Topic : CLEANER ROUTES: HEAVY CRUDE OIL PROCESSING

Group no

Names and contribution

Name	Contribution

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ABSTRACT

Crude oil is one of the most important sources of energy. As the reservoirs of light crude oil are decreasing over the years, a shift to the production and use of heavy crude oil is seen. Heavy crude oils can be converted into different products like gasoline, diesel, LPG and feedstock for various petrochemicals. Over the years, various methods have been used for processing heavy crude oils. This work discusses some of the pre-requisites before processing, problems faced and the operational changes made for the processing. It also describes the conventional refining method in detail and the limitations and challenges faced during this process. Further, it highlights the need for wellhead processing of crude oils, with special emphasis on technologies like Heavy Oil Upgrading Technology, Improved Delayed Coking Unit, Shell

Upgrader Technology, GHU Upgrading Process and Solvent Extraction Process and their advantages and limitations.

1. INTRODUCTION

The demand for energy has been increasing continuously since industrialization. This is primarily due to the fact that energy demand and the social and economic development of a country are interrelated with each other. Fossil fuels like coal and crude oil are the major sources to meet this growing energy demand. Presently, around 80 million barrels of crude oil are produced every day, out of which more than 11 million barrels are those of heavy crude oil. Countries like Mexico, Canada, United States, Venezuela, Russia, Iraq, Kuwait and Saudi Arabia are the major producers of heavy crude oil. Being relatively cheaper than conventional light crude oil, their demand is increasing and is expected to rise by 10% over the years. As a result, it is imperative to know about the existing technologies and develop new and better methods for their production and processing.

Several works have been carried out on the processing of heavy crude oil. Amongst the major studies include a book entitled 'Processing of Heavy Crude Oils-Challenges and Opportunities,' edited by Ramasamy Marappa Gounder. This book gives a comprehensive account of the challenges faced during the extraction, processing and transportation of heavy crude oils. In addition to this, it describes various methods for pre-treatment and removal of impurities from heavy crude oils. It also provides an account of the toxic compounds and pollutants released during processing and the environmental challenges that arise due to these toxins. However, technologies related to wellhead processing are beyond the scope of this book. Another book entitled 'Heavy Crude Oils-From Geology to Upgrading,' by Alain Yves deals with the geological origin, properties and methods for determining the physical and chemical properties of heavy crude oils. It also discusses methods for upgrading and transportation of heavy crudes. In addition to this, an article entitled 'Refiners Processing Heavy Crudes Can Experience Crude Distillation Problems' by Steve White and Tony Barletta also discusses the challenges during processing and distillation of heavy crudes. However, this article is limited to the operational problems faced in the refinery. The report entitled 'The Genoil Hydroconversion Upgrading System for Heavy and Extra Heavy Crude' submitted by Genoil Clean Technology highlights the history of the development of GHU process, compares it with the delayed coking process and discusses its advantages over the delayed coking process. It also describes the fixed bed process for hydroprocessing of residues in detail.

Before discussing the processing of heavy crude oil, it is necessary to define it. Liquid petroleum having an API gravity less than 22.3^{o} is known as a heavy crude oil. While the viscosity of a conventional oil is between 1 cP and 10 cP, the viscosity of a heavy crude oil can be as high as 1,000,000 cP. The Canadian Center for Energy further classifies heavy crude oil into three categories:

a) Heavy Oil: It has API gravity greater than 10, viscosity less than 10000 cP and can flow at reservoir conditions.
b) Extra Heavy Oil: It has API gravity less than 10, viscosity less than 10000 cP and has low mobility at reservoir conditions.
c) Bitumen: It has API gravity less than 10, viscosity greater than 10000 cP and does not flow at reservoir conditions. It is used in the production of synthetic crude and used in oil sand production.

Unconventional oils obtained from enhanced oil recovery, tar sands and shale oil are also considered as heavy crude oil.

