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LOW- AND MEDIUM-BTU GASIFICATION SYSTEMS: Technology Overview

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LOW- AND MEDIUM-BTU GASIFICATION SYSTEMS: Technology Overview

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Abstract

This report gives an overview of systems which are most likely to find commercial application for production of low- and medium- BTU gas from coal. Present and projected applications of the technology are reviewed. Individual processes are described and all potential discharges to air, water or land are identified and discussed.

The coverage of the subject is felt to be complete in the sense that all applications of the technology and all potentially polluting discharges have been considered. The report does not, however, present detailed information on composition of discharges, control technology, economics and the like. It is designed for use in development of programs and studies needed to quantify potential pollution control problems, prioritize environmental protection needs and related activities. It was felt that inclusion of all background data would detract from, rather than enhance, its usefulness for broad analysis. For those needing more detailed information references to background documents have been supplied.

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I. INTRODUCTION

The Environmental Protection Agency's Industrial Environmental Research Laboratory at Research Triangle Park is conducting a series of environmental assessments. These activities involve continuing iterative studies aimed at 1) identification and characterization of industrial process discharges, 2) evaluation of pollution control and waste disposal options, 3) comparison of estimates for environmental loadings with applicable standards and projected environmental goals, and 4) prioritization of potential pollution problems and control technology needs. This overview report, which deals with low- and medium-Btu gas, is one of a series which is being developed for the technologies which deal with processing of coal. It was developed in connection with activities to accumulate current process technology for the overall assessment program which is described in Figure 1 of Appendix A.

The objective of this report is to describe the system* or combinations of processes which are likely to be used for production of low- and medium-Btu gas from coal. This involves

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* Certain terms, such as "systems", which have a number of commonly accepted meanings have been defined specifically for use in environmental assessment activities of I.E.R.L/RTP. A glossary of these terms is included in Appendix B.

making judgments as to types of coal that will be processed, types of gasifier (and auxiliary processes) which will be employed, and markets which will develop for gas from coal. After definition of the overall systems of greatest potential for commercialization, it is expected that conceptual designs will be developed for use in predicting and assessing potential environmental impacts. Data supporting statements in the overview report are mainly contained in Radian Corporation's report to the Environmental Protection Agency entitled "Environmental Assessment Data Base for Low/Medium-Btu Gasification Technology" (EPA-600/7-77-125a and b, November 1977) (1). Where other sources of information were used, they are cited in the text.

The balance of the overview report is divided into three sections. Section II, "Status of Technology", presents information intended to define the future prospects for coal gasification in relatively broad terms. Section III "Description of Technology" presents more specific information on individual processes which are considered likely to be employed commercially and Section IV "Environmental Impacts" discusses the kinds of pollutant discharges which must be anticipated.

II. STATUS OF TECHNOLOGY

The production of low- (5.6×10^5 J/Nm^3, 150 Btu/scf) and medium- (13.1×10^6 J/Nm^3, 350 Btu/scf) 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 an estimated 11,000 coal gasifiers were in service in the U.S. Most of these were retired when cheap natural gas became available. For many years the technology for gasification was dormant. Improvements were limited to evolutionary changes in the relatively few systems which were installed. Beginning in the 1960's the Federal government, in concert with industry, started programs to develop improved gasification systems which would be more widely useful than those on the market. The early programs were mainly aimed at development of processes for production of high-Btu gas which could be used to supplement supplies of natural gas used for home heating. Now, with gas supplies dwindling and petroleum prices escalating, there is increasing interest in evaluating the possibility of substituting gas from coal for natural gas or petroleum derived fuels used by industry.

Low- and medium-Btu gasification systems being considered are in varying stages of development. Also they are extremely variable as far as scale of operation and other features are concerned. Several now in operation involve fixed-bed gasifiers about 8-10 feet in diameter which process about 15 tons per day of low sulfur coal. The gas, not requiring sulfur removal to meet present standards, is passed through a dust collector and burned to provide process heat. The most complex system would involve production of fuel for "combined cycles" in which electricity is produced when the gas is burned, expanded through a gas turbine, and then sent to a boiler where the sensible heat is used to produce steam for a steam turbine. For a 500 MW plant 5-10 gasifiers around 10 feet in diameter processing 50-80 Kg/sec (5000-8000 tons day day of coal) (2) would be required.

A number of the smaller systems are offered commercially and a few are operating in the U.S. The larger systems are strictly conceptual and it would require 7-10 years for design and construction of such a plant. Neither the older systems, such as those offered commercially, nor the new processes under development, have been proved to be satisfactory solutions to today's clean fuel supply problems. 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 the standpoint of either process considerations or environmental impacts) which could be built today. Hence, more information is needed to determine the commercialization potentials of the various candidate systems.

Because of the lack of information, 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 with flue gas desulfurization and fluidized-bed combustion. It is possible, however, to comment on some of the factors for judging the status of development. The most important of these factors are:

- The cost of the fuel gas produced,
- Energy efficiency of the process,
- Applicability of process to different end-use requirements,
- Extent of on-going development work, and
- Factors relating to possibilities for, and potential rate of commercialization of environmentally sound systems.

COST

Projecting the costs of low- and medium-Btu fuel gas produced from coal is difficult because of uncertainities in the limited cost data available and because costs are sensitive to the type of system and plant location. It appears, however, that small, relatively simple gasification systems which convert low sulfur fuels into fuel for direct process heat could produce gas for about $\$2.50/10^9$J ($\$2.60/10^6$ Btu). Such a system would employ a hot cyclone for particulate collection. If more sophisticated gas cleaning including sulfur removal was required, it could easily add an additonal \$1.00-\$2.00/10^9J (\$1.05 to \$2.10 per 10^6 Btu) to the cost of the fuel. Such a unit would produce anywhere from 0.1 to 2.4 x 10^9J/sec (10 to 200 x 10^6 Btu/day).

The use of gasifiers in combined cycles to produce electricity presents a very different situation. Such a plant would produce on the order of 1.8 x 10^9 J/sec (150 x 10^6 Btu/day) of product gas. The gasification system would cost in the neighborhood of \$250-\$400 million dollars and would produce gas costing 2 to 3 times as much as the coal supplied (3). These amounts represent great increases over costs estimated when expanded usage of low-Btu systems began receiving serious consideration in the U.S. This continuing escalation is attributable to rising construction costs, rising fuel costs, and a better understanding of problems associated with commercialization of the technology. Other developing energy technologies being considered for electrical generation have undergone, or are subject to, similar escalation of projected cost.

Despite the apparent high cost of gas from coal relative to fuels available in the past, it appears that low- and medium-Btu gasification systems will be competitive in numerous critical applications where clean, gaseous fuels are required but will not be available from other sources. For many industrial applications the increased fuel cost will have to be weighed against the losses which would be suffered by not operating and gasification at any cost that can reasonably be foreseen will be attractive.

Energy Efficiency

Like costs, the energy efficiencies of the various gasification systems being studied are difficult to determine. Thermal efficiency is a cost factor with special significance as far as the applicability of the technology is concerned. Low efficiencies will tend, in specific applications, to make the gasification non-competitive with technologies serving the same need, e.g., the energy efficiency of a low-Btu gasification/combined-cycle system must be high enough to make it competitive with coal-fired power plants equipped with sulfur and particulate emission control hardware. Efficiency will be less critical in some of the other proposed industrial applications for gasification plants where gas must be used and is either not available or prohibitively expensive. However, with prices escalating, efficiency of coal utilization will be of increasing importance in all applications.

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, it was reported that no more than 65 percent of the heat content of the coal supplied to an entrained-bed, pressurized, slagging ash gasification system and the associated boiler supplying electrical power could appear as product heating value. A 4 percent penalty was estimated if the product fuel was to be used for coal drying. This reduced the net process efficiency to 61 percent. When the associated boiler was assumed to be fired with product gas instead of coal, the estimated overall plant efficiency dropped to 53 percent. If the process operating pressure was assumed to be 0.10 MPa (15 psig) instead of 1.03 MPa (150 psig), the savings in compression energy increased the base efficiency of 61 percent to 69 percent (4). From these and other data it would appear that the figures of 85 percent and above figures which have been quoted in the literature are either optimistic or are not taking into account all energy requirements. Efficiency of 60-65 percent for present day gasifiers and perhaps 75 percent for improved gasifiers of the future are considered more reasonable estimates.

The importance of process efficiency for both gasifiers and gas turbines in combined cycles operation can be illustrated by considering the advancement of turbine technology needed to make combined cycle power using gas from present day gasification processes economically competitive. Increasing present tolerable turbine inlet temperatures of about 1400°K (2000°F) to temperatures of about 1600°K (2400°F) has been estimated to be necessary to make combined cycles about equal in cost to conventional boilers for production electricity. Further success in turbine development would be required for a clear economic advantage (3). Thus while combined-cycle power generation from low-Btu gas offers substantially higher overall cycle efficiencies, success in development of more efficient turbines and gasifiers will be necessary to realize potential advantages.

Applicability

At this point low- and medium-Btu gasification systems appear to be of greatest near-term interest for their ability to supply gases for industrial usage. The industrial applications of probable future importance are (1) synthesis gas for ammonia and methanol, (2) fuel for direct process heat in processes such as brick and lime kilns, glass furnaces, paint drying ovens, etc. and (3) fuel for small and intermediate size industrial boilers. Gasification, especially for synthesis gas and direct process heat systems such as those now in operation could become commercially important a few years in the future.

Use of coal gasification to produce medium-Btu gas as a source of synthesis gas for ammonia and methanol could serve as a replacement for 400 Nm^3/sec (4.7×10^{11} scf/yr) of natural gas (5). This total market is small compared to other demands, but substitution of gas from coal in this application would probably be economically more acceptable because of the limited number of alternatives which are available. Further, such a substitution of gas would represent a modest technical advance since commercially available technology appears to be applicable to design of plants which meet present environmental standards.

Production of low- or medium-Btu gas for production of direct heating for industrial processes appears promising for the same economic and technical reasons. However, the overall market is greater, amounting to some 4×10^{15} Btu/yr (equivalent to 340 Nm^3/sec, 4×10^{12} scf/yr of natural gas) (6).

