

11.11 Coal Conversion

In addition to its direct use for combustion, coal can be converted to organic gases and liquids, thus allowing the continued use of conventional oil- and gas-fired processes when oil and gas supplies are not available. Currently, there is little commercial coal conversion in the United States. Consequently, it is very difficult to determine which of the many conversion processes will be commercialized in the future. The following sections provide general process descriptions and general emission discussions for high-, medium- and low-Btu gasification (gasification) processes and for catalytic and solvent extraction liquefaction processes.

11.11.1 Process Description¹⁻²

11.11.1.1 Gasification -

One means of converting coal to an alternate form of energy is gasification. In this process, coal is combined with oxygen and steam to produce a combustible gas, waste gases, char, and ash. The more than 70 coal gasification systems available or being developed in 1979 can be classified by the heating value of the gas produced and by the type of gasification reactor used. High-Btu gasification systems produce a gas with a heating value greater than 900 Btu/scf (33,000 J/m³). Medium-Btu gasifiers produce a gas having a heating value between 250 - 500 Btu/scf (9,000 - 19,000 J/m³). Low-Btu gasifiers produce a gas having a heating value of less than 250 Btu/scf (9,000 J/m³).

The majority of the gasification systems consist of 4 operations: coal pretreatment, coal gasification, raw gas cleaning, and gas beneficiation. Each of these operations consists of several steps. Figure 11.11-1 is a flow diagram for an example coal gasification facility.

Generally, any coal can be gasified if properly pretreated. High-moisture coals may require drying. Some caking coals may require partial oxidation to simplify gasifier operation. Other pretreatment operations include crushing, sizing, and briquetting of fines for feed to fixed bed gasifiers. The coal feed is pulverized for fluid or entrained bed gasifiers.

After pretreatment, the coal enters the gasification reactor where it reacts with oxygen and steam to produce a combustible gas. Air is used as the oxygen source for making low-Btu gas, and pure oxygen is used for making medium- and high-Btu gas (inert nitrogen in the air dilutes the heating value of the product). Gasification reactors are classified by type of reaction bed (fixed, entrained, or fluidized), the operating pressure (pressurized or atmospheric), the method of ash removal (as molten slag or dry ash), and the number of stages in the gasifier (1 or 2). Within each class, gasifiers have similar emissions.

The raw gas from the gasifier contains varying concentrations of carbon monoxide (CO), carbon dioxide (CO₂), hydrogen, methane, other organics, hydrogen sulfide (H₂S), miscellaneous acid gases, nitrogen (if air was used as the oxygen source), particulates, and water. Four gas purification processes may be required to prepare the gas for combustion or further beneficiation: particulate removal, tar and oil removal, gas quenching and cooling, and acid gas removal. The primary function of the particulate removal process is the removal of coal dust, ash, and tar aerosols in the raw product gas. During tar and oil removal and gas quenching and cooling, tars and oils are condensed, and other impurities such as ammonia are scrubbed from raw product gas using either aqueous or organic scrubbing liquors. Acid gases such as H₂S, COS, CS₂, mercaptans, and CO₂ can