Attributes	Conventional Oil	Heavy Oil
Viscosity (77°F)	13.7 cp	100,947 cp
Asphaltenes	2.5 wt%	12.7 wt%
Aluminium	1.174 ppm	236.02 ppm
Iron	6.443 ppm	371.05 ppm
Nickel	8.023 ppm	59.106 ppm
Titanium	0.289 ppm	8.025 ppm
Vanadium	16.214 ppm	177.36 ppm

Table 1: Comparison of Properties of Heavy Crude and Conventional Crude (Source: The Challenges of Processing and Transporting Heavy Crude)

Heavy crude oils are characterised by various physical and chemical properties including high density, high viscosity and a high proportion of resins and asphaltenes, i.e., asphaltic molecules.

Further, they have high acidity, low hydrogen to carbon ratio, increased levels of nitrogen, sulphur, heteroatoms and metals like iron, aluminium, vanadium and nickel as compared to light and medium grade oils. Methods like Nuclear Magnetic Resonance, Infrared Spectroscopy, Liquid Chromatography and X-ray and neutron scattering help in determining the composition and structure of these molecules.

2. PROBLEMS DURING DISTILLATION AND PROCESSING OF HEAVY CRUDE

As described above, heavy crude oils comprise high molecular weight components, including asphaltenes, resins and wax. Due to the presence of these compounds, heavy crude oil has a high viscosity which leads to deposition of asphaltenes and wax on the inner wall of pipes. This results in clogging of pipes, causing an extra burden on the pumping system, thus, increasing the cost and power requirement. Furthermore, as the wax-rich heavy crude flows in a pipeline, temperature decreases along the length of the pipe as a result of heat transfer from the pipe to the surroundings. This decreases the pipe temperature below the pour point of the wax, causes a change in the rheological properties of the wax, adding to the problem of a high pressure drop along the crude side.

In addition to this, the presence of several salts, naphthene, carbon residues, metals and sulphur increases the total acid number (TAN) of the crude oil, causing corrosion and fouling in the distillation units. This makes their distillation more difficult and decreases the reliability of the units. Desalters are added to the heavy crude to separate the salts from the emulsion. However, it is necessary to maintain the temperature as the performance of a desalter depends on it. Low temperatures result in poor desalting. Because of this, a huge amount of brine in sent to the distillation unit and the heater, further increasing the fouling problems.

Other problems include low yield of heavy vacuum gas oil (HVGO) and low draw temperature. To maximise the yield of HVGO, optimisation of the cut point of atmospheric tower bottom products is required. Maintaining this cut point is a challenge because an increase in the ATB cut point leads to a heavier feed in the vacuum unit, thus, increasing the vacuum tower bottom (VTB) yield.

3. OPERATIONAL CHANGES FOR PROCESSING HEAVY CRUDE OILS

Because of the several problems highlighted above, several operational changes have to be made before the processing of heavy crude oils is done. In order to maintain the HVGO cut point and obtain a lower vacuum column pressure, it is required to have a lower operating pressure, higher outlet temperature and better stripping of VTB. A better ATB-VTB stripping ensures a higher recovery of distillates, and thus, a better yield and quality of the product. This can be made possible by increasing the temperature in both the columns, decreasing the operating pressure of these columns and decreasing the flash zone partial pressure in the atmospheric and vacuum columns. Furthermore, the wash section efficiency has to be improved to maintain the quality and yield of the product.

4. PRE-REQUISITES FOR CRUDE OIL PROCESSING

Before further processing and refining, heavy crude containing a high quantity of acid, metals, and nitrogen has to undergo several treatment processes. Due to the presence of high molecular weight compounds like asphaltenes, resins and wax, heavy crude has a higher pour point. Since it can lead to clogging of pipes and extra cost and power requirements, reducing the pour point is essential. This is done by using pour point depressants (or wax crystal modifiers). They are chemicals which decrease the viscosity of the crude oil and prevent crystallization of paraffins. Viscosity reduction can also be achieved by preheating of crude oil and the pipelines.

For a crude with TAN (Total Acid Number) greater than 0.6, crude blending is required. Crude blending involves the blending of heavy crudes with lighter oils or organic solvents to upgrade its physical and chemical properties and obtain a better-quality synthetic crude. This crude can then be easily transported via pipelines. Crudes which are highly acidic due to the presence of sulphur and naphthenic acid have to be neutralised during pre-treatment. This can be done by using strong bases like metal oxides (MOH), zeolites or polymeric compounds which are basic in nature. Esterification can also be used (by the addition of alcohols) to remove naphthenic acid from heavy crudes. To prevent the harmful effects of corrosion, chemicals have to be injected to the crude to reduce its acidic level below some threshold levels. In addition to this, materials which are resistant to corrosion, like SS 317, should be used for storage and transport of heavy crudes.

