

PETROLEUM AND ITS PRODUCTS

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Summary

Perhaps, one of the defining attributes of the 20th Century was the ever increasing dependency of the human race on hydrocarbons (petroleum in particular) to supply the energy needs for the rapid industrialization of the planet. The abundant and cheap supply of petroleum has fuelled unprecedented economic growth and enabled two world wars to be prosecuted. Now at the beginning of the 21st Century the threat posed by global warming is challenging humankind to find alternatives to petroleum as a means of supplying the energy needed to sustain and improve the quality of life for many people. Petroleum will continue to play an important role in supplying energy for the foreseeable future but it also enables other improvements in the quality of people's lives through the many products which are derived from it.

Petroleum has also played an important role in the development of Chemical Engineering as a discipline. Some of the processes employed in petroleum refining discussed in this paper have significantly progressed the understanding of major Chemical Engineering unit operations such as distillation, heat exchange and fluidization.

1. Introduction

Petroleum is a naturally occurring raw material, consisting mainly of hydrocarbons, and found in accumulations in porous reservoir rocks underground. Hydrocarbons are molecules comprising carbon and hydrogen atoms which range from methane (CH_4) to substances containing more than 100 carbon atoms. Petroleum at atmospheric pressure and temperature comprises both crude oil and natural gas. Natural gas is gaseous at room temperature and pressure, consisting mainly of hydrocarbons with few carbon atoms up to butane (C_4H_{10}). Crude oils are predominantly made up of higher carbon atom numbers (C_{5+}) and are liquids at room temperature and pressure. Because the reservoirs are at considerable depth the hydrocarbons are contained at elevated pressure (2 to 1,300 barg) and temperature (25 to 180°C) and can therefore be in a gaseous or liquid state.

When petroleum is produced from reservoirs it will often have associated non-hydrocarbons, such as nitrogen, carbon dioxide, sulfur, hydrogen sulfide, metals and water. Therefore, processing is normally required before it can be used to produce usable fuels or derivative products. Oil and gas from the reservoir is usually processed close to the point of production to remove undesirable hydrocarbons and the non-hydrocarbon contaminants in order to meet a specification suitable for transportation and onward sales. Natural gas at this point is often ready to be used directly as a fuel, whereas, crude oil will need further refining.

Petroleum accumulations are located across the globe and often the larger reservoirs are in regions remote from areas of high demand. Crude oil can be readily transported in liquid form from its source to the point of use by pipeline and/or sea-going tankers. However, due to its volume, natural gas requires more complex infrastructure for transport, which for remote locations can be uneconomic and hence natural gas associated with crude oil is either burned as a waste gas or re-injected to maintain reservoir pressure.

2. Global Supply and Demand

The products from petroleum contain circa 50% more energy per unit mass than coal, in other words, 1.5 tonnes of coal is equivalent to one tonne of oil. This relatively high “energy density” coupled with the relative ease of handling liquids and gases is one of the main reasons why petroleum (oil and natural gas) is utilized to generate a large proportion of the world’s energy needs (~60% in 2009) as primary energy.

Figure 1 illustrates how demand for petroleum increased throughout the 20th Century with major growth occurring between 1965 and 19788 after which demand fell for several years before resuming a slower rate of increase through to the end of the 20th Century. This trend has continued in the first ten years of the 21st Century, although the global recession in 2009 has caused the first overall decline since 1982.

Figure 2 shows similar overall growth in demand and consumption of natural gas, however, whilst the growth rate in oil consumption has slowed, natural gas demand has grown at an increasing rate for the first ten years of the 21st Century. Natural gas produces less carbon dioxide per unit mass consumed when compared to liquid

petroleum products and coal, hence, natural gas has displaced liquid petroleum based fuels and coal in efforts to reduce the amount of carbon dioxide generated in meeting energy needs.

