

## XII. APPENDIX IV

### DESCRIPTION OF EQUIPMENT USED IN COAL LIQUEFACTION

The items below are listed in the order they normally appear in a coal liquefaction plant when following the process from receiving coal to storing the end product.

<u>Item</u>	<u>Description</u>
Storage bins	Usually cylindric steel storage bins with a storage capacity of >1,000 tons (907 kg); closed facilities reduce weathering effects and combustion hazards, and require less land area for storage.
Surge hopper	Stores coal intermittently in the process. Coal is sent to process equipment, ie, preheater or gasifier, through a surge hopper.
Lift pipe	Part of coal preparation/pretreatment sector of the processing plant; conveys pulverized coal from lower to higher elevations. Usually, the conveying medium is inert gas.
Pulverizer	Term used for size-reduction equipment. Depending on the desired size of prepared coal, a ball mill or roller mill can be used to pulverize coal.
Screw conveyor, bucket conveyor	Convey coal from one piece of equipment to another. Bucket conveyors usually carry coal to elevated equipment.
Screens	Used in coal preparation section of the plant to size coal; may be stationary or moving. Oversized coal is returned to a pulverizer for further size reduction. Desired size of coal is sent to the processing unit.

<u>Item</u>	<u>Description</u>
Slurry mix tank	Part of coal preparation section of the plant. Generally, coal and oil are mixed in this piece of equipment to form a slurry.
Slurry pumps	Part of coal slurry feed system; generally reciprocating or centrifugal pumps.
Fired preheater	Preheats the coal-oil slurry before it goes to a dissolver or coal liquefaction reactor.
Pyrolysis reactor	Heats coal in the absence of oxygen.
Dissolver	Dissolves or liquefies coal in a solvent in processes such as solvent-refined coal and Exxon donor-solvent (solvent-extraction processes).
Catalytic hydrogenation reactor	Used for direct liquefaction of coal; may be fixed bed (Synthoil) or ebullated bed (H-coal).
Hydrocarbonization reactor	Heats coal in the presence of hydrogen.
Filtration unit	Used for solid-liquid separation. Generally separates ash and unreacted or undissolved coal from dissolver or liquefaction reactor.
Gas Purification System Equipment:	
Cyclone separator	Separates char ash and other solid particulates from gaseous stream.
Quench towers and venturi scrubbers	Used to remove particulates and droplets (oil, tar, liquor, etc) from the product gas.
Quench water separator	Usually separates oil, tar, and char particulates from gases.
Absorber	Absorbs acid gas (H <sub>2</sub> S, CO <sub>2</sub> , etc) from product gas.

<u>Item</u>	<u>Description</u>
Desorber or stripper	Desorbs gases from absorbent and cleans gas.
Solvent (coal) recovery unit	Recovers solvent from coal solution or coal liquids; recycles it back to prepare slurry from process-derived solvent.
Hydroclone	Device used extensively for classification and/or removal of fluid from slurries; generally used to separate ash and unreacted coal from coal solutions or coal liquids.
Centrifuge	Developed for solid-liquid separation, particularly when solids are very small (<200 mesh).
Fractionator or distillation column	Distills liquid product to separate the various components.
Hydrotreater	Pressure vessel in which the quality of liquid hydrocarbon streams is improved by subjecting them to mild or severe conditions of hydrogen pressure in the presence of a catalyst.
Atmospheric tanks	Any tank that is designed to be used within a few psi of atmospheric pressure. Syncrudes produced by coal liquefaction processes may be stored in American Petroleum Institute (API) standard 12A tanks.

XIII. APPENDIX V

EXPOSURE LIMITS OF SOME CONTAMINANTS THAT MAY BE PRESENT IN COAL LIQUEFACTION PROCESSES

Compound	OSHA Standard <sup>a,b</sup>		NIOSH-Recommended Exposure Limit <sup>b</sup>		Area Affected and/or Health Effects	Reference <sup>d</sup>
	ppm <sup>c</sup>	mg/m <sup>3c</sup>	ppm <sup>c</sup>	mg/m <sup>3c</sup>		
Acetic acid	10	25				
Acetone	1,000	2,400				
Alkanes			(varies)	350	Skin and nervous system	157
Ammonia	50	35	(50)	(34.8)	Airway irritation	60
Aniline--skin	5	19				
Antimony		0.5				
Arsenic		0.5		(0.002)	Dermatitis; lung and lymphatic cancer	158
Arsine		0.2				
Barium		0.5				
Benzene	10 (50)		(1)	(3.2)	Blood changes, including leukemia	132
Beryllium		0.002		0.002 (0.025)	Lung cancer	159
Boron oxide		15				
1,3-Butadiene	1,000	2,200				
Cadmium dust		0.2 (0.6)		0.04 (0.2)	Lungs and kidneys	160
Cadmium fume		0.1 (0.3)				

