Coal to Liquids: Overview of Process Integrity Issues

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Coal is primarily used as fuel in power generation. However, coal can also be used as an alternate source for making liquid fuels. Recent advancements in technology have successfully demonstrated conversion of coal into liquid fuels and into many other useful chemicals. CTL (Coal to liquid) technology can be considered as an alternate source to crude oil or natural gas in producing liquid fuels. The fuels made from coal are cleaner as compared to the fuels made using crude oil, owing to the process schemes followed.

A typical CTL complex involves number of processing units. These include coal preparation unit, Gasification block, Air separation unit, Shift reactors, Acid gas removal units, Sulphur recovery unit, Fischer Tropsch process, Methanation process, etc. There are different process licensors or technology suppliers for individual process units involved. While integrating all individual process units into one complex, it is important to understand the impact of design of one process unit on another process unit. This paper is intended to provide a brief overview of some of the process related aspects while integrating various units in a CTL complex.

Amalgamation of Technologies:

Coal is first gasified to produce syngas which is then converted to liquid fuels and other chemicals. Part of the syngas generated from coal gasification process can be used for power generation. Syngas can be then converted either to commonly used products such as methanol, ammonia, acetic acid or to liquid fuels such as Naphtha, Diesel, Jet fuel, etc. Fischer –Tropsch (FT) process can be employed for converting syngas into liquid fuels. Methanol can be further processed using MTO (Methanol to olefins) technology to produce olefins or can be converted to gasoline using MTG (Methanol to gasoline) technology. Figure-1 provides brief overview of possible product slate from the CTL process.

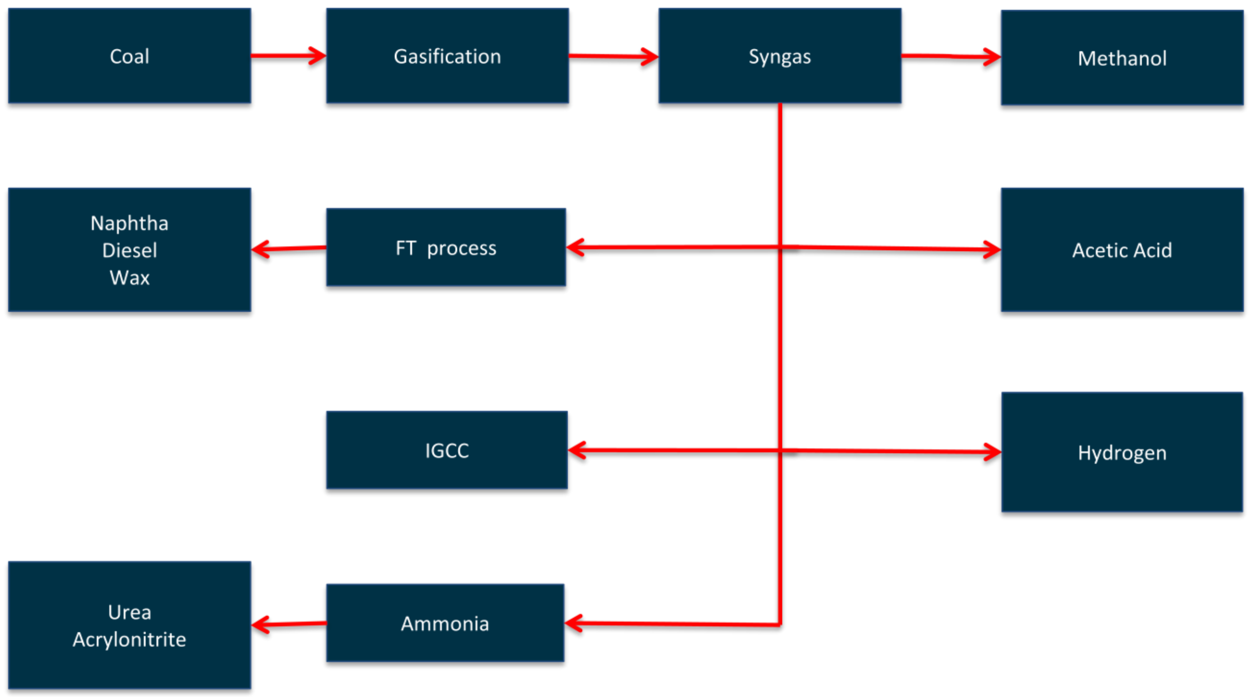

Figure 1: Products from Coal.

