be promising candidates for near-term commercial application are discussed in the second section. This prioritization exercise was used to select gasifiers for which detailed environmental analyses appear to be justified. A general discussion of how feedstock and operating parameter changes affect gasifier performance is presented in the third section. In the fourth section, direct comparisons of promising gasifiers are made on the basis of their important process characteristics. The fifth section contains information pertaining to the environmental aspects of coal gasification processes. In that section, air emission, liquid effluent and solid waste stream sources, quantities, compositions and potential control methods are discussed. Current trends in low/medium-Btu gasification technology which are environmentally significant and which will warrant attention are described in the sixth section.

3.2.1 Types of Gasifiers

Many types of gasifiers have been developed to produce low/medium-Btu gas from coal. These gasifiers are usually classified according to their distinguishing mechanical characteristics. This basis of classification is also significant from an environmental assessment viewpoint since variations in gasifier design account for many of the differences which are observed in the environmental impacts of different gasification systems. Among the important characteristics in this regard are the following:

- Bed type
    - Fixed or supported bed (includes moving bed designs)
    - Fluidized bed
    - Entrained bed

- Operating conditions
  - Pressure: atmospheric or pressurized
  - Temperature
- Gasification media
  - Reactants: steam, air, oxygen, other additives
  - Coal feed/reactant ratios
  - Mode of reactant introduction
- Coal feeding
  - Mode: continuous or intermittent
  - Mechanism: lock hopper, slurry, screw, etc.
  - Location: top or center of gasifier
- Ash removal
  - Mode: continuous or intermittent
  - Ash condition: dry or slagged (fused)
  - Location: from the gasifier or from the product gas stream
- Energy input for gasification
  - Autothermic: energy supplied by partial combustion of the feed coal in the gasifier
  - Electrothermic: energy supplied by electrical resistance heating
  - Solids circulation/heat transfer: energy supplied by external heating and circulation of additives or inert solids

A total of 68 different types of gasifiers have been identified which either have been used or are under development to produce low/medium-Btu gas from coal. These gasifiers are classified in Table 3-3 according to bed type and ash removal condition. Most of these gasifiers are fixed-bed/dry ash, fluidized-bed/dry ash, or entrained-bed/slagging units.

3.2.2 Gasification Process Prioritization

Promising gasification processes (those which appear to have the highest probability of near-term commercial application in the United States) have been identified by a prioritization process which is described below. This is a useful exercise because it also identifies those gasification processes for which detailed environmental information will probably be needed the soonest.

In generating a list of priority gasifiers, the six basic criteria discussed in the following paragraphs were considered.

Applicability to Low/Medium-Btu Gasification -

This criterion was applied to identify those gasifiers that are best suited to the production of low/medium-Btu gas from coal. The gasifiers that have been developed primarily to produce either high-Btu gas or liquid fuels were not considered to be the most promising low-Btu gas producers, even though they can also be operated to produce low/medium-Btu gas.

Development Status -

There are many gasifiers which are not likely to be used in the near future. This includes gasifiers that have been operated in the past but have been abandoned for various reasons. Other gasifiers are in such early stages of development that their technical and economic feasibility cannot be adequately assessed. All gasifiers that are not either commercially available or currently being tested on a demonstration or large pilot-plant scale were not included in the list of promising processes.

Table 3-3. TOTAL POPULATION OF LOW/MEDIUM-BTU GASIFIERS

Gasifier type Gasifier name	Licensor/Developer	Status
Fixed-Bed, Dry Ash		
Lurgi	American Lurgi Corp. (USA)	Present commercial operation
Wellman-Galusha	McDowell-Wellman Engr. Co. (USA)	Present commercial operation
Chapman (Wilputte)	Wilputte Corp. (USA)	Present commercial operation
Woodall-Duckham/Gas Integrale	Woodall-Duckham, Ltd. (USA)	Present commercial operation
Riley Morgan	Riley Stoker Corp. (USA)	Present demonstration unit testing; commercially available
Pressurized Wellman-Galusha (MERC)	Morgantown Energy Research Center/ERDA (USA)	Present development unit testing
Foster Wheeler/Stoic	Foster Wheeler Energy Corp. (USA)	Demonstration unit planned
Kilngas	Allis Chalmers Corp. (USA)	Present development unit testing; commercially available
Kellogg Fixed Bed	M. W. Kellogg Co. (USA)	Present development unit testing
GEGAS	General Electric Research and Development (USA)	Present development unit testing
Consol Fixed Bed	Consolidation Coal Co. (USA)	Present development unit testing
IFE Two Stage	International Furnace Equipment Co., Ltd.	Past commercial operation
Karpely Producer	Bureau of Mines/ERDA (USA)	Past commercial operation
Marischka	Unknown	Past commercial operation; anthracite or coke only
Pintsch Hillebrand	Unknown (Germany)	Past commercial operation
U.G.I. Blue Water Gas	U.G.I. Corp./DuPont (USA)	Past commercial operation; coke only
Power Gas	Power Gas Co. (USA)	Past commercial operation
Wellman Incandescent	Applied Technology (USA)	Past commercial operation
BCR/Kaiser	Unknown	Past development unit testing
Fixed-Bed, Slagging Ash		
BGC/Lurgi Slagging Gasifier	British Gas Council (GB) Lurgi Mineralöltechnik (W. Germany)	Present development unit testing
GFERC Slagging Gasifier	Grand Forks Energy Research Center/ERDA (USA)	Present development unit testing; lignite only
Luena	Unknown	Past commercial operation; coke only
Thyssen Galocsy	Unknown	Past commercial operation; coke only

Continued

Table 3-3. TOTAL POPULATION OF LOW/MEDIUM-BTU GASIFIERS (continued)

Gasifier type / Gasifier name	Licensor/Developer	Status
Fluidized-Bed, Dry Ash		
Winkler	Davy Powergas Co. (USA)	Present commercial operation
Hygas	Institute of Gas Technology (USA)	Present development unit testing
Synthane	Pittsburgh Energy Research Center/ERDA (USA)	Present development unit testing
Hydrane	Pittsburgh Energy Research Center/ERDA (USA)	Present development unit testing
Cogas	Cogas Development Co. (USA)	Present development unit testing
Exxon	Exxon Corp. (USA)	Present development unit testing
BCR Low-Btu	Bituminous Coal Research (USA)	Present development unit testing
CO_2 Acceptor	Consolidation Coal Co. (USA)	Present development unit testing
Electrofluidic Gasification	Iowa State Univ./ERDA (USA)	Present development unit testing
LR Fluid Bed	Unknown (Germany)	Past commercial operation
HRI Fluidized Bed	Hydrocarbon Research Inc. (USA)	Past development unit testing
BASF-Flesch-Demag	Badische Anilin und Soda Fabrik (West Germany)	Past development unit testing
GEGB Marchwood	Unknown	Past development unit testing
Heller	Unknown (Germany)	Past development unit testing
Fluidized-Bed, Agglomerating Ash		
U-Gas	Institute of Gas Technology (USA)	Present development unit testing
Battelle/Carbide	Battelle Memorial Institute (USA)	Present development unit testing
Westinghouse	Westinghouse Electric Corp. (USA)	Present development unit testing
City College of NY Mark 1	Hydrocarbon Research Inc./ A.M. Squires (USA)	Present development unit testing
Two-stage Fluidized	British Gas Council (England)	Present development unit testing
ICI Moving Burden	Imperial Chemical Industries, Ltd. (England)	Past development unit testing
Entrained-Bed, Dry Ash		
Garrett Flash Pyrolysis	Garrett Research and Development Co. (USA)	Present development unit testing
Bianchi	Unknown (France)	Past development unit testing; lignite only

Continued

Table 3-3. TOTAL POPULATION OF LOW/MEDIUM-BTU GASIFIERS (continued)

Gasifier type Gasifier name	Licensor/Developer	Status
Panindco	Unknown (France)	Past development unit testing; lignite only
USBM Annular Retort	Bureau of Mines/ERDA (USA)	Past development unit testing; lignite only
USBM Electrically Heated	Bureau of Mines/ERDA (USA)	Past development unit testing
Entrained-Bed, Slagging Ash		
Koppers-Totzek	Koppers Co. (USA)	Present commercial operation
Bi-Gas	Bituminous Coal Research, Inc. (USA)	Present development unit testing
Texaco	Texaco Development Corp. (USA)	Present development unit testing
Coalex	Inex Resources, Inc. (USA)	Present development unit testing; commercially available
PAMCO/Foster Wheeler	Pittsburgh and Midway Coal Co./ Foster Wheeler (USA)	Present development unit testing
Combustion Engineering	Combustion Engineering (USA)	Present development unit testing
Brigham Young University	Brigham Young University/ Bituminous Coal Research (USA)	Present development unit testing
Babcock and Wilcox	The Babcock and Wilcox Co. (USA)	Past commercial operation
Ruhrgas Vortex	Ruhrgas A. G. (West Germany)	Past commercial operation
IGT Cyclonizer	Institute of Gas Technology (USA)	Past development unit testing
Inland Steel	Inland Steel Co. (USA)	Past development unit testing
USBM, Morgantown	Morgantown Energy Research Center/ERDA (USA)	Past development unit testing
Great Northern Railway	Great Northern Railway Co. (USA)	Past development unit testing
FRS Cyclone	Unknown (England)	Past development unit testing
Molten Media, Slagging Ash		
Kellogg Molten Salt	M. W. Kellogg Co. (USA)	Present development unit testing
Atgas/Patgas	Applied Technology Corp. (USA)	Present development unit testing
Rockgas	Atomics International (USA)	Present development unit testing
Rummel Single Shaft	Union Rheinische Braun Kohlen Kraftstoff A. G. (West Germany)	Past commercial operation
Sun Gasification	Sun Research and Development Co. (USA)	Past development unit testing
Otto-Rummel Double Shaft	Dr. C. Otto and Co.	Past development unit testing

References: 7, 8, 9, 10, 11, 12, 13

Energy Efficiency -

Gasifiers that have high energy requirements (or low [<40%] conversion efficiencies) and those with special energy features (electric plasma arc or a molten media) were not included on the list.

Process Limitations -

This criterion was used to identify the gasifiers that have limited flexibility with respect to:

- Feedstocks
- Operating conditions
- Raw material requirements

The gas producers that were developed to use charcoal or coke feedstocks, for instance, were not considered to be promising gasifiers, nor were those that have low (<100/60) turndown ratios, unstable operating characteristics, and/or unusual raw material requirements.

Environmental Impacts -

Gasifiers can be excluded from the list on the basis that they produce uncontrollable fugitive emissions or discharge streams containing hazardous constituents that cannot be controlled with existing technology. This criterion is somewhat difficult to apply at the present time, however, because of the limited information available concerning the quantities and compositions of discharge streams and fugitive emissions from gasification processes.

Costs -

This criterion should be used to identify the gasifiers that have high capital and/or operating costs, and are therefore of questionable commercial viability. Because of the limited availability of accurate cost data and the dependency of costs on site-specific factors, this criterion was not used as a basis for the selection of promising gasifiers.

Ultimately, of course, economic factors will be very significant in determining which gasifiers will be used in the United States. These factors include a) the rapidly changing energy cost/supply situation, b) proposed government incentives to switch to coal, c) the availability of currently used fuels such as natural gas and oil, d) federal, state, and local environmental regulations, and e) various site-specific factors such as the type of energy required at a specific location.

The first two economic factors, the cost/supply situation and proposed government policies are related. If the regulations on natural gas prices are eliminated, the cost of natural gas will rise. Also, if industrial use taxes on gas and oil are implemented, the cost of using these fuels will increase. In order to provide an incentive for companies to use coal as their primary fuel feedstock, various economic incentives are proposed in the National Energy Act. These incentives include investment credits for companies up to the amount of their federal income taxes. Either a dollar for dollar credit against corporate income taxes or an additional 10 to 12 percent investment credit over and above the current 10 percent credit for qualifying investments can be realized. The dollar for dollar credit is based on the amount of energy currently produced from natural gas and oil that is replaced by using coal.

The availability of natural gas and oil is another significant economic factor affecting the commercialization of low-Btu gasification. For example, last winter there were certain areas in the U.S. that had curtailments of natural gas used in industrial processes which caused companies to reduce or shut down production. These curtailments will be more widespread once natural gas supplies are further diminished. Therefore, the costs associated with a cutback in production will affect the economic viability of replacing natural gas fuel with fuels produced from coal.

The costs associated with controlling the multimedia emissions from low-Btu gasification plants will also be a significant economic factor in determining the gasification systems to be commercialized. For example, a small gasification system using anthracite coal to produce a low-Btu combustion gas will require minor pollution control technology. However, large gasification systems using high sulfur bituminous coals will have significant problems in controlling gaseous, water, and solid waste discharge streams. Therefore, small gasification plants will probably be the first to be commercialized in significant quantities.

Site-specific factors such as coal cost and availability and product gas end use will also affect the economic viability of low-Btu gasification. In areas where low sulfur coal is readily available and electricity is the primary energy need, direct coal combustion processes coupled with flue gas cleaning will probably be more economical than combusting low-Btu gas to produce electricity. However, developments in combined-cycle units may improve the economics associated with using gasification as a means for producing electrical power. Economic considerations of using coal gasification with an acid gas removal process versus direct coal-fired processes with flue gas cleaning will also affect the costs for using high sulfur coals to produce electricity.

Promising Gasifiers -

Based on the above criteria, fourteen coal gasifiers have been identified as those which appear to have the highest potential for near-term commercial application in this country. These gasifiers, which are listed in Table 3-4, can be divided into three categories based on their development status. The first group includes the gasifiers that are commercially available and are currently being widely used in the U.S. or in foreign countries. Gas producers that are commercially available but are not currently in widespread use are listed in the second group. The third group consists of the gasifiers that are either operating or being constructed for evaluation on a demonstration unit scale.

It should be emphasized that the data used to classify these gasifiers were obtained from currently available sources of information. Additions to or deletions from this prioritized list of gasifiers are anticipated as development work progresses and more data are obtained.

Detailed information pertaining to operating parameters, discharge streams, control technology requirements, and flow diagrams for each of these "most promising" gasifiers is presented in Appendix A. Also shown on the flow diagrams for these gasifiers are the discharge streams from the particulate removal,

Table 3-4. COAL GASIFIERS WITH POTENTIAL NEAR-TERM COMMERCIAL APPLICATION IN THE U.S.

Gasifier	Plant/Location[4]	Coal types tested	Part. removal	Quenching/cooling	Acid gas removal	End Use	Status
Lurgi	SASOL Salsolburg, S.A.	Bituminous	Wash cooler	Wash cooler, waste heat boilers, trim	Rectisol	Synthesis gas/fuel gas for domestic consumption	1
Wellman-Galusha	Glen-Gery Brick Co. Reading, PA	Anthracite	Hot cyclone	None	None	Fuel gas for brick kiln	1
	National Lime Co. Carey, OH	Bituminous	Hot cyclone	None	None	Fuel gas for lime kiln	1
Woodall-Duckham/ Gas Integrale	Chomutov Tube Works Czechoslovakia	Lignite	Hot cyclone/hot ESP, wash cooler	Wash cooler, trim cooler	None	Fuel gas for metallurgical process	1
Koppers-Totzek	Azot Sanayii T.A.S. Kutahya, Turkey	Lignite	WHB, wash cooler, wet cyclone	WHB, wash cooler, wet cyclone	Sulfinol/ Rectisol	Synthesis gas for ammonia production	1
Winkler	Azot Sanayii T.A.S. Kutahya, Turkey	Lignite	WHB, hot cyclone, wash cooler	WHB, wash cooler	Iron oxide, water wash, NaOH wash	Synthesis gas for ammonia production	1
Chapman (Wilputte)	U.S. Army Holston Arsenal Kingsport, TN	Bituminous	Hot cyclone	Water sprays, wash cooler	None	Fuel gas for acetic anhydride process	2
Riley Morgan	Riley Research Center Worcester, MA	Anthracite, bituminous	Hot cyclone	None	None	PDU* - product gas flared	2
Coalex	Inex Resources, Inc. Lakewood, CO	All types except liquids	None	None	Chemical additive to coal feed	Fuel gas to boiler (commercial unit under construction)	2
Pressurized Wellman-Galusha (MERC)	ERDA Morgantown Energy Research Center, Morgantown, WV	Subbituminous, bituminous	Hot cyclone	None	None	PDU* - product gas flared	3
BGC/Lurgi Slagging Gasifier	Westfield Development Centre Westfield, Scotland	Bituminous	Wash cooler	Wash cooler, WHB	Rectisol	PDU* - product gas flared, feed to methanation demonstration plant	3
GFERC Slagging Gasifier	ERDA Grand Forks Energy Research Center Grand Forks, ND	Lignite	Wash cooler	Wash cooler, trim cooler	None	PDU* - product gas flared	3
Texaco	Montebello Research Laboratory Montebello, CA	Lignite, bituminous	Water sprays, quench tank, wash cooler	Water sprays, quench tank, wash cooler	DNA	PDU* - product gas flared	3
Bi-Gas	Bituminous Coal Research, Inc. Homer City, PA	Lignite, subbituminous bituminous	Hot cyclone, wash cooler	Wash cooler	Selexol	PDU* - product gas flared	3
Foster Wheeler/ Stoic	University of Minn. Duluth, MN	Subbituminous	Hot ESP, hot cyclone	None	None	Fuel gas steam boiler	3[5]
Wellman Incandescent	York, PA	Bituminous	Hot ESP, cyclone	None	Stretford	Fuel gas	2

[1] Commercially available; significant numbers of units currently operating in the U.S. or in foreign countries.

[2] Commercially available or operating; near-term application possible.

[3] Operating or being constructed as demonstration units; technology is promising

[4] Location of largest operating plant

[5] Under contract

*Process development unit

and gas quenching/cooling processes that have been proposed for use with each gasifier.

3.2.3 Effects of Feedstock and Operating Parameter Changes

Changes in: 1) the nature of the coal feedstock, 2) operating pressure, 3) operating temperature, and 4) steam/oxygen (or steam/air) ratio can have significant effects on the performance and environmental impact of a gasifier. Changes in these parameters can affect the coal throughput rate, the thermal efficiency, and the raw gas and ash compositions. These compositions in turn are directly related to the environmental impact of a gasifier, since the discharge streams from coal feeding and ash removal devices may contain ash and raw gas components. The composition of the raw gas can also affect the requirements for downstream gas purification and pollution control processes. The significant effects of feedstock and operating parameters are summarized in the following text.

Coal Feedstock Effects -

The composition of the coal feedstock has little effect on coal throughput rate or raw gas composition in entrained-bed gasifiers. In fixed-bed and fluidized-bed gasifiers, however, an increase in the amount of volatile matter in the coal feed will tend to decrease the maximum coal throughput rate and increase the amounts of methane, tars, and oils in the raw gas (Ref. 14).

For a given coal type, the method of coal feeding will also affect the amounts of tars and oils produced in fixed- and fluidized-bed gasifiers. Gasifiers which feed coal at the top of the bed will tend to produce larger amounts of tars and oils than gasifiers which inject the coal at the center of the bed. Feeding coal to the top of the bed allows the coal to come into contact with rising hot gases before it reaches the gasification zone. This facilitates the devolatilization of tars and oils. The types and concentrations of sulfur compounds and trace elements in the coal feed will also directly affect the composition of the raw gas from all types of gasifiers.

Pressure Effects -

The operating pressure of the gasifier affects both the throughput rate and the raw gas composition. For entrained-bed gasifiers, throughput is roughly proportional to the absolute operating pressure (doubling the absolute pressure will approximately double the throughput rate). For fixed-bed and fluidized-bed gasifiers, throughput rate is roughly proportional to the square root of the absolute operating pressure. The limiting factor in fixed-bed and fluidized-bed gasifiers is the maximum gas velocity that can be achieved without excessive pressure drop or solids carryover (Refs. 15, 16).

The raw gas composition is also affected by changes in operating pressure. Increasing operating pressure favors methane and carbon dioxide formation and increases the heating value of the product gas. Carbon monoxide and hydrogen formation are suppressed at higher operating pressures (Ref. 17). High pressures also favor the formation of metal carbonyls and hydrogen cyanide which are extremely hazardous and which, if formed, may present difficult downstream removal problems.

Temperature Effects -

The gasification temperature affects the coal throughput rate, the raw gas composition, and the thermal efficiency of the gasifier. Higher gasification temperatures are usually obtained by increasing the O_2/coal feed ratio. Temperature has a pronounced effect on the coal throughput rate in fixed-bed gasifiers as the transition is made from dry ash conditions at approximately 1255°K (1800°F) to slagging ash conditions at greater than 1530°K (2300°F). A temperature increase of this magnitude has been observed to result in a fourfold increase in the maximum coal throughput rate (Ref. 18). This temperature effect can be attributed to the increased rates of the gasification reactions. At temperatures above 1530°K (2300°F), gasification reactions tend to become limited by mass transfer, and therefore further increases in temperature do not increase the maximum throughput rate appreciably (Ref. 19).

Thermal efficiency tends to decrease with increasing gasification temperature because of the increased heat content of the ash and product gas at higher temperatures. This effect is most pronounced for fixed-bed gasifiers as the transition is made from dry ash to slagging conditions. The heat carried out of the gasifier in the liquid slag is difficult to recover. On the other hand, steam consumption for this type of operation is lower, which tends to compensate somewhat for the heat lost in the liquid slag.

The composition of the raw gas is affected by changes in gasification temperature because of shifts in the equilibrium constants of the principal gasification reactions. Also, the rates of thermal cracking of tars, oils, phenols, and hydrocarbons increase as the temperature increases. For fixed- and fluidized-bed gasifiers, methane and carbon dioxide concentrations in the raw gas decrease with increasing gasification temperature while carbon monoxide and hydrogen concentrations increase. The heating value of the raw gas from these gasifiers increases slightly with increasing gasification temperature (Refs. 20, 21). The composition of the raw gas from an entrained-bed gasifier is not very sensitive to gasifier temperature changes.

Steam/Oxygen and/or Steam/Air Ratio Effects -

Changes in the ratios of reactants fed to the gasifier can affect the coal throughput rate, thermal efficiency, and raw gas composition. The coal throughput rate is affected indirectly, since lowering the steam/oxygen (or steam/air) ratio will increase the gasification temperature which will result in an increase in the coal gasification rate. Fixed-bed and fluidized-bed gasifiers that operate at temperatures below the ash fusion (slagging) temperature require excess steam to moderate the exothermic gasification reactions; therefore, the steam/oxygen (or steam/air) ratio is normally higher than that required to supply the reactants necessary for gasification.

This is important from an energy efficiency point of view. Any excess steam used for moderation purposes ultimately must be condensed and removed from the raw gas. This is a loss of useful energy and usually results in a decrease in the overall thermal efficiency of the gasification process. The hydrogen, methane, and carbon dioxide concentrations in the raw gas tend to increase with increasing steam/oxygen (or steam/air) ratios while the carbon monoxide concentration tends to decrease. Increasing this ratio may also favor the formation of H_2S over COS in the gasifier. Changing this ratio has little effect on the heating value of the raw gas.

3.2.4 Gasification Process Comparisons

In this section, the fourteen previously identified "most promising" gasifiers are compared with respect to:

- Development status
- Thermal efficiency
- Feedstock limitations
- Product gas end-use options

The development status, thermal efficiencies, and coal feedstock limitations of the fourteen priority gasifiers are summarized in Table 3-5. The most suitable end-use options for the low/medium-Btu gas produced by these gasifiers are presented in Table 3-6.

Development Status -

Seven of the gasifiers listed in Table 3-5 are considered to be commercially available. These include six gasifiers which are operating in commercial gasification plants and one gasifier, the Riley-Morgan, which has been tested in a commercial scale demonstration unit. The other seven gasifiers listed in Table 3-5 are classified as being demonstration scale units. These include six gasifiers which are operating at single unit process development plants and one gasifier, the Foster-Wheeler/Stoic, which is presently being constructed at a semi-commercial process demonstration facility.

Thermal Efficiency -

The cold gas and overall thermal efficiencies listed in Table 3-5 are defined as follows:

$$\text{Cold gas efficiency} = \frac{[\text{Product gas energy output}]}{[\text{Coal energy input}]} \times 100$$

$$\text{Overall thermal efficiency} = \frac{[\text{Total energy output (product gas + by-products + steam)}]}{[\text{Total energy input (coal + steam + electricity)}]} \times 100$$

Table 3-5. COMPARISON OF PROMISING COAL GASIFIERS

	Gasifier Type	Development Status	Cold Gas Efficiency (%)[a]	Overall Thermal Efficiency (%)[b]	Feedstock Limitations			
					Coal Size mm(in)	Maximum Coal Moisture Content (%)	Coal Caking Properties	Coal Ash Content
Wellman-Galusha	Fixed-Bed	Commercial	75	81	8-51(0.3-2.0)	NR	Requires agitator; reduces throughput	Any
Lurgi	Fixed-Bed	Commercial	63-75	76	3-38(0.1-1.5)	<35	Requires agitator; reduces throughput	Any
Woodall-Duckham/ Gas Integrale	Fixed-Bed	Commercial	77	88	6-38(0.25-1.5)	Any	Swelling index <2.5	NR
Chapman(Wilputte)	Fixed-Bed	Commercial	NR	NR	<102(<4.0)	NR	Requires agitator; reduces throughput	Any
Riley Morgan	Fixed-Bed	Commercial Scale Demo. Unit Tested	72	NR	3-51(0.1-2.0)	NR	Requires agitator; reduces throughput	Any
Pressurized Wellman-Galusha Gasifier (MERC)	Fixed-Bed	Demo. Unit Operational	79	NR	50%<13(50%<0.5)	Any	Requires agitator; reduces throughput	Any
GFERC Slagging Gasifier	Fixed-Bed	Demo. Unit Under Const.	NR	NR	6-10(0.25-0.75)	Any	Non-caking coals only	Low ash or refractory type ash may require flux

(continued)

Table 3-5. COMPARISON OF PROMISING COAL GASIFIERS (continued)

	Gasifier Type	Development Status	Cold Gas Efficiency (%)[a]	Overall Thermal Efficiency (%)[b]	Feedstock Limitations: Coal Size mm(in)	Maximum Coal Moisture Content (%)	Coal Caking Properties	Coal Ash Content
BGC/Lurgi Slagging Gasifier	Fixed-Bed	Demo. Unit Operational	NR	NR	13-51(0.5-2.0) Fines may be injected into tuyeres	<20	Requires agitator; reduces throughput	Low ash or refractory type ash may require flux
FW/Stoic Wellman-Incandesc.	Fixed-Bed	Demo. Unit Under Const.	NR	NR	NR	Any	Non-caking coals only	NR
Winkler	Fluidized-Bed	Commercial	55-72	69	<9.5(<0.4)	<30	Swelling index <4.0	Any
Koppers-Totzek	Entrained-Bed	Commercial	65-75	68	70%<0.1(70%<0.04)	2-8	All coals	>40% refactory type ash may require flux
Bi-Gas	Entrained-Bed	Demo. Unit Operational	69	65	70%<0.1(70%<0.04)	Any	All coals	Refractory type ash may require flux
Texaco	Entrained-Bed	Demo. Unit Under Const.	NR	NR	<0.1(<0.04)	Any	All coals	NR
Coalex	Entrained-Bed	Commercial Unit Under Const.	NR	88-93	<0.07(<0.003)	Any	All coals	Any

NR: Not reported

[a] Cold gas efficiency = $\frac{\text{[Product gas energy output]}}{\text{[Coal energy input]}} \times 100$

[b] Overall thermal efficiency = $\frac{\text{[Total energy output (product gas + by-products + steam)]}}{\text{[Total energy input (coal + steam + electricity)]}} \times 100$

The useful overall thermal efficiency of a gasifier may vary from the ranges given depending upon the ability of the integrated system to use the energy contained in by-product hydrocarbons and waste steam.