APPENDIX V (CONTINUED)

Compound	OSHA Standard <sup>a, b</sup>		NIOSH-Recommended Exposure Limit <sup>b</sup>		Area Affected and/or Health Effects	Reference <sup>d</sup>
	ppm <sup>c</sup>	mg/m <sup>3c</sup>	ppm <sup>c</sup>	mg/m <sup>3c</sup>		
Carbon dioxide	5,000	9,000	10,000 (30,000)	18,000 (54,000)	Respiratory system	161
Carbon disulfide	20 (100)		1 (10)	3 (30)	Heart; nervous and reproductive systems	128
Carbon monoxide	50	55	35 (200)	40 (229)	Heart	58
Chromium Soluble salts		0.5		0.001	Lung cancer; skin ulcers; lung irritation	162
Chromium Insoluble salts		1		0.025 (0.05)		162
Coal tar pitch volatiles		0.15		0.1	Lung and skin cancer	17
Cobalt		0.1				
Copper fumes		0.1				
Dusts and mists		1				
Creosote				0.1	Lung and skin cancer	17
Cresol--skin	5	22	2.3	10	Skin, liver, kidneys, and pancreas	127
Cyanides (HCN)--skin		5	(4.7)	(5)	Thyroid, blood, and respiratory system	66
Ethyl mercaptan						
Free silica				0.050	Chronic lung disease (silicosis)	129

APPENDIX V (CONTINUED)

Compound	OSHA Standard <sup>a,b</sup>		NIOSH-Recommended Exposure Limit <sup>b</sup>		Area Affected and/or Health Effects	Reference <sup>d</sup>
	ppm <sup>c</sup>	mg/m <sup>3c</sup>	ppm <sup>c</sup>	mg/m <sup>3c</sup>		
Hydrogen chloride	(5)	(7)				
Hydrogen fluoride	3		6 (12)	2.5 (50)	Skin, eyes, airway irritation; bone	163
Hydrogen sulfide	ceiling limit only		(10)	(15)	Eye irritation; severe acute effects on nervous and respiratory systems	65
Hydroquinone		2		(2)	Eyes and skin	164
Iron oxide (fume)		10				
Lead fumes and dusts		0.05		0.10	Kidneys, blood, and nervous system	133
Manganese		(5)				
Mercury Alkyl Nonalkyl				0.05	CNS and behavior	165
Methyl ethyl ketone	200	590				
Methyl mercaptan						
Naphtha (coal tar)	100	400				
Naphthalene	10	50				
β-Naphthylamine	(See 29 CFR 1910.1009)					
Nickel		1		0.015	Skin; lung and nasal cancer	166

APPENDIX V (CONTINUED)

Compound	OSHA Standard <sup>a,b</sup>		NIOSH-Recommended Exposure Limit <sup>b</sup>		Area Affected and/or Health Effects	Reference <sup>d</sup>
	ppm <sup>c</sup>	mg/m <sup>3c</sup>	ppm <sup>c</sup>	mg/m <sup>3c</sup>		
Nickel carbonyl	0.001	0.007	0.001	0.007	Lung and nasal cancer	167
Nitric oxide	25	30	25	30	Blood	168
Nitrogen dioxide	5	9	(1)	(1.8)	Airway irritation	168
Ozone	0.1	0.2				
Phenol--skin	5	19	5.2 (15.6)	20 (60)	Skin, eyes, CNS, liver, and kidneys	61
Propane	1,000	1,800				
Pyridine	5	15				
Refined petroleum solvent	500	2,950		350	Eye, skin, nose, and throat irritation; nervous system	130
Resorcinol						
Selenium		0.2				
Sulfur dioxide	5	13	2	5	Respiratory system	131
Thallium		0.1				
Tin-- Organic compounds		0.1				
Inorganic compounds (except oxides)		2				
Toluene--skin	200 (500)		100 (200)	375 (750)	CNS depressant	169

APPENDIX V (CONTINUED)