Heavy crudes contain metals like Na, K, Ca, Fe, Co, Pb, Ni and V in the form of inorganic salts or organometallic compounds like porphyrins. Since they can cause corrosion and deactivation of catalyst, several methods have been developed to remove them. Demetallization can be done by crude blending, hydrotreating, deasphalting and hydrocracking. Other methods include adsorption of metals over the surface of a suitable catalyst (dehydrogenation of porphyrins), solvent extraction (removal of nickel and vanadium using organic solvents like cyclohexane), oxidation of metals and electrochemical processes.

Moreover, heavy crude oils also have various nitrogen containing compounds like quinolines, pyridine, porphyrin and pyrroles, which can deactivate acid catalysts and form NO_X during combustion. However, in order to remove these compounds, more heat is required as they are thermally stable. The most common method of nitrogen removal is hydrodenitrogentaion. In this process, nitrogen is removed from the crude oil by reacting with hydrogen over catalysts like Mo, Co and Ni to form ammonia. The hydrocarbon part of the nitrogen containing compound stays in the oil while nitrogen gets removed. Other methods for denitrogenation include crude blending, solvent extraction and adsorption over zeolites, activated carbon, silica gel and polymers.

5. CONVENTIONAL REFINING TECHNOLOGIES

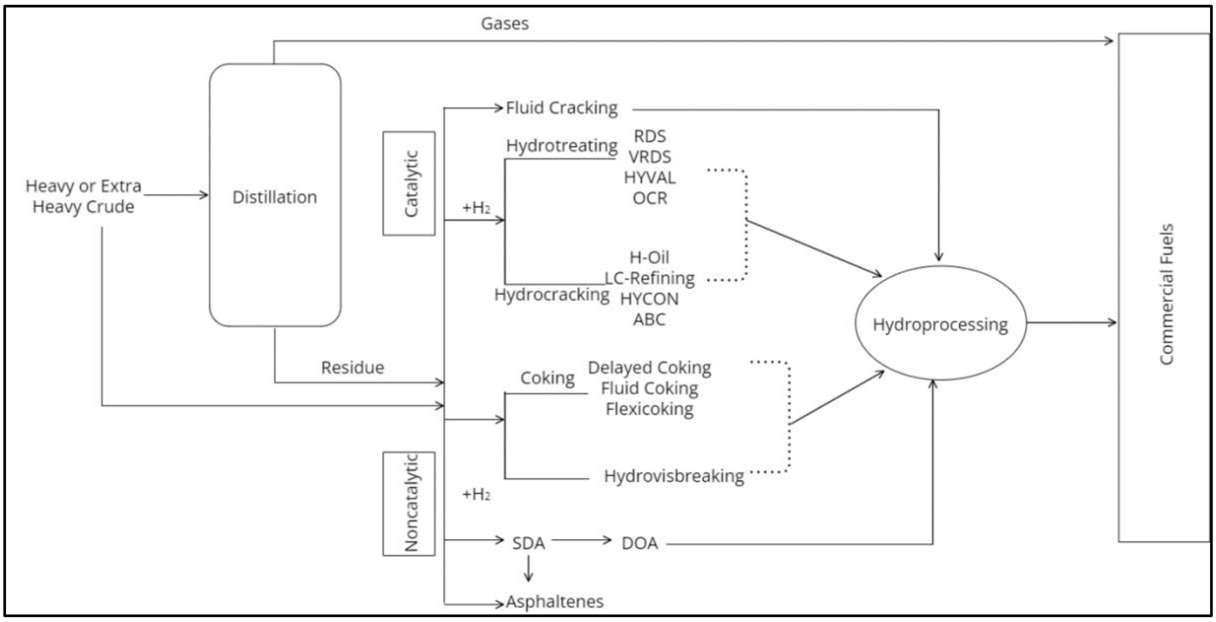

Figure 1: Refinery for Upgrading Heavy and Extra Heavy Feeds

In a conventional refinery, desalting of crude oil takes place to remove salts and water from the crude. After this, the crude undergoes atmospheric distillation to give various products like gas, light and heavy naphtha, gasoline, kerosene, diesel and residues. The residues from the atmospheric distillation unit, known as atmospheric bottoms are further processed in a vacuum distillation unit to give products like vacuum gas oil (light and heavy) and vacuum residue.