Table 3-6. LOW/MEDIUM-BTU GASIFICATION SYSTEM PRODUCT GAS UTILIZATION OPTIONS

Gasifier type Gasifier name	Significant operating characteristics	Utilization option for which each gasifier is best suited
Fixed-Bed (Dry Ash)		
Wellman-Galusha	Atmospheric; air or oxygen blown	On-site combustion
Lurgi	Pressurized; air or oxygen blown	Off-site combustion; combined cycle
Woodall-Duckham/ Gas Integrale	Atmospheric; air or oxygen blown	On-site combustion
Chapman (Wilputte)	Atmospheric; air or oxygen blown	On-site combustion
Riley Morgan	Atmospheric; air or oxygen blown	On-site combustion
Pressurized Wellman-Galusha (MERC)	Pressurized; air or oxygen blown	Off-site combustion; combined cycle
Foster Wheeler/Stoic	Atmospheric; air blown only	On-site combustion
Fixed-Bed (Slagging Ash)		
GFERC Slagging Gasifier	Pressurized; oxygen blown only	Off-site combustion; combined cycle
BGC/Lurgi Slagging Gasifier	Pressurized; oxygen blown only	Off-site combustion; combined cycle
Fluidized-Bed (Dry Ash)		
Winkler	Atmospheric; air or oxygen blown	On-site combustion
Entrained-Bed (Slagging Ash)		
Koppers-Totzek	Atmospheric; oxygen blown only; high CO, low CH_4 in product gas	Synthesis/reductant gas
Texaco Gasifier	Pressurized; air or oxygen blown; high CO, low CH_4 in product gas	Synthesis/reductant gas, combined cycle
Bi-Gas	Pressurized; air or oxygen blown; high CH_4 in product gas	Off-site combustion; combined cycle
Coalex	Atmospheric; air-blown; solid additive for sulfur removal	On-site combustion

Bases for selecting best utilization technology:

1) Atmospheric gasifiers are limited to on-site combustion applications.
2) Pressurized, oxygen-blown gasifiers are best suited to off-site combustion applications.
3) Pressurized gasifiers, both air- and oxygen-blown, are suitable for combined-cycle applications.
4) Product gases which are high in CO and H content, and low in CH and hydrocarbon content are suitable for use as synthesis/reductant gases.

Energy outputs are based on producing a quenched and cooled product gas at a reference temperature of 300°K (80°F).

Reported cold gas efficiencies for eight of the fourteen gasifiers listed range from 55% to 79%. Cold gas efficiencies for six of the gasifiers were not reported in available sources. The highest cold gas efficiency reported was for the Pressurized Wellman-Galusha Gasifier (MERC), while the lowest was that given for the Winkler gasifier.

Reported overall thermal efficiencies for seven of the fourteen gasifiers range from 65% to 93%. Overall efficiencies for the other seven gasifiers were not reported in available sources. The Coalex gasifier has the highest reported overall thermal efficiency (88-93%), although this range of efficiencies may be somewhat optimistic.

Feedstock Limitations -

The coal feedstock limitations summarized in Table 3-5 include:

- Size requirements
- Moisture content
- Caking properties
- Ash content

These feedstock limitations are an indication of the flexibility of each gasifier to accommodate variations in coal feedstock properties. Although a feed size requirement is not specified for the Foster Wheeler/Stoic gasifier, its size requirement is probably similar to that for the Woodall-Duckham/Gas Integrale gasifier because of their design and operating similarities.

Maximum allowable moisture content is specified for four gasifiers. Any moisture content is acceptable for seven gasifiers, and no moisture content limitations have been reported for three gasifiers.

Caking properties are not considered limiting factors in entrained-bed gasifiers. The GFERC and BGC/Lurgi Slagging Gasifiers may require the addition of flux to the coal input when a low ash content or a high percentage of refractory type ash is present in the feed coal. The Koppers-Totzek and Bi-Gas gasifiers may require the addition of flux to the coal input when gasifying coals containing high percentages of refractory type ash. Three of the gasifiers do not have reported limitations on ash content or composition.

Product Gas End-Use Options -

Of the many significant end-use options for low/medium-Btu gas, the three uses which appear to be the most reasonable bases for the future development of a low/medium-Btu gasification industry in the U.S. are:

- Combustion fuel - both on-site and off-site (pipeline) applications
- Gas turbine fuel - including combined cycles
- Synthesis/reductant gas

The selection of an optimum gasifier design for each of these end-use options involves consideration of many factors. Atmospheric gasifiers are best suited to applications which require a low pressure fuel gas (on-site combustion). Atmospheric gasifiers are not competitive in applications which require a pressurized low- or medium-Btu gas. Since a gasifier's product gas flow exceeds its feed gas (steam and air or oxygen) flow on a molar or volumetric basis, it is cheaper to compress the gasifier feed gas than the gasifier product gas whenever a pressurized product gas is needed (e.g., for feed to a pipeline for off-site consumption).

Off-site consumption requirements may also justify the use of an oxygen-blown rather than an air-blown gasifier. For on-site combustion fuel applications, the increased throughput which can be realized through the use of oxygen rather than air does not compensate for the cost of oxygen production. The reduced transportation costs associated with pipelining medium-Btu gas (relative to low-Btu gas), however, may justify the use of oxygen in a pressurized system.

In combined-cycle operations, the fuel gases are burned in a pressurized system, and the combustion products are expanded through a gas turbine which produces shaft work. The sensible heat of the combustion products is recovered by heat exchange and converted by means of a steam turbine cycle to produce additional shaft work. Combined cycles appear to be well suited to the generation of electricity. Only pressurized gasifiers are applicable to this end-use option. Either air-blown or oxygen-blown gasifiers can be used to produce a combined-cycle fuel.

Synthesis/reducing gases are used as raw materials in a variety of chemical processes. In most applications, high concentrations of hydrogen and carbon monoxide and low concentrations of methane and other hydrocarbons are desirable. Because of this composition requirement, the Koppers-Totzek and Texaco gasifiers are considered to be well suited to this end-use option.

As a result of these considerations, the end-use options can be identified for which the fourteen promising gasification systems appear to be best suited. These options are listed in Table 3-6.

3.2.5 Discharge Stream and Control Technology Summary - Coal Gasification Operation

The types of emission problems which must be dealt with in the coal gasification operation are shown schematically in Figure 3-2. From this figure, six sources of potential emissions are indicated.

- O_2 production unit,
- utility (process steam; electric power) production facilities,
- coal handling and feeding system,
- ash removal and disposal system,
- gasifier product gas start-up vent, and
- fugitive emissions

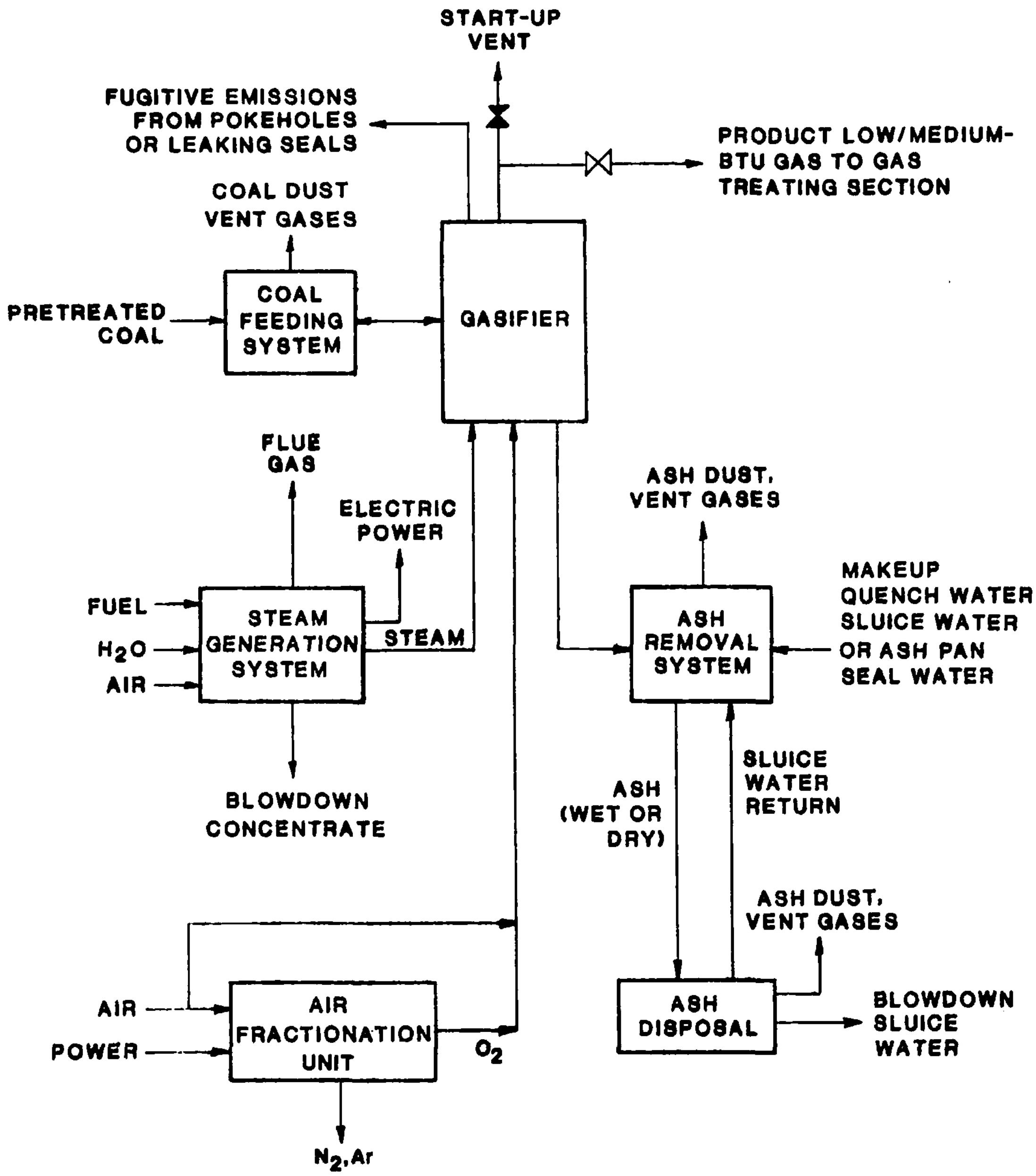


Figure 3-2. Sources of potential emissions in the coal gasification operation

Each of these environmental problem areas is discussed in the following text along with the control methods which can be used to minimize the impacts of emissions from these sources.

Oxygen Production Unit -

Current technology for generating the high purity oxygen stream needed to produce medium-Btu gas involves the use of a cryogenic air fractionation unit. In such a unit, inlet air is compressed, pre-cooled and liquefied by flash cooling and by contact with cold product gas streams. The only potential direct emissions from this processing step are the high purity nitrogen and argon streams which are produced as by-products of the liquid air fractionation step. Although these streams could be vented to the atmosphere, it is more likely that they would be used to satisfy on-site purge gas needs or sold as by-products.

Emissions which would result from this processing step are associated with the facility supplying the power needed by the air fractionation unit. These emissions are discussed in the following section.

Steam and/or Electric Power Production Facilities -

The utility needs of the gasification operation will vary considerably depending upon the nature of the gasification process which is employed. A high-pressure oxygen-blown gasification system (gasifier + O_2 production facility) will consume significant quantities of high-pressure steam and/or electric power. An atmospheric-pressure, air-blown gasifier on the other hand, generally will have relatively minor requirements for steam and electric power. In fact, the process steam requirements of all existing air-blown, atmospheric pressure gasification systems are satisfied by the vaporization of water in the gasifier cooling jacket.

If a high pressure steam boiler is used to supply the on-site utility needs of the gasification complex, the emission streams and the control needs of this unit will be identical to those of a typical utility company power plant. The composition of the flue gas emitted from the boiler will be a function of the fuel which is consumed. The best alternative environmentally would be the consumption of product low/medium-Btu gas. In this instance, the boiler flue gas would have very low particulate, sulfur oxide and nitrogen oxide concentrations. This option may not be very attractive from a process efficiency or cost point of view however, because it increases significantly the load on the gasification unit. A more desirable alternative from both an energy efficiency and cost point of view is the consumption of feed coal directly in the utility boiler. In this case, flue gas treatment to control particulate and perhaps sulfur emissions would be necessary.

The other emission streams associated with a utility boiler which would have to be handled are boiler feed water treatment wastes, boiler blowdown, and, if coal is used as the boiler fuel, bottom and fly ashes. The treatment and disposal options which are available for these streams are discussed in Section 4.0 in the liquid and solid waste control discussions, respectively.

Coal Handling and Feeding System -

This system is a major source of potential air emissions from coal gasifiers. Emissions from coal feeding systems may contain raw gasifier product gas components, coal or ash dust, and, in pressurized systems, pressurizing gas components. The rates and compositions of the vent gases from coal feeding systems will be affected by several factors. Among these are:

- the mechanical design of the device,
- gasification system operating and maintenance procedures, and
- the physical characteristics and compositions of the feed coal, raw gasifier product gas and pressurizing gas.

Coal dust - Some coal dust will always be generated as a result of transporting coal to the gasifier feed hopper. Although steps can be taken in the design of a coal handling system to minimize its dust forming tendencies, some coals are inherently more friable than others. In most systems, the use of a covered coal transportation system along with gas collection ducts and particulate removal equipment would be desirable to control these emissions.

Vent gases - The rate of vent gas release from a coal feeding device will be a function mainly of the design of the device, its mode of operation and the operating pressure of the gasifier. The composition of the vent gas will be affected by a variety of factors including:

- the operating procedures of the unit
- the composition of the raw product gas, and
- the feed system pressurizing gas, if used.

There are four general types of coal feeding devices which are in widespread use:

- Lock hoppers
- Rotary feeders
- Screw feeders
- Slurry or entrained-flow injection devices.

Lock hoppers and slurry injection devices are used to feed coal to high-pressure gasifiers while lock hoppers, rotary feeders, and screw feeders are used to feed coal to atmospheric pressure gasifiers.

Vent gases from lock hoppers and rotary feeders used on atmospheric pressure gasifiers will contain raw gasifier product gas components, unless steps are taken to insure that a continuous flow of a suitable purge or blanketing gas into the gasifier is maintained. The composition of air emissions from lock hoppers used on pressurized gasifiers will depend on the method of pressurizing the lock hopper. Various operating procedures and sources of pressurizing gas can be used: 1) Prior to dumping the coal from the lock into the gasifier, the lock may be pressurized to the gasifier operating pressure with a stream of cooled raw gas or with a vent stream from an acid gas removal or oxygen production process. 2) If the pressurizing gas is added continuously as the coal dumps into the gasifier, the gas remaining in the lock will have approximately the same composition as the pressurizing gas. 3) If no gas is added as the coal is dumped, raw gas from the gasifier will fill the void space created as the coal falls into the gasifier, and the gas remaining in the lock will be composed of pressurizing gas and raw gas from the gasifier. 4) If no pressurizing gas is used, the lock will fill with raw gas as the coal is dumped into the gasifier, and the gas remaining in the lock will be composed of raw gas. For any of these above cases, as raw gases pass countercurrently through the incoming coal and into the lock, tars, oils, water and other constituents of the raw gas may condense on the coal feed.

In addition to the components in the raw gas and the lock pressurizing gases, the vent gas from a lock hopper may also contain entrained coal dust particles. Potential vent gases from screw feeders will consist primarily of raw gas although entrained coal dust particles may also be present in this discharge stream.

An approach to coal feeding that avoids problems associated with gas leakage back through the feeder is to suspend the feed coal in either the gasifier feed gas or a water or oil slurry prior to its injection into the gasifier. Although this approach does prevent the direct leakage of raw gas back through the feed device, it does have its problems.

With the use of a liquid slurry, there is usually an efficiency penalty which results from the vaporization of the coal carrier liquid. Also, the slurry blending step may be a source of potential vent gas release, depending on the nature of makeup liquid. Gas-solid carrier systems can be difficult to control and maintain and are limited to use with fluid- or entrained-bed gasifiers.

The same collection system used to contain the coal dust generated as a result of coal transportation can also be used to collect the vent gases from a coal feeding system. Depending on the nature of the components present in the feed system vent gas, this stream could either be released after particulate cleanup or else scrubbed or incinerated prior to its release. The presence of tar aerosols would complicate the handling of this stream, since heavy hydrocarbons in the aerosols can cause a variety of fouling problems.

Ash Removal and Disposal System -

The initial requirement of this system is the removal of hot ash or slag from the gasifier and the cooling or quenching of that material, usually with water. This discussion will deal mainly with the ash handling problems of fixed- and fluid-bed gasification systems since in entrained-bed systems the ash must be separated from the product gas and this problem is discussed in connection with the gas purification operation.

The ash handling devices used by fixed- and fluid-bed gasifiers include:

- Water-sealed ash pans
- Screw conveyers
- Lock hoppers

Water-sealed ash pans and screw conveyers are best suited for atmospheric pressure gasifiers which produce a dry or agglomerated ash. Lock hoppers can be used with any dry or agglomerating ash gasifier. Quench systems are used to cool the ash or slag removed directly from the gasifier. The quench system will include a pressure let-down device when it is used with a high pressure gasifier.

Air Emissions - A problem that will be common to all gasifiers that are not slagging or agglomerating ash units will be the release of ash dust. Air emissions from water sealed ash pans and other quench systems will contain volatile materials that evaporate from the ash pan water. These volatiles may either be components which enter the system with the ash pan makeup water or they may be products of reactions between the ash pan water and the hot gasifier ash. The composition of the gasifier ash will obviously have a significant affect upon the quantities and compositions of the volatile materials released by this mechanism. Very little volatile material should be derived from the quenched ash leaving a fixed-bed gasifier. There is a greater potential for the release of hydrocarbons from the ash leaving a fluid-bed gasifier because this material is more "char-like" than the more completely oxidized residue of a fixed-bed gasification process.

The composition of air emissions from lock hoppers will be dependent on its mode of operation. For atmospheric pressure gasifiers which discharge a dry, unquenched ash, the air emissions will consist of steam and air (or oxygen), and ash particles. If the ash is quenched prior to discharge from the lock hopper, products of reactions between the quench water and the hot gasifier ash may be present in the air emissions. Fixed-bed, slagging ash gasifiers use a slag retaining burner and a slag drawdown quench vessel. Air emissions from these systems would most likely be limited to the volatile materials present in the quench water. Control technologies that are applicable to the control of air emissions from ash handling systems are similar to those which can be employed to control coal feeding system emissions. Containment and collection of particulate-laden air followed by processing in a suitable particulate control process will be needed with dry ash systems where ash dust emissions are a problem. The control of hydrocarbon emissions from these systems can involve:

- the use of quench or sluicing system makeup water that does not contain hazardous materials that are or will form volatile components upon contact with hot gasifier ash, and/or

- the collection and treatment or incineration of hydrocarbon-laden vapors which are released as a result of the quenching step.

Because of the considerable potential expense associated with the second of the above options, the first alternative is preferable.

Liquid effluents - An ash quenching and/or sluicing system, if used, is a major source of potential liquid effluents from the coal gasification operation. Ash removal devices which discharge a dry, unquenched ash do not produce liquid effluents. The liquid effluents produced by ash quenching sluicing systems will contain varying amounts of suspended ash or slag particles, and soluble components leached from the ash as well as components initially present in the quench water makeup. Candidate treatment methods for this liquid effluent stream are discussed in Section 4.2.

Solid Wastes - All ash removal devices are sources of solid wastes since the mineral matter in the gasifier ash or slag is a solid waste. In addition to the mineral matter from the feed coal, coal feed additives and unreacted coal may also be present in this solid waste stream. Components present in the quench water input may also be present in the ash or slag. The ultimate composition of the waste ash or slag will depend upon the gasifier type, its operating conditions, the coal feedstock and additive compositions, and the makeup quench water composition.

Options for disposing of the ash will be determined primarily by its chemical stability. These options are discussed in detail in Section 4.3 that deals with solid waste treatment and disposal methods.

Gasifier Start-up Vent -

When a gasifier is brought on-line from a "cold start" position, a considerable period of time is required to bring the gasifier up to its required operating temperature. In a commercial-scale unit, this period of time usually ranges from 6 to 12 hours.

In most commercial installations, it is not possible to utilize the low grade product gas which is produced during the start-up period. For this reason, a suitable method of disposing of this gas stream must be found.

In most systems, the flow of this stream will vary from almost zero initially to about 50% of the design gas flow of the producer. Its temperature will increase steadily. Its composition will be similar to that of a combustion gas initially but it will begin to assume low-Btu gas properties more and more as the producer is brought up in temperature.

Because of the magnitude of this stream, it must be considered to be one of the major potential sources of air emissions from a coal gasification unit, even though it is produced only on an infrequent basis. Current plans for most new low-Btu gasification units call for the collection and incineration (flaring) of this stream. One of the problems which must be considered in this step is the problem of tar condensation in the flare line. In order to avoid problems of this nature, some gasification unit operators use charcoal or coal char as a start-up fuel and only start feeding coal to the system after the system is hot and the gasifier product gas has been routed to the gas treating section.

Fugitive Emissions -

The whole area of fugitive emissions from coal gasification systems is one which has received very little attention. Because of the hazardous nature of many of the components in the raw product gas from a coal gasifier, and from an operator safety point of view, it is recognized that it will be necessary to take all reasonable steps to minimize these emissions. At the same time, however, no meaningful documentation of the severity of this problem has been reported in the literature. Clearly, it is inevitable that some inadvertent release of hazardous materials from the gasification operation will occur. Knowledge as to the levels to which these emissions can be controlled with current technology is a significant gap in the existing gasification system environmental data base.

One very likely source of product gas leakage from these systems is represented by the pokeholes which are found in the air-blown, atmospheric pressure, fixed-bed gasifiers which are in current use in several industrial facilities in this country. These pokeholes serve several functions. They allow the gasifier operator to make visual inspections of the gasifier coal bed in the event that an operating problem is suspected. The pokeholes are also used as access ports for probing the beds with metal rods and steam lances. The former is used to monitor the position of the combustion zone in the bed while either device may be used to knock clinkers off the wall of the gasifier. Using pokeholes as a mechanism for monitoring the performance of a gasifier is one area where improvements in gasifier monitoring instrumentation might be justified on an environmental basis.

Another aspect of the fugitive emission problem which has not been studied is the effect of pressurized operation. It is reasonable to expect that fugitive leaks from a pressurized system would exceed those of a well designed, atmospheric pressure system. The magnitude of this difference is hard to estimate.

3.2.6 Environmentally Significant Trends in Gasification Process Development Activities

The areas in which gasification process development work is currently being concentrated include:

- improving process efficiencies,
- improving throughput rates,
- improving feedstock flexibility, and
- improving the performance of coal feeding and ash removal devices.

Except for this last category, very little research effort is being directed toward problems which will affect the environmental acceptability of gasification processes directly. However, much of the work in other areas will yield useful information about how the compositions of coal gasifier product gas vary as functions of feedstock type and gasifier operating conditions. Since process and effluent stream characterization is one of the most significant current environmental assessment data needs, research efforts in all of these areas need to be monitored.

3.3 GAS PURIFICATION OPERATION

The purpose of the gas purification operation is to remove undesirable constituents such as particulates, tars, oils, and acid gases from the raw product gas. The performance specifications for the modules in this operation are defined by the intended end use of the product gas. Product gas specifications with respect to particulates and H_2S for each end use are summarized in Table 3-7. Typical particulate and H_2S ranges for the inlet gas stream are also shown in the table. The modules needed to satisfy these cleanup requirements are illustrated in Figure 3-3. These modules include:

- particulate removal,
- gas quenching and cooling, and
- acid gas removal.

Table 3-7. PRODUCT GAS SPECIFICATIONS FOR THE VARIOUS END USES FOR LOW/MEDIUM-BTU GAS

Product Gas End Use	Typical Raw Gas Composition		Product Gas Specifications		Comments
	Particulates	H_2S	Particulates	H_2S	
Direct Combustion	0.002-0.7 Kg/Nm³ (1-300 gr/scf)	0.2-1.5 Vol%	[1]Low enough to comply with NSPS for combustion stack gas.	[2]Low enough to comply with NSPS for combustion stack gas.	
Gas Turbine	0.002-0.7 Kg/Nm³ (1-300 gr/scf)	0.2-1.5 Vol%	Size / Concentration <2μm: <2.0×10^{-5} Kg/Nm³ (<0.01 gr/scf) >2μm: 2.0×10^{-7} Kg/Nm³ (0.0001 gr/scf) >10μm: None	Equivalent to less than 100 ppmv total sulfur	Total alkali metals less than 0.040 ppm
Chemical Synthesis or Reducing Gas	0.002-0.7 Kg/Nm³ (1-300 gr/scf)	0.2-1.5 Vol%	Essentially particulate free	Essentially sulfur free (<4 ppmv H_2S)	Requirements for other components, i.e. NH_3, will depend upon individual processes and products

NSPS = New Source Performance Standards

[1]NSPS for particulate emissions vary, depending on the type and size of combustion equipment. NSPS specify the allowable mass of particulate emissions per unit of heat input; e.g., 0.043 g/M Joule (0.1 lb/10^6 Btu) for combustion of greater than 7.33 M Joule/s (25 x 10^6 Btu/hr). Therefore, product gas specifications for particulates must be determined on a site-specific basis. The acceptable product gas particulate loading may be higher than the NSPS equivalent, depending on the amount of combustible particulate matter that can be consumed in the firebox.