Compound	OSHA Standard <sup>a, b</sup>		NIOSH-Recommended Exposure Limit <sup>b</sup>		Area Affected and/or Health Effects	Reference <sup>d</sup>
	ppm <sup>c</sup>	mg/m <sup>3c</sup>	ppm <sup>c</sup>	mg/m <sup>3c</sup>		
Vanadium					Eyes, skin, and lungs	170
V <sub>2</sub> O <sub>5</sub> , dust		(0.5)		0.05		
V <sub>2</sub> O <sub>5</sub> , fume		(0.1)		0.05		
Xylene	100	435	100 (200)	434 (868)	CNS depressant; airway irritation	171
Zinc oxide fume		5		5 (15)	Metal fume fever	1/2

NOTE: Parentheses indicate a ceiling value.

<sup>a</sup> See 29 CFR 1910.1000

<sup>b</sup> For some of these substances, ceiling limits have been established that vary with duration of exposure, and these can be found in the original reference.

<sup>c</sup> 8-hour time-weighted average

<sup>d</sup> Only for NIOSH exposure limits and health effects data



XIV. APPENDIX VI

CHEMICAL SUBSTANCES POTENTIALLY ASSOCIATED WITH COAL LIQUEFACTION PROCESSES

Category	Where Found	Ref
<b>Aliphatic Hydrocarbons</b>		
n-Butane, isopentane, n-pentane, n-paraffins, i-paraffins, monocycloparaffins, dicycloparaffins, tricycloparaffins, unsaturated mono-, di-, and tricycloparaffins, olefins, diolefins	Liquid products from H-coal conversion processes	12
Various hydrocarbons	Vents and exhausts of coal pretreatment equipment; some wastewater streams of coal liquefaction operation	31
Ethylene, propylene	Major products of the clean coke process	11
Cyclohexane, methylcyclohexane, dimethylcyclohexane, dihydroxylene, hexahydromesitylene	Major constituents of neutral oil from liquid-phase hydrogenation of coal	173
<b>Alcohols</b>		
Methyl alcohol, ethyl alcohol	Identified from the carbonization of coal	173
<b>Epoxides</b>		
Diphenylene oxide	Gasworks tar	174
2-Hydroxybiphenylene oxide	Identified from the carbonization of coal	173
<b>Aldehydes</b>		
Acetaldehyde, paraldehyde	"	173

APPENDIX VI (CONTINUED)

Category	Where Found	Ref
<b>Ketones</b>		
Acetone, methyl ethyl ketone	Identified from the carbonization of coal	173
Methyl heptyl ketone	"	
Acetophenone	"	
Methyl tolyl ketone	"	
<b>Carboxylic Acids and Derivatives</b>		
Ethyl propionate, formic acid, acetic acid, propionic acid	"	173
n-Valeric acid, oxalic acid	"	
<b>Nitriles</b>		
Cyanogen	"	173
Acetonitrile	"	
Benzonitrile	"	
1- and 2-Naphthonitrile	"	
<b>Amines</b>		
Aminobenzenes, naphthylamines, aminobiphenyls	Coal tars	12
Toluidines	Low-temperature tar from coal carbonization	174
Aniline	Product of the clean coke process; product of a coal liquefaction plant	11
Diethylamine, triethylamine	Identified from the carbonization of coal	173
Aniline	"	
o- and p-Toluidine	"	
2,3-Xylidine	"	

APPENDIX VI (CONTINUED)

Category	Where Found	Ref
<b>Mercaptans, Sulfides, and Disulfides</b>		
Methylmercaptan, ethylmercaptan, dimethylsulfide, diethylsulfide	Identified from the carbonization of coal	173
Tolylmercaptan	"	
Diphenylene sulfide	"	
<b>Benzene and Substituted Benzene Hydrocarbons</b>		
C <sub>6</sub> -C <sub>12</sub> alkyl benzenes	Liquid products from H-coal conversion processes	12
Biphenyls	"	175
Biphenyl, triphenylbenzene	Coal liquefaction products	10
Benzene	Significant commercial product of a coal liquefaction plant	11
Benzene, toluene, xylene, polyalkylbenzenes	Significant constituents of neutral oil liquid-phase hydrogenation of coal	173
Ethylbenzene, styrene, cumene, ethylbenzene, propylbenzene, o-, m-, and p-ethyltoluene, mesitylene, hemimellitene, cymene, 3,4-dimethylethylbenzene	"	
<b>Phenols</b>		
Phenols (components only defined by 108, 122, 136, and 150 mol wt)	Liquid products from H-coal conversion process	12
Phenols (undefined components)	Liquid products from Synthoil conversion processes	175
Phenols (undefined components)	Some wastewater streams of coal liquefaction operation	31
Phenol, cresols, xylenols, pyrocatechin	Low temperature (below 450-500°C) tar from coal carbonization	174