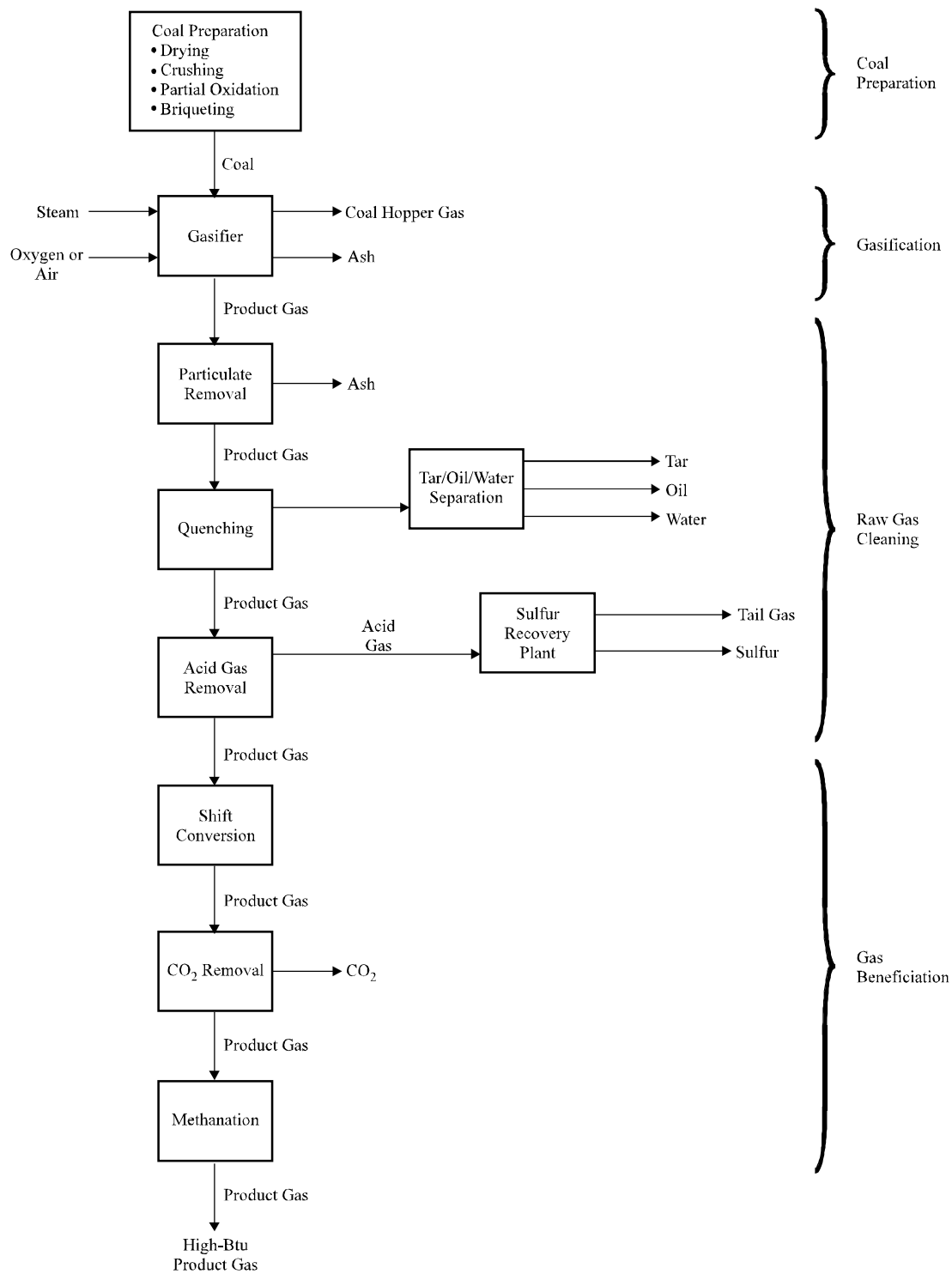


Figure 11.11-1. Flow diagram of typical coal gasification plant.

be removed from gas by an acid gas removal process. Acid gas removal processes generally absorb the acid gases in a solvent, from which they are subsequently stripped, forming a nearly pure acid gas waste stream with some hydrocarbon carryover. At this point, the raw gas is classified as either a low-Btu or medium-Btu gas.

To produce high-Btu gas, the heating value of the medium-Btu gas is raised by shift conversion and methanation. In the shift conversion process, H_2O and a portion of the CO are catalytically reacted to form CO_2 and H_2 . After passing through an absorber for CO_2 removal, the remaining CO and H_2 in the product gas are reacted in a methanation reactor to yield CH_4 and H_2O .

There are also many auxiliary processes accompanying a coal gasification facility, which provide various support functions. Among the typical auxiliary processes are oxygen plant, power and steam plant, sulfur recovery unit, water treatment plant, and cooling towers.

