1.0 GASIFICATION
(Gasifiers, Gas Cooling, Rectisol, Gas Liquor Separation, Phenosolvan, Ammonia Recovery, POX)

1.1 PROCESS DESCRIPTIONS

1.1.1 Unit 10 - Lurgi Gasification

This Unit consists of 12 parallel Lurgi gasifiers, 9 operating and 3 spare, to gasify sized coal (2-1/2" x 1/4"). A flow sheet illustrating general configuration is included in Section 1.2. Material balances are given in Section 1.3.

The Lurgi gasifier is a moving bed reactor in which coal moves downward under gravity countercurrent to the upward flowing gasification agent, a mixture of superheated steam and 98.5 percent pure oxygen. The coal bed is supported by a revolving grate through which superheated steam and oxygen are added and ash is removed. The gasifier is operated at a pressure of about 450 psia. The gasifier is jacketed with about 10 percent of the feed steam for the gasification agent being generated in the jacket.

Coal feeding is done on a batch mode of operation. The sized coal required in the Lurgi gasifiers is transported by conveyor belts from the coal preparation building to the coal bunkers located on top of the gasifiers. Coal from the coal bunker is charged into the gasifier via a lock hopper arrangement. Coal is fed to the lock hopper by first depressurizing the hopper and then filling the unit with coal. The gas released during depressurization is utilized in the plant as a fuel gas. Any residual gas left in coal lock after depressurization is removed by eductors and vented to the atmosphere. Depressurization of the coal lock is followed by the opening of the coal feed valve at the top of the lock hopper. After filling the lock hopper with coal, the top valve is closed, and the lock hopper is pressurized with raw gas to a pressure equal to that inside the gasifier. Next, the bottom valve on the coal lock hopper is opened and the coal is introduced into the gasifier. When the coal lock hopper is empty, the refilling procedure is repeated.

The coal passes slowly through the gasifier, continuously changing chemical composition as it goes through four distinct zones. From top to bottom, these zones are: coal preheat and devolatilization, gasification, combustion, and ash zones. Coal is fed in the top section of the reactor countercurrent to the upward flowing gas stream which dries and devolatizes the coal in the top zone. Devolatilization of coal is followed by gasification of the resulting char at

1.1.1 Unit 10 - Lurgi Gasification (Continued)

temperatures ranging from 1150°F to 1600°F. Chemical reactions that occur in the gasifier are described below:

1) The gasification of the carbon takes place by the reaction:

$$C + H_2O \text{ (steam)} + \text{Heat} \longrightarrow CO + H_2$$

2) Hydrogen is produced by the "water gas reaction";

$$CO + H_2O \longrightarrow CO_2 + H_2 + \text{Heat}$$

3) Some carbon also reacts with carbon dioxide to form carbon monoxide:

$$C + CO_2 + \text{Heat} \longrightarrow 2\ CO$$

4) Methane is produced by the hydrogasification reaction:

$$C + 2H_2 \longrightarrow CH_4 + \text{Heat}$$

5) The net heat input for the above reactions is supplied by the combustion of carbon with oxygen in the combustion zone.

$$C + O_2 \longrightarrow CO_2 + \text{Heat}$$

Oxygen and steam enter as a mixture near the bottom of the gasifier and the mixture passes upward through the ash zone to the combustion zone. The steam to oxygen ratio, dictated by the coal composition, determines the temperature in the combustion zone. The temperature must be maintained below the ash melting point but high enough to ensure the gasification of the coal.

The raw gas leaving the gasifier will be at a temperature of about 1000°F and a pressure of about 450 psia. The raw gas is quenched by direct contact in a wash cooler where it is rapidly cooled. The quenched gas if further cooled in waste heat boilers by heat exchange with boiler feed water thus recovering waste heat as steam. The gas is then fed to the Gas Cooling Unit for further cooling and heat recovery. As the raw gas is cooled, water, tars and oils, and entrained coal fines condense and are routed to the Gas Liquor Separation Unit for further processing.

