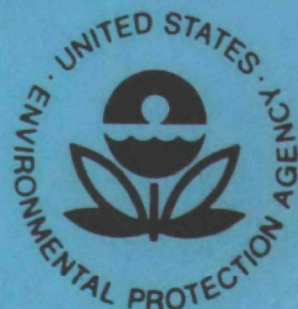


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POTENTIALLY HAZARDOUS EMISSIONS FROM THE EXTRACTION AND PROCESSING OF COAL AND OIL



U.S. Environmental Protection Agency
Office of Research and Development
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POTENTIALLY HAZARDOUS EMISSIONS FROM THE EXTRACTION AND PROCESSING OF COAL AND OIL

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ABSTRACT

In this task, a list of specifically identified, potentially hazardous materials which may be associated with the air, water, and solid waste from a refinery, a coke plant, a Lurgi-high-Btu gas process, and the solvent refined coal process was compiled. This task was completed essentially in one month in order to provide information to EPA for future program planning. Thus, the list of the potentially hazardous emission sources and their components were developed with the best engineering judgment and from the readily available published documents.

Fugitive losses were identified as the major source of emissions in the refinery. The compositions of the fugitive emissions are difficult to quantify. Among the four assessed coal and oil processes, coking is the most offensive one. Coal gasification is likely to produce equally dangerous materials as the coke plant, but they will probably be somewhat more contained than coke oven emission. The environmental impact of coal liquefaction is not well defined. However, the liquefaction products will probably be more hazardous than crude oil products, and their refining and utilization will be worse offenders than the corresponding petroleum operations.

This study indicated that available documents were not adequate to develop accurately a list of potentially hazardous emissions from these processes. A detailed assessment of the processes, field sampling, and analysis are needed to identify the potentially hazardous emissions.

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SECTION I

EXECUTIVE SUMMARY

INTRODUCTION

The U.S. is in the process of making substantial increases in its domestic capability for extraction and processing of crude oil and coal to produce useful fuel products. Quantities to be dealt with at specific sites will greatly exceed those now handled; in addition, new potentially "dirty" processes are to be employed, especially in the case of coal. The products and emissions from present day systems involving thermal and catalytic processing of fossil fuels are known to contain potentially harmful substances. The potential harmful impact from certain processes which may be employed in the immediate future is well established in that the streams contain known carcinogenic materials. On the other hand, little is known about whether the emissions, which can be anticipated, are in fact economically controllable to levels which will permit elimination of all potential environmental threat. This study is a first step in development of specific information on potentially harmful emissions from fossil fuel processes. It was designed to provide information needed to plan programs necessary for full definition of problems which we need to anticipate in future energy programs.

OBJECTIVE

It was intended that the study should develop a list of specifically identified, potentially hazardous materials which might be associated with the air, water, and solid waste from processes used to separate coal or crude oil into useful products. It was agreed that the list should be developed in the shortest possible time and that

materials readily available to EPA and the contractors would serve as a data base. Best engineering judgment was to be applied in development of the first specific recommendations for materials to be considered in future environmental assessment programs concerned with advanced processing of fossil fuels.

APPROACH

Because the project was to be essentially complete in 2-3 weeks, a two-pronged approach was developed. Battelle-Columbus was commissioned to collect information on materials known to be potentially hazardous to human health and identify those which might be associated with emissions from processes extracting useful fuels from crude oil and coal. Radian Corporation was commissioned to identify present-day processes which might be expected to produce potentially hazardous materials and develop an approach to identify specific emissions which should be anticipated. After an initial phase in which the two organizations completed preliminary studies a meeting to develop a detailed plan for completion of the project was held. The overall program decided upon involved the following basic steps:

- (1) The present-day processes utilizing crude oil and coal were identified and classified. A modular approach was used to divide the technologies concerned with extraction, processing, or consumption of crude oil or coal into modular segments for purposes of analyses of environmental impacts.

- (2) After definition of process modules for analysis of present-day emissions, all points of emission for air, water, and solid waste (including fugitive emissions) were identified and individual streams were assessed from the standpoint of specific potentially hazardous emissions believed to be present. Where it appeared that emission streams from various processes could, because of their similar character, be combined for purposes of analysis, this was done.

- (3) A list of twenty-five classes of chemical species which might be potentially toxic, carcinogenic, or otherwise potentially hazardous was developed to provide a system for cataloging materials

identified as potentially hazardous emissions. This list was provided by EPA.

(4) A system for classification of pollutants according to what is known about their potential for harmful impact was defined. Three classes of pollutants were defined; Status 1 included all materials which were known to be present, and known to be potentially hazardous. This class included carcinogenic compounds present in any amount and toxic substances present in concentrations exceeding the TLV. The TLV is the list of threshold limit values of airborne contaminants published by the American Conference of Governmental and Industrial Hygienists (A-10). Status 2 pollutants were those known to be present and suspected to be potentially hazardous. This status was mainly comprised of toxic materials known to be present in emission streams but in undefined concentration. Status 3 pollutants were those potentially harmful materials which from indirect analysis of process conditions were suspected to be present in emission streams in concentrations exceeding the TLV. Suspected emission of carcinogenic material was placed in this class.

(5) A data sheet was developed for each process emission stream and, after assessment of all available information on potentially hazardous emissions, all were classified as Status 1, 2, or 3 and identified both by class of compound and specific compounds.

(6) After identification of all compounds and chemical classes of compounds present, or suspected present in potentially hazardous emissions from present-day processes, an assessment was made of the degree to which the emissions would be representative of those which could be anticipated from future fossil fuel technologies.

(7) Recommendations for future action were developed. These recommendations and conclusions on which they are based are discussed briefly in the following section. Additional background is incorporated in Section III--Discussion of Results.

CONCLUSIONS AND RECOMMENDATIONS

(1) Over 200 compounds (or classes of compounds) have been tentatively identified as potentially hazardous emissions from processes which presently extract commercial fuels from coal and oil. There is evidence to suggest that these and similar materials may be emitted by processes which will be employed to meet future energy needs.

(2) These potentially hazardous emissions have been associated with about 50 present-day processes which should be considered as candidates for comprehensive testing to confirm and quantify levels of emissions for potentially hazardous materials. The first requirement for a test program will be development of a sampling and analytical strategy which can be integrated with the methodology that has been developed for the assessment of emissions expected to be present.

(3) The present exercise to tentatively assess potentially hazardous emissions from processing of oil and gas has developed a data base for planning near-term activities. Also it has resulted in demonstration of a methodology which can and should be utilized to further refine the list of materials which will be used for general assessment of energy processes.

(4) The linking of emissions associated with present-day processes with potential impacts from advanced energy systems was made by making time-limited comparisons of present and projected energy technologies. There is little question that potential for hazardous emissions will be similar for present and projected processes in a qualitative sense, e.g., coke ovens are known to be serious sources of carcinogenic materials. The planned processes involving liquefaction employ similar technology, and could have similar impacts if proper precautions are not taken. The difficulty of control for massive plants of the future, and the likelihood of serious environmental impact, should be the subject of further assessment. Proposed processes would be better evaluated in light of what we know or can determine now about the toxic nature of materials such as residual oils, coal tars, asphalt, which now are being handled in refineries, coke plants, and the like.

SECTION II

METHODOLOGY

A modular approach was employed to identify the potentially hazardous emissions. The extraction and processing of crude oil and coal were put into three classes of process flow sheets, namely, petroleum, conventional coal, and advanced coal process flow sheets. A complete description of each type of process flow sheet and the identification of the potentially hazardous emission sources will be presented in the next section--Discussion of Results. The basic approach and the definitions of toxicity will be outlined in this section.

A list of 25 potentially hazardous chemical emission classes was provided by EPA as characteristic of the materials processed in the modules being investigated. This list is shown in Table 2-1. Under many of these classes are listed examples of specific potentially hazardous components. There are also some potentially hazardous chemicals involved which can be classified into more than one of the 25 classes. It is felt that the classes suggested generally include most of the components currently considered hazardous and provide a consistent pattern to categorize the components.

Every potentially hazardous chemical was assessed for its importance, its physical state, and its concentration in the specific process stream. Some of this information was obtained from the published literature, by material balances on the process module, and by engineering estimate. Three classes of status were set up and they were intended to demonstrate the relative standings of the potentially hazardous materials.

- Status 1--Known to be present, known to be hazardous

- Status 2--Known to be present, suspected of being hazardous
- Status 3--Suspected of being present, known to be hazardous.

For known carcinogens, presence alone qualified them in a Status 1 category. For toxic chemicals, presence in concentrations that appear to be potentially hazardous at the point of contact was required before a Status 1 was assigned. When toxic chemicals fell into Status 2, their emissions were usually determined by material balance on the module or from published literature. However, in most instances, the quantities of these chemicals which can cause harmful effects are not well defined. The toxic chemicals in Status 2 may also indicate that their toxic properties are uncertain. Status 3 was assigned to the toxic chemicals whose emission levels in the process stream was possible but uncertain either because of their physical properties, such as solubility, vapor pressure, etc., or because of the lack of information on existing commercial processes. However, the toxic effects of these chemicals have been studied or reported in published literature.

An attempt has been made to compare the toxicities of the potentially hazardous chemicals. There are two scales (T and C) for the potentially hazardous air pollutants and one for hazardous water pollutants (W). The first scale for air (T) is based on the allowable emission limits from the TLV list. The second scale (C) is basically for carcinogenic materials in air. This scale is only applied to the materials whose carcinogenic effects have been tested in animals. In many cases, the chemicals are put into this category because of the similarities of their chemical structures with those of the known carcinogens. There is only one collective scale (W) for the water pollutants. The units on this scale are the Lethal Dose Fifty, LD_{50} , and the threshold limit of the corresponding pollutant. The Lethal Dose Fifty is defined as the calculated dose of a chemical substance which is expected to cause the death of 50 percent of the entire population of an experimental animal species, as determined from the exposure to the substance, by any route other than inhalation, of a significant number from the population. The designation numbers of these three scales are summarized in Table 2-2.

Table 2-1. THE MODULAR CLASSIFICATION FOR POTENTIALLY HAZARDOUS MATERIALS PROPOSED BY EPA

1. Acids and Anhydrides	13. Lactones
Aliphatic (maleic anhydride)	(β -propiolactone,
Aromatic (benzoic acid)	butyrolactone, para-
Inorganic (sulfuric acid)	sorbic acid, vinylene
2. Alcohols	carbonate)
3. Amines	14. Nitro Compounds
Ammonia	(PAN, methylethyl
Aliphatic	nitrites)
Aromatic (anilines,	15. Nitrosamines
naphthylamines)	(dimethylnitrosamine)
4. Inorganic Salts	16. Ozonides
5. Carbonyl Compounds	17. Peroxides
Aldehydes	(Lauroyl peroxide)
Ketones (phenylvinyl	18. Phenols
ketone)	19. Polychlorinated Polynuclear
6. Combustion Gases	(polychlorobiphenyl,
(SO_x , NO_x , CO, etc.)	polychlorotriphenyl,
7. Epoxides	polychlorodibenzylfuran,
(styrene oxide, 1,2-	polychlorodibenzo-p-
epoxyhexadecane)	dioxin)
8. Ethers	20. Polynuclear
(α -Chloroalkyl ethers)	Aromatic Hydrocarbons
9. Halocarbons	(pyrenes, anthracene,
(Freons, CCl_4 , CHCl_3 , etc.)	chrysene)
10. Heterocyclic (monocyclic)	Aza arenes (acradene)
Imino Heterocyclic	Imino Arenes (carbazole)
(aziridines, ethyleneimine)	Oxa Arenes (dibenzofuran)
Oxa (furan)	Ring-carbonyl Arenes
Pyridines	(anthraquinone)
Pyrroles	Thio Arenes (dibenzo-
Thiophene	thiophene)
11. Hydrocarbons	21. Sulfur Compounds
Aliphatic (saturated)	H_2S , Mercaptans
Olefins	Sulfates (diethyl sulfate,
Aromatics (monocyclic-	ethylene sulfate)
benzene, toluene, xylene)	Sulfides
12. Hydroperoxides	Sulfites
Cyclohexene Hydroperoxide	Sulfonates (ethylmethane
	sulfonate)
	Sultones (propane sultone)

TABLE 2-1 (continued). PROPOSED CLASSIFICATIONS FOR POTENTIALLY
HAZARDOUS MATERIALS FROM FUELS

22. Trace Elements

Metals

Nonmetals

23. Organometallics

24. Fine Particulates

25. Cyanides

Table 2-2. SUMMARY OF THE TOXICITY SCALES FOR AIR AND WATER POLLUTANTS

Designation	Description
T-0	Emission limit in TLV $< 1 \text{ mg/M}^3$
T-1	$1 \text{ mg/M}^3 \leq \text{Emission limit in TLV} \leq 10 \text{ mg/M}^3$
T-2	Emission limit in TLV $\geq 10 \text{ mg/M}^3$
C-1	Identified primary procarcinogen (in humans)
C-2	Definite high tumor-promoting effect in animal tests
C-3	Evidence of tumor-promoting effect in animal tests
C-4	Suspected procarcinogen by structure
W-0	$\text{LD}_{50} < 50 \text{ mg/Kg}$, Threshold limit $< 1 \text{ ppm}$
W-1	$50 < \text{LD}_{50} \leq 5000 \text{ mg/Kg}$, $1 < \text{Threshold limit} < 1000 \text{ ppm}$
W-2	$\text{LD}_{50} > 5000 \text{ mg/Kg}$, Threshold limit $\geq 1000 \text{ ppm}$

SECTION III

DISCUSSION OF RESULTS

PETROLEUM PROCESS MODULES

The first step of the approach to analyze the potentially hazardous emission from the extraction and processing of crude oil was to identify the representative major operations. All operations were described in terms of process "modules". These identified operations were grouped into six process flow sheets. These process flow sheets and the flow of materials through them are shown in Figures 3-1 to 3-6. A list of 42 modules is shown in Table 3-1.

The second step of the approach was to identify and to assess all potentially hazardous emission streams by one or a combination of the following steps:

- (1) Information from published literature
- (2) Material balance on the process module
- (3) Experience in similar existing commercial operations
- (4) Prediction through group discussion.

Emissions streams which were essentially the same were classified for further detailed analysis. The 25 classes of emission streams which cover all the potentially hazardous emission from petroleum operations are shown in Table 3-2.

For the detailed assessment, all published information on emission stream composition was sought and the emissions which might be expected on the basis of process conditions were estimated. The potentially hazardous chemicals were identified and assigned status numbers as described in the previous section. Some identified chemicals were assigned toxicity numbers whenever sufficient

information was available. The definitions of these toxicity numbers have been discussed in the previous section. In this detailed assessment, each of the 25 compound classes (Table 2-1) was considered for each stream. A data sheet was made up for the results of the detailed assessment of every identified emission stream from the modules. The data sheets of all the emission streams as described in Table 3-2 are shown in Table 3-3. Table 3-4 summarizes the assessment of the fugitive emission streams. Fugitive losses are by far the largest source of emissions from petroleum processing. They are also difficult to quantify. Each process module was assessed on the basis of the operating pressure and temperature, concentration of potentially hazardous volatiles, corrosiveness, and general housekeeping. The extent of fugitive losses will vary with respect to these factors. However, it is difficult to quantify the degree of dependence. The classification and rating were made essentially by engineering judgment.

A fact sheet was made for each module from which potentially hazardous emissions would be expected. These fact sheets are included in Appendix A.

Conclusions

On the basis of a 3-week assessment of process flowsheets and modules, streams, and chemicals encountered in the petroleum industry, the classifications of process streams and modules concerning their potential for emitting hazardous chemicals were made.

(1) Among the process streams known to contain known hazardous components are Claus plant tailgas, catalyst regeneration off gas from catalytic reformers, catalytic hydrocrackers, HDS units, and moving bed catalytic crackers. Off gases from fluid cokers, asphalt air blowing, decoking, and oil-fired process heaters are also in the known/known category.

(2) Literature information on specific carcinogens in refinery process streams was sparse, although specific published data on polynuclears [benzo(a)pyrene and others] indicate these to be known hazards in catalytic cracker regeneration off gas and asphalt blowing streams.

(3) The process streams with the greatest number of compounds in the known/known, known/suspected, and suspected/known categories were moving bed catalyst regeneration, fluid coker off gas, asphalt air blowing, spent acid sludge, and brine water streams. Sour aqueous condensates, cooling water systems, and fugitive emissions come from all parts of the refinery and thus contain many of the suspected categories.

(4) Potentially hazardous fugitive emissions were judged to be the most likely from gas and oil wells and field separation units, visbreakers, cokers, and lube oil processing units. Waste-water systems (open sewers) and oil-fired heaters were also considered high potential emitters. Process modules judged to have medium to high hazardous fugitive losses are acid gas removal, sulfur recovery, atmospheric distillation, catalytic crackers, lube oil HDS, and asphalt blowing.

(5) It is generally difficult to characterize fugitive losses as to chemical class or specific component. These should be similar in nature to the fluids being processed in the module rather than that of a specific stream leaving the module. The matrix entries therefore indicate that all potentially hazardous emissions are only suspected of being present in the fugitive losses, but that all such hazardous chemicals previously mentioned in connection with stream classes could be present.

(6) There was no evidence that epoxides, hydroperoxides, nitro compounds, ozonides, peroxides, and polychlorinated polynuclears are among the components to be classified on any level.

(7) The 25 chemical classes suggested by EPA appear to be representative of the hazardous chemicals that might be found in petroleum streams.