The use of low- or medium-Btu gas in small industrial boilers (<10MW equivalent) to replace distillate oil or natural gas would require 2.1×10^{11} J/sec (6.2×10^{15} Btu/yr), an amount far exceeding supplies which could be generated by gasification in the foreseeable future. The extent to which gas from coal would be in demand for existing boilers is doubtful. Retrofit of gas fired boilers is not likely to be practical in many situations. The cost of installing coal handling equipment would be high even if space were available. Further, reduced output of the boiler, compared to that which would be obtained using natural gas, would result in additional economic penalties. Technology being developed for production of gaseous fuels from residual oil may however, find application where feedstocks are available and the use of gas from coal for new boilers may prove practical. Also on-site combustion of low-Btu gas in boilers designed for its use may be economically attractive for the near future and medium-Btu gas distributed to new and existing boilers from a central gas generating plant to consumers within 100 miles appears to be a viable option (3).

The economic competitiveness of low- and medium-Btu gas in industrial boilers will be strongly influenced by the advances which are made in development of fluidized bed combustion systems and in development of flue gas cleaning systems which are applicable to boilers in the 5 to 50 MW equivalent size range. At present large quantities of gas and petroleum derived fuels are burned in industrial boilers of this size. It seems that some method of burning coal will be substituted for gas and oil in these applications as the shortages of energy become more critical.

The only potential application of low- and medium-Btu gas other than feedstocks, direct industrial process heat, and industrial boilers is in production of electricity. In this application conversion of existing boilers to gas produced from coal will be impractical with available technology. Gasification units could be designed for operation with new boilers of conventional design but this is unlikely. In utility applications design of new units equipped with coal gasifiers must compete with existing technology, i.e., large conventional boilers equipped with flue gas cleaning systems. Comparative analysis of the two systems indicates that substantial improvements in the economics of gasification will be required before this potential market can be penetrated (3).

The outlook for low-Btu gasifications systems integrated in new combined cycle plants is, as indicated in the discussion of gasification costs, somewhat more optimistic. If gas turbine and/or gasifier efficiencies can be increased sufficiently, the economics of combined cycles burning gas from coal will become attractive.

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 Environmental Protection Agency, Department of Energy and National Institute of Occupational Safety and Health, as well as a significant number of industrial organizations, are sponsoring research aimed at understanding and improving the capabilities of gasification systems. Work in this connection is being concentrated on evaluations of both presently available and advanced gasification system designs which utilize features enhancing the efficiency, environmental acceptability, and the operability of systems which are representative of currently available or developmental technology. This research has been directed toward improved:

- Characterization of the environmental impacts from gasification plant discharges,
- High temperature product gas cleanup processes,
- Coal feeding and ash removal devices (particularly for pressurized systems),
- Water treatment methods,
- Materials of construction, and
- Reactor designs.

Much of the on-going work is hardware oriented. Commercial and demonstration projects are the subject of many projects. At present most of the expenditures are for projects aimed at fitting existing technology to newly identified markets in environmentally sound systems. It is believed, however, that fundamental studies of gasification are needed (3). Also, it is clear that analysis of control technology for gasifier discharges is needed. And studies to better define the level of tolerable discharges of potentially harmful emissions are essential to effective use of gasification for present and future energy needs. Work to meet these needs has been initiated and future activity will provide support for development programs on large scale equipment.

Commercial Prospects

The prospects for expanded commercialization of low- and medium-Btu gasification will be influenced by many factors. Expanded use of presently available gasification systems to produce medium-Btu gas for use in chemical synthesis or off-site combustion, and low-Btu fuel for use in on-site direct process heat or as a reducing gas, will require demonstration that the available systems can be installed with appropriate pollution control equipment. The rate of installation of units demonstrated to be adequately controlled will depend primarily on the rate at which process suppliers can respond to demand for new units. Until 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. Increasing awareness of the potential for the application of gasification systems in recent years led to an expansion in the number of groups that are actively developing and marketing gasification systems. It is expected, however, that the growth of the existing coal gasification industry during the next few years will tend to be limited by the time required to design and build the specialized equipment required in such 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, between 1980 and 1990.

Commercial application of medium-Btu gas systems supplying fuel for off-site combustion may be more complicated. Even if presently available, or advanced developmental gasification systems, are successfully demonstrated in other service, a central plant large enough to supply fuel via pipeline to customers within a one-hundred mile radius would present significantly different problems. The time required to build the plant would be longer. Business arrangements would be more complicated. The number of sites where coal is available, where capital for such a plant is available, and customers for the product are available, may be limited. Finally, fluid bed combustion may be more attractive to some customers who need alternative sources of heat.

Successful development of combined cycle systems for generation of electricity in commercial systems may be dependent on more intangibles than other potential applications. Large scale gasification must be demonstrated to be economically viable and environmentally sound. Improvements in efficiency of the gasifier and the gas turbines which are available will be needed to make the approach competitive with conventional power boilers equipped with flue gas cleaning equipment. Further, fluidized bed combustion systems which are being developed for use in combined cycle systems for electrical generation could prove to be more attractive.

In summary, it appears that low- and medium-Btu gasification systems probably can be supplied to meet demand for fuels when gas and oil are no longer available for some industrial usage. The systems considered most likely to find wide application are shown in Table 1. Fluid bed combustion may be

Table 1. POTENTIALLY IMPORTANT GASIFICATION SYSTEMS

Type of gasification system	Product
Pressurized (low-Btu)	Fuel for combined electrical generating cycles
Pressurized (medium-Btu)	Fuel for off-site boilers Fuel for off-site process heat Synthesis gas for on-site use Synthesis gas for off-site use
Atmospheric (low-Btu)	Fuel for on-site boiler firing Fuel for on-site process heat Reducing gas for on-site processes

competitive for some of these markets but for others coal gasification seems to be the only viable alternative. For industrial boilers and electric utility fuels, gas from coal may prove to be competitive. It will, however, have to be more economical and effective than conventional boilers with available pollution control systems or other technologies which are under development.

III. DESCRIPTION OF TECHNOLOGY

The gasification systems which are most likely to be employed for production of low- or medium-Btu gas are not, as might be supposed from the many combination of processes which might be visualized, numerous. In this discussion the most promising systems (and their constituent processes) are identified and discussed from the standpoint of raw material requirements, and product gas characteristics.

Gasification Systems

The gasification process is a key element of a total system comprised of three operations (coal pretreatment, gasification, and raw gas cleaning) which are likely to be necessary for any facility in which coal is converted to gaseous fuels or chemical feedstocks. The specific processes employed for any of the three operations will be determined by 1) the properties of the feedstock coal, 2) product quality requirements, and 3) the type of gasifier that is employed. All three operations have potential for discharge of pollution. The discharges and the potential severity of their environmental impact will depend on the characteristics of the specific processes employed. Figure 1 depicts the processes which would be employed for basic systems with greatest potential for commercialization. These are as follows:

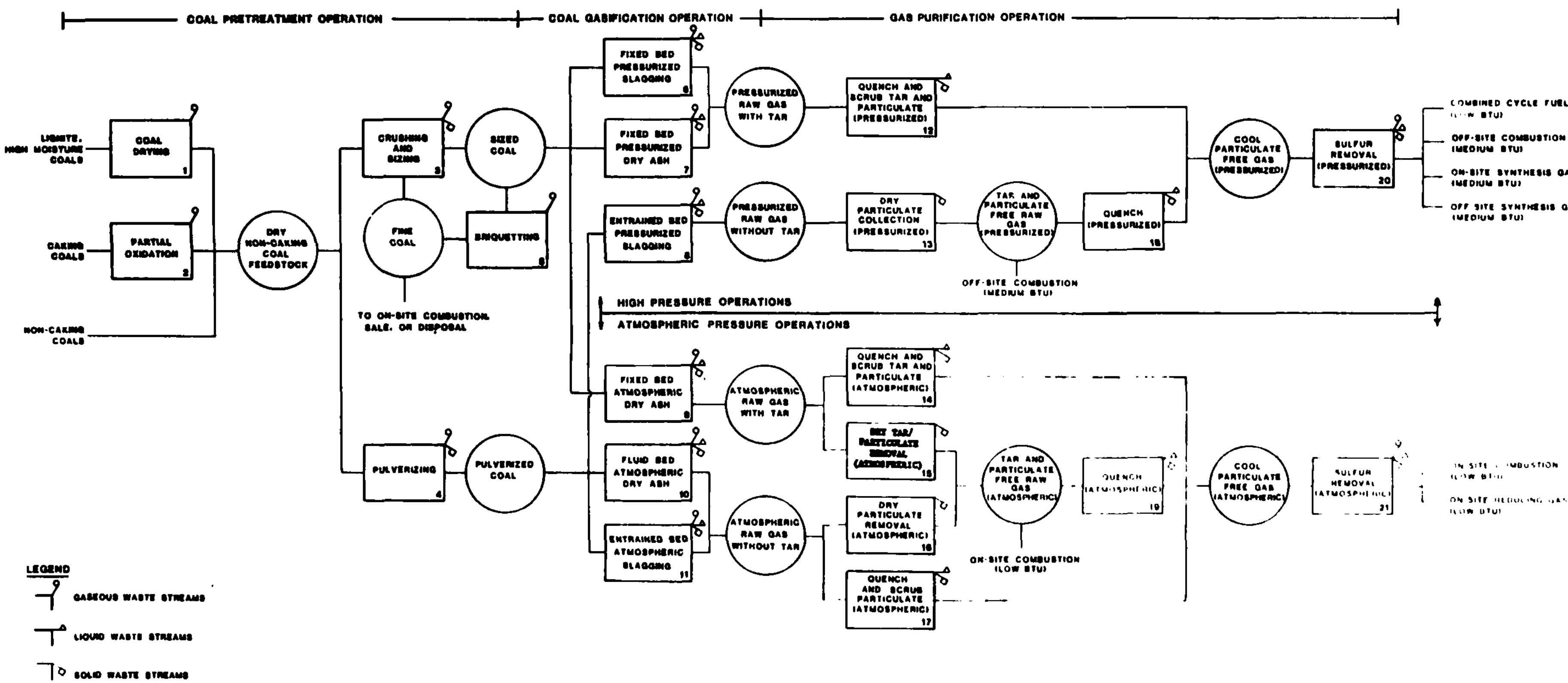

Figure 1. PROCESSES FOR LOW- AND MEDIUM-BTU GASIFICATION SYSTEMS

1) Pressurized gasifiers producing low-Btu fuel "combined cycles",

2) Pressurized gasifiers for production of medium-Btu synthesis gas for ammonia and methanol synthesis for on-site or off-site usage,

3) Pressurized gasifiers for off-site combustion of medium-Btu fuel,

4) Atmospheric gasifiers for production of low-Btu fuel for on-site combustion, and

5) Atmospheric gasifiers for on-site production of low-Btu reducing gas.