The CTL plant consists of number of processing units. Simplified block flow diagram of a typical CTL facility is shown in figure 2.

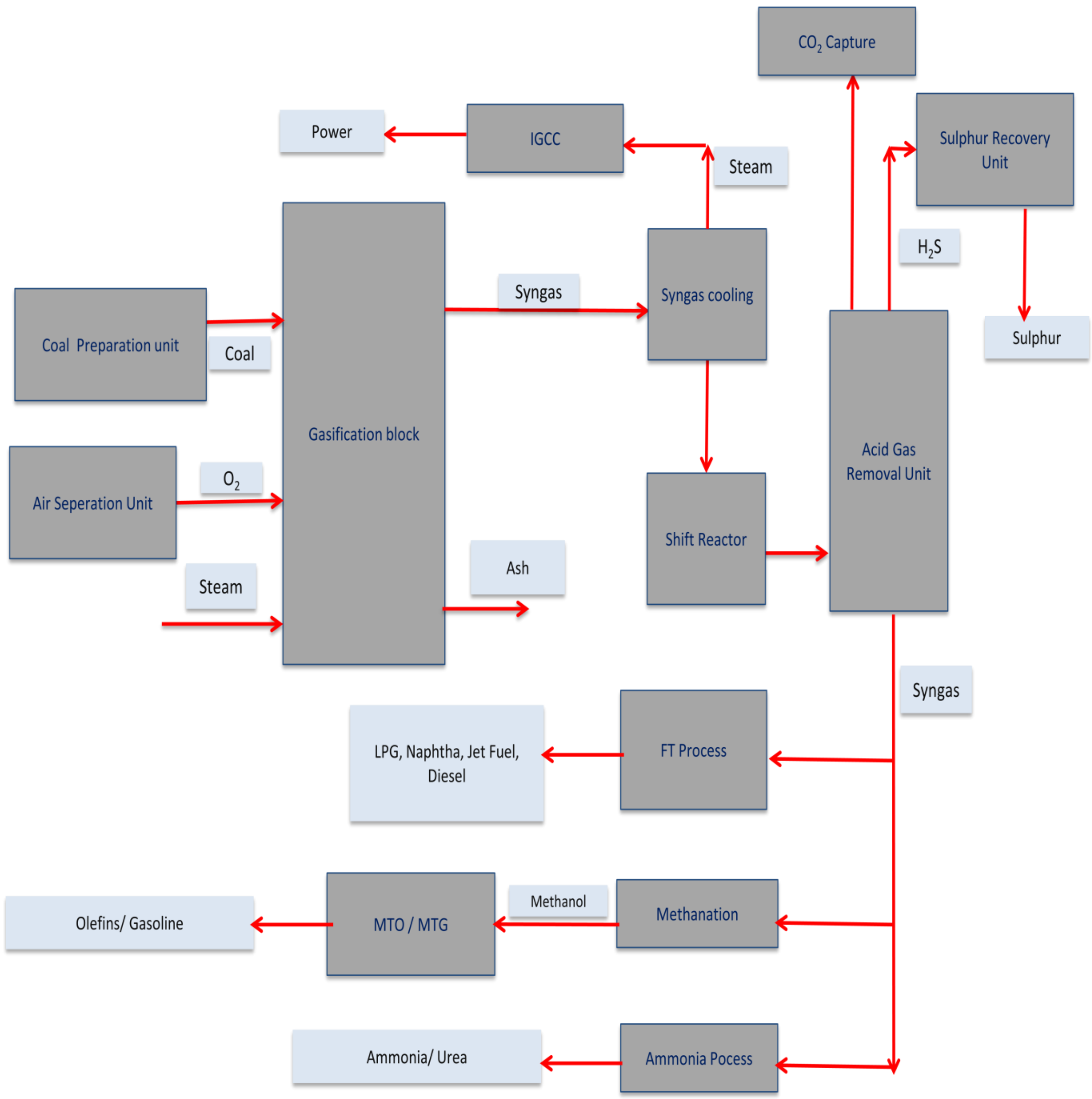

Figure 2: Block diagram of a typical CTL plant.

It starts with coal preparation unit which conditions and feeds coal to the gasification reactors. The coal is reacted with oxygen in the gasifiers. This oxygen is supplied by an air separation unit. (ASU) The raw syngas obtained from gasifiers is then sent to water shift reactions to adjust the composition of syngas and making it suitable for downstream processing. The acid gases coming from the gasification section typically consist of H_2S, COS, and CO_2. This gas is cleaned up in acid gas recovery (AGRU) unit. The tail gases from AGRU are sent to Claus process (SRU) for recovery of elemental sulphur. And finally the syngas needs to be processed in downstream units such as FT or MTG process for making liquid fuels. Additionally, the utility systems like nitrogen, steam, etc need to be designed with adequate capacities meeting requirements of the overall complex.

Since all the above process units may be supplied by different technology suppliers, it is necessary that the interactions of various parameters are understood while specifying, selecting and integrating various process units in the CTL plant. Below are some of the important factors in each process unit that may influence design of other process units. This paper takes example of a few key process related aspects to demonstrate the need of process integrity; it does not intend to cover all aspects related to process integration. Though this is not very exhaustive and complete list of all the integration issues, below sections provide an overview of such parameters.

Coal Quality and Gasifier Design:

Coal properties and quality over the geographic locations is not constant and it varies depending on the supply source. Quality of the coal plays a major role in selection of appropriate gasification technology. Also, the gasifier technology must be suitable to handle different variety and quality of coal, providing feedstock flexibility. Considering the constraints posed by available coal quality and selected gasification technology, it may be sometimes necessary to blend various quality coals to get the required feedstock quality for gasification.