APPENDIX VI (CONTINUED)

Category	Where Found	Ref
<b>Phenols (continued)</b>		
$\alpha$ - and $\beta$ -Naphthol	Gasworks tar	174
Phenol, o-cresol, m- and p-cresols, xylenols	Products of the clean-coke process	11
Phenol, cresols, mixed xylenols	Products of a coal liquefaction plant	11
m-, p-, and o-Ethylphenols, 2,3-, 3,5-, 2,4-, 2,5-, and 2,6-xylenols	Identified from the carbonization of coal	173
Isohomocatechol	"	173
Paraphenylphenol	"	173
Tertramethylbiphenol	"	173
Resorcinol	"	173
Phenol, cresols, xylenols, undefined phenols	Heavy oil from Synthoil process	12
<b>Fused Aromatic Hydrocarbons and Derivatives</b>		
Naphthalenes, phenanthrenes, chrysenes, 1,2-benzanthracenes, 3,4-benzophenanthrenes, pyrenes, 5-ring compounds	Liquid products from H-coal conversion products	12
Anthracenes, phenanthrenes, phenylnaphthalenes, 4- and 5-ring aromatics (both peri- and cata-condensed), peri-condensed 6-ring compounds	Liquid products from Synthoil conversion products	175
Naphthalene, 2-methylnaphthalene, 7-methylnaphthalene, azulene, 2,6-dimethylnaphthalene, 1,3-dimethylnaphthalene, 1,5- and/or 2,3-dimethylnaphthalene, acenaphthalene, acenaphthene, phenanthrene and/or 1,3,6-trimethylnaphthalene, 2-methylphenanthrene, 1-methylphenanthrene, 2-phenylnaphthalene, 9-methylanthracene, 1,2-dihdropyrene, fluoranthene, pyrene, 1,2-benzofluorene, 4-methylpyrene, 1-methylpyrene, 1,2-benzanthracene, chrysene and/or triphenylene	Coal liquefaction products	10

APPENDIX VI (CONTINUED)

Category	Where Found	Ref
Fused Aromatic Hydrocarbons and Derivatives (continued)		
Chrysene, 2-methylchrysene, 3-methylchrysene, 5-methylchrysene, 6-methylchrysene	Coal liquefaction products	176
1,2- and 4,5-Benzopyrene, crackene, benzerythrene, perylene, picene, triphenylene	Identified from the carbonization of coal	173
Fused Nonalternant Polycyclic Hydrocarbons		
Indans, indenenes, acenaphthylenes, ( $C_n H_{2n-14}$ and $C_n H_{2n-16}$ )	Liquid products from H-coal conversion processes	12
Indans, indenenes, acenaphthylenes	Liquid products from Synthoil conversion processes	175
Octahydroanthracene, 9,10-dihydrophenanthrene, fluorene, 9-methylfluorene	Coal liquefaction products	10
Naphthalene	Significant product of a coal liquefaction plant	11
Heterocyclic Nitrogen Compounds		
Carbazole, phenyl p-naphthylcarbazole, acridine, a-dimethylquinoline	Gasworks tar	174
Pyridine, a-picoline	Products of the clean-coke process	11
Pyridine, pyrrole	Products of a coal liquefaction plant	11
Quinoline	Identified from the carbonization of coal	173
Acridine, carbazole, 2- and 3-methylcarbazole	"	
Heterocyclic Oxygen Compounds		
$\beta$ -Naphthofuran	Gasworks tar	174
3-, 4-, and 5-Methylcoumarone	Identified from the carbonization of coal	173
1,9-Benzoxanthene	"	

APPENDIX VI (CONTINUED)