[2]At the present time, there is no NSPS for direct combustion of gaseous fuels. However, permissible sulfur emissions from combustion of low-Btu gas are often compared to the NSPS for combusting coal. This NSPS specifies the allowable mass of sulfur dioxide emissions per unit of heat input; e.g., 0.52 g/M Joule (1.2 lb/10^6 Btu) for combustion of greater than 7.33 M Joule/s (25 x 10^6 Btu/hr).

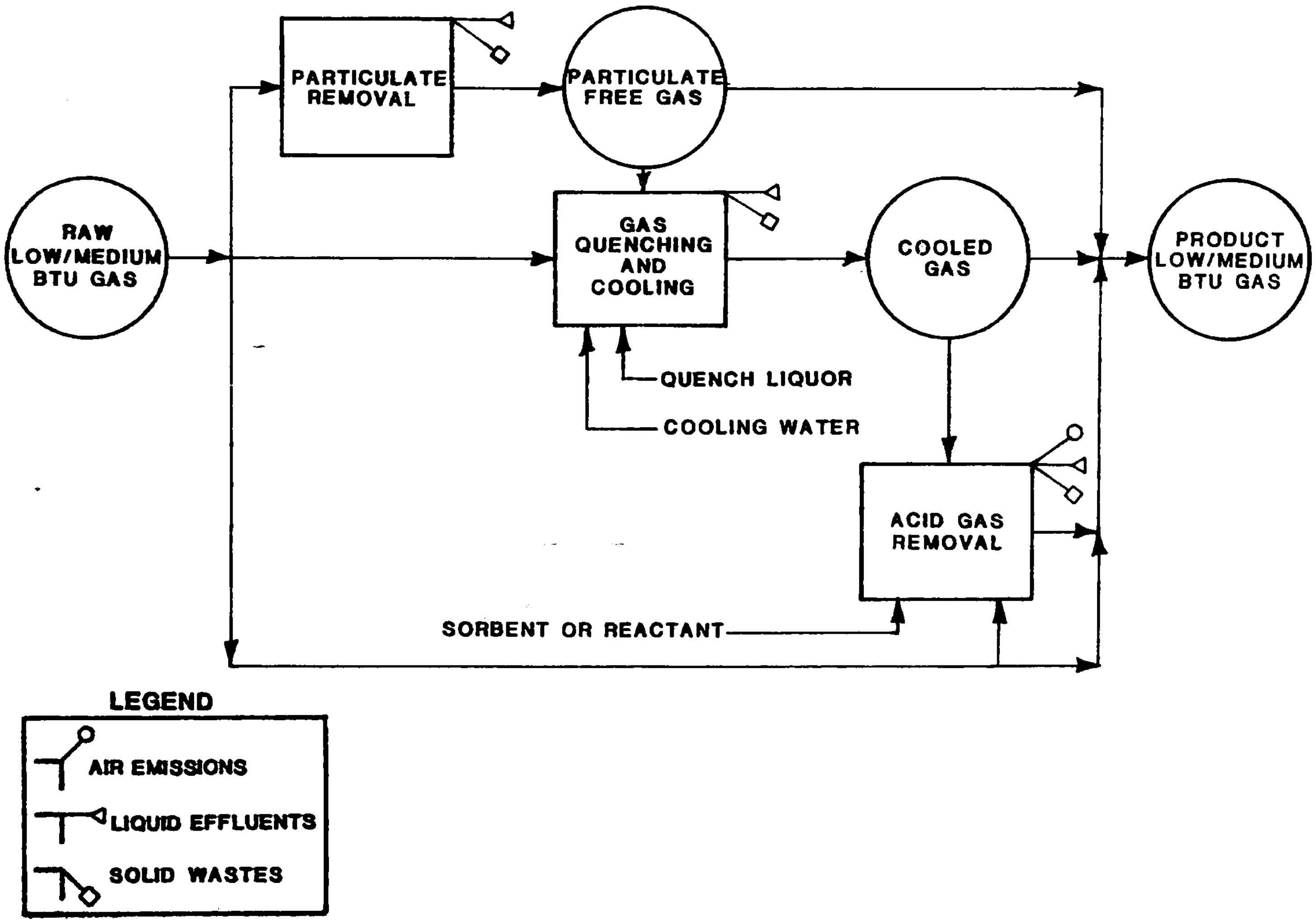


Figure 3-3. Flow diagram for the modules in the gas purification operation

In this section, each of these modules and their potential emission streams are discussed, although major emphasis is placed on the acid gas removal module. The processes within each module which appear to have a reasonable chance of eventual commercial application are identified. These processes are then compared with respect to development status, contaminant removal effectiveness, operating characteristics, raw material and utility requirements, and process limitations in cases where it appears that there are a number of technically feasible process options.

3.3.1 Particulate Removal Module

Removal of coal dust, ash and tar aerosols entrained in the raw product gas leaving the gasifier is the primary function of this module. Specific processes commonly used to accomplish this are:

- cyclones,
- electrostatic precipitators (ESP), and
- water or oil scrubbers

As shown in Table 3-4, cyclones are used as an initial cleanup step on all of the commercial gasifiers which are currently operating in this country. This popularity of cyclones stems from the fact that they are relatively inexpensive, low energy consuming devices. Unfortunately, they are effective in removing only the larger particulates; other techniques are necessary to achieve efficient removal of small particulates. For example, cyclone collection efficiencies for removing 10 μm particles from a 1100°C (2000°F) gas stream have been reported to be 90%, while the efficiency for removing 1 μm particles is only about 40% (Ref. 22).

Extremely small particulates (1 μm or less) can be removed from the raw gas stream only by using more costly and more energy intensive devices such as electrostatic precipitators and/or wet scrubbers (which also serve to quench and cool the product gas). Collection efficiencies of over 99.9% have been reported in removing particulates from a raw gas produced by a Koppers-Totzek gasifier using an ESP/wet scrubber in combination (Ref. 23).

When extensive cooling of the raw gas is not necessary because of acid gas removal process temperature constraints, it is not particularly useful to use wet scrubbers. For example, an end use involving the direct combustion of the gas may not require sulfur removal to meet sulfur emission requirements. Since the use of a wet scrubber lowers the temperature of the raw gas stream, the overall process thermal efficiency is reduced. In the final analysis, the increased cost of obtaining additional particulate removal at this point must be balanced against operating cost savings which result from decreased particulate loadings in subsequent process steps.

A summary of gas purification equipment used in a variety of commercial and demonstration coal gasification plants is shown in Table 3-4. This table gives some indication of how the types of gas purification equipment used are dictated by the end use of the product gas and by the gasifier and feed coal type. For example, fuel gas produced by gasification of anthracite coal usually requires only particulate removal because of the low sulfur content of this fuel and the negligible quantities of tars produced. The gasification of bituminous coal or lignite produces more tars and usually more sulfur compounds than does the gasification of anthracite. The need to remove these compounds, and the extent to which they must be removed, is again dictated by the end use; fuels used in direct combustion may require only limited particulate removal while those used as synthesis gases must be further purified.

All particulate removal processes produce a solid waste consisting mainly of the collected particulates (unreacted coal fines and ash). Liquid effluents are also produced in the case of wet scrubbers in the form of blowdown liquids and other materials condensed or scrubbed from the raw gas. These liquids will require considerable treatment to remove dissolved and suspended organics and inorganics prior to their disposal or reuse. The composition and quantities of these liquids will depend upon the nature of the raw gas and the scrubbing process employed.

3.3.2 Gas Quenching and Cooling Module

In the gas quenching and cooling module, tars and oils are condensed and particulates and other impurities such as ammonia are scrubbed from the raw product gas. Quenching involves the direct contact of the hot raw gas with an aqueous or an organic quench liquor. Extensive cooling of the gas stream occurs initially, primarily through vaporization of the quenching medium. Further gas cooling can be accomplished using waste heat boilers followed by air- and/or water-cooled heat exchangers.

The choice of gas quenching and cooling processes to be used depends upon the nature of the hot raw gas and whether or not an acid gas removal process will be needed. Waste heat recovery is always desirable but fouling problems due to tar and oil condensation in the waste heat boiler must be considered. In addition, it may be necessary to remove tar and oil constituents from the gas prior to treatment in an acid gas removal process to prevent contamination of the solvent. The amount of cooling required is dictated by the acid gas removal process temperature constraints.

The gas quenching and cooling module is a source of liquid effluents and solid wastes. The liquid effluents consist of the quench liquor and the tars and oils condensed in the quenching process. The composition and amounts of these tars and oils depends on gasifier process considerations (coal type, pressure, temperature, etc.) and the nature of the quenching medium (i.e., water or light oil). The amount of condensate produced is directly affected by the temperature to which the gas is cooled. This liquid effluent stream, typically referred to as a tarry gas liquor, requires extensive treatment prior to reuse or disposal.

The solid wastes generated in the quenching and cooling module primarily consist of coal dust and ash suspended in the liquid effluents. Treatment, reuse and disposal options for the liquid effluents produced as a result of product gas cooling processes are discussed in Section 4.2.

3.3.3 Acid Gas Removal Module

Acid gases such as H_2S, COS, CS_2, mercaptans, and CO_2 are removed from the raw product gas in the module. Processes used for acid gas removal may remove both sulfur compounds and CO_2 or they may be operated selectively to remove only the sulfur compounds in cases where carbon dioxide removal is not required to meet product gas specifications. For example, it would not be desirable to remove CO_2 from a pressurized, combined-cycle feed gas.

There are two reasons for removing sulfur compounds from low/medium-Btu gases. One is to meet the emission regulations for a utilization process such as direct combustion. The other is to meet product gas specifications which are dictated by the end use of the gas. In this section the acid gas removal processes which appear to be best suited to low/medium-Btu gas cleanup needs are identified and compared.

The processes used for acid gas removal may be divided into two general categories:

- High-temperature processes requiring minimal cooling of the feed gas before treatment; and

- Low-temperature processes requiring extensive cooling of the feed gas before treatment.

Each of these general categories is discussed below. Major emphasis is placed on low temperature processes because the high temperature processes mentioned are still generally in early stages of development.

High-Temperature Processes -

Presently, there are no commercially available processes for removing acid gases from raw low-Btu gas at high temperatures (>420°K, 300°F). Processes currently under development involve the use of molten salts, molten metals, iron oxide, and dolomite as hot sorbents. The specific developers of these processes are:

- Bureau of Mines (Iron Oxide)
- Babcock and Wilcox (Iron Oxide)
- Conoco (Dolomite)
- Air Products (Dolomite)
- Battelle Northwest (Molten Carbonate)
- IGT-Meissner (Molten Metal)

High temperature acid gas removal, if feasible, would have several advantages over existing low temperature processes. The most significant of these is the higher overall thermal efficiency which would result from the retention of the raw gas sensible heat. Another potential advantage is the improvement of gas heating value due to the reduced condensation of combustible mid-boiling range hydrocarbons. Cooling equipment fouling by tars and oils may also be minimized or eliminated.

Due to these advantages of high temperature cleanup, much research and development effort in the acid gas removal area has been aimed at developing high temperature processes. These high temperature processes will probably be tested initially in second generation combined-cycle power generation systems.

Low-Temperature Processes -

For purposes of this discussion, acid gas cleanup processes that operate below 420°K (300°F) are defined as low-temperature processes. Processes of this type are widely available, having been used in both the natural gas and chemical process industries. The low-temperature processes considered here can be further divided into the following categories:

- Physical Solvent Processes
- Chemical Solvent Processes
- Combination Chemical/Physical Solvent Processes
- Direct Conversion Processes
- Catalytic Conversion Processes
- Fixed-bed Adsorption Processes

Table 3-8 presents the total population and development status of the low-temperature acid gas removal processes which were identified from available information. The following text presents a brief description of the processes in the six categories listed above.

Table 3-8. LOW-TEMPERATURE ACID GAS REMOVAL PROCESSES

Process Category	Process Name and Status*
Physical Solvent	Selexol [a]
	Fluor solvent [a]
	Purisol [a]
	Rectisol [a]
	Estasolvan [a]
	Union Oil [b]
Chemical Solvent	
- Amine Solvent	Monoethanolamine (MEA) [a]
	Diethanolamine (DEA) [a]
	Triethanolamine (TEA) [a]
	Methyldiethanolamine (MDEA) [a]
	Glycol-amine [a]
	Diisopropanolamine (DIPA) [a]
	Diglycolamine (DGA) [a]
- Alkaline Salt Solution	Caustic Wash [a]
	Seaboard [c]
	Vacuum Carbonate [c]
	Hot Potassium Carbonate [a]
	Catacarb [a]
	Tripotassium Phosphate [c]
	Benfield [a]
	Alkazid [a]
	Sodium Phenolate [c]
	Lucas [a]

Continued

*[a] Commercially Available
[b] Under Development
[c] Obsolete/Inactive
[d] Pilot Plant

Table 3-8. Continued

Process Category	Process Name and Status*
- Ammonia Solution	Chemo Trenn [a]
	Collins [a]
<u>Combination Chemical/Physical Solvent</u>	Amisol [a]
	Sulfinol [a]
<u>Direct Conversion</u>	
- Dry Oxidation	Iron Oxide (Dry Box) [a]
	Activated Carbon [a]
	Claus [a]
	Great Lakes Carbon Co. [b]
- Liquid Oxidation	Burkheiser [c]
	Ferrox [c]
	Konox [b]
	Gludd [c]
	Manchester [c]
	Cataban [d]
	Thylox [c]
	Giammarco-Vetrocoke [a]
	Fischer [a]
	Staatsmijnen-Otto/ Autopurification [a]
	Perox [c]
	Stretford [a]
	Takahax [a]
	CAS [d]

Continued

* [a] Commercially Available
[b] Under Development
[c] Obsolete/Inactive
[d] Pilot Plant

Table 3-8. Continued

Process Category	Process Name and Status*
- Liquid Oxidation (Cont.)	Townsend [d]
	Wiewiorowski [d]
	Sulfonly [d]
	Nalco [d]
	Sulphoxide [d]
	Permanganate and Dichromate [a]
	Lacey-Keller [d]
	Sulfox [d]
	Direct Oxidation [a]
Catalytic Conversion	
- Organic Sulfur to H_2S	Carpenter Evans [a]
	Peoples Gas Co. [a]
	Holmes-Maxted [a]
	British Gas Council [d]
	Iron Oxide Catalysts [a]
	Chromia-Aluminum Catalysts [d]
	Copper-Chromium-Vanadium Oxide Catalysts [d]
	Cobalt Molybdenum Catalysts [a]
- Organic Sulfur to H_2S and SO_2	Appleby-Frodingham [a]
	Katasulf [a]
	North Thames Gas Board [a]
	Soda Iron [a]

Continued

* [a] Commercially Available
[b] Under Development
[c] Obsolete/Inactive
[d] Pilot Plant

Table 3-8. Continued

Process Category	Process Name and Status*
<u>Fixed-Bed Adsorption</u>	Activated Carbon [a] Haines [d] Molecular Sieve [a] Zinc Oxide [a]

* [a] Commercially Available
[b] Under Development
[c] Obsolete/Inactive
[d] Pilot Plant

References: 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42

Physical Solvent Processes - remove acid gases from the raw product gas by physical absorption in an organic solvent. These processes must operate at high pressures since the solubilities of acid gases in the solvents are not sufficiently high at low pressures. Most of the solvents used in these processes have an appreciably higher affinity for H_2S than for CO_2, and can therefore be used in a manner that allows for selective removal of H_2S.

Chemical Solvent Processes - remove acid gases by forming chemical complexes. In most of these processes the solvent is regenerated by thermal decomposition of the chemical complex. These processes are generally identified by the type of solvent used. Amine, ammonia, and alkaline salt solutions are the three solvents in common use.

Combination Chemical/Physical Solvent Processes - use a physical solvent together with an alkanolamine chemical solvent additive. The physical solvent absorbs acid gases such as CS_2, mercaptans, and COS, which are not easily removed by chemical solvents, while the chemical solvent removes the bulk of the CO_2, H_2S, and HCN.

Direct Conversion Processes - produce elemental sulfur from H_2S by oxidation. Some of these processes, such as the Claus and Stretford processes, are not classified as acid gas removal processes in this report; however, they could be used as such. These direct conversion processes are divided into two general categories; dry oxidation and liquid phase oxidation.

Catalytic Conversion Processes - are divided into two categories: a) those that convert organic sulfur to H_2S, and b) those that convert organic sulfur and H_2S to SO_2. Most of these processes are generally not considered to be acid gas removal processes; however, they can be used to convert hard-to-remove acid gases such as COS, CS_2, and mercaptans into compounds such as H_2S and SO_2, which can then be handled by other acid gas removal processes.

Fixed-Bed Adsorption Processes - remove acid gases by adsorption on a fixed sorbent bed. The amount of acid gases removed is dependent on the surface area available for adsorption. Regeneration of the sorbent is accomplished by thermal methods or by chemical reaction.

Low-Temperature Process Prioritization -

The low-temperature acid gas removal processes presented in Table 3-8 were screened to identify those processes which have the highest probabilities of near-term application in low/medium-Btu gasification systems. The following criteria were used as bases to identify these processes.

- Applicability to low/medium-Btu gasification
- Development status
- Environmental impacts
- Energy requirements
- Costs
- Process limitations

In the following text a discussion of how these criteria were applied to the low-temperature acid gas removal processes is presented.

Applicability to low/medium-Btu gasification - This criterion was used to eliminate those processes which are not capable of reducing acid gas concentrations to levels which will meet specific end use product gas specifications and to determine which processes have operated successfully in coal gasification systems. At present, only two processes, Rectisol and Benfield, have been used in commercial coal gasification processes. However, many other processes have been successfully operated in the natural gas and refinery industries and should be technically acceptable for removing acid gases from coal gasification product gas.

Development status - This criterion was used to determine whether a process is under development, commercially available, or in declining use. Only those processes which are currently commercially available were given detailed consideration.

Environmental impacts - This criterion involved characterizing the discharge streams from each process and investigating potential control technologies for the hazardous constituents in those streams. There are commercially available techniques for controlling all of the discharge streams from the processes which appear to be applicable to low/medium-Btu gasification process cleanup needs.

Energy requirements - Processes that require excessive amounts of energy or special utilities were eliminated from further consideration for purposes of this analysis.

Costs - Costs were not used specifically as a basis for the elimination of any acid gas removal processes, however, it was assumed that commercially available processes are generally competitive with respect to capital and operating costs.

Process limitations - Process limitations with respect to unusual raw materials requirements, sensitivity to variations in feedstocks and operating parameters, and ability to achieve required product gas specifications are important considerations in the selection of a process. These limitations can take several forms including unfavorable economics and actual process operating problems. For example, certain compounds which may be present in the raw gas feed can be the cause of solvent degradation problems. This is both an economic and operating problem because of the cost of replacing the solvent and because the degradation products may adversely affect the process performance. Another example of an operating parameter limitation is the high acid gas partial pressure required for economical operation of physical solvent type processes.

Promising processes - Using the criteria described above, the following were identified to be the processes which appear to have the greatest likelihood of near-term commercial application:

- Physical Solvent Processes
  - Rectisol
  - Selexol
  - Purisol
  - Estasolvan
  - Fluor Solvent

- Chemical Solvent Processes
  - MEA
  - MDEA
  - DEA
  - DIPA
  - DGA
  - Benfield

- Combination Chemical/Physical Solvent Processes
  - Amisol
  - Sulfinol

- Direct Conversion Process
  - Stretford

A detailed discussion of the Stretford, Claus and other prioritized sulfur emission control processes is presented in Section 4.1.2. It should be emphasized that the acid gas removal processes listed above were selected using currently available data. Additions to or deletions from this list are likely as new information is obtained.

Low-Temperature Process Comparison -

In this section, the acid gas removal processes just discussed are compared on the basis of their similarities, advantages, and limitations. Important considerations in this comparison include feed gas composition, operating conditions, and ability to meet required product gas specifications. The primary acid gas removal processes are compared in Table 3-9 with respect to:

- Control effectiveness,
- Ability to be operated selectively (removal of H_2S),
- Utility requirements,
- Discharge streams requiring further control,
- By-products, and
- Process limitations.

Table 3-9. COMPARISON OF LOW TEMPERATURE ACID GAS REMOVAL PROCESSES

	Chemical Solvent Processes					
	MEA	MDEA	DEA	DIPA	DGA	Benfield
Control Effectiveness						
• H_2S	99.9+%	99.9+%	99.9+%	99.9+%	99.9+%	99.9+%
• CO_2	99+%	99+%	95+%	DNA	99+%	99.9+%
• COS/CS_2	D	DNA	90-99%	DNA	D	75-99%
• R-SH	D	DNA	DNA	DNA	D	68-92%
• HCN	DNA	DNA	DNA	DNA	D	99+%
• NH_3	DNA	DNA	DNA	DNA	DNA	DNA
Capable of Being Operated Selectively (to remove H_2S without CO_2	DNA	yes	DNA	yes	DNA	yes
Operating Requirements						
• Steam	✓	✓	✓	✓	✓	✓
• Electricity	✓	✓	✓	✓	✓	✓
• Cooling Water	✓	✓	✓	✓	✓	✓
• Fuel Gas						
• Chemicals						✓
Discharge Streams Requiring Further Control						
• Gaseous	✓	✓	✓	✓	✓	✓
• Aqueous	✓	NR	NR	NR	✓	✓
• Solid	NR	NR	NR	NR	NR	NR
By-Products	NR	NR	NR	NR	NR	NR
Process Limitations	Organic sulfur compounds degrade solvent	Corrosion problems greater than MEA	Corrosion problems greater than MEA		Organic sulfur compounds degrade solvent	

(continued)

Table 3-9. COMPARISON OF LOW TEMPERATURE ACID GAS REMOVAL PROCESSES (continued)

	Physical solvent processes					Combination processes	
	Rectisol	Selexol	Purisol	Estasolvan	Fluor solvent	Sulfinol	Amisol
Control Effectiveness							
• H_2S	99.9+%	99.9+%	99.9+%	99.9+%	99.9+%	99.9+%	99.9+%
• CO_2	99.9+%	99.9+%	99.9+%	99.9+%	99.9+%	99+%	99+%
• COS/CS_2	99.9+%	99.9+%	99+%	98+%	DNA	90+%	99+%
• R-SH	99.9+%	99.9+%	DNA	97+%	DNA	90+%	DNA
• HCN	DNA	DNA	DNA	DNA	DNA	DNA	DNA
• NH_3	DNA	DNA	DNA	DNA	DNA	DNA	DNA
Capable of Being Operated Selectively (to remove H_2S without CO_2	yes	yes	yes	yes	yes	yes	DNA
Operating Requirements							
• Steam	✓	✓	✓	✓	✓	✓	✓
• Electricity	✓	✓	✓	✓	✓	✓	✓
• Cooling Water	✓	✓	✓	✓	✓	✓	✓
• Fuel Gas	✓	✓	✓	✓	✓		
• Chemicals	✓	✓	✓	✓	✓		
Discharge Streams Requiring Further Control							
• Gaseous	✓	✓	✓	✓	✓	✓	✓
• Aqueous	✓	NR	✓	NR	NR	NR	NR
• Solid	NR	NR	NR	NR	NR	NR	NR
By-Products	Naphtha	NR	NR	NR	NR	NR	NR
Process Limitations	Low temp. required to limit solvent losses; retains heavy hydrocarbons, high pressure	Retains heavy hydrocarbons, high pressure	Retains heavy hydrocarbons, high pressure	Retains heavy hydrocarbons, high pressure	Retains heavy hydrocarbons, high pressure	Solvent is expensive	

NR - none reported
DNA - data not available
D - solvent degrades forming nonregenerable compounds
✓ - indicates presence of a utility requirement or discharge stream

The following text summarizes the major conclusions derived from the information presented in this table.

Control effectiveness - The control effectiveness is reported in Table 3-9 as the percentage removal of an input species that can be obtained by the process. In some cases a compound may be removed but in a nonregenerable manner. This is indicated in the table by the symbol (D) indicating solvent degradation. An example of this is the removal of COS, CS_2, and R-SH with the MEA process. All of the processes can meet the most stringent H_2S product gas specification of 4 ppmv or less and most can meet a CO_2 specification of less than 1.0 vol. %.

Selective H_2S removal - The need for selective removal of H_2S depends on the end use of the cleaned, desulfurized gas. Most product gas utilization options require extensive desulfurization of the raw gas. If the gas is to be used for combined cycle power generation, the removal of CO_2 is not desirable since it would reduce the amount of useful work which would be recovered in the gas turbine section. For simple combustion applications, removal of CO_2 will increase the heating value of the gas. However, this advantage must be weighed against the added cost of removing the CO_2.

Utility requirements - The entries in this section of the table are intended to show how the processes compare with respect to utility requirements. This is important in process selection as some utilities may not be readily available at all sites. The presence of a check (✓) indicates the types of utility required by the processes. These utility requirements have not been quantified at this point.

Discharge streams requiring further control - The purpose of this section is to indicate the types of discharge streams, gaseous, aqueous, or solid produced by each process which require further control prior to disposal. All of these processes produce gas streams which must be treated further to remove H_2S and other sulfur compounds before the streams may be discharged to the atmosphere. While most of the processes do not report an aqueous effluent stream, all require periodic solvent blowdown to prevent buildup of contaminants and solvent degradation products. Some of the processes, such as Rectisol and Purisol do produce a condensate or blowdown stream which will require further treatment prior to disposal. Solid wastes removed from these processes would include coal fines and ash entrained in the process gas feed and solvent degradation products. These wastes will be contained in the solvent blowdown stream.