Syngas heating value is impacted by the variations in coal quality. Therefore, specific and select coals are considered while deciding on size and number of gasifiers required in achieving nameplate capacity. The process economics by large is dependent on the coal reactivity in the gasifier. Syngas yield (and coal to carbon conversion) is determined by coal reactivity. Consequently, the size influences the capital cost of a coal gasifier.

Coal properties which can affect gasifier design include volatile matter content, ash content and moisture content. Reactivity of the coal is characterized by its volatile matter content. Higher volatile matter content indicates more reactive coal. Such coal can be more readily converted to gas while producing less char.

Ash content of the coal is one of the important factors in gasifier design. Coals having high ash content impose a limit on gasifiers operating temperature. Melted ash can clog the gasifier. Slagging could be an issue due to the melting and agglomeration of ash in the gasifier. Slagging can affect operability and safety of the gasifier. Ash removal from the gasifier becomes a critical problem. Oxygen quantity to the gasifiers may need to be increased.

When the coal has high moisture content, it will lower the gasifier temperature as water evaporates and thus thermal efficiency of the gasifier will be reduced. Coal drying can be considered to limit the moisture content of coal fed to the gasifiers.

There are number of gasifier types offered by different technology suppliers. Coal properties may set a limitation in operating a particular type of gasifier. For example, when fluidized or fixed bed gasifiers are selected, the ash is normally removed as a solid. This poses a constraint on operating temperatures of the gasifier as it needs to operate well below the ash melting point. The slagging gasifiers are designed to operate at temperatures above the ash melting temperature.