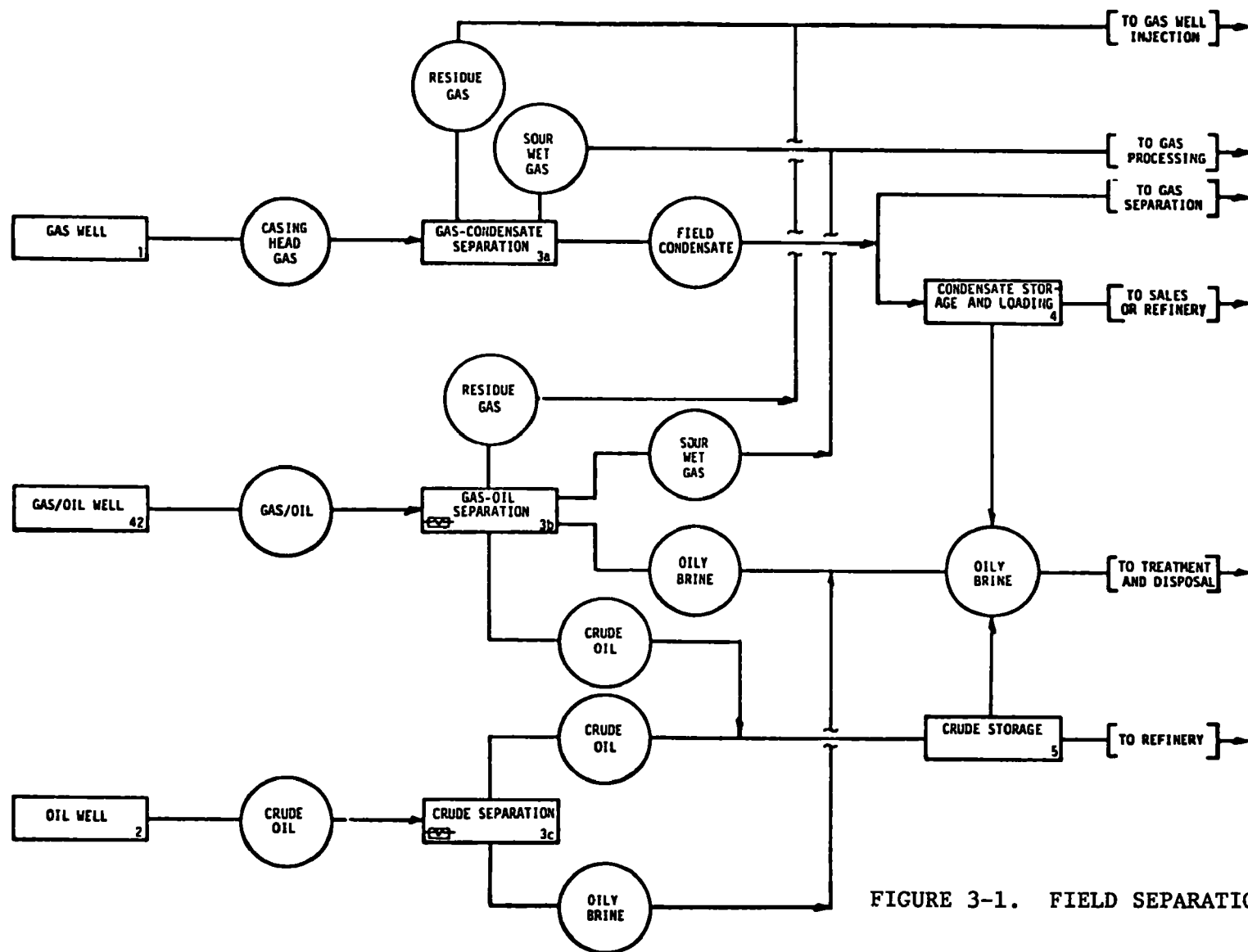


FIGURE 3-1. FIELD SEPARATION

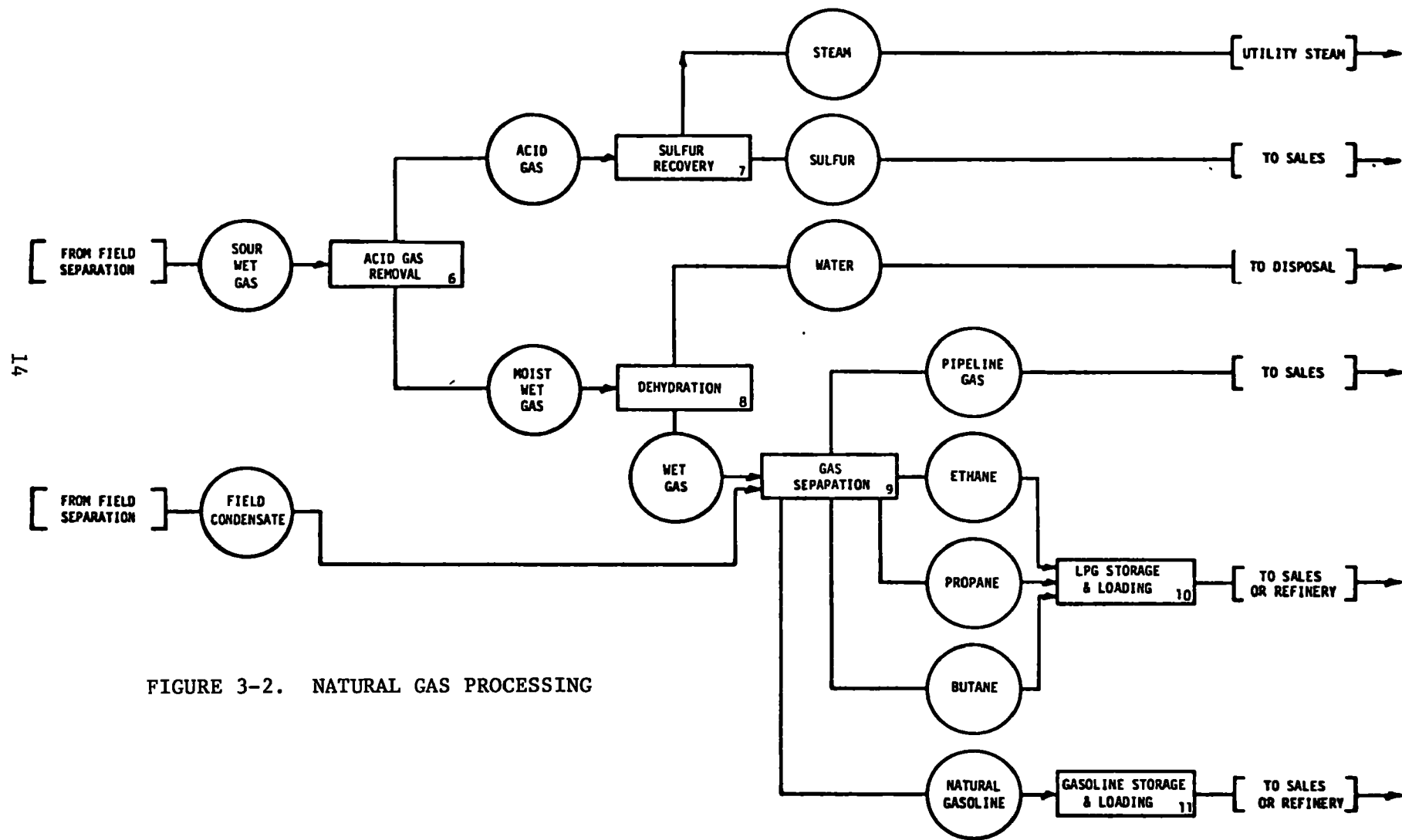


FIGURE 3-2. NATURAL GAS PROCESSING

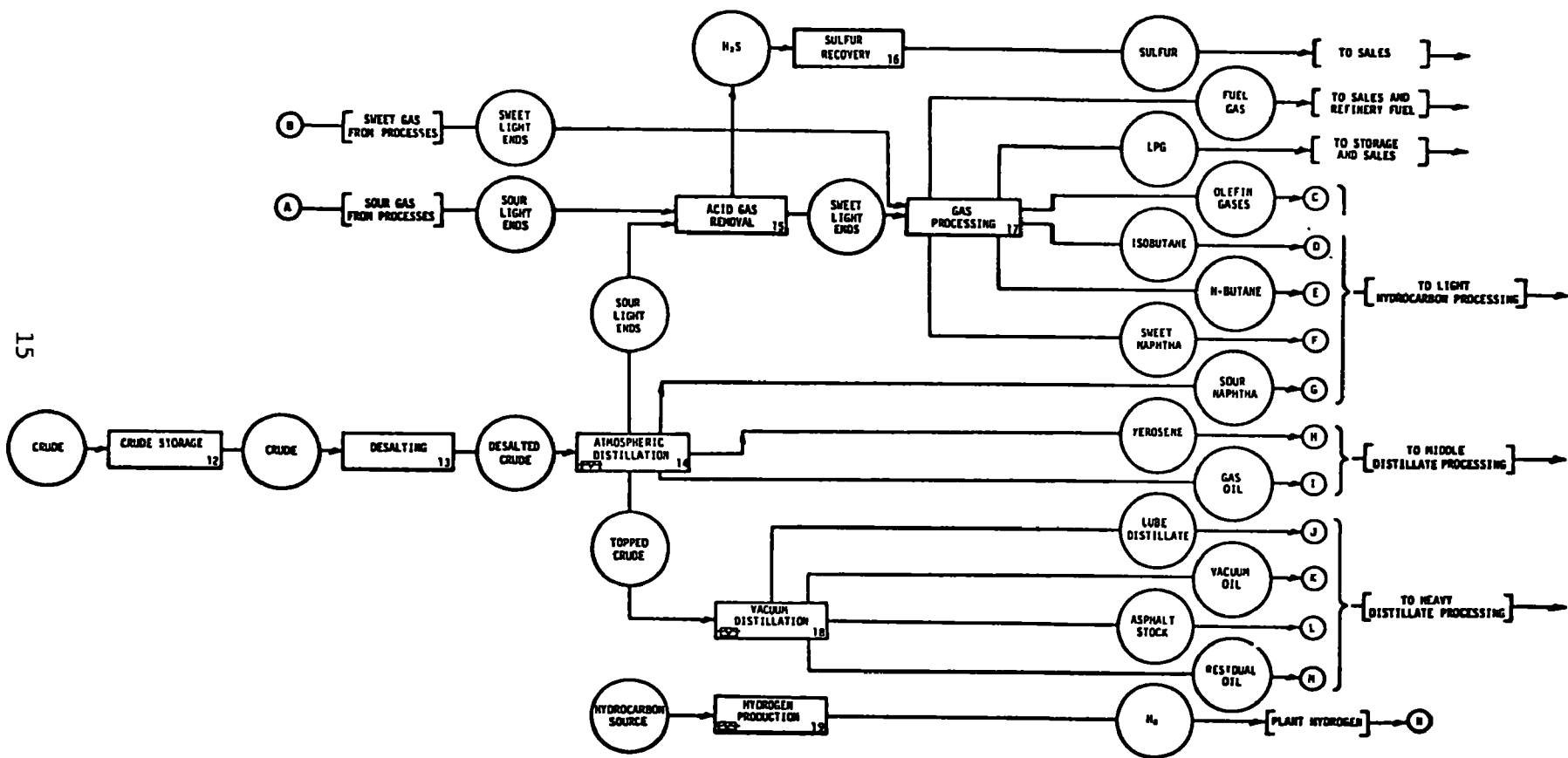


FIGURE 3-3. REFINERY - CRUDE SEPARATION

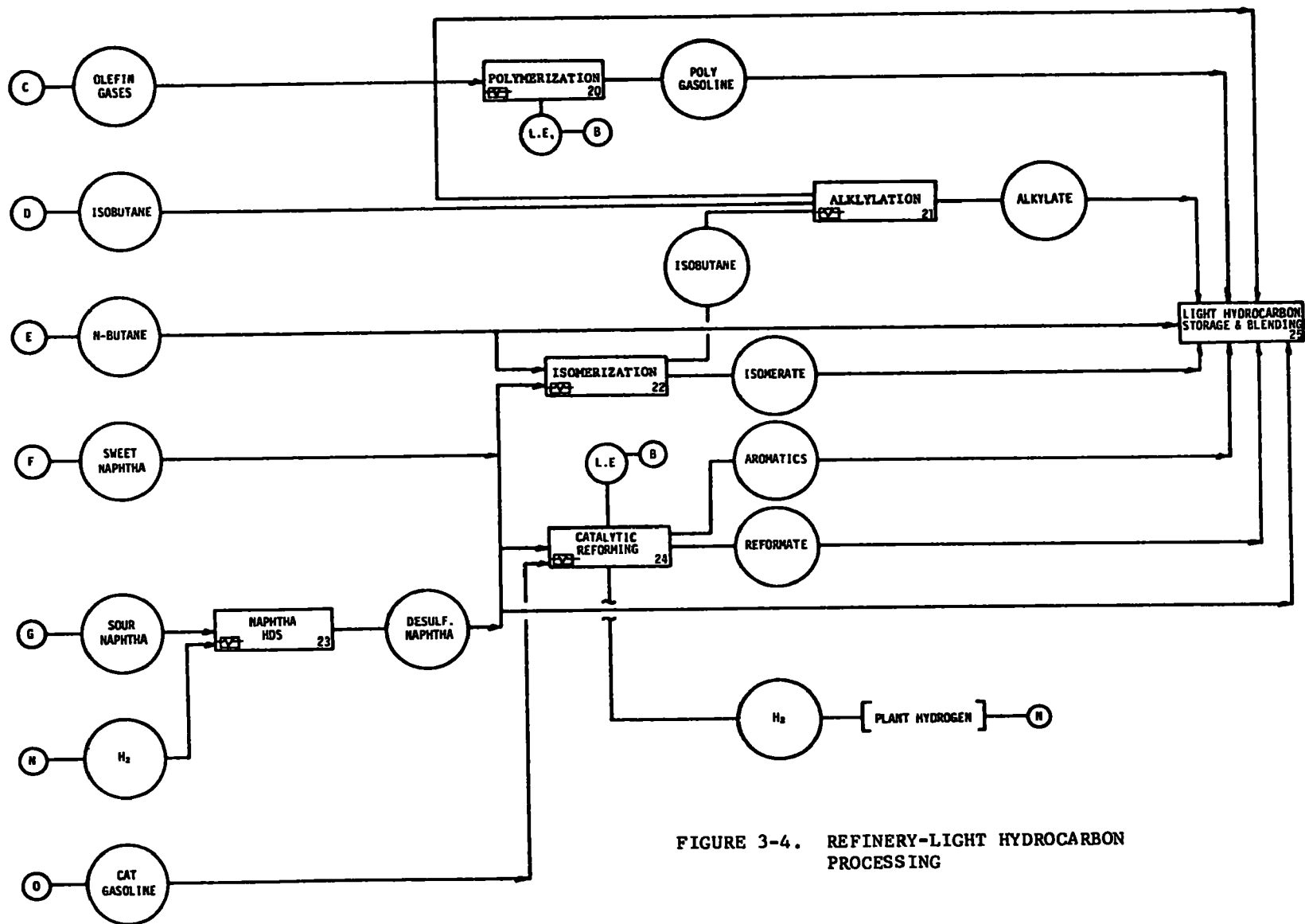


FIGURE 3-4. REFINERY-LIGHT HYDROCARBON PROCESSING

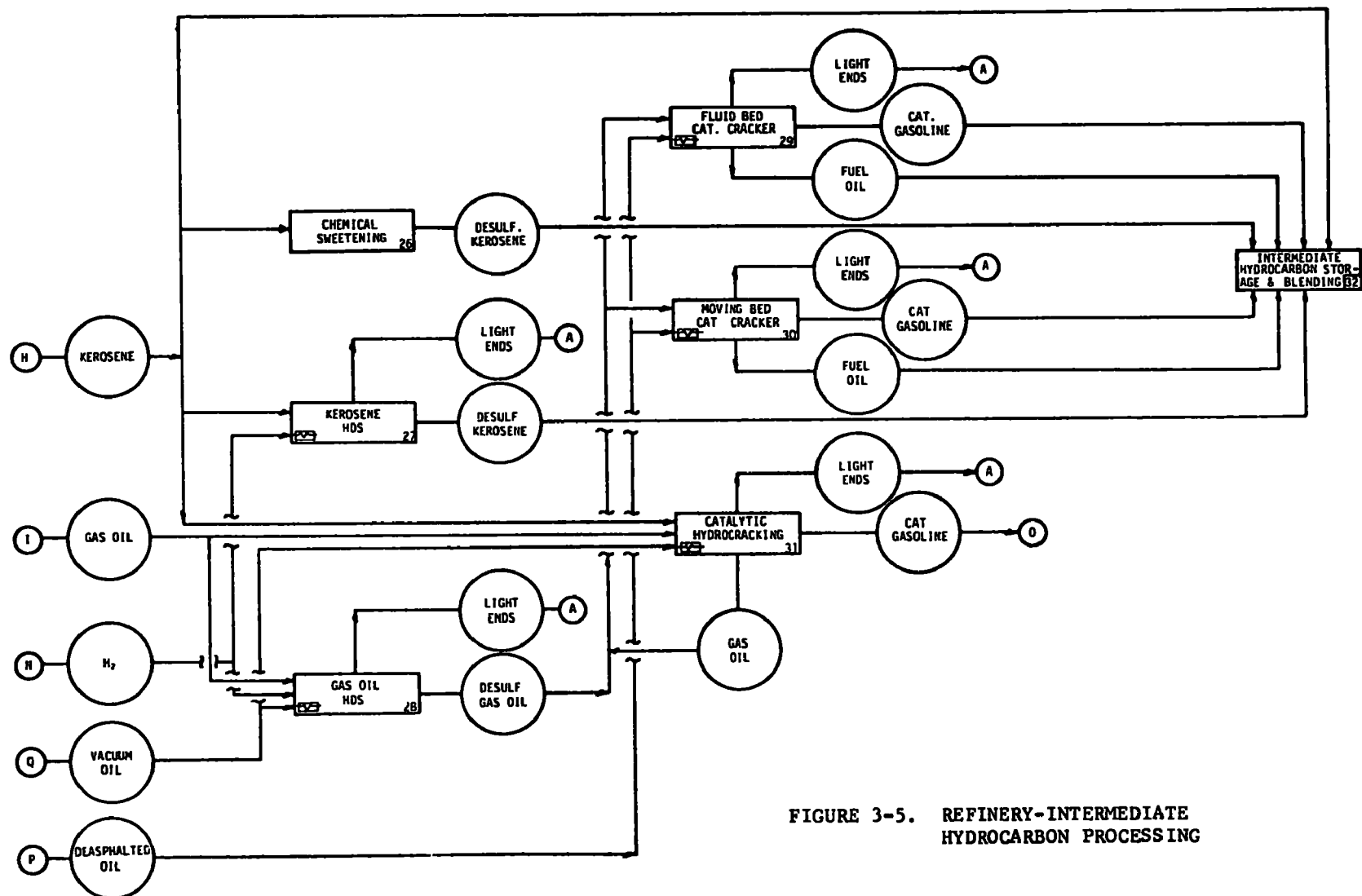


FIGURE 3-5. REFINERY-INTERMEDIATE HYDROCARBON PROCESSING

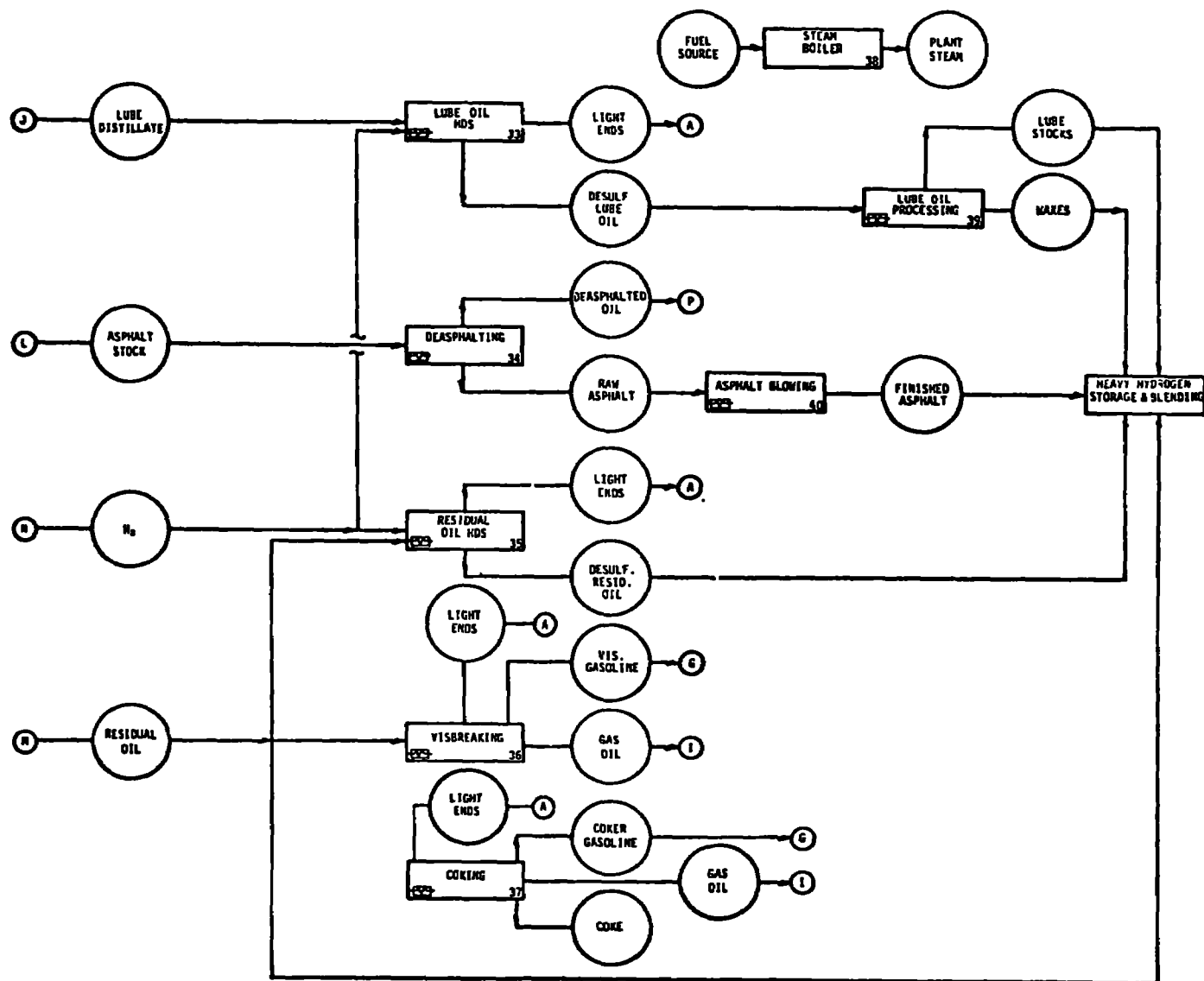


FIGURE 3-6. REFINERY - HEAVY HYDROCARBONS PROCESSING

Table 3-1. LIST OF PROCESS MODULES IN THE PETROLEUM PROCESS FLOW SHEETS

Module	Name
1	Gas Well
2	Oil Well
3	Field Separations (a, b, and c)
4	Condensate Storage and Loading
5	Crude Storage (field)
6	Acid Gas Removal (field)
7	Sulfur Recovery (field)
8	Dehydration
9	Gas Separation
10	Low Pressure Gas (LPG) Storage and Loading
11	Gasoline Storage and Loading
12	Crude Storage (refinery)
13	Desalting
14	Atmospheric Distillation
15	Acid Gas Removal (refinery)
16	Sulfur Recovery (refinery)
17	Gas Processing
18	Vacuum Distillation
19	Hydrogen Production
20	Polymerization
21	Alkylation
22	Isomerization
23	Naphtha Hydrodesulfurization (HDS)
24	Catalytic Reforming
25	Light Hydrocarbon Storage and Blending
26	Chemical Sweetening
27	Kerosene HDS
28	Gas Oil HDS
29	Fluid Bed Catalytic Cracker
30	Moving Bed Catalytic Cracker
31	Catalytic Hydrocracker
32	Intermediate Hydrocarbon Storage and Blending

Table 3-1 (continued). LIST OF PROCESS MODULES IN THE
PETROLEUM PROCESS FLOW SHEETS

Module	Name
33	Lube Oil HDS
34	Deasphalting
35	Residual Oil HDS
36	Visbreaking
37	Coking
38	Steam Boiler
39	Lube Oil Processing
40	Asphalt Blowing
41	Heavy Hydrocarbon Storage and Blending
42	Oil/Gas Well

Table 3-2. PROCESS STREAM CLASSIFICATION

A. <u>Brine Water Systems</u>		
	<u>Module Number</u>	<u>Unit Name</u>
	3	Field Separations
	4	Condensate Storage and Loading
	5	Crude Storage (Field)
	12	Crude Storage (Refinery)
	13	Desalting
B. <u>Sour Aqueous Condensates</u>		
	14	Atmospheric Distillation
	18	Vacuum Distillation
	27	Kerosene HDS
	28	Gas Oil HDS
	29	Fluid Bed Catalytic Cracker
	30	Moving Bed Catalytic Cracker
	31	Catalytic Hydrocracking
	33	Lube Oil HDS
	34	Deasphalting
	35	Residual Oil HDS
	36	Visbreaking
	37	Coking
	39	Lube Oil Processing
C. <u>Acid Gas Solvent Regeneration</u>		
	6	Acid Gas Removal (Field)
	15	Acid Gas Removal (Refinery)
D. <u>Claus Plant Tail Gas</u>		
	7	Sulfur Recovery (Field)
	16	Sulfur Recovery (Refinery)
E. <u>Fixed-Bed Catalyst Regeneration (Group I)</u>		
	20	Polymerization
	22	Isomerization

