FATE OF POLLUTANTS IN INDUSTRIAL GASIFIERS

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Abstract

There is currently a growing interest in using low-Btu gas produced from coal as a combustion fuel for industrial boilers, kilns, and furnaces. In light of this, the Environmental Protection Agency has initiated a comprehensive assessment program with Radian Corporation to evaluate the environmental impacts associated with this growing technology.

The purpose of this paper is to present the current data on the fate of pollutants from industrial gasifiers used to produce low-Btu combustion gas from various types of coal. The two gasification systems considered in this paper use atmospheric, fixed-bed, single-stage gasifiers; one produces a hot gas, the other a cooled or quenched low-Btu gas.

Data on the fate of sulfur and nitrogen species, organics, trace elements, and particulate matter are presented. Analyses of these data indicate that: a) 81 to 97% of the coal sulfur can be converted to H_2S *and COS in low-Btu gas produced from high volatile bituminous coals and lignite having the lower sulfur conversion, b) the amount of* NO_x *formed by combusting low-Btu gas should be lower than direct-firing of coal; however, there may be a potential for incomplete combustion of* NH_3 *and HCN in the low-Btu gas, c) there are small amounts of organics in the gasifier ash and cyclone dust (20 to 380 ppm, respectively); however, quench liquors will contain high concentrations of organics consisting primarily of phenols, d) from trace element analysis of the gasifier ash, cyclone dust, quench water, and by-product tar, the cyclone dust had the highest amounts of Pb, Se, As, and Fl while the by-product tar was highest in Hg, and e) the physical and chemical characteristics of the particulate matter entrained in the low-Btu gas are highly dependent on coal type and gasifier operating parameters.*

INTRODUCTION

In recent years the nation's energy picture has changed drastically due to increasingly severe shortages of oil and natural gas. Because of these shortages, there is currently a growing interest in using low-But gas (~150 Btu/scf) produced from coal as a combustion fuel for industrial boilers, furnaces, and kilns. In response to this, the Environmental Protection Agency has contracted Radian Corporation to perform a multimedia environmental and control technology assessment for low/medium-Btu gasification technology.

To date, there are little actual data on the environmental and health effects of the discharge steams from low-Btu gasification systems, along with the technology used to control these streams. In light of this, one of the main objectives of the low-Btu environmental assessment program is to characterize the nature of the waste streams generated by commercial low-Btu gasification plants.

The purpose of this paper is to present current data on the fate of pollutants from industrial gasifiers producing low-Btu gas. The two gasification systems considered in this paper use atmospheric, fixed-bed, single-stage gas producers with one system producing a hot combustion gas and the other a cooled/quenched gas. The coal feedstocks considered for these systems include anthracite, high volatile bituminous, low volatile bituminous, and lignite. The sulfur concentrations of these coals ranged from 0.6 to 3.7 weight percent.

The information given in this paper deals with the fate of sulfur and nitrogen species in low-Btu gasification systems along with the nature and content of organic compounds, trace elements, and particulate matter in the multimedia discharge streams. Conclusions that can be drawn from these data and recommendations for further work are also discussed.

System I

System I for producing low-Btu gas from coal is illustrated in Figure 1. This system contains the following three process modules: a) an atmospheric, fixed-bed, single-stage gasifier, b) a hot cyclone, and c) a combustion process.