These heavy fractions, mainly vacuum residues, atmospheric gas oil and vacuum gas oil further undergo primary conversion reactions which include catalytic processes like hydrotreating and hydrocracking, and non-catalytic processes like coking and solvent deasphalting. This is followed by secondary processing, which includes hydroprocessing to give commercial fuels like jet fuels, gasoline and diesel to meet the market demand. During this process, some amounts of heavy and extra heavy crude oil do not undergo distillation and are directly processed by catalytic and non-catalytic processes.

6. DIFFICULTIES IN CONVENTIONAL REFINING AND THE NEED FOR WELLHEAD PROCESSING

Refining of heavy crude oil by a conventional refinery process poses several issues. The high viscosity of the heavy crude causes many problems during shipping. To facilitate the transport of heavy crude oil, its viscosity is reduced by adding a diluent, that is, a suitable light oil like naphtha or kerosene, to it. Since the acceptable viscosity limits for the transport of heavy crude can be achieved by increasing the volume fraction of the diluent to around 30%, it causes issues related to the availability of the diluents and the high pumping costs associated with it. An alternate method to reduce the viscosity is to heat the crude oil. However, this requires high capital and operating costs and has a lower reliability. Moreover, the high carbon content, high content of sulphur and metals and high Conradson Carbon Residue add to the refining problems as they can cause fouling and corrosion of distillation.

As a result, a preliminary removal of impurities is required at the production sites. Processing of heavy crude is done at the oil head to decrease the costs associated with refining and transportation. Some of the technologies available for wellhead processing include:

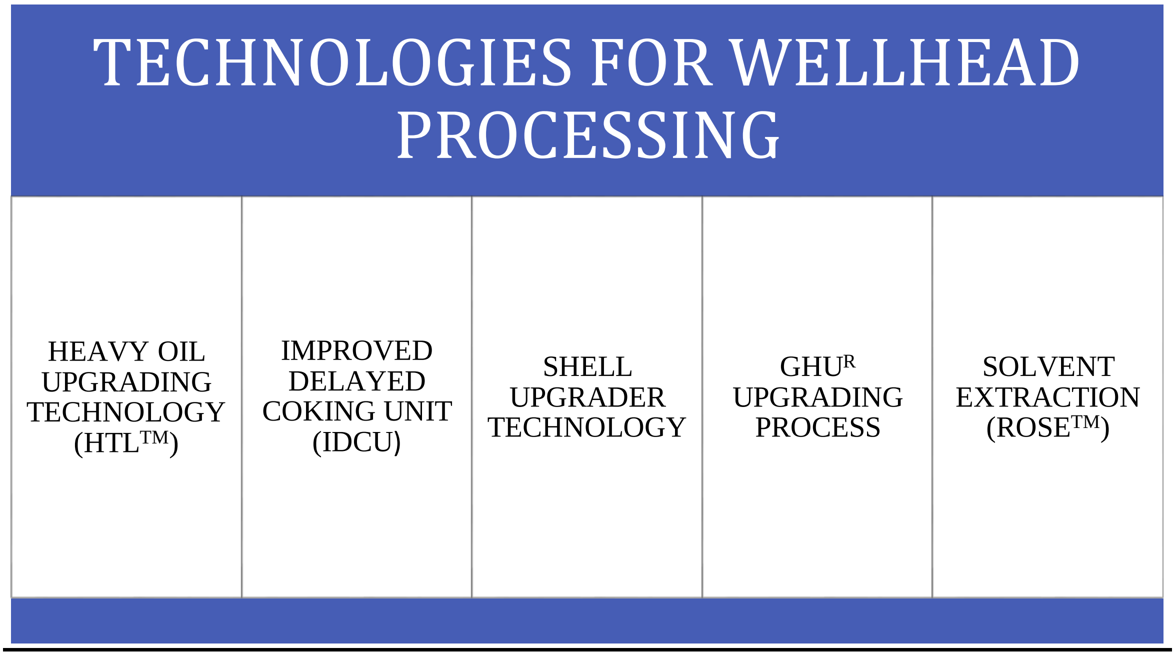

Figure 2: Technologies for Wellhead Processing

6.1 HEAVY OIL UPGRADING TECHNOLOGY (HTL™)

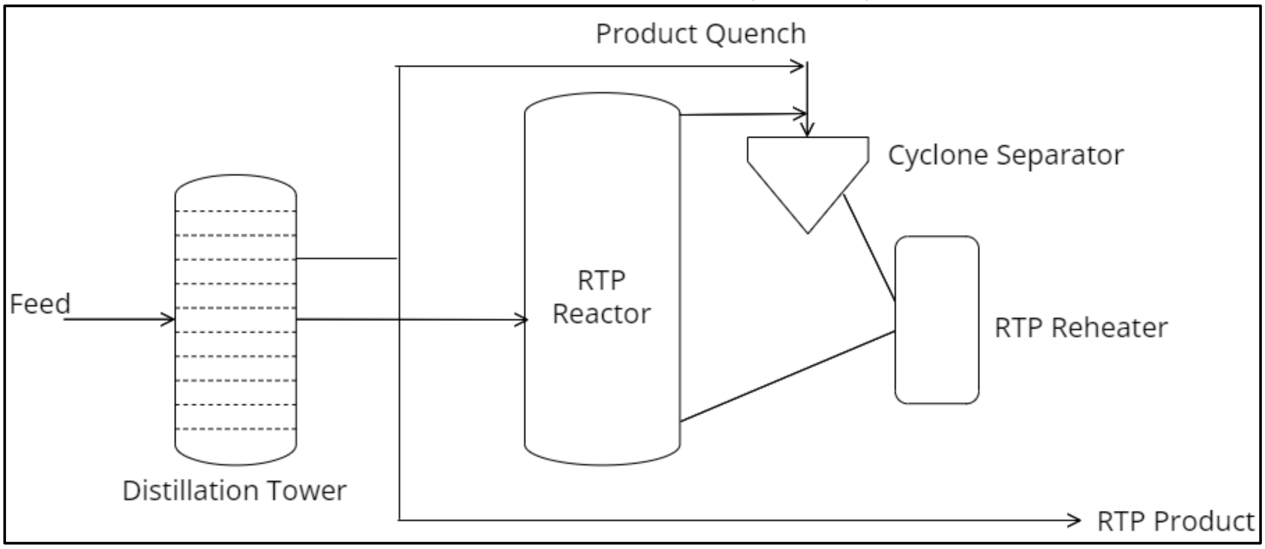

Figure 3: Flowsheet for Heavy to Light Oil Technology

Ivanhoe Energy patented the Heavy to Light Oil (HTL) process in 2011 to upgrade heavy oil. It is a selective thermal cracking process as the thermal cracking of only the heaviest molecules takes place. This process uses a circulating transport bed wherein hot sand is used to heat the heavy feed and convert it to lighter products. A cyclone separator is then used to separate these light products from the sand particles. They are then quenched and sent to an atmospheric distillation unit.

The HTL process has several benefits. It is an integrated process that uses a unique thermal cracking technology. So, the viscosity of the heavy oil reduces, thus, producing a high-quality synthetic crude with a very small quantity of residual oil (less than 5%). The upgraded products formed during the process do not require the addition of diluents or blending agents before they get transported via a pipeline. Furthermore, this process can operate under various types of configurations, depending upon the requirements and applications of the final product. Also, this process is simple, cheap and energy efficient. It avoids the extra costs associated with handling and transport of materials and reduces waste, particulate emissions and other volatile gaseous emissions. The by product energy is utilised in steam and power generation.

However, the process has a few drawbacks. The process has a low capacity of processing extra heavy oil and the yield of the upgraded crude is low. Also, there is a low reduction of sulphur content and a high coke formation takes place.