11.11.1.2 Liquefaction -

Liquefaction is a conversion process designed to produce synthetic organic liquids from coal. This conversion is achieved by reducing the level of impurities and increasing the hydrogen-to-carbon ratio of coal to the point that it becomes fluid. There were over 20 coal liquefaction processes in various stages of development by both industry and Federal agencies in 1979. These processes can be grouped into 4 basic liquefaction techniques:

- Indirect liquefaction
- Pyrolysis
- Solvent extraction
- Catalytic liquefaction

Indirect liquefaction involves the gasification of coal followed by the catalytic conversion of the product gas to a liquid. Pyrolysis liquefaction involves heating coal to very high temperatures, thereby cracking the coal into liquid and gaseous products. Solvent extraction uses a solvent generated within the process to dissolve the coal and to transfer externally produced hydrogen to the coal molecules. Catalytic liquefaction resembles solvent extraction, except that hydrogen is added to the coal with the aid of a catalyst.

Figure 11.11-2 presents the flow diagram of a typical solvent extraction or catalytic liquefaction plant. These coal liquefaction processes consist of 4 basic operations: coal pretreatment, dissolution and liquefaction, product separation and purification, and residue gasification.

Coal pretreatment generally consists of coal pulverizing and drying. The dissolution of coal is best effected if the coal is dry and finely ground. The heater used to dry coal is typically coal fired, but it may also combust low-BTU-value product streams or may use waste heat from other sources.

The dissolution and liquefaction operations are conducted in a series of pressure vessels. In these processes, the coal is mixed with hydrogen and recycled solvent, heated to high temperatures, dissolved, and hydrogenated. The order in which these operations occur varies among the liquefaction processes and, in the case of catalytic liquefaction, involves contact with a catalyst. Pressures in these processes range up to 2000 psig (14,000 Pa), and temperatures range up to 900°F (480°C). During the dissolution and liquefaction process, the coal is hydrogenated to liquids and some gases, and the oxygen and sulfur in the coal are hydrogenated to H_2O and H_2S .