By-products - In this entry, by-products from the acid gas removal processes are shown. While only one process, Rectisol, is known to produce a naphtha by-product, many of the other processes should produce similar by-products when used in coal gasification systems.

Process limitations - In this section, major process limitations specific to each process are briefly listed. In some cases these limitations may be serious enough to eliminate the process from consideration for a particular application. For example, if the gas to be treated contains large amounts of organic sulfur compounds (>150 ppmv), serious consideration must be given to the economics and potential operating problems which may occur if the MEA process is selected. In other cases, the limitation may present a problem which is not serious enough to eliminate a process. For example, the corrosion problems which have been experienced with the DEA and other processes may be eliminated by a careful selection of materials of construction.

Another limitation which affects acid gas removal process selection is the pressure of the cooled gas stream. Low pressures, less than 1.7 MPa (250 psia), eliminate physical solvent processes from prime consideration since they require significant acid gas partial pressures to be economical. At pressures greater than 1.7 MPa, all of the processes can be used successfully but the physical solvent processes become more economical at high pressures.

3.3.4 Discharge Stream and Control Technology Summary - Gas Purification Operation

Air Emissions -

The modules in the gas purification operation are sources of hazardous air, water, and solid waste emission streams. The air emissions from the acid gas removal module may contain CO_2, H_2S, COS, mercaptans, NH_3, hydrocarbons, and other toxic constituents. These emissions require treatment before being vented to the atmosphere. Treatment methods for these pollutants, primarily hydrocarbon control and sulfur control processes, are commercially available and are discussed further in the Air Pollution Control Section.

Liquid Effluents -

Liquid effluents from this operation may contain a variety of pollutants such as tars, oils, phenols, dissolved acid gases and hydrocarbons, and trace elements. These effluents will therefore require treatment prior to reuse or disposal. The composition of these liquid effluents will depend upon the nature of the raw gas from the gasifier, the method of raw gas cooling used, and the specific acid gas removal process employed. All of the acid gas removal processes mentioned here, except for the Benfield process, use some type of organic solvent which will be present to some extent in these streams. In addition, solvent degradation products will be present which may be difficult to treat with currently available water pollution control processes. The Benfield process uses an inorganic potassium carbonate solvent which will be present to some extent in the blowdown stream from this process. Treatment of this stream using processes currently available should present minimal problems. Processes available to treat these effluents are discussed in the Water Pollution Control Section.

Solid Wastes -

Solid wastes are generated by all of the modules in this operation. These solid wastes are composed primarily of unreacted coal fines and ash entrained in the raw product gas. These solids may be collected dry by cyclones or electrostatic precipitators or they may be collected wet in the quenching and acid gas removal process. In the case of wet collection, the solids may be suspended in the quench liquor and/or the acid gas removal process solvent. These solid wastes may be a usable by-product or they may require ultimate disposal which is discussed in the Solid Waste Pollution Control Section.

In addition to the solid wastes discussed above, some of the solvent degradation products may exist in solid form. These contaminants will be removed in the solvent blowdown stream. Proper treatment of these compounds may represent a significant research and development need since they may not be compatible with existing wastewater treatment processes.

SECTION 4.0
POLLUTION CONTROL MODULES

Air emissions, liquid effluents, and solid wastes from the process operations described in Section 3.0 will require pollution control modules. The function of these modules is to achieve levels of control that are consistent with environmentally acceptable plant practices.

Air pollutants from low-Btu gasification processes are primarily coal dust, coal feeder vent gases, combustion gases, process tail gases and tank vents. These streams are processed in various combinations of control modules to achieve particulate control, sulfur control and recovery, hydrocarbon control and nitrogen oxides control. These modules and their use are described in Section 4.1.

Water pollution control includes treating modules designed to separate oils from aqueous liquids and to remove solids, and organic and inorganic compounds from wastewaters. The ultimate design philosophy for water pollution control systems embodies the concept of zero liquid discharge in which all used water is treated then recycled to the process operations and their supporting auxiliaries. Solid wastes and by-products are removed from the wastewater and sold or disposed of. The rationales for the selection and arrangement of wastewater treating systems are described in Section 4.2.

Reducing solid wastes to unobjectionable, nonpolluting products and by-products also requires the use of specific processing modules. These modules are described in Section 4.3.

The multimedia waste streams and the pollution control modules are described in the following section only in such detail as to characterize the waste streams and the control module designs. More detailed descriptions of the pollution control modules are provided in Appendices C, D, and E.

4.1 AIR POLLUTION CONTROL

The air pollution control modules receive contaminated gaseous emissions from the various process operations within low/medium-Btu coal gasification plants and reduce the concentrations of these contaminants in the gas streams to levels acceptable for discharge to the environment. There are four basic control modules:

- Particulate Control
- Sulfur Control
- Hydrocarbon Control
- Nitrogen Oxide Control

A flow diagram of these modules is presented in Figure 4-1. In this figure, the gaseous effluents which may be directed to these four modules and potential flow paths between the modules are identified. The nature of the contaminated gaseous effluents dictate which modules are required to treat the gases.

The gaseous effluents of major concern in this environmental assessment program are the process tail gases from the acid gas removal module and wastewater stripping process. These streams contain the bulk of the sulfur originally present in the coal feedstock along with substantial quantities of hydrocarbons. Sulfur and hydrocarbon control techniques are therefore given prime emphasis in this section.

There are many proven processes available for use in the sulfur control module. A list of sulfur control processes which are or will be of primary interest in low/medium-Btu gasification technology was prepared. The prioritization criteria discussed in Section 3.0 were also used in classifying these processes.

Because of the importance of the sulfur and hydrocarbon control modules, detailed process and discharge stream data sheets for the high-priority sulfur control processes and the hydrocarbon control processes were prepared. These data sheets, which are included in Appendix C, contain the following types of information for each process:

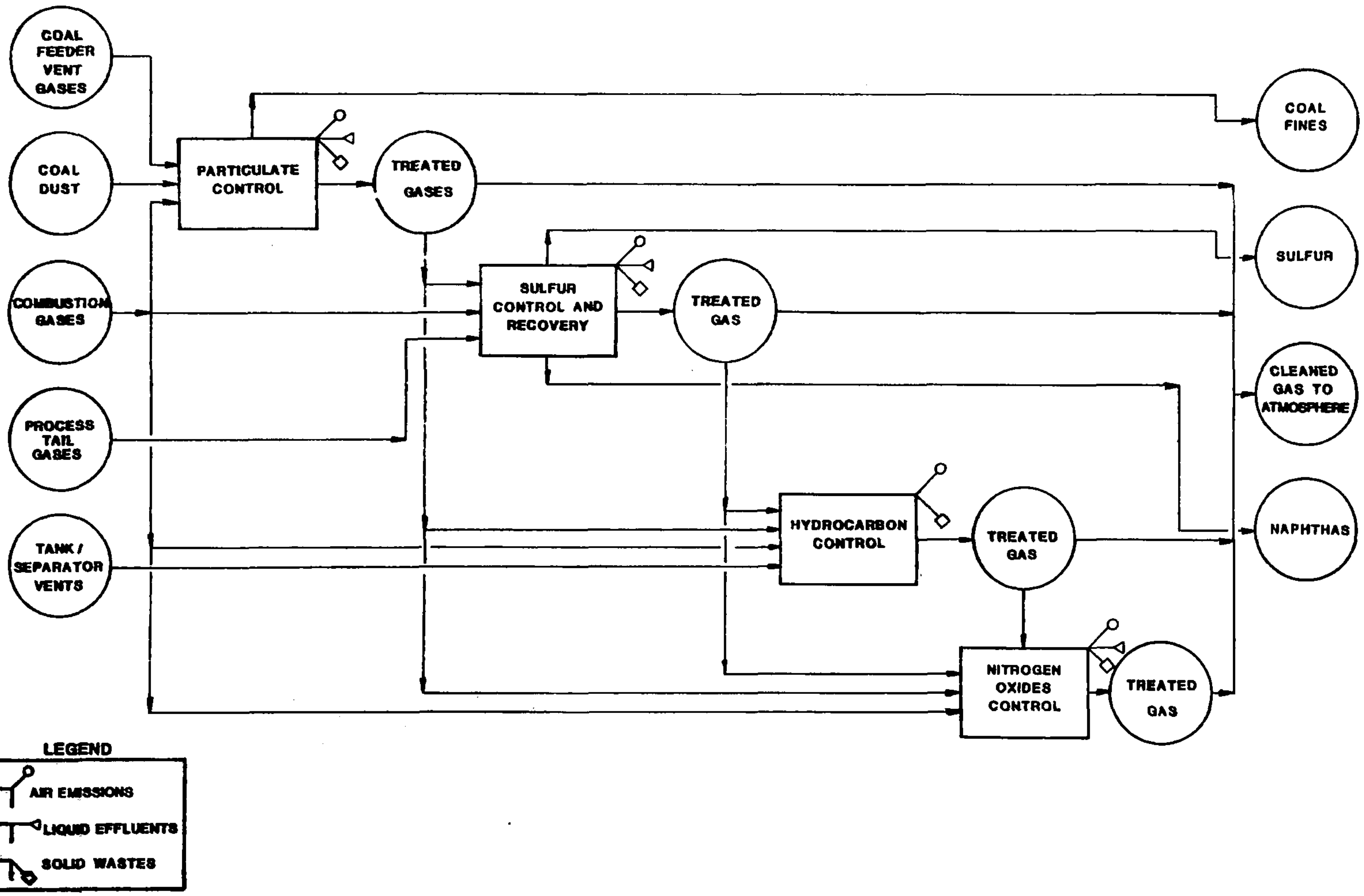


Figure 4-1. Flow diagram for the modules in the air pollution control operation

- Flow diagrams
- Commercial applications
- Operating parameters
- Raw material and utility requirements
- Process advantages and limitations
- Discharge stream compositions

In the following sections, each of the air pollution control modules are discussed with respect to a) the types of gaseous effluents to be treated, b) the processes capable of treating these effluents, and c) the operating principles and waste streams associated with each process. The advantages and disadvantages of the processes and their applicability to low/medium-Btu gasification are also addressed.

4.1.1 Particulate Control Module

Coal dust from the coal pretreatment and coal gasification operations are the principle particulate emissions requiring control. Other emission sources include the ash handling system and the permanent coal storage pile. The severity of the particulate emission problem will vary from site to site. Water sprays are used at coal conveying transfer points at some sites; however, these may or may not be effective control devices.

The control of particulate emissions actually entails three steps. First, the particulate containing gases must be collected and directed to the control process. For example, a coal conveyor belt might be completely enclosed, with the vapor space vented to the control process. Next, the particulates are removed from the gases; and finally, the collected particulates are removed from the control process.

The many processes and variations of processes that could be used to control particulate emissions from coal gasification processes are generally divided into the following four categories, based on the collection mechanism used:

- Mechanical Collectors
- Electrostatic Precipitators
- Wet Collectors
- Afterburners

Mechanical Collectors -

Mechanical collectors remove particulate matter from gas streams by the actions of physical forces such as gravity, centrifugal force, impingement, and diffusion. Three types of mechanical collectors which are widely used to control particulate emissions from industrial processes include:

- Settling chambers
- Cyclones
- Filters

The effectiveness of each of these types of collectors depends mainly upon the size distribution of the particulate matter and the flow rate and physical properties of the gas stream. Filters generally provide better collection efficiencies than the other two types of collectors, especially if very small particles (<5 μm) must be collected.

Electrostatic Precipitators -

Electrostatic precipitators (ESP's) remove particulate matter from gas streams by the action of an electrical field on charged particles. Two types of ESP's (high- and low-voltage) are commercially available.

High-voltage ESP's are used most frequently when predominantly small particles (<20 μm) must be removed from large volumes of gas. Collection of particulate matter by high-voltage ESP's involves three basic steps:

- Transmitting an electrical charge to the particulate matter.

- Collecting the charged particles on a grounded surface.

- Removing the collected particulates from the precipitator.

Because of the high collection efficiencies associated with high-voltage ESP's they are generally applicable to control of particulate emissions from coal gasification plants.

Low-voltage ESP's are two-stage devices which were originally designed to purify the inlet air to air-conditioning systems. They are used only to treat small volumes of gas containing nonsticky liquid particulates, and they do not collect solid particulate matter. For this reason, it does not appear that low-voltage ESP's will play an important role in low/medium-Btu gasification technology.

Wet Collectors -

Wet collectors use a liquid, usually water, either to remove particulate matter from a gas stream by direct contact or to increase collection efficiency by preventing reentrainment of the collected particles. There are many types of wet collectors, all of which are some variation of a spray chamber or a wet scrubber. The principal mechanisms by which particulate matter is contacted with the liquid in these collectors are:

- Interception
- Gravitational force
- Impingement
- Diffusion
- Electrostatic forces
- Thermal gradients

Wet scrubbers are relatively high energy using devices. This is especially true in those designed for highly efficient particulate removal. For this reason, wet scrubbers often do not compare favorably with mechanical collectors or ESP's, in applications where particulate removal is the only control required. Scrubbers can be useful when dealing with troublesome particulates (e.g., a sticky metal fume) or when concurrent removal of another pollutant such as SO_2 is required. Therefore, while a baghouse or ESP's might be better suited to the removal of coal and ash dust from gas streams which are collected in the vicinity of solids handling operations, wet scrubbers appear to have application in the removal of particulates and SO_2 from on-site combustion stack gases.

Afterburners -

Direct flame afterburners can be used to remove combustible particulates from gas streams. Generally, they are used to control fumes, vapors, and odors when relatively small quantities of combustible matter are present.

Process Comparison -

The relative merits of these particulate control devices are summarized in Table 4-1. Baghouse filters and high-voltage ESP's appear to be best suited to the requirements of coal gasification plants because of their high efficiencies in the collection of fine particulate matter. However, final selection of a particulate control device will also depend on its capital and operating costs, and on how effectively the device can be integrated into a particular gasification plant. Particulate emissions from portions of the gasification plant, such as the ash handling system, are not completely combustible; afterburners would be ineffective in controlling this emission. Also, direct flame afterburners usually require supplemental fuel.

Particulate Control Module Discharge Streams -

The particulate control module can be a source of air emissions, liquid effluents and solid wastes. Properly treated air emissions are essentially particulate-free gases which may or may not require additional treatment for control of sulfur compounds, hydrocarbons, or nitrogen oxides. For example, the coal dust-laden air collected from the vicinity of the coal handling operations can generally be vented to the atmosphere after the particulates have been removed. Combustion gases from on-site power generation facilities, on the other hand, may require additional treatment, e.g., for SO_2 removal.

Table 4-1. SUMMARY OF PARTICULATE CONTROL DEVICES

Device	Advantages	Disadvantages	Comments
Mechanical Collectors			
1. Settling Chambers	• Low Energy Devices	• Large size due to high residence time and low flow requirements • Low removal efficiency for fine particulates	• Does not appear to be well suited to coal gasification plant particulate control applications.
2. Cyclones	• Mechanically Simple • Low Cost	• Not an effective collector of fine particulates	• Is a low energy device for large particulates, but requires higher energy dissipation to remove fine particulates.
3. Filters (Baghouses)	• High collection efficiency	• Caking/Plugging problems incurred with wet, saturated gases	• Medium Energy Device. • Of the mechanical collectors, probably the best suited to the control of gasification plant coal and ash dust emissions.
Electrostatic Precipitators			
1. High-Voltage	• High collection efficiency • Suitable for fine particulate collection • High gas flows can be treated • Can collect liquid and solid particulate matter	• High voltages required • Sticky liquids can collect on the collection electrode and decrease efficiency	• Very effective device for removing fine particulates from large gas flows. Typical applications have been on coal fired boiler flue gases.
2. Low-Voltage	• Low voltages required	• Cannot handle solid or sticky liquid particulate matter	• Since only application is to non-sticky liquid particulates, this device does not appear to be suited to coal gasification plant particulate control applications.
Wet Collectors (Scrubbers)	• High efficiency can be obtained with certain scrubber types	• Liquid wastes are produced • To obtain high collection efficiencies requires high energy dissipation	• The need for treating the resultant liquid waste detracts from wet scrubbers as a particulate-only control device.
Afterburners			
1. Direct Flame	• High removal efficiency • Simple construction and low maintenance	• Requires auxilliary fuel • Can handle only combustible particulates • Fire hazards	• The fuel penalty associated with particulate-removal-only afterburners detracts from their applicability.

Liquid effluents are generated only when wet collectors are utilized for particulate control. These effluents are directed to the water pollution control operation for treatment. Solid wastes mainly consist of coal dust and ash. The coal dust may be disposed of (e.g., as landfill), used as a fuel, or sold as a by-product, while the ash is generally used as landfill.

4.1.2 Sulfur Control Module

All operations in low/medium-Btu coal gasification plants are potential sources of sulfur-bearing gaseous effluents. Examples of these effluents are:

- Tail gases from the acid gas removal module,
- On-site power generation flue gases,
- Vent gases from the water pollution control module,
- Coal feeder vent gases from the coal gasification module, and
- Gases from the particulate module.

The function of the sulfur control module is to reduce the concentrations of the sulfur compounds such as H_2S, COS, CS_2, and SO_2 to levels acceptable for discharge to the environment.

The processes capable of removing sulfur compounds from gas streams can be divided into three general categories.

- Primary sulfur recovery processes
- Tail gas cleanup processes (secondary recovery)
- Sulfur oxides control processes

The principles of operations of the sulfur control processes are discussed in the following paragraphs. A priority list, based on the merits of each process, is presented.

Primary Sulfur Recovery Processes -

There are numerous processes based on removal of sulfur compounds from gas streams, followed by recovery of the sulfur as a by-product. These direct conversion processes can be classified as either dry oxidation or liquid phase oxidation and are listed in Table 4-2. The principle of operation involves the oxidation of sulfur compounds to elemental sulfur, which is a salable by-product. The two most widely used direct conversion processes are the Claus (dry oxidation) and the Stretford (liquid phase oxidation) processes.

Tail Gas Cleanup Processes -

Tail gas cleanup processes are used to remove and, in some cases, recover the sulfur compounds remaining in the tail gases of primary sulfur recovery processes. These processes, when combined with a Claus unit for example, can provide an overall sulfur removal effectiveness of up to 99.9+%. Commercially available tail gas cleanup processes are classified as follows:

Process Type	Process Name
Removal of sulfur compounds and recovery of elemental sulfur	Beavon Cleanair CBA Sulfreen
Reduction of sulfur compounds to H_2S which is recycled to a Claus unit	SCOT Trencor-M

Sulfur Oxides Control Processes -

Sulfur oxides control processes are not major functions within coal desulfurization plants. They are primarily flue gas desulfurization processes and are generally used to control sulfur emissions from on-site coal-fired heaters and boilers. Therefore, these processes are not discussed in detail in this report.

Table 4-2. DIRECT CONVERSION PRIMARY SULFUR RECOVERY PROCESSES

Dry Oxidation Processes	
Iron Oxide (Dry Box)	
Activated Carbon	
Claus	
Sulfreen	
Great Lakes Carbon	
Liquid Oxidation Processes	
Burkheiser	Stretford
Ferrox	Takahax
Konox	C.A.S.
Gludd	Townsend
Manchester	Wiewiorowski
Cataban	Sulfonly
Thylox	Nalco
Giammarco-Vetrocoke	Sulphoxide
Fischer	Permanganate and Dichromate
Staatsmijnen-Otto	Lacey-Keller
Autopurification	Sulfox
Perox	Direct Oxidation

References: 43, 44, 45

There are three primary types of sulfur oxides control process: nonregenerable, regenerable, and catalytic conversion. Nonregenerable processes remove SO_x from gas streams by sorbing and/or reacting the SO_x with an alkali salt. The products formed from these processes are not suitable for reuse and require disposal. Regenerable processes remove SO_x by absorption, reaction, and/or adsorption, and produce salable or reusable products. SO_x control processes using catalytic conversion either oxidize or reduce the SO_x to form solid or liquid by-products.

While there are numerous sulfur oxides control processes available, most of them have not been completely proven in commercial applications and are still in a developmental stage. For this reason data on removal efficiency, utility usage, reliability and costs are not available for many of the processes.

Process Prioritization -

The sulfur control processes with the highest likelihood of being used in future coal gasification plants were selected using the criteria discussed below.

Applicability - Sulfur emissions consist mainly of H_2S, COS, CS_2 and mercaptans. Flue gas desulfurization (SO_x removal) is not a principle process need.

Development status - Only commercially available processes were considered.

Environmental impacts - Processes producing troublesome secondary effluent streams were not considered to be promising. For example, the Phylox and the Giammarco-Vetrocoke processes, use arsenic-based solutions and purge streams from these processes would contain arsenic compounds. They were not included among the promising sulfur control processes.

Energy requirements - This criterion was used to eliminate processes requiring excessive amounts of energy.

Costs - Limited economic data were available for these processes. It was assumed that all "promising" processes are competitive on a cost basis.

Process limitations - This criteria was used to identify special raw material requirements, sensitivity to variation in feedstock and operating parameters, and the ability to meet sulfur emission requirements. Some processes simply cannot remove contaminants to desired levels. For example, the Stretford process, while effective in removing H_2S, does not remove organic sulfur compounds such as COS and CS_2.

Promising processes - Using the above criteria, the following sulfur control processes were identified as those that will most likely be used in coal gasification plants in the near future:

- Primary Sulfur Recovery Processes
  - Claus
  - Stretford
- Tail Gas Cleanup Processes
  - Beavon
  - SCOT

These processes are compared in Table 4-3. Detailed information on each promising sulfur recovery and control process is presented in Appendix C. It must be emphasized that no process has been totally eliminated from consideration. As new data become available, it may be necessary to add or delete processes from the above list.

Sulfur Control Philosophy -

The combinations of sulfur control processes that might be used to treat three types of contaminated gases are discussed in the following paragraphs. The three example gas streams are characterized as those containing:

Table 4-3. SUMMARY OF SULFUR RECOVERY AND CONTROL PROCESSES

	Sulfur recovery process		Tail gas cleanup processes		
	Claus	Stretford	Beavon	SCOT	Wellman-Lord
Development Status	Commercial	Commercial	Commercial	Commercial	Commercial
Control Effectiveness					
• H_2S	90-95%	99.9+%	99.9+%	99.8+%	99.0+%
• COS/CS_2	90%	-	98+%	98+%	99+%
• R-SH	95%		DNA	DNA	99+%
• HCN	DNA	D	D	DNA	DNA
• NH_3	DNA	-	DNA	DNA	DNA
• Hydrocarbons	90%	-		-	
Operating Requirements					
• Steam		✓	✓	✓	✓
• Electricity		✓	✓	✓	✓
• Cooling Water	✓				✓
• Fuel Gas			✓	✓	
• Chemicals (including catalyst)	✓	✓	✓		✓
• Process Water		✓	✓		
Discharge Streams Requiring Further Control					
• Gaseous	✓		✓*		
• Aqueous			✓	✓	✓
• Solid	✓				
By-Products					
• Sulfur	✓	✓	✓		
• Other					Steam
Applicability To Coal Gasification					
• Proven					
• Technically Feasible	✓	✓	✓	✓	✓
Process Limitations	High hydrocarbon feed can result in formation of organic sulfur compounds	Does not remove organic sulfur compounds			

*If organic sulfur compounds are present in feed stream

D - Solvent degrades forming nonregenerable compounds

DNA - Data not available

✓ - Indicates presence of an operating requirement, discharge stream, by-product, or applicability characteristic

- small amounts of H_2S and organic sulfur compounds,

- large amounts of organic sulfur and small amounts of H_2S, and

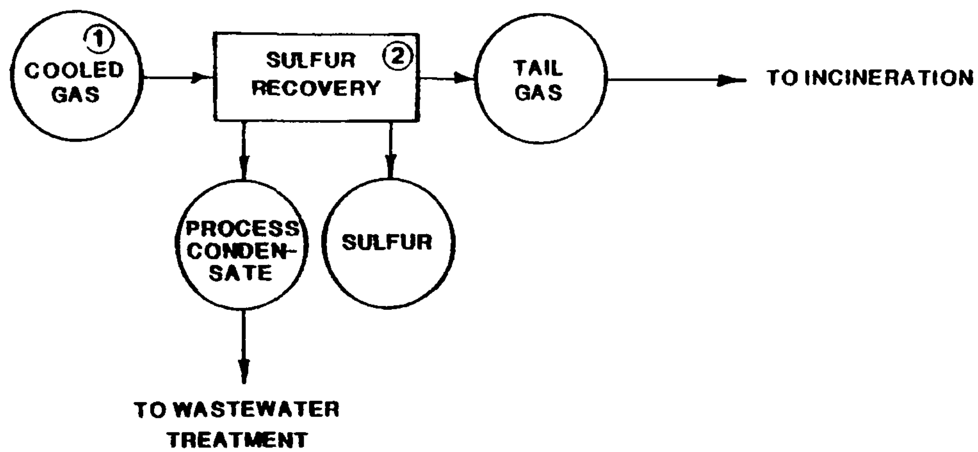
- large amounts of H_2S and small amounts of organic sulfur compounds

If high concentrations of hydrocarbons are present in any of these streams, further treatment by the hydrocarbon control processes discussed in Section 4.1.3 will be required. The following are examples of control schemes that are capable of removing 99.9+% of the sulfur compounds from the three gas streams listed above.

Example 1 - Figure 4-2 shows a potential control scheme for a feed gas containing small amounts of H_2S and organic sulfur compounds. This stream may be treated in a Stretford unit for sulfur recovery. However, it may be necessary to incinerate the Stretford tail gas to control hydrocarbon emissions or to convert the remaining sulfur species to SO_2 prior to release into the atmosphere.

Example 2 - For a feed gas containing large amounts of organic sulfur but little H_2S, the control scheme shown in Figure 4-3 may be used. This is basically the same as that described in Example 1 except that an organic sulfur compound conversion process step is added before the Stretford unit. In this process step, organic sulfur compounds such as COS, CS_2, and mercaptans are catalytically converted to H_2S. The H_2S can then be removed by the Stretford unit.