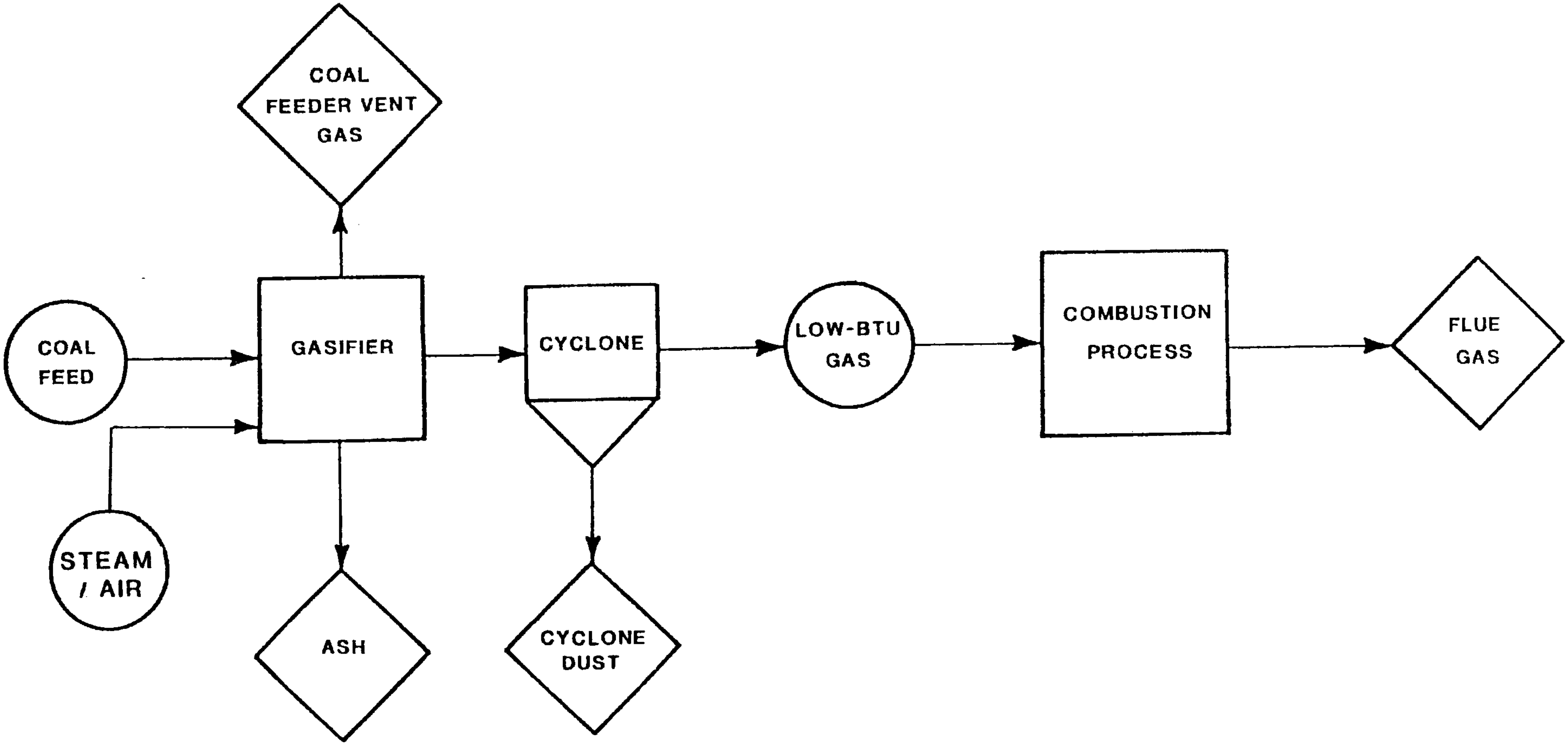


Figure 1. Low-Btu gas production.

Coal is fed into the gasifier where it is reacted with steam and oxygen to produce a hot (~870°K, 1100°F) low-Btu gas having a higher heating value of approximately 150 Btu/scf. The hot gas then enters the cyclone where entrained particulate matter is removed. The particulate-free gas is then combusted.

The discharge streams from this gasification system include both gaseous emissions and solid wastes. The gaseous emissions are the coal feeder vent and combustion gases. The solid wastes are the gasifier ash and the particulate matter collected by the cyclone (cyclone dust).

System II

Figure 2 illustrates System II for producing low-Btu gas from coal. This gasification system contains the same process modules as System I with three additional modules: a) a gas quench, b) a tar/liquor separator, and c) a tar combustion process. This system also has a water pollution control module, forced evaporation, to control the spent quench liquor.

As in System I, coal is reacted with steam and oxygen to produce a hot, low-Btu gas. The particulate matter in the gas exiting the gasifier is removed by a hot cyclone. The particulate-free gas is then quenched and cooled to remove the tars and oils and sent to the gas combustion process. The tar is separated from the quench liquor in a separator and sent to the tar combustion process. The quench liquor from the separator is then recycled to the gas quenching process. Any liquor build up in the system is sent to a force evaporator where volatile liquids are vaporized and vented to the atmosphere.

The discharge streams from this gasification system include gaseous emissions, liquid effluents and solid wastes. The gaseous emissions are the coal feeder and tar/liquor separator vent gases; and the flue gases from the low-Btu gas and tar combustion processes. The liquid effluent is the spent quench liquor while the gasifier ash and cyclone dust are the solid wastes.

COAL FEEDSTOCKS

The data presented in this paper were obtained during the production of low-Btu gas from six different coal feedstocks. The proximate and ultimate analyses and the higher heating values for these coals are given in Table 1. These feedstocks include anthracite-, bituminous-, and lignite-type coals which are representative of the various types of coals which are or will be used to produce low-Btu gas on a commercial scale.

POLLUTANTS FROM LOW-BTU GAS PRODUCTION

In this section the fate and characteristics of the pollutants from the two gasification systems producing low-Btu gas from various coal feedstocks are discussed. The fate of coal sulfur and the concentrations of specific sulfur species in the low-Btu gas are presented. The fate of coal nitrogen and specific nitrogen containing compounds in the product gas are discussed along with data concerning the combustion of these nitrogen-containing compounds. The nature and content of organics and trace elements in liquid and solid waste streams are presented followed by a discussion of the physical characteristics of the particulate matter entrained in the product gas.

Sulfur Series

The fate of sulfur species during the gasification of high volatile A (HVA) bituminous and lignite coals is given in Table 2. According to these data, approximately 97 percent of the HVA bituminous coal sulfur was converted to H_2S and COS while only 81 percent of the lignite sulfur was converted. This variation is probably due to the chemical characteristics of the lignite ash since alkaline ashes will retain significant amounts of sulfur. This is exemplified by the high sulfur content (14.2%) found in the ash from gasifying lignite. This phenomenom has also been demonstrated in fluidized-bed combustion tests for lignite.[4]

The actual amounts of sulfur species in the process and discharge streams from gasification systems I and II are given in Table 3. There are no data on five of the discharge streams from these systems: a) the coal feeder vent gases, b) the tar/liquor separator vent gases, c) tar combustion gases, d) low-Btu gas combus-