As shown in Figure 1, gas quenching and sulfur removal may not be needed for production of combustion gases. Generally direct combustion of gases without sulfur removal will be limited to situations where low sulfur coal feedstocks are locally available hence such applications may be very limited in number.

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. These are shown in Appendix C. Twenty-five of the most prominent of these gasification processes are shown in Table 2. 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 heating value of about 13.1×10^6 J/Nm^3 (350 Btu/scf) is obtained.

Seven of the gasifiers in Table 2 are currently being used

Table 2. STATUS OF U.S. AND FOREIGN LOW- AND MEDIUM-BTU GASIFICATION SYSTEMS

Gasifier	Licensor/developer	Number 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
Wellman Incadenscent	Applied Technology Corp.	(2*)**	-	-	US/Foreign	Commercial/ Demonstration
BGC/Lurgi Slagging	British Gas Corp. and Lurgi Mineralöltechnik GebH		1		Foreign	Demonstration
Bi-Gas	Bituminous Coal Research, Inc.		1		US	Demonstration
Foster Wheeler/Stoic	Foster Wheeler/Stoic Corp	1*(2)**	-	-	US	Demonstration
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)
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.	1	-	-	US	Pilot (400 lb/hr coal)
Westinghouse	Westinghouse Electric Corp.	1	-	-	US	Pilot
Coalex	Inex Resources, Inc.	1 (1*)	-	-	US	Pilot

*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 currently in operation.

to satisfy some commercial demand for low- and medium-Btu gas. These are:

- Chapman (Wilputte),
- Koppers-Totzek,
- Lurgi,
- Wellman-Galusha,
- Wellman Incandescent,
- Winkler, and
- Woodall-Duckham/Gas Integrale.

A number of the remaining gasifiers listed in Table 2 appear to have significant commercialization potential. For example, a commercial-scale Riley-Morgan gasifier has been operated as a development unit and a commercial-scale Coalex plant and Foster Wheeler/Stoic gasifiers are or will be under construction in the near future.

The seven commercial gasification processes together with seven others, which are currently under development, make up a population of fourteen, which on the basis of a screening analysis have been identified as the most promising candidates for satisfying near-term commercial needs for low- and medium-Btu gas.

The fourteen which are considered to be members of this "most promising" group are shown in Table 3. All fall into one of six classes of gasifier (shown in Figure 1) which have unique environmental impacts. These six classes and the proprietary processes which comprise each class are as follows:

Table 3. PROMISING LOW AND MEDIUM-BTU GASIFICATION SYSTEMS

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

[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;

- Chapman (Wilputte),
- Foster Wheeler/Stoic,
- Riley-Morgan,
- Wellman-Galusha,
- Wellman Incandescent, and
- Woodall-Duckham/Gas Integrale

Fixed-bed pressurized dry ash gasifier;

- Lurgi, and
- Pressurized Wellman-Galusha (MERC)

Fixed-bed pressurized slagging ash gasifier;

- BGC/Lurgi Slagging Gasifier

Fluid-bed atmospheric dry ash gasifier;

- Winkler

Entrained-bed atmospheric slagging ash gasifier;

- Coalex, and
- Koppers-Totzek

Entrained-bed pressurized slagging ash gasifier;

- Bi-Gas, and
- Texaco.

Raw Gas Cleaning Processes

As indicated earlier, the specific processes making up a system will be determined mainly by type of coal processed and product requirements. Where sulfur in the input coal is low, sulfur removal may not be required if the gas is to be used for direct process heat or burned in boilers. Coals that are low enough in sulfur to meet present air pollution requirements are, however, scarce and more stringent standards would make the applicability of such systems very rate. Where the gas is for combined cycles, for synthesis gas, or for transportation in pipelines, sulfur removal will be required. The type of gasifier employed will also have an independent influence in that several of the six basic types of gasifiers, as shown in Figure 1, may meet the same input and output requirements. This influence will be reflected mainly in the raw gas cleaning requirements. Whether a gasifier is pressurized or operated at atmospheric pressure and whether it operates at a high temperature, producing a tar-free gas or at a low temperature producing gas with condensible hydrocarbons are important factors which dictate the type of gas cleaning processes which will be used. For tar-free gases, high temperature dust collectors and heat recovery equipment will precede the gas quenching needed to adjust the temperature for the sulfur removal process needed for present day systems.

For gases containing tar, wet or dry systems may be employed to remove contaminants and cool the gas. For pressurized systems "physical solvent" processes which are most applicable at high pressures up to 7 MPa (1000 psia) would be favored for sulfur recovery from gases which are generated for combined power cycles, for distribution in medium-Btu gas transportation systems, or for use in synthesis of methanol or ammonia. Systems delivering gas at these high pressures would maximize the efficiency of the power production cycle and would supply compressed gases, most economically for pipeline transport. Also they would be more compatible with the high pressures used in the synthesis of chemicals than atmospheric systems.

Pressurized systems supplying medium-Btu gas for usage as synthesis gas will be likely to employ gas cleaning systems which operated as near as possible to the operating pressure of ammonia synthesis units 20 MPa (2900 psia) or methanol synthesis units 5-10 MPa (700-1500 psia). Cleaning systems operating in this range would include physical solvents and hot carbonate.

Processes which appear attractive for cleaning sulfur from product gases produced by atmospheric gasifiers include chemical solvent and direct conversion. Examples of solvent used in chemical solvent processes include amines and alkaline salts. An example of a direct conversion system is the Stretford process.

The primary advantage of using a direct conversion process for cleaning sulfur from raw gases is that it produces sulfur directly. Chemical solvent processes operate only as concentration steps. They produce tail gases containing sulfur compounds which require subsequent processing to produce sulfur. The primary disadvantage of using a Stretford process is that organic sulfur compounds (COS, CS_2, mercaptans, etc.) are not converted to sulfur and exit with the product gas. These factors along with economic considerations must be considered when selecting a sulfur cleaning system for atmospheric gasification systems.

Coal Pretreatment Processes

Generally any coal can be gasified if proper pretreatment is employed, however, certain gasifier designs are better suited to some coals than others, and the type of pretreatment will vary for different coals. With some high moisture coals, coal drying may be desirable. Also where caking coals are to be gasified, partial oxidation may be employed to simplify gasifier operation. Other pretreatment operations include crushing and sizing and briquetting of fines for feed to fixed-bed gasifiers. For fluid- or entrained-bed gasifiers, the coal feed is pulverized.

Raw Materials

The properties which are important in determining the suitability of a given coal for use in a specific gasification process are:

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

Particle size and caking properties are probably the most critical factors as far as the operability of fixed-bed gasifiers is concerned. Since "fixed-bed" systems actually utilize slowly moving beds to which coal is added and ash is withdrawn regularly, uniform coal throughput, and good gas-solid contact can be maintained only if both of these factors are maintained within limits specified by the design of the gasifier. For fixed-bed gasifiers, fines (<3mm in diameter) from the crushing and sizing will generally have to be burned in a boiler or briquetted if they are to be fed to the gasifier.

Moisture content and ash content are generally less critical than particle size and caking properties. Coal feedstocks with a high mosture content can, however, cause operational problems for coal feeding devices. The high moisture content may also result in low gas outlet temperature 400°K (300°F) which can produce condensation of tars and oils in particulate removal equipment. 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 coal.

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.

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.

Products

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

- On-site combustion fuel (Low-Btu),
- Off-site combustion fuel (Medium-Btu),
- Combined-cycle fuel (Low-Btu),
- Off-site use as synthesis gas (Medium-Btu),

- On-site use as synthesis gas (Medium-Btu), and
- Reducing gas (Low-Btu).

On-site combustion refers to a direct combustion process which consumes the product gas within a relatively short distance, i.e., within 16 Km (10 miles) of the coal gasification plant (3). Although any of the fourteen gasifiers just discussed would 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 can be up to 160 Km (100 miles) from the coal gasification plant (3). 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 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. Combined cycle plants will have to be quite large. To be competitive, economy of scale advantages will have to be maximized. For plants of this size, cost and complexity of adding an oxygen plant will probably make oxygen blowing to produce medium-Btu gas unattractive compared to firing of low-Btu gas (3).

Synthesis gas is used as a raw material for the production of chemicals. It seems unlikely that coal gasification will be used extensively for chemical products other than ammonia or methanol which is presently made in large quantities from natural gas. Other chemicals such as benzene, ethylene, propylene, etc. will continue to come from oil or perhaps in the future from coal derived liquids. 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.

Gas from coal is expected to find some application in direct reduction of iron ore and may be used in other applications where a reducing gas is needed, e.g., to regenerate sorbent materials used in flue gas cleaning systems for collection of SO_2. Neither oxygen blowing nor pressurization would offer any advantage hence, atmospheric air blown systems are most likely to be used.

IV. 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 gaseous emissions (hydrocarbons, H_2S, CO, HCN, etc.) which, because of their probable noxious character, will require the design of special systems for their control. The coal feed will typically contain 5-15 percent ash and will have a large number of trace metals which are potential pollutants. Also the chemical structure of coal is such that thermal processing tends to liberate toxic and carcinogenic organic materials. The ash will probably contain a small amount of organics and the disposal problem will be similar to that associated with ash from a conventional power plant. The trace metals and organic materials produced by thermal treatment must be controlled. The point at which hazardous discharges appear, depends on the nature of the coal gasification system, e.g. those systems which produce raw fuel gas containing tars and particulate that are removed with wet scrubbers, can produce both waste water and solid waste which is contaminated with highly offensive organic and inorganic materials. Even where processes are operated so that tars and condensible organics are largely eliminated, gas quench water contaminated with materials such as cyanides, sulfides, etc. will be produced.

The various points for discharge of emissions have been identified for the important system configurations. These are shown in Table 4. All of the three basic operations associated with gasification technology (coal pretreatment, gasification, and gas cleaning) can produce discharges with potential for environmental impacts. At present the nature of most discharges have been described only in qualitative terms. The minimum amount of operating experience with gasifiers which we now have, is in large part, not applicable to systems of the future. However, it is possible through engineering analysis of present gasification systems and related operations such as utility boilers, coke ovens, and coal preparation plants to develop some perspective on the overall problem. Such background information has been used to develop this overview which will serve as a tool in designing of programs for sampling and analysis and conceptual design studies needed to quantify and prioritize environmental control problems. General discussion of emissions from the three basic operations is presented in the following sub-sections.