Coal Preparation Unit:

The integration of coal preparation unit into CTL complex mainly requires planning of space considerations for coal storage. As coal is a very heterogeneous material, the preparation plant need to condition the available coal to meet the quality requirements of gasification plant.

Coal is typically fed into gasifier as a dry solid or as coal-water slurry depending upon gasifier requirement. In some cases, to limit the moisture content, a coal dryer is provided. The coal preparation unit needs to meet the particle size requirements of coal feed. Some gasifiers are designed to operate with a limited particle size range. Too small particle size may result in flow ability across gasifier throat increasing the pressure drop. For downwind type of gasifier, the gas load reduces if the pressure drop increases.

Air Separation Unit:

An air separation unit (ASU) provides oxygen to the gasifier. The selection of oxygen supply – either through air or pure oxygen is mainly driven by target usage of the syn gas. If air is used, the N_2 in air dilutes the syn gas components and calorific value. Hence, oxygen is preferred. The quantity of oxygen required for the gasification reaction is dictated by type of the gasifier selected. For smooth functioning of gasifiers, uninterrupted and reliable oxygen supply is desired. Stoppage of oxygen supply may lead to the shut down of the entire complex. Cold box in the ASU may be required to undergo a cleaning operation. (Typically, two days in every two years) Buffer oxygen capacity needs to be planned in case of outage of oxygen due to either planned maintenance activities of cold box or due to any other unplanned interruption such as compressor trip.

ASU plant capacities are finalized considering the nitrogen requirements of the entire CTL complex. This includes nitrogen required for pneumatic conveying of coal. ASU is one of the most expensive units of CTL complex; therefore it is important to optimize its design philosophy.

Syngas Cooling:

Raw syngas leaving the gasifier is at high temperature and needs to be cooled. Heat recovery is essential to increase thermal efficiency. The process of cooling offers few design options. Cooling can be accomplished by using either direct quench method or by indirect heat recovery method. In direct quench method, hot syngas is contacted directly with cold water to cool it to its saturation temperature. The temperature decrease is obtained by evaporating water. In indirect heat recovery method, hot syngas is sent to a waste heat boiler to produce high pressure steam which can be utilized for power generation.

Based on the desired product slate from the CTL complex, an optimum syngas cooling method can be selected. When direct quench designs are used, the sensible heat of raw syngas will be converted to a low level heat. When power generation is desired, this will result in lower efficiency. Direct quench method is however advantageous when CO_2 capture is intended. Cooled syngas is fed to shift reaction section. The excess water vapour in syngas reduces steam requirements of downstream water shift reaction. Thus, the selection of cooling method affects overall steam balance of the CTL complex.

The cooling section can also be utilised to generate steam and power to satisfy the overall requirements of the entire CTL complex. Hence, the cooling method selection also depends on final product slate desired /downstream processes and need for power generation with overall economics.

Shift Reaction Unit:

Coal is relatively cheap feedstock used in the gasification process to produce synthesis gas. However, CTL installations are capital intensive process. Coal gasification process produces syngas with a H_2/CO ratio close to unity. But, the downstream processes (such as ammonia or methanol or FT) require this ratio to be higher than one. There is a technical challenge to reduce the capex and opex requirements while meeting flexible H_2/CO ratio specifications of syngas. The technical challenge is to adjust the H_2/CO ratio of coal derived syngas so that it becomes suitable feedstock for processing in downstream units. This is achieved by the water-gas-shift reaction.

When CTL plant is to be designed to maximize the diesel production, H_2/CO ratio in the syngas becomes an important design variable. Since the design of FT process requires certain syngas composition, the design of shift reactor section needs to be synchronized with demands of FT section. The most effective design for both units can only be obtained by considering the mutual interaction between these units into account.

The shift reaction operates between temperature ranges of 200 ^{0}c to 500 ^{0}C with a variety of catalysts. Gasification technologies based on partial or full quench will require additional steam to obtain proper process conditions for the shift reactor. The shift reaction catalyst types are generally distinguished by their operating temperature range and by syngas sulphur content. The shift reactions can be carried out either through a sour shift or through sweet shift.

