ISSN No:-2456-2165

Determiners of Refinery Complexity: An Overview

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Abstract:- Energy is essential in all human activities, including industrial development, commerce, telecommunication, engineering, and medicine, to name a few. Currently, petroleum contributes 31.2% of the total energy consumed globally. The petroleum refinery converts crude oil into various useful products, including but not limited to fuel for powering engines and machinery. A petroleum refinery's complexity is determined by several factors, including the targeted product(s), crude quality, integration with the petrochemical unit, economics, environmental management issues, feed availability, product market, and others. Considering those mentioned earlier, the choice of products or targeted products has the most significant influence on refineries' complexity.

Keywords:- *Refinery, Petroleum, Petroleum Products, Crude Oil, Distillation, Hydro Skimming.*

I. INTRODUCTION

Energy is indispensable as far as human activities, growth, and development are concerned **[Turkoglu et al., 2018]**. Most economic activities would be impossible without energy, and more energy is consumed, indicating increased economic activity and profitable living **[Odularu et al., 2009]**. According to British Petroleum's statistical report 2021, crude oil constitutes 31.2% of the world's total energy mix consumed in 2020, and this is the largest energy source consumed in the same year, considering other energy sources **[BP Energy, 2022]**. Crude oil, also known as petroleum, is a naturally occurring liquid that can be subjected to a series of physical and chemical refining processes to produce a wide range of petroleum products **[David et al., 2006]**. Five major processes are globally deployed in refining crude oil into lighter and more valuable hydrocarbon products. These are: (i) separation processes using voatility and the boiling points to saparate into petroleum fractions in an atmospheric distillation column; (ii) using the conversion processes to rearrange or break down heavy long-chain molecules into smaller ones by either heating or catalyst activity; (iii) treating processes deployed to remove impurities and other non-desired components from petroleum products; (iv) blending or combination processes used to make a mixture of a final product by adding two or more petroleum fractions together; (v) and the auxiliary processes upon which the main petroleum refining processes depend for ease of operation. The auxiliary process could be in the form of utility or waste treatment plants **[Anjorin and Amos, 2020]**. This work aims to identify the various configurations of petroleum refineries and analyze the factors that determine the configuration or complexity of a particular refinery.

II. PETROLEUM REFINERIES AND VARIOUS CONFIGURATIONS

The complexity of a petroleum refining plant ranges from single topping unit to more complex high conversion systems.

A. The Topping Refineries:

This type of refinery is an assembly of atmospheric and vacuum distillation units. It is the simplest petroleum refinery configuration to prepare feedstock for the production of industrial fuels and petrochemicals manufacture **[Speight 2017].**

B. Atmospheric Distillation Unit:

The main objective of this unit is to separate petroleum into light-end hydrocarbons (Ci-C4), naphtha/ gasoline, kerosene, diesel, and atmospheric residue by taking advantage of their different boiling points. Some of the mentioned products can be marketed directly, while others require further processing in refinery downstream units to make them saleable. Although various arrangements of this distillation unit abound, the prime equipment include an atmospheric distillation column, De-salter, Condenser, networks of heat exchangers, fired furnace and storage tanks [Parkash S, 2003, and Mamudu et al, 2016]. The crude oil from storage is pumped through a set of Pre-heaters (heat exchangers) to temperatures between 65-1800C so as to reduce the crude's viscosity and surface tension for ease of mix and separation with water. At the de-salter, ammonia may be added to reduce corrosion and caustic may also be added to adjust the PH of the water wash. The crude from the de-salter enters another network of heat exchangers (Pre-heaters) before being channeled to the wired furnace where the de-salted crude's temperature is raised to 343-3990C. The partly vaporized crude is fed into the atmospheric distillation column at the column's flash zone where the vapor and the liquid separates. Products such as kerosene, AGO and Naphtha are withdrawn from the sides of the column while the atmospheric residue is sent to the vacuum distillation unit **[Gary JH et al, 2001 and University of Oklahoma 2022]**.

C. Vacuum Distillation Unit:

This is where the atmospheric residue distillation takes place to enhance the recovery of heavy distillate cuts from the atmospheric distillation unit. The products from this unit undergo further conversion or serve as lube oil feedstock **[Wauquier, 1995]**. The bottom residue withdrawn from the atmospheric distillation column is composed of high-boiling-point hydrocarbons. As such, distillation under atmospheric pressure would cause thermal cracking, and the heated residue decomposes and polymerizes, thereby causing equipment fouling. Vacuum creation decreases pressure and results in a decrease in the boiling point. The vacuum distillation occurs at a reduced pressure range of 25–40

ISSN No:-2456-2165

mmHg and 370–425^{0}C. The products of this distillation are light vacuum gas oil (LVGO) and heavy vacuum gas oil (HVGO) **[Gary JH et al. 2007, Parkash S 2003, and US-EPA 2022].**

D. Hydro-skimming Refineries:

This type of refinery combines the topping unit and one or more pre-treatment facilities, hydro-treating units, and catalytic reforming or isomerization units to produce naphtha reformate of a higher-octane number **[Gary JH et al., 2007; and Sarkar, 2008]**. Hydro-treating is one of the critical processes deployed to treat petroleum fractions of impurities such as sulfur, nitrogen, oxy-compounds, chlorine compounds, waxes, aromatics, and metals by using hydrogen. At the same time, catalytic reforming is a process that employs the use of a platinum metal supported by silica or silica-based alumina catalysts for the restructuring of naphtha (C6-C10) into aromatics and iso-paraffins **[Liu et al. 2018]**.