Coal Pretreatment

Emissions from coal pretreatment processes generally fall in the category of problems which appear to be solvable. Wastes from coal storage, handling, size reduction, and classification

Table 4. DISCHARGES FROM LOW- AND MEDIUM-BTU GASIFICATION SYSTEMS

Discharge stream source	Discharge streams	Description	Remarks
Operation			
Coal Pretreatment			
Storage, handling and crushing/sizing	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 for coal storage piles and dust control or suspression processes are minimal.	Proper runoff water management techniques have been developed. More data on the characteristics of this waste water 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 is little 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 to evaluate the potential environmental impacts associated with this solid waste.
Coal drying, partial oxidation and briquetting	Vent gases	These emissions will contain coal dust and combustion gases along with a variety of organic compounds liberated as a result of coal devolitization reactions. There are currently little 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	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 method.

Table 4. DISCHARGES FROM LOW- AND MEDIUM-BTU GASIFICATION SYSTEMS

Continued

Operation: Discharge stream source	Discharge streams	Description	Remarks
Ash removal device	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.	Many sources of contaminated water may be used for ash quenching. Therefore, volatile organics and inorganics may be released in these vent gases. Characterization of emissions is needed to define control technology rements.
	Spent ash quench water	There are limited data on the discharge stream. This stream will contain dissolved and suspended organics and inorganics and will require control.	Characterization of this waste stream is required to define control technology requirements. Further treatment of this stream is essential.
	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. The organic content of the liquor used to quench the ash may affect the final disposal of the ash.
Coal gasifier	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 combustile 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.
	Fugitive emissions	There are no data available on these emissions. They can be expected to contain hazardous species that are in the raw product gas such as hydrogen sulfite, carbon monoxide, and hydrogen cyanide.	These emissions will determine the extent of workers exposure to hazardous species and define the need for continuous area monitoring of toxic compounds and personal protection equipment.

Table 4. DISCHARGES FROM LOW- AND MEDIUM-BTU GASIFICATION SYSTEMS

Continued

Operation

Discharge stream source	Discharge streams	Description	Remarks
Gas Purification			
Particulate removal	Collected particulate matter	There are little data on the characteristics of this solid waste stream. This stream will contain unreacted carbon, sulfur species, organics, and trace element.	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 little data on the composition of this stream; however, current data indicates 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 little 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.

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 and trace metals which can be liberated as the coal is heated. The exact character of these materials has not be 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.

Gasification

The coal gasification operation appears to be the most serious source of potential gasification system pollution problems. Experience with coke ovens and other work with thermal processing of coal has demonstrated that organic emissions from the gasifier can be expected to contain toxic and carcinogenic materials. 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, but slagging gasifiers because of their low production of tars and condensible hydrocarbons may prove to be an easier pollution control problem at the inlet and outlet points. 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. High temperature and pressurized gasifiers may be more difficult to control from the standpoint of fugitive emissions.

Gas Cleaning

The gas cleaning operations also appear to present difficult control problems. The particulate collection and gas cleaning steps will, for many systems, produce ash and water contaminated with organics and inorganics, many of which are toxic. All sulfur collection systems will produce a bleed stream of contaminated sorbent liquid. In addition volatilization or carryover of sorbent can be a potential source of air pollution.

The sulfur removal processes will also produce fugitive emissions which are similar to those generated during gasification. Where Claus plants are used for sulfur recovery the tail gases are a potential source of pollution. 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.

In summary, it can be said that work to better define control technology is needed. It is apparent, however, that work to keep the cost of control equipment (which is expected to amount to 10 to 25 percent of the total process cost) (3) within tolerable limits will be needed. Experience with coke ovens, coal preparation plants, power plants and related coal processing operations indicate that given proper attention most discharges from coal gasification systems should not produce serious pollution. Development of in-depth understanding of the character of the discharge streams and their potential for harm to humans or the environment, is however, critical. Only with such information available can adequate control methods be developed and applied without jeopardy to the economic viability and environmental acceptability of future systems.

Further details relative to the operating characteristics and potential discharges from processes depicted in Figure 1 are presented in Appendix D.

REFERENCES

1. Cavanaugh, E. C., W. E. Corbett, and G. C. Page, "Environmental Assessment Data Base for Low/Medium-Btu Gasification Technology". EPA-600/7-77-125a and b (NTIS # PB 274-844/AS and PB 274-843/AS) November 1977.

2. Lacey, J. A., "The Gasification of Coal in a Slagging Pressure Gasifier", Amer. Chem. Soc., Div. Fuel Chem., Prepr. October 1966.

3. National Research Council, National Academy of Science, "Assessment of Low- and Intermediate-Btu Gasification of Coal". Washington, D. C., 1977.

4. Magee, E. M., C. E. Jahnig, and H. Shaw, "Evaluation of Pollution Control in Fossil Fuel Conversion Processes, Gasification; Section 1: Koppers-Totzek Process", EPA-650/2-74-009a, (NTIS # PB 231-675/AS) January 1974.

5. Hess, Martin, "Ammonia: Coal vs Gas", Hydrocarbon Processing. November 1976.

6. Putnam, A. A., E. L. Kropp, and R. E. Barrett, "Evaluation of National Boiler Industry", Battelle - Columbus Laboratories. October 1975.

Appendix A

Environmental Assessment/Control Technology

Development Protocol

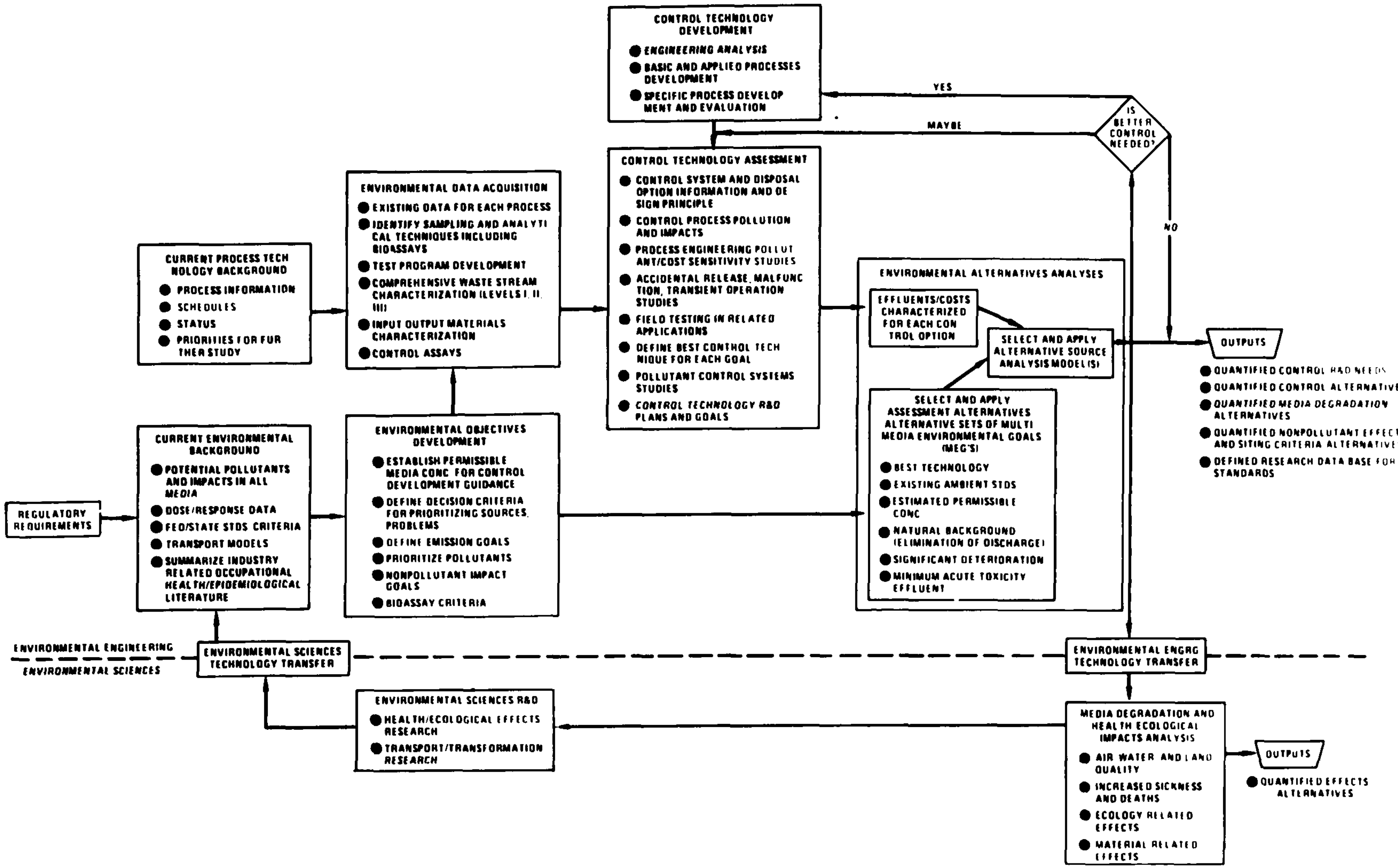

Figure A-1 Environmental Assessment/Control Technology Development Protocol

Appendix B

Nomenclature Definitions for Energy Technologies

Nomenclature for Energy Technologies

1. Energy Technology

An energy technology is made up of systems which are applicable to the production of fuel, electricity, or chemical feedstocks from fossil fuels, radioactive materials, or natural energy sources (geothermal or solar). A technology may be applicable to extraction of fuel, e.g., underground gasification; or processing of fuel, e.g., low-Btu gasification, light water reactor, conventional boilers with fuel gas desulfurization.

2. Operation

An operation is a specific function associated with a technology and consists of a set of processes that are used to produce specific products from certain raw materials. For example, the operations for low/medium-Btu gasification technology are coal pretreatment, coal gasification, and gas purification. The processes used in each of these operations are:

Coal Pretreatment - drying, partial oxidation, crushing and sizing, briquetting, and pulverizing.

Coal Gasification - fixed-bed/pressurized/slagging; fixed-bed/pressurized/dry ash; entrained-bed pressurized/slagging; fixed-bed/atmospheric/dry ash; fluid-bed/atmospheric/dry ash; and entrained/bed/atmospheric/slagging.

Gas Purification - wet or dry particulate and tar removal, gas quenching, and acid gas removal.