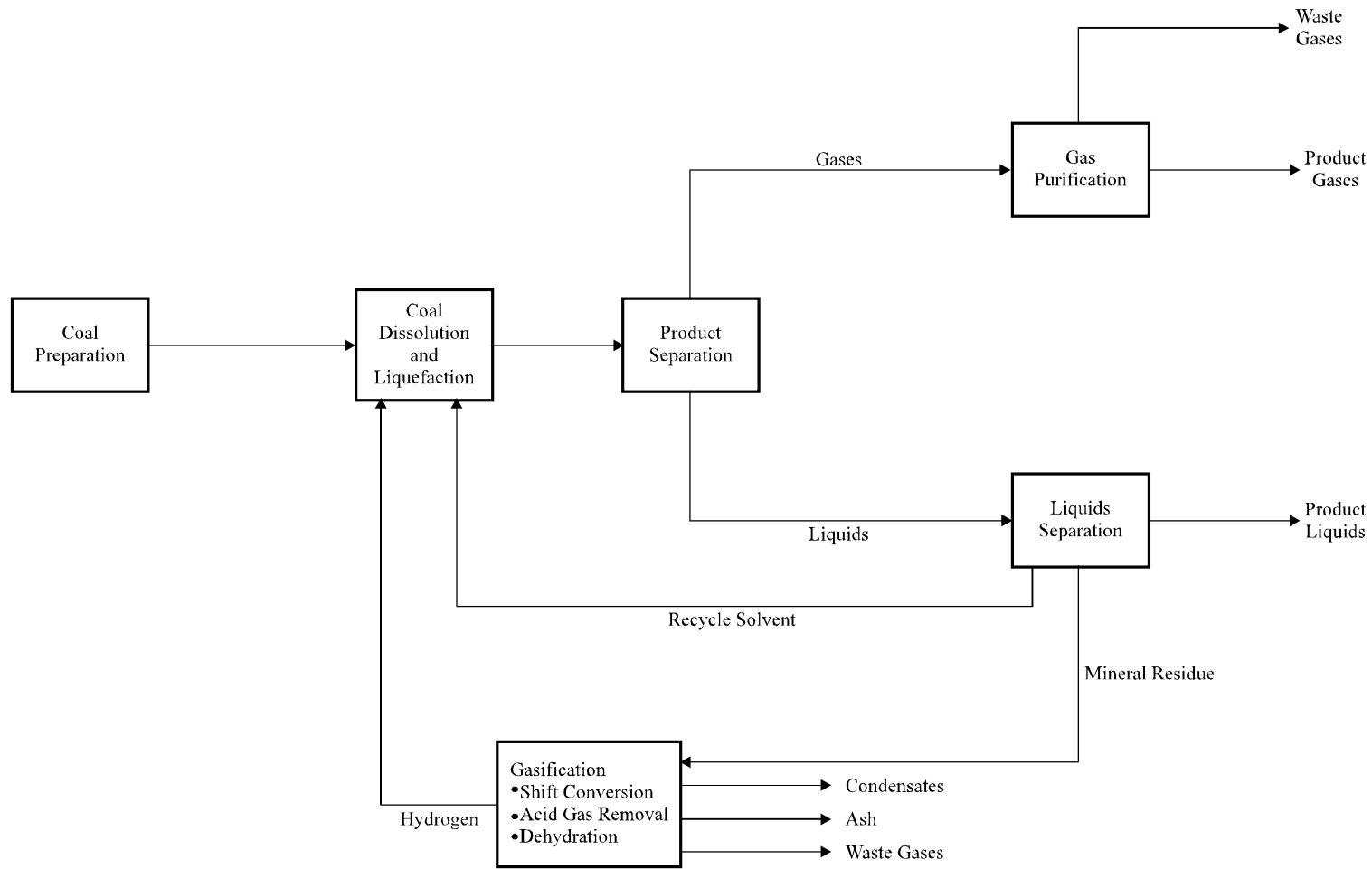


Figure 11.11-2. Flow diagram for an example coal liquefaction facility.

After hydrogenation, the liquefaction products are separated through a series of flash separators, condensers, and distillation units into a gaseous stream, various product liquids, recycle solvent, and mineral residue. The gases from the separation process are separated further by absorption into a product gas stream and a waste acid gas stream. The recycle solvent is returned to the dissolution/liquefaction process, and the mineral residue of char, undissolved coal, and ash is used in a conventional gasification plant to produce hydrogen.

The residue gasification plant closely resembles a conventional high-Btu coal gasification plant. The residue is gasified in the presence of oxygen and steam to produce CO, H₂, H₂O, other waste gases, and particulates. After treatment for removal of the waste gases and particulates, the CO and H₂O go into a shift reactor to produce CO₂ and additional H₂. The H₂-enriched product gas from the residue gasifier is used subsequently in the hydrogenation of the coal.

There are also many auxiliary processes accompanying a coal liquefaction facility that provide various support functions. Among the typical auxiliary processes are oxygen plant, power and steam plant, sulfur recovery unit, water treatment plant, cooling towers, and sour water strippers.

11.11.2 Emissions And Controls¹⁻³

Although characterization data are available for some of the many developing coal conversion processes, describing these data in detail would require a more extensive discussion than possible here. So, this section will cover emissions and controls for coal conversion processes on a qualitative level only.

11.11.2.1 Gasification -

All of the major operations associated with low-, medium- and high-Btu gasification technology (coal pretreatment, gasification, raw gas cleaning, and gas beneficiation) can produce potentially hazardous air emissions. Auxiliary operations, such as sulfur recovery and combustion of fuel for electricity and steam generation, could account for a major portion of the emissions from a gasification plant. Discharges to the air from both major and auxiliary operations are summarized and discussed in Table 11.11-1.