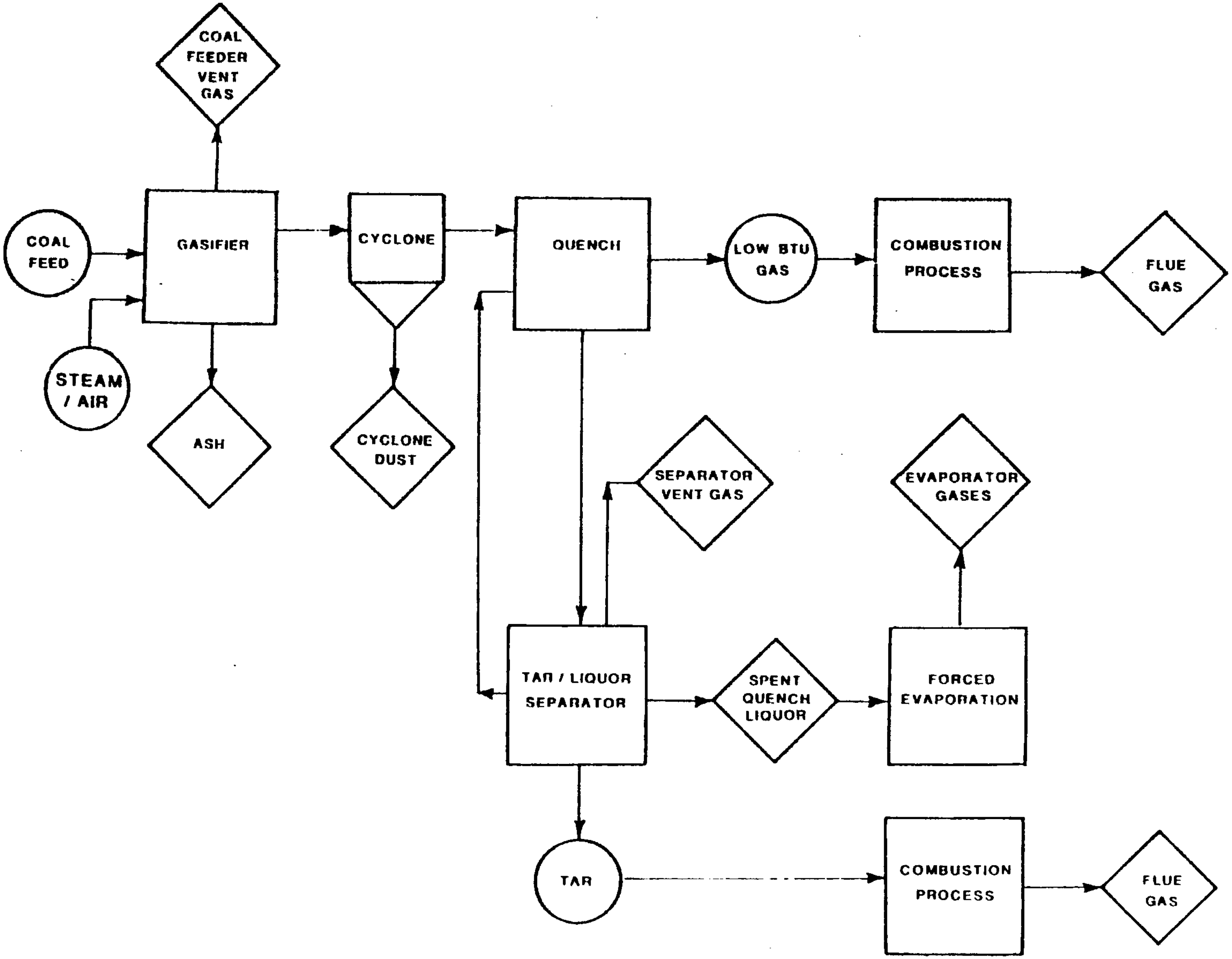


Figure 2. System II—Low-Btu gas production.

TABLE 1

COAL FEEDSTOCK ANALYSES FOR FIXED-BED, ATMOSPHERIC GASIFICATION SYSTEMS

	Anthracite	High Volatile A Bituminous			High Volatile C Bituminous	Medium Volatile Bituminous	Lignite
Proximate Analysis (wt %)							
Moisture	3.6	5.5	3.5	2.3	7.2	7.1	32.1
Ash	8.0	7.1	4.5	5.0	15.7	5.0	7.6
Volatile Matter	3.6	30.8	29.1	36.4	34.4	21.4	29.0
Fixed Carbon	84.8	56.6	62.9	56.3	42.7	66.5	31.3
Ultimate Analysis (wt %, dry)							
Carbon	86.6	80.0	81.0	—	62.3	85.2	64.8
Hydrogen	2.0	5.1	5.0	—	4.7	4.7	4.5
Nitrogen	}2.3	}6.6	1.5	—	1.0	}4.0	1.5
Oxygen			3.9	—	5.7		17.0
Sulfur	0.8	0.8	0.7	0.6	3.7	0.7	1.0
Ash	8.3	7.5	—	—	—	5.4	11.2
HHV (Btu/lb as received)	11,430	13,405	14,335	13,960	11,315	13,830	7327

Sources: Refs. 1, 2, 3.

TABLE 2

FATE OF COAL SULFUR IN ATMOSPHERIC, FIXED-BED, SINGLE-STAGE, LOW-BTU GASIFICATION SYSTEMS

Coal Sulfur Converted To	Coal Type	
	HVA Bituminous	Lignite
H_2S (wt %)	95.1	78.4
COS (wt %)	2.0	3.1
Tar Sulfur (wt %)	2.1	3.3
Cyclone Dust Sulfur (wt %)	0.7	1.0
Gasifier Ash Sulfur (wt %)	0.1	14.2
	100.0	100.0

TABLE 3

SULFUR SPECIES IN THE PROCESS AND MULTIMEDIA DISCHARGE STREAMS FROM LOW-BTU GASIFICATION SYSTEMS

Coal Type	Gasification System	Coal Sulfur (wt % dry)	Low-Btu Gas Sulfur (ppmv)	Tar/Oil Sulfur (wt %)	Cyclone Dust Sulfur (wt %)	Gasifier Ash Sulfur (wt %)
Anthracite	I	0.8	H_2S = 900	—	—	—
HVA Bituminous	I	0.8	H_2S = 1634 COS = 60	0.5	0.7	0.01
HVA Bituminous	II	0.7	H_2S = 1200	0.5	—	—
HVC Bituminous	II	3.7	H_2S = 11,000	1.6	—	—
Medium Volatile Bituminous	I	0.7	H_2S = 1213 COS = 50	—	—	—
HVA Bituminous	II	0.8	—	520 ppm*	0.67	250 ppm*
Lignite	I	0.91	H_2S = 2877 COS = 133	1.3	2.0	4.1

*SSMS Analysis
Sources: Refs. 1, 2, 3,

tion gases, and e) the vapors from the forced evaporation of the quench liquor.