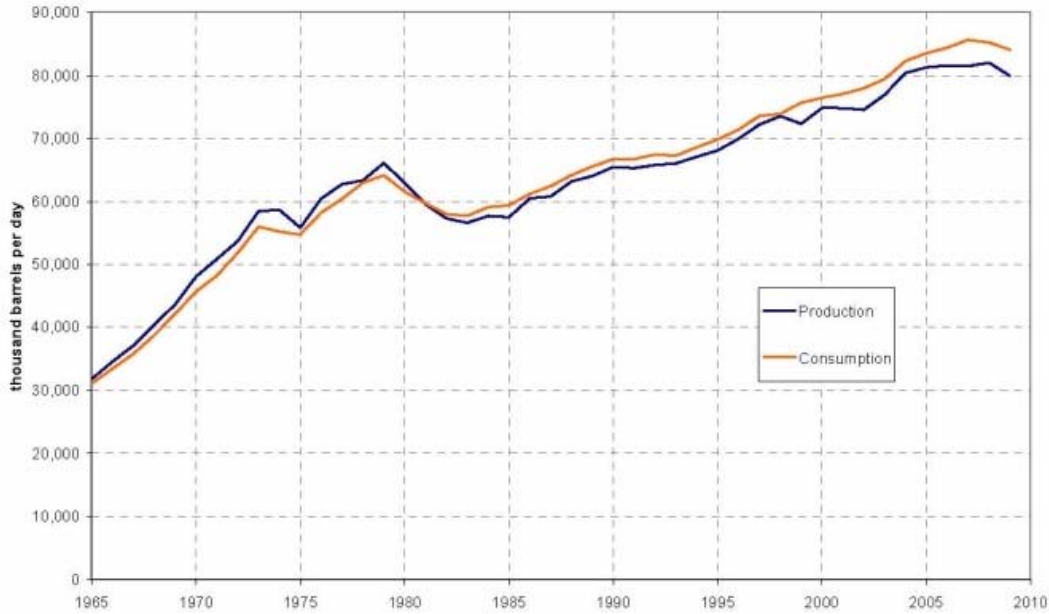


Figure 1 Historical Oil Production and Consumption

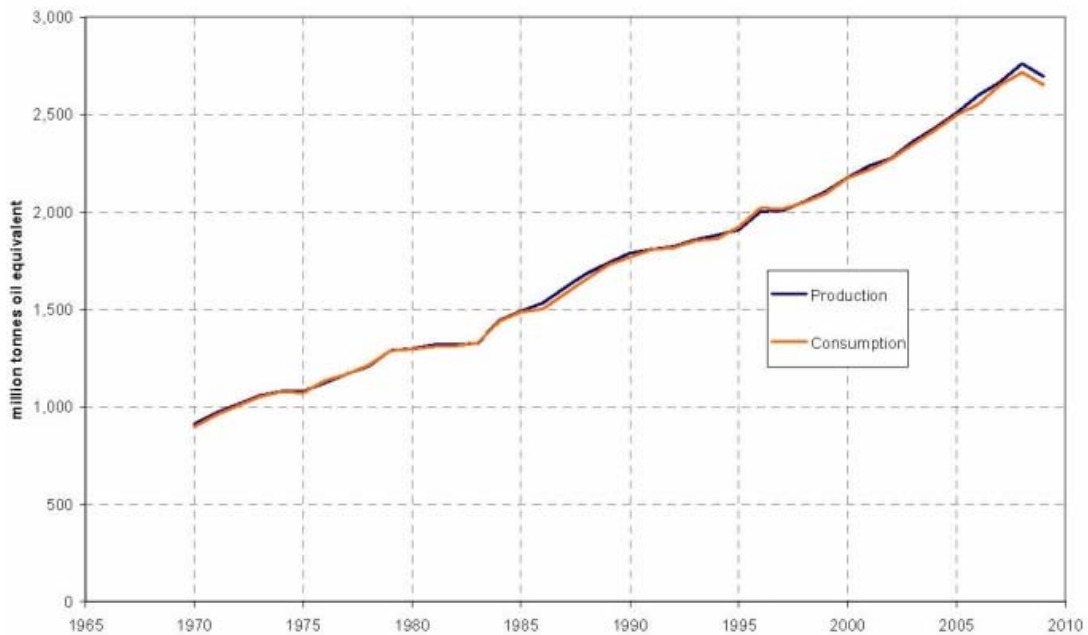


Figure 2. Historical Gas Production and Consumption

It is one of the quirks of nature that the petroleum is deposited in areas remote from the major centers of development across the globe. This has given rise to an industry that is truly global in reach and scale with oil being the largest internationally traded commodity by whatever measure is chosen (volume or monetary value).