Dust emissions from coal storage, handling, and crushing/sizing can be controlled with available techniques. Controlling air emissions from coal drying, briquetting, and partial oxidation processes is more difficult because of the volatile organics and possible trace metals liberated as the coal is heated.

The coal gasification process itself appears to be the most serious potential source of air emissions. The feeding of coal and the withdrawal of ash release emissions of coal or ash dust and organic and inorganic gases that are potentially toxic and carcinogenic. Because of their reduced production of tars and condensable organics, slagging gasifiers pose less severe emission problems at the coal inlet and ash outlet.

Gasifiers and associated equipment also will be sources of potentially hazardous fugitive leaks. These leaks may be more severe from pressurized gasifiers and/or gasifiers operating at high temperatures.

Raw gas cleaning and gas beneficiation operations appear to be smaller sources of potential air emissions. Fugitive emissions have not been characterized but are potentially large. Emissions from the acid gas removal process depend on the kind of removal process employed at a plant. Processes used for acid gas removal may remove both sulfur compounds and CO₂ or may be operated

Table 11.11-1. SUMMARY OF EMISSIONS FROM COAL GASIFICATION PLANTS¹⁻³

Operation/Emission Source/Stream	Characterization Of Emission	Summary Of Emission Control Choices
Coal Pretreatment		
Storage, handling, and crushing/sizing - Dust emissions	Emissions from coal storage, handling, and crushing/sizing mainly consist of coal dust. These emissions vary from site to site depending on wind velocities, coal and pile size, and water content.	Water sprays and polymer coatings are used to control dust emissions from coal storage piles. Water sprays and enclosed equipment are vented to a baghouse to reduce or capture particulates from coal handling. Emissions from crushing/sizing are also usually vented to a baghouse or other particulate control device.
Drying, partial oxidation, and briquetting - Vent gases	These emissions comprise coal dust and combustion gases along with a variety of organic compounds devolatilized from the coal. Organic species have not been determined.	In addition to particulate control devices, afterburners may be needed to destroy organic species.
Coal gasification		
Feeding - Vent gases	These gases contain all the hazardous species found in the raw product gas exiting the gasifier including H ₂ S, COS, CS ₂ , SO ₂ , CO, NH ₃ , CH ₄ , HCN, tars and oils, particulates, and trace organics and inorganics. The size and composition of this stream depend on the type of gasifier, e. g., fluidized bed gasifiers emit substantially fewer tars and oils than fixed bed gasifiers.	This stream could represent a significant environmental problem. Control could include scrubbing or incineration (to capture or destroy the most hazardous species), or venting to the raw product gas or gasifier inlet air. The desired control depends on the type and size of gasification facility. Screw fed conveyors can be used instead of lock hoppers.
Ash removal - Vent gases	Emissions from ash removal and disposal depend on the type of gasifier. Ash dust will be released from all gasifiers that are not slagging or agglomerating ash units. If contaminated water is used for ash quenching, volatile organic and inorganic species may be released from the quench liquor.	These emissions have not been sufficiently characterized to recommend necessary controls. Particulate or organic emission controls could be needed. Clean water may be used for quenching to avoid the potential emission of hazardous volatile organic and inorganic species.
Startup - Vent gases	This vent gas initially resembles a coal combustion gas in composition. As the operating temperature of the gas increases, the startup gas begins to resemble the raw product gas.	A flare can incinerate the combustible constituents in the startup gas, but heavy tars and coal particulates will affect the performance of the flare. Potential problems with tars and particulates can be avoided by using charcoal or coke as the startup fuel.

Table 11.11-1 (cont.).

