Stepwise Liquefaction Technology

Overview

To improve the efficiency of liquefaction for various feedstocks such as low-rank coal, heavy oil, coal tar, and biomass, a novel stepwise liquefaction technology has been developed by Synfuels China. Stepwise Liquefaction utilizes both Direct Liquefaction (DCL) and Indirect liquefaction (IDCL) technology. The two sub-processes of stepwise liquefaction are DCL of the feedstock under mild operating conditions by hydropyrolysis, and IDCL which consist of gasification of residual followed by Synfuels China's propriety high temperature slurry Fischer-Tropsch process (HTSFTP).

The DCL (hydropyrolysis) of feedstock takes place in a suspended bed reactor under a pressure between 2.0-5.0 MPa by mixing feedstock with certain high activity catalyst in a solvent with high hydrogen-donor ability. The residual from the direct liquefaction process is then gasified to produce syngas. After being purified, the syngas is converted to oil products using our standard HTSFTP technology.

Synfuels China has carried out comprehensive R&D work on the process of direct liquefaction, such as high-performance and low-cost catalysts, hydrogen transfer mechanism, as well as the property of different feedstocks. For brown coal A in China, as shown below in Table 1, its conversion can reach 85-88%, and oil yield is up to 60.0% after direct liquefaction at 3.0 MPa. If the residual after the liquefaction is gasified and converted to oil product using HTSFTP technology, the total heat efficiency of the process can reach 50-55 %, which is 10-15 percent higher than the 35-38% of gasification + HTSFTP process. Much better results have also been reached from heavy oil and coal tar using stepwise liquefaction technology, due to their smaller molecules, higher H/C mol ratio, lower oxygen/nitrogen/sulfur contents, and lower Inorganic matter content. A 10 kt/a pilot plant, shown in Figure 1, has been constructed in 2010, and several pilot tests have been completed.

Table 1: Analysis of Brown Coal

Item	Proximate Analysis					Elemental Analysis			
	M_{ad}, %	A_{ad}, %	V_{ad}, %	$S_{t,ad}$, %	FC_d, %	C_{ad}, %	H_{ad}, %	O_{ad}, %	N_{ad}, %
Brown Coal A	14.43	4.71	41.81	0.22	45.64	60.21	4.10	15.55	0.78

Figure 1: (Left) 10 kt/a Pilo Plant and (Right) Samples of Crude Oils and Products (diesel and naphtha)

History

2002-2008 R & D of stepwise liquefaction technology on laboratory scale

2008 Construction of the stepwise liquefaction pilot plant

2010 The liquefaction pilot plant commissioned successfully

2010-2014 Pilot test for the partly hydrogenation of brown coal, soft coal, coal tar and heavy oil

Advantages

- The overall energy efficiency could be increased from 44-47% to 50-55%
- The reaction condition of partly hydrogenation is milder than that of the direct liquefaction technology, and is easy to be realized and operated stably.
- The oil product produced from stepwise liquefaction technology is easy to be refined and blended, and is suitable for the production of high quality gasoline and diesel

Stepwise Liquefaction Process

Step-wise liquefaction consists of two main sections that run in parallel. These are the DCL section, which directly converts solid coal into liquid fuel, and the indirect coal liquefaction (IDCL) section, which indirectly converts solid coal into liquid fuel by using the coal-to-liquids (CTL) process. The liquid fuel produced from these parallel sections can be sold as value-added products. Figure 2 illustrates a simplified process flow diagram of stepwise liquefaction.