The data in Table 3 indicate that the amount of COS formed during the gasification of all the coals is approximately 4 volume percent of the total gaseous sulfur species. This amount of COS in the product gas will affect the selection and design of an acid gas removal process to remove H_2S from low-Btu gas. The sulfur content of the tar produced in gasifying lignite was two to three times greater than for gasifying HVA bituminous coals having similar amounts of sulfur. This would indicate that the sulfur emissions from a combustion process using tar produced from lignite would be significantly greater than using tar produced from HVA bituminous coal having the same amount of sulfur. There were also higher concentrations of sulfur in the cyclone dust and ash produced in gasifying lignite compared to gasifying HVA bituminous coals.

Nitrogen Species

In this section the formation of gaseous nitrogen species during coal gasification and the subsequent combustion of these components is discussed. The two gaseous nitrogen species of importance are ammonia and hydrogen cyanide. The date, there are minimal data on the amount of HCN in the product low-Btu gas with no data on the amount of HCN in the following discharge streams: coal feeder and tar/liquor separator vent gases, forced evaporator vapors, and combustion gases from burning the low-Btu gas. However, there are data on the concentration of ammonia in low-Btu gas along with estimates on the fate of ammonia during low-Btu gas combustion.

The current data on the formation of NH_3 and HCN during the gasification of high and medium volatile bituminous coals are given in Table 4. These data indicate that there can be a significant variation in the amount of ammonia formed during the gasification of the same coal feedstock. These variations can probably be attributed to the following operating parameters:

- Amount of steam used to gasify the coal
- Surface moisture content of the coal
- Time-temperature history of the coal particle in the gasifier.

The first two variables affect the hydrogen partial pressure inside the gasifier which is directly proportional to the amount of NH_3

TABLE 4

COAL NITROGEN CONVERTED TO NH_3 AND HCN

	Coal Nitrogen (wt %)	Ammonia Concentration in Low-Btu Gas (ppmv)	Hydrogen Cyanide Concentration in Low-Btu Gas (ppmv)	Molar Conversion of Coal Nitrogen to Ammonia (%)
High Volatile A Bituminous	1.5	109	107	—
High Volatile A Bituminous	1.54	1940		35.0
		622		12.0
		385		5.2
		666		9.0
		486		5.3
		658		7.2
		452		6.8
Medium Volatile Bituminous	1.0	113	129	—

Sources: Refs. 1, 2

formed. The last variable would affect the amount and characteristics of nitrogen intermediates formed in the gasifier.

The data in Table 4 also show the molar conversion of coal nitrogen to ammonia. For all tests except one where the molar conversion was 35.0 percent, the conversions were fairly consistent with the average molar conversion of coal nitrogen to NH_3 being approximately 8 percent.

The amount of HCN in the product low-Btu gas is also significant and deserves special attention when designing low-Btu gas cleaning or combustion processes. Hydrogen cyanide will affect the performance of certain acid gas removal processes that are currently being proposed for cleaning low-Btu gas produced from high sulfur coals. For example, HCN will cause a build up of thiocyanates in the solvent used in a Stretford process.

The fate of nitrogen species during the combustion of low-Btu gas has been investigated with respect to the amount of NH_3 converted to NO_x[2]. These studies indicated that the conversion of coal nitrogen to NO_x in low-Btu gasification systems was approximately 3 to 4 percent. This is much lower when compared to the direct combustion of coal where 10 to 15 percent of the coal nitrogen is emitted as NO_x.

There are, however, two other aspects to be considered in assessing the characteristics of nitrogen species in combustion gases. These are the amounts of NH_3 and HCN not converted to NO_x. The amount of ammonia emitted in the combustion process flue gas can be estimated from Figure 3. For example, if the NH_3 concentration in the low-Btu gas is 500 ppmv, 54 percent will be converted to NO_x while 46 percent will be emitted as NH_3. There are currently no data on the amount of HCN converted to NO_x in a low-Btu gas combustion process. Therefore, the quantity of HCN in the combustion gases is unknown.

Organic Species

The information presented in this section is primarily concerned with the amount and characteristics of the organic compounds in the following process and discharge streams from low-Btu gasification systems:

- Quench liquor
- Cyclone dust
- Gasifier ash
- By-product tar

The first three of these streams represent discharge streams while the byproduct tar is the feed to the tar combustion process.

Total Organics - Grab samples of the quench liquor, cyclone dust, and ash were collected from a gasification plant represented by System II as shown in Figure 2. The feedstock to this plant was a high volatile A bituminous coal. The total amount of organics in these three streams is presented in Table 5. The values for the total amount of organics were determined using the methods specified by the EPA Level 1 Environmental Assessment procedures[3] plus an additional ether extraction for the quench liquor. From the data in Table 5, the spent quench liquor contains a significant quantity of organics (~4000 mg/l). Since this liquor is sent to a forced evaporator, there is a potential for significant vapor emissions. However, there are no data on the emissions from this evaporator.

Organic Characteristics - The characteristics of the organic species in the quench liquor, by-product tar, and cyclone dust are shown in Figure 4. These results were obtained by using the extraction, column chromatography, and infrared (IR) spectra analysis methods specified by the EPA Level 1 Environmental Assessment[5].