Table 3-2 (continued). PROCESS STREAM CLASSIFICATION

F. Fixed-Bed Catalyst Regeneration (Group II)

<u>Module Number</u>	<u>Unit Name</u>
24	Catalytic Reforming

G. Fixed-Bed Catalyst Regeneration (Group III)

23	Naphtha HDS
27	Kerosene HDS
28	Gas Oil HDS
31	Catalytic Hydrocracking
33	Lube Oil HDS
35	Residual Oil HDS
39	Lube Oil Processing (Clay)

H. Fixed-Bed Catalyst Regeneration (Group IV)

26	Chemical Sweetening
----	---------------------

I. Moving-Bed Catalyst Regeneration

29	Fluidized-Bed Catalytic Cracker
30	Moving-Bed Catalytic Cracker

J. Barometric Condenser Off Gas

18	Vacuum Distillation
36	Visbreaking

K. Fluid Coker Off Gas

37	Coking
----	--------

L. Asphalt Air Blowing

40	Asphalt Blowing
----	-----------------

M. Spent Acid Sludge

39	Lube Oil Processing
----	---------------------

N. Decoking

36	Visbreaking
----	-------------

O. Oil-Fired Process Heaters

3b and 3c	Field Separation
14	Atmospheric Distillation
18	Vacuum Distillation
19	Hydrogen Production

Table 3-2 (continued). PROCESS STREAM CLASSIFICATION

O. Oil-Fired Process Heaters (continued)

<u>Module Number</u>	<u>Unit Name</u>
20	Polymerization
21	Alkylation
22	Isomerization
23	Naphtha HDS
24	Catalytic Reforming
27	Kerosene HDS
28	Gas Oil HDS
29	Fluid Bed Catalytic Cracker
30	Moving Bed Catalytic Cracker
31	Catalytic Hydrocracking
33	Lube Oil HDS
34	Deasphalting
35	Residual Oil HDS
36	Visbreaking
37	Coking
39	Lube Oil Processing
40	Asphalt Blowing

P. Cooling Water Systems

Cooling Towers

Q. Storage and Blending (Group I)

4	Condensate Storage and Loading
5	Crude Storage (Field)
6	Crude Storage (Refinery)

R. Storage and Blending (Group II)

25	Light Hydrocarbons Storage and Blending
32	Intermediate Hydrocarbon Storage and Blending

S. Storage and Blending (Group III)

41	Heavy Hydrocarbon Storage and Blending
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T. Fugitive Sources

Total Petroleum Industry

Table 3-2 (continued). PROCESS STREAM CLASSIFICATION

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- U. Flares
 - V. API Grit Chambers
 - W. Biological Sludges
 - X. Spent Catalysts
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Table 3-3. POTENTIALLY HAZARDOUS EMISSIONS FROM THE IDENTIFIED STREAMS AND PROCESSES

(A) Brine Water Systems

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	13. Lactones		Aqueous		C-1, 2, 3
Known Present/ Suspected Hazardous	1. Acids and Anhydrides	Maleic Anhydride Benzoic Acid	Aqueous Aqueous		
	4. Inorganic Salts	Chlorides	Aqueous		
	5. Carbonyl Compounds	Ketones Aldehydes	Aqueous Aqueous		
	10. Heterocyclic	Pyridines Pyrroles	Aqueous Aqueous	W-2	A-8
	11. Hydrocarbons	Benzene	Aqueous	W-1	A-8
		Toluene	Aqueous	W-1	A-8
		Xylene	Aqueous	W-1	A-8
	18. Phenols	Phenol	Aqueous	W-1	A-5, 7
		Dimethyl Phenol	Aqueous	W-1	A-5, 7
		Cresol	Aqueous	W-1/C-3	A-5
	21. Sulfur Compounds	Sulfides Sulfites Sulfonates Sulfones Mercaptans	Aqueous Aqueous Aqueous Aqueous Aqueous		

Table 3-3 (Continued). (A) Brine Water Systems

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	10. Heterocyclic	Dibenzofuran Quinolines	Aqueous Aqueous		
	20. Polynuclear	Carbazoles Anthracenes	Aqueous Aqueous		
	21. Sulfur Compounds	Thiophenes	Aqueous		
	22. Trace Elements	Vanadium	Aqueous	W-2	A-7, 8, 9
		Nickel	Aqueous		
		Zinc	Aqueous		
		Lead	Aqueous	W-1	A-8
	23. Organometallics	Metalloporphyrins	Aqueous		

Table 3-3 (continued). (B) Sour Aqueous Condensates

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	1. Acid and Anhydride	Cresylic Acid Maleic Acid	Aqueous Aqueous		
	2. Alcohols	Alkyl Alcohols Aromatic Alcohols	Aqueous Aqueous		
	3. Amines	Ammonia	Aqueous	W-1	A-5
	5. Carbonyls	Aldehydes Ketones	Aqueous Aqueous	W-1	A-8
	10. Heterocyclic	Pyridines Pyrroles	Aqueous Aqueous	W-2	A-8
	11. Hydrocarbons	Benzene	Aqueous	W-1	A-8
		Toluene	Aqueous	W-1	A-8
		Xylene	Aqueous	W-1	A-8
	18. Phenols*	Cresols	Aqueous	W-1	A-5
		Xylenols	Aqueous		
		Phenols	Aqueous	W-1	A-5, 7
	21. Sulfur Compounds	Hydrogen Sulfide Methyl Mercaptan Sulfides Sulfonates Thiophenes	Aqueous Aqueous Aqueous Aqueous Aqueous	W-0	A-5, 6, 7

Table 3-3 (continued). (B) Sour Aqueous Condensates

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	25. Cyanides*		Aqueous		
	20. Polynuclear**		Aqueous		
	22. Trace Elements		Aqueous		
	23. Organometallics**		Aqueous		

* Predominate in effluent from catalytic cracking units.

** Predominate in deasphalting and lube oil processing unit effluents.

Table 3-3 (continued). (C) Acid Gas Solvent Regeneration

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	1. Acids and Anhydrides	Acetic	Aqueous		
		Formic	Aqueous		
		Maleic	Aqueous		
	3. Amines	Methylethylamine	Aqueous		
		Diethylamine	Aqueous		
	21. Sulfur Compounds	Carbon disulfide	Aqueous		
		Carbonyl sulfide	Aqueous		
		Methyl Mercaptan	Aqueous		
		Thiosulfide	Aqueous		
	25. Cyanides*		Aqueous		

* From refinery off gas treatment only.

Table 3-3 (continued). (D) Claus Plant Tail Gas

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	C-4
		Carbonyl Sulfide	Gas		C-4
		Carbon Disulfide	Gas		C-4
Known Present/ Suspected Hazardous	3. Amines	Diethylamine	Gas	T-2	
		Methylethylamine	Gas		
		Ammonia	Gas		
	6. Combustion Gases	Carbon Monoxide	Gas	T-2	
		Sulfur Dioxide	Gas	T-2	
	24. Fine Particulates	Sulfur Particulates	Gas	T-1	
Suspected Present/ Known Hazardous	25. Cyanide		Gas		

Table 3-3 (continued). (E) Fixed Bed Catalyst Regeneration (Group I)

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	6. Combustion Gases	Carbon Monoxide	Gas	T-2	
	24. Fine Particulates	Carbon Compounds Catalyst Fines	Gas Gas	T-0	

Table 3-3 (continued). (F) Fixed Bed Catalyst Regeneration (Group II)

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	C-4
		Carbonyl Sulfide	Gas		C-4
Known Present/ Suspected Hazardous	6. Combustion Gases	Carbon Monoxide	Gas	T-1	
		Sulfur Dioxide	Gas	T-2	
	11. Hydrocarbons	Benzene	Gas	T-2	A-2
		Toluene	Gas	T-2	
		Xylene	Gas	T-2	
	24. Fine Particulates		Gas		
Suspected Present/ Known Hazardous	20. Polynuclear		Gas		

Table 3-3 (continued). (G) Fixed Bed Catalyst Regeneration (Group III)

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	C-4
		Carbonyl Sulfide	Gas		C-4
		Carbon Disulfide	Gas		--
		Mercaptans	Gas	T-0	C-4
Known Present/ Suspected Hazardous	6. Combustion Gases	Carbon Monoxide	Gas	T-1	
		Sulfur Dioxide	Gas	T-2	
	11. Hydrocarbons	Benzene	Gas	T-2	A-2
		Toluene	Gas	T-2	
		Xylene	Gas	T-2	
	22. Trace Elements	Vanadium	Gas	T-0	A-4
		Nickel	Gas	T-0	C-1
		Cobalt	Gas		
		Molybdenum	Gas		
	24. Fine Particulates	Catalyst	Gas		
		Coke	Gas	T-1	
Suspected Present/ Known Hazardous	10. Heterocyclic		Gas		
	20. Polynuclear		Gas		
	23. Organometallics	Nickel Carbonyl	Gas	T-0	
		Cobalt Carbonyl	Gas		

Table 3-3 (continued). (H) Fixed Bed Catalyst Regeneration (Group IV)

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	21. Sulfur Compounds	Hydrogen Sulfide	Gas and Aqueous	T-2/W-0	A-5, 6, 7
		Sulfides	Gas and Aqueous		
		Mercaptans	Gas and Aqueous	T-0	

Table 3-3 (continued). (I) Moving Bed Catalyst Regeneration

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	20. Polynuclear	Benzo(a)pyrene	Gas	T-1/C-1	A-1, D-4
		Pyrene	Gas	T-0/C-3	A-1, D-4
		Benzo(e)pyrene	Gas	T-1/C-2	A-1, D-4
		Perylene	Gas	T-1/C-4	A-1, D-4
		Benzo(ghi)perylene	Gas	C-4	A-1, D-4
		Coronene	Gas	T-1	
		Anthracene	Gas	T-0/C-4	A-1, D-4
		Phenanthrene	Gas	T-0/C-4	A-1
		Fluoranthene	Gas		
	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	C-4
		Carbonyl Sulfide	Gas		C-4
		Carbon Disulfide	Gas		C-4
Known Present/ Suspected Hazardous	22. Trace Elements	Vanadium	Gas	T-0	C-1
		Nickel	Gas	T-0	C-1
		Copper	Gas	T-0	C-1
		Zinc	Gas	T-1	C-1
	24. Fine Particulates		Gas	T-0	C-6, D-4
	3. Amines	Ammonia	Gas	T-2	
		Aromatic Amines	Gas		
	6. Combustion Gases	Sulfur Dioxide	Gas	T-2	
		Carbon Monoxide	Gas	T-1	

Table 3-3 (continued). (I) Moving Bed Catalyst Regeneration

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
36 Suspected Present/ Known Hazardous	11. Hydrocarbons	Benzene Toluene Xylene	Gas Gas Gas	T-2 T-2 T-2	A-2
	18. Phenols	Phenol Cresol	Gas Gas	T-1 T-1	
	25. Cyanides		Gas		
	5. Carbonyl Compounds	Aldehydes Formaldehyde Acetaldehyde	Gas Gas Gas	T-1 T-1 T-2	
	10. Heterocyclic	Pyridines Pyrroles Indoles	Gas Gas Gas	T-1	A-1
	15. Nitrosamines		Gas	C-3	
	21. Sulfur Compounds	Thiophenes	Gas		

Table 3-3 (continued). (J) Barometric Condenser Off Gas

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	5. Carbonyl Compounds	Aldehydes	Gas	T-1	A-2
		Ketones	Gas		
	10. Heterocyclic	Pyrroles	Gas		
		Pyridines	Gas	T-1	
	11. Hydrocarbons	Benzene	Gas	T-2	
		Toluene	Gas	T-2	
		Xylene	Gas	T-2	
	18. Phenols	Cresols	Gas	T-1	
		Xylenols	Gas	T-1	
		Phenols	Gas	T-1	
	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	
		Methyl Mercaptan	Gas		
		Thiophenes	Gas		

Table 3-3 (continued). (K) Fluid Coker Off Gas

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	
		Mercaptans	Gas	T-0	
		Carbonyl Sulfide	Gas		
		Carbon Disulfide	Gas		
38	22. Trace Elements	Vanadium	Gas	T-0	C-1
		Copper	Gas		C-1
		Nickel	Gas	T-0	C-1
		Zinc	Gas		C-1
	24. Fine Particulates		Gas	T-0	C-6,D-4
Known Present/ Suspected Hazardous	3. Amines	Ammonia	Gas	T-2	
		Aromatic Amines	Gas		
	6. Combustion Gases	Sulfur Oxides	Gas	T-2	
		Carbon Monoxide	Gas	T-1	
	11. Hydrocarbons	Benzene	Gas	T-2	A-2
		Toluene	Gas	T-2	
		Xylene	Gas	T-2	
	18. Phenols	Phenol	Gas	T-1	
		Xylenol	Gas	T-1	
		Thiophenols	Gas	T-1	
	23. Organometallics		Gas		
	25. Cyanides		Gas		

Table 3-3 (continued). (K) Fluid Coker Off Gas

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	5. Carbonyl Compounds	Formaldehyde	Gas	T-1	
		Acetaldehyde	Gas	T-2	
	10. Heterocyclic	Pyridines	Gas	T-1	
		Pyrroles	Gas		
		Indoles	Gas		
	13. Lactones		Gas		
	15. Nitrosamines		Gas		
	20. Polynuclear	Benzo(a)pyrene	Gas	T-1/C-1	A-1
		Pyrene	Gas	T-0/C-3	A-1
		Benzo(e)pyrene	Gas	T-1/C-2	A-1
		Perylene	Gas	T-1/C-4	A-1
		Coronene	Gas	T-1	A-1
		Anthracene	Gas	T-0/C-4	A-1
		Phenanthrene	Gas	T-0/C-4	A-1
		Fluoranthene	Gas	C-4	A-1
	21. Sulfur Compounds	Thiophenes	Gas		

Table 3-3 (continued). (L) Asphalt Air Blowing

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	10. Heterocyclic	Pyrroles	Aqueous and Gas	T-1	C-1, 5
		Pyridines	Aqueous and Gas	T-1	C-1, 5
		Dibenzofuran	Aqueous and Gas	T-1	D-4
		Furans	Aqueous and Gas		C-1, 5
		Quinolines	Aqueous and Gas	T-0	C-1, 5
	20. Polynuclear	Carbazoles	Aqueous and Gas	C-3	A-2, D-4
		Anthracene	Aqueous and Gas	T-0/C-4	A-1, D-4
		Benzo(a)pyrene	Aqueous and Gas	T-1/C-1	A-1, D-4
	21. Sulfur Compounds	Dibenzo Thiophene	Aqueous and Gas		D-4
		Thiophenes	Aqueous and Gas	T-2	C-1, 5

Table 3-3 (continued). (L) Asphalt Air Blowing

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	1. Acids and Anhydrides	Cresylic	Aqueous and Gas		
		Maleic	Aqueous and Gas		
	5. Carbonyl Compounds	Aldehydes	Aqueous and Gas		
		Ketones	Aqueous and Gas		
	11. Hydrocarbons	Benzene	Aqueous and Gas	W-1/T-2	A-2, 8
		Toluene	Aqueous and Gas	W-1/T-2	A-8
		Xylene	Aqueous and Gas	W-1/T-2	A-8
	18. Phenols	Cresols	Aqueous and Gas	W-1/C-3/ T-1	A-5
		Xylenols	Aqueous and Gas		
		Phenols	Aqueous and Gas	W-1/T-1	A-5, 7

Table 3-3 (continued). (L) Asphalt Air Blowing

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	21. Sulfur Compounds	Alkyl Sulfides	Aqueous and Gas		
		Sulfonates	Aqueous and Gas		
	22. Trace Elements	Vanadium	Aqueous and Gas	W-2/T-0	
		Nickel	Aqueous and Gas	--/T-0	
		Zinc	Aqueous and Gas	--/T-1	
		Copper	Aqueous and Gas	--/T-0	
		Strontium	Aqueous and Gas	W-2/--	
		Barium	Aqueous and Gas	W-2/T-0	
	24. Fine Particulates		Gas		
	13. Lactones		Aqueous and Gas		
	23. Organometallics		Aqueous and Gas		

Table 3-3 (continued). (M) Spent Acid Sludge

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	1. Acids and Anhydrides	Sulfuric Acid	Aqueous	W-1	A-8
	2. Alcohols		Aqueous		
	4. Inorganic Salts	Sulfates	Aqueous		
	5. Carbonyl Compounds	Aldehydes Ketones	Aqueous Aqueous	W-1	A-8
	10. Heterocyclic	Pyridines Pyrroles Furan	Aqueous Aqueous Aqueous	W-2	A-8
	11. Hydrocarbons	Benzene Toluene Xylene	Aqueous Aqueous Aqueous	W-1 W-1 W-1	A-8 A-8 A-8
	18. Phenols	Cresols Xylenols Dimethylphenol	Aqueous Aqueous Aqueous	W-1/C-3	A-5
	21. Sulfur Compounds	Sulfides Sulfonates	Aqueous Aqueous		
	23. Organometallics		Aqueous		

Table 3-3 (continued). (M) Spent Acid Sludge

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	13. Lactones		Aqueous		
	10. Heterocyclic	Quinolines	Aqueous	W-1	
	22. Trace Elements		Aqueous		

Table 3-3 (continued). (N) Decoking

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	
		Carbonyl Sulfide	Gas		
		Carbon Disulfide	Gas		
		Methyl Mercaptans	Gas	T-0	
Known Present/ Suspected Hazardous	6. Combustion Gases	Carbon Monoxide	Gas	T-1	A-2
		Sulfur Dioxide	Gas	T-2	
	11. Hydrocarbons	Benzene	Gas	T-2	
		Toluene	Gas	T-2	
		Xylene	Gas	T-2	
	22. Trace Elements	Vanadium	Gas	T-0	
		Nickel	Gas	T-0	
		Copper	Gas	T-0	
		Zinc	Gas	T-0	
	24. Fine Particulates	Coke	Gas	T-1	
Suspected Present/ Known Hazardous	20. Polynuclears		Gas		

Table 3-3 (continued). (O) Oil Fired Process Heaters

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	20. Polynuclear	Benzo(a)pyrene	Gas	T-1/C-1	A-1, D-4
	24. Fine Particulates		Gas	T-0	D-4
Known Present/ Suspected Hazardous	5. Carbonyl Compounds	Aldehydes	Gas	T-2	
	6. Combustion Gases	Sulfur Oxides	Gas	T-2	
		Nitrogen Oxides	Gas	T-2	
		Carbon Monoxide	Gas	T-1	
	20. Polynuclear	Benzoperylene	Gas	T-1/C-4	A-1
		Coronene	Gas	T-1	
		Anthracene	Gas	T-0/C-4	A-1
		Phenanthrene	Gas	T-0/C-4	A-1
		Fluoranthene	Gas	C-4	A-1
		Benzopyrenes	Gas	T-0	
	22. Trace Elements	Vanadium	Gas	T-0	
		Nickel	Gas	T-0	
		Lead	Gas	T-0	A-4
Suspected Present/ Known Hazardous	10. Heterocyclic		Gas		

Table 3-3 (continued). (P) Cooling Water System

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	1. Acids and Anhydrides	Sulfuric Acid	Aqueous	W-1	A-8
	4. Inorganic Salts	Chlorides Chromates	Aqueous Aqueous		
	11. Hydrocarbons	Alkyl	Gas and Aqueous		
		Aromatic	Gas and Aqueous		
	18. Phenols	Phenol	Aqueous	W-1	A-5, 7
	21. Sulfur Compounds	Sulfides Sulfates	Aqueous Aqueous		
Suspected Present/ Known Hazardous	1. Acids and Anhydrides	Sulfuric Acid	Gas	T-0	
	2. Alcohols		Gas and Aqueous		
	3. Amines		Gas and Aqueous		
	5. Carbonyl Compounds	Aldehydes and Ketones	Gas and Aqueous		

Table 3-3 (continued). (P) Cooling Water Systems

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	8. Ethers		Gas and Aqueous		
	10. Heterocyclic		Gas and Aqueous		
	13. Lactones		Gas and Aqueous		
	15. Nitrosoamines		Gas and Aqueous		
	18. Phenols		Gas		
	20. Polynuclear		Gas and Aqueous		
	21. Sulfur Compounds		Gas		
	22. Trace Elements		Gas and Aqueous		
	23. Organometallics		Gas and Aqueous		
	25. Cyanides		Gas and Aqueous		

Table 3-3 (continued). (Q) Storage and Blending (Group I)*

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	5. Carbonyl Compounds	Aldehydes	Gas		
		Ketones	Gas		
	11. Hydrocarbons	Benzene	Gas	T-2	A-2
		Toluene	Gas	T-2	
		Xylene	Gas	T-2	
	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	
		Mercaptans	Gas	T-0	

* Aqueous streams covered on sheet A, brine water systems.