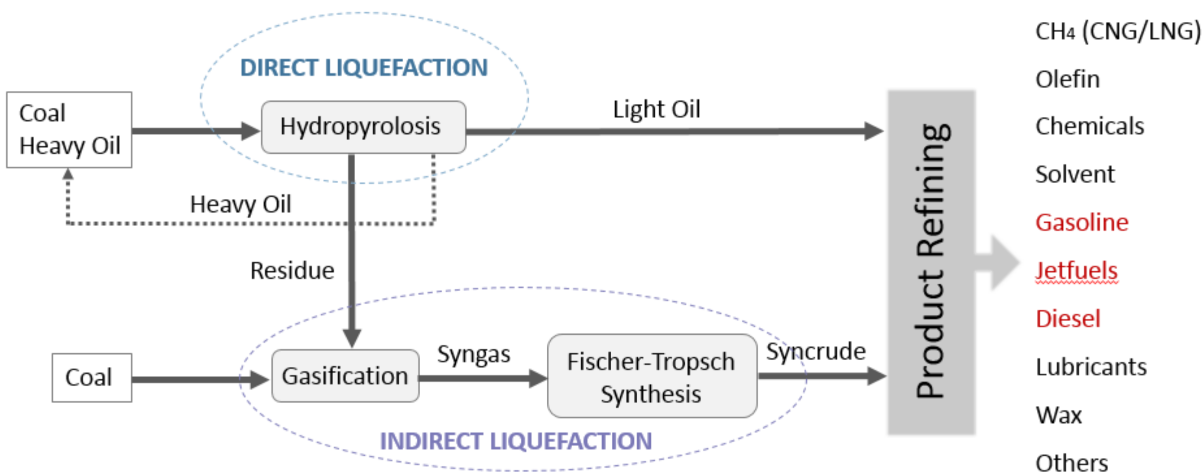

Figure 2: Simplified Stepwise Liquefaction Process

In DCL, solid coal is pulverized into a powder, mixed with heavy oil and hydrogen, and then reacted to form liquid hydrocarbons through hydropyrolysis. These liquid hydrocarbons can be divided into three groups: light oil, heavy oil, and residue. Light oil is further refined into value-added fuels that can be sold, such as naptha, gasoline, and diesel. Heavy oil is used as a solvent and is recycled to the beginning of the process so that it can be mixed with fresh coal powder. Residue is either sold for heat value or transferred to the IDCL stage to be converted to liquid hydrocarbons. The DCL process is explained in further detail in the subsequent section.

For IDCL, the CTL process is used, which means that coal is first gasified with steam to form syngas. The syngas is reacted to form hydrocarbons through the Fischer-Tropsch process, and these hydrocarbons are then refined into value-added products. For further detail on IDCL and the Fisher-Tropsch process, consult our document on the "Slurry-Bed Fischer-Tropsch Synthesis Process"

Direct Coal Liquefaction

DCL begins with lignite coal being dewatered and dried and then pulverized to a coal powder. Before coal can be processed, the water contained in the coal must be removed. Dewatering is done to reduce the water content of the coal. Low grade coal may contain 20% water which must be reduced before the coal can sent to the furnace. The dewatering of coal can reduce the water content from about 3% to 5%. The dewatering heats the coal from a range of 80-90 °C to about 105 °C. The dewatered coal is then sent to a dryer that operates at 150-170 °C to remove the rest of the water content in the coal. The dried coal is then pulverized in a mill to achieve a fine coal powder.