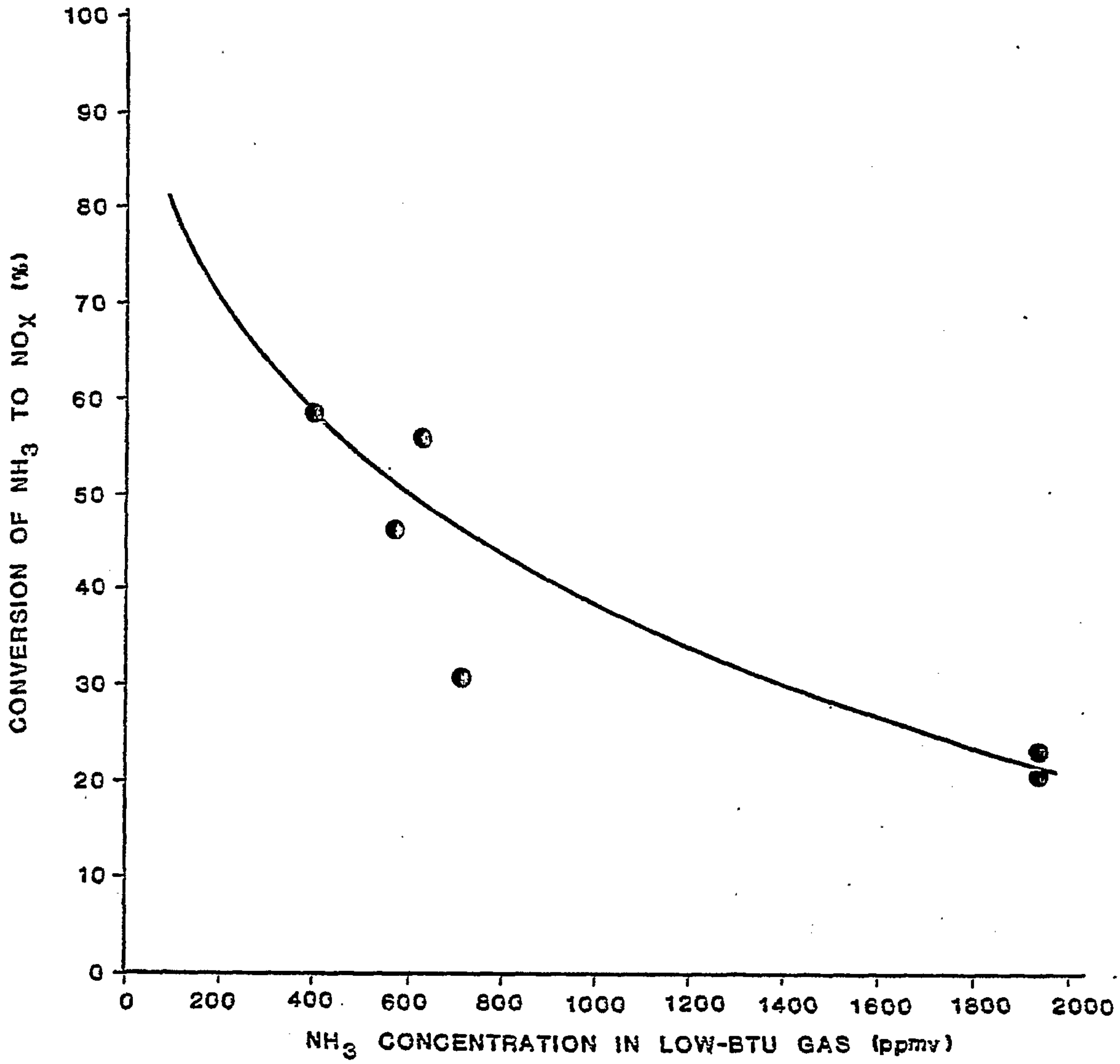
The organic components in the quench liquor consisted primarily of phenols with smaller amounts of acids. The by-product tar contained

TABLE 5

ORGANIC CONCENTRATIONS IN AQUEOUS AND SOLID WASTE DISCHARGE STREAMS FROM LOW-BTU GASIFICATION SYSTEMS

Discharge Stream	Organic Concentration
Spent Quench Liquor	3865 mg/l
Cyclone Dust	381 ppm
Gasifier Ash	18 ppm

Source: Ref. 3.



SOURCE: L-2137

Figure 3. Conversion of ammonia to NO_x in a turbulent-diffusion flame.