While, sour shift reactions require presence of sulphur in the feed syngas so as to maintain the catalyst in active sulfided state, sulphur must be removed prior to the shift reaction in case of the sweet shift reaction process. Sour shift allows operation at a lower steam to CO ratio than the sweet shift. Another parameter differentiating the shift reaction process is the ability to handle COS. Sour shift has the ability to handle COS. When sweet shift process is used, the COS compounds are first hydrolysed to convert them into H_2S. This H_2S is then removed prior to sweet shift reaction.

Extent of shift reaction and the ratio of CO/H_2 at the outlet of shift reactions depend on the requirements of downstream process. The shift reaction configuration is optimized based on CO/H_2 ratio as demanded by downstream units. For example, for satisfying the $CO:H_2$ ratio of the FT unit , only a part of syngas can be sent to sour shift whereas other part can be sent for dedicated COS hydrolysis unit. Shifted syngas from sour shift unit and the COS hydrolysis unit outlet gas can be combined to further route to acid gas removal (AGRU) unit.

Another example is when the syngas is processed in downstream units for methanol production. For such cases, only a partial conversion of carbon monoxide is required. The typical configuration of a shift reaction then consists of only one high temperature shift reactor.

If the syngas is to be used for ammonia manufacturing, and also in IGCC, then high conversion of carbon monoxide is necessary. Shift gas reaction configuration then includes a high temperature and low temperature shift reactors operating in series.

Gas Clean Up Unit:

Coal gasification process typically produces syngas having acid gases such as H_2S, COS, HCN, and CO_2. AGRU removes these acid gases from raw syngas through a typical absorber- regenerator type of unit using a regenerative solvent. Based on the selected solvent, It may be necessary to first convert COS to H_2S using a COS hydrolysis unit. HCN reacts with primary amines (which are absorber solvents) causing degradation. HCN is also known to poison FT reaction catalyst and hence it must be removed to protect the downstream processes.

H_2S and CO_2 need to be removed either simultaneously or selectively depending on CTL complex configuration. For an IGCC application, CO_2 in syngas contributes to the total mass flow rate through gas turbine and so the power output. It is therefore, in principle desirable to leave any CO_2 in syngas rather than removing it.

Cobalt or iron based catalysts are used in FT process. Zeolite or ZSM-5 catalyst is used in MTG (Methanol to gasoline) process. These catalysts are sensitive to poisoning by sulphur containing compounds. Hence their removal is essential. The gasifier as well as shift reactors produce CO_2. AGRU design specifications need to specify the CO_2 quantity at AGRU inlet; CO_2 balance thus is again dependent on overall CTL complex configuration.

Purity levels of syngas after AGRU unit vary based on the demands of downstream syngas processing units. When the syngas is to be used for ammonia or methanol manufacturing, then the required residual sulphur levels are 100 ppb (vol.) or lower. When the syngas is to be used for IGCC power plant, then the required residual sulphur levels of 5 ppm may be desired. Apart from the residual sulphur levels, the downstream process dictates the maximum allowable CO_2 content of the syngas. For example- ammonia process may require syngas to have a maximum of 10ppm (vol.) of CO_2.

The acid gases removed from the syngas are usually processed in a Claus sulphur recovery unit (SRU) for recovery of elemental sulphur. Concentration of H_2s in feed gas to Claus process is an important factor as the amount of CO_2 present in feed stream will dilute the feed gas H_2S concentration. Excess CO_2 in the sour gas will inflate cost of SRU. When looking at the selectivity of AGRU, it is therefore necessary to consider the effect on SRU.

Concluding Remarks:

While selecting process technology for multiple process units within the CTL complex, it is extremely important to understand interactions of few of the critical parameters that can impact design of process units. The individual units are though supplied by different process licensors, a thorough process integrity study is required to define the inlet and outlet conditions of every unit and set a firm design basis for every process licensor to design the respective plants.