Table 3-3 (continued). (R) Storage and Blending (Group II)

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	3. Amines	Ammonia Aliphatic Amines Aromatic Amines	Aqueous Aqueous Aqueous	W-1	A-5
	11. Hydrocarbons	Benzene	Gas and Aqueous	T-2/W-1	A-2, 8
		Toluene	Gas and Aqueous	T-2/W-1	A-8
		Xylene	Gas and Aqueous	T-2/W-1	A-8
	18. Phenols		Aqueous	W-1	A-5, 7
Suspected Present/ Known Hazardous	23. Organometallics	Tetraethyl lead	Aqueous		

Table 3-3 (continued). (S) Storage and Blending (Group III)

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	1. Acids and Anhydrides		Aqueous		
	5. Carbonyl Compounds	Aldehydes	Gas and Aqueous		
		Ketones	Gas and Aqueous		
	11. Hydrocarbons	Benzene	Gas and Aqueous	T-2/W-1	A-2, 8
		Toluene	Gas and Aqueous	T-2/W-1	A-8
		Xylene	Gas and Aqueous	T-2/W-1	A-8
	18. Phenols		Aqueous	W-1	A-5, 7
	21. Sulfur Compounds	Sulfides Sulfonates	Aqueous Aqueous		
	22. Trace Elements		Aqueous		
	10. Heterocyclic		Gas and Aqueous		
Suspected Present/ Known Hazardous	20. Polynuclear		Gas and Aqueous		
	23. Organometallics		Aqueous		

Table 3-3 (continued). (U) Flares

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	3. Amines	Ammonia	Gas		
	5. Carbonyl Compounds	Aldehydes	Gas		
	6. Combustion Gases	Carbon Monoxide	Gas	T-1	
		Sulfur Oxides	Gas	T-2	
		Nitrogen Oxides	Gas	T-1	
	11. Hydrocarbon	Benzene	Gas	T-2	A-2
		Toluene	Gas	T-2	
		Xylene	Gas	T-2	
	21. Sulfur Compounds	Carbonyl Sulfide	Gas	T-1	
		Carbon Disulfide	Gas	T-1	
		Mercaptans	Gas	T-1	
		Hydrogen Sulfide	Gas	T-2	
	24. Fine Particulates	Carboniferous Compounds	Gas		
	25. Cyanides		Gas		
Suspected Present/ Known Hazardous	10. Heterocyclics	Pyridines	Gas	T-1	A-1
		Pyrroles	Gas		
		Indoles	Gas		

Table 3-3 (continued). (U) Flares

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
20.	Polynuclear	Pyrenes	Gas	T-0/C-3	A-1, 2, 3
		Perylenes	Gas	T-1/C-4	A-1
		Anthracenes	Gas	T-0/C-4	A-1
21.	Sulfur Compounds	Thiophenes	Gas		

Table 3-3 (continued). (V) API Grit Chambers

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	1. Acids and Anhydrides	Cresylic Maleic	Solid Solid		
	2. Alcohols		Solid		
	3. Amines	Diethylamine Methylethylamine Aromatic Amines	Solid Solid Solid		
	4. Inorganic Salts		Solid		
	5. Carbonyl Compounds	Ketones Aldehydes	Solid Solid		
	10. Heterocyclics	Pyridines Pyrroles Indoles Furans Quinolines	Solid Solid Solid Solid Solid		
	11. Hydrocarbons	Benzene Toluene Xylene	Solid Solid Solid		
	13. Lactones		Solid		
	15. Nitrosamines		Solid		

Table 3-3 (continued). (V) API Grit Chambers

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
55	18. Phenols	Cresols	Solid		
		Xylenols	Solid		
		Phenols	Solid		
		Thiophenols	Solid		
	20. Polynuclear	Pyrenes	Solid		
		Perylenes	Solid		
		Anthracenes	Solid		
		Carbazoles	Solid		
	21. Sulfur Compounds	Sulfides	Solid		
		Sulfites	Solid		
		Sulfonates	Solid		
		Sulfones	Solid		
		Mercaptans	Solid		
		Thiophenes	Solid		
	22. Trace Elements	Vanadium	Solid		
		Nickel	Solid		
		Zinc	Solid		
		Copper	Solid		
	23. Organometallics	Metalloporphyrins	Solid		
	25. Cyanides		Solid		

Table 3-3 (continued). (W) Biological Sludge

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	22. Trace Elements	Vanadium	Solid		
		Nickel	Solid		
		Zinc	Solid		
		Copper	Solid		
	23. Organometallics		Solid		

Table 3-3 (continued). (X) Spent Catalysts

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	3. Amines		Solid		
	4. Inorganic Salts		Solid		
	5. Carbonyl Compounds	Aldehydes	Solid		
	11. Hydrocarbons	Aromatic	Solid		
	21. Sulfur Compounds	Sulfides	Solid		
		Sulfites	Solid		
		Sulfonates	Solid		
		Sulfones	Solid		
		Mercaptans	Solid		
	22. Trace Elements	Vanadium	Solid		
Nickel		Solid			
Zinc		Solid			
Copper		Solid			
Suspected Present/ Known Hazardous	10. Heterocyclic	Pyridines	Solid		
		Pyrroles	Solid		
		Indoles	Solid		
		Furans	Solid		
		Quinolines	Solid		
	15. Nitrosamines	Solid			

Table 3-3 (continued). (X) Spent Catalysts

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
	20. Polynuclear	Pyrenes Perylenes Anthracenes Carbazoles	Solid Solid Solid Solid		
	21. Sulfur Compounds	Thiophenes	Solid		
	23. Organometallics	Metalloporphyrins	Solid		

Table 3-4. POTENTIAL FOR FUGITIVE EMISSIONS FROM
PETROLEUM PROCESS SUBMODULES

Module No.	Process Name	Pressure ^(a)	Temp. ^(b)	Potentially Hazardous Volatiles	Corrosive- ness	General House- keeping	Potential For Hazardous Fugitive Emissions
I. PROCESSING EQUIPMENT							
1	Gas Well	High	Low	High	Low	Poor	High
2	Oil Well	High	Low	High	Low	Poor	High
3	Field Separations	High	Low	High	Low	Poor	High
4	Condensate Storage & Loading	Low	Low	Low	Low	Poor	Med.
5	Crude Storage (field)	Low	Low	Med.	Low	Poor	Med.
6	Acid Gas Removal (field)	Low	Low	High	Med.	Med.	Med.-High
7	Sulfur Recovery (field)	Low	High	High	Med.	Med.	Med.-High
8	Dehydration	Low	Low-Med.	Low	Low	Med.	Low
9	Gas Separation	Med.	Low	Low	Low	Med.	Low
10	LPG Storage & Loading	Med.	Low	Low	Low	Med.	Low
11	Gasoline Storage & Loading	Low	Low	Low	Low	Med.	Med.
12	Crude Storage (refinery)	Low	Low	Med.	Low	Poor	Med.
13	Desalting	Low	Med.	Low-Med.	Low	Med.	Low
14	Atmospheric Distillation	Low	Med.	High	Med.	Med.	High
15	Acid Gas Removal (refinery)	Low	Low	High	Med.	Med.	Med.-High
16	Sulfur Recovery (refinery)	Low	High	High	Med.	Med.	Med.-High
17	Gas Processing	Med.	Low	Low	Low	Med.	Low
18	Vacuum Distillation	Low	High	High	Med.	Low-Med.	Med.
19	Hydrogen Production	High	High	Low	Low	Good	Low
20	Polymerization	High	High	Low	Med.	Good	Low
21	Alkylation	Med.	Low	Low	High	Good	Low

Table 3-4. (continued)

Module No.	Process Name	Pressure (a)	Temp. (b)	Potentially Hazardous Volatiles	Corrosive- ness	General House- keeping	Potential For Hazardous Fugitive Emissions
22	Isomerization	High	High	Low	Low	Good	Low
23	Naptha HDS	High	High	High	Med.	Good	Med.
24	Catalytic Reforming	Med.	High	Low	Low	Good	Low
25	Light Hydrocarbon Storage and Blending	Low	Low	Low	Low	Good	Med.
26	Chemical Sweetening	Low	Low	Low	Low	Good	Low
27	Kerosene HDS	High	High	High	Med.	Good	Med.
28	Gas Oil HDS	High	High	High	Med.	Good	Med.
29	Fluid Bed Cat. Cracker	Low	High	High	Med.	Med.	Med.-High
30	Moving Bed Cat. Cracker	Low	High	High	Med.	Med.	Med.-High
31	Catalytic Hydrocracking	High	High	High	Med.	Med.	Med.-High
32	Int. HC Storage & Blending	Low	Low	Low	Low	Good	Med.
33	Lube Oil HDS	High	High	High	Med.	Good	Med.
34	Deasphalting	Low	High	High	Low-Med.	Poor	Med.-High
35	Resid. Oil HDS	High	High	High	Med.	Good	Med.
36	Visbreaking	Low	High	High	Med.	Poor	High
37	Coking	Low	High	High	Med.-High	Poor	High
38	Steam Boiler	Low	High	Low	Low	Good	Low
39	Lube Oil Processing	Low	Med.	High	High	Poor-Med.	High
40	Asphalt Blowing	Low	High	High	Low-Med.	Poor	Med.-High
41	Heavy HC Storage & Blending	Low	Low	Med.	Low	Med.	Med.
42	Gas/Oil Well	High	Low	High	Low	Poor	High

Table 3-4. (continued)

Module No.	Process Name	Pressure (a)	Temp. (b)	Potentially Hazardous Volatiles	Corrosive- ness	General House- keeping	Potential For Hazardous Fugitive Emissions
II. AUXILIARY EQUIPMENT							
	Wastewater Systems	Low	Low	High	High	Poor	High
	Oil Fired Heaters	Low/High	High	High	Low	Poor	High
	Sour Water Stripper	Low	Med.	High	High	Med.	High
(a)	(PSIG)	<u>Low</u> > 50	<u>Med.</u> 50-150	<u>High</u> <150			
(b)	(°F)	>150	150-300	<300			

CONVENTIONAL COAL PROCESS MODULE

The same approach to analyze the potentially hazardous emission from the extraction and processing of crude oil was used to analyze the potentially hazardous emission from coal mining and processing. The identified operations were grouped into three process flow sheets. These process flow sheets and the flow of materials through them are shown in Figures 3-7 and 3-8. A list of 16 process modules is also shown in Table 3-5.

The identification and the assessment of all the potentially hazardous emission streams were conducted in a fashion similar to that employed for the petroleum process modules. Seven classes of emission streams were defined. They are listed in Table 3-6.

The data sheets of the emission streams were made with a similar approach. The assessment of the emission streams was made with the published information on emission stream compositions and with the consideration of the process conditions. The data sheets showing the results of the analysis of the emission streams, as described in Table 3-6, are shown in Table 3-7.

The assessment of fugitive losses from each coal conventional process module is summarized in Table 3-8. The fact sheets of some of the modules from which potentially hazardous emissions are expected are included in Appendix B.

Conclusions

(1) Among the conventional coal processes, coking is the most offensive technology because of the high toxic materials emitted, such as known carcinogens. Although the combustion of coal is the cleanest process per unit of coal processed, it is probably the most significant due to the massive tonnages involved.

(2) The coke oven and the coal tar storage areas have been identified as the major sources of potentially hazardous emissions in a coke plant. The potentially hazardous materials are emitted from the

coke oven primarily during the charging, pushing, and coking operations.

(3) Coke quenching and cooling is the major source of fugitive loss in the coke plant.

(4) Some known carcinogens, such as benzo(a)pyrene, chrysene, Dibenzo(a,h)anthracene and Dibenzo(a,g)fluorene have been identified in the coal tar volatiles and in the atmosphere surrounding the coke oven.

(5) The emission streams with the greatest numbers of compounds in the known/known status are coke oven off gas and coke quenching and cooling.

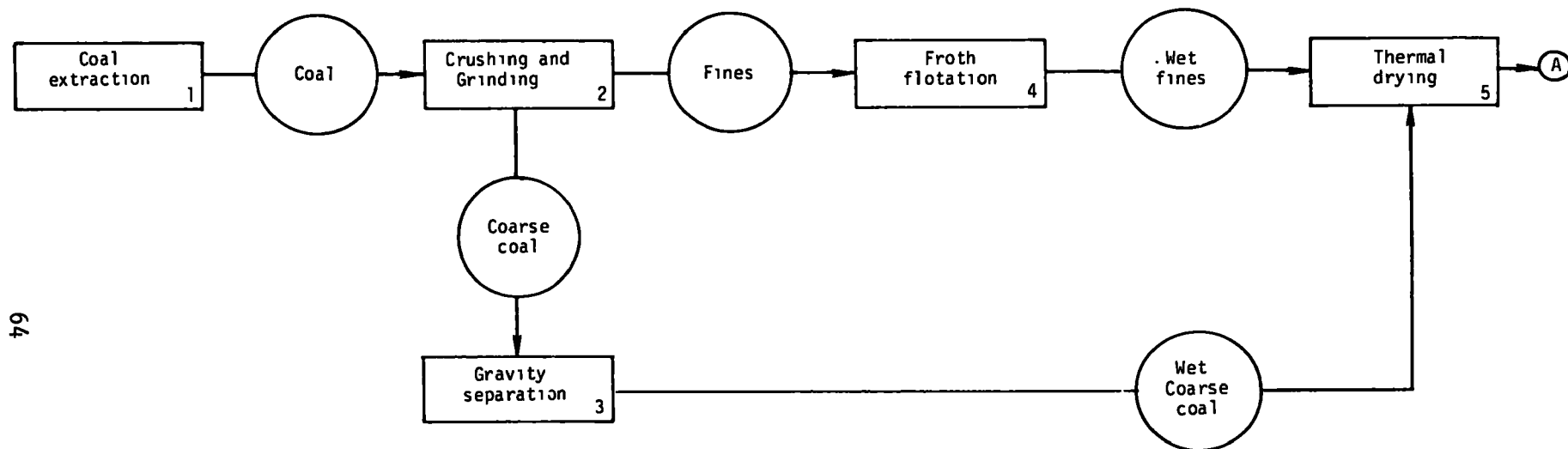


FIGURE 3-7. COAL PREPARATION

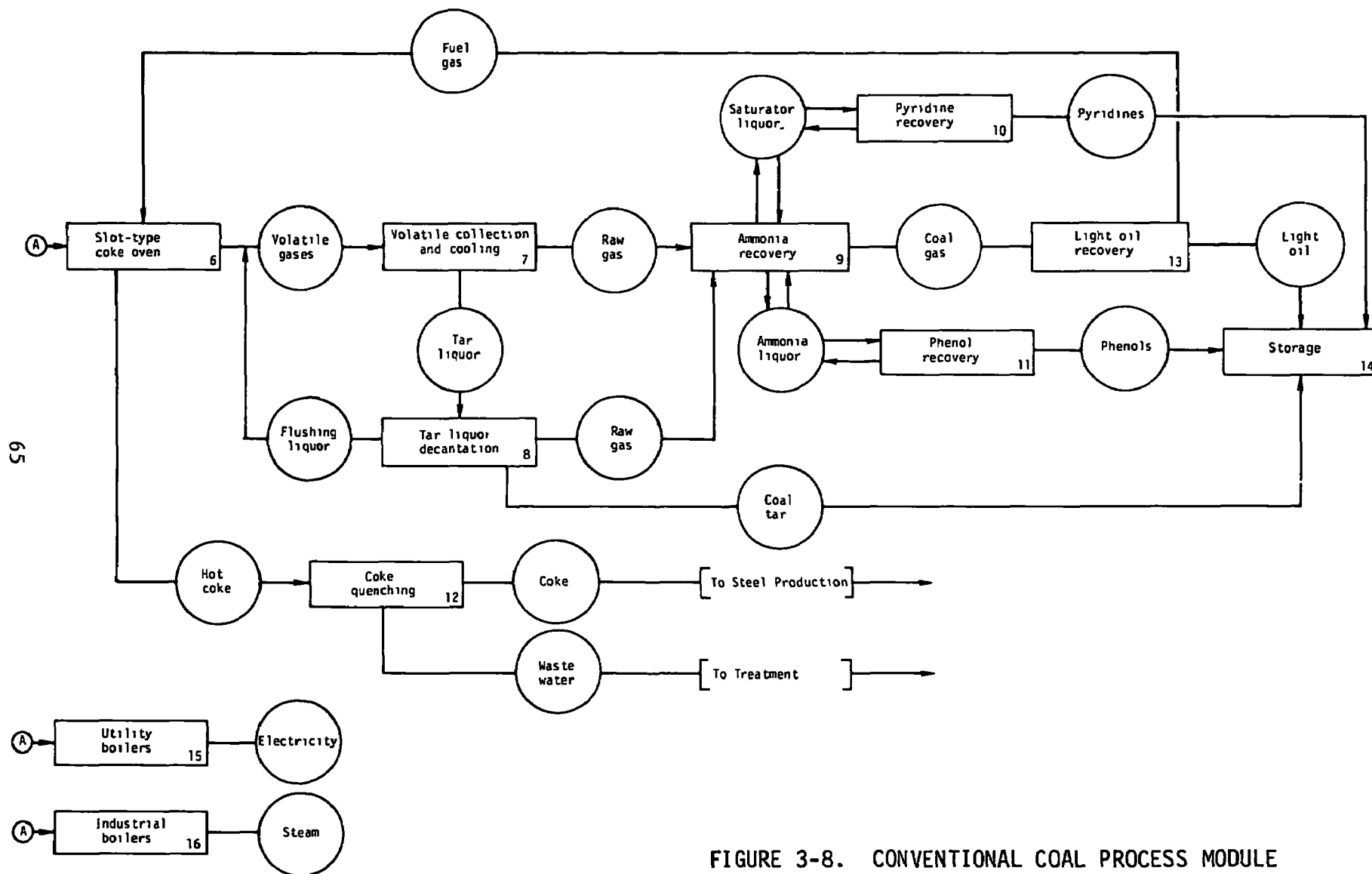


FIGURE 3-8. CONVENTIONAL COAL PROCESS MODULE

Table 3-5. PROCESS MODULES OF COAL USAGE (CONVENTIONAL)

Module	Name
1	Coal Extraction
2	Crushing and Grinding
3	Gravity Separation
4	Froth Flotation
5	Thermal Drying
6	Slot Type Coke Oven
7	Volatile Collection and Cooling
8	Tar Liquor Decantation
9	Ammonia Recovery
10	Pyridine Recovery
11	Phenol Recovery
12	Coke Quenching
13	Light Oil Recovery
14	Storage
15	Utility Boilers (Coal)
16	Industrial Boilers (Coal)

Table 3-6. PROCESS STREAM CLASSIFICATION (CONVENTIONAL COAL)

(A) Coal Preparation

1. Coal Extraction
2. Crushing and Grinding
3. Gravity Separation
4. Froth Flotation
5. Thermal Drying

(B) Coke Oven Off Gas

6. Slot Type Coke Oven (including charging and pushing)

(C) Quenching and Direct Cooling Operations

7. Volatile Collection and Cooling
8. Tar Liquor Decantation
12. Coke Quenching

(D) Boiler Off Gas

15. Utility Boiler (Coal)
16. Industrial Boiler (Coal)

(E) Storage and Blending (Group II)

14. Storage (Light Oil, Coal Tars)

(F) Ash

15. Utility Boiler (Coal)
16. Industrial Boiler (Coal)

(G) Fugitive Sources

- Total Conventional Coal and Residual Oil Usage Module
-

TABLE 3-7. POTENTIALLY HAZARDOUS EMISSIONS FROM CLASSIFIED STREAMS AND PROCESSES
(CONVENTIONAL COAL)

(A) Coal Preparation

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	24. Fine Particulates	Respirable Coal Dust	Gas	T-0	
Suspected Present/ Known Hazardous	1. Acid and Anhydrides	Sulfuric Acid	Aqueous		
	22. Trace Elements	Beryllium	Solid	T-0	
		Selenium	Solid	T-0	
		Arsenic	Solid	T-0	
		Lead	Solid	T-0	
		Cadmium	Solid	T-0	

Table 3-7 (continued). (B) Coke Oven Off-Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	3. Amines	$\alpha + \beta$ Naphthyl amine	Gas	C-1	A-2; B-1
		4-aminobiphenyl	Gas	C-1	B-1
	6. Combustion Gases	Carbon monoxide	Gas	T-1	
	20. Polynuclear	Pyrene	Gas	T-0/C-3	A-1; B-1,3,4
		Chrysene	Gas	T-0/C-3	A-1,2,3; B-1,3
		Benzo(a)pyrene	Gas	T-1/C-1	A-1; B-1,2,3,4
		Benzo(e)pyrene	Gas	T-1/C-2	A-1; B-1,3
		Dibenzo(a,h)-anthracene	Gas	T-1/C-1	A-1; B-1
		Dibenzo(a,g)fluorene		T-1/C-1	A-1; B-1
	23. Organometallics	Nickel carbonyl	Gas	T-0/C-1	
	24. Fine Particulates	Tar	Gas	C-1	
		Soot	Gas	C-2	
Known Present/ Suspected Hazardous	25. Cyanides	Hydrogen cyanide	Gas	T-1	B-1
	1. Acid & Anhydrides	Benzoic acid	Gas	T-1	B-1
		Hydroxybenzoic acid	Gas	T-1	B-1
		Hydrochloric acid	Gas	T-1	B-1
	3. Amines	Ammonia	Gas	T-2	B-1
		Aniline	Gas	C-3	A-2; B-1
		Methylaniline	Gas	T-1	B-1

Table 3-7 (continued). (B) Coke Oven Off-Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
70	5. Carbonyl Compounds	Formaldehyde	Gas	T-1	B-1
		Acetaldehyde	Gas	T-2	B-1
		Paraldehyde	Gas	T-2	B-1
	20. Polynuclear	Methylchrysene	Gas	T-1/C-3	A-1,2; B-1
		Benzo(a)anthracene	Gas	T-1/C-3	A-1,2; B-1,3
		Dimethylbenzanthracenes	Gas	T-1/C-2	A-1; B-1
	21. Sulfur Compounds	Methyl mercaptan	Gas	T-0	
		Ethyl mercaptan	Gas	T-0	
	22. Trace Elements	Beryllium	Gas	T-0	
		Silver metals and soluble compounds	Gas	T-2	A-4; E-4
		Mercury	Gas	T-0	A-4; E-4
		Vanadium	Gas	T-0	E-4,5
		Lead	Gas	T-0	A-4; E-4
		Cadmium	Gas	T-0	A-4; E-4
		Antimony	Gas	T-0	E-4
		Arsenic	Gas	T-0	A-4; E-4,5
		Barium	Gas	T-0	E-5
	Suspected Present/ Known Hazardous 10. Heterocyclics	Pyridine	Gas	T-1	A-1; B-1
		Alkyl pyridine	Gas	T-1	B-1
		Phenyl pyridine	Gas	T-1	B-1
		(Mono) Benzofurans	Gas	T-2	B-1
		Quinoline	Gas	T-0	B-1
		Alkyl quinoline	Gas	T-0	