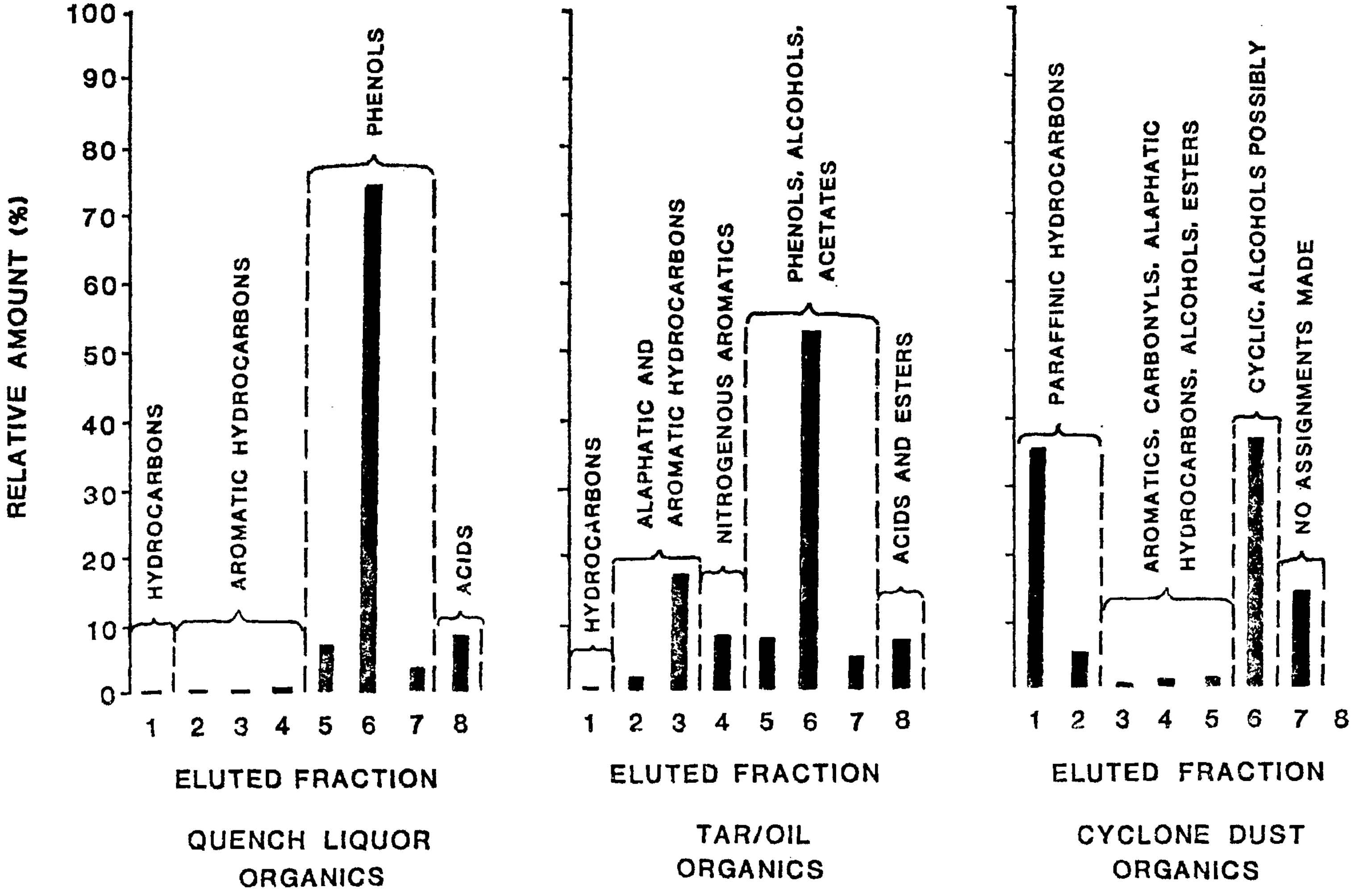


Figure 4. Results of Level 1 organic extraction, column chromatography, and IR analysis (bituminous coal).

a wide range of organic compounds including phenols, alcohols, acetates, acids, esters, etc. The organic constituents extracted from the cyclone dust were primarily paraffinic hydrocarbons and possibly cyclic alcohols. It should be emphasized that using IR spectroscopy to identify the nature of organic species is subject to doubt, especially for complex mixtures. Therefore, caution must be exercised in interpreting the spectra of these mixtures.

Trace Elements

Grab samples of the ash, cyclone dust, quench liquor, and byproduct tar were collected and analyzed for trace elements using Spark Source Mass Spectrometry (SSMS). These samples were taken from a gasification plant similar to System II. The results of these analyses are presented in Tables 6 through 9. A summary of the data in these tables is given in Table 10. From the data in Table 10, the trace element concentrations in the byproduct tar are higher than the quench liquor except for selenium and sulfur.

The six trace elements highlighted in Table 10 indicate certain important aspects of trace element distribution in these samples. The levels of Pb, Hg, As, Fl, and B are higher in the tars compared to the quench liquor while Se levels are essentially the same, Hg levels in the tar are also higher than in the cyclone dust.

In order to identify which trace elements need to be controlled in the spent quench

TABLE 6

TRACE ELEMENTS IN GASIFIER ASH BY SSMS

Element	ppm w/w	Element	ppm w/w	Element	ppm w/w
Uranium	56	Niobium	82	Thorium	86
Zirconium	430	Bismuth	0.4	Yttrium	260
Lead	7	Strontium	MC	Thallium	0.5
Rubidium	120	Rhenium	0.3	Bromine	12
Tungsten	10	Selenium	20	Tantalum	2
Arsenic	4	Hafnium	10	Germanium	4
Lutetium	2	Gallium	66	Ytterbium	12
Zinc	26	Thulium	1	Copper	540
Erbium	8	Nickel	120	Holmium	11
Cobalt	61	Dysprosium	17	Iron	MC
Terbium	4	Manganese	680	Gadolinium	10
Chromium	510	Europium	5	Vanadium	MC
Samarium	28	Titanium	MC	Neodymium	56
Scandium	29	Praseodymium	42	Calcium	MC
Cerium	260	Potassium	MC	Lanthanum	280
Chlorine	230	Barium	MC	Sulfur	250
Cesium	10	Phosphorus	MC	Iodine	0.3
Silicon	MC	Antimony	1	Aluminum	MC
Tin	4	Magnesium	MC	Indium	STD
Sodium	MC	Cadmium	3	Fluorine	≈56
Silver	≤0.3	Boron	130	Molybdenum	22
Beryllium	22	Lithium	190		

MC = Major Component

Note - Any element not listed - Concentration < 0.2 ppm by wt

Carbon, hydrogen, nitrogen & oxygen are excluded from these analyses.

Source: Ref. 3.

TABLE 7

TRACE ELEMENTS IN CYCLONE DUST BY SSMS

Element	ppm/wt	Element	ppm/wt
Bismuth	2	Arsenic	27
Lead	60	Germanium	5
Mercury*	0.01	Gallium	130
Terbium	9	Zinc	85
Gadolinium	2	Copper	130
Europium	1	Nickel	30
Samarium	9	Cobalt	16
Neodymium	21	Iron	MC
Praseodymium	5	Manganese	120
Cerium	45	Chromium	90
Lanthanum	45	Vanadium	100
Barium	460	Titanium	MC
Cesium	1	Scandium	12
Iodine	4	Calcium	MC
Antimony	8	Potassium	MC
Tin	2	Chlorine	720
Indium	STD	Sulfur	MC
Cadmium	<2	Phosphorus	MC
Silver	3	Silicon	MC
Molybdenum	14	Aluminum	MC
Mobium	12	Magnesium	MC
Zirconium	80	Sodium	MC
Yttrium	70	Fluorine	≃720
Strontium	340	Boron	70
Rubidium	33	Beryllium	6
Bromine	20	Lithium	27
Selenium	24		

*Flameless atomic absorption

MC = Major Component

Note: Any element not listed - concentration < 0.2 ppm by wt

Carbon, hydrogen, nitrogen and oxygen are excluded from these analyses.