3. Process

Processes are basic units that make up a technology. A process is used to produce chemical or physical transformations of input materials into specific output streams. Every process has a definable set of waste streams which are, for practical purposes, unique. The term "process" used without modifiers is used to described generic processes. Where the term "process" is modified (e.g., Lurgi process), reference is made to a specific process which falls in some generic class consisting of a set of similar processes. For example, a generic process in low/medium-Btu gasification technology is the fixed-bed/ atmospheric/dry ash gasification process. Specific processes which are included in this generic class are Wellman-Galusha, Woodall-Duckham/Gas Integrale, Chapman (Wilputte), Riley-Morgan, Foster Wheeler/Stoic and Wellman-Incandescent.

4. Process Module

A representation of a process which is used to display process input and output stream characteristics. When used with other necessary process modules, they can be used to describe a technology, a system or a plant. One example of the "process module" approach to environmental studies of energy technologies involved study of emissions from petroleum refining. A description was developed for the basic processes which make up a petroleum refinery, e.g., atmospheric distillation, catalytic cracking, etc. Information on air emissions, as a function of throughput, was collected as descriptive information for each process module. Individual process modules were assembled to describe plants with the process configuration which is typical of specific areas of the country, e.g., a refinery in the Southwest United States, which maximized gasoline output and another in the Northeast United States, which produced more distillate fuel. Data on emissions and weather and air quality information from specific locations, for assumed plant sites, were used for diffusing modelling studies aimed at predicting air pollution, which would be experienced if a refinery was in operation at the assumed location.

5. Auxiliary Process

Processes, associated with a technology, which are used for purposes that are in some way incidental to the main functions involved in transformation of raw materials into end-products. Auxiliary processes are used for recovery of by-products from waste streams, to furnish necessary utilities, and to furnish feed materials such as oxygen which may or may not be required depending on the form of the end-product, which is desired. For example, some auxiliary processes for low/medium-Btu gasification technology include a) oxygen production used to produce medium-Btu gas, b) the Claus process used to recover sulfur from gaseous waste streams, and c) the Phenolsolvan process used to recover phenols from liquid waste streams.

6. <u>System</u>

A specified set of processes that can be used to produce a specific end-product of the technology e.g., low- and medium-Btu gasification. The technology is comprised of several systems. The simplest system is producing combustion gas from coal using a small fixed-bed, atmospheric, dry ash gasifier coupled with a cyclone. One of the most complex systems has very large gasifiers with high efficiency gas cleaning being used to produce a fuel clean enough to be fired in the gas turbines of a combined-cycle unit for production of electricity.

7. <u>Plant</u>

An existing system (set of processes) that is used to produce a specific product of the technology from specific raw materials. A plant may employ different combinations of processes but will be comprised of some combinations of processes which make up the technology. For example, the Glen-Gery Brick Company low-Btu gasification facilities are plants used to produce combustion gas from anthracite coal.

8. <u>Input Streams</u>

Materials that must be supplied to a process for performance of its intended function. Input streams will include primary and secondary raw materials, streams from other processes, chemical additives, etc. For example, the input streams to a

Lurgi gasifier consist of sized coal, lock hopper filling gas, oxygen, steam, and boiler feedwater. For auxiliary processes a waste stream from which a by-product is recovered is an input streams.

9. Output Streams

Confined discharges from a process which can be products, waste streams, streams to other processes, or by-products. For example, output streams from a Lurgi gasifier include coal feeder vent gases, ash hopper vent gases, wet ash, steam blow-down, and crude medium-Btu gas.

10. Raw Materials

Raw materials are feed materials for processes. They are of two types: 1) primary raw materials that are used in the chemical form in which they were taken from the land, water, or air, and 2) secondary raw materials that are produced by other industries or technoloiges. For example, primary raw materials for low/medium-Btu gasification technology include coal, air, and water. Secondary raw materials include fluxes, makeup solvent, catalysts, etc.

11. Process Streams

Process streams are output streams from a process that are input streams to another process in the technology. For example, the crude medium-Btu gas from the Lurgi gasification process is the feed (input) stream to the tar and particulate removal quench process.

12. Products

Process output streams that are marketed for use or consumed in the form that they exit the process. For example, the product from low-Btu gasification technology is the low-Btu gas exiting the final gas purification process.

13. By-Products

By-products are auxiliary process output streams that are produced from process waste streams and are marketed or consumed in the form in which they exit the process. For example, tar is a by-product produced by certain low-Btu gasification facilities. It may either be consumed in a tar boiler or sold.

14. Waste Streams

Waste streams are confined gaseous, liquid, and solid process output streams that are sent to auxiliary processes for recovering by-products, pollution control equipment or final disposal processes. Unconfined "fugitive" discharges of gaseous or aqueous waste and accidental process discharges are also considered waste streams. The tail gas from an acid gas removal process is an example of a waste stream in low/medium-Btu gasification technology. This stream can be sent to an auxiliary process, to recover the sulfur as a by-product.

15. Source

Equipment which discharges either confined waste streams (solids, liquid, gaseous or combinations) or significant quantities of unconfined, potentially polluting substances in the form of leaks, spills, and the like. Examples of sources include gasifier coal feed lock hoppers which discharge emissions during coal feeding, the Claus reactor which recovers sulfur and discharges tail gases containing polluting sulfur compounds.

16. Effluent Streams

Confined aqueous process waste streams which are potentially polluting. These will be discharged from a source.

17. Emission Streams

Confined gaseous process waste streams which are potentially polluting. These will be discharged from a source.

18. Fugitive Emissions

Unconfined process associated discharges, including accidental discharges, of potential air pollutants. These may escape from pump seals, vents, flanges, etc., or as emissions in abnormal amounts when accidents occur and may be associated with storage, processing, or transport of materials as well as unit operations associated with a process. They will escape from a source.

19. Fugitive Effluents

Unconfined process associated discharges, including accidental discharges, of potential water pollutants which are released as leaks, spills, washing waste, etc., or as effluents in abnormal amounts when accidents occur. These may be associated with storage, processing, or transport of materials as well as unit operations associated with industrial processes, and may be disposed of to municipal sewers, and can lead generation of contaminated runoff waters. They will escape from a source.

20. Accidental Discharge

Abnormal discharges (solid, liquid, gaseous or combinations) which occur as a result of upset process conditions.

21. Unit Operation

Unit operations, like processes described above, are employed to take input materials and perform a specific physical or chemical transformation. The equipment making up a unit operation may or may not have one or more waste stream(s). A process is made up of one or more unit operations which have at least one source of waste stream(s). Examples of unit operations are: distillation, evaporation, crushing, screening, etc.

22. Final Disposal Processes

Processes that are used to ultimately dispose of liquid and solid wastes from processes, auxiliary processes, and control equipment employed in a technology. Examples of final disposal processes are landfills and evaporation ponds.

23. Control Equipment

Equipment such as electrostatic precipitators, wet scrubbers, adsorption systems, etc., whose primary function is to minimize the pollution to air, water or land, resulting from process discharges. While the collected materials may be sold, recycled or sent to final disposal, control equipment is not essential to the economic viability of the process. Where such equipment is designed to be an integral part of a process, e.g. scrubbers which recycle process streams, they are considered a part of the basic process.

24. Residuals

Gaseous, liquid, or solid discharges from control equipment and final disposal processes. Examples of residuals include gaseous emissions from control equipment, such as scrubbers, cleaning the tail gases from an auxiliary process (e.g. a Claus sulfur recovery unit) and vapors from an evaporation pond.

APPENDIX C

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
Kerpely 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)	Present 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

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
GECB 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

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

Appendix D

Description of Processes for Low- and Medium- BTU Gasification Systems

Coal Drying Process No. 1

1. General Information

Coal drying may be a necessary step in producing gas from coal. Coals with high moisture content, such as certain lignites, should generally be dried until the coal moisture content is between 30 to 35%. Two types of gasification processes that are more sensitive to coal moisture are entrained-bed (Koppers-Totzek) and fluidized-bed (Winkler) gasifiers. Koppers-Totzek gasifiers require a coal moisture content of less than 8% while Winkler gasifiers specify less than 30% moisture for lignite coals and less than 18% for higher grade coals.

2. Process Information

Thermal drying of coal is accomplished by contacting the coal with hot combustion gases at temperatures around 755^oK (900^oF). Various types of thermal dryers including rotary, cascade, reciprocating screen, conveyer, suspension and fluidized-bed, are used. Fluidized-bed dryers are most frequently used because of their high gas-solid contacting efficiency.

3. Waste Streams

Off-gases from the dryer are the only significant waste stream. Emissions may contain coal dust, volatile organics and combustion products (CO_2, H_2O, SO_2, NO_x.) Particulates are usually controlled by cyclones or baghouses. Scrubbers may be needed to reduce gaseous emissions such as SO_x The volatile organics are known to be potentially toxic. If they are present in high concentrations afterburners may be needed for control.

Partial Oxidation

Process No. 2

1. General Information

For high caking coals, partial oxidation may be necessary to reduce the coal caking tendencies for certain gasifiers. Gasification processes that require coal with low caking tendencies are two-stage, fixed-bed, atmospheric gasifiers (Woodall-Duckham/Gas Integrale, Foster Wheeler/Stoic, and Wellman Incandescent); fluidized-bed, atmospheric gasifiers (Winkler) and single-stage, fixed-bed gasifiers without an agitator (Lurgi.) The most stringent coal caking specifications are for two-stage, fixed-bed, atmospheric gasifiers. For example, a Woodall-Duckham/Gas Integrale gasifier requires a coal having a free swelling index of less than 2.5 and any coals having a higher index would require treatment.

2. Process Information

Partial oxidation is carried out in thermal dryers (cascade, rotary, reciprocating screen, conveyer, suspension, and fluidized-bed.) Conditions are controlled so that coal drying and partial oxidation is accomplished simultaneously.

3. Waste Streams

See Process 1.

Crushing and Sizing   Process No. 3

1. General Information

Crushing and sizing steps are used to produce sized coal feedstocks for fixed-bed gasifiers (Lurgi, Wellman-Galusha, etc.) Particle sizes required are generally in the range of 2-50 mm (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 and/or channeling. Oversized coal particulates can reduce the maximum throughput of fixed-bed gasifiers because of their lower reactivity (low surface area/volume ratio.) Oversized coal particles are recycled to the crusher. Fines are rejected and burned separately or briquetted.

2. Process Information

A wide variety of size-reduction equipment is available. The basic types include jaw crushers, gyratory crushers, roll crushers, hammer mills and ball mills. The sizing equipment employed includes gravity types (sieves and screens) or centrifugal-type such as air classifiers.