Table 3-7 (continued). (B) Coke Oven Off-Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	11. Hydrocarbons	Aliphatics	Gas	T-2	B-1
		Olefins	Gas	T-2	B-1
		Benzene	Gas	T-2	A-2; B-1
		Toluene	Gas	T-2	B-1
		Xylene	Gas	T-2	B-1
		Alkylbenzenes	Gas	T-2	B-1
	18. Phenols	Phenol	Gas	T-1	B-1
		o,m,p-cresols	Gas	T-1	B-1
		Phenyl phenol	Gas	T-1	B-1
		Xylenols	Gas	T-1	B-1
		Alkyl phenols	Gas	T-1	B-1
		Alkyl cresols	Gas	T-1	B-1
	20. Polynuclear	Biphenyl	Gas	T-1/C-4	B-1
		Naphthalene	Gas	T-2	B-1
		Alkyl naphthalene	Gas	T-2	B-1
		Phenyl naphthalene	Gas	T-2	B-1
		Tetralin	Gas	T-2	B-1
		Methyl tetralin	Gas	T-2	B-1
		Acenaphthylene	Gas	T-2	B-1
		Acenaphthene	Gas	T-2	B-1
		Fluorene	Gas	T-1/C-4	A-1; B-1
		Anthracene	Gas	T-0/C-4	A-1; B-1,4
		Alkyl anthracenes	Gas	T-1/C-4	A-1; B-1
		Phenanthrenes	Gas	T-0/C-4	A-1; B-1
		Alkyl phenanthrenes	Gas	T-1/C-4	A-1
		Coronene	Gas	T-1	B-1,3,4

Table 3-7 (continued). (B) Coke Oven Off-Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
		Carbazole	Gas	C-3	A-2; B-1
		Acridine	Gas	T-0	A-1; B-1
		Benzocarbazoles	Gas	C-3	A-1; B-1
		Akylacridines	Gas	T-0	
		Benzo(a)anthrone	Gas	C-2	A-2; B-3
		Perylene	Gas	T-1/C-4	A-1; B-1,3
	21. Sulfur Compounds	Hydrogen sulfide	Gas	T-2	E-5
		Thiophenes	Gas		B-1; E-5
		Methyl thiophene	Gas		B-1; E-5
		Carbon disulfide	Gas		
		Carbonyl sulfide	Gas		
	22. Trace Elements	Selenium	Gas		A-4; E-4
	24. Fine Particulates	Coke	Gas	T-1	
		Coal	Gas	T-1	
	25. Cyanides	Ammonium cyanide	Gas		B-1
		Naphthyl cyanide	Gas		

Table 3-7 (continued). (C) Quenching and Direct Cooling Operation

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	3. Amines	$\alpha + \beta$ Naphthyl amine 4-aminobiphenyl	Gas Gas	C-1 C-1	A-2; B-1 B-1
	6. Combustion Gases	Carbon monoxide	Gas	T-1	
	18. Phenols	Phenol	Aqueous	W-1	A-5,7
	20. Polynuclear	Pyrene	Gas	T-0/C-3	A-1; B-1,3,4
		Chrysene	Gas	T-0/C-3	A-1,2,3; B-1,3
		Benzo(a)pyrene	Gas	T-1/C-1	A-1; B-1,2,3,4
		Benzo(e)pyrene	Gas	T-1/C-2	A-1; B-1,3
		Dibenzo(a,h)anthracene	Gas	T-1/C-1	A-1; B-1
		Dibenzo(a,g)fluorene	Gas	T-1/C-1	A-1; B-1
	23. Organometallics	Nickel carbonyl	Gas	T-0/C-1	
	24. Fine Particulates	Tar	Gas	C-1	
		Soot	Gas	C-2	
	25. Cyanides	Hydrogen cyanide	Gas	T-1	B-1
Known Present/ Suspected Hazardous	1. Acid and Anhydrides	Benzoic acid	Gas	T-1	B-1
		Hydroxybenzoic acid	Gas	T-1	B-1
		Hydrochloric acid	Gas	T-1	B-1
		Sulfuric acid	Aqueous	W-1	A-8

Table 3-7 (continued). (C) Quenching and Direct Cooling Operation

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	3. Amines	Ammonia	Gas	T-2	B-1
		Aniline	Gas	C-3	A-2; B-1
		Methylanilines	Gas	T-1	B-1
		Ammonia	Aqueous	W-1	A-5
	4. Inorganic Salts	Ammonium sulfate	Aqueous	W-2	A-2
	5. Carbonyl Compounds	Formaldehyde	Gas/Aqueous	T-1/W-1	A-8; B-1
		Acetaldehyde	Gas/Aqueous	T-2/W-1	A-8; B-1
		Paraldehyde	Gas	T-2	B-1
	10. Heterocyclics	Pyridine	Aqueous	W-2	A-8
	11. Hydrocarbon	Benzene	Aqueous	W-1	A-8
		Toluene	Aqueous	W-1	A-8
		Xylene	Aqueous	W-1	A-8
	18. Phenols	o,m,p-Cresol	Aqueous	W-1/C-3	A-5
	20. Polynuclear	Methylchrysenes	Gas	T-1/C-3	A-1,2; B-1
		Benzo(a)anthracene	Gas	T-1/C-3	A-1,2; B-1,3
		Dimethylbenzanthracene	Gas	T-1/C-2	A-1; B-1
	21. Sulfur Compounds	Methyl mercaptan	Gas	T-0	
		Ethyl mercaptan	Gas	T-0	
		Thiophenes	Aqueous	W-1	A-8

Table 3-7 (continued). (C) Quenching and Direct Cooling Operation

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	22. Trace Elements	Beryllium	Gas	T-0	A-4; E-4
		Silver metals and soluble compounds	Gas	T-2	
		Mercury	Gas/Aqueous	T-0/W-1	A-8; E-4
		Vanadium	Gas	T-0	E-4, 5
		Lead	Gas/Aqueous	T-0/W-1	A-8; E-4
		Cadmium	Gas	T-0	A-4; E-4
		Antimony	Gas	T-0	E-4
		Arsenic	Gas	T-0	A-4; E-4, 5
		Barium	Gas	T-0	E-4
		Selenium	Aqueous	W-1	A-8
	23. Organometallics	Nickel carbonyl	Aqueous	W-1/C-1	A-6
	25. Cyanides	Hydrogen Cyanide	Aqueous	W-1	A-5
		Ammonium Cyanide	Aqueous	W-1	A-8
		Ammonium Thiocyanate	Aqueous	W-1	A-8
Suspected Present/ Known Hazardous	10. Heterocyclics	Pyridine	Gas	T-1	A-1; B-1
		Alkyl pyridines	Gas	T-1	B-1
		Phenyl pyridine	Gas	T-1	B-1
		(Mono) Benzofurans	Gas	T-2	B-1
		Quinoline	Gas	T-0	B-1
		Alkyl quinolines	Gas	T-0	

Table 3-7 (continued). (C) Quenching and Direct Cooling Operation

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous		Dibenzofuran	Gas	T-1	
		Alkyldibenzofurans	Gas	T-1	
	11. Hydrocarbons	Aliphatics	Gas	T-2	B-1
		Olefins	Gas	T-2	B-1
		Benzene	Gas	T-2	A-2; B-1
		Toluene	Gas	T-2	B-1
		Xylene	Gas	T-2	B-1
		Alkylbenzenes	Gas	T-2	B-1
	18. Phenols	Phenol	Gas	T-1	B-1
		o,m,p-Cresols	Gas	T-1	B-1
		Phenyl phenol	Gas	T-1	B-1
		Xylenols	Gas	T-1	B-1
		Alkyl phenols	Gas	T-1	B-1
		Alkyl cresols	Gas	T-1	B-1
	20. Polynuclear	Biphenyl	Gas	T-1/C-4	B-1
		Naphthalene	Gas	T-2	B-1
		Alkyl naphthalenes	Gas	T-2	B-1
		Phenyl naphthalenes	Gas	T-2	B-1
		Tetralin	Gas	T-2	B-1
		Methyl tetralins	Gas	T-2	B-1
		Acenaphthylene	Gas	T-2	B-1
		Acenaphthene	Gas	T-2	B-1
		Fluorene	Gas	T-1/C-4	A-1; B-1
		Anthracene	Gas	T-0/C-4	A-1; B-1,4
		Alkyl anthracenes	Gas	T-1/C-4	A-1; B-1
		Phenanthrenes	Gas	T-0/C-4	A-1; B-1

Table 3-7 (continued). (C) Quenching and Direct Cooling Operation

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
		Alkyl phenanthrenes	Gas	T-1/C-4	A-1
		Coronene	Gas	T-1	B-1,3,4
		Carbazole	Gas	C-3	A-2; B-1
		Acridine	Gas	T-0	A-1; B-1
		Benzocarbazoles	Gas	C-3	A-1; B-1
		Alkylacridines	Gas	T-0	
		Benzo(a)anthrone	Gas	C-2	A-2; B-3
		Perylene	Gas	T-1/C-4	A-1; B-1,3
	21. Sulfur Compounds	Hydrogen sulfide	Gas	T-2	E-5
		Thiophenes	Gas		B-1; E-5
		Methyl thiophenes	Gas		B-1; E-5
		Carbon disulfide	Gas		
		Carbonyl sulfide	Gas		
	22. Trace Elements	Selenium	Gas		A-4; E-4
		Arsenic (arsenic tri-oxide, sodium arsenate, sodium arsenite)	Aqueous	W-1/C-4	A-8
		Barium (acetate, chloride, nitrate)	Aqueous	W-2	A-8
		Cadmium (chloride, nitrate, sulfate)	Aqueous	W-1	A-8
	24. Fine Particulates	Coke	Gas	T-1	
		Coal	Gas	T-1	
	25. Cyanides	Ammonium cyanide	Gas		B-1
		Naphthyl cyanide	Gas		

Table 3-7 (continued). (D) Boiler Off-Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	4. Inorganic Salts	Chromium CrCl ₃ , CrS	Gas	T-0	D-5
	6. Combustion Gases	Sulfur oxides	Gas	T-2	
		Nitrogen oxides	Gas	T-2	
	10. Heterocyclics	Benzo(f)quinoline	Gas	T-0	D-6
		Benzo(h) quinoline	Gas	T-0	D-6
	20. Polynuclears	Benzo(a)pyrene	Gas	C-1	A-1; D-2,3,4
		Benzo(e)pyrene	Gas	C-1	A-1
		Pyrene	Gas	C-3/T-0	A-1; D-4
		Chrysene	Gas	C-2/T-0	A-1,2,3
		Benzo(a)anthracene	Gas	C-3/T-1	A-1,2,3
		Phenanthrene	Gas	T-0/C-4	A-1; D-4
	24. Fine Particulates	Soot	Gas	C-2	
		Ash	Gas	T-1	
Known Present/ Suspected Hazardous	1. Acid and Anhydrides	Sulfuric acid	Gas	T-1	
		Nitric acid	Gas	T-1	
		Hydrogen chloride	Gas	T-1	D-1
	3. Amines	α + β Naphthylamines	Gas	C-1/T-0	
		4-Aminobiphenyl	Gas	C-1/T-0	
		Benzidine	Gas	C-1/T-0	
	5. Carbonyl Compounds	Formaldehyde	Gas	T-2	

Table 3-7 (continued). (D) Boiler Off-Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
	6. Combustion Gases	Carbon monoxide	Gas	T-2	
	10. Heterocyclic	Indeno (1,2,3-ij) isoquinoline	Gas		D-6
	20. Polynuclear	Perylene	Gas	C-4/T-1	A-1; D-4
		Coronene	Gas	T-1	D-4
		Anthracene	Gas		D-4
		Acridine	Gas	T-0	D-4
		Benzo(a)acridine	Gas	T-0	D-6
		Benzo(c)acridine	Gas	T-0	D-6
		Fluoranthene	Gas		D-4
		Dibenzo(a,h)acridine	Gas	T-0	D-6
		Phenanthridine	Gas		D-3
	22. Trace Elements	Mercury	Gas	T-0	A-4
		Beryllium	Gas	T-0	A-4
		Selenium/Selenium oxides(SeO_2 , SeO_3)	Gas	T-0	A-4; D-5
		Arsenic/ As_2O_3 , As_2S_3	Gas	T-0	A-4; D-5
		Lead	Gas	T-0	A-4
		Barium	Gas	T-0	D-5
		Fluorine	Gas	T-1	
		Uranium	Gas	T-0	
		Vanadium	Gas	T-0	
		Copper	Gas	T-0	
		Cadmium/Cadmium oxide (CdO)	Gas	T-0	D-5

Table 3-7 (continued). (D) Boiler Off-Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous		Thallium/Thallium Oxide	Gas	T-0	D-5
		Antimony/Sb ₂ O ₃	Gas	T-0	D-5
		Zinc	Gas	T-1	D-5
	3. Amines	Aniline	Gas	C-3/T-2	
	5. Carbonyl Compounds	Cr(CO) ₆	Gas	T-0	
	10. Heterocyclic	Pyridine	Gas	T-1	
	18. Phenols	Phenol	Gas	T-1	
	20. Polynuclear	Dibenzo(a,g)fluorene	Gas	C-1/T-1	A-1
	21. Sulfur Compounds	Thiophene	Gas	T-2	
		Benzothiophenes	Gas		
		Dibenzothiophenes	Gas		

Table 3-7 (continued). (E) Storage and Blending

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	3. Amines	Ammonia	Aqueous		
		Aliphatic amines	Aqueous		
		Aromatic amines	Aqueous		
	11. Hydrocarbons	Benzene	Gas & Aqueous	T-2/W-1	A-2,8
		Toluene	Gas & Aqueous	T-2/W-1	A-8
		Xylene	Gas & Aqueous	T-2/W-1	A-8
Suspected Present/ Known Hazardous	18. Phenols		Aqueous		
	23. Organometallics	Tetraethyl lead	Aqueous		

Table 3-7 (continued). (F) Ash

Status	Chemical Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Emission/ Known Hazardous	22. Trace Elements	Mercury	Solid	T-0	
		Beryllium	Solid	T-0	
		Selenium	Solid	T-0	
		Arsenic	Solid	T-0	
		Lead	Solid	T-0	
		Barium	Solid	T-0	
		Fluorine	Solid	T-0	
		Uranium	Solid	T-0	
		Vanadium	Solid	T-0	
		Copper	Solid	T-0	
		Cadmium	Solid	T-0	
		Thallium	Solid	T-0	
		Antimony	Solid	T-0	
		Zinc	Solid	T-1	
	24. Fine Particulates	Respirable dust	Solid	T-0	

Table 3-8. POTENTIAL FOR FUGITIVE EMISSIONS FROM CONVENTIONAL COAL PROCESS MODULE

Module No.	Process Name	Pressure ^(a)	Temperature ^(b)	Potentially Hazardous Volatiles	Corrosiveness	General House-keeping	Potential for Hazardous Fugitive Emissions
1	Coal Extraction	low	low	med	low	poor	med
2	Crushing and Grinding	low	low	med	med	poor	med
3	Gravity Separation	low	low	low	low	med	low
4	Froth Floatation	low	low	low	low	med	low
5	Thermal Drying	low	high	med	low	med	low
6	Slot Type Coke Oven	low	high	high	med	poor	high
7	Volatiles Collection and Cooling	low	high	high	high	poor	high
8	Tar Liquor Decantation	low	low	high	med	med	high
9	Ammonia Recovery	low	med	high	high	med	high
10	Pyridine Recovery	low	med	high	med	med	med
11	Phenol Recovery	low	med	high	high	med	med
12	Coke Quenching	low	med	high	low	poor	high
13	Light Oil Recovery	low	med	high	low	med	med
14	Storage	low	low	high	low	med	med
15	Utility Boilers (Coal)		high	high	high	med	med
16	Industrial Boilers (Coal)		high	high	high	med	med

		<u>Low</u>	<u>Med</u>	<u>High</u>
(a)	PSIG	< 50	50-150	> 150
(b)	°F	< 150	150-300	> 300

ADVANCED COAL PROCESS MODULE

A gasification process and a liquefaction process were selected for the advanced coal process flow sheets. A high-Btu gas Lurgi-type process and the solvent refined coal process were chosen for the gasification process flow sheet and the liquefaction process flow sheet, respectively. The major operations and the flow of materials through them are identified and shown in Figures 3-9 and 3-10 by similar procedures described in the petroleum and conventional coal process flow sheets. A list of 25 modules is shown in Table 3-9.

Each module was assessed and the potentially hazardous emission streams were identified. The emission streams from the water-oil separation, fractionation, hydrotreating, and hydrocracking modules are similar to those in the refinery process flow sheet. Thus, the discussion and the detailed assessment of the potentially hazardous emission streams were not repeated in this section. Ten classes of emission streams were defined and listed in Table 3-10.

A data sheet was prepared for each class of emission stream. However, the assessment was heavily dependent on the experience from the similar operations of other conventional processes. There is very little published information about the composition of the process streams in the gasification and liquefaction plants. The data sheets of these classes of emission streams are shown in Table 3-11. The "ash" emission stream is similar to the one in the conventional coal process flow sheet and its data sheet is not included in this section.

The assessment of the fugitive losses from these advanced coal processes are difficult because there is no commercial scale operating experience of these plants. There are some Lurgi gasification plants outside the United States. However, these plants are old. They were initially designed to produce low-Btu gas. Through experience from other similar operations of the conventional processes, an assessment was made in a similar fashion as in the refinery and the conventional coal process flow sheets. Table 3-12