Ash removal is accomplished on a batch mode of operation through a lock hopper arrangement similar to the coal feed operation. The ash is removed by a rotating grate and discharged via a semi-automatically operating ash lock which is pressurized with superheated steam. The operation

1.1.1 Unit 10 - Lurgi Gasification (Continued)

closely parallels the operation of a coal lock. The ash leaving the ash lock drops into a sluiceway to be carried to the ash dewatering plant. Any steam produced by the quenching of the hot ash is routed through a wet cyclone separator for particulate and condensate removal and any non-condensables are vented to the atmosphere.

1.1.2 Unit 11 - Gas Cooling

The raw gas leaving the gasification unit is further cooled in the Gas Cooling Unit. The Gas Cooling Unit consists of two parallel trains. The gas is first cooled in a tempered water system to about 305°F and then in air coolers to about 130°F. Final cooling to about 95°F is accomplished by water cooling. The cooled gas is then fed to the Rectisol Gas Purification Unit.

Tarry gas liquor and oily gas liquor are separated from the gas stream during the cooling process. The gas liquor streams are sent to the Gas Liquor Separation Unit for further processing.

1.1.3 Unit 12 - Rectisol

The raw gas leaving the Gas Cooling Unit is fed to the Rectisol Unit to remove sulfur compounds and CO_2 from the gas stream. The Rectisol Unit which consists of two parallel trains, utilizes cold methanol to purify the gas.

First, the gas in the unit is washed with medium-cold methanol to remove gas naphtha components, i.e., pentanes, hexanes, benzene, toluene, and heavier aromatics. The prewash methanol stream is then flashed to release dissolved gases and naphtha. This recovered naphtha is mixed with the tar and oil recovered in the Gas Liquor Separation Unit for gasification in POX (partial oxidation) gasifiers. The flashed gases are routed to the Sulfur Recovery Unit.

The prewashed gas exiting the prewash column is routed to the main wash column where the bulk of the H_2S and CO_2 are removed by washing with very cold methanol. After the main wash column, the gas is finally washed in the fine wash column where the H_2S content of the gas is reduced to less than 0.1 ppmV.

1.1.3 Unit 12 - Rectisol (Continued)

Loaded methanol from the main and fine wash systems is regenerated by flashing in several stages. Part of the flashed methanol is hot regenerated by steam stripping the H_2S and sulfur compounds for use in the fine wash section. Flashed gas from the first stage is recycled for recovery of CO, H_2, and CH^4. Gas from subsequent flashes and hot regenerator off gas, containing H_2S and CO_2 are sent to the Sulfur Recovery Unit for H_2S removal. Gas condensate from the Rectisol Unit is routed to the Gas Liquor Separation Unit.

1.1.4 Unit 13 - Gas Liquor Separation

The Gas Liquor Separation Unit which consists of one train, processes the various gas liquor streams produced in the cool down of the raw gas. These gas liquor streams contain dissolved gases such as crude gas components, ammonia, and hydrocyanic acid, as well as tar, oil, phenols, chlorine, fluorine, fatty acids, and some amounts of coal and ash dust.

The gaseous components are separated by flashing to atmospheric pressure. The liquids (aqueous and non-aqueous) and solid components are separated by gravity separation.

The Gas Liquor fed to this unit is cooled and depressurized using control valves and a specially designed expansion drum. The released gases are routed to the Sulfur Recovery Unit for H_2S removal.

Gas liquor then flows into the primary separators where the heavy component tar is separated. Present in this tar is a small amount of coal dust carried over in the gasifier. Tar containing the bulk of this dust settles to the bottom of the conical separator, and there it is pumped back into the top of the gasifier.

Gas liquor and oil with some tar flows from the top of the primary separator into the secondary separator. Oil is drawn from the top of the secondary separator, water from the middle, and a small quantity of tar is drawn periodically from the bottom.

The gas liquor flowing out of the secondary separators flows into tertiary separators for the separation of light oils and tars still present. The aqueous phase then goes into the Phenosolvan Unit for additional processing. The oils and tars separated are sent to POX Unit for gasifying to synthesis gas.