E. Conversion Refineries:

These types of refineries have the topping and the hydro-skimming refineries combined with gas oil processing plants such as the catalytic cracking and the hydrocracking units, olefins processing and conversion plants such as the alkylation and polymerization plants. These refineries are also called cracking refineries **[Speight 2017 and Gary JH et al. 2007]**.

F. Deep Conversion Refineries:

The deep conversion refineries process the vacuum residue by the coking process, also called coking refineries. The refinery converts the whole crude feed into valuable light products **[Gary JH et al., 2007]**. It is a refinery that combines all the features of topping, hydro-skimming, and conversion refineries with units that convert the atmospheric or vacuum residue into light products **[Elsevier, 2010]**. The feedstock for a petroleum refinery is crude oil. Even though the physical characteristics of crude oil vary from crude to crude, the chemical compositions are uniform **[Gary et al., 2007]**.

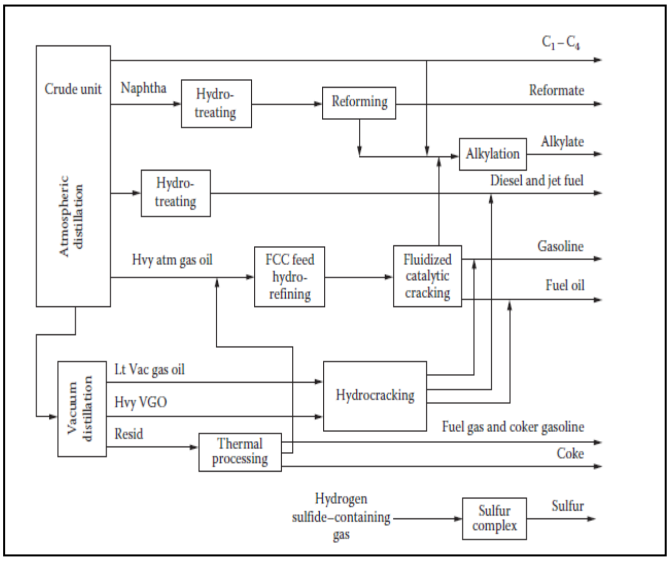

Fig. 1: Typical Petroleum Refinery [Speight, 2017].

III. MATERIALS AND METHODS

This work obtains secondary data from past and present studies, government and non-government bodies, and existing literature. World Bank Reports, the United Nations Environmental Protection Program, published materials, books, conferences, seminar papers, journals, and the internet are among the data sources. The obtained data would be analyzed, and the descriptive method would be used to present and interpret the results logically.

IV. DETERMINERS OF REFINERY COMPLEXITY

A. Targeted Petroleum Products

Many users seem to think that petroleum products consist of only a few products, such as motor gasoline, jet fuel, home heating oils, and kerosene, but a survey conducted by the American Petroleum Institute (API) in some refineries and petrochemical plants revealed that over 2000 products of different specifications **[Gary JH et al., 2007]**. Some of the products from petroleum include liquefied petroleum gas (LPG), light and heavy naphtha, kerosene, light and heavy atmospheric gas oil, light and heavy vacuum gas oil, gasoline, aviation fuel, fuel oil, petroleum coke, lube oil products, and asphalt products, to mention a few. These products are basically classified according to their carbon content, boiling temperature, and API gravity. The targeted product(s) is the most important factor in determining the complexity of a petroleum refinery. The reason is that to get some selected products, one must further crack both atmospheric and vacuum residue, and this makes the refining process more complex **[Springer Reference 2015 and Speight 2014]**.

Year	Refining Process	Targeted Product	By-Products
1862	Atmospheric Distillation	Kerosene	Naphtha, Tar
1870	Vacuum Distaillation	Lubricant	Asphalt, Residual Oil
1913	Thermal Cracking	Increase Gasoline	Residual Oil
1937	Catalytic Cracking	High Octane Gasoline	Petrochemical Feed
1940	Alkylation	High Octane Gasoline	Petrochemical Feed
1942	Fluid Catalytic Cracking	High Octane Gasoline	Petrochemical Feed
1952	Catalytic Reforming	High Octane Gasoline	Petrochemical Feed

Table 1: Timelines of Petroleum Refining Technologies

[Larraz R, 2021 and Jechura J, 2018]