Operation/Emission Source/Stream	Characterization Of Emission	Summary Of Emission Control Choices
Fugitives	These emissions have not been characterized, but they comprise hazardous species found in the raw product gas such as H ₂ S, COS, CS ₂ , CO, HCN, CH ₄ , and others.	Control methods mainly involve good maintenance and operating practices.
Raw Gas Cleaning/Benefication		
Fugitives	These emissions have not been characterized, but they comprise hazardous species found in the various gas streams. Other emissions result from leaks from pump seals, valves, flanges, and byproduct storage tanks.	Control methods mainly involve good maintenance and operating practices.
Acid Gas Removal - Tail gases	The composition of this stream highly depends on the kind of acid gas removal employed. Processes featuring the direct removal and conversion of sulfur species in a single step (e. g., the Stretford process) produce tail gases containing small amounts of HN ₃ and other species. Processes absorbing and consequently desorbing a concentrated acid gas stream require a sulfur recovery process to avoid the emission of highly toxic gases having quantities of H ₂ S.	Some tail gas streams (from the Stretford process, for example) are probably not very hazardous. These streams have not been characterized, nor have control technology needs been demonstrated. Tail gases from other processes always require the removal of sulfur species. Trace constituents such as organics, trace elements and cyanides affect the performance of the auxiliary sulfur removal processes.
Auxiliary Operations		
Sulfur recovery	See Section 8.13	
Power and steam generation	See Section 1.1	
Waste Water Treatment - Expansion gases	These streams comprise volatile organic and inorganic species that desorb from quenching/cooling liquor. The streams potentially include all the hazardous species found in the product gas.	Three streams could pose significant environmental problems. Potential controls are generally similar to those needed to treat coal feeding vent gases.
Cooling Towers - Exhaust gas	Emissions from cooling towers are usually minor. However, if contaminated water is used as cooling water makeup, volatile organic and inorganic species from the contaminated water could be released.	The potential emission of hazardous volatile organic and inorganic species may be avoided by using clean water for cooling.

selectively to remove only the sulfur compounds. Typically, the acid gases are stripped from the solvent and processed in a sulfur plant. Some processes, however, directly convert the absorbed hydrogen sulfide to elemental sulfur. Emissions from these direct conversion processes (e. g., the Stretford process) have not been characterized but are probably minor, consisting of CO₂, air, moisture, and small amounts of NH₃.

Emission controls for 2 auxiliary processes (power and steam generation and sulfur recovery) are discussed elsewhere in this document (Sections 1.1 and 8.13, respectively). Gases stripped or desorbed from process waste waters are potentially hazardous, since they contain many of the components found in the product gas. These include sulfur and nitrogen species, organics, and other species that are toxic and potentially carcinogenic. Possible controls for these gases include incineration, byproduct recovery, or venting to the raw product gas or inlet air. Cooling towers are usually minor emission sources, unless the cooling water is contaminated.

11.11.2.2 Liquefaction -

The potential exists for generation of significant levels of atmospheric pollutants from every major operation in a coal liquefaction facility. These pollutants include coal dust, combustion products, fugitive organics, and fugitive gases. The fugitive organics and gases could include carcinogenic polynuclear organics, and toxic gases such as metal carbonyls, hydrogen sulfides, ammonia, sulfurous gases, and cyanides. Many studies are currently underway to characterize these emissions and to establish effective control methods. Table 11.11-2 presents information now available on liquefaction emissions.

Emissions from coal preparation include coal dust from the many handling operations and combustion products from the drying operation. The most significant pollutant from these operations is the coal dust from crushing, screening, and drying activities. Wetting down the surface of the coal, enclosing the operations, and venting effluents to a scrubber or fabric filter are effective means of particulate control.

A major source of emissions from the coal dissolution and liquefaction operation is the atmospheric vent on the slurry mix tank. The slurry mix tank is used for mixing feed coal and recycle solvent. Gases dissolved in the recycle solvent stream under pressure will flash from the solvent as it enters the unpressurized slurry mix tank. These gases can contain hazardous volatile organics and acid gases. Control techniques proposed for this source include scrubbing, incineration, or venting to the combustion air supply for either a power plant or a process heater.