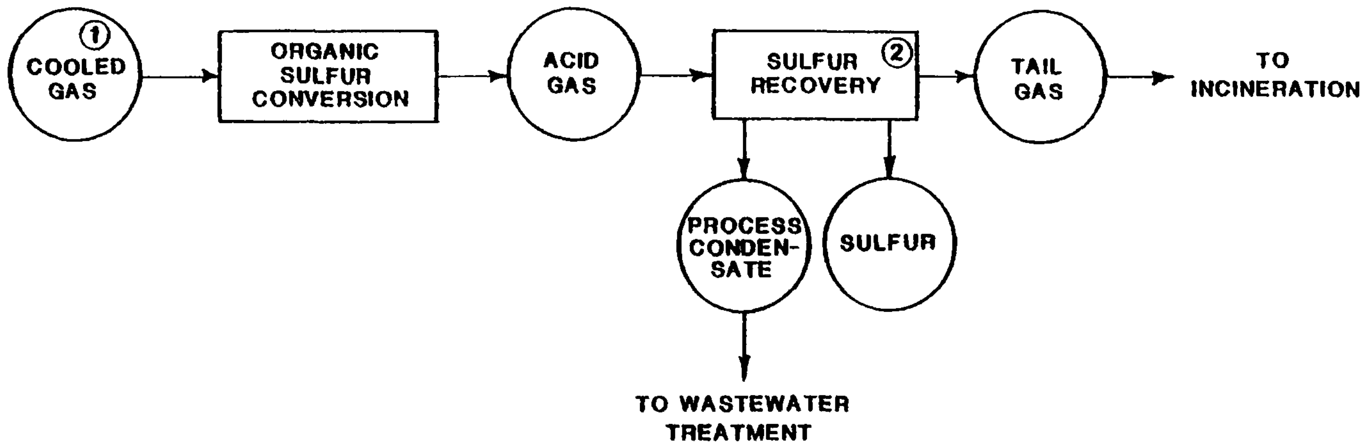
Example 3 - Gas streams containing large amounts of H_2S but low hydrocarbon and organic sulfur contents, such as might be produced from a selective acid gas removal process, can be controlled using the scheme presented in Figure 4-4. At high concentrations of H_2S ($\geq$15 vol %) a Claus unit becomes economically attractive for sulfur recovery. The tail gas from the Claus unit would still contain significant quantities of sulfur and would need further control. Because of the low hydrocarbon content of the feed gas, little organic sulfur is formed in the Claus process; therefore, a Stretford process is suitable for tail gas cleanup. This is desirable since a selective acid



① LOW ORGANIC SULFUR AND LOW H_2S. EITHER PRODUCT GAS FROM GAS COOLING OR ACID GAS FROM ACID GAS REMOVAL PROCESS

② STRETFORD PROCESS SUITABLE

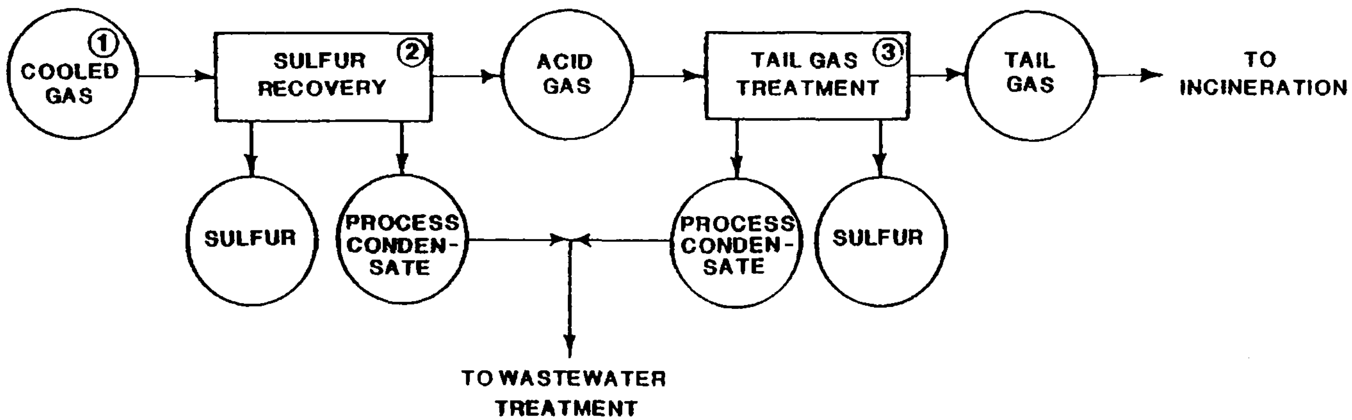
Figure 4-2. Treating sequence for example 1.



(1) HIGH ORGANIC SULFUR AND LOW H_2S. EITHER PRODUCT GAS FROM GAS COOLING OR ACID GAS FROM AN ACID GAS REMOVAL PROCESS

(2) STRETFORD PROCESS SUITABLE

Figure 4-3. Treating sequence for example 2.



(1) LOW HYDROCARBON AND LOW ORGANIC SULFUR, HIGH H_2S

(2) CLAUS PROCESS SUITABLE

(3) STRETFORD PROCESS SUITABLE

Figure 4-4. Treating sequence for example 3.

gas removal process also generates a lean H_2S stream which can also be treated in the Stretford unit.

Sulfur Control Module Discharge Streams -

The sulfur control module can be a source of air emissions, liquid effluents, and solid wastes. The air emissions consist of essentially sulfur-free gases which may require hydrocarbon and NO_x control before being vented to the atmosphere. Liquid effluents include spent scrubbing solutions and reaction liquors which may contain dissolved and suspended organics and inorganics. Since further treatment of these materials will almost always be required, these liquid effluents are sent to the water pollution control section. The solid wastes include spent catalysts, sorbents, and by-products. If necessary, these solid wastes are sent to the solid wastes control section for further treatment and/or ultimate disposal.

Discharge Streams Requiring Further Control -

The tail gases from the Claus and SCOT process require further control of sulfur compounds. If high concentrations of organic sulfur compounds are present in the fuel gas, the tail gas from the Stretford process may need further treatment. Liquid effluents consisting of spent sorbents, scrubbing liquors, or sour condensates are discharged from all of the processes except the Claus process. (The Claus process generates a solid waste stream containing spent catalyst).

4.1.3 Hydrocarbon Control Module

The function of this module is to reduce the hydrocarbon content of process tail gases, vent streams and other waste streams to levels acceptable for discharge to the environment. There are two basic methods of hydrocarbon control: afterburners and adsorbers. Afterburners simply convert hydrocarbons to CO_2 and H_2O by oxidation. Adsorbers use sorbents such as activated carbon to remove the hydrocarbons from the gas stream. Fact sheets containing detailed information on the hydrocarbon control processes are presented in Appendix D.

Afterburners -

Two types of afterburners are used to control hydrocarbon emissions, direct flame and catalytic. These are essentially identical to the particulate control afterburners discussed in Section 4.1.1. The direct flame afterburners depend upon direct contact of the hydrocarbons with a relatively high-temperature flame. High temperatures are required to insure complete combustion. This may be accomplished in a steam or utility-type boiler or a separate combustion chamber may be required. In catalytic afterburners, the hydrocarbons are first preheated and then passed over an oxidizing catalyst bed.

Afterburners can provide very high hydrocarbon control efficiencies (>99+%), but they have some disadvantages. First, if the hydrocarbon content of the gas stream is too low to support combustion, a supplemental fuel must be fired to maintain the required high operating temperatures in direct flame units. In catalytic afterburners, the catalyst is susceptible to poisoning by components likely to be present in the gas stream and may require frequent reactivation.

Adsorbers -

Adsorptive hydrocarbon control processes can be used to remove organic vapors present in dilute concentrations in gas streams. Two basic steps are required for these processes: first is collection of the vapors on adsorbents such as activated carbon; second is thermal regeneration of the sorbent. While adsorptive control processes provide effective control of hydrocarbons (>99+%), the desorbed hydrocarbons emitted from the regeneration step require further control. The desorbed hydrocarbon vapors can be partially recovered via condensation, or they may be burned, usually without the need for supplemental fuel firing.

Hydrocarbon Control Module Waste Streams -

The hydrocarbon control module can be a source of both gaseous emissions and solid wastes. The gaseous emissions are essentially hydrocarbon-free gases which can usually be discharged to the atmosphere. The solid wastes primarily consist of spent sorbents or catalyst (from catalytic afterburners).

4.1.4 Nitrogen Oxides Control Module

A nitrogen oxide control strategy for the combustion gases emitted from coal or low/medium-Btu gas-fired boilers and furnaces may be required. NO_x formation in the gasification module is expected to be low since the raw gas passes through a reducing atmosphere before leaving the gasifier. The nitrogen that does react in the gasifier should form NH_3, HCN, thiocyanates, and other nitrogen-containing organics rather than nitrogen oxides (Ref. 46).

There are three basic processes that can be used to control NO_x emissions from boilers and furnaces:

- Combustion modifications
- Post-combustion flue gas cleaning
- Fluidized-bed combustion

These are processes which would not be considered central to those in coal gasification plants; therefore, no further attention is given to them in this report. These processes are being assessed by EPA via other contractors and with in-house studies.

4.1.5 Discharge Stream Summary

The air pollution control modules are sources of air, liquid, and solid waste discharge streams. These secondary discharge streams may require further treatment before being discharged to the environment or they may be salable by-products.

The air emissions from these modules consist of treated gases which are either discharged directly to the atmosphere or sent to another air pollution control module for further treatment. Most of the air pollution control processes have not been used to treat the air emissions from low-Btu gas production. Also, adequate control of minor hazardous constituents such as hydrogen cyanide, COS, CS_2, mercaptans, thiophenes, trace elements, etc. has not been completely demonstrated.

Liquid effluents from air pollution control modules include spent sorbents (sulfur control module), scrubbing liquors (particulate, sulfur, and nitrogen oxide control modules) and sour condensates (sulfur control module). These effluents will contain varying levels of pollutants and would be treated in water pollution control modules before being discharged or reused.

All of the air pollution control modules produce solid wastes. These include coal fines, ash, sulfur, and spent sorbents and catalysts. The sulfur and coal fines can be salable by-products. Ash and spent sorbents and catalysts would be treated in solid waste control modules.

4.2 WATER POLLUTION CONTROL

In a coal gasification facility, the specific sources which generate wastewaters will determine the type of contaminants that are present in those streams. Wastewater sources in a coal gasification plant are shown in Figure 4-5 along with descriptions of the particulate type of wastewaters they generate. The types of contaminants these streams contain are briefly described in Table 4-4.

The suspended solid contaminants are primarily coal particulates that are generated when the coal is crushed and sized and/or ash is quenched as it is discharged from the gasifier. Dissolved organics are volatile hydrocarbons that are condensed in the quench liquor during the subsequent raw gas cooling step. Dissolved inorganic gas contaminants such as CO_2, H_2S, and NH_3 are produced in the same manner as the dissolved organics. Dissolved salts accumulate when reuse of the upgraded wastewaters is maximized. At higher concentrations, salts begin to scale-out on exchanger surfaces; consequently, close monitoring of dissolved solids in the wastewater will be an essential control practice.

The composition of coal gasification wastewater is highly dependent upon certain process variables. For instance, lignite coals have substantially different moisture, volatile hydrocarbon, and inorganic contents than do bituminous or subbituminous coals. Therefore, the amounts of tars, oils, phenols, and other volatile organics that appear in the wastewaters are greatly affected by the type of coal used. The type of gasifier used can also affect the wastewater produced. A Lurgi gasifier

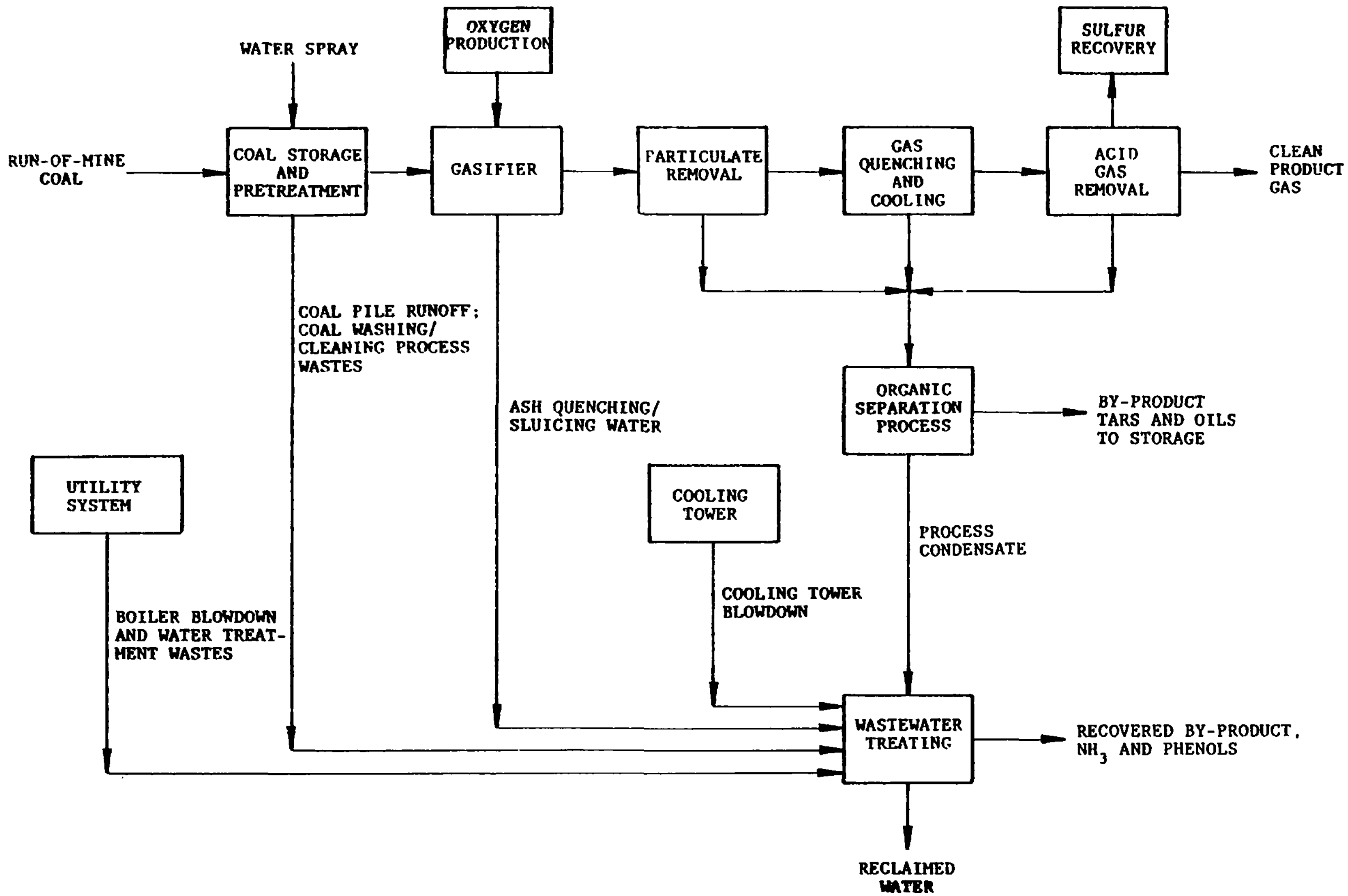


Figure 4-5. Major process modules generating wastewater in a typical coal gasification plant.

Table 4-4. COAL GASIFICATION PLANT WASTEWATER SOURCES AND CHARACTERISTICS

Process Module	Source	Contaminant
Coal Pretreatment and Storage	Coal-pile runoff; coal crushing/ cleaning wastes	Suspended solids; dissolved organics
Gasifier	Ash quench/sluice water	Suspended solids; dissolved inorganics
Particulate Removal; Gas Quenching and Cooling; Acid Gas Removal	Gas liquor; process condensate; unrecoverable solvent	Suspended solids; non-emulsified oils; dissolved organics and inorganics; spent solvent
Cooling Tower	Blowdown	Suspended solids; dissolved organics and inorganics (volatiles and salts)
Utility System	Blowdown	Dissolved inorganics; suspended solids
Organics Separation	Process condensate	Suspended solids; dissolved organics and inorganics
Wastewater Treatment	Sludges	Semisolids

which operates at high pressures and relatively low temperatures will produce wastewaters containing condensed volatile organics which have been carried overhead in the gasification process. However, the same volatile organics are cracked in Koppers-Totzek gasifiers, which operate at higher temperatures and lower pressures. The result is a wastewater that is essentially free of dissolved organics.

Gas Liquor -

Gas liquor is just one of several wastewaters from a typical gasification facility, however, it is the wastewater that has been the most extensively investigated. The composition of the gas liquor produced at the SASOL gasification plant is presented in Table 4-5 and shows some of the contaminants and relative concentrations that might be expected for a gasification gas liquor. This gas liquor composition was used as a screening standard for the various process modules whose applicability to coal gasification wastewaters was evaluated. Those process modules shown on Table 4-6 were determined to be the most promising in terms of control effectiveness, operating cost, reliability, and energy consumption, for treating a wastewater similar to SASOL's gas liquor.

Zero Discharge -

Because water quality standards have not been established, several companies considering construction of coal gasification plants are planning to achieve zero discharge of aqueous effluents. This will allow them to meet any future standards that may be established. Unfortunately, the costs of obtaining zero discharge are usually high.

To successfully attain zero discharge, the wastewater treating steps must produce an effluent of a quality that may be reused in the process or discharged to an evaporation pond. The treating modules necessary to accomplish this include:

- removal of suspended solids and non-emulsified oils,
- removal of dissolved organic contaminants,

Table 4-5. COMPOSITION OF GAS LIQUOR FROM SASOL COAL GASIFIERS

Component	Approximate Composition
Phenols	3,000 - 4,000 ppm
Ammonia (free)	500 - 750 ppm
Ammonia (fixed)	100 - 200 ppm
Sulfides (total)	200 - 250 ppm
Suspended Tar, Oil	∿5,000 ppm
Cyanides	<50 ppm
CO_2	<1.0%
Fatty Acids	<.05%

(Ref. 47)

Table 4-6. PROMISING WASTEWATER TREATING MODULES FOR SASOL GAS LIQUOR

Process Module	Process
Suspended Solids Removal	Filtration, Flocculation and Flotation, and Oil-Water Separator
Dissolved Organics Removal	Phenosolvan, Carbon Adsorption, Biological Oxidation, Cooling Tower Stripping (Oxidation)
Dissolved Volatile Inorganics Removal	Acid Gas Stripping, WWT Acid Gas Stripping
Dissolved Salts Removal	Forced Evaporation
Ultimate Disposal	Evaporation Ponds

- removal of dissolved salts and inorganic volatile contaminants, and

- use of an ultimate disposal process (evaporation pond) to facilitate final disposition of any wastewater that cannot be economically upgraded.

4.2.1 Water Pollution Control Modules

In addition to the unique problems associated with gas liquor treating and zero discharge attainment, standard industrial water treating problems (such as treatment of cooling tower and boiler blowdowns) must also be considered in coal gasification plants. Certainly the types of contaminants present in a waste stream will determine the treatment required to upgrade that stream. Typical wastewaters and the modules required to treat them are shown schematically in Figure 4-6.

The water pollution control modules generally considered for use in coal gasification plants are discussed in the following text.

Oil/Water Separation and Suspended Solids Removal Modules -

The functions of these modules are to remove suspended solids and oils from process wastewater. The processes generally used in these modules are:

- Oil-Water Separation
- Filtration
- Flocculation/Flotation (dissolved air)

Oil-water separator - An oil-water separator utilizes the difference in the densities of the contaminants and the water to achieve separation of nonemulsified oils and suspended solids from the wastewater. Oil-water separation processes have a history of successful application in the petroleum industry. These oil/water separation processes are highly reliable, have

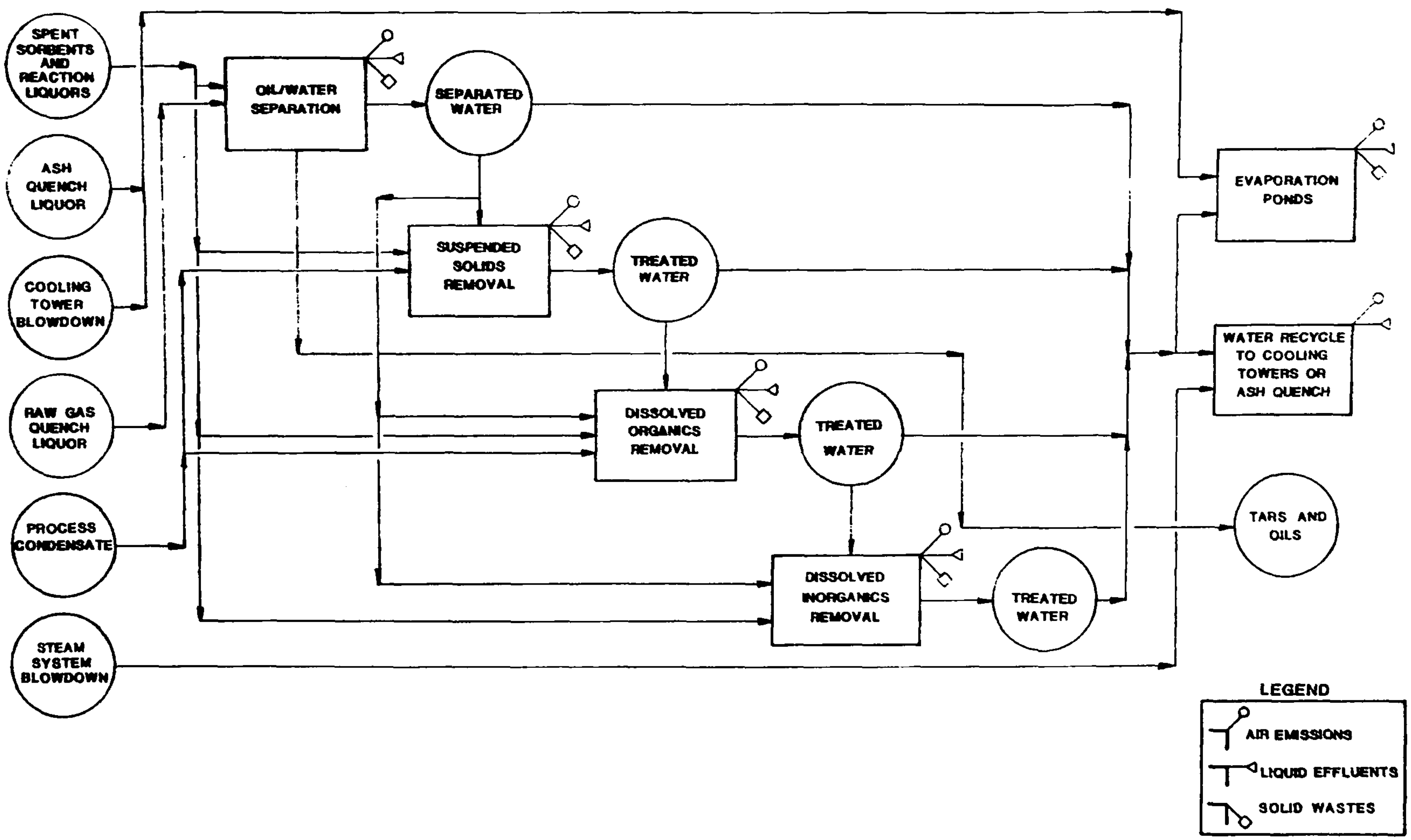


Figure 4-6. Flow diagram for the modules in the water pollution control operation

demonstrated good control effectiveness, and are low cost operations compared to other oil-water separation techniques.

There are several disadvantages associated with this process. These include its sensitivity to oil droplet density and size and to the types of solids in the wastewater. These variables influence the control effectiveness of a separator and significant variations in these parameters from those which were the basis for the design of the separator will affect the degree of contaminant removal. To remove small/emulsified oil droplets, it is sometimes necessary to use a coalescer/separator.

Filtration - These processes rely on the adherence of suspended particles to the filter media and/or entrapment of the particles in the filter interstices to remove suspended contaminants from wastewaters. The major types of filters used in industries requiring treatment of large volumes of wastewaters are hay and sand filters. Backwashing is used to "regenerate" the filtration media.

Filtration is a highly reliable means of reducing the suspended contaminant loading in the wastewater. It has proven successful in treating the wastewaters generated at the SASOL coal gasification complex in South Africa.

The major disadvantage of the filtration process is the backwashing process that is required to regenerate the spent filter media. This procedure generates an additional contaminated water effluent whose final disposition must be further considered. This effluent has been disposed of in the past by incineration or landfilling. However, these procedures may create significant problems if they are not closely controlled. An alternative disposal scheme would be to separate the effluent by gravity, send the bottoms liquid to a mechanical dewatering system, dispose of the solids in an evaporation pond, and treat the waters from the gravity separator and dewatering system for possible reuse.

Flocculation-flotation - This process involves the addition of chemicals to the wastewater in order to coagulate and subsequently accelerate the ascension of fine oil droplets that are present in the water. Water from the flocculating chamber flows into a vessel where the oil droplets are floated to the surface by air bubbles. These bubbles are skimmed off to achieve final separation of the oil from the water. The air is introduced through a sparger at the bottom of the vessel. Addition of the flocculant also removes suspended solids by increasing the rate at which the solids settle.

The effluents from a flocculation-flotation process are the oily scum skimmed from the surface of the water, the settled sludge, and the wastewater free of suspended contaminants. Both the oily scum and the sludge can be sent to an evaporation pond. The effluent wastewater will require further processes prior to its reuse or final disposal.

Flocculation-flotation is a promising water treating process. It is a proven and highly reliable process. It has exhibited good control effectiveness in other industrial applications, and it is a simple operation. While flocculation can be combined with other separation techniques such as gravel-bed or sand-bed filters to remove suspended solids and oils, the advantage of combining flocculation with air flotation is that there is minimal contamination of additional water since no backwashing is required. Its major disadvantage is the high cost of the chemicals used. The oil separation step is also sensitive to temperature and oil density.