1.1.5 Unit 16 - Phenosolvan

The Phenosolvan Unit, consisting of one train processes the gas liquor from the Gas Liquor Separation Unit to recover phenols. A storage tank to accommodate gas liquor production for 14 days is installed at the inlet of this unit. The liquor storage is provided so maintenance work on the unit can be performed without shutting down the entire facility. The unit, licensed by Lurgi, consists of three main parts: filtration, extraction, and solvent recovery.

Gas liquor from the Gas Liquor Separation Unit will be filtered to remove any suspended particles. The liquor then enters a five stage counter-current extractor, where phenols are extracted from the liquor by counter-current contact with isopropyl ether solvent. The extract containing the solvent and phenols is distilled to separate the solvent. The distilled solvent is recycled to the extractors. The solvent contained in the phenol after distillation is recovered by steam stripping and recycled to a distillation column. The crude phenols are mixed with tar, oil, and naphtha recovered from the Lurgi Gasification Process for charging into the POX gasifiers to produce synthesis gas. The dephenolized gas liquor is next stripped with N_2 in a stripping column to remove the residual isopropyl ether solvent dissolved in the liquor. The N_2/ isopropyl ether is washed with phenol to recover the solvent for recycle. After N_2 stripping, the dephenolized gas liquor is fed to the Ammonia Recovery Unit for recovering ammonia.

1.1.6 Unit 17 - Ammonia Recovery

The dephenolized gas liquor is fed to the Cyam process to recover ammonia. This process is licensed by U.S. Steel Corporation. Licensing agreements have not been made with them. The USS Cyam process recovers both free and fixed ammonia from waste water. The gas liquor stream is fed into a free ammonia still where the free ammonia and acid gases are recovered by live steam injection. The liquid leaving the bottoms of the free ammonia still are fed to a lime mixing vessel where a lime slurry is added to free the fixed ammonia. The mixture from the lime slurry vessel is fed to a fixed ammonia still to recover the remaining ammonia using steam stripping. The ammonia vapors leaving the top of the fixed ammonia still are combined with the vapor leaving the free ammonia still and fed to a Phosam-W absorber for recovering ammonia.

1.1.6 Unit 17 - Ammonia Recovery (Continued)

The fixed ammonia still bottoms are cooled and fed to a clarifier. The lime sludge from the clarifier is fed to a sludge filtration system to dewater the sludge, which is then sent to the landfill site for disposal. The water removed from the clarifier and sludge filtration system is then sent to waste water treatment.

The combined ammonia vapors from the free ammonia still and fixed ammonia still enter at the bottom of the Phosam-W absorber, where an ammonium phosphate solution removes the ammonia. The vapors leaving the top of the ammonia absorber contain less than 100 ppmv of NH_3. This stream is sent to the Sulfur Recovery Unit (Unit 18). The ammonia is removed from the rich bottoms solution by stripping with high pressure steam in the Phosam-W stripper.

Aqueous vapor containing 10 to 20 weight percent ammonia exiting the top of the stripper is condensed and collected in a fractionator feed tank. This aqueous ammonia is pumped from the fractionator feed tank into an ammonia fractionator column. Pure ammonia with at least 99.5 wt % of ammonia leaves the top of the fractionator and water containing less than 100 ppm by wt. of ammonia leaves the bottom. This water is combined with the stripped gas liquor from the lime sludge clarifier for waste water treating.

1.1.7 Unit 82 - Lurgi Liquids POX Gasification

Lurgi liquids are gasified to make more synthesis gas in a partial oxidation unit. The partial oxidation gasifier operates in the slagging mode. The liquids derived from the Lurgi Coal Gasification process, i.e., tar, oils, naphtha, and phenols are fed to the gasifier burners along with steam and oxygen and undergo partial oxidation resulting in the production of medium Btu gas. The gasification temperature must be sufficiently above the ash flow point to ensure free flowing molten slag which falls into the water quench chamber at the bottom of the gasifier. The molten slag is collected in a lock hopper and periodically discharged.

The hot crude gas leaving the gasifier passes through a radiant type waste heat boiler generating 600 psig saturated steam, and then is scrubbed with water to remove particulates from the gas stream. Following the scrubbing operation, the remaining waste heat of the gas is recovered in a waste heat boiler generating 60 psig steam. The gas is then cooled to about 100°F in water cooled shell and tube heat exchangers.