6.2 IMPROVED DELAYED COKING UNIT (IDCU)

In a delayed coking unit, a fraction comprising a mixture of residual oils is heated and then fed to a coke drum at sufficient pressure such that the heavier fractions are partially decomposed to form needle coke. This process uses a thermal cracker and a coker, which are two separate units, independent of each other but operate simultaneously with the help of interconnected streams.

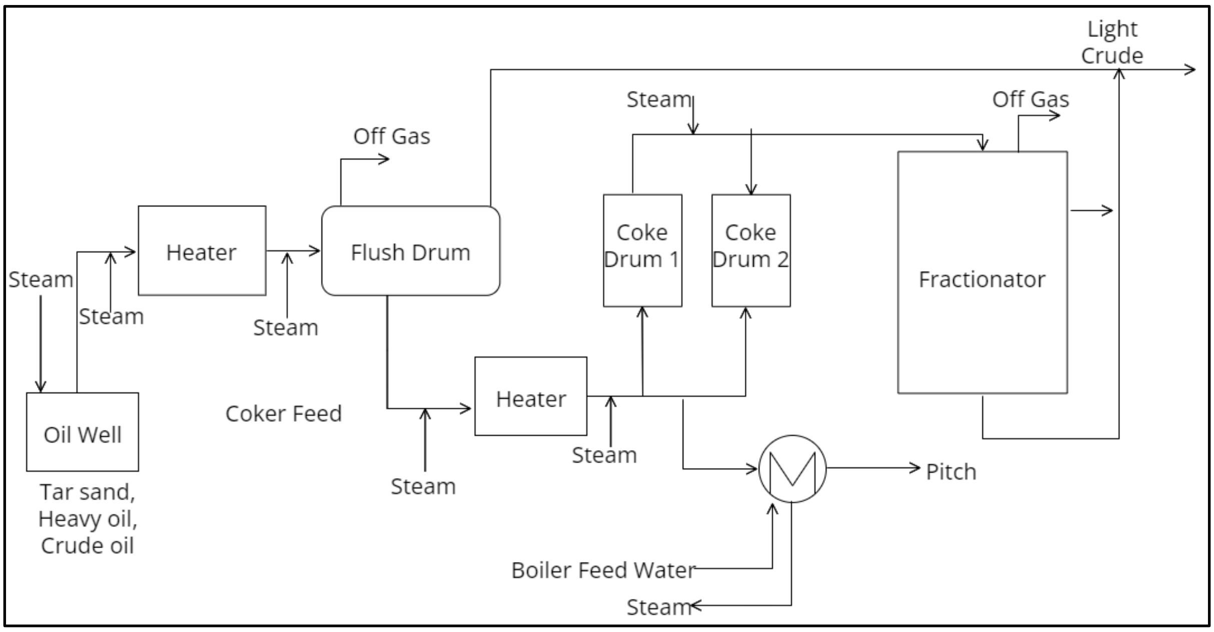

Figure 4: Flowsheet for Integrated Delayed Coking

The Improved Delayed Coking Unit (IDCU) is an integrated unit which utilises a single fractionator for thermal cracking and coking. It can handle any pumpable hydrocarbon feed and can upgrade low API crude, tar sands, bitumen and heavy oil at the well head. The single fractionator receives a hydrocarbon rich feedstock and separates it into various fractions. Each fraction is heated using a thermal cracking tube heater and sent back into the fractionator using a coker tube so that coking can take place. Since a single fractionator is used in this process, the amount of equipment required and the associated cost is reduced. Further, intermediate steps like heating and cooling can be avoided. High-quality liquid products with an optimum yield can be produced from an IDCU when the products from the coker tubes and the thermal cracking tubes are simultaneously sent to the single fractionator. As compared to a delayed coking unit, IDCU decreases the yield of coke and reduces the coking cycle to 6 hours, which was 18 hours otherwise. Moreover, it has a better coker efficiency, is more reliable, profitable and safer to operate.

