Writing for Engineers
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Petroleum Refining: A Process

Crude oil is a naturally occurring combination of organic matter and hydrocarbons. It is more commonly known as unrefined petroleum, which is too heavy to burn. Oil deposits are located throughout the world and the methods of oil location, drilling, and extraction have evolved over time. Oil recovery methods, for example, vary greatly in complexity—from using water to flood the oil reservoir, resulting in the "lifting" of the oil due to their differing polar properties, to complex systems of valves, pumps, and retention tanks [1]. According to Schmidt [2] petroleum refining annual plant capacity is 10^6-10^8 tons; whereas, food plants produce 100-10,000 tons and pharmaceutical plants produce 10-1000 tons annually.

Although the Chinese are credited with first discovering oil in 600 B.C., Colonel Drake's 1859 Pennsylvania oil unearthing served as a catalyst for making oil an economic powerhouse [3]. John D. Rockefeller created Standard Oil Company in 1865, becoming the world's first oil "baron" [3]. Prior to the usage of oil as the primary fuel for heating, coal dominated worldwide. In the early 20th century; however, refining technological breakthroughs catapulted oil into the predominant fuel source globally. Petroleum refining is the process of turning the crude oil into useable, burnable derivatives. Generally, crude oil extracted, transported via a pipeline, sent through a fractioning column to break down crude into different components, and the components are sent to different reactors to yield the final, desired products. Figure 1 [2] illustrates the macroscopic process of petroleum refining.

Detailed Process Steps:

1. Extraction of oil:

   A. *Deposit Location*: Geologists use their knowledge of rock formation and seismology to detect the location of oil and natural gas deposits. Oil and gas will reflect the seismic shock waves differently than rock or other metals would [1].

   B. *Drilling*: Due to the high financial requirement for drilling a single oil well (approximately $50 million [1]), an exploratory test drill is performed upon discovery of a deposit. If the test illustrates the well is profitable and favorable for extraction, different drilling methods are used. The location of the well determines the method of drilling that would be used. Subaquatic deposits require a drill housing that can withstand the increasing pressure of water as ocean depth increases. Two of the primary onshore drilling methods are directional and injection wells [4]. Directional digging is used when the deposit is an area such that it cannot be reached by traditional vertical drilling, such as under a lake or under a city. Injection wells use the injection of gas into drilled bores to increase pressure to displace the oil [4].

   C. *Extraction*: Extraction of the crude oil depends on the location and type of well. Most of the selected wells are known as positive pressure wells. Wells under natural, positive pressure, will flow to the service without the need of pumps or other pressure increasing process equipment, known as primary extraction [1]. As the height of the oil in the well decreases over time, the natural positive pressure generated will decline. As a result, secondary and tertiary extraction methods are necessary. Secondary extraction is the application of pressure to bring the oil to the surface [1]. Typically, natural gas and pumps raise the well pressure to displace the oil. Finally, tertiary extraction is required for a nearly “dry” well. In a dry well, the oil is not entirely liquid, so heating and chemical treatments are used to liquify the oil [1].

2. Fractioning Column: Once the crude oil is brought to the surface, it is transported via pumps and piping to a refining facility. Initially, salt is removed from the crude and is sent to a fractioning column [2]. The fractioning column, or distillation column, is a column under vacuum or atmospheric pressure and uses the differing boiling points (BP) and molecular structures of the crude oil to separate the oil into its constituents (Figure 2 [5]):

   A. *Light Alkanes and Gases:* Light alkanes have a boiling point less than 400^oC [2]. Alkanes are organic molecules that contain only carbon and hydrogen (C_2-C_8) [2] and collect at the top of the column due to their low molecular weight and boiling point.

   B. *Naphtha:* Naphtha has nearly a perfect molecular weight; therefore, it needs little refining prior to use [2]. Its boiling point is between 400-500^oC and has a carbon content of C_5-C_9 [2].

   C. *Gas Oil:* Gas oil has a boiling point between 450-550^oC [2]. They are heavier than naphtha and further refining is required [2].

   D. *Heavy Oil:* The heaviest of all crude oil constituents with a boiling point greater than 550^oC and C_8-C_{12} [2]. Heavy oils require the most refining and some of them cannot be refined into useable products [2].