1.2 FLOW SHEETS

Flow sheets for the Gasification area are proprietary with the licensors involved. Details of the processes cannot be revealed until a licensing agreement is signed.

1.3 UNIT MATERIAL BALANCES

Stream compositions for the Gasification area are proprietary with the licensors involved. Details of the processes cannot be revealed until a licensing agreement is signed.

1.4 ACCOMPLISHMENTS AND DECISIONS

The current plant design uses the results of our process alternative study Case 13 (See Volume X). This is a preliminary process design that uses data supplied by Lurgi for gasification and Rectisol yields. No other licensor designs are incorporated into the work. MTG yields are based on data available in the literature.

1.5 CURRENT STATUS

A process design has been established on a preliminary basis. The preliminary design data on Coal Gasification Units was furnished by Lurgi based on data obtained during test runs with Kentucky No. 9 coal at the Sasol plant.

Mark IV gasifiers, fitted with coal distributors and stirring devices, will be used to gasify Kentucky No. 9 coal. The special stirring device is added to the standard Mark IV gasifier. The design gas yield per Lurgi mark IV gasifier has been established by Lurgi based on test results at SASOL. For the design Case 13, the total number of gasifiers is twelve, which includes sufficient spare gasification capacity to ensure desired raw gas design output consistent with anticipated gasifier maintenance downtime.

The gasifiers will operate with a steam/oxygen ratio of 7.2 kg steam/Nm^3 of O_2 for the specified coal. The design steam/oxygen ratio will be 7.4.

A decision has been made to utilize coal lock gas as a fuel gas in the plant. A process optimization study has shown that the recycle of lock gas to the Rectisol Unit is uneconomic.

The coal Gasification, Gas Cooling, Rectisol, Gas Liquor Separation, and Phenosolvan Units will be licensed by Lurgi.

The liquids obtained from the gasification process, i.e., tars, oils, phenols, and naphtha will all be combined and gasified in a Texaco Partial Oxidation Unit to produce more gas. This route was found to be the most economical one for disposition of these liquids.

For the Ammonia Recovery Unit, the Cyam process, licensed by U.S. Steel, has been selected.

1.6 LICENSORS AND EVALUATIONS

For the synthesis gas production units, Lurgi has been selected as the licensor. Licensing arrangements have been made between Lurgi and Tri-State. Lurgi will provide licensor packages for the following units:

No.	Description
10	Coal Gasification
11	Gas Cooling
12	Rectisol
13	Gas Liquor Separation
16	Phenosolvan

In addition, Lurgi will perform the detailed engineering for units 10 and 13.

Lurgi has tentatively been selected as the licensor for the Methanol Synthesis Unit; however, the licensing agreement negotiations for this unit are not completed.

For the Lurgi Liquids Partial Oxidation Unit, Texaco was tentatively selected as the licensor. Licensor negotiations between Texaco and Tri-State have not been started. The results of the process optimization studies indicated that the most viable disposition for Lurgi liquids was to gasify them to make more synthesis gas. Several licensors offer a partial oxidation process to gasify hydrocarbon liquids. Texaco and Shell Oil both offer this process. The Shell Unit is designed to handle clean solids-free liquids while Texaco's design can cope with solids. The Lurgi tar will have a varying quantity of coal dust in the solution. For that reason Texaco was the choice for the POX Unit.

The U.S. Steel Cyam process was selected for the Ammonia Recovery Unit. A competing process licensed by Chemie Linz thru Lurgi was installed at Sasol II and Sasol III. On the basis of the economic evaluation between these two processes performed for the WESCO project, Tri-State has elected to use the U.S. Steel process. Texas Eastern, a partner in the Tri-State Synfuels Company, was a partner in the WESCO project and had access to the WESCO study. The Cyam process was selected. This process is a variation of U.S. Steel's Phosam-W process. Cyam will release all of the fixed ammonia in the gas liquor. This prevents having a problem with nitrogen in the biological treatment of the stripped gas liquor.