Source: Ref. 3.

TABLE 8

TRACE ELEMENTS IN QUENCH LIQUOR BY SSMS

Element	μg/l	Element	μg/l
Lead	0.04	Gallium	0.006
Mercury	0.007	Zinc	0.07
Neodymum	⩽0.01	Copper	0.1
Praseodymium	0.005	Nickel	0.1
Cerium	0.01	Cobalt	⩽0.008
Lanthanum	⩽0.01	Iron	3
Barium	0.1	Manganese	0.03
Cesium	1	Chromium	0.03
Iodine	0.5	Vanadium	0.004
Antimony	0.1	Titanium	0.05
Tin	0.02	Scandium	⩽0.006
Indium	Std	Calcium	MC
Cadmium	⩽0.02	Potassium	MC
Molybdenum	0.06	Chlorine	0.3
Xirconium	0.01	Sulfur	MC
Yttrium	0.004	Phosphorus	MC
Strontium	0.2	Silicon	7
Rubidium	0.03	Aluminum	1
Bromine	0.2	Magnesium	2
Selenium	4	Sodium	MC
Arsenic	0.2	Fluorine	≃2
Geranium	⩽0.02	Boron	2
Lithium	0.2		

*Flameless atomic absorption
MC = Major Component
Note: Any element not listed - concentration ⩽ 0.004
Carbon, Hydrogen, nitrogen and oxygen are excluded from these analyses.
Source: Ref. 3.

TABLE 9

TRACE ELEMENTS IN TAR BY SSMS

Element	ppm	Element	ppm
Lead	10	Copper	3
Mercury*	0.12	Nickel	5
Neodymium	0.6	Cobalt**	5
Praseodymium	0.3	Iron	120
Cerium	0.5	Manganese	0.9
Lanthanum	0.6	Chromium	3
Barium	27.0	Vanacium	0.8
Cesium	0.1	Titanium	29
Iodine	1	Scandium	0.7
Antimony	0,8	Calcium	630
Tin	0.9	Potassium	100
Molybdenum	1	Chlorine	6
Zirconium	0.7	Sulfur	520
Yttrium	⩽0.2	Phosphorus	17
Strontium	10	Silicon	170
Rubidium	0.2	Aluminum	25
Bromine	2	Magnesium	23
Selenium	3	Sodium	71
Arsenic	4	Fluorine	≃22
Germanium	1	Boron	19
Gallium	8	Beryllium	0.1
Zinc	7	Lithium	4

*Flameless atomic absorption
**Heterogeneous
MC = Major Component
Note: Any element not listed - concentration ⩽ 0.004 ppm
Carbon, hydrogen, nitrogen, and oxygen are excluded from these analyses.
Source: Ref. 3.

TABLE 10

TRACE ELEMENTS IN GRAB SAMPLES BY SSMS

	Ash	Cyclone Bottom Dust	Liquor	Tar
Uranium	56	—	—	—
Bismuth	0.4	<2	—	—
Lead	7	60	0.04	10
Mercury	NR	0.01	0.007	0.12
Barium	MC	460	0.1	27
Antimony	1	8	0.1	0.8
Cadmium	3	< 2	⩽0.02	—
Molybdenum	22	14	0.06	1
Selenium	20	24	4	3
Arsenic	4	27	0.2	4
Zinc	26	85	0.07	7
Copper	540	130	0.1	3
Nickel	120	30	0.07	5
Chromium	510	90	0.03	3
Vanadium	MC	100	0.004	0.8
Titanium	MC	MC	0.05	29
Chlorine	230	720	0.3	6
Sulfur	250	MC	MC	520
Fluorine	≃56	≃270	≃2	≃22
Boron	130	70	2	19
Beryllium	22	6	—	0.1
Lithium	190	27	0.2	4

Note. All values expresses as ppm except liquor in which values are expressed as μg/ml.
MC = Major Component

liquor, trace element standards for surface, irrigation, and public intake waters are compared to the trace element concentrations found in the quench liquor. These comparisons are given in Table 11. From these data, the most important trace element requiring control is selenium since the concentration of selenium is approximately 400 times greater than the standards set for surface and public intake waters and 80 times greater than for irrigation water standards.

Particulate Matter

The physical characteristics of the particulate matter entrained in the low-Btu gas produced using various coal feedstocks is presented in Table 12. From these data, the physical characteristics of the particulate matter depend upon both the coal feedstock and gasifier operating conditions.

The particulates collected by the cyclone varied with respect to all three physical characteristics analyzed (average particle diameter (dp), ash content, and bulk density). The particulates collected from the gasification system using anthracite coal had the highest values for all three physical characteristics. The system gasifying lignite coal had the lowest average particle diameter while the system used to gasify bituminous coal had the lowest particulate matter ash content and bulk density. From these data, the particulate characteristics for the gasification of bituminous coals varied significantly which in-

TABLE 11

LEVELS OF TRACE ELEMENTS IN LIQUIDS FROM THE QUENCH LIQUOR AND BY-PRODUCT TAR VERSUS WATER QUALITY STANDARDS

Element	Surface Water	Irrigation Water	Public Water Intake	Liquor μg/l	Tar ppm
Antimony	—	—	—	0.1	0.8
Arsenic	0.05	1.0	0.1	0.2	4
Barium	1.0	—	—	0.1	27
Beryllium	—	—	—	—	0.1
Boron	1.0	0.75	1.0	2.0	19
Cadmium	0.01	0.005	0.01	⩽0.02	—
Chromium	0.05	5.0	0.05	0.03	3
Fluorine	—	—	—	2	22
Mercury	—	—	0.002	0.007	0.12
Lead	0.05	5.0	0.05	0.04	10
Manganese	0.05	2.0	0.00	0.03	0.9
Molybdenum	—	0.005	—	0.06	1
Nickel	—	0.5	—	0.07	5
Selenium	0.01	0.05	0.01	4	3
Vanadium	—	10.0	—	—	—
Zinc	5.0	5.0	5.0	0.07	7
Copper	1.0	0.2	1.0	0.1	3