3. Waste Streams

Waste streams include mineral wastes which are sent to landfill and fugitive emissions which are controlled using hoods and cyclones or baghouses for collection. Collected fines are combined with those rejected from crushing and sizing.

Pulverizing Process No. 4

1. General Information

Coal pulverizing is used to produce a coal feed for fluidized-bed gasifiers (Winkler) and entrained-bed gasifiers (Koppers-Totzek.) Typical coal size specifications for fluidized- and entrained-bed gasifiers are less than 9.4 mm (0.38 inches) and less than 0.07 mm (0.003 inches) respectively.

2. Process Information

Pulverizing equipment which is used includes hammer mills, cage mills, impactors and ball mills.

3. Waste Streams

The principal waste stream from pulverizing is fugitive emissions of coal dust. These are controlled by using hoods and conventional particulate control equipment (cyclones, baghouses. wet scrubbers) and ducts can be used to collect and transport coal dust from the pulverizing operation to conventional control equipment such as cyclones, baghouse filters, or scrubbers. The coal fines are consumed on-site as a fuel or recycled to the pulverizer.

Briquetting Process No. 5

1. General Information

Excessive quantities of coal fines cause excessive bed pressure drop, severe channeling, or poor gas distribution in fixed bed gasification processes. Therefore, coal fines rejected from crushing and sizing or collected from fugitive dusts must be compacted into briquettes which are of suitable size for feed to a gasifier or used as fuel.

2. Process Information

To produce briquettes, coal fines are usually 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 or may not be needed in order to give the briquette sufficient structural strength. The briquette may also need to be baked in hot gases to provide additional structural strength. The nature of the operations needed will be determined by characteristics of the coal. Typical equipment would include conveyor, cascade, or reciprocating screen thermal dryers. Sizes of briquettes to be fed to fixed-bed gasifiers range from 3.2 to 38.1 mm (0.13 to 1.5 inches).

3. Waste Streams

Waste streams from the briquetting process are air emissions consisting of coal dust and, if baking is involved, volatile coal components. The coal dusts are collected in conventional control equipment and is recycled to the briquetting operation, or used as fuel. Hydrocarbon control may be required if the briquettes are baked and volatile, potentially toxic hydrocarbons are emitted in sufficient amounts. These can be controlled by afterburners or an adsorption process.

Fixed-bed, Pressurized Slagging, Gasifier

Process No. 6

1. General Information

Experimental work on fixed-bed, pressurized, slagging gasifiers has been conducted by the U.S. Energy Research and Development Administration at their Grand Forks Energy Research Center and by the British Gas Corporation which is working with Lurgi Mineraloltechnik Gmbh. At Grand Forks, N.D. a pilot plant with capacity of 40-190 g/sec (300-1500lb/hr) was operated from 1958 to 1965 was reactivated in 1977. This unit is operated solely to produce research data, and scale-up for demonstration purposes is not anticipated. The British Gas Corp. operated a pilot plant with capacity of 0.5 to 1.3 Kg/sec (4000-10,000 lb/hr) from 1955 to 1964 and started up a demonstration plant in 1976. No operating data are available for the demonstration unit.

2. Process Information

The process is operated with a bed temperature of around 1500°K (2300°F) depending on the ash fusion temperature of the coal, and at pressures on the order of 2.07 to 2.76 MPa (300-400 psia). Coal is fed intermittently through a pressurized lock hopper. Molten ash is drained into a water quench bath and slag lock. The slag lock is discharged periodically. The raw gas is quenched and cooled in a scrubber-waste heat boiler combination.

3. Waste Streams

Waste streams with potential for pollution are as follows;

1) Vent gases (containing raw gas particulates, tars, phenols, ammonia) which escapes from the coal feeder.

2) Wet ash and contaminated water discharged from the ash lock hopper.

3) Quench water and condensate from the waste heat boiler used in connection with raw gas cooling. These waste waters contain tars, phenols, and particulate matter.

4) Blowdown water from the slag lock hopper water recirculation system. Contaminates would include soluble ash components and impurities that might be introduced with the make-up water.

5) Vent gases from the ash-lock hopper water recirculation system.

The high temperature of operation tends to reduce the amount of tars and oils exiting with the ash. The lower temperatures in the upper zones do however generate organics which leave with the raw gas. It is expected however that the amount of organics produced will be less than those produced by low temperature systems.

The composition of the blowdown water and vent gases from the slag lock hopper water system will depend on overall water management practices. If make up water contains impurities such as organics from other parts of the operation they will exit with these streams.

The process condensate and quench water will contain significant amounts of tars, condensible hydrocarbons, particulates, sulfur compounds and other constituents of the raw gas stream. Processing for removal of by-products and intensive treatment of any discharge waters will be needed.

Fixed-bed, Pressurized
Dry-ash, Gasifier

Process No. 7

1. General Information

Two fixed-bed, pressurized, dry ash gasifiers have been offered commercially or are under development. Lurgi Mineraloltechnik Gmbh has offered such gasifiers commercially since 1936. Over 50 commercial installations are being operated to produce synthesis gas or medium-Btu fuel gas. The units range in capacity from about 0.6 to 6.0 Kg/sec (2.4 to 24 ton/hr) of coal. A pressurized Wellman-Galusha pilot plant with capacity of0.2 Kg/sec (1500 lb/hr) has been in operation since 1958.

2. Process Information

These units operate below the fusion point of the ash fed. For the Lurgi plants and the Wellman-Galusha pilot the respective bed temperatures of 1250-1650°K (1800-2500°F) and 1600-1650°K (2400-2500°F) have been reported. Gas outlet temperatures are reported to be 730°K (850°F) for the Lurgi and 750-920°K (900-1200°F) for the Wellman-Galusha. The coal is fed intermittently through pressurized two-chamber locks. The ash is also intermittently removed through a pressurized lock which receives the ash from the gasifier and introduces it into cooling water sprays or quench water.

3. Waste Streams

Waste streams with potential for pollution are as follows;

1) Vent gas from the coal feeder which contain all components of the raw gas stream, i.e., tars, condensible hydrocarbons, particulates, sulfur compounds and ammonia.

2) Wet ash and contaminated water from the ash cooling or ash quench operations will contain mineral matter from coal, carbon and possible some organics.

3) Vent gases from the ash cooling or ash quenching steps will contain steam, raw gas, and particulates.

4) Particulates, mostly fine coal contaminated with organics, will be collected when cyclones are used for raw gas cleaning.

5) Contaminated water produced by gas quenching and as process condensate. Will contain large amounts of tars, condensible hydrocarbons, and particulate plus some reduced sulfur compounds, ammonia and other components of the raw gas.

The relatively low temperature of operation results in tars and hydrocarbons being present in some amount in all gasifier discharges. The vent gases from coal feeding are recycled to the process or incinerated. Where inert lock-hopper pressurizing gas is used and the raw gas content is low they may be sent to cyclones for particulate removal and vented. Vent gases from the ash quench are passed through steam condensers, and in some cases cyclones as well, for particulate removal and are then vented or incinerated.

The gas quenching liquor and process condensate contains about 95% water and 5% of the impurities indicated above. It is generally combined with other waste water streams or it may be used for ash transport. The liquor is then sent to by-product recovery and for treatment prior to discharge. The ash, after transport to dewatering equipment may require careful disposal since it may contain trace elements, and potentially toxic organic materials.

Entrained-bed, Pressurized
Slagging ash, Gasifier

Process No. 8

1. General Information

Two entrained-bed, pressurized, slagging gasifiers are presently under development. Bituminous Coal Research has been operating a pilot plant with coal capacity of about 1.3 Kg/sec (10,000 lb/hr) for their Bigas process at Homer City, Pennsylvania. Texaco Development Corp. has operated a pilot plant with coal capacity of .5 kg/sec (4000 lb/hr) for their similar process at their Montebello, California laboratories.

Both plants feed coal in a water slurry and are felt to be capable of operation with any type of coal using either air and steam or oxygen and steam to gasify the coal.

2. Process Information

This process operates at high temperature and pressure with bed temperatures up to 1900°K (3000°F) and reactor pressure up to 8.3 to 10.3 MPa (1200-1500psia). For both the mode of operation is such that a minimum of tars and condensible hydrocarbons will be produced in the raw gas. Both processes use a water quench in connection with slag removal and water scrub of the raw gas to remove impurities and reduce the temperature. For the Texaco pilot plant slag removal and gas quenching is carried out in a combined step.

3. Waste Streams

The principal waste streams with potential for pollution from the Bi-Gas and Texaco gasifiers are as follows:

1) Vent gases from preparation of hot water slurries of pulverized coal for process feed.
2) Gases lost with discharge of slag quench water from gasifier.

3) Waste water from slag quench and raw gas cleaning operations.

4) Waste water from the raw gas quench used to condition the gas for sulfur removal.

Because the high temperature of operation for Bi-gas and Texaco tends to minimize the tars and condensible hydrocarbons which will be lost from any of the above points of discharge some of the pollution control problems may be simplified, e.g., it is likely that control of vent gases from coal feeding will involve only collection of particulate using available technology. The presence of tars and condensibles would make control of emissions at this point much more difficult. This would apply also to gases lost during the discharge of slag.

The character of problems associated with the water discharges from the slag quench and raw gas quench operations will depend largely on overall water management practices. If water is recycled for quench of raw gas or to slag quench, build up of contaminants may necessitate treatment and/or disposal of a bleed stream. Also it is possible that high concentration of impurities could build up in water recycled to either slurry preparation or quenching operations. This could lead to volatilization of hydrocarbons which could exit with air emissions in objectionable quantities.

Fixed-bed, Atmospheric
Dry ash, Gasifier

Process No. 9

1. General Information

Fixed-bed, atmospheric, dry ash gasifiers have been offered commercially since the 1940's. Five are still being sold (Wellman-Galusha, Woodall-Duckham, Chapman/Willputte, Wellman Incandescent and Foster-Wheeler/Stoic. One pilot plant which is a modification to earlier designs is also in operation (Riley/Morgan). These gasifiers typically are about 10 ft. in diameter with throughput rates from about 0.3 to 1.3 kg/sec (2000 to 10,000 lb/hr). Applications include production of fuel for direct process heat, synthesis gas, and town gas.