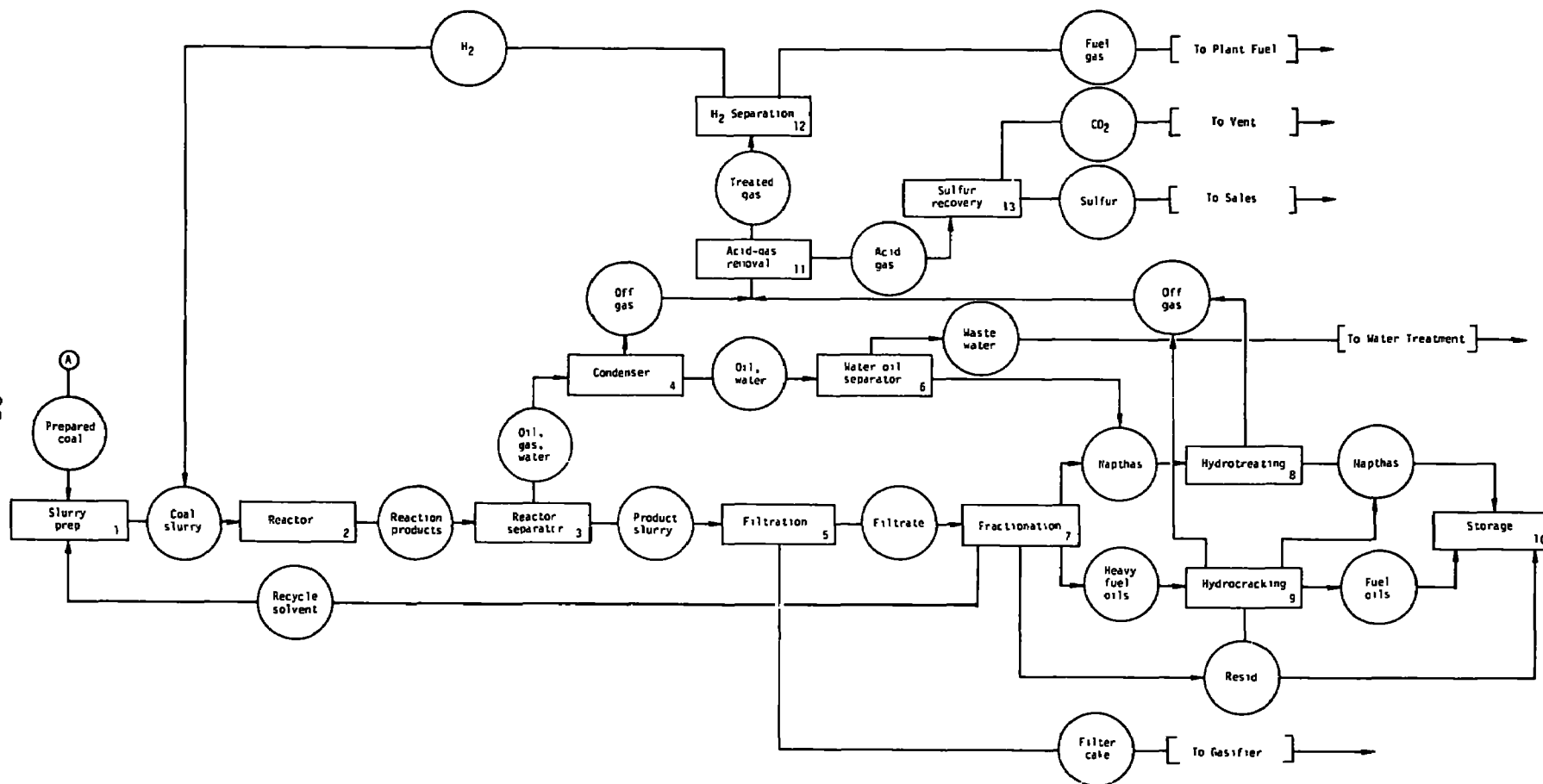


FIGURE 3-9. LIQUEFACTION PROCESS MODULE

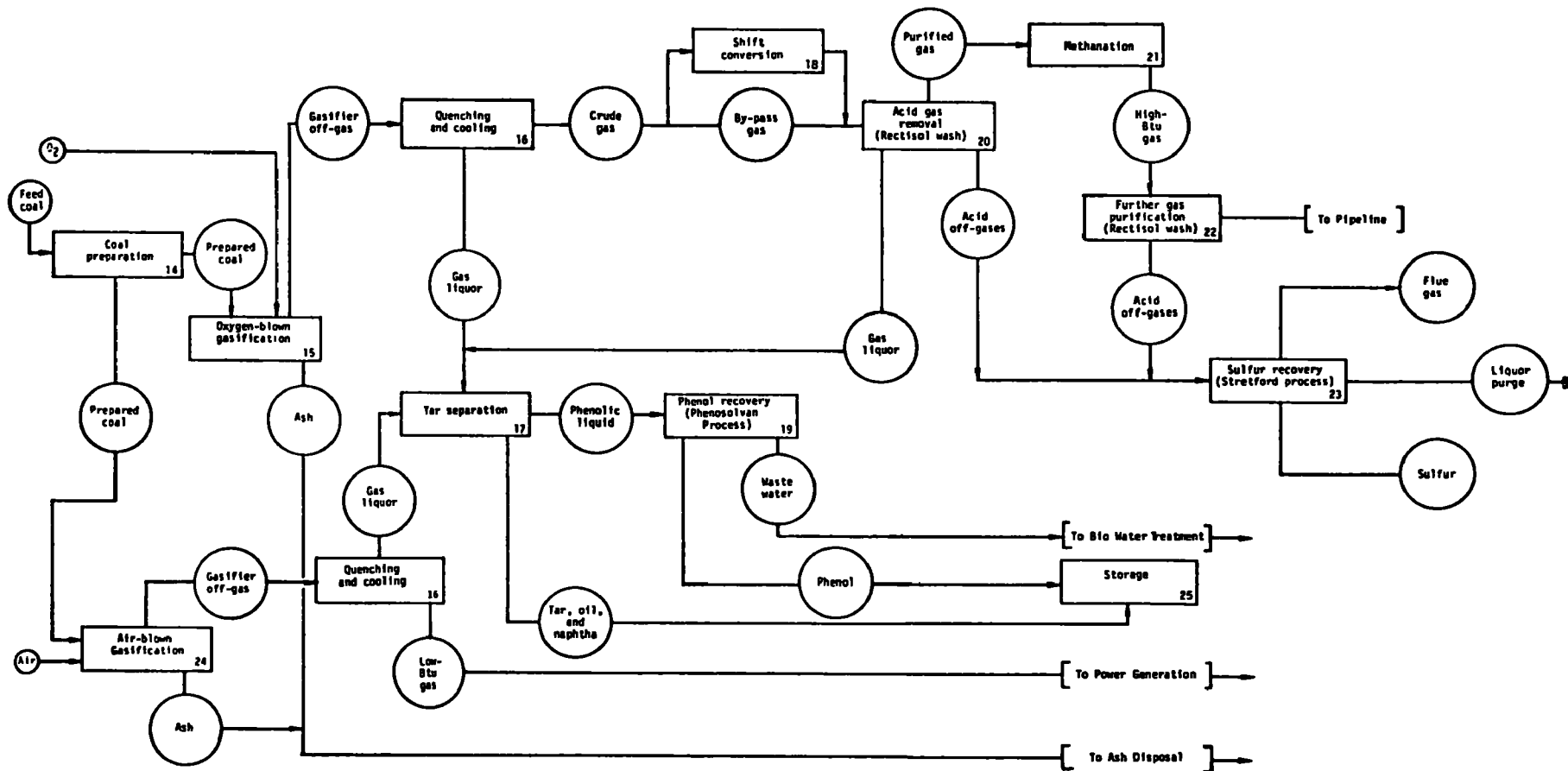


FIGURE 3-10. GASIFICATION PROCESS MODULE

summarizes the results of the analysis. The fact sheets of the process modules as listed in Table 3-9 are included in Appendix A.

Conclusions

The published information of the composition of the emission streams are sparse because there is no existing commercial Lurgi nor solvent refined coal plant in the United States. On the basis of the information from some European operations and the similarities with the other conventional processes, the following conclusions are made.

(1) Coal gasification is likely to produce equally dangerous substances as the coke plant, but they will probably be somewhat more contained than coke oven emission.

(2) The quenching and cooling of gasifier off gas and the tar separation unit are the most important potential sources of toxic materials emissions in a gasification plant.

(3) Coal liquefaction will probably also produce extremely dangerous products but they may be more contained than those from a gasification operation.

(4) The primary potentially hazardous emission sources in a liquefaction plant are the slurry preparation and fugitive losses from leaks and equipment failures.

(5) Liquefaction products will probably be more hazardous than crude oil products, and their refining and utilization will be worse offenders than the corresponding petroleum operations.

Table 3-9. PROCESS MODULES OF COAL USAGE (ADVANCED)

Module	Name
1	Slurry Preparation
2	Reactor
3	Reactor Separator
4	Condenser
5	Filtration
6	Water-oil Separation
7	Fractionation
8	Hydrotreating
9	Hydrocracking
10	Storage
11	Acid Gas Treatment
12	Hydrogen Separation
13	Sulfur Plant
14	Coal Preparation
15	Oxygen Blown Gasification
16	Quenching and Cooling
17	Tar Separation
18	Shift Conversion
19	Phenol Recovery (Phenosolvan Process)
20	Acid Gas Removal (Rectisol Wash)
21	Methanation
22	Further Gas Purification (Rectisol Wash)
23	Sulfur Recovery (Stretford Process)
24	Air Blown Gasification
25	Storage

Table 3-10. PROCESS STREAM CLASSIFICATION (ADVANCED COAL)

-
-
- (A) Coal Preparation
 - 1. Slurry Preparation
 - 14. Coal Preparation
 - (B) Quenching and Direct Cooling Operations
 - 3. Reactor Separator
 - 16. Quenching and Cooling
 - (C) Sour Aqueous Condensate
 - 4. Fractionation
 - 5. Hydrocracking
 - 9. Condenser
 - 19. Phenol Recovery
 - (D) Fixed-Bed Catalyst Regeneration
 - 8. Hydrotreating
 - 9. Hydrocracking
 - (E) Barometric Condenser Off Gas
 - 7. Fractionation
 - (F) Storage and Blending
 - 10. Storage (Fuel Oil, Naphthas)
 - 25. Storage (Tar, Oil, Naphthas, Phenol)
 - (G) Sulfur Plant
 - 13. Sulfur Recovery (Claus Plant)
 - 23. Sulfur Recovery (Stretford Process)
 - (H) Reactor Off Gas
 - 2. Reactor^(a)
 - 15. Oxygen Blower Gasifier
 - 21. Methanation
 - 24. Air-Blown Gasifier
 - (I) Tar Separation
 - 17. Tar Separation
-

Table 3-10 (continued). PROCESS STREAM CLASSIFICATION
(ADVANCED COAL)

(J) Ash

15 . Oxygen-Blown Gasifier

24 . Air-Blown Gasifier

(K) Fugitive Sources

- Liquefaction Processing Module
 - Gasification Processing Module
-
-

(a) The gas emission of the coal liquefaction reactor occurs most often during reactor accident or reactor clean-up.

Table 3-11. POTENTIALLY HAZARDOUS EMISSIONS FROM CLASSIFIED STREAMS AND PROCESSES
(ADVANCED COAL)

(A) Coal Preparation

Status	Chemicals Potentially Present			Toxicity	Reference
	Emission Class	Specific Components	Phase		
Known Present/ Known Hazardous	24. Particulates	Respirable Coal Dust	Gas	T-0	
Suspected Present/ Known Hazardous	1. Acid & Anhydride	Sulfuric Acid	Aqueous	W-1	A-8
	11. Hydrocarbons*		Gas/Aqueous		
	18. Phenols*		Gas/Aqueous		
	21. Sulfur Compounds		Gas		
	24. Particulates	Beryllium	Solid	T-0	
		Selenium	Solid	T-0	
		Arsenic	Solid	T-0	
		Lead	Solid	T-0	
		Cadmium	Solid	T-0	

*The presence of these compounds depends on the type of solvent used in coal slurry preparation.

Table 3-11. POTENTIALLY HAZARDOUS EMISSIONS FROM CLASSIFIED STREAMS AND PROCESSES
(ADVANCED COAL)

(B) Quenching and Direct-Cooling Operations

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	18. Phenols	2,5-Dimethylphenol	Aqueous	W-1	A-5, 7, E-7
		3,4-Dimethylphenol	Aqueous	W-1	A-5, 7, E-7
		2,4-Dimethylphenol	Aqueous	W-1	A-5, 7, E-7
		2,6-Dimethylphenol	Aqueous	W-1	A-5, 7, E-7
92 Known Present/ Suspected Hazardous	21. Sulfur Compounds	Hydrogen sulfide	Gas and Aqueous	T-2/W-0	A-5, 6, 7, E-5
	3. Amines	Ammonia	Gas and Aqueous	T-2/W-1	A-1
	11. Hydrocarbons	Benzene	Gas	T-2	A-2
		Toluene	Gas	T-2	
		Aliphatic	Gas	T-2	
		Olefins	Gas	T-2	
	18. Phenols	<u>o</u> -Cresol	Aqueous	W-1/C-3	A-5, E-7
		<u>m</u> -Cresol	Aqueous	W-1/C-3	A-5, E-7
	21. Trace Elements	Selenium	Aqueous	W-1	A-8, E-7
	25. Cyanides	Hydrogen Cyanide	Aqueous	W-1	A-5
Suspected Present/ Known Hazardous	10. Heterocyclic	Dibenzofurans	Gas	T-2	E-5

Table 3-11 (continued). (B) Quenching and Direct-Cooling Operations

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
93	18. Phenols	Phenol	Gas	T-1	
		o,m,p-Cresols	Gas	T-1	
		Phenyl Phenol	Gas	T-1	
		Alkyl Phenol	Gas	T-1	
		Alkyl Cresols	Gas	T-1	
	19. Polynuclear	Benzo(a)pyrene	Gas	T-0	A-1
		Dibenzo(a,l)pyrene	Gas	C-3	
		Dibenzo(a,h)pyrene	Gas	C-2	
		Dibenzo(a,i)pyrene	Gas	C-2	
		Methylpyrenes	Gas		
		Indeno (1,2,3-c,d) Pyrene	Gas	C-3	
		Benzo(e)pyrene	Gas	T-1/C-2	A-1
		Benzo(a)anthracene	Gas	C-3	
		Dibenzoanthracene	Gas	C-2	
		Anthracene	Gas	T-0	
		Chrysene	Gas	T-0/C-3	
		Benzo(g,h,i)perylene	Gas	C-4	A-1
		Fluoranthene	Gas	C-4	A-1
		Perylene	Gas	T-1/C-4	A-1
		Coronene	Gas	T-1	
		Benzoacridine	Gas	C-2	A-1
		Benzoanthrone	Gas	C-2	A-2
		Acridine	Gas	T-0	A-1
		Phenanthrene	Gas	T-0/C-4	A-1

Table 3-11 (continued). (B) Quenching and Direct-Cooling Operations

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
21. Sulfur Compounds		Thiophene	Gas		E-5
		Methyl Thiophene	Gas		E-5
		Dimethyl Thiophene	Gas		E-5
		Methyl Mercaptan	Gas	T-1	E-5
22. Trace Elements		Mercury	Gas	T-0	E-3, 4
		Selenium	Gas	T-0	E-3, 4, 5
		Arsenic	Gas	T-0	E-3, 4, 5
		Lead	Gas	T-1	E-3, 4
		Cadmium	Gas	T-0	E-3, 4
		Antimony	Gas	T-0	E-3, 4
		Vanadium	Gas	T-0	E-4, 5
		Nickel	Gas	T-1	E-3, 4, 5
		Beryllium	Gas	T-0	E-4
		Cobalt	Gas	T-0	E-5
		Phosphorus	Gas	T-0	E-5
		Manganese	Gas	T-1	
		Arsenic (arsenic trioxides, sodium arsenate, sodium arsenite)	Aqueous	W-1/C-4	E-7
		Chromium (hexavalent, trivalent)	Aqueous	W-1	A-8, E-7
		Phosphorus (phosphate)	Aqueous	W-2	A-8, E-7
		Strontium (nitrate)	Aqueous	W-2	A-8, E-7
		Vanadium (pentoxide, vanadyl sulfate)	Aqueous	W-2	A-7, 8, 9, E-7
25. Cyanides		Thiocyanate (ammonium, potassium, sodium)	Aqueous	W-1	A-8

Table 3-11 (continued). (C) Sour Aqueous Condensate

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	1. Acid and Anhydrides	Cresylic Acid Maleic Acid	Aqueous Aqueous		
	2. Alcohols	Aliphatic Alcohols Aromatic Alcohols	Aqueous Aqueous		
	3. Amines	Ammonia	Aqueous	W-1	A-5
	5. Carbonyls	Aldehydes Ketone	Aqueous Aqueous	W-1	A-8
	10. Heterocyclics	Pyridines Pyrroles	Aqueous Aqueous	W-2	A-8
	11. Hydrocarbons	Benzene	Aqueous	W-1	A-8
		Toluene	Aqueous	W-1	A-8
		Xylene	Aqueous	W-1	A-8
	18. Phenols	Cresols	Aqueous	W-1	A-5
		Xylenols	Aqueous		
		Phenol	Aqueous	W-1	A-5, 7
Suspected Present/ Known Hazardous	21. Sulfur Compounds	Hydrogen sulfide	Aqueous	W-0	A-5, 6, 7
		Methyl Mercaptan	Aqueous		
		Sulfides	Aqueous		
		Sulfonates	Aqueous		
		Thiophenes	Aqueous		
	22. Trace Elements		Aqueous		

Table 3-11 (continued). (D) Fixed Bed Catalyst Regeneration

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	C-4
		Carbonyl Sulfide	Gas		C-4
		Carbon Disulfide	Gas		
		Mercaptans	Gas	T-0	C-4
Known Present/ Suspected Hazardous	6. Combustion Gases	Carbon Monoxide	Gas	T-1	
		Sulfur Oxide	Gas	T-2	
	11. Hydrocarbons	Benzene	Gas	T-2	A-2
		Toluene	Gas	T-2	
		Xylene	Gas	T-2	
	22. Trace Elements	Vanadium	Gas	T-0	A-4
		Nickel	Gas	T-0	C-1
		Cobalt	Gas		
		Molybdenum	Gas		
	24. Fine Particulates	Catalyst	Gas		
		Coke	Gas	T-1	
Suspected Present/ Known Hazardous	10. Heterocyclics		Gas		
	20. Polynuclear		Gas		
	23. Organometallics	Nickel Carbonyl	Gas	T-0	
		Cobalt Carbonyl	Gas		

Table 3-11 (continued). (E) Barometric Condenser Off Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	5. Carbonyl Compounds	Aldehydes Ketones	Gas Gas	T-1	
	10. Heterocyclic	Pyrroles Pyridines	Gas Gas	T-1	
	11. Hydrocarbons	Benzene Toluene Xylene	Gas Gas Gas	T-2 T-2 T-2	A-2
	18. Phenols	Cresols Xylenols Phenol	Gas Gas Gas	T-1 T-1 T-1	
	21. Sulfur Compounds	Hydrogen Sulfide Methyl Mercaptans Thiophenes	Gas Gas Gas	T-2	

Table 3-11 (continued). (F) Storage and Blending

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Suspected Hazardous	3. Amines	Ammonia	Gas/Aqueous	T-2/W-1	A-5
	11. Hydrocarbons	Benzene	Gas	T-2	A-2
		Toluene	Gas	T-2	
		Aliphatic	Gas	T-2	
		Olefins	Gas	T-2	
Suspected Present/ Known Hazardous	18. Phenols	o,m-Cresols	Aqueous	W-1/C-3	A-5, E-7
	18. Phenols	Phenol	Gas	T-1	
		o,m,p-Cresols	Gas	T-1	
		Phenyl Phenol	Gas	T-1	
		Alkyl Phenol	Gas	T-1	
		Alkyl Cresols	Gas	T-1	
	20. Polynuclear	Benzo(a)pyrene	Gas	T-0	A-1
		Dibenzo(a,l)pyrene	Gas	C-3	
		Dibenzo(a,h)pyrene	Gas	C-2	
		Dibenzo(a,i)pyrene	Gas	C-2	
		Methyl Pyrene	Gas		
		Indeno (1,2,3-c,d) Pyrene	Gas	C-3	A-1
		Benzo(e)pyrene	Gas	T-1/C-2	
		Benzo(a)anthracene	Gas	C-3	
		Dibenzoanthracene	Gas	C-2	
		Anthracene	Gas	T-0	
		Chrysene	Gas	T-0/C-3	A-1
		Benzo(g,h,i)perylene	Gas	C-4	
		Fluoranthene	Gas	C-4	

Table 3-11 (continued). (F) Storage and Blending

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
		Perylene	Gas	T-1/C-4	A-1
		Coronene	Gas	T-1	
		Benzoacridine	Gas	C-2	A-1
		Benzoanthrone	Gas	C-2	A-2
		Acridine	Gas	T-0	A-1
		Phenanthrene	Gas	T-0/C-4	A-1
	22. Trace Elements	Arsenic (arsenic trioxides, sodium arsenate, sodium arsenite)	Aqueous	W-1/C-4	E-7
		Chromium (hexavalent, trivalent)	Aqueous	W-1	A-8, E-7
		Phosphorus (phosphate)	Aqueous	W-2	A-8, E-7
		Strontium (nitrate)	Aqueous	W-2	A-8, E-7
		Vanadium (pentoxide, vanadyl sulfate)	Aqueous	W-2	A-7, 8, 9, E-7
	25. Cyanides	Thiocyanate (ammonium, potassium, sodium)	Aqueous	W-1	A-8

Table 3-11 (continued). (G) Sulfur Plant

Status	Chemicals Potentially Present			Toxicity	Reference
	Emission Class	Specific Components	Phase		
Known Present/ Known Hazardous	21. Sulfur Compounds	Hydrogen Sulfide	Gas	T-2	C-4
		Carbonyl Sulfur	Gas		C-4
		Carbon Disulfide	Gas		C-4
Known Present/ Suspected Hazardous	1. Acid and Anhydrides	Anthraquinone Disulfonic Acid	Aqueous	W-2	A-7
	3. Amines	Diethylamines	Gas		
		Methylethylamines	Gas		
		Ammonia	Gas	T-2	
	6. Combustion Gases	Carbon Monoxide	Gas	T-2	
		Nitrogen Oxides	Gas	T-1	
		Sulfur Oxides	Gas	T-2	
	24. Fine Particulates	Sulfur Particulates	Gas		
	20. Polynuclear	Benzo(a)pyrene	Gas	T-0	A-1
		Dibenzo(a,l)pyrene	Gas	C-3	
		Dibenzo(a,h)pyrene	Gas	C-2	
		Dibenzo(a,i)pyrene	Gas	C-2	
		Methyl Pyrene	Gas		
		Indeno (1,2,3-c,d) Pyrene	Gas	C-3	
		Benzo(e)pyrene	Gas	T-1/C-2	A-1
		Benzo(a)anthracene	Gas	C-3	
		Dibenzoanthracene	Gas	C-2	
		Anthracene	Gas	T-0	
		Chrysene	Gas	T-0/C-3	
Suspected Present/ Known Hazardous					

Table 3-11 (continued). (G) Sulfur Plant

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
		Benzo(g,h,i)perylene	Gas	C-4	A-1
		Fluoranthene	Gas	C-4	A-1
		Perylene	Gas	T-1/C-4	A-1
		Coronene	Gas	T-1	
		Benzoacridine	Gas	C-2	A-1
		Benzoanthrone	Gas	C-2	A-2
		Acridine	Gas	T-0	A-1
		Phenanthrene	Gas	T-0/C-4	A-1
	22. Trace Elements	Mercury	Gas	T-0	E-3, 4
		Selenium	Gas	T-0	E-3, 4, 5
		Arsenic	Gas	T-0	E-3, 4, 5
		Lead	Gas	T-1	E-3, 4
		Cadmium	Gas	T-0	E-3, 4
		Antimony	Gas	T-0	E-3, 4
		Vanadium	Gas	T-0	E-4, 5
		Nickel	Gas	T-1	E-3, 4, 5
		Beryllium	Gas	T-0	E-4
		Cobalt	Gas	T-0	E-5
		Phosphorus	Gas	T-0	E-5
		Manganese	Gas	T-1	

Table 3-11 (continued). (H) Reactor Off Gas

Status	Chemicals Potentially Present			Toxicity	Reference
	Emission Class	Specific Components	Phase		
Known Present/ Known Hazardous	5. Carbonyl Compounds	Nickel Carbonyl*	Gas	T-0	E-1
	21. Sulfur Compounds	Carbonyl Sulfide	Gas	T-1	E-5
		Carbon Disulfide	Gas	T-1	
		Hydrogen Sulfide	Gas	T-2	
Known Present/ Suspected Hazardous	3. Amines	Ammonia	Gas	T-2	A-2
	6. Combustion Gases	Carbon Monoxide	Gas	T-3	
		Nitrogen Oxides	Gas	T-1	
	11. Hydrocarbon	Benzene	Gas	T-2	
		Toluene	Gas	T-2	
Suspected Present/ Known Hazardous	10. Heterocyclic	Dibenzofurans	Gas	T-2	E-5
	18. Phenols	Phenol	Gas	T-1	A-1
		o,m,p-Cresols	Gas	T-1	
		Phenyl Phenol	Gas	T-1	
		Alkyl Phenol	Gas	T-1	
		Alkyl Cresols	Gas	T-1	
	20. Polynuclear	Benzo(a)pyrene	Gas	T-0	
		Dibenzo(a,l)pyrene	Gas	C-3	
		Dibenzo(a,h)pyrene	Gas	C-2	

Table 3-11 (continued). (H) Reactor Off Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
103		Dibenzo(a,i)pyrene	Gas	C-2	
		Methyl Pyrene	Gas		
		Indeno (1,2,3-c,d) Pyrene	Gas	C-3	
		Benzo(e)pyrene	Gas	T-1/C-2	A-1
		Benzo(a)anthracene	Gas	C-3	
		Dibenzoanthracene	Gas	C-2	
		Anthracene	Gas	T-0	
		Chrysene	Gas	T-0/C-3	
		Benzo(g,h,i)perylene	Gas	C-4	A-1
		Fluoranthene	Gas	C-4	A-1
		Perylene	Gas	T-1/C-4	A-1
		Coronene	Gas	T-1	
		Benzoacridine	Gas	C-2	A-1
		Benzoanthrone	Gas	C-2	A-2
		Acridine	Gas	T-0	A-1
		Phenanthrene	Gas	T-0/C-4	A-1
Suspected Present/ Known Hazardous	21. Sulfur Compounds	Thiophene	Gas		E-5
		Methyl Thiophene	Gas		E-5
		Dimethyl Thiophene	Gas		E-5
		Methyl Mercaptan	Gas	T-1	E-5
	22. Trace Elements	Mercury	Gas	T-0	E-3, 4
		Selenium	Gas	T-0	E-3, 4, 5
		Arsenic	Gas	T-0	E-3, 4, 5
		Lead	Gas	T-1	E-3, 4
		Cadmium	Gas	T-0	E-3, 4

Table 3-11 (continued). (H) Reactor Off Gas

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
		Antimony	Gas	T-0	E-3, 4
		Vanadium	Gas	T-0	E-4, 5
		Nickel	Gas	T-1	E-3, 4, 5
		Beryllium	Gas	T-0	E-4
		Cobalt	Gas	T-0	E-5
		Phosphorus	Gas	T-0	E-5
		Manganese	Gas	T-1	

104 * This is found only in the methanation unit.