Emissions from process heaters fired with waste process gas or waste liquids will consist of standard combustion products. Industrial combustion emission sources and available controls are discussed in Section 1.1.

The major emission source in the product separation and purification operations is the sulfur recovery plant tail gas. This can contain significant levels of acid or sulfurous gases. Emission factors and control techniques for sulfur recovery tail gases are discussed in Section 8.13.

Emissions from the residue gasifier used to supply hydrogen to the system are very similar to those for coal gasifiers previously discussed in this section.

Emissions from auxiliary processes include combustion products from onsite steam/electric power plant and volatile emissions from the waste water system, cooling towers, and fugitive emission sources. Volatile emissions from cooling towers, waste water systems, and fugitive

Table 11.11-2. SUMMARY OF EMISSIONS FROM A COAL GASIFICATION PLANTS¹

Operation/Emission Source/Stream	Characterization Of Emission	Summary Of Emission Control Choices
Coal Preparation		
Storage, handling and crushing/sizing	Emissions primarily consist of fugitive coal dust generated at transfer points and points exposed to wind erosion. A potentially significant source.	Water sprays and polymer coatings are used to control dust from storage sites. Water sprays and enclosures vented to baghouses are effective on crushing and sizing operations.
Drying	Emissions include coal dust, combustion products from heater, and organics volatilized from the coal. A potentially significant particulate source.	Scrubbers, electrostatic precipitators, and baghouses are effective coal dust controls. Low drying temperatures reduce organics formation.
Coal Dissolution and Liquefaction		
Process heater (fired with low-grade fuel gas)	Emissions consist of combustion products (particulates, CO, SO ₂ , NO _x , and HC).	Fuel desulfurization for SO ₂ control and combustion modifications for reduced CO, HC, and NO _x
Slurry mix tank	Evolution of dissolved gases from recycle solvent (HC, acid gases, organics) due to low pressure (atmospheric) of tank. Some pollutants are toxic even in small quantities.	Controls might include scrubbing, incineration, or venting to heater combustion air supply.
Product Separation and Liquefaction - Sulfur recovery plant	Tail gases containing acids (H ₂ S, SO ₂ , COS, CS ₂ , NH ₃ , and particulate sulfur).	Venting to tail gas treatment plant, or operating sulfur recovery plant at higher efficiency.
Residue Gasification	See 11.11.2.1 in text	
Auxiliary Processes		
Power and steam generation	See Section 1.1	
Waste water system	Volatile organics, acid gases, ammonia, and cyanides, that evolve from various waste water collection and treating systems.	Enclosure of the waste water system and venting gases from system to scrubbers or incinerators.
Cooling towers	Any chemical in the facility can leak to cooling water systems from leaking heat exchangers and can be stripped to the atmosphere in the cooling tower.	Good heat exchanger maintenance and surveillance of cooling water quality.
Fugitives	All organic and gaseous compounds in plant can leak from valves, flanges, seals, and sample ports. This may be the largest source of hazardous organics.	Good housekeeping, frequent maintenance, and selection of durable components are major control techniques.

emission sources possibly can include every chemical compound present in the plant. These sources will be the most significant and most difficult to control in a coal liquefaction facility. Compounds that can be present include hazardous organics, metal carbonyls, trace elements such as mercury, and toxic gases such as CO₂, H₂S, HCN, NH₃, COS, and CS₂.

Emission controls for waste water systems involve minimizing the contamination of water with hazardous compounds, enclosing the waste water systems, and venting the waste water systems to a scrubbing or incinerating system. Cooling tower controls focus on good heat exchanger maintenance, to prevent chemical leaks into the system, and on surveillance of cooling water quality. Fugitive emissions from various valves, seals, flanges, and sampling ports are individually small but collectively very significant. Diligent housekeeping and frequent maintenance, combined with a monitoring program, are the best controls for fugitive sources. The selection of durable low leakage components, such as double mechanical seals, is also effective.

References for Section 11.11

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