2. Process Information

This type of gasifier operates below ash fusion temperatures with maximum bed temperatures in the neighborhood of 1250-1500°K (1800-2200°F) and gas outlet temperatures of 700-1100°K (800-1500°F). Three of the processes (Woodall-Duckham, Foster-Wheeler/Stoic, and Wellman Incandescent) represents variations in which two product streams are withdrawn from the gasifier. One is a tar-free side stream with a temperature around 920°K (1200°F); the other is an overhead stream which contains volatiles and tar and exits at about 400°K (250°F). All processes may produce tars and condensible hydrocarbons from which by-products are recovered. Particulates entrained in the raw gas will be removed in part by cyclones and most of the balance will be removed when the gas is scrubbed to quench it. Coal feed is introduced intermittently through devices such as lock-hoppers or rotary feeders which are designed to limit gaseous emissions. Ash is removed either dry by similar mechanisms or "plowed" from a water sealed ash pan. Waste water is generated when water in the raw gas is removed as condensate and by water scrubbing employed to quench the raw gas and remove contaminants.

3. Waste Streams

Waste streams with potential for environmental pollution are as follows.

1) Vent gases escaping when coal is fed. This gas contains all materials found in the raw gas, i.e., tars, particulates, condensible organics, sulfur compounds, ammonia, and hydrogen cyanide.

2) Wet ash and contaminated water from ash cooling or ash quenching. Mineral matter from coal, unreacted carbon, and possibly some organics either from the gasifier or introduced by recycled waste water used for quenching, may be contained in the wet ash.

3) Vent gases escaping when ash is discharged and quenched. Steam, oxygen, particulates or volatile impurities introduced with the quench liquor may be present.

4) Process condensate and raw gas quench water will contain tars, condensible hydrocarbons, particulates, and other soluble components found in the raw gas

5) Particulate matter carried over in raw gas from the gasifier and collected in cyclones will contain variable amounts of fine coal and ash contaminated with tars and oils present in the raw stream.

The relatively low temperature of operation produces tars and condensible organics which will tend to be present (along with sulfur compounds, ammonia, HCN, particulates and raw gas) in any of the discharges from the gasifier. The gaseous wastes genera will be recycled to the process, incinerated, or if amounts of contaminant are small, simply vented.

The gas quench liquor and process condensates may contain all of the materials in the raw gas and will be processed to recover by-products and will be given extensive treatment before it is discharged.

The ash will contain mineral matter from the coal, unreacted carbon, and possibly some organic residues coming from the gasifier or from the use of contaminated quench water in ash handling. Other solid residues will be generated by removal of particulat prior to the quench or from recovery of solids that are picked up by the quench water. These residues may be contaminated with a considerable amount of potentially hazardous organic materials and may require careful disposal.

Fluidized-bed, Atmospheric
Dry ash, Gasifier

Process No. 10

1. General Information

The Winkler gasifier is the only fluidized bed, atmospheric, dry-ash process now being operated. It has been commercially available since 1926 and 36 units have been built for production of synthesis or water gas. Seven are still in operation. Capacity is around 4.2 to 4.5 Kg/sec (30,000-36,000 lb/hr).

2. Process Information

The process is operated at bed temperature of 1100°K to 1250°K (1500 to 1800°F) and outlet temperature of 978°K (1300°F). Coal is transferred continuously from a nitrogen blanketed hopper to the gasifier, by a screw conveyor. Part of the ash (30%) is removed on a continuous basis when it settles to the bottom of the fluidized bed and is carried by way of screw conveyor to a nitrogen blanketed ash hopper. Most of the remaining ash is carried out of the reactor with the product gas and is subsequently collected in cyclones and sent to the ash hopper. The remaining ash is washed out in the quench scrubber and a downstream electrostatic precipitator (ESP) which is used for final cleanup. The ash from the scrubber is combined with that collected by the ESP and sent to a settling tank. The underflow from the settler is combined with dry ash from the ash hopper and slurried for transport to disposal or the wet and dry ash streams may be processed separately.

3. Waste Streams

Waste streams with potential for pollution are as follows.

1) Vent gases from the coal bin contain nitrogen used to blanket the coal and fine coal particulates.

2) Vent gases from the ash hopper contain nitrogen used to blanket the ash to prevent further reaction or combustion of the char in the ash, particulates, and possible product gas or gases evolved from the hot char.

3) Vent gases from the ash slurry settlings tank may contain any components of the raw gas stream which are dissolved in the direct contact scrubber-cooler and evaporate in the settler. Entrained droplets of gas quench liquor or particulates from ash may also be present.

4) Process condensate and gas quench liquor will contain all soluble components in the raw gas stream including fine particulates, ammonia, sulfur compounds, trace elements, and nitrogen compounds.

5) Dry ash from ash hopper contains coarse ash from the bottom of the gasifier and an intermediate size fraction removed from the raw gas in the waste heat boiler or the cyclones. The ash may contain mineral matter in the coal, 10 to 30% unreacted carbon and some adsorbed components from the raw gas.

6) Ash slurry (25-35% solids) from the settler contain fine ash not removed by the waste heat boiler or the cyclones preceeding the scrubber-cooler. The liquid portion is composed of process condensate and gas quench liquor containing soluble components in the raw gas stream.

The vent gases from the coal feeder and ash handling can be cleaned of particulate matter using conventional dry collectors. If gaseous contaminants are present in significant amounts the gases can be recycled to the process or incinerated.

The wastewater (process condensate and quench liquor) is drawn off the settler. It contains fine particulate and other components of the raw gas such as ammonia, hydrogen sulfide, hydrogen cyanide, and trace elements but is largely free of suspended tars and hydrocarbons. A similar wastewater may be produced by dewatering the ash slurry.

The ash will contain mineral matter from the coal and 10-30% unreacted carbon which must be utilized as fuel or as an adsorbent to avoid economic penalties associated with loss of fuel and higher disposal costs for the waste.

Entrained-bed, Atmospheric
Slagging, Gasifier

Process No. 11

1. General Information

Two processes, the Kopper-Totzek (KT) and the Coalex involve entrained-bed, atmospheric pressure, slagging ash gasification. The KT process has been offered commercially since 1952. Over forty are in operation producing synthesis gas. These process around 3.8-6.3 Kg/sec (25,000-70,000 lb/hr) of coal. The Coalex process has been studied on pilot scale since 1976. A commercial unit which would process about 0.8Kg/sec (6000 lb/hr) of coal is being designed to provide process heat. Many process details of the Coalex process are considered proprietary.

2. Process Information

The gasifiers now in operation have maximum bed temperatures of about 2200°K (3500°F) and raw gas outlet temperatures of about 1750°K (2700°F). The high temperature of the exit gases necessitates the use of heat recovery to maintain satisfactory thermal efficiency. Coal is fed from a nitrogen blanketed coal bin, by screw conveyor, to mixing nozzles where it is entrained in steam and oxygen and injected into the gasifier through burners. Ash leaves the gasifier partly (50%) as molten ash which flows down the walls of the gasifier into a slag quench tank and partly (50%) as fine particles entrained in the exit gas which can be collected by filtering or when the gas is scrubbed in the quench step.

3. Waste Streams

The waste streams with potential for environmental pollution are as follows;

1) Vent gases exit from the coal bin and from the slag quench. Gases from the coal bin contains nitrogen and entrained coal dust. Off gases from slag quench may contain any components of the raw gas.

2) Contaminated water from raw gas scrubbing, condensate from the waste heat boiler and gas cooler, and overflow from the slag quench tank in a combined stream. Contains fine slag particles and components of the raw gas, e.g., particulates, ammonia, hydrogen sulfide, tract elements, and hydrogen cyanide.

3) One slag discharge consisting of the larger particles in the slag quench tank and a second which consists of fine slag particles collected in the quench wash cooler and separated in a settling tank. Slag contains 5-55% carbon, minerals in the coal and components of the raw gas.

The operating conditions in the gasifier are such that none of the exit streams will contain significant amounts of tars, oils and other condensible organics. The ash will be similar to that produced by a coal fired power plant. Waste streams will require application of conventional technology for disposal. Sulfur is generally the only by-product produced from the raw gas.

Quench and Scrub Tar
and Particulates
(Pressurized)

Process No. 12

1. General Information

Combined gas quenching and scrubbing of tars and particulates from raw gas streams is used with all pressurized fixed-bed-gasifiers. The process involves the direct contact of the hot raw gas with aqueous or organic quench liquor which removes tars, oils, and particulate matter and cools the raw gas to levels specified by the gas end-use or temperature requirements for the sulfur removal process. The amount of cooling required usually ranges between -35 to +38°C (-30 to 100°F) The choice of gas quenching and cooling equipment depends in part upon the tar and particulate content in the gas and whether or not sulfur removal is required. Waste heat recovery equipment may be used. Where it is, heavy tars are removed before the gas enters the waste heat recovery equipment.

2. Process Information

Quenching is usually carried out in pressurized spray towers or packed columns.

3. Waste Streams

The only waste stream is spent quench liquor containing suspended and dissolved tars, oils, coal fines, ash, dissolved gases, and raw gas bubbles containing H_2S, CO, NH_3, HCN, etc. Control equipment used includes:

1) Filtration, flocculation-flotation and gravity separators to remove suspended tars, oils, and solids.
2) Extraction, stripping, adsorption, biological and cooling tower oxidation to remove dissolved constituents.

The solids and liquids from the primary treatment processes are burned or recycled. Residuals from further processing go to controlled final disposal sites.

Dry Particulate Removal (Pressurized) Process No. 13

1. General Information

Removal of dry particulates from pressurized raw gas is practiced in conjunction with entrained-bed, pressurized, slagging gasifiers (Bi-Gas, Texaco) which produce tar-free gases. Dry removal simplifies waste heat recovery and minimizes problems of treating spent quench liquor.

2. Process Information

Cyclones or electrostatic precipitators can be used for pressurized dry particulate removal. Because of the high temperatures of the raw gas (800 to 1500°K, 1000 to 2200°F) and the potential problems associated with pressurized ESP's, cyclones may be preferred. However, the low efficiency (60-90%) of cyclones allows greater amounts of particulate matter to enter the gas quenching process.

3. Waste Streams

The only waste stream is the collected particulate matter consisting of coal fines and ash which may be landfilled or used as a fuel, depending on coal content.

Quench and Scrub Tar and Particulates (Atmospheric)

Process No. 14

1. General Information

Combined quench and scrubbing is used for fixed bed atmospheric gasifiers except for Woodall-Duckham, Foster-Wheeler/Stoic and Wellman Incandescent which employ dry tar removal (Process No. 15). This group includes Wellman-Galusha, Chapman Willputte, Riley-Morgan. General information for pressurized quenching and scrubbing (Process 12) is applicable to atmospheric systems.