6.3 SHELL UPGRADER TECHNOLOGY

Shell Canada Ltd launched its oil sand upgrader in December 1999 next to its Scotford refinery near Fort Saskatchewan. The aim of this plant is to process bitumen (low viscosity crude oil) using hydrogen addition into a vast array of synthetic crude oils. A froth treatment technology is used to remove clay, water and sand from oil sands before bitumen is further processed. The hydrogen to carbon ratio is increased during the upgrading process to break down larger hydrocarbon molecules into smaller ones by addition of hydrogen. As a result of hydrogen addition to bitumen, sweet and light crude oil is obtained. This upgraded oil is then used as a feedstock for refineries and processed into products like petrol. The major advantage of this process is that it maintains low levels of SO_2 emissions, no residues and produces clean and high-quality products with reduced amounts of aromatics and particulate matter. Currently, this plant has a processing capacity of 255,000 barrels per day.

6.4 GHU^R UPGRADING PROCESS

The Genoil Hydroconversion Upgrading System is majorly used for upgradation and hydroprocessing of residues, bitumen and heavy crude oil which have a high sulphur content and are acidic in nature. They are also utilised for hydroprocessing of kerosene, naphtha, vacuum gas oil and diesels. The reactors used for hydroprocessing include fixed bed, ebullating bed and slurry phase reactors. Out of these, the fixed bed reactor is most frequently used (85% of the total capacity) while there are only four units of slurry phase reactors in operation.

Bitumen Upgrading by GHU[R]	Feed (vol%)	Product (vol%)
Gravity, °API	8.5	24.8
Sulphur, wt%	5.14	0.24
Nitrogen, wt%	0.27	0.14
C_5 Asphaltenes	17.3	1.6
C_7 Asphaltenes	12.6	1.2
CCR, wt%	12.8	2.6

Table 2: Properties of Feed and Product from GHU Process (Source: The Genoil Hydroconversion Upgrading System (GHU) for Heavy and Extra Heavy Crude)

In a fixed bed reactor system, the sequence of the reactors and the catalyst distribution is such that it can protect the more active catalysts used for hydroprocessing. In this system, the first reactor is a guard reactor which contains a hydrodemetallization catalyst (to remove metals from the feed). It is followed by another reactor that utilises highly active hydrodesulphuration and hydrodenitrogenation catalysts in order to remove sulphur and nitrogen from the feed. After this step, the heavy crude gets converted to light and sweet crude and the residue is upgraded so that it can be utilised in the refinery. The unconverted residue is gasified in a Synthesis Gas Unit. Some amount of this syngas is used for hydrogen recovery while the rest is used for power generation in an IGCC (Integrated Gasification Combined Cycle) unit.

	GHU[R] (Hydrogen Addition)	Delayed Coking (Carbon Rejection)
Residue Conversion	Up to 90%	70-85%
Temperatures	Low/Medium	High
Volume Output	100-104%	75-80%
Coke production	0%	20-25%

Desulphurization	>90%	37%
Hydrotreating	Process includes hydrotreating	Needs further hydrotreating
Capital Cost	$ 7,000 – 12,000 per barrel	$ 8,000 – 14,000 per barrel
Equipment	Fewer Processes	More Processes
Natural gas usage	Optional or None	Yes

Table 3: Comparison of GHU Process with Delayed Coking (Source: The Genoil Hydroconversion Upgrading System (GHU) for Heavy and Extra Heavy Crude)

The Genoil GHU upgrader has a capacity of 10,000 barrels per day and is applicable to sour and acidic heavy crude. This process is flexible as it allows conversion and hydrogenation in a single step. It leads to a high conversion of heavy feed at moderate operating conditions, producing a high quality sweet crude product, without the use of any expensive diluents. One of the major advantages of the Genoil GHU plant is that it can operate at milder conditions, that is, lower temperature, pressure and space velocity than the conventional plants for hydroprocessing. Also, in this plant, the precipitation of asphaltenes can be avoided and a greater conversion of the vacuum residue can be achieved. In addition to this, the plant has lower capital costs, greater liquid yields and produces a stable, more superior product than other plants.