Dissolved Organics Removal Module -

The processes in this module are normally considered to be secondary or tertiary wastewater treatment techniques. These processes remove dissolved organics by the following mechanisms:

- Extraction
- Adsorption
- Biological treatment
- Cooling tower oxidation (stripping)

Extraction processes - These processes are often used to remove phenols from process wastewater. These processes consist of two steps: an extraction step in which the solvent extracts the phenols from the wastewater and a regeneration step in which the phenols are separated from the solvent. Countercurrent extraction columns, mixers, and distillation columns are used in these processes. A wide variety of solvents can be employed in phenol extraction processes, including:

- Benzene
- Tricresyl phosphate
- Isopropyl ether
- Aliphatic esters
- Light oils (tar base)
- Light aromatics (tar base)
- Sodium hydroxide solutions
- Various proprietary solvents

The Phenosolvan process was developed by Lurgi. It is a liquid-liquid extraction process involving contacting the wastewater in which phenols are dissolved with a suitable solvent. During regeneration of the solvent, the phenols are recovered as a by-product. The dephenolized wastewater is treated for the removal of dissolved inorganics and any residual contaminants before it is recycled for reuse.

Phenosolvan is considered to be a very promising process for application in coal gasification plants because:

- It is very effective in removing the phenols from the wastewater.
- This process has been successfully applied in the SASOL coal gasification plant, plus some 32 other industrial installations since 1940. (Lurgi includes this process as part of its overall gasification technology.)
- The phenols are recovered as by-products from the process.

The major disadvantage of this process is that the solvent is slightly soluble in water; therefore, it is necessary to remove the solvent thoroughly to prevent contamination of the phenol-free wastewater.

Adsorption processes - These processes utilize a solid sorbent to remove dissolved organics from wastewater. After the sorbent has become saturated, it is regenerated and returned to service. The major types of adsorbents used are:

- Aluminas
- Siliceous materials
- Carbonaceous materials
- Synthetic polymers

If the wastewater contains phenols, activated carbon or synthetic polymer sorbents are normally used to treat the wastewater. However, in instances when the flowrates of the wastewater are high, only activated carbon can be used economically.

There are several possible regeneration techniques available. Aluminas and siliceous and carbonaceous sorbents are thermally regenerated. Polymer sorbents are regenerated by a solvent wash in which the spent solvent is separated from the organics by distillation.

Activated carbon adsorption has been extensively used to remove contaminants from air and water. When the carbon bed becomes saturated with the organic contaminants, it is usually regenerated by heating the carbon to a high temperature (1140-1260°K, 1600-1800°F) in the presence of a gas with a low oxygen content. Under these conditions the adsorbed organics are selectively oxidized. The carbon is then cooled with quench water and readied for reuse.

Carbon adsorption of dissolved organics in wastewater is considered a promising process because it:

- has been successfully applied to upgrading wastewaters from coke oven plants,

- has been proven to have a high operating reliability and good control effectiveness,
- is simple to operate, and
- is insensitive to organic loading, toxicity and temperature change.

The disadvantages of this process are:

- phenols cannot be readily recovered from activated carbon, and
- regeneration of the carbon generates a contaminated aqueous stream and a potentially contaminated gaseous emission.

Biological treating processes - Biological treating processes use the natural metabolic processes of bacteria and other microbes to remove dissolved organics from wastewaters. Overall reactions associated with the two basic types of biological treating systems, aerobic and anaerobic, are represented in the equations below.

Aerobic:

Organic matter + microbes + O_2 $\rightarrow$
more microbes + CO_2 + H_2O + waste energy

Anerobic:

Organic matter + microbes + NO_x + SO_x $\rightarrow$
more microbes + HCO_3 + N_2 + CH_4 + H_2S +
CO_2 + H_2O + waste energy

There are several techniques which are based on biological oxidation; they are: a) activated sludge, b) trickling filters, c) aerated lagoons, and d) aerobic and anaerobic waste stabilization ponds. Since these techniques all have a 90-99% phenol removal efficiency, the selection and use of any of these techniques will depend on the process to which it is applied.

Biological oxidation is considered a promising process because:

- It has been successfully used to upgrade wastewater from coke oven plants.
- It has good control effectiveness for the removal of phenols.
- Although its primary function is the removal of dissolved organics, it also removes some trace metals, ammonia, sulfides, BOD, and cyanides that the wastewater may contain.

The major disadvantages of this process are its sensitivity to temperature, wastewater pH, oxygen concentration, and organic and hydraulic loadings. It also requires that nitrogen and phosphorus nutrients be present to maintain an optimum oxidation level; this requirement increases the costs and maintenance involved with this process.

Cooling tower oxidation (air stripping) - Cooling towers have been used in the refinery industry as a means of removing phenols from wastewater. This process involves the normal countercurrent contact of air and wastewater in a cooling tower. Phenols and other dissolved contaminants are removed from the wastewater as a secondary function while the primary function (cooling) is occurring.

The mechanism by which the contaminants are removed is uncertain. There are claims that the phenols and other contaminants are destroyed by a biological oxidation mechanism. However, the residence time in a cooling tower is short compared to other biological oxidation processes; therefore, there is some speculation that the dissolved contaminants are removed to some degree by stripping. There is a basic difference between these two mechanisms. Biological oxidation reduces the contaminants to harmless compounds while the stripping mechanism simply transports the contaminants from the wastewater to the air leaving the cooling tower. Therefore, a potentially hazardous air emission may be created.

Cooling tower oxidation was selected as a promising process because:

- phenol removal efficiency is high,
- operating costs are low (cooling towers are normally required plant equipment; no additional expense is incurred in using them for phenol removal), and
- this method for treating gas liquor has been used successfully at SASOL.

Dissolved Inorganics Removal Module -

The function of this module is removal of dissolved inorganics from wastewater. There are four basic types of processes available:

- Stripping
- Brine concentration
- Ion exchange
- Membrane desalination

Effluents requiring the removal of dissolved inorganics include process condensates, cooling tower blowdown, ash quench water, coal-pile runoff, and spent scrubbing liquors.

Stripping processes - These processes are used to remove dissolved inorganic gases (H_2S, CO_2, and NH_3) from process wastewaters and are generally classified as sour water or acid gas stripping processes. Acid gas stripping has been extensively used in the refinery industry for the removal of the inorganic gases plus phenols and cyanides. In coal gasification, this process would be primarily used to remove H_2S and NH_3 from the water effluent.

Removal of acid gases is usually achieved in a two-stage process. In the first stage the wastewater is contacted countercurrently with steam and the least soluble of the two gases (H_2S) is removed. The NH_3-rich effluent is then fed to the second stage where it is, again, contacted countercurrently with steam to remove NH_3. The overhead gases from the two stages can be further processed to yield elemental sulfur and liquid ammonia, which are potential by-products. The sulfur recovery processes used are discussed in Section 4.1.2.

Acid gas stripping is a promising process because:

- it is a reliable process with a history of successful application in the coke and oil refining industries, and

- it has exhibited good control effectiveness for removal of H_2S and NH_3.

Its major disadvantages are:

- the removal efficiency is related to stripping steam rates; it can therefore have high operating costs,

- removal of NH_3 and cyanide is sensitive to pH level, and

- the overhead and bottom effluents from the process require further environmental control.

<u>Brine concentration processes</u> - Dissolved salts can be removed from wastewater using brine concentrators or forced evaporators. In the brine concentrator, the water is vaporized from an aqueous stream containing a high concentration of dissolved salts. The salts are accumulated as a concentrated brine or sludge, then sent to an ultimate disposal system. The evaporated water is recirculated as heating steam to an earlier stage in the evaporator. The steam is condensed and used as boiler feed water. Other reasons for selecting this as a promising process are:

- it requires less energy input than thermal drying, and

- it can be used in geographical locations where it is impractical to use solar evaporation ponds.

Ion-exchange processes - Ion-exchange processes utilize solid resins to replace undesirable ions with H^+ and OH^- ions. The ion-exchange resins can be a variety of high molecular weight, cross-linked polymers that contain numerous sites for ion exchange. During ion-exchange, cations such as Mg^{++} and Ca^{++} replace H^+ ions on the polymer while anions such as $SO_4^=$ and Cl^- replace OH^- ions. As the resin exchange capacity decreases, a point is reached where regeneration of the resin is required. During regeneration the ion-exchange polymer is backwashed with strong acids (sulfuric acid) and bases (sodium hydroxide) to replace the undesirable ions with H^+ and OH^-.

Membrane desalination processes - Membrane desalination processes are divided into two categories: reverse osmosis and electrodialysis. Reverse osmosis uses semipermeable membranes which allow essentially pure water to pass through the membrane, but not water impurities, which are rejected. Electrodialysis processes employ membranes with cation and anion selective characteristics. These processes produce dilute water and concentrated brine streams.

Ultimate Disposal Module -

The final treatment of wastewater which contains residual organic and inorganic contaminants, and semi-solid contaminants, and which cannot be economically upgraded is usually the evaporation pond. In this ultimate disposal technique, wastewater is simply evaporated in place. This process has been included as part of the wastewater treating scheme in a number of preliminary coal gasification plant designs. It can be an inexpensive and effective technique for disposing of unprocessable wastes, and it requires minimum maintenance.

This method also has some disadvantages. It requires substantial land area and it is not generally effective in an area that has an annual evaporation rate of less than 20 inches.

Also, these ponds may require an impermeable lining to prevent leaching of contaminants into the groundwater.

4.2.2 Process Comparisons

Water treating processes described in this section are likely to be utilized in first-generation coal gasification plants for the following reasons:

- All are commercially available processes with histories of successful industrial application.

- All have demonstrated good control effectiveness for wastewater treating applications similar to those required for coal gasification plants.

- All have exhibited good operating reliability.

A fact sheet for each of the processes of interest is included in Appendix D. Specific information about the various water pollution control processes is summarized in Table 4-7. Factors to be considered in selection of these wastewater treating processes are summarized below.

- Development status - All are commercially available.

- Coal gas applicability - All the processes shown in Table 4-7 are being used or potentially can be used in coal gasification plants.

- Control effectiveness - These are statements as to the removal efficiency that can be expected for a given contaminant using a given process.

Table 4-7. SUMMARY OF WATER POLLUTION CONTROL PROCESSES

Treatment function	Suspended solids and oils removal			Dissolved organics removal			Dissolved inorganics removal	Residual contaminant removal			Ultimate disposal
	Flocculation Flotation	Oil-water separation	Filtration	Liquid-liquid extraction (Phenosolvan)	Activated carbon adsorption	Biological oxidation (activated sludge)	Acid gas stripping	Forced evaporation	Activated carbon adsorption	Cooling tower oxidation	Evaporation ponds
Development Status	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial
Coal Gas Applicability											
• Presently used	yes	yes	yes	yes	no	yes	yes	no	no	yes	no
• Potential future use	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Control Effectiveness											
• Suspended solids removal	~75%	~90%	52-83%		~90%	70%			~90%		
• Free oil removal	~97%	~90%	52-83%		~93%	80%			~93%		
• Phenol removal		~25%		>94%	99+%	95-99%	20-40%	~99+%			
• Total organics removal				~90%	~90-95%	~90-95%	~90-95%		~90-95%	~90-95%	
• BOD removal	~80%		36%			~90%				90%	
• Sulfide removal						~97%	~99%				
• NH_3 removal						15%	~90%				
• Cyanate removal					~1%	~70%			1%		
• COD removal	80%	~50 ppm ≤	25-44%		~90%	~99.9%			~90%	~99.9%	
• Trace element removal	✓					✓		✓			
• Total dissolved solids removal								99%			
Utility Requirements											
• Steam				✓							
• Electricity	✓	✓	✓	✓	✓		✓	✓	✓	✓	
• Cooling/backwash H_2O			✓	✓	✓	✓	✓	✓	✓	✓	
• Fuel gas					✓	✓			✓		

(continued)

Table 4-7. SUMMARY OF WATER POLLUTION CONTROL PROCESSES (continued)

Treatment function	Suspended solids and oils removal			Dissolved organics removal			Dissolved inorganics removal	Residual contaminant removal			Ultimate disposal
	Flocculation Flotation	Oil-water separation	Filtration	Liquid-liquid extraction (Phenosolvan)	Activated carbon adsorption	Biological oxidation (activated sludge)	Acid gas stripping	Forced evaporation	Activated carbon adsorption	Cooling tower oxidation	Evaporation ponds
Raw Materials Required											
• Solvent				✓							
• Chemical additives	✓					✓				✓	
Allows By-Product to be Recovered	✓	✓	✓	✓			✓				
Generates Effluents Requiring Further Control											
• Gaseous					✓		✓	✓	✓		
• Aqueous	✓			✓	✓				✓		
• Treated effluent	✓	✓		✓			✓				
• Solid/semisolid	✓	✓				✓		✓		✓	
Process Limitation/ Sensitivity											
• Temperature change						✓				✓	
• pH level					✓	✓			✓	✓	
• Contaminant size distribution	✓	✓									
• Requires regeneration			✓	✓	✓				✓		
• Adversely affected by trace elements						✓				✓	
• Nutrients required						✓				✓	
• Chemical additives required	✓					✓			✓	✓	
• Hydraulic loading	✓					✓				✓	

✓ - Although it cannot be quantified, it is a factor to be considered for the processes.

- Utility requirements - The various types of utilities required by the respective processes are shown under this heading (little or no information is available on the quantities of utilities required).

- Raw materials required - Processes requiring solvents or chemical additives are indicated.

- By-product recovery - Processes recovering contaminants of commercial value are identified under this heading.

- Effluents requiring further control - Contaminant streams subject to further treatment are indicated. Examples of sources and types of contaminant streams are:

Contaminated Effluent Source	Contaminated Effluent Type	Specific Effluent
Flocculation - flotation	Aqueous	Oily scum
Activated sludge	Solid/semi-solid	Excess sludge
Activated carbon adsorption/ regeneration	Gaseous	Flue gas from regeneration heater

4.2.3 Water Pollution Control Philosophy

No single process can remove all of the impurities required to yield an acceptable wastewater. It is usually necessary to combine several processes to achieve the desired effluent quality.

The sequence of wastewater treating processes selected will depend upon the overall treating philosophy. In coal gasification it is likely this philosophy will be to achieve zero discharge and to recover contaminants as by-products whenever economically feasible. For example, the following sequence of treatment processes reflects this philosophy.

- 1st Step - Separate tar and oil from the wastewater. (The tar and oil can subsequently be separated from one another and recovered as by-products.)

- 2nd Step - Remove suspended solids and oils. This is to insure that the subsequent wastewater treating processes will not be plugged or fouled.

- 3rd Step - Remove dissolved phenols and, if possible, recover them as a by-product. Maximum removal of the phenols at this point will reduce the amount that could be present as a contaminant during subsequent acid gas stripping operations.

- 4th Step - Remove acid gases from the wastewater by a two-stage steam stripping process. H_2S is less soluble in water than is NH_3. It is stripped out in the first stage; NH_3 is removed in the second stage.

- 5th Step - Remove residual contaminants. The acid gas stripping effluent will contain small amounts of the major contaminants which must be removed to achieve desired effluent water quality.

- Ultimate Disposal - Evaporation ponds are normally required for the disposal of wastewaters that cannot be economically upgraded. The general climate of the region in which the coal gasification plant will be located will determine whether solar evaporation ponds are feasible. Sanitary landfills are used for ultimate disposal of solids or semisolids (sludge) from the wastewater treating processes.

Treating Sequence Selection - Examples

The logic for selection of treating sequences is illustrated by three examples described below. The concentrations of various contaminants determine, in part, the processes chosen. For the three example cases, the contaminants are characterized as follows:

Contaminant Concentration	Example 1	Example 2	Example 3
phenols	high	low	low
dissolved acid gases	high	high	low
dissolved solids	low	low	high

Example 1 - The approach to achieving zero discharge would probably consist of recovery phenols as by-products and recovering acid gases for further processing to elemental sulfur and liquid ammonia. The treating processes are described on Table 4-8 and the treating sequence is shown on Figure 4-7.

Three processes can be used in Example 1 for removing the residual organic and inorganic contaminants in the wastewater. These processes and the criteria for their selection are as follows:

Treating Process	Criteria for Selecting Processes
• Carbon Adsorption	- should be used when an effluent of high quality is desired.
• Cooling Tower	- this is a low cost process; however, its effectiveness in removing dissolved inorganics is unknown.
• Forced Evaporation	- useful where it is impractical to use solar evaporation ponds and where the wastewater contains a high concentration of dissolved solids.

Table 4-8. TREATING PROCESSES FOR EXAMPLE 1

Contaminant Throughput	Probable Approach to Attain Zero Discharge	Treating Sequence	Treating Process
• High amounts of phenols; high amounts of dissolved acid gases; low quantity of of dissolved solids	Recover phenols as by-products. Recover acid gases for further processing to sulfur and liquid ammonia	• Tar, oil/H_2O separation	• Oil/H_2O separator
		• Removal of suspended solids and oils	• Flocculation-flotation
		• Phenol recovery	• Phenosolvan
		• Acid gas removal	• Acid gas stripping
		• Removal of residual organic and inorganic contaminants	• Carbon adsorption • Cooling tower Oxidation • Forced evaporation
		• Ultimate disposal of sludge	• Evaporation pond • Sanitary landfill

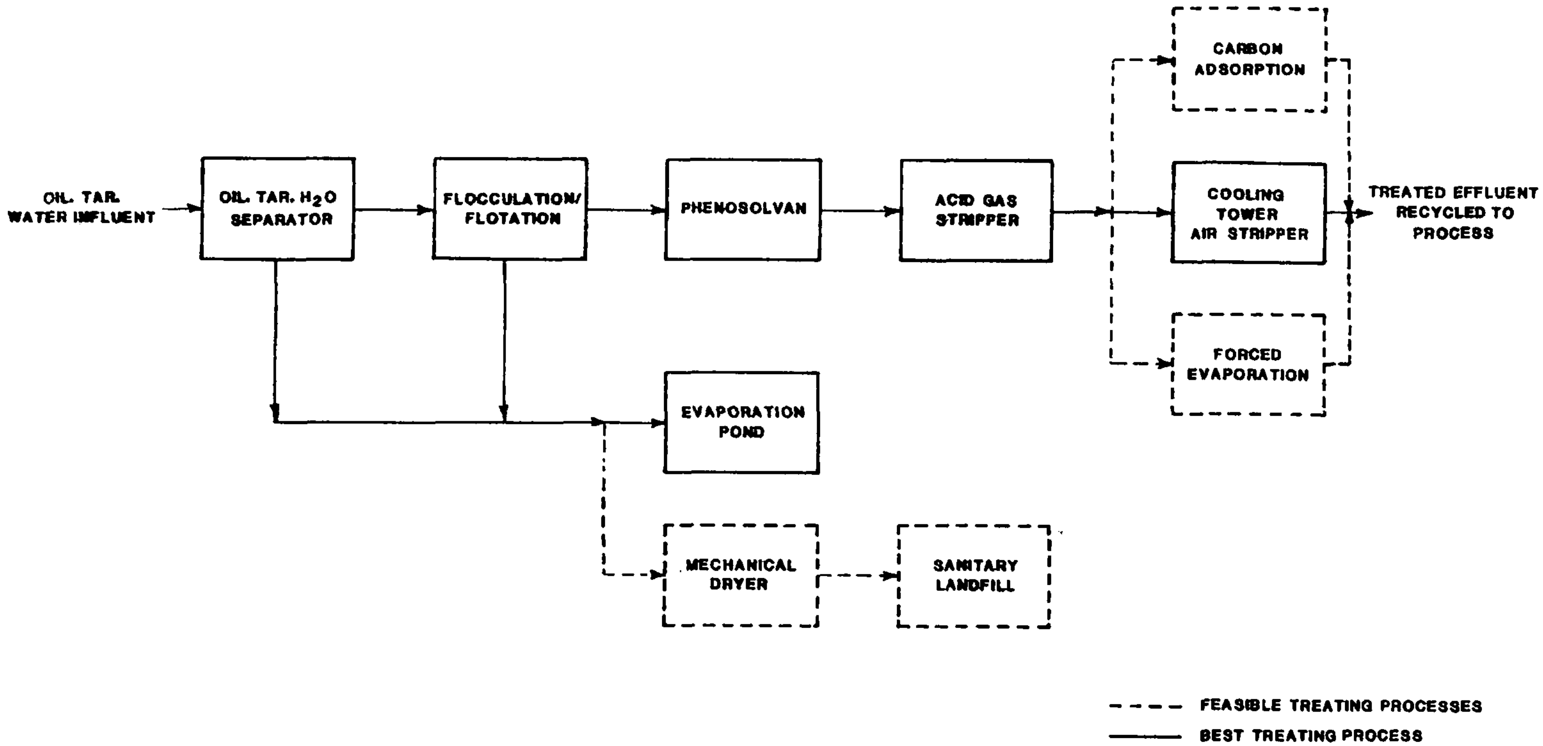


Figure 4-7. Wastewater treating sequence for example 1

Evaporation ponds and sanitary landfills are commonly used for the ultimate disposal of sludges. Evaporation ponds are used whenever possible for the disposal of wastewaters that cannot be economically treated. Sanitary landfills are generally used for the ultimate disposal of any solids or semisolids (sludge) generated in the plant; however, before sludges can be disposed of in a landfill they must be mechanically dewatered so that any possible leaching is minimized.

Example 2 - The approach to achieving zero discharge would probably consist of removing and destroying phenols, and recovering acid gases for further processing to elemental sulfur and liquid ammonia. The treating processes are described on Table 4-9 and the treating sequence is shown on Figure 4-8.

Two processes can be used for phenol removal in Example 2. The criteria for selecting these processes are discussed below.

Removal Processes	Criteria for Selecting Processes
• Carbon Adsorption	- has good control effectiveness, but not the most economical process for this example. It would yield a higher quality effluent than is required for recycling to the process.
• Biological Oxidation	- would be good process for this example. It requires no regeneration and is easily maintained. Effluent pH must be controlled between 5.5-9.5. The optimum pH level is 7.0. A high concentration of sulfides can adversely effect this process; therefore, biological oxidation should follow acid gas stripping in this example.

Three processes can be used in Example 2 for removing residual organics and inorganic contaminants.

Table 4-9. TREATING PROCESSES FOR EXAMPLE 2

Contaminant Throughput	Probable Approach to Attain Zero Discharge	Treating Sequence	Treating Process
• Low amounts of phenols; high quantity of dissolved gases; low quantity of dissolved solids	Phenol recovery uneconomic, therefore, remove phenols. Recover acid gases for further processing to elemental sulfur and liquid ammonia	• Tar, oil, water separation	• Oil/H_2O separator
		• Removal of suspended solids and oils	• Flocculation-flotation
		• Phenol removal	• Carbon adsorption • Biological oxidation
		• Acid gas removal	• Acid gas stripping
		• Removal of residual organic and inorganic contaminants	• Carbon adsorption • Forced evaporation • Cooling tower oxidation
		• Ultimate disposal of sludge	• Evaporation pond • Sanitary landfill

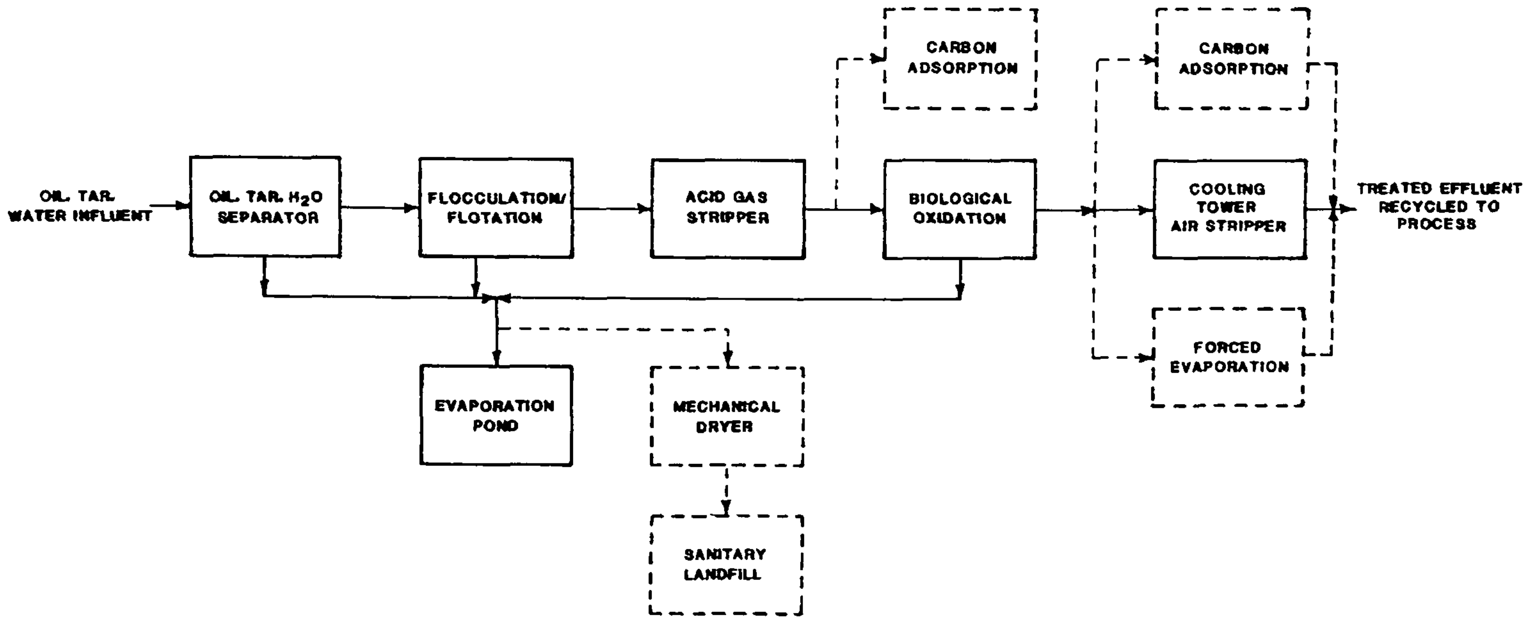


Figure 4-8. Wastewater treating sequence for example 2

Removal Processes	Criteria for Selecting Processes
• Carbon Adsorption	- after the biological oxidation and acid gas treating steps, the residual contaminants in the wastewater should primarily be dissolved NH_3 and H_2S. Carbon adsorption is most effective in removing dissolved organics, which are not present in great quantity in this example.
• Cooling Tower Oxidation (Air Stripping)	- would be effective for treating waters with low contaminant concentrations and is economical if air emissions are within allowable limits.
• Forced Evaporation	- is the least desired process because of its high operating costs.