2. Process Information

Quench is carried out in atmospheric spray towers or packed columns.

3. Waste Streams

Spent quench liquor is the only waste stream. Its composition will be similar to that of the liquor from pressurized systems (Process No. 12). However, the amount of dissolved gases, being directly proportional to pressure, will be lower. Treatment of the liquor will be the same as for pressurized systems. Treatment technology described under Process No. 12 would be employed.

Dry Tar and Particulate Removal (Atmospheric) Process No. 15

1. General Information

Dry tar removal processes are used to collect tars in the top gas from two-stage, atmospheric, fixed-bed, dry ash gasifiers (Woodall-Duckham/Gas Integrale, Foster Wheeler/Stoic, and Wellman Incandescent) and from some one-stage fixed-bed gasifiers (Wellman-Galusha). In current gasification plants that process low sulfur coal to generate gas for on-site combustion, the only gas purification process used is a cyclone to remove coal fines, ash, and heavy tars entrained in the raw gas. These plants have been in operation for a number of years. Dry removal results in minimal gas cooling thereby increasing thermal efficiency. Dry removal also simplifies treatment spent quench liquor by removing a major portion of the tars and oils prior to quenching.

2. Process Information

The types of equipment currently used for dry tar removal are cyclones, where low tar collection efficiency can be tolerated, and electrostatic precipitators (ESP's) where high efficiencies are needed to meet the end-use specifications for the product gas.

3. Waste Streams

The primary waste stream from this process is the collected tars and oils. These are generally used as combustion fuel, but they may be sold for recovery of by-products. Neither the tars or residues from by-product recovery can be safely discharged into the environment because of the hazardous nature of the tar and oil constituents.

Dry Particulate Removal (Atmospheric) | Process No. 16

1. General Information

Atmospheric dry particulate removal is used in connection with fixed-bed, atmospheric, dry ash and entrained-bed, atmospheric gasifiers except where particulate removal is combined with gas quenching. (Winkler, Koppers-Totzek and Coalex gasifiers may be operated with particulate removal and quench combined or in separate steps) Dry removal simplifies waste heat recovery and minimizes problems associated with treatment of spent quench liquor.

2. Process Information

Discussion for pressurized particulate removal (Process 13) is also applicable for atmospheric removal.

3. Waste Streams

Discussion for pressurized particulate removal (Process 13) is also applicable for atmospheric removal.

Quench and Scrub Particulate (Atmospheric) — Process No. 17

1. General Information

Combined quenching and scrubbing of particulate is practiced for fluid-bed, atmospheric, dry ash gasifiers where particulate collection is not a separate step. (Winkler, Koppers-Totzek and Coalex gasifiers may be operated with combined or separate quench and particulate removal steps).

This process is basically the same as the pressurized quenching and scrubbing (Process No. 12). However, the gasification systems that utilizes this process produce only trace amounts of tars in the raw gas. Atmospheric quenching and scrubbing is generally used in conjunction with sulfur removal processes or a specific end-use that require a low temperature less than about 311°K, 100°F gas.

2. Process Information

Quenching and scrubbing is carried out in spray towers or packed columns operated at atmospheric pressure.

3. Waste Streams

The spent quench liquor is the only waste stream. Its composition will be similar to spent liquors from pressurized quenching and scrubbing (Process No. 12) except for a reduced tar and oil content.

Quench (Pressurized) Process No. 18

1. General Information

Pressurized quenching in an independent step is employed with entrained bed, pressurized, slagging ash gasifiers (Bi-Gas, Texaco) which produce gases low in tars which can be processed to gain the advantages associated with dry particulate collection (Processs No. 13). It is used to reduce gas temperature for sulfur removal and to remove trace amounts of tars and oils. Sulfur removal is required for all end uses except direct combustion of gases produced from low sulfur fuels.

2. Process Information

Quenching is carried out in pressurized spray towers or packed columns.

3. Waste Streams

The only waste stream is the spent quench liquor. Its composition will be similar to that of the spent quench liquor from quenching and scrubbing operations (Process No. 12) except that concentrations of tars, oils, and particulates will be much lower. Treatment technology described under Process No. 12 would be employed.

Quench (Atmospheric) Process No. 19

1. General Information

Atmospheric quenching in an independent step is employed for all atmospheric systems in situations where gases are processed to gain advantages associated with dry tar and particulate collection (Process No. 15, Process No. 16). It is used to reduce the gas temperature for sulfur removal which is required for all end-uses except for direct combustion of gases produced from low sulfur fuels.

2. Process Information

Quenching is carried out in spray towers and packed columns.

3. Waste Streams

The only waste stream is the spent quench liquor. The components of the liquor will be similar to those in liquor from quenching and scrubbing operations (Process No. 12). However, the amounts of heavy tars and particulate matter should be much lower. The overall composition would be close to that from pressurized quenching (Process No. 18) except that dissolved materials will be lower in atmospheric systems. Treatment technology described under Process No. 12 would be employed.

Sulfur Removal
(Pressurized)

Process No. 20

1. General Information

There are many commercially available processes for pressurized (1.4 to 6.9 MPa, 200 to 1000 psia) removal of reduced sulfur species such as H_2S, COS, CS_2, etc. These processes have been used to clean natural gas and coke oven gases. One process, the Rectisol Process, is currently being used in commercial gasification plants. Other pressurized sulfur removal processes will probably be used in future commercial systems to clean low- and medium-Btu gas. These are 1) physical solvent processes (Rectisol, Selexol, Purisol, Estasolvan, and Fluor Solvent) that operate between 2.1 and 6.9 MPa (300 to 1000 psia); 2) combination physical/chemical solvent processes (Amisol and Sulfinol); and 3) the Stretford process. All of these processes operate at temperatures below 420°K (300°F).

2. Process Information

Physical solvent processes remove sulfur compounds from gas streams by physical absorption in an organic solvent. These processes operate at high pressures because the solubilities of these sulfur compounds are not sufficiently high at low pressures. The operating conditions such as temperature and liquid flow rate depend upon the type of organic solvent used.

Combination chemical/physical solvent processes use a physical solvent together with an alkanolamine chemical solvent additive. The physical solvent absorbs sulfur compounds such as CS_2, COS, and mercaptans which are not easily removed by chemical solvents while the chemical solvent removes the bulk of compounds such as H_2S. As before, the operating conditions are dependent upon the combination of solvents used.

Both the physical solvent and combination chemical/physical solvent processes function as concentration steps which require treating of the regenerator off-gas streams to recover the sulfur as elemental sulfur. The Stretford process recovers sulfur directly from gas streams containing H_2S. The major disadvantages of the Stretford process are that 1) it removes only H_2S and is not effective for removing other sulfur compounds such as COS, CS_2, or mercaptans, and 2) HCN will form non-regenerable complexes with the Stretford solution.

3. Waste Streams

The principle waste streams from the pressurized sulfur removal processes are:

1) Gaseous emissions from the processes which are used to recover sulfur from the regenerator off-gases. These off-gases will contain COS, CS_2, CO_2, NH_3, HCN, hydrocarbons (including solvent vapor) along with H_2S in concentrations high enough for economical recovery of sulfur. While most of the H_2S will be removed, some unreacted H_2S and SO_2 will exit along with other impurities in the regenerator off-gases.

2) Gaseous emissions from the Stretford process oxidizer vent which will contain water vapor, oxygen, nitrogen, ammonia, and other trace impuri

3) Liquid effluents that are withdrawn from the process to prevent buildup of solvent impurities. This waste stream will contain the solvent, solvent degradation products, hydrocarbons, trace elements, etc. which are removed from the product gas stream.

The tail gases from the sulfur recovery units may require scrubbing to remove SO_2 and other impurities. If the organic content is high in these gaseous waste streams, afterburners may be required. Afterburners can also be used to control tail gas emissions of compounds such as CO and NH_3 by thermal decomposition.

Liquid effluents containing oils, tars, and organic compounds may require several treatment steps. These include oil-water separation and/or flocculation-flotation for removing suspended tars and oils and extraction, adsorption, biological treatment and/or cooling tower oxidation for removing dissolved organic compounds. Final or ultimate disposal of liquid effluents containing residual organic and inorganic contaminants is usually an evaporation pond. The liquid effluent from the Stretford process may contain thiosulfates, thiocyanates, sulfates, and vanadium salts. Techniques are under development to recover the vanadium present in this stream.

Sulfur Removal (Atmospheric) Process No. 21

1. General Information

There are many commercially available processes which have been used to remove sulfur compounds from natural gas, refinery gases, and coke oven gas. The sulfur removal processes that have the greatest potential for cleaning of low- and medium-Btu gas at atmospheric pressure are the chemical solvent processes. These include amine absorption processes (monoethanolamine, methyl diethanolamine, diethanolamine, etc.) the Benfield molten carbonate absorption process, and the Stretford process. All processes in this class operate at temperatures below 420°K (300°F)

2. Process Information

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 and alkaline salt solutions are solvents in common use. The operating conditions such as temperature and liquid flow rate depend upon the type of solvent used.

The amine and molten carbonate processes collect H_2S from relatively dilute streams and discharges them in concentrations high enough for economical conversion to sulfur. The Stretford process is a direct conversion process which removes and recovers elemental sulfur from H_2S by liquid phase oxidation. This process is not very pressure sensitive and can be used for both pressurized and atmospheric applications.

3. Waste Streams

The principal waste streams associated with gas cleaning for atmospheric operations are essentially the same as those associated with pressurized operation. These are discussed under Process No. 20.

Liquid effluents from absorber blow-down can be treated by the same techniques discussed for the pressurized process. However, some chemical solvents produce nonregenerable complexes which may require special treatment before they are disposed of.

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16. ABSTRACT The report gives an overview of low- and medium-Btu gasification systems. It describes systems or combinations of processes which are likely to be used for production of low- and medium-Btu gas from coal. This involves making judgments as to types of coals that will be processed, types of gasifiers (and auxiliary processes) which will be employed, and markets which will develop for gas from coal. The report is divided into three main sections: Status of Technology gives a relatively broad definition of future prospects for coal gasification; Description of Technology gives more specific information on processes that are likely to be used commercially; and Environmental Impacts discusses the kinds of pollutant discharges that must be anticipated. Low- and medium-Btu gasification systems can be supplied to meet some industrial fuel requirements. Work is needed to develop a better understanding of both the potential of discharge streams for adverse effects and control technology and development needs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Coal Gasification	Stationary Sources	13H
Coal Gas	Industrial Fuels	21D
Marketing		05C

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