6.5 SOLVENT EXTRACTION (ROSE™)

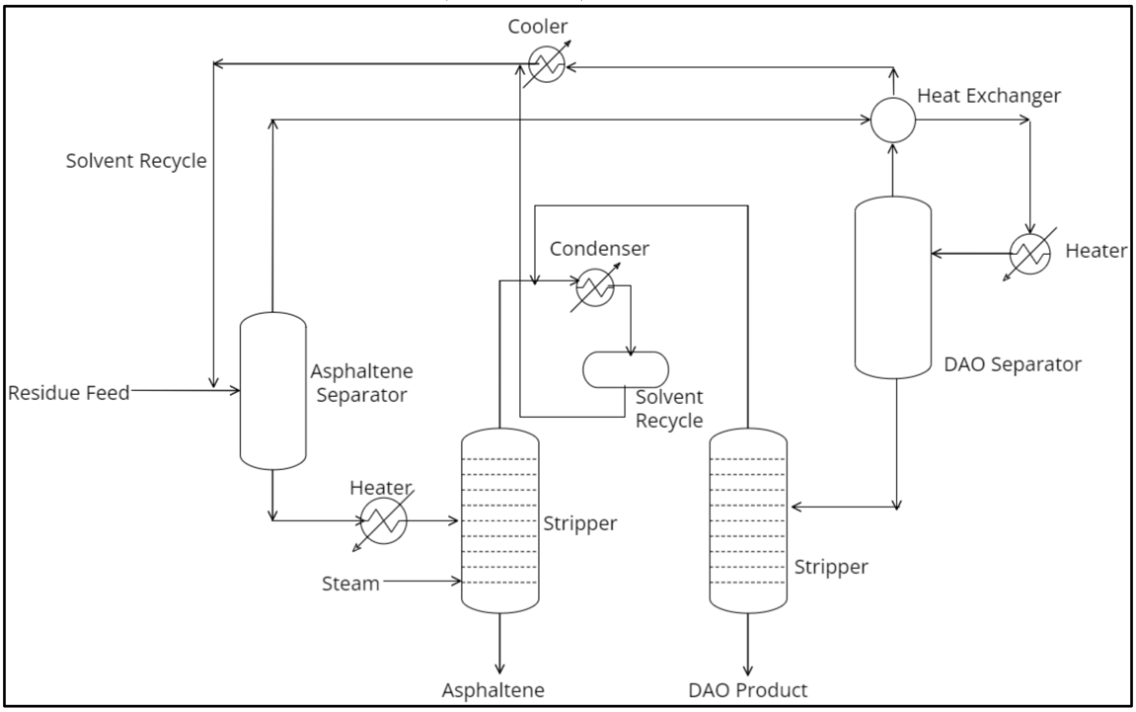

Figure 5: Flowsheet for ROSE Process

Solvent Deasphalting (SDA) is a residue upgradation process which separates the residue on the basis of molecular weight. It is a low-cost process which produces a deasphalted oil (DAO) which is rich in paraffins, has fewer contaminants and satisfies various DAO qualities. The ROSE process is a commonly used solvent deasphalting process which is energy efficient. During this process, the feedstock and the solvent are mixed and then fed to an asphaltene separator at high temperature and pressure. In the separator, some additional amount of solvent is added to the mixture in a counter-current manner. The heavier asphaltene molecules settle at the bottom of the separator from where they get removed. Then, the solvent is separated and extracted from the mixture and recycled back to the separating unit. The percentage of deasphalting can be increased by decreasing the temperature or increasing the solvent to oil ratio.

7. CONCLUSION

It has been observed that the demand for petroleum products has been continuously increasing for the last half a century or so. To meet this rising demand, new methods have been used by different petroleum refineries. A shift from conventional refining processes to heavy oil upgradation processes has been seen over the years. Some of the major processes for wellhead processing of heavy crude oil include Heavy Oil Upgrading Technology, Improved Delayed Coking Unit, Shell Upgrader Technology, Solvent Extraction and Genoil Hydroconversion

Upgrading Process. However, as the industry is continuously expanding, new and improved technologies are being researched upon and implemented. For example, the Nex-Gen Ultrasound Technology is an emerging technology which uses ultrasound to treat heavy crudes by breaking hydrocarbons and adding hydrogen. However, such newer technologies are still in the research phase and not operated on an industrial level.

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