Example 3 - The approach to achieving zero discharge would probably consist of completely removing and destroying phenols and acid gases; their recoveries would not be economically justified. The treating processes are described on Table 4-10 and the treating sequence is shown on Figure 4-9.

Carbon adsorption and forced evaporation can be used to remove residual contaminants. For this example, forced evaporation is best choice because of the relatively large quantities of dissolved solids to be removed from the wastewater.

4.2.4 Discharge Stream Summary

The water pollution control modules are sources of air, liquid and solid waste discharge streams. A summary of these discharge streams is presented in Table 4-11.

Air emissions - Air emissions from these modules contain organic vapors, ammonia, and acid gases (H_2S, CO_2, COS, etc).

Table 4-10. TREATING PROCESSES FOR EXAMPLE 3

Contaminant Throughput	Probable Approach to Attain Zero Discharge	Treating Sequence	Treating Process
• Low quantity phenols; low quantity of dissolved acid gases; high dissolved	Uneconomical to recover either phenols or acid gases; consequently, remove both from the wastewater	• Tar, oil, water separation	• Oil/H_2O separator
		• Removal of suspended solids and oils	• Flocculation-flotation
		• Phenol and dissolved acid gas removal	• Biological oxidation
		• Residual contaminant removal	• Carbon adsorption • Cooling tower oxidation • Forced evaporation
		• Ultimate disposal of sludge	• Evaporation pond • Sanitary landfill

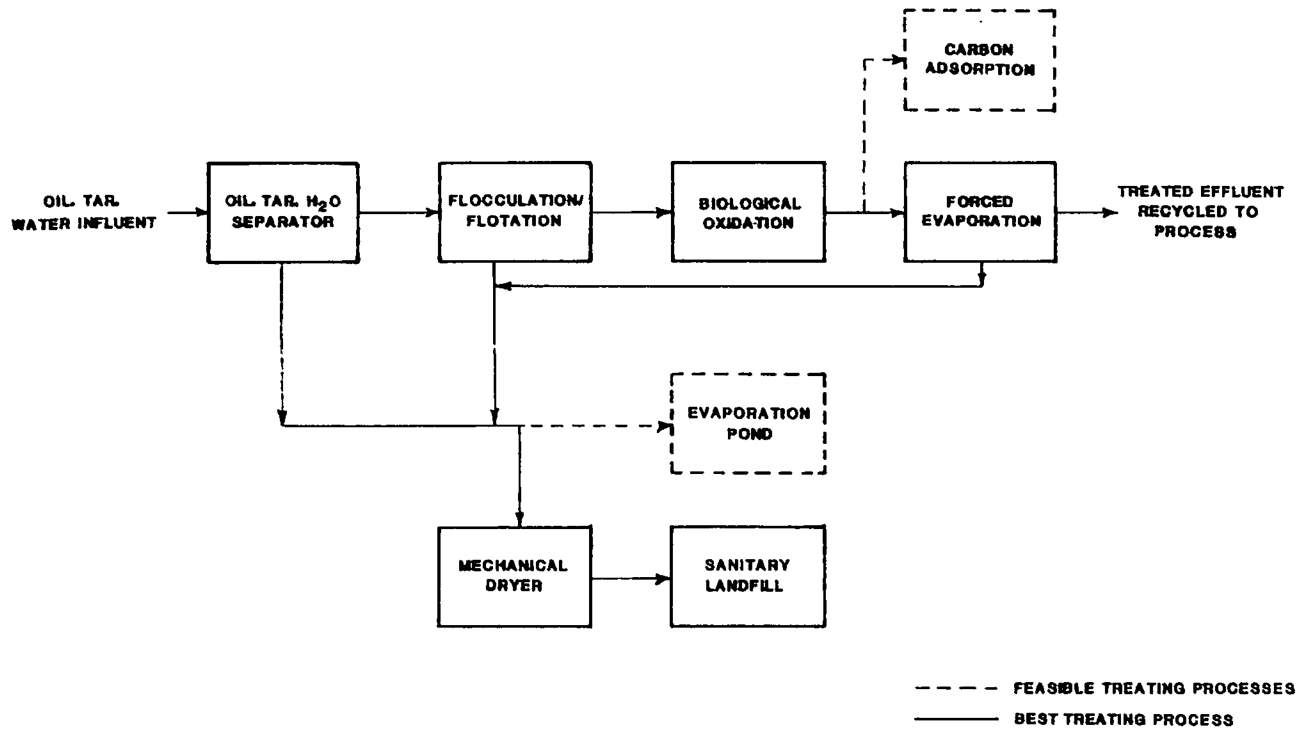


Figure 4-9. Wastewater treating sequence for example 3

Table 4-11. WATER POLLUTION CONTROL DISCHARGE STREAMS

Process Module	Processes	Probable and Potential Waste Streams
Suspended solids removal	Filtration, flocculation-flotation, oil-water separator	Aqueous - treated wastewater, oily scum, backwash water Solid - sludge
Dissolved organics removal	Liquid-liquid extraction, activated carbon adsorption, biological oxidation, cooling tower stripping	Aqueous - Regeneration quench, blowdown, spent solvent, treated wastewater Solid - sludge Gaseous - vent gases, cooling tower outlet, regeneration flue gas
Dissolved volatile inorganics removal	Acid gas stripping	Aqueous - treated wastewater Gaseous - potential H_2S and NH_3 emissions
Dissolved salts removal	Forced evaporation, ion exchange, membrane desalination	Aqueous - concentrated brine, spent ion exchange regeneration solution Gaseous - vent gases Solids - spent ion exchange resins

These emissions are either recycled to air pollution control modules for treatment or they are collected as a by-product.

Liquid effluents - The liquid effluents from water pollution control modules consist of tar, oil, and phenol by-products, spent regeneration solutions, concentrates, stripper condensates, and treated wastewater. The tar, oil, and phenols are useful by-products. Concentrates, sludges, and condensates are sent to a dewatering system and then to an evaporation pond for ultimate disposal. The treated water is either sent to evaporation ponds, recycled to other processes, or used as cooling tower feed. There are predictable air emissions from evaporation ponds and cooling towers. Improper evaporation-pond operation may result in water runoff which could contaminate surface waters. Groundwater contamination may occur if the pond is not properly lined. Liquid effluents (blowdown streams) from cooling towers are sent to evaporation ponds or to ash quench.

Solid wastes - The solid wastes consist of coal fines, ash, spent sorbents, biological sludge, spent ion-exchange resins, and evaporation pond sludge. These wastes are sent to the solid waste control modules for disposal.

4.3 SOLID WASTE POLLUTION CONTROL

The solid waste pollution control module treats and disposes of the following classes of wastes:

- Ash
- Coal residue
- Biological oxidation sludge
- Spent catalysts and filter media
- Coal fines
- Sulfur

Coal fines may be collected and burned on site; coal fines and sulfur may be sold as by-products. The other wastes may or may not require treatment before disposal, depending upon their composition. Chemical fixation and sludge reduction modules can be used to treat these solid wastes. Figure 4-10 is a flow diagram of the modules for solid waste control. Landfill, by definition, is the ultimate disposal technique for these wastes. The functions of and waste streams generated by these modules are described in the following paragraphs.

4.3.1 Sludge Reduction Module

The function of the sludge reduction module is to reduce the volatile matter and to destroy or detoxify the hazardous constituents in biological oxidation sludge. This can be accomplished either by incineration or by pyrolysis. Multiple-hearth and fluidized-bed incinerators are the types in common use.

In multiple-hearth incinerators, the sludge enters the top of the unit where it is dried. The dried sludge is then burned as it moves slowly down through the lower hearths. In fluidized-bed incinerators, sludge is combusted in a hot, suspended bed of sand.

Pyrolysis of biological oxidation sludge is a controlled thermal process that reduces sludge volumes and detoxifies solid residues. The carbon and volatiles in the sludge are not combusted because the pyrolysis takes place in an oxygen-deficient environment. The resulting pyrolysis gas may be used as a combustion fuel or it may be condensed to recover tars and oils.

The sludge reduction module is a source of both air and solid waste pollution. Air emissions which consist of particulates, combustion gases, and odors, require control. The solid waste generated by this module primarily consists of ash, which may either be sent to the chemical fixation module or to landfill.

4.3.2 Chemical Fixation Module

The chemical fixation module treats solid wastes to produce environmentally safe materials that can be used for either landfill or salable by-products. Most fixation processes consist of mixing proprietary chemicals with solid wastes and pumping the resulting mixture onto the land where solidification occurs in several days to weeks.

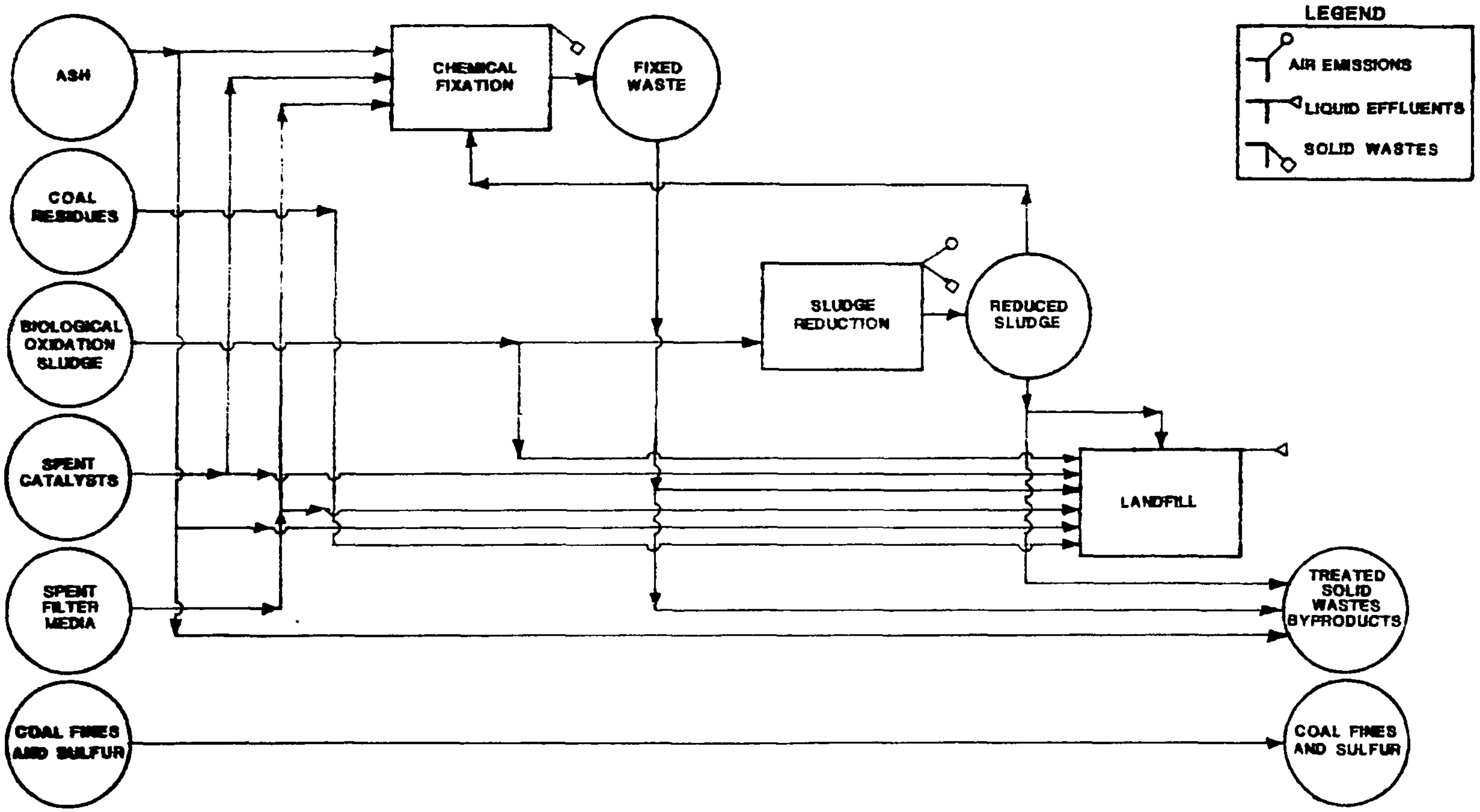


Figure 4-10. Flow diagram for the modules in the solid waste control operation.

The only waste stream generated by the chemical fixation module is the treated solid waste. This solid waste is either disposed of in landfill or can be sold as a soil conditioner.

4.3.3 Discharge Stream Summary

The solid waste pollution control module is a source of air and solid waste emissions. Air emissions are from the sludge reduction module. They consist primarily of volatile organics, combustion products and particulate matter. These emissions require further treatment before being vented to the atmosphere. The solid wastes generated by this module consist of "fixed" solids from chemical fixation and ash from sludge reduction. For ultimate disposal, these wastes may be sent to landfills or sold as by-products.

Landfilling solid wastes may also be a source of water pollution because of the potentially toxic compounds that can be leached from the solid wastes. These toxins may contaminate surface and/or ground waters depending upon the quality and quantity of runoff water at the landfill and the ground permeability characteristics.

With the exception of the spent filter media and coal residues, virtually all of the solid wastes generated during the production of low-Btu gas from coal are potentially salable products. The sludge from the biological wastewater treatment process can be sold as a soil conditioner or as fertilizer if trace elements or toxic compounds are not present in significant concentrations. Coal fines can be sold or recycled as a fuel for combustion processes. The spent catalyst can, in some cases, be sold to catalyst manufacturers for regeneration. The sulfur recovered from the air pollution control operation can be sold to sulfur users.

SECTION 5.0
SUMMARY OF TECHNOLOGY ASSESSMENTS

This report has been prepared as a reference and planning document for use in a comprehensive multimedia environmental assessment of coal conversion processes which produce low/medium-Btu gases. Control techniques needed to guarantee environmental acceptability of these technologies are also identified in this document.

5.1 ASSESSMENT PROGRAM PHILOSOPHY

For successful execution of a comprehensive environmental and control technology assessment program, it is required that specific information about the processes and pollution control technologies in question be gathered. A logical manner to gather this information is as follows:

a) Characterize the technology - This is a factual description of how each process works, its operating conditions, its history of performance, economics of operation, how the plants are assembled section by section, and so forth. This is the type of information that would be of prime importance to parties interested in designing and building low/medium-Btu coal gasification plants.

b) Identify problem areas - The next step is to identify specific sections of the processes where environmental problems are most likely to occur. To do this, the investigators must first have a thorough knowledge of the design of equipment being used in these process plants. They must also have specific knowledge of the compositions, physical properties, and sizes of streams flowing into and out of each process operation or module, and of the operating conditions (temperature, pressure, etc.) in these process units.

Finally, the investigators must develop the capability to judge the potential environmental problems associated with any given process. This judgment sense includes the ability to determine _if_ any environmental problem exists; _specifically where_ it is occurring; _why_ it is occurring; _and_ whether or not _more information_ will be needed. Some of _the information_ needed to develop this judgment comes from the literature; some from engineering assessment of the processes; and some will come from inspection of operating plants.

c) _Develop and execute test programs_ - Much of the essential information is simply not available from known sources. It will have to be obtained from actual tests in pilot units and commercial plants. These tests are costly. It is therefore critical that investigators determine early in the program just what information is most critically needed and what test work can reasonably be deferred.

Much of the cost in these test programs is related to chemical analyses. Complete analysis of some streams can be very expensive because of the large number of organic compounds and/or trace elements that may be present in these streams.

EPA is working on various methods to obtain maximum useful environmental data, while holding analytical costs to a practical level. One approach has been identified as Level 1. This involves a screening procedure which allows investigators to qualitatively identify groups of compounds and to broadly assess the health effects of pollutants (by bioassay testing) at relatively low costs.

d) <u>Perform environmental assessment</u> - The combined results of the engineering assessment, problem definition, and testing program will provide the basis for an environmental assessment. There are two primary questions to be answered in this step. What parts of these processes are environmentally unacceptable, and what is required to make them environmentally sound?

e) <u>Recommend control technology</u> - In the final analysis, a process is judged environmentally acceptable, or it is not. In many cases, it may be made acceptable by adding available and practical control equipment. It may be possible in some cases to reduce pollutants to a suitable level by altering operating conditions (gasification temperature can be raised; feedstock characteristics can be modified, and so forth). In still other cases, principle changes in the plant design may produce the desired pollution control.

5.2 CONTENT OF TECHNOLOGY STATUS REPORT

This report was prepared to provide investigators with an up-to-date source of information on low/medium-Btu coal gasification technology. Special emphasis has been placed on matters which might be considered environmentally and commercially significant. This is important in that it gives proper direction to investigators in subsequent studies and test programs.

In Sections 1.0 through 4.0, technologies are discussed in a conceptual manner. This is to acquaint investigators with the nature of commercially available processes and control systems. The practical problems and the characteristics of emissions that would be expected are also presented.

The appendices (Appendix A through E) contain detailed fact sheets for those process modules and control system modules that have been judged to be significant elements of the technology.

All information in this report and its appendices is related to these specific flow processes. Major processing steps such as coal gasification are identified as operations. Each operation has well defined input and output streams and performs a specific function. Smaller, but equally distinct process steps, are defined as modules. One or more of these modules may be combined to form either a major process operation or a pollution control technique.

5.3 SUMMARY OF ASSESSMENTS

As test programs are developed, investigators will continue to search out those matters of principle concern such as environmental impacts, economic factors, pollution control efficiency, and so forth. The following tables are summaries of such items which, based on results to date, are considered areas of concern.

Table 5-1 contains data requirements for environmental assessments. Input and output streams at major pollution sources are characterized. What is or is not known about each stream cited is listed under Remarks. This, in many cases, is the most important information on the table. Table 5-2 is a comparable summary for control technology assessments.

It is expected that these tables will be expanded to include new problem areas. Fugitive emissions, for example, while referred to only briefly, are an acknowledged emission problem that currently suffer from lack of definition. Better definitions of health effects and ecological effects attributable to specific pollutants are being made; these judgments will certainly alter the areas of concern in these tables.

Table 5-1. ENVIRONMENTAL ASSESSMENT DATA REQUIREMENTS

Operation Discharge Stream Source	Feedstock and Discharge Streams Requiring Characterization	Current Status of Environmental Data	Remarks
Coal Pretreatment			
Storage, Handling, and Crushing/Sizing Modules	Raw coal feedstock	There are many data on the major species in coal feedstock. However, there are little data on minor constituents such as trace elements and the types of sulfur in the coal.	More data on the trace constituents in the coal are needed.
	Dust emissions	The air emission from coal storage piles, crushing/sizing and handling will consist primarily of coal dust. The amount of these emissions will vary from site to site depending on wind velocities and coal size.	Asphalt and various polymers have been used to control dust emissions from coal storage piles. Water sprays and enclosed equipment have been used to control coal handling emissions. Enclosures and hoods have been used for coal crushing/sizing.
	Water runoff	The amount of data on dissolved and suspended organics and inorganics in runoff water produced from coal storage piles and dust control or supression processes is minimal.	Proper runoff water management techniques have been developed. More data on the characteristics of this wastewater need to be obtained to determine the need for treating this effluent.
	Solid wastes from crushing and sizing	This stream consists of rock and mineral matter rejected from crushing and sizing coal. There are few data concerning the trace components in this stream and the potential of these components to contaminate surface and groundwaters is not known.	This waste has been disposed of in landfills. Leaching data need to be obtained.
Coal Drying, Partial Oxidation and Briquetting Modules	Coal feedstock	Same as for the raw coal feedstock for the coal storage, crushing/sizing, and handling modules.	Same as for the raw coal feedstock for the coal storage, crushing/sizing, and handling modules.
	Vent gases	These emissions will contain coal dust and combustion gases along with a variety of organic compounds liberated as a result of coal devolitilization reactions. There are currently few data on the characteristics of these organic species.	The organic compounds need to be characterized to determine whether this discharge stream needs to be controlled. Afterburners in addition to particulate collection devices may be required.
Coal Gasification			
Coal Feeding Device	Pretreated coal feed	There are many data on the major components in the pretreated coal; however, there is little or no data on trace elements, the distribution of sulfur compounds, and the alkalinity of the coal ash.	Data needs to be obtained on the distribution of sulfur species and trace elements in the pretreated coal. The characteristics of the coal ash need to be determined to assess the potential for the ash retaining coal sulfur species.

(Continued)

Table 5-1. ENVIRONMENTAL ASSESSMENT DATA REQUIREMENTS

(continued)

Operation Discharge Stream Source	Feedstock and Discharge Streams Requiring Characterization	Current Status of Environmental Data	Remarks
	Input pressurizing gas for lock hoppers and transport gases for entrained-flow injection devices	There are very few data on the characteristics of these input streams. The constituents in these streams will exit in the gasifier output streams or be vented to the atmosphere.	In medium-Btu gasification plants, the use of the nitrogen vent stream from oxygen production is a good candidate for these gas input streams
	Vent gases	There are currently no data on the characteristics of these gases. These vent gases may contain hazardous species found in the raw product gas exiting the gasifier.	Vent gases from coal feeders can represent a significant environmental and health problem. Control of these emissions is required; however, the characteristics of these gases need to be determined to implement an adequate control device.
Ash Removal Device	Ash quench water	There are currently few data on process condensates that are used for ash quench water.	Many sources of contaminated water may be used as ash quench water. Characterization of these waste waters will be required to determine the potential effect of the ash removing some of the organics contained in these waters.
	Vent gases	There are currently no data on the characteristics of this discharge stream. This stream may contain hazardous species found in the raw product gas and may require control.	The type of ash removal device and the characteristics of the quench water will determine the characteristics of this stream.
	Spent ash quench water	There are currently no data on this discharge stream. This stream will contain dissolved and suspended organics and inorganics and will require control.	The magnitude of this stream can be minimized by designing an ash quench water recycle process.
	Ash or slag	There are limited data on the characteristics of the ash and slag especially concerning the amount of unreacted coal, trace elements and total organics.	Leaching tests need to be done on this solid waste to determine whether further treatment is necessary before ultimate disposal.
Coal Gasifier	Coal, additives, steam, and air/oxygen feedstocks	The coal characterization needs are the same as for Pretreated Coal. Additives to the coal will affect the characteristics of the discharge stream and there are currently few data on the composition of these additives.	Characterization of these input streams will provide a basis for correlating the characteristics of the gasifier discharge streams and raw product gas for various types of coal and coal additives.
	Start-up vent stream	There are currently no data on the composition of start-up vent stream. Depending on the coal feedstock, there may be tar and oil aerosols, sulfur species, cyanides, etc. in this stream; therefore, control of pollutants generated during start-up is required.	This stream can be controlled using a flare to burn the combustible constituents. The amount of heavy tars and coal particulates in this stream will affect the performance of the flare. Problems with tars and coal particles can be minimized by using charcoal or coke as the start-up fuel.

(Continued)

Table 5-1. ENVIRONMENTAL ASSESSMENT DATA REQUIREMENTS

(continued)

Operation Discharge Stream Source	Feedstock and Discharge Streams Requiring Characterization	Current Status of Environmental Data	Remarks
	Raw product gas	There are many data on the major constituents in this stream; however, few data are available on the minor components such as H_2S, COS, NH_3, NCN, trace elements, tar and particulate loadings, etc.	The concentrations of these minor gas constituents will affect the types of gas purification techniques (*i.e.*, acid gas removal processes) used to treat the raw product gas.
	Fugitive emissions	There are no data available on these emissions. These emissions will contain hazardous species that are in the raw product gas.	These emissions will determine the extent of worker exposure to hazardous species and define the need for continuous area monitoring of toxic compounds and personal protection equipment.
Gas Purification			
Particulate Removal	Raw product gas from the gasifiers	The characteristics of the particulate matter entrained in this stream need to be determined. There are few data reported on these characteristics.	The nature of the entrained particulate matter depends upon the coal feedstock and gasifier operating parameters. The particulate characteristics will affect the performance of particulate removal devices such as cyclones and electrostatic precipitators.
	Collected particulate matter	There are few data on the characteristics of this solid waste stream. This stream will contain unreacted carbon, sulfur species, organics, and trace elements.	Characterization of this stream is needed to determine whether it can be used as a by-product or whether further treatment is necessary before disposal. Current data indicate that there is a significant amount of unreacted carbon in this stream and it may be used as a combustion fuel.
Gas Quenching and Cooling	Spent quench liquor	There are few data on the composition of this stream; however, current data indicate that there are significant quantities of suspended and dissolved organics (primarily phenols) and inorganics present in this stream.	Characterization of this stream will determine the type of water pollution control techniques required to treat the spent quench liquor. These control techniques will vary depending upon the quantity and composition of this effluent stream.
Acid Gas Removal	Tail gases	There are few data on the composition of these tail gases. These gases will contain sulfur species and hydrocarbons.	These gases are the primary feedstock to the sulfur recovery and control processes. Trace constituents such as hydrocarbons, trace elements, and cyanides will affect the performance of these sulfur recovery processes.
	Spent sorbents and reactants	No data have been reported on these streams. These streams will contain hazardous species such as cyanides, heavy metals, organics, etc. and will require further treatment before disposal.	Characterization of this stream is required if it is to be treated using on-site pollution control devices.