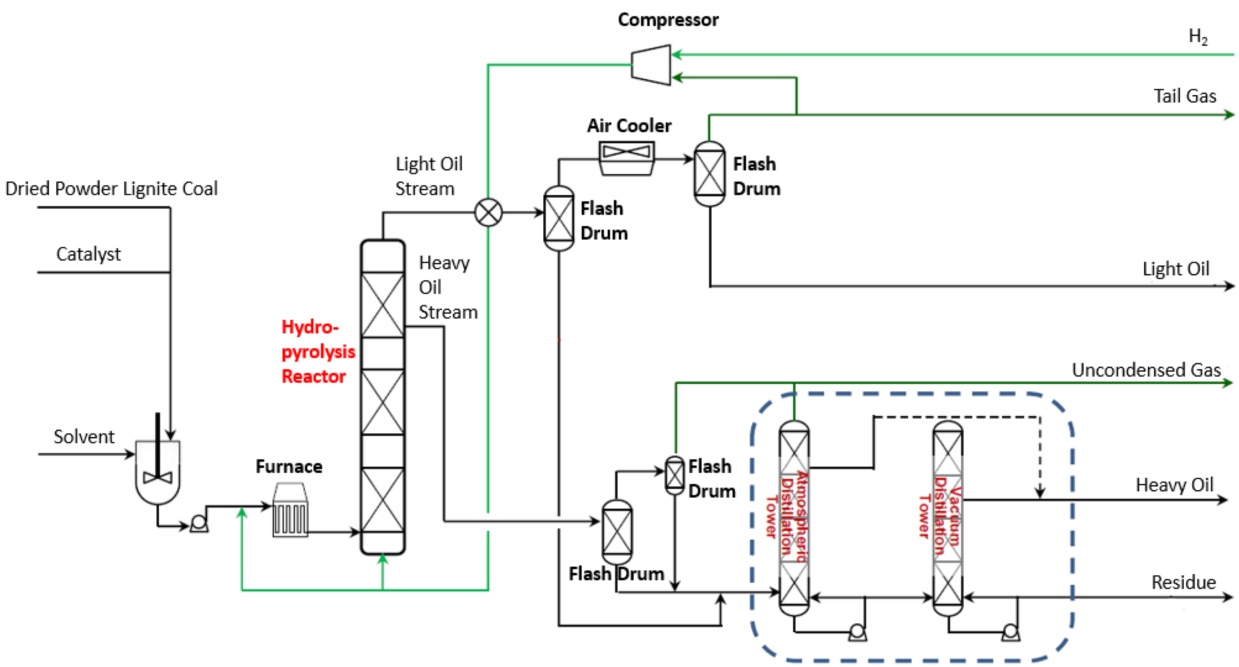

Figure 3: Direct Coal Liquefaction Process Flow Diagram

The coal powder is mixed with catalyst and the mixture contacts a solvent (heavy oil) in a mixing tank. The slurry is mixed with a stream of hydrogen gas and the mixture then enters a furnace to increase its temperature from 150 °C to 400 °C. The heated mixture then enters the hydropyrolysis reactor. The coal powder's long-chain aromatic hydrocarbons are heated and hydrogenated to form smaller aromatics with fewer double-bonds. These smaller hydrocarbons are separated into three categories based on their size: light oil, heavy oil, and residue. The light oil exits the top of the reactor as vapor, and a slurry of heavy oil and residue with some gas bubbles exits the reactor as a side stream.

The light oil stream that left the top of the reactor is further fractionated by entering a heat exchanger that cools the stream from 430 °C to 300 °C, causing some hot gas to condense. This mixture of hot gas and liquid enters a flash tank, where the lighter components exit the top as vapor. This vapor stream is further fractionated by passing it through an air cooler and a flash tank, which condenses and removes any water that was still remaining in the light oil stream. The light oil then moves on to a hydrorefining section, where distillation is used to further fractionate the light oil and eventually refine each component into a value-added product.

The heavy oil and residue that left the hydropyrolysis reactor as a side stream travel to the atmospheric column for fractionation. Before the heavy oil and residue reach the atmospheric column, they are separated into several different streams based on volatility, with each separated stream entering a different portion of the atmospheric column. To facilitate this separation, the stream of heavy oil and residue passes through a valve to reduce its pressure from 50 bar to 20 bar and then enters a tank. The reduction in pressure causes some lighter components in the stream to vaporize in the tank and exit through the top, while the heavier slurry components remain liquid and exit through the bottom. The top stream of vapor undergoes further separation by passing through a cooler and flash tank. The top and bottom streams from this flash tank eventually enter the atmospheric column. The bottom stream of slurry from the low-pressure tank is sent to a lower section of the atmospheric column.

The atmospheric column fractionates the various hydrocarbons based on volatility. The atmospheric column distillate is light oil, an effluent side stream is a slightly heavier light oil, and column bottoms are heavy oil and distillate. The column bottoms is sent to the vacuum column for further fractionation. The vacuum column side stream is heavy oil, and the column bottoms is residue. The side streams from the atmospheric column and vacuum column are mixed together to form a new composition of heavy oil, which is then sent to the heavy oil storage tank. Some of the heavy oil is sold as a final product for its heat value, but most of it is recycled as solvent for the hydropyrolysis reactor. The light oil proceeds to the hydrorefining section to be refined into value-added products. Residue can be sold as a final product for its heat value or be fed to the IDCL section to be converted into value-added products.