Table 3-11 (continued). (I) Tar Separation

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Known Present/ Known Hazardous	18. Phenols	Phenol	Aqueous	W-1	A-5, 7
Known Present/ Suspected Hazardous	1. Acids and Anhydrides	Sulfuric Acid	Aqueous	W-1	A-8
	3. Amines	Ammonia	Aqueous	W-1	A-5
	4. Inorganic Salts	Ammonium Sulfate	Aqueous	W-2	A-8
	5. Carbonyl Compounds	Formaldehyde	Aqueous	W-1	A-8
		Acetaldehyde	Aqueous	W-1	A-8
	10. Heterocyclics	Pyridines	Aqueous	W-2	A-8
	11. Hydrocarbons	Benzene	Aqueous	W-1	A-8
		Toluene	Aqueous	W-1	A-8
		Xylene	Aqueous	W-1	A-8
	18. Phenols	o,m,p-Cresol	Aqueous	W-1/C-3	A-5
	21. Sulfur Compounds	Thiophenes	Aqueous	W-1	A-8
	22. Trace Elements	Lead	Aqueous	W-1	A-8
		Mercury	Aqueous	W-1	A-8
		Selenium	Aqueous	W-1	A-8

Table 3-11 (continued). (I) Tar Separation

Status	Chemicals Potentially Present		Phase	Toxicity	Reference
	Emission Class	Specific Components			
Suspected Present/ Known Hazardous	23. Organometallics	Nickel Carbonyl	Aqueous	W-1/C-1	A-6
	25. Cyanides	Hydrogen Cyanide	Aqueous	W-1	A-5
		Ammonium Cyanide	Aqueous	W-1	A-8
		Ammonium Thiocyanate	Aqueous	W-1	A-8
	22. Trace Elements	Arsenic (arsenic triiodide, sodium arsenate, sodium arsenite)	Aqueous	W-1/C-4	A-8
		Barium (acetate, chloride, nitrate)	Aqueous	W-2	A-8
		Cadmium (chloride, nitrate, sulfate)	Aqueous	W-1	A-8
		Vanadium (pentoxide, vanadyl sulfate)	Aqueous	W-2	A-7, 8, 9

Table 3-12. POTENTIAL FOR FUGITIVE EMISSIONS FROM ADVANCED COAL PROCESS MODULE

Module No.	Process Name	Pressure	Temperature	Potentially Hazardous Volatiles	Corrosiveness	General House-keeping	Potential for Hazardous Fugitive Emissions
1	Slurry Preparation	low	low	med	low	med	med
2	Reactor	high	high	high	med	med	high
3	Reactor Separator	med-high	high	high	med	med	high
4	Condenser	low	med	med	high	med	high
5	Filtration	low	med	high	med	med	med
6	Water-Oil Separation	med	low	high	low	poor	high
7	Fractionation	low	med	high	med	med	high
8	Hydrotreating	high	high	high	med	med	high
9	Hydrocracking	high	high	high	med	med	med-high
10	Storage	low	low	med	low	med	med
11	Acid Gas Treatment	low	low	high	med	med	med-high
12	Hydrogen Separation	high	high	low	med	med	low
13	Sulfur Plant	low	high	high	med	med	med-high
14	Coal Preparation	low	low	med	low	poor	med
15	Oxygen Blown Gasification	high	high	high	med-high	med	med-high
16	Quenching and Cooling	low	med-high	high	high	med	med-high
17	Tar Separation	low	low	high	med	poor	high

Table 3-12 (continued). POTENTIAL FOR FUGITIVE EMISSIONS FROM ADVANCED
COAL PROCESS MODULE

Module No.	Process Name	Pres- sure	Tempera- ture	Potentially Hazardous Volatiles	Corrosive- ness	General House- keeping	Potential for Hazardous Fugitive Emissions
18	Shift Conversion	high	high	low	low	good	low-med
19	Phenol Recovery (Phenosolvan Process)	low	med	high	med	med	med
20	Acid Gas Removal (Rectisol Wash)	low	low	high	low	med	med
21	Methanation	high	high	low	low	good	low
22	Further Gas Purification (Rectisol Wash)	low	low	med	low	med	med
23	Sulfur Recovery (Stretford Process)	low	low	med	low	med	low-med
24	Air Blown Gasification	high	high	high	med-high	med	med-high
25	Storage	low	low	med	low	med	med

RECOMMENDATIONS

Because of the short-term nature of this study, it was necessary to accumulate process and chemical data from known and readily available sources. There was little time for follow-up and confirmation work on the data sources. The final assessments concerning the degree of potential hazards involved with the emissions was not sharp. Most of the classifications were in the suspected range. The following recommendations are aimed at confirming, expanding, and sharpening the data base in anticipation of subsequent test programs.

(1) Confirmation and expansion of the data base, especially as it relates to Class 1 emissions, should be performed in the following manner:

- Additional literature searches should be made to increase the data base on compositions of all process flow streams in the three primary process modules. This would include accumulating examples of all stream components, both hazardous and nonhazardous, contained in flow streams, plus operating temperatures, pressures, and material balances.
- Additional literature searches and investigation of industrial experience regarding analyses performed on operating plant streams should be made. In the case of advanced coal processes, these studies can be initiated in the existing pilot plants located in the United States. In addition to specific chemical analysis (mostly by GC), boiling point curves, carbon residues, tests for aromaticity, nitrogen and sulfur analyses could be helpful in better characterizing the streams.
- The disposition of all components within each process module should be assessed. For separations, the distribution of primary, trace, and hazardous components should be predicted. For reactions, molecular rearrangements should be estimated.

- The assessment as performed in this report should be repeated but with improved input on process modules and chemicals.

(2) The compatibility of the classes used for process assessment with classes that would be best from the standpoint of a long-range analytical strategy should be evaluated.

- The suitability and completeness of the chemical classifications suggested by EPA in light of more detailed analyses of plant streams should be assessed. Classes for hazardous components not presently detected should be added. Regrouping or expansion of classes may also be indicated.

(3) A better grading of the toxic and the carcinogenic compounds should be made through a more organized and thorough study of the health effects of the concerned compounds.

(4) A methodology for selecting the best sampling points for hazardous emissions should be developed, including a

- Compilation of a list of locations within petroleum process modules, conventional coal process modules, and advanced coal process modules where future sampling should be performed, and an
- Outline of a program for determining the level of hazardous emissions from fugitive sources. This could include tests at specific points within the process (such as pump seals and valves).

SECTION IV

SUMMARY OF RESULTS

A summary of all emission classes from the stream classes specified are included in Table 4-1 and Table 4-2. These tables indicate the status of the potentially hazardous chemical classes from the specific emission sources. The 25 chemical classes are described in Table 2-1, and the specific emission sources or streams are described in Tables 3-2, 3-5, and 3-10 for the petroleum, conventional coal, and advanced coal process modules, respectively. The gaseous, aqueous, and solid phases of the chemical classes are designated by "a", "w", and "s", respectively. The status numbers, as described in Section II are also incorporated into these matrices. Table 4-3 lists the potentially hazardous chemicals which have been included in this study.

Table 4-1. POTENTIALLY HAZARDOUS CHEMICAL CLASSES IN CLASSIFIED STREAMS OF PETROLEUM PROCESS MODULE

	ACIDS + ANHYDRIDES 1	ALCOHOLS 2	ANINES 3	INORGANIC SALTS 4	CARBONYL COMPOUNDS 5	COMBUSTION GASES 6	EPOXIDES 7	ETHERS 8	HALOCARBONS 9	HETEROCYCLIC 10	HYDROCARBONS 11	HYDROPEROXIDES 12	LACTONES 13	NITRO COMPOUNDS 14	NITROSANINES 15	OZONIDES 16	PEROXIDES 17	PHENOLS 18	POLYCHLORINATED POLYNUCLEAR 19	POLYNUCLEAR 20	SULFUR COMPOUNDS 21	TRACE ELEMENTS 22	ORGANOMETALLICS 23	FINE PARTICULATES 24	CYANIDES 25
A. Brine Water Systems	2w			2w	2w					2w	2w		1w					2w		3w	2w	3w	3w		
B. Sour Aqueous Condensates	2w	2w	2w		2w					2w	2w							2w		3w	2w	3w	3w		2w
C. Acid Gas Solvent Regeneration	2w		2w																		2w				2w
D. Claus Plant Tail Gas			2a			2a															1a			2a	3a
E. Fixed Bed Catalyst Regeneration Group I						2a																		2a	
F. Fixed Bed Catalyst Regeneration Group II						2a					2a									3a	1a			2a	
G. Fixed Bed Catalyst Regeneration Group III						2a				3a	2a									3a	1a	2a	3a	2a	
H. Fixed Bed Catalyst Regeneration Group IV																					2 ^a _w				
I. Moving Bed Catalyst Regeneration			2a		3a	2a				3a	2a				3a			2a		1a	1a	1a		1a	2a
J. Barometric Condenser Off Gas					2a					2a	2a							2a				2a			
K. Fluid Coker Off Gas			2a		3a	2a				3a	2a		3a					2a		3a	1a	1a	2a	1a	2a
L. Asphalt Air Blowing	2 ^a _w				2 ^a _w					1 ^a _w	2 ^a _w		3 ^a _w					2 ^a _w		1 ^a _w	2 ^a _w	2w	3 ^a _w	2a	
M. Spent Acid Sludge	2w	2w		2w	2w					2w	2w		3w					2w		3w	2w	3w	2w		
N. Decoking						2a					2a									3a	1a	2a		2a	

Table 4-1. (Continued) POTENTIALLY HAZARDOUS CHEMICAL CLASSES IN CLASSIFIED STREAMS OF PETROLEUM PROCESS MODULE

	ACIDS + ANHYDRIDES	ALCOHOLS	AMINES	INORGANIC SALTS	CARBONYL COMPOUNDS	COMBUSTION GASES	EPOXIDES	ETHERS	HALOCARBONS	HETEROCYCLIC	HYDROCARBONS	HYDROPEROXIDES	LACTONES	NITRO COMPOUNDS	NITROSAMINES	OZONIDES	PEROXIDES	PHENOLS	POLYCHLORINATED POLYNUCLEAR	POLYNUCLEAR	SULFUR COMPOUNDS	TRACE ELEMENTS	ORGANOMETALLICS	FINE PARTICULATES	CYANIDES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
O. Oil Fired Process Heaters					2a	2a				3a										1a		2a		1a	
P. Cooling Water Systems	2w 3a	3a w	3a w	2w	3a w			3a w		3a w	2a w		3a w		3a w			2w 3a		3a w	2w 3a	3w	3a w		3a w
Q. Storage & Blending Group I					2a						2a											2a			
R. Storage & Blending Group II			2w								2w a							2w					3w		
S. Storage & Blending Group III	2w				2w a					3w a	2w a							2w		3w a	2w	2w	3w		
T. Fugitive Emissions	3w a	3w a	3w a	3w	3w a			3w a		3w a	3w a		3w a		3w a			3w a		3w a	3w a	3w a	3w a	3a	3w a
U. Flares			2a		2a	2a				3a	2a									3a	2a			2a	2a
V. API Crit Chambers	3s	3s	3s	3s	3s					3s	3s		3s		3s			3s		3s	3s	3s	3s		3s
W. Biological Sludges																						3s	3s		
X. Spent Catalysts			2s	2s	2s					3s	2s				3s					3s	2s	2s	3s		

Table 4-2. POTENTIALLY HAZARDOUS CHEMICAL CLASSES IN THE CLASSIFIED STREAMS OF CONVENTIONAL COAL PROCESS MODULES

	ACID AND 1 ANHYDRIDES	AMINES 3	INORGANIC SALTS 4	CARBONYLS 5	COMBUSTION GASES 6	HETEROCYCLICS 10	HYDROCARBONS 11	PHENOLS 18	POLYNUCLEAR 20	SULFUR COMPOUNDS 21	TRACE ELEMENTS 22	ORGANO METALLICS 23	PARTICULATES 24	CYANIDES 25
A. Coal Preparation	3w										3s		1a	
B. Coke Oven Off Gas	2a	1,2a*		2a	1a	3a	3a	3a	1,2,3a*	2,3a*	2,3a*	1a	1,3a*	1,3a*
C. Quenching & Direct Cooling Operation	2 ^a _w	1,2a* 2w	2w	2 ^a _w	1a	2w 3a	2w 3a	1,2w 3a	1,2,3a*	2,3a* 2w	2,3a* 2,3w*	1a 2w	1,3a*	1,3a* 2w
D. Boiler Off Gas	2a	2,3a*	1a	2,3a*	1,2a*	1,2,3a*		3a	1,2,3a*	3a	2a		1a	
E. Storage & Blending Group II		1w					1 ^a _w	1w				3w		
F. Ash											3s		3s	

*Potentially hazardous chemicals in this chemical class were found in more than one status.

Table 4-3. POTENTIALLY HAZARDOUS CHEMICAL CLASSES IN THE CLASSIFIED STREAMS OF ADVANCED COAL PROCESS MODULES

	ACIDS AND 1 ANHYDRIDES	ALCOHOLS 2	AMINES 3	INORGANIC SALTS 4	CARBONYLS 5	COMBUSTION 6 GASES	HETEROCYCLICS 10	HYDROCARBONS 11	PHENOLS 18	POLYNUCLEAR 20	SULFUR COMPOUNDS 21	TRACE ELEMENTS 22	ORGANO METALLICS 23	PARTICULATES 24	CYANIDES 25
A. Coal Preparation	3w							3 ^a _w	3 ^a _w		3a			1,3a*	
B. Quenching Direct Cooling Operations			2 ^a _w				3a	2a	1,2w* 2w	3a	1,3a* 1,2w*	3 ^a _w			2,3w*
C. Sour Aqueous Condensate	2w	2w	2w		2w		2w	2w	2w		2w	3w			
D. Fixed-Bed Catalyst Regeneration						2a	3a	2a		3a	1a	2a	3a	2a	
E. Barometric Condenser Off Gas					3a		3a	3a	3a		3a				
F. Storage and Blending		2 ^a _w						2a	3a 2w	3a		3w			3w
G. Sulfur Plant	2w		2a			2a				3a	1a	3a		2a	
H. Reactor Off Gas			2a		1a	2a	3a	2a	3a	3a	1,3a*	3a			
I. Tar Separation	2w		2w	2w	2w		2w	2w	1,2w*		2w	2w	2w	3w	2w

*Potentially hazardous chemicals in this chemical class were found in more than one status.

Table 4-4. LIST OF POTENTIALLY HAZARDOUS CHEMICALS

Chemical Classification	Compounds	Phases		
		Petro- leum	Conven- tional Coal	Advanced Coal
(1) Acid and Anhydrides	Maleic Anhydride	w	w	w
	Benzoic Acid	w	a	
	Carboxylic Acids	w		
	Cresylic Acid	w	w	w
	Acetic Acids	w		
	Formic Acids	w		
	Sulfuric Acid	w/a	w	w
	Hydroxybenzoic Acid		a	
	Hydrochloric Acid		a	
	Nitric Acid		a	
	Anthraquinone Disulfonic Acid			w
(2) Alcohols	Aliphatic alcohols	w		w
	Aromatic alcohols	w		w
(3) Amines	Diethylamines	w/a/s		a
	Methylethylamines	w/a/s		a
	Aromatic Amines	s		
	Ammonia	w/a	w/a	w/a
	Aliphatic Amines	w	w	
	Aromatic Amines	w/a	w	
	$\alpha+\beta$ Naphthyl Amine		a	
	4-aminobiphenyl		a	
	Aniline		a	
	Methylaniline		a	
	Benzidine		a	
(4) Inorganic salts	Ammonium sulfate			w
	Chromium/ CrCl_3 , CrS		a	
	Chlorides	w		
	Sulfates	w		
	Chromates	w		
(5) Carbonyl Compounds	Ketones	w/a/s		w/a
	Aldehydes	w/a/s		w/a
	Formaldehyde	a	w/a	
	Acetaldehyde	a	w/a	
	Paraldehyde		a	
(6) Combustion Gases	Carbon Monoxide	a	a	a
	Sulfur Oxides	a	a	a
	Nitrogen Oxides	a	a	a

Table 4-4 (continued). LIST OF POTENTIALLY HAZARDOUS CHEMICALS

Chemical Classification	Compounds	Phases		
		Petro- leum	Conven- tional Coal	Advanced Coal
(10) Hetero- cyclics	Pyridines	w/a/s	w/a	w/a
	Pyrroles	w/a/s		w/a
	Quinolines	w/a/s	a	
	Indoles	a/s		
	Furans	w/a/s		
	Alkyl Pyridine		a	
	Phenyl Pyridine		a	
	(Mono) Benzofurans	w/a	a	a
	Alkyl Quinolines		a	
	Benzo(f)quinoline		a	
	Benzo(h)quinoline		a	
	Indeno(1,2,3-ij)isoquinoline		a	
	11 H-Indeno(1,2-b)quinoline		a	
(11) Hydrocar- bons	Benzene	w/a/s	w/a	w/a
	Toluene	w/a/s	w/a	w/a
	Xylene	w/a/s	w/a	w/a
	Aliphatics		a	a
	Olefins		a	a
	Alkylbenzene		a	
(13) Lactones		w		
(18) Phenols	Phenol	w/a/s	w/a	w/a
	Dimethyl Phenol	w		w
	Cresols	w/a/s	w/a	w/a
	Xylanols	w/a/s	a	w/a
	Thiophenols	a/s		
	Phenyl Phenols		a	a
	Alkyl Phenols		a	a
	Alkyl Cresols		a	a
(20) Polynu- clears	Carbazoles	w/a/s	a	
	Anthracenes	w/a/s	a	a
	Benzo(a)pyrene	w/a	a	a
	Pyrene	a/s	a	
	Benzo(e)pyrene	a	a	a
	Perylene	a/s	a	a
	Benzo(ghi)perylene	a		a
	Coronene	a	a	a
	Anthracene	a	a	
	Phenanthrene	a	a	a
	Fluoranthene	a		a
	Chrysene		a	a
	Dibenzo(a,h)anthracene		a	
	Dibenzo(a,g)fluorene		a	

Table 4- 4 (continued). LIST OF POTENTIALLY HAZARDOUS CHEMICALS

Chemical Classification	Compounds	Phases		
		Petro- leum	Conven- tional Coal	Advanced Coal
(20) Polynu- clears (Continued)	Methylchrysene		a	
	Benzo(a)anthracene		a	a
	Dimethylbenzoanthracene		a	
	Biphenyl		a	
	Naphthalene		a	
	Alkyl Naphthalene		a	
	Phenyl Naphthalene		a	
	Tetralin		a	
	Methyltetralin		a	
	Acenaphthylene		a	
	Acenaphthene		a	
	Fluorene		a	
	Alkyl Anthracenes		a	
	Alkyl Phenanthrene		a	
	Acridine		a	a
	Benzocarbazoles		a	
	Alkyl Acridines		a	
	Benzo(a)anthrone		a	a
	Dibenzo(a,l)pyrene			a
	Dibenzo(a,n)pyrene			a
	Dibenzo(a,i)pyrene			a
	Methyl Pyrene			a
	Indeno(1,2,3-c,d)Pyrene			a
	Benzoacridine			a
(21) Sulfur Compounds	Sulfides	w/a/s		w
	Sulfites	w/ /s		
	Sulfonates	w/a/s		w
	Sulfones	w/ /s		
	Mercaptans	w/a/s		a
	Thiophenes	w/a/s	w/a	w/a
	Hydrogen sulfides	w/a	a	w/a
	Methyl Mercaptans	w	a	w/a
	Carbon Disulfides	w/a	a	a
	Carbonyl Sulfide	w/a	a	a
	Thiosulfide	w		
	Dibenzo Thiophene	w/a		
	Alkyl Sulfide	w/a		
	Ethyl Mercaptans		a	
	Methyl Thiophene		a	a
(22) Trace Elements	Vanadium	w/a/s	a/s	w/a
	Nickel	w/a/s		a
	Zinc	w/a/s	s	
	Lead	w	a/s	a

Table 4-4 (continued). LIST OF POTENTIALLY HAZARDOUS CHEMICALS

Chemical Classification	Compounds	Phases		
		Petro- leum	Conven- tional Coal	Advanced Coal
(22) Trace Elements (Continued)	Cobalt	a		a
	Molybdenum	a		a
	Copper	a/s	s	
	Strontium	w/a		w
	Barium	w/a	w/a/s	
	Beryllium		a/s	a
	Selenium		a/s	w/a
	Arsenic		a/s	
	Cadmium		w/a/s	a
	Silver metals & soluble compounds		a	
	Mercury		a/s	a
	Antimony		a/s	a
	Arsenic (arsenic trioxide, sodium arsenate, sodium arsenite)		w	w
	Fluorine		a/s	
	Uranium		a/s	
	Thallium/Thallium Oxide		a/s	
	Phosphorous			w/a
	Manganese			a
(23) Organo - metallics	Metalloporphyrins	w /s		
	Nickel Carbonyl	a	a	a
	Cobalt Carbonyl	a		a
	Tetraethyl lead	w	w	
(24) Fine particu- lates	Sulfur Particulates	a		a
	Carbon Compounds	a		
	Catalyst Fines	a		a
	Coke	a	a	a
	Carboniferous Compounds	a		
	Respirable Coal Dusts		a/s	
	Tar		a	
	Soot		a	
(25) Cyanides	--	w/a		
	Hydrogen Cyanide		a	w
	Ammonium Cyanide		a	
	Naphthyl Cyanide		a	
	Ammonium Thiocyanate		a	w

SECTION V

APPENDIXES

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APPENDIX A
FACT SHEETS OF PETROLEUM PROCESS MODULES

Production

1. Gas Wells
2. Oil Wells
42. Gas/Oil Wells

- Wells generally produce a wide variety of hydrocarbon compounds ranging from methane through very heavy oils.
- Crude and natural gas is often produced under high pressures and temperatures.
- Remoteness of wells results in poor housekeeping and maintenance.
- Acidic crudes and brines are corrosive.
- Fugitive emissions and spills, attributable to poor housekeeping, high pressures and corrosive environment, contain small quantities of the hazardous components found in crude and gas.
- Effluent waste streams are limited to fugitive emissions and spills.
- H_2S found in many natural gases and crudes is very toxic.