(Continued)

Table 5-1. ENVIRONMENTAL ASSESSMENT DATA REQUIREMENTS

(continued)

Operation Discharge Stream Source	Feedstock and Discharge Streams Requiring Characterization	Current Status of Environmental Data	Remarks
Air Pollution Control			
Particulate Removal	Particulate-free gas	There are many data on the collection of particulates using a variety of devices. The efficiency of these devices depends upon the nature of the particulate matter and gas stream to be treated.	These devices are mainly used to collect coal dusts from the coal pretreatment and feeding processes. The particulate-free gas is a discharge stream from the gasification plant and is usually vented to the atmosphere.
	Coal dust	The physical characteristics (particle size) needs to be determined.	This stream is a usable by-product. It may be combusted on-site, briquetted, or sold.
Sulfur Recovery and Control	Treated gases	There are few data on the characteristics of the treated-gases from sulfur recovery and control processes used in low-Btu gasification systems. These gases will contain small amounts of sulfur species and hydrocarbons.	Many data are available on the treated gases from processes that are used in other industries (petroleum, petrochemical, natural gas, etc.). These data should be applicable to low-Btu gasification.
	Spent sorbents and reactants	There are no data on the composition of these blowdown streams. These streams will contain hazardous species such as organics, heavy metals, cyanides, etc.	These streams need to be characterized to determine the treatment processes required before they are disposed of.
	Sulfur	There are no data concerning the amount of trace elements in the by-product sulfur.	The amount and kinds of trace elements in the by-product sulfur will determine its usefulness in the production of various products such as fertilizer, chemicals, etc. In certain instances, the sulfur may be disposed of in a landfill rather than being sold. Therefore, the environmental acceptability of landfilling sulfur may need to be evaluated.
Hydrocarbon Removal	Treated gases	There are no data on hydrocarbon removal processes used in low-Btu gasification systems. These gases are vented to the atmosphere and may contain sulfur and nitrogen oxides along with trace elements.	Many data have been reported for controlling hydrocarbon emissions from other industries. These data should be applicable to low-Btu gasification systems.
	Liquid streams from regenerating activated carbon or polymers	No data are reported on the characteristics of these effluents for coal gasification. These streams will contain suspended and dissolved organics and inorganics and will require further treatment.	Characterization of these streams is needed to determine the processes required to control the pollutants in these effluents.

(Continued)

Table 5-1. ENVIRONMENTAL ASSESSMENT DATA REQUIREMENTS

(continued)

Operation Discharge Stream Source	Feedstock and Discharge Streams Requiring Characterization	Current Status of Environmental Data	Remarks
	Spent sorbent and catalysts	No data are reported on the characteristics of these solid wastes. These wastes will contain organic species, heavy metals, and other hazardous constituents and need to be treated before being disposed of.	Characterization of these solid wastes and leaching tests need to be made to determine the treating processes and disposal techniques required.
Water Pollution Control			
Oil/Water Separation	Separator vent gases	No data have been reported on the composition of these gases. These gases will contain sulfur species, cyanides, and hydrocarbons.	Characterization of these gases are required to determine the processes necessary to control these emissions before they are vented to the atmosphere.
	By-product tar/oil	There are few data on the composition of major components in this stream and no data on the minor constituents such as dissolved gases and trace elements.	The characterization of this stream is necessary to evaluate the type of end uses for the by-product tar/oil. Using the tar/oil as a combustion fuel may require flue gas treating processes if the concentration of sulfur in the tar is excessive.
	Sludge and semi-solids	No data have been reported on this solid waste stream for gasification plants. This stream will contain hazardous organics and inorganic species and will need to be treated before disposal.	Characterization of this stream is needed to determine the processes required to control the pollutants in this solid waste stream.
Flocculation-Flotation	Vent gases	Same as for separator vent gases.	Same as for separator vent gases.
	Oily scum	Same as for spent quench liquor.	
Dissolved Organics Removal (Liquid Extraction)	By-product phenols	There are few data on the composition of this stream. This stream will contain a variety of phenolic compounds along with other organics and trace elements.	Characterization of this stream is needed to help evaluate the phenol removal efficiency of these processes and to evaluate the potential end-uses of the phenol by-product.
	Treated wastewater	Few data are available on the major components in this stream and no data are available on the minor components such as trace metals, chlorides, fluorides, ammonia, and organics.	Characterization of this stream is necessary to determine the types of processes required to further treat this effluent.
Dissolved Organics Removal (Biological Oxidation)	Treated wastewater	Same as for the above treated wastewater.	
	Sludge and semisolids	No data are available on the characteristics of this solid waste stream from coal gasification. This stream will contain hazardous pollutants such as organics, cyanides, trace elements, etc. and will require further treatment.	Characterization of this stream is necessary to determine the processes required to control the pollutants before disposal. Data on the treatment of coke oven effluents should be applicable.

(Continued)

Table 5-1. ENVIRONMENTAL ASSESSMENT DATA REQUIREMENTS

(continued)

Operation Discharge Stream Source	Feedstock and Discharge Streams Requiring Characterization	Current Status of Environmental Data	Remarks
Dissolved Organics Removal (Carbon Adsorption)	Regeneration gases	No data are currently available on the composition of these gases for coal gasification. These gases will contain organics and inorganics that need to be controlled.	Data on the characteristics of these gases have been reported for using carbon adsorption in other industries. The applicability of these data to coal gasification is uncertain.
Dissolved Organics Removal (Cooling Tower Oxidation)	Gaseous emissions	No data are available on the composition of the gaseous emissions from cooling towers that are used to control dissolved organics from coal gasification. These emissions may contain partially oxidized organics, cyanides, sulfur species, and trace elements.	Characterization of these emissions is required to determine whether the dissolved organics are actually oxidized or stripped from the aqueous effluent in cooling towers.
	Cooling tower blowdown	Same as for the treated wastewater for Liquid Extraction.	
Dissolved Organics Removal (Acid Gas and Ammonia Stripping)	Stripped gases	There are few data on the composition of major and minor species in these gases. These gases will contain H_2S, COS, CS_2, mercaptans, thiopenes, ammonia, trace elements, and cyanides.	The gases from acid gas stripping provide a portion of the feed to the sulfur recovery and control process. The composition of trace constituents in this stream will affect the performance of the recovery process. The stripped ammonia represents a by-product. The characteristics of this stream will determine whether additional ammonia purification processes are required.
	Treated wastewater	Same as for the treated wastewater for Liquid Extraction.	
Dissolved Organics Removal (Forced Evaporation)	Vent gases	No data have been reported on the composition of these gases. These gases will contain organic vapors, cyanides, ammonia, and trace elements and need to be controlled.	Characterization of these gases is needed to determine the processes required to control these emissions before venting to the atmosphere.
	Treated wastewater	Same as for the treated wastewater for Liquid Extraction.	
	Sludge or concentrate	Same as for the sludge for Biological Oxidation.	
Evaporation Ponds	Gaseous emissions	No data are currently available on the gaseous emissions from evaporation ponds. These emissions will contain volatile organics and sulfur species.	Characterization of these gases is required to determine the environmental acceptability of using evaporation ponds as an ultimate disposal technique.
	Sludge	Same as for the sludge from Biological Oxidation.	

(Continued)

Table 5-1. ENVIRONMENTAL ASSESSMENT DATA REQUIREMENTS

(continued)

Operation Discharge Stream Source	Feedstock and Discharge Streams Requiring Characterization	Current Status of Environmental Data	Remarks
Solid Wastes Control			
Sludge Reduction (Incineration and Pyrolysis)	Gaseous emissions	No data are currently available on these emissions for coal gasification processes. These emissions may contain organics, chlorides, fluorides, sulfur species, and nitrogen oxides and may require control.	Characterization of these gases is needed to determine whether further treatment is required before venting to the atmosphere.
	Reduced sludge	Same as for sludge produced from Biological Oxidation.	
Chemical Fixation	Fixed Solids	No data have been reported on the characteristics of this solid waste for coal gasification systems. Leaching and stability studies are needed to evaluate the feasibility of this process.	Data on fixed solid wastes have been reported for other industries such as the petroleum, petrochemical, nonferrous metal, and utility industries. The applicability of these data is uncertain.
Product Gas End Uses			
Direct Combustion in Process Heaters and Boilers	Combustion gases	There are few data on the composition of these flue gases. These flue gases may contain significant amounts of NH_3, HCN, and trace elements depending upon the operating characteristics of the combustion process.	Characterization of these gases is required to determine the type of process required to adequately combust the trace constituents in the product low-Btu gas.
Direct Combustion in Gas Turbines for Combined Cycle Units	Combustion gases	No data are currently available; however, because of the strict specification for gas purity, there should be minimal pollution from these emissions.	There are strict specifications for particulate loading and sulfur and alkaline metal compounds for using low-Btu gas in combined cycle units.
Synthesis/Reductant Gas	Process vent gases	Because of strict specifications on the purity of the low-Btu fuel gas, the pollution attributable to the low-Btu gas should be negligible.	

Table 5-2. DATA REQUIREMENTS FOR CONTROL TECHNOLOGY ASSESSMENT

Operation Discharge Stream Source	Streams to be Characterized	Applicable Control Technologies	Data Requirements	Remarks
Coal Pretreatment				
Coal Handling and Storage	Particulate emissions and aqueous effluents from water runoff	Coal dust control using water sprays, wastewater treatment	Particulate characterization and emission rates of trace elements, solids, and organics in the water runoff.	Data from coal-fired power plants should be applicable.
Coal Crushing and Sizing	Emissions and hood collection efficiency	Coal dust control using hoods, cyclones, bag houses or ESP's	Particulate collection efficiencies.	Data from coal-fired power plants and particulate control devices should be applicable.
Coal Drying, Partial Oxidation, and Briquetting	Coal fines, organic binder, and air emissions	Hydrocarbon control using afterburners or adsorption	Particulate, hydrocarbon, and trace element emission rates.	Limited data is available for these emissions.
Coal Gasification				
Coal Feeding Devices	Vent gases	Particulate collection, incineration, recycle	Particulate and gaseous components from various coal feeding mechanisms.	No data are available on these emissions.
Ash Removal Devices	Vent gases	Particulate collection, cooling, incineration, recycle	Particulate and gaseous components from various ash removal devices.	No data are available on these emissions.
	Ash quench water	Recycle, wastewater treatment processes	Data on suspended and dissolved organics and inorganics are needed.	No data are currently available on this effluent.
	Ash or slag	Landfill, chemical fixation, by-product	Data on organics, unreacted carbon, and trace elements along with leaching tests are needed.	Limited data are available on this solid waste stream.
	Start-up vent stream	Incineration, particulate collection (cyclone, ESP)	Data on the amount and type of organics, H_2S, COS, SO_2, HCN, NH_3, and trace elements are needed along with incineration and particulate collection efficiencies.	No data are available on this emission.
	Raw product gas	See gas purification operation	Data on acid gases, particulate and tar loadings, NH_3, HCN, sulfur species, and trace elements are needed.	Limited or no data on particulate and tar loadings, H_2S, COS, CS_2, mercaptans, thiopenes, NH_3, HCN, and trace elements are available.
	Fugitive emissions	New designs, automatic pokers, good maintenance	Same as for the raw product gas stream.	No data are available.

(Continued)

Table 5-2. DATA REQUIREMENTS FOR CONTROL TECHNOLOGY ASSESSMENT

(continued)

Operation

Discharge Stream Source	Streams to be Characterized	Applicable Control Technologies	Data Requirements	Remarks
Gas Purification				
Particulate Removal	Inlet and outlet gas and collected particulates	Cyclones, ESP	Data on the particulate loadings and size distributions in each gas stream and the physical characteristics of the collected particulates are needed to determine collection efficiencies.	Limited data are available on these streams. Characteristics of the particulate matter will effect the performance of particulate removal devices.
Gas Quenching and Cooling	Inlet and outlet gas and collected tar and particulates	Spray chambers, hydrocarbon, packed or plate towers, air and water heat exchangers	Data on the collection efficiency of particulates, tars, oils, NH_3, HCN, H_2S, COS, CS_2, and trace elements are needed.	Limited or no data are available on the removal efficiencies for these species.
	Spent quench liquor	Recycle or wastewater treatment processes	Data on dissolved and suspended organics and inorganics along with trace elements are needed.	Limited data are available for this effluent. These data will be used to determine the wastewater for treatment processes required.
Acid Gas Removal	Inlet and outlet gas streams and blowdown sorbent or solvent	Chemical or physical sorption and direct conversion processes	Data are needed to determine the acid gas removal efficiencies, the solvent or solvent degradation characteristics, composition of the tail gases, and solvent/sorbent blowdown.	Limited data have been reported on most of the acid gas removal processes used to treat low/medium-Btu gas.
Air Pollution Control				
Particulate Control	Particulate generating sources such as coal handling and storage processes	Cyclones, ESP, baghouses, wet scrubbers	Data are needed to determine the effective means of collecting these emissions so they may be treated by typical particulate control techniques.	The methods of controlling these emissions are currently available; however, collecting the particulates from the source may be difficult.
Sulfur Recovery and Control	Inlet and outlet gas streams, sulfur by-product characteristics, and blowdown sorbents or reactants	Direct conversion and Claus tail gas cleanup processes	Data are needed to determine the sulfur removal efficiencies, the sorbent or reactant degradation characteristics, and blowdown stream composition.	Limited data are available on most of these processes for treating sulfur laden gases in gasification plants.
Hydrocarbon control	Inlet and outlet gas streams, and spent sorbents and catalysts	Afterburners and carbon adsorption	Data are needed to determine the hydrocarbon removal effectiveness and sorbent and catalyst degradation characteristics.	No data on these processes for controlling hydrocarbon emissions from gasification plants have been reported.

(Continued)

Table 5-2. DATA REQUIREMENTS FOR CONTROL TECHNOLOGY ASSESSMENT

(continued)

Operation

Discharge Stream Source	Streams to be Characterized	Applicable Control Technologies	Data Requirements	Remarks
Water Pollution Control				
Oil/Water Separation	Inlet and outlet waste-water streams and sludge	Filtration, separators	Data are needed to determine the oil removal effectiveness.	Limited data have been reported for gasification plants. Coke oven and refinery data may be applicable.
Suspended Solids Removal	Inlet and outlet waste-water streams and oily scum	Flocculation-flotation	Data are needed to determine the suspended solid removal effectiveness.	No data have been reported for this process in treating gasification wastewater. Data from other industries may be applicable.
Dissolved Organics Removal	Inlet and outlet waste-water streams, by-product phenols, and solvent blowdown	Liquid-liquid extraction	Data are needed to determine the phenol recovery effectiveness and solvent degradation characteristics.	Limited data are available on this process because of its proprietary nature.
Dissolved Organics Removal	Inlet and outlet waste-water streams and the semisolid wastes	Biological oxidation	Data are needed to determine the organic removal efficiency and the wastewater composition effects on the microorganisms.	Limited data have been reported for treating gasification waste-waters by this process.
Dissolved Organics Removal	Inlet and outlet waste-water streams and the spent sorbent	Carbon adsorption	Data are needed to determine the organic removal efficiency and the sorbent degradation characteristics.	No data have been reported for treating gasification wastewaters by this process.
Dissolved Organics Removal	Inlet and outlet waste-water streams and the air emissions from the cooling tower	Cooling tower oxidation	Data are needed to determine the amount of organics that are either oxidized or stripped in the cooling tower.	No data have been reported on the amount of organics oxidized or stripped in cooling towers.
Dissolved Inorganic Removal	Inlet and outlet waste-water streams and tail gases	Acid gas and ammonia stripping	Data are needed to determine the acid gas and ammonia removal efficiency and the composition of the acid gas and ammonia by-product tail gases.	Limited data have been reported on treating gasification wastewaters by this process.
Dissolved Inorganic Removal	Inlet and outlet waste-water streams and the concentrated liquor	Forced evaporation	Data are needed to determine the amount of volatile constituents in the vaporized water and the efficiency of reducing dissolved solids.	Limited data are available on treating gasification wastewaters by this process.
Evaporation ponds	Inlet wastewater streams and the bottom sludge	------	Data are needed to determine the amount of air emissions generated by evaporation ponds and the potential need for treating the sludge before disposal.	No data have been reported for evaporation ponds for disposing of wastewaters generated from gasification plants.

(Continued)

Table 5-2. DATA REQUIREMENTS FOR CONTROL TECHNOLOGY ASSESSMENT

(continued)

Operation

Discharge Stream Source	Streams to be Characterized	Applicable Control Technologies	Data Requirements	Remarks
Solid Waste Control				
Sludge Reduction and Chemical Fixation	Gasifier ash, sludge, spent sorbents, and other solid wastes	Incineration, pyrolysis, chemical fixation processes	Data are needed to determine the need for further treatment by sludge reduction or chemical fixation of the solid wastes before ultimate disposal.	Limited data have been reported on the characteristics of these solid wastes. Data from refineries and coal-fired power plants may be applicable.
Landfilling	Gasifier ash, sludge, spent sorbents, and other solid wastes	------	Leachate tests for trace elements and for dissolved organics and inorganics are needed.	Limited data have been reported on gasification process solid wastes. Data from coal-fired power plants and refineries may be applicable.

VOLUME I

REFERENCES

1. Wells, R. M., and W. E. Corbett, Electrical Energy as an Alternate to Clean Fuels for Stationary Sources. Volume I. Report No. PB 251-829. Austin, TX, Radian Corp., March 1976. L-5253

2. Putnam, A. A., E. L. Kropp and R. E. Barrett, Evaluation of National Boiler Inventory. Report No. PB 248-100, EPA 600/2-75-067, EPA Contract No. 68-02-1223. Columbus, OH, Battelle Columbus Lab., October 1975. L-1447

3. Magee, E. M., C. E. Jahnig and H. Shaw, Evaluation of Pollution Control in Fossil Fuel Conversion Processes. Gasification, Section 1: Koppers-Totzek Process. Final Report. Report No. PB-231 675, EPA-650/2-74-009a, EPA Contract No. 68-02-0629. Linden, NJ, Esso Research & Engineering Co., 1974. L-811

4. "Coal Preparation Today", Coal Age 73(7), 222-37 (1968). L-4718

5. Quazi, H. A., Coal Pretreatment Study. Interim Report. Report No. FE-2240-20, Series No. 1: A-1, ERDA Contract No. E(49-18)-2240. Alhambra, CA, C. F. Braun & Co., May 1975. L-9340

6. Hale, Dean, "Coal Gasification Takes on a New Look", Pipeline Gas J. 201 23-26 (3 March 1974). L-636

7. Howard-Smith, I., and G. J. Werner, Coal Conversion Technology. Park Ridge, NJ, Noyes Data Corp., 1976. L-1436

8. Squires, Arthur M., "Clean Fuels from Coal Gasification", Science 184 340-45 (1974). L-1046

9. Conn, A. L., "Low-Btu Gas for Power Plants", Chem. Eng. Progr. 69(12), 56-61 (1973). L-1243

10. Hall, E. H., et al., Fuels Technology. A State-of-the-Art Review. Report No. PB-242 535, EPA-650/2-75-034, EPA Contract No. 68-02-1323, Task 14. Columbus, OH, Battelle Columbus Labs., April 1975. L-1445

11. Bunas, Stanley J., An Annual Review of the Clean Fuels and Energy Program. Research Triangle Park, NC, Control Systems Lab., EPA, March 1975. L-48

12. Newman, L. I., Oxygen Gasification Processes in Germany. Tech. Pub. No. 2116. Washington, DC, U.S. Bur. Mines, November 1946. L-1597

13. Hendrickson, Thomas, comp., Synthetic Fuels Data Handbook. Denver, CO, Cameron Engineers, Inc., 1975. L-8343

14. American Gas Association, Proceedings of the Fourth Synthetic Pipeline Gas Symposium, Chicago, IL, 30-31 October 1972. Arlington, VA, 1972. L-8584

15. Bituminous Coal Research, Inc., Gas Generator Research and Development, Survey and Evaluation, Phase I, Volume I. Report No. PB-234 523, OCR-20, Int. 1, Vol. 1, OCR Contract No. DI-14-01-0001-324. Monroeville, PA, August 1965. L-7971

16. Hoy, H. R., and D. M. Wilkins, "Total Gasification of Coal", Brit. Coal Util. Res. Assoc. Mon. Bull. 22 57-110 (1958). L-9214

17. Odell, W. W., Gasification of Solid Fuels in Germany by the Lurgi, Winkler and Leuna Slagging-Type Gas-Producer Processes. U.S. Bur. Mines, Inform. Cir. No. 7415. Washington, DC, U.S. Bur. Mines, 1947. L-1600

18. Lacey, J. A., "The Gasification of Coal in a Slagging Pressure Gasifier", Amer. Chem. Soc., Div. Fuel Chem., Prepr. 10(4), 151-67 (1966). L-9100

19. Hoy, H.R., and D. M. Wilkins, "Total Gasification of Coal", Brit. Coal Util. Res. Assoc. Mon. Bull. 22 57-110 (1958). L-9214

20. Odell, W. W., Gasification of Solid Fuels in Germany by the Lurgi, Winkler and Leuna Slagging-Type Gas-Producer Processes. U.S. Bur. Mines, Inform. Cir. No. 7415. Washington, DC, U.S. Bur. Mines, 1947. L-1600

21. Donath, E. E., and R. A. Glenn, "Computer Study of Stage 2 Reactions in BCR Two-Stage Super-Pressure Coal Gasification Process", Amer. Chem. Soc., Div. Fuel Chem., Prepr. 11(4), 333-47 (1967). L-4788

22. Calvert, Seymour, and Richard Parker, "Collection Mechanisms at High Temperature and Pressure", in Proceedings of the Symposium on Particulate Control in Energy Processes, San Francisco, CA, 11-13 May 1976. Mountain View, CA, Acurex Corp., Aerotherm Div., September 1976. (pp. 491-521) L-9084

23. Franzen, Johannes E., and Eberhard K. Goeke, "Gasify Coal for Petro-chemicals", Hydrocarbon Process. 55(11), 134-38 (1976). L-9062

24. Kasai, Takeshi, "Konox Process Removes H S", Hydrocarbon Process. 54(2), 93-95 (1975). L-730

25. Richardson, James T., "SNG Catalyst Technology", Hydrocarbon Process. 52(12), 91-95 (1973). L-967

26. Bratzler, K., and A. Doerges, "Amisol Process Purifies Gases", Hydrocarbon Process. 53(4). 78-80 (1974). L-1353

27. Dingman, J. C., and T. F. Moore, "Compare DGA and MEA Sweetening Methods", Hydrocarbon Process. 47(7), 138-40 (1968). L-1354

28. Riesenfeld, F. C., and A. L. Kohl, Gas Purification. Second edition. Houston, TX, Gulf Publishing Co., 1974. L-1359

29. Rosenwald, R. H., et al., "Sulfide Oxidation: Sulfox System of Pollution Control", Ind. Eng. Chem., Prod. Res. Div. 14(4), 218-26 (1975). L-1360

30. "Sulfur Recovery Process Sweetens Sour Gas", Chem. Eng. News 48(18), 68-69 (1970). L-1428

31. Raney, Donald R., "Remove Carbon Dioxide with Selexol", Hydrocarbon Process. 55(4), 73-75 (1976). L-1439

32. Talley, Dennis B., "Startup of a Sour Gas Plant", Hydrocarbon Process. 55(4), 90-92 (1976).

33. Franckowiak, S., and E. Nitschke, "Estasolvan. New Gas Treating Process", Hydrocarbon Process. 49(5), 145-48 (1970). L-1504

34. Robson, Fred L., et al., Fuel Gas Environmental Impact: Phase Report. Report No. EPA-600/2-75-078, EPA Contract No. 68-02-1099. East Hartford, CT, United Technologies Research Center, November 1975. L-1521

35. Reid, L. S., and F. M. Townsend, "New Two-Way Process Sweetens Gas and Recovers Sulfur", Oil Gas J. 56(41). 120-22, 124 (1958). L-1606

36. Maddox, R. N., Gas and Liquid Sweetening. Norman, OK, John M. Campbell Co., 1974. L-1643

37. Woertz, R. B., "A Selective Solvent for Purifying Natural Gas", J. Petrol. Tech. 23 483-90 (April 1971). L-1644

38. Booz-Allen Applied Research, Evaluation of Techniques to Remove and Recover Sulfur Present in Fuel Gases Produced in Heavy Fossil Fuel Conversion Plants. Report No. 9075-015, EPA Contract No. 68-02-1358. Bethesda, MD, January 1975. L-1669

39. Goar, B. G., "Sulfinol Process Has Several Key Advantages", Oil Gas J. 67 117-20 (30 June 1969). L-1916

40. Grekel, H., "H_2S to S...by Direct Oxidation", Oil Gas J. 57(30), 76 (1959). L-3103

41. "Hydrocarbon Processing Gas Processing Handbook", Hydrocarbon Process. 54(4), 79-138 (1975). L-4565

42. Doerges, A., K. Bratzler and J. Schlauer, "LUCAS Process Cleans Lean H_2S Streams", Hydrocarbon Process. 55(10), 110-11 (1976). L-8560

43. Kasai, Takeshi, "Konox Process Removes H_2S", Hydrocarbon Process. 54(2), 93-95 (1975). L-730

44. Riesenfeld, F. C., and A. L. Kohl, Gas Purification. Second edition. Houston, TX, Gulf Publishing Co., 1974. L-1359

45. Maddox, R. N., Gas and Liquid Sweetening. Norman, OK, John M. Campbell Co., 1974. L-1643

46. Rawdon, A. H., R. A. Lisauskas and S. A. Johnson, "NO_x Formation in Low and Intermediate BTU Coal Gas Turbulent-Diffusion Flames", Presented at the NO_x Control Technology Seminar, sponsored by Electric Power Research Inst., San Francisco, CA, 5-6 February 1976. L-2137

47. Personal Communications with W. J. Rhodes.
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16. ABSTRACT The report represents the current data base for the environmental assessment of low- and medium-Btu gasification technology. Purpose of the report is to determine: processes that can be used to produce low/medium-Btu gas from coal, uses of the product gas, multimedia discharge streams generated by the processes, and the technology required to control the discharge streams. Attention is on the processes that appear to have the greatest likelihood of near-term commercialization. This type of screening provides the preliminary basis for establishing priorities for subsequent phases of the low/medium-Btu gasification environmental assessment program. Processes required to produce low/medium-Btu gas from coal are divided into discrete operations: coal pretreatment, gasification, and gas purification. Each operation is divided into discrete modules, each having a defined function and identifiable raw materials, products, and discharge streams. This volume includes a discussion of the status, significant trends, major process operations, multimedia discharge stream control strategies, and recommendations for future program activities. Volume II contains appendices including detailed process, environmental, and control technology data for the processes considered to have the greatest potential for near-term commercialization.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Air Pollution	Air Pollution Control	13B
Assessments	Stationary Sources	14B
Coal	Environmental Assessment	21D
Gasification		13H,07A
Treatment	Pretreatment	
Gas Purification		

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