3. Reactors used in the refining of crude oil constituents:

A. *Alkylation:* Molecules that were cracked into pieces that are too small for use, require alkylation to increases carbon chain length and molecular weight. Alkylation, an exothermic reaction, is favorable towards equilibrium at low temperatures. An example of alkylation of a light alkane is the addition of benzene to propylene: $C_3H_6 + C_6H_6 \rightarrow C_6H_5C_3H_7$ [2]. Cumene, $C_6H_5C_3H_7$, can be oxidized to acetone, which is the most widely used organic solvent. Generally, light alkanes undergo alkylation to produce petrochemicals or gasoline [2].

B. *Reforming:* Also known as catalytic reforming, reforming reshapes the carbon backbone of naphtha, without cracking the bonds, into a highly reactive and useable product, such as petrochemicals or gasoline [2].

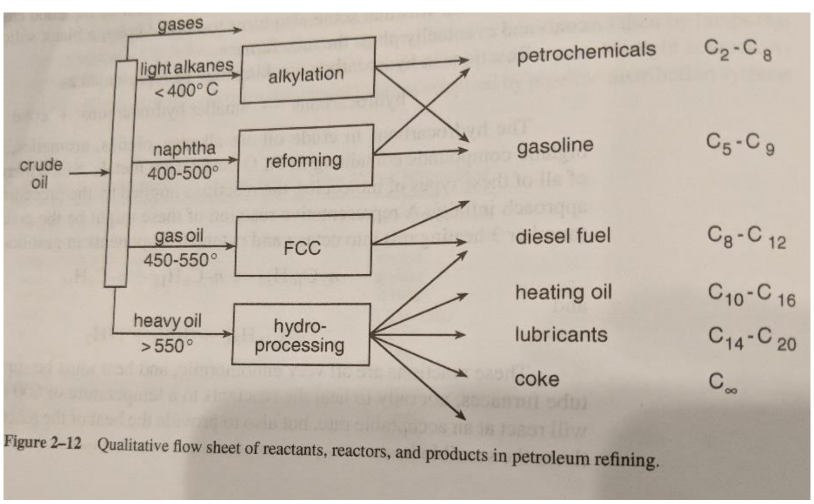
C. *Fluidized Catalytic Cracking (FCC):* FCC, the primary process in a refinery, uses a fluidized catalytic bed, heat, and a regenerator to crack heavier oils into gasoline and diesel fuel. When a gas or liquid's drag force, produced by the gas or liquid velocity, equals the total mass of beads in a packed bed, the beads will 'float' in a suspended, or fluidized state. Coke, or unwanted carbon, will deposit on the catalyst; however, the coke-catalyst is sent through a regenerator to remove the carbon waste (as CO_2) and is recycled to the incoming gas oil stream [2].

D. *Hydroprocessing:* The bottom of the distillation column contains the heavy oils, which are rich in sulfur, nitrogen, and other elements that poison an FCC [2]. These heavy oils require the addition of hydrogen gas to remove the sulfur or other heavy metals. After undergoing hydroprocessing, some products are sent to the FCC to produce diesel fuel. Other hydroprocessing products are used as heating oil (C_{10}-C_{12}), lubricants (C_{14}-C_{20}), or coke, unusable oil (C_{∞}) are produced [2].

Figure 1: Simple Process of Refining Crude Oil [5]

Desalinated crude oil is separated into its constituents in a distillation column. Four different reactors: reformer, alkylation, cracker, and coker (hydroprocessor), further refine the column products into useable, final products.

Figure 2: Reactants, Reactors, and Product Flow Sheet [2]



Overview of distillation, crude oil constituents, reactors, and products of petroleum refining, with boiling points and carbon content.

The advent of combustion engines [6] led to the further processing and refining of crude oil. The exploitation of crude oil constituent boiling points and the use of chemical reactors to further refine those constituents, has led to the production of petrochemicals, gasoline, diesel fuel, heating oil, and lubricants [2]. Although alternate fuel sources, such as electric, solar, and hybrid power sources, have tried to challenge petroleum as the primary automobile fuel source, gasoline combustion engines reign supreme. In the United States, up to half a million barrels of crude oil are refined daily [2]. As global population increases, nanotechnology and biotechnology become more prevalent and specialty chemicals continue to evolve, the demand for refining more crude oil increases annually. As a society, we will have to decide if the obvious economic positives from the entire pre- and post-refining process outweigh the quantifiable and noticeable negative side effects, such as human-accelerated global warming.

Reference List

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