Field Separations

3a. Gas-Condensate Separation

3b. Gas-Oil Separation

3c. Crude Separation

- Primary function is to physically separate the gas, crude oil, and aqueous brine phases.
- Emulsion breaking operations are included if necessary.
- Intermediate temperatures are encountered if thermal emulsion breaking is employed.
- High pressures are involved if the well pressures are high.
- Primary effluent waste stream is oily brine which has been in contact with crude and possibly will leach out some toxic compounds.
- Remoteness of some field separation units lead to poor house-keeping and maintenance which result in fugitive emissions and leaks.
- Acidic crudes and brines are corrosive, and contribute to leaks and fugitive emissions.

Raw Products Storage Facilities

4. Condensate storage and loading
5. Crude storage (field)
11. Gasoline storage and loading (field)
12. Crude storage (refinery)

- Field storage facilities are used to store raw petroleum products prior to shipment.
- Most raw products are shipped by pipeline.
- Field storage facilities often include loading facilities for transporting low volume products by rail or truck.
- Major emission streams are aqueous wastes decanted from storage tanks, and volatile products evaporating from vented tanks and loading facilities.
- Hazardous compounds present in the product may leach into the decanted aqueous wastes.
- Volatile hazardous compounds are suspected present in vented vapors.

Acid Gas Removal

6. Acid Gas Removal (field units)

15. Acid Gas Removal (refinery units)

- Employed for the removal of acid gas species from gaseous hydrocarbon streams.
- Commonly absorbs the acid gas species in an amine solution.
- Operating pressures and temperatures are low.
- The corrosive environment is conducive to leaks and spills.
- Effluent acid gas stream contains hazardous compounds including H_2S , COS, CS_2 , CH_3SH , CO, and HCN.
- Regeneration of spent amine solution is expected to release amines, acid gas species and any other hazardous compounds existing in gaseous hydrocarbon streams.

Sulfur Recovery Units

7. Sulfur Recovery (field)

16. Sulfur Recovery (refinery)

- Purpose is conversion of acid gases to salable elemental sulfur.
- Commonly employ the Claus process which involves high reaction temperatures in a relatively corrosive environment.
- The major effluent stream is the tailgas which may contain unreacted sulfur compounds and other hazardous compounds which enter with the acid gases.
- The corrosive environment is conducive to leaks and spills, and consequently fugitive emissions.

8. Dehydration

- Employed for the dehydration of gaseous hydrocarbon streams.
- Most common processes involve glycol absorption, silica gel adsorption, or molecular sieve adsorption of the water vapor.
- Pressures are low and temperatures are moderate.
- Primary effluent stream is the recovered water which may contain glycols and traces of sulfur compounds not removed by the acid gas removal system.

Light Ends Separation

9. Gas Separation

17. Gas Processing

- Separates desulfurized light hydrocarbon streams into their primary compounds (predominantly C_1 , C_2 , C_3 , C_4 , and C_5^+).
- Separation processes include compression, refrigeration, absorption, adsorption, or a combination of these.
- Temperatures are low and pressures are intermediate.
- Hazardous compounds are rarely present in these units in significant quantities.
- Generally considered one of the cleaner petroleum processes.

10. LPG Storage and Loading

- LPG is stored and loaded under moderate and high pressures.
- Temperatures involved are low.
- Although the elevated pressures are conducive to fugitive emissions, hazardous compounds are generally not found in LPG streams.

13. Desalting

- For the removal of inorganic salts and brines from incoming crude. These salts lead to fouling, corrosion, and catalyst poisoning.
- Crude is heated to lower its viscosity and contacted with process water to absorb impurities from the crude.
- Electrostatic charges are commonly employed to deemulsify the organic and aqueous phases.
- Chemical deemulsifying is a little used alternative.
- Primary effluent stream is a gritty brine containing small quantities of hazardous compounds in the crude, especially trace metal salts.
- Housekeeping is fair and fugitive emissions are not expected to be a problem.

Crude Separation

14. Atmospheric Distillation

18. Vacuum Distillation

- Atmospheric and vacuum distillation are used to separate the components of crude into various boiling point fractions.
- Stripping steam and vacuums are used to depress the boiling points of heavier fractions.
- High temperatures are involved in the process.
- Sour condensates are the primary effluent stream and due to their intimate contact with the crude, contain small quantities of the hazardous compounds found in crude oil.
- High temperatures, corrosive environments, poor maintenance, and the presence of hazardous compounds combine to make these units prime sources of potentially hazardous fugitive emissions.

19. Hydrogen Production

- Commonly employ steam reforming of a clean hydrocarbon feedstock.
- Hydrocarbons and steam are reduced to CO_2 and H_2 .
- Processing temperatures and pressures are both high.
- No direct effluent waste streams.
- Fugitive emissions can be high because of high operating temperatures and pressures; however, the presence of hazardous compounds is dependent on the hydrocarbon source selected.

20. Catalytic Polymerization

- Feed is light olefins.
- Produces a gasoline blending stock.
- High temperature.
- High pressure.
- Being phased out as feedstocks are in demand for petrochemical production.
- Main emissions from heaters and regeneration of fixed bed catalyst.

21. Alkylation

- Feed is light isoparaffins and olefins.
- Produces high octane, branched paraffin gasoline blending stock.
- Low temperature.
- Intermediate pressure.
- Catalysts are highly concentrated sulfuric and hydrofluoric acids.
- Main emissions are from the process heater.

22. Isomerization

- Rearranges straight chain paraffins to branched chain for octane improvement.
- Catalyzed by platinum-aluminum oxide catalyst.
- High temperature.
- High pressure.
- Main emissions from heaters and catalyst regenerations.

24. Catalytic Reforming

- Produces a high octane aromatic blending stock.
- High temperature.
- Intermediate-to-high pressure.
- High interest in recent years caused by no-lead gasoline requirements.
- Main emissions result from process heaters and regeneration of fixed bed catalyst.

26. Chemical Sweetening

- Converts mercaptans to sulfides in liquid petroleum streams.
- Low temperature.
- Low pressure.
- In limited use with advent of chemical inhibitors for product sweetening.
- Main emissions from the regeneration of the fixed bed catalyst.

Hydrodesulfurization

- 23. Naphtha HDS
- 27. Kerosene HDS
- 28. Gas Oil HDS
- 33. Lube Oil HDS
- 35. Residual Oil HDS

- Removes sulfur and nitrogen from liquid feeds.
- Produces H_2S and NH_3 which are steam stripped and sent to Acid Gas Removal.
- High temperature.
- High pressure.
- Emission streams:
 - (1) Aqueous condensate
 - (2) Catalyst regeneration flue gas
 - (3) Process heater flue gas.

Catalytic Cracking

29. Fluid Bed

30. Moving Bed

- Converts heavy distillates into lighter components.
- High temperature.
- Low pressure.
- Emission streams:
 - (1) Aqueous condensate
 - (2) Regenerator flue gas
 - (3) Process heater flue gas.
- Benzo(a)pyrene measured on catalyst emitted from regenerator.

31. Hydrocracking

- Converts heavy gas oils into desulfurized gasolines and light hydrocarbon fractions.
- High temperatures.
- High pressures.
- Produces H_2S and NH_3 which are steam stripped and sent to Acid Gas Removal.
- Emission Streams:
 - (1) Aqueous condensate
 - (2) Catalyst regeneration flue gas
 - (3) Process heater flue gas.
- Generally not among the processes being included in new refineries.

34. Deasphalting

- Separates asphalts from vacuum resid by extraction with propane or light hydrocarbon solvent.
- High temperature.
- Low pressure.
- Emissions result from an aqueous condensate stream and process heater flue gases.

36. Visbreaking

- Produces a maximum amount of fuel oil (minimizes gasoline) from topped crude.
- Thermalcracking.
- High temperature.
- Low pressure.
- Emission Sources:
 - (1) Process Heater Flue Gas
 - (2) Aqueous Condensate
 - (3) Barometric Off Gas
 - (4) Decoking.
- Sulfur compounds (H_2S , CO_2) are emitted during decoking operations.
- Not being considered in current refinery design plans.

37. Coking

- Converts residual oil to coke and to wide range of gaseous and liquid fuel products.
- High temperature.
- Low pressure.
- Emission sources:
 - (1) Aqueous Condensate
 - (2) Process Heater
 - (3) Coking Off Gas.
- Fine coke particles emitted in the off gas will contain trace elements and possibly some polynuclear components.

39. Lube Oil Processing

- Converts desulfurized lube oils into marketable lube stocks.
- Medium temperatures.
- Low pressure.
- Main Emission Streams:
 - (1) Aqueous Condensate
 - (2) Process Heater Flue Gas
 - (3) Catalyst Regeneration Gases
 - (4) Spent Acid Sludge.

40. Asphalt Air Blowing

- Polymerizes raw asphalts to a more viscous product asphalt.
- High temperature.
- Low pressure.
- Emissions are found in the process heater flue gases and the off gases from air blowing.
- Polynuclear and heterocyclic compounds have been found in the off gas from this unit.

APPENDIX B

FACT SHEETS OF CONVENTIONAL AND ADVANCED COAL PROCESS MODULES

1. Coal Extraction

- Two major types of coal extraction:
 - (1) Underground mining
 - (2) Surface mining.
- In underground mining, the mining machines (giant saws and mechanical "moles") are used. In surface mining, giant mechanical shovels are used to remove the overburden and to dig up the coal.
- Major hazardous emission is the respirable coal dust. The modern mechanized mining methods have increased the emission.

Coal Preparation

2. Crushing and Grinding

3. Gravity Separation

4. Froth Flotation

5. Thermal Drying

19. Slurry Preparation

- The purposes of the gravity separation and froth flotation are to remove partially the ash and some pyritic sulfur of coal.
- Grind coal to various sizes according to its application. Ball mills are commonly employed to prepare coal for the utility furnaces.
- Two major emission sources:
 - (1) Respirable coal dust in handling and transporting coal
 - (2) Tailings from the physical separation of coal.

6. Slot Type Coke Oven

- The slot type coke oven consists essentially of three main parts: coking chamber, heating chamber, and the regenerative chamber.
- The coal is charged through openings in the top of the oven. The coke is pushed out from one end by a power-driven ram or pusher, acting through the other end.
- The coking time depends on the depth of coal and usually ranges from 16 to 20 hours.
- The coking temperature is from 1700 to 2700 F.
- In the coking period, the volatile materials of coal are released. Some known carcinogens have been identified in this gas stream.
- The potentially hazardous materials are emitted during the charging, coking, and pushing operations.

7. Volatile Collection and Cooling

- The volatile products are carried through the ducts in each oven top and are collected in the main.
- A liquid spray is installed in the main to cool the gas.
- This flushing liquid which contains the condensate from the volatile products is collected for further chemical recovery processes.
- The gas stream passes through an electrostatic precipitator to further remove the tar from raw coke-oven gases before it enters the ammonia recovery unit.
- The gas stream contains many potentially hazardous materials and fugitive emission is high.

Tar Treatment

8. Tar Liquor Decantation

35. Tar Separation

- The primary objective is to separate the condensed tar from the liquor.
- The tar settles in the flush-liquor decanter tank because of its high density.
- The overflow is recycled back to the volatile collection and cooling unit.
- Operating temperature and pressure are low.

9. Ammonia Recovery

- Three different methods are currently used to recover ammonia from the coke-oven gases as ammonium sulfate:
 - (1) Direct process -- the tar-free coke-oven gases are passed through a saturator containing a solution of sulfuric acid
 - (2) Indirect process -- ammonia is scrubbed off the coke-oven gases by water and is recovered from water by distillation and alkaline treatment. Then, the ammonia is passed through a sulfuric acid saturator
 - (3) Semi-direct process -- ammonia is removed from the flush liquor by distillation and alkaline treatment and then is passed through the sulfuric acid saturator.
- The operating temperature is medium.

10. Pyridine Recovery

- The primary function is to recover the pyridine bases from the coke-oven gases. These bases include pyridine, picolines (methyl pyridines), lutidines (dimethyl pyridines), etc.
- There are two types of recovery processes:
 - (1) Continuous -- the saturator liquor from the ammonia recovery unit is passed to a neutralizing still where the pyridine bases, ammonia, carbon dioxide and water, are given out as overhead gases. These gases are condensed and the pyridine bases are separated from this ammonium carbonate solution as a top liquid layer
 - (2) Batch-type -- the pyridine bases are recovered by distillation of the saturator liquor and are purified by a series of cooling and fractionation operations.
- Operation temperature is medium.

11. Phenol Recovery

- Phenol is recovered from the liquor in the ammonia recovery unit.
- Two methods are available to recover phenol from the ammonium liquor:
 - (1) Vapor-Recirculation Process -- Phenol is steam-stripped off the liquor which contains phenol, ammonia and other soluble carbonization products. The phenol is extracted from the water-phenol mixture by caustic soda to form sodium phenolate.
 - (2) Solvent Extraction Process -- The phenol is extracted out from the liquor by benzene or light oil in which phenol is more soluble than water. The extraction is a counter-current flow process. The phenol is then removed from the solvent by reacting with caustic soda to form sodium phenolate.
- Operating temperature is medium and the pressure is low.
- The degree of corrosiveness depends on the concentration of sodium hydroxide.

12. Coke Quenching

- The purpose of coke quenching is to stop the further combustion.
- There are two methods of quenching:
 - (1) Wet Quenching -- the coke is loaded in the quenching cars which are carried to the quenching station by an electric locomotive, where the coke is quenched with water
 - (2) Dry Quenching -- the coke is put in a closed system in which air is circulated to pick up the sensible heat from the coke. The hot air is used to generate low pressure steam.
- Overall operating temperature is medium to high.
- High fugitive emission of volatile matters from coke is expected.

13. Light Oil Recovery

- To recover the light hydrocarbons from the coke-oven gases.
- Three major constituents to be recovered are benzene, toluene and xylene.
- Three methods are available for light oil recovery:
 - (1) A series of refrigeration (-70 C) and compression (10 atm)
 - (2) Adsorption by activated carbon which is regenerated by direct or indirect heating of steam
 - (3) Absorption by a liquor solvent which is recovered by steam distillation.
- Temperature ranges from low to medium and pressure from low to high.
- No corrosive environment exists in this section. Oil spill and housekeeping will be major factor in fugitive emission.

Storage

14. Storage (Coking)

28. Storage (Liquefaction)

43. Storage (Gasification)

- A large variety of hydrocarbons are stored as end-products or intermediate products.
- The coal tar is usually piled up on the open ground. Hazardous volatile materials are involved in this storage area of coal tar.
- Temperatures involved are low.
- The hydrocarbons are stored under moderate and high pressure.

20. Reactor (SRC Process)

- Dissolve the coal in a solvent with hydrogen.
- Temperature and pressure involved are high (825 F and 1000 psi).
- No continuous emission from the pressurized vessel. Fugitive emission from the high pressure pump and valves is expected.
- Reactor accident such as rupture of safety head will emit the potentially hazardous materials.

21. Reactor Separator

- Separate the gases from the reaction products.
- Separation is done by flashing the reaction products.
- Temperature is high and pressure is moderate.

Gas Treatment

22. Condenser

24. Water Oil Separator

- Cool the gases from the flash tank and separate the oil from the condensate.
- Temperature and pressure involved ranges from low to moderate.

Gasifier (Lurgi Process)

33. Oxygen Blown Gasification

42. Air Blown Gasification

- Combustion of coal to produce methane.
- Methane is produced from coal in the gasifier through a 3-stage process, namely, devolatilization and drying, gasification, and partial combustion.
- Temperature and pressure are high (1400 F and 400 psig).
- Most of the potentially hazardous materials are produced in the gasifiers, but there is no direct continuous atmospheric emission of these materials from the gasifier.
- Coal ash is the only direct waste discharge from the gasifiers to the atmosphere.

34. Quenching and Cooling

- Cool the product gases and separate the coal tar and other condensates from the product gases.
- A scrubbing and cooling tower is used to remove the tar from the gas stream.
- Temperature is high and pressure is low.
- Potentially hazardous materials present in the system and housekeeping is a key factor to reduce the fugitive emission of these materials.

High-BTU Gas Production

36. Shift Conversion

39. Methanation

- Produce hydrogen in the shift converter from the reaction of carbon monoxide and water.
- Produce more methane in the methanator from the catalytic reaction of carbon monoxide and hydrogen.
- Temperature in shift converter is very high (700 to 1000 F). Temperature and pressure in methanator are high (800 F and 225 psi).
- Nickel carbonyl, a carcinogen, is emitted from the methanator in which nickel is used as a catalyst.
- Fugitive emission from leaks of pump seals and valves is likely in these systems.

Gas Cleaning

38. Acid Gas Removal (Rectisol Wash)

40. Further Gas Purification (Reactisol Wash)

- Remove acid gases such as hydrogen sulfide, carbonyl sulfur and carbon dioxide down to a level of about 0.1 ppmv.
- The acid gases are washed out by methanol at low temperature. Methanol is recovered in a flash tank and a methanol-water separator. The acid gases are regenerated in a multi-stage operation.
- Temperature and pressure are low (-50 F and 1 psi).

Sulfur Removal

31. Sulfur Recovery (Claus Process)

41. Sulfur Recovery (Stretford Process)

- Claus process removes sulfur from gas stream in a catalytic reaction of sulfur dioxide and hydrogen sulfide.
- Stretford process removes hydrogen sulfide from the gas stream by a counter-current liquid-gas absorption column.
- The end product is the salable elemental sulfur.
- Both processes involve corrosive and hazardous materials.
- Major effluent stream of the Claus process is the tail gas which contains sulfur compounds and may also contain other hazardous compounds.
- There are two major effluent streams for the Stretford process:
 - (1) Tail gas which contains unreacted sulfur
 - (2) Purge stream from the absorption column.

37. Phenol Recovery (Phenosolvan Process)

- Recover phenol from the water-effluent stream.
- Phenol is extracted by isopropyl ether which is regenerated in a distillation column.
- Temperature involved is moderate.
- Only major effluent stream is the slightly phenolic water to bio-water treatment.

APPENDIX C

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15. SUPPLEMENTARY NOTES

16. ABSTRACT The report lists potentially hazardous materials which may be associated with the air, water, and solid waste from a refinery, a coke plant, a Lurgi high-Btu gas process, and the solvent refined coal process. Fugitive loss was identified as the major emissions source in the refinery, although its composition is difficult to quantify. Coking is the most offensive of the four processes assessed. Coal gasification may produce materials as dangerous as those from the coke plant, but the former will probably be more contained than coke oven emissions. The environmental impact of coal liquefaction is not well defined; however, liquefaction products will probably be more hazardous than crude oil products, and their refining and utilization will be worse offenders than corresponding petroleum operations. The study indicates that available documents are not adequate to develop an accurate list of potentially hazardous emissions from these four processes. A detailed assessment of the processes, field sampling, and analysis are needed to identify the potentially hazardous emissions more accurately.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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