ISSN No:-2456-2165

B. Crude Oil Assay and Quality

A crude oil assay reveals the composition information and the thermo-physical properties of crude oil and petroleum fractions. A typical crude assay reveals the bulk and fractional properties **[Liu et al., 2018]**. The bulk properties of crude include: specific gravity, viscosity, sulphur content, nitrogen content, and contents of metals such as iron, nickel, vanadium, carbon to hydrogen ratio, octane number, pour point, flash point, smoke point, freeze point, cloud point, aniline point, carbon residue, Reid vapour pressure, light hydrocarbon yields, acid number, refractive index, base sediments and water (BS&W), asphaltene content, True boiling point distillation, and ASTM distillation. The specific gravity is related to the API gravity, a measure of crude's heaviness or lightness. Crude with an API of less than 30 is considered heavy crude, while 30 API is considered light crude **[Bridjanian and Samimi, 2011]**. Light crudes produce a greater quantity of gasoline than heavy crudes. The API determines the commercial ability of the crude and hence the type of refining units and residue upgrading units to be incorporated into a petroleum refining plant. The crude assay should contain distillations and a specific gravity curve **[Elsevier 2010, Springer Reference 2015 and Liu et al. 2018]**.

C. Integration with Petrochemical Units

Industrial developments led to the integration of the petroleum industry with more complex petrochemical processes. Three major feedstocks exist for the petrochemical industry from the petroleum refining operations. These include (i) aromatics, a product from the catalytic reformation of naphtha or solvent extraction technique; (ii) the unsaturated hydrocarbons (olefins and diolefins) produced from the fluid catalytic cracking process, steam cracking, or by polymerization, (iii) and the saturated hydrocarbons (paraffin and cycloparaffins) produced from crude distillation. Utilizing these feedstocks for the petrochemical process adds to the complexity of the petroleum refinery **[Gary JH et al., 2001]**.

D. Economics

Although several other business objectives abound, every business's main objective is to maximize profit, and the petroleum refining business is not an exception **[Singh et al., 2015]**. Attention has recently shifted to upgrading refinery residue, which has resulted in the development of newer technologies to maximize profit. Future refining options such as super oil cracking and catalyst development technology, deep catalytic cracking, distillate de-waxing, residue slurry hydrocracking, and crude to chemicals technology, among others, would add to the complexity of the petroleum refinery when deployed as options to maximize profits **[Sarkar, 2008 and Larraz, 2021]**.

E. Environmental Management Issues

Environmental regulations on crude oil refining resulted in the integration of waste treatment plants within the oil refinery. Clean Air Act of 1990, the Montreal Protocol of 1987, and the Kyoto Protocol of 1997 provided air quality and emission limitations and other mandatory regulatory compliance **[Whitman et al., 2012]**. Air contaminants such as oxides of sulphur, nitrogen, and carbon, among others, generated during petroleum refining have tendencies to inhibit living organisms' survival. Polluted air from the refineries causes diseases such as respiratory diseases, heart diseases, and lung cancer **[The World Bank Group 2016, 1998]**. Also, the Clean Water Act of 1948, amended in 1972, provided water quality and effluent discharge limitations. To achieve environmental standard on waste discharge clean up, industries must deploy the most effective control systems currently available. **[Claudia, 2016]**. The laws mentioned above mandate that air and water quality must be maintained. Because petroleum refineries are major sources of air and water pollution, they must install systems like De-NOx and De-SOx cleaning plants to maintain the air quality and wastewater treatment plants to maintain the effluent discharge into the water bodies. These installations make the petroleum refinery more complex.

F. Availability of Crude Oil

Like every manufacturing process, the raw material's composition and availability determine the product and production. The blend of crude oil forecast availability also determines the refinery's configuration. Sour and heavy crude are more difficult to process than sweet and light crude. Feedstock availability for refining is determined by factors such as political and economic events, supply and demand conditions, government policies, and regulations, amongst others. The price of petroleum in the international market is dynamic, and crude oil availability can be impacted within the shortest possible time. The prices of petroleum products can be correlated directly to the price of petroleum itself, especially gasoline and the middle distillates. **[Gary JH et al., 2007 and Liu et al., 2018]**.

G. Market for Particular Product

With increasing stringent environmental laws and future fuel quality requirements for modern engines, getting marketable fuels from only petroleum distillation is challenging. This development brings about the need for more complex processes that produce fuels of the desired quality **[Schobert, 2013]**.

H. Energy and Utilities Requirements

Utilities are essential for the proper functioning of a petroleum refinery. The complexity of a petroleum refinery determines the energy and utility requirements. The more processes are available, the more energy is required to drive the additional equipment. Demand for utilities such as service air, instrument air, steam (low pressure, medium pressure, and high pressure), cooling water, firefighting, hydrant water system, and nitrogen also increases as the plant becomes more complex because of the need to crack further or upgrade residue **[Bahadori, 2016]**.

V. CONCLUSION

A petroleum refinery is a processing plant that converts crude oil into useful petroleum products. There are four types of petroleum refineries, namely: the topping refinery, the hydro-skimming refinery, the conversion refinery, and the deep conversion or coking refinery.

A refinery configuration depends on several factors, among which are targeted petroleum products, crude oil assay and quality, integration with petrochemical units, economics, environmental management issues, crude oil availability, the market for a particular product, as well as energy and utility requirements. The targeted product is the primary determining factor in determining a petroleum refinery's complexity or configuration.

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