TABLE 12

CHARACTERISTICS OF THE PARTICULATE MATTER ENTRAINED IN LOW-BTU GAS

	Collected by the Cyclone			Not Collected by the Cyclone			Suspended in Tar
Coal Type	Average dp (μ)	Ash Content (wt %)	Bulk Density	Average dp (μ)	Ash Content (wt %)	Bulk Density	Average dp (μ)
Bituminous	170	10.2	0.40	—	—	—	2-20
Bituminous	95	15.4	0.53	20*	10.4	0.31	—
Anthracite	200	47.3	0.93	<1*	54.7	—	—
Lignite	70	23.0	—	—	—	—	—

*Agglomerated
Source: Ref. 3.

dicates the dependency of these characteristics on the gasifier operating parameters.

The particulate matter collected after the cyclone consisted of particulates that settled in or escaped from the main product gas line. The particulates in the tar were collected by solution filtration. The particulates not collected by the cyclone were agglomerated. However, this may not be representative of the actual characteristics of the particular matter passing through the cyclone.

These results indicate that the physical nature of the particulate matter carried over in the product low-Btu gas will probably vary from site to site depending on the type of coal feedstock and the operating parameters of the gasifier. Therefore, the design of cyclones and other particulate collecting devices wll be site specific since the design of these devices is highly dependent upon these physical characteristics.

CONCLUSIONS

Data currently available on multimedia discharge streams is not sufficient to make a completely accurate assessment of the health and environmental effects and control technology requirements for producing low-Btu gas from coal. However, judgments on some of these discharge stream characteristics can be made from the data presented in this paper. The following are specific conclusions and recommendations derived from this study.

Sulfur Species

1) The amount of coal sulfur that is converted to gaseous sulfur species (H_2S and COS) is primarily dependent upon the ash characteristics of the coal feedstock. For example, the amount of feedstock sulfur converted to H_2S and COS in gasifying lignite will usually be significantly less than in gasifying high volatile bituminous coals. This is due to the alkalinity of the lignite ash which retains and/or collects sulfur species.
2) The ratio of COS to the total amount of sulfur species in the low-Btu gas was not highly dependent upon coal feedstocks and remained at about 0.04. This may indicate that the mechanisms for H_2S and COS formation during coal gasification are directly related. If this relationship is valid, the amount of COS in this product gas can be estimated for various coals which can be used as a factor in selecting and designing sulfur recovery processes for low-Btu gasification systems.
3) The concentration of sulfur in the by-product tar is dependent upon the nature of the coal feedstock. Sulfur concentrations were found to be two to three times greater in tar produced from lignite than from high volatile bituminous coal. This would affect the amount of sulfur emissions if the tar is to be used as a combustion fuel.

Nitrogen Species

1) The amount of ammonia produced during coal gasification is dependent upon the quantity of steam used, coal feedstock moisture content, and the time-temperature history of a coal particle in the gasifier. Generally, less that 10 mole percent of the coal nitrogen is converted to NH_3 in systems designed to produce low-Btu gas for combustion fuel.
2) The amount of NO_x formed during the combustion of low-Btu gas is a function of the NH_3 concentration in the product gas and the combustion process operating parameters. Past studies have indicated that NO_x formation would be two to three times lower when burning low-Btu gas compared to burning the coal feedstock directly.
3) There may be significant quantities of NH_3 and HCN in the flue gases from low-Btu combustion processes. The current data indicate that up to 50 percent of the NH_3 in the product gas can be emitted in the combustion gases while there is no actual data on the amount of HCN emitted.

Organics

1) The liquor used to quench low-Btu gas will contain significant quantities of

organic compounds consisting primarily of phenols. Forced evaporation of large quantities of spent quench liquor will cause a significant quantity of organics to be emitted into the atmosphere.

2) The ash produced from coal gasification will contain very small quantities of organics (~20 ppm) while the organics in the particulate matter entrained in the product gas will be much higher (~400 ppm).

Trace Elements

1) Concentrations of Pb, Se, As, and Fl were highest in the cyclone dust compared to the ash, quench liquor, and by-product tar while the Hg concentration was highest in the by-product tar.

2) The levels of trace elements in the quench liquor equaled or exceeded the levels listed in the Federal Water Quality Standards for nearly every element. The largest deviation was shown by selenium at 4 ppm (400 times greater than the standard for surface water).

Particulate Matter

1) The particulate matter entrained in the low-Btu gas had different particle size distributions, bulk density, and ash contents. These physical and chemical properties seem to be dependent on coal type and the gasifier operating characteristics. These variations will significantly affect the operation of cyclones and other collection devices used to remove particulate matter from the product gas.

RECOMMMENDATIONS

The characteristics of certain discharge streams should be determined. There are currently no data on the composition of the following streams: coal feeder and tar/liquor separator vent gases, vapors from the forced evaporation of spent quench liquor, and tar combustion gases. There are some data on the flue gases produced during the combustion of low-Btu gas; however, the fate of trace constituents such as HCN in these combustion processes has not been determined. The organic constituents in the spent quench liquor need to be further characterized and leaching tests for the ash and cyclone dust need to be performed.

In conjunction with further characterization of the multimedia waste streams from low-Btu gasification systems, methods to determine the health and environmental effects of these streams need to be developed. These methods will provide the goals for control technology implementation and development along with defining technologies necessary to minimize worker exposure to hazardous fugitive emissions from these processes.

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