Category	Where Found	Ref
<b>Heterocyclic Sulfur Compounds</b>		
Benzothiophene, methylbenzothiophene, dimethylbenzothiophene, methylthiophene	Light oil product of coal hydrogenation	175
Benzylthiophene, tetrahydrobenzothiophene, dibenzothiophene, methyl dibenzothiophene, benzo(d,e,f)dibenzothiophene, naphthobenzothiophene, methyl naphthobenzothiophene, dinaphthothiophene	Heavy oil product of coal hydrogenation	175
Diphenylene sulfide	Gasworks tar	174
Dimethylthiophene	Identified from the carbonization of coal	173
Thionaphthene	"	173
Dibenzothionaphthene	"	173
<b>Organometallics</b>		
Metal porphyrins	Coal	177
Iron, nickel, and cobalt carbonyls	Gas phase after conversion	177
Iron, nickel, chromium, vanadium, tantalum, molybdenum, and tungsten metallocenes	Potentially in coal liquids	177
Arene carbonyls	"	177
Metal chelates	Potentially in aqueous process streams	177
<b>Inorganic Elements</b>		
Aluminum, antimony, arsenic, barium, beryllium, boron, bromine, cadmium, calcium, cesium, chlorine, chromium, cobalt, copper, europium, fluorine, gallium, germanium, hafnium, iodine, iron, lanthanum, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, phosphorus,	Coal	12

APPENDIX VI (CONTINUED)

Category	Where Found	Ref
<b>Inorganic Elements (continued)</b>		
potassium, rubidium, scandium, selenium, silicon, sodium, strontium, sulfur, tantalum, thorium, tin, titanium, uranium, vanadium, yttrium, zinc, zirconium, cerium, dysprosium, gold, indium, lutetium, samarium, silver, tellurium, terbium, thallium, tungsten, ytterbium		
<b>Inorganic Oxides</b>		
SiO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> , Fe <sub>2</sub> O <sub>3</sub> , TiO <sub>2</sub> , P <sub>2</sub> O <sub>5</sub> , CaO, MgO, Na <sub>2</sub> O, K <sub>2</sub> O, SO <sub>3</sub>	Ash, Illinois No. 6 Coal	12
TiO <sub>2</sub>	Spent catalyst of H-coal liquefaction plant	178
<b>Inorganic Chemicals (General)</b>		
Ammonia, hydrogen sulfide	Gas phase of coal hydrogenation reactions	12
Carbon monoxide, nitrogen oxides	Vents and exhausts of coal pre- treatment equipment and from gas leaks during coal liquefaction	12
Sulfur dioxide, other sulfur oxides, ammonia, hydrogen sulfide	Separation operations, auxiliary processes, purification and upgrading operations	12
Ammonia, thiocyanates, sulfides, chlorides	Some wastewater streams of coal liquefaction operation	12
Boron, sulfur, molybdenum, and cobalt compounds	Spent catalyst of H-coal liquefaction plant	178
Hydrogen sulfide	Concentrated in gas stream from acid gas removal operation of H-coal liquefaction plant	178

APPENDIX VI (CONTINUED)

Category	Where Found	Ref
Inorganic Chemicals (General) (continued)		
Sulfur, ammonia	Marketable byproducts of the clean coke process	11
Hydrogen chloride, ammonium cyanate, carbon disulfide, ammonium sulfide	Identified from the carbonization of coal	173



## XV. APPENDIX VII

### SYSTEM SAFETY REFERENCES

Several sources concerning system safety are currently available. Useful references concerning fault-tree analysis and system safety analysis were recommended by NIOSH in Appendix IV of the coal gasification criteria document [16]. Other useful references are listed below.

- (1) Johnson WG: The Management Oversight and Risk Tree-MORT--Including Systems Developed by the Idaho Operations Office and Aerojet Nuclear Company (SAN 821-2). US Government Printing Office, 1974 (GPO-052-010-00-329-1)
- (2) Knox NW, Eicher RW: MORT User's Manual--For Use with the Management Oversight and Risk Tree Analytical Logic Diagram/ERDA-76-45-4/SSDC-4. Idaho Falls, Aerojet Nuclear Company, 1976 (Submitted to ERDA under Contract No. E(10-11)-1375)
- (3) Nertney RJ, Bullock MG: Human Factors in Design/ERDA-76-45/SSDC-2. Idaho Falls, Aerojet Nuclear Company, 1976 (Submitted to ERDA under Contract No. E(10-11)-1375)
- (4) Nertney RJ, Clark JH, Eicher RW: Occupancy-Use Readiness Manual--Safety Considerations/ERDA-76-45-1/SSDC-1. Idaho Falls, Aerojet Nuclear Company, 2nd printing, 1976 (Submitted to ERDA under Contract No. E(10-11)-1375)
- (5) Rodgers P: Introduction to System Safety Engineering. New York, John Wiley and Sons, Inc, 1971