This imbalance in supply and demand is illustrated for oil in Figure 3 below:

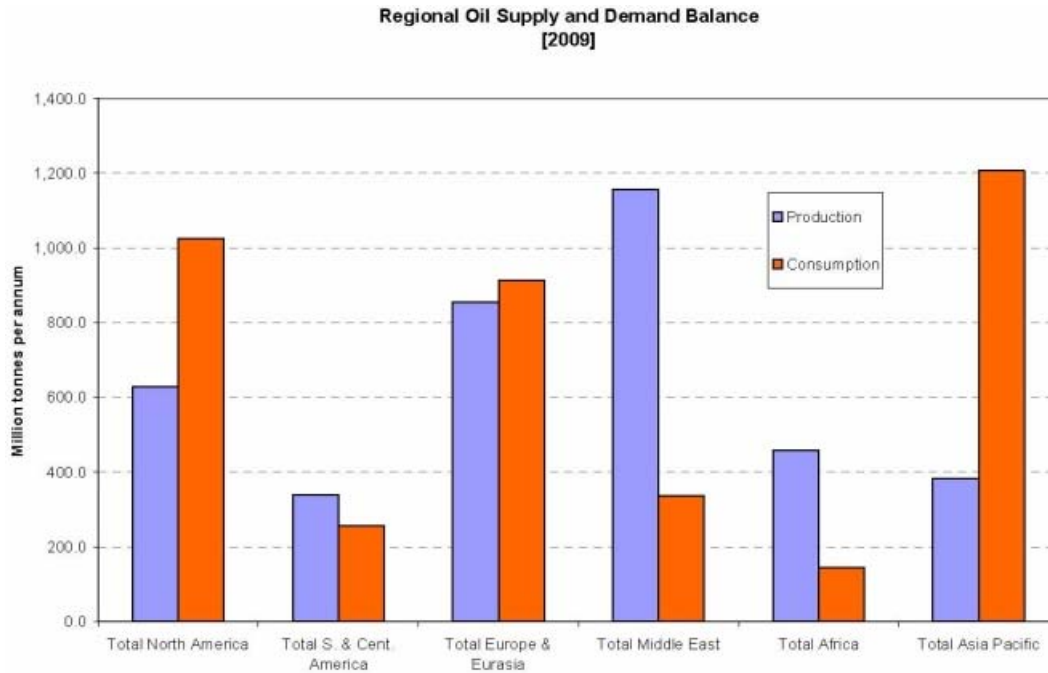


Figure 3. Regional Oil Supply and Demand

Due to the difficulties in storing and transporting gas over long distances there is less of a regional imbalance for natural gas as illustrated in Figure 4:

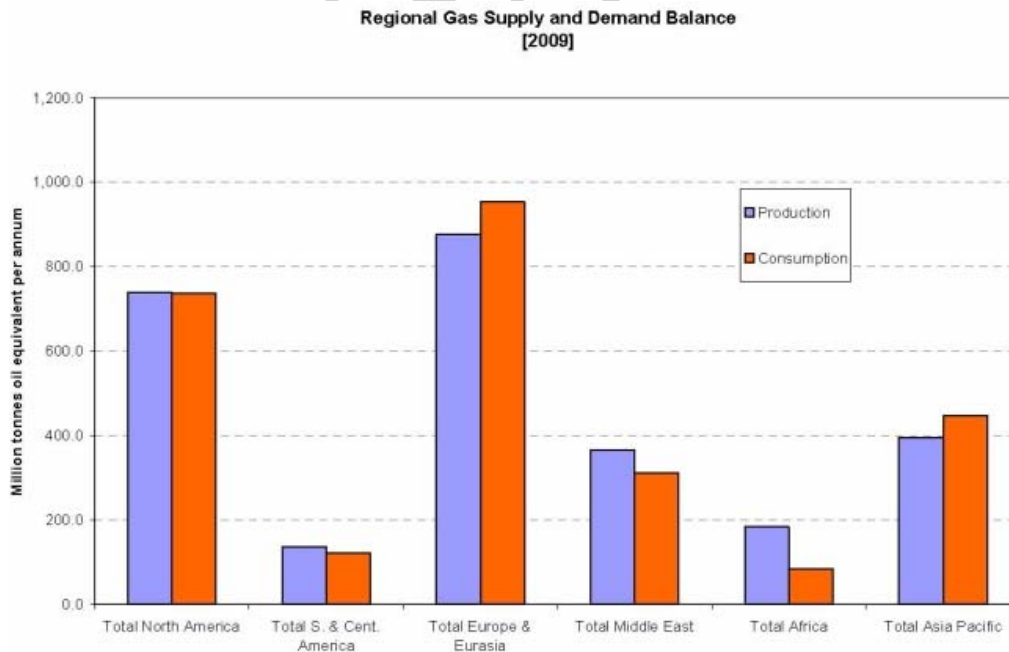


Figure 4. Regional Gas Supply and Demand

However, as demand for gas has increased in major developed markets to reduce carbon dioxide emissions, there has been an increase in the quantity of natural gas which is

liquefied at temperatures down to -162°C in order to transport it as a liquid – liquefied natural gas (LNG). In 2009 approximately 244 billion cubic meters of LNG was traded.

Proven reserves for oil and gas as of 2009 which remain to be produced are shown in Figure 5 and Figure 6 below:

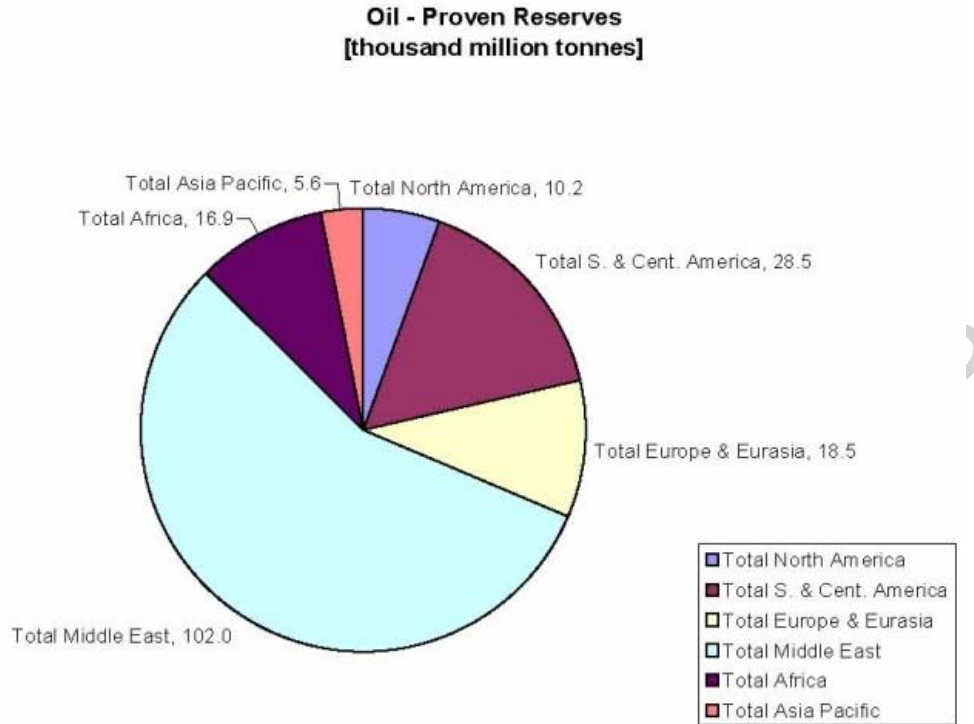


Figure 5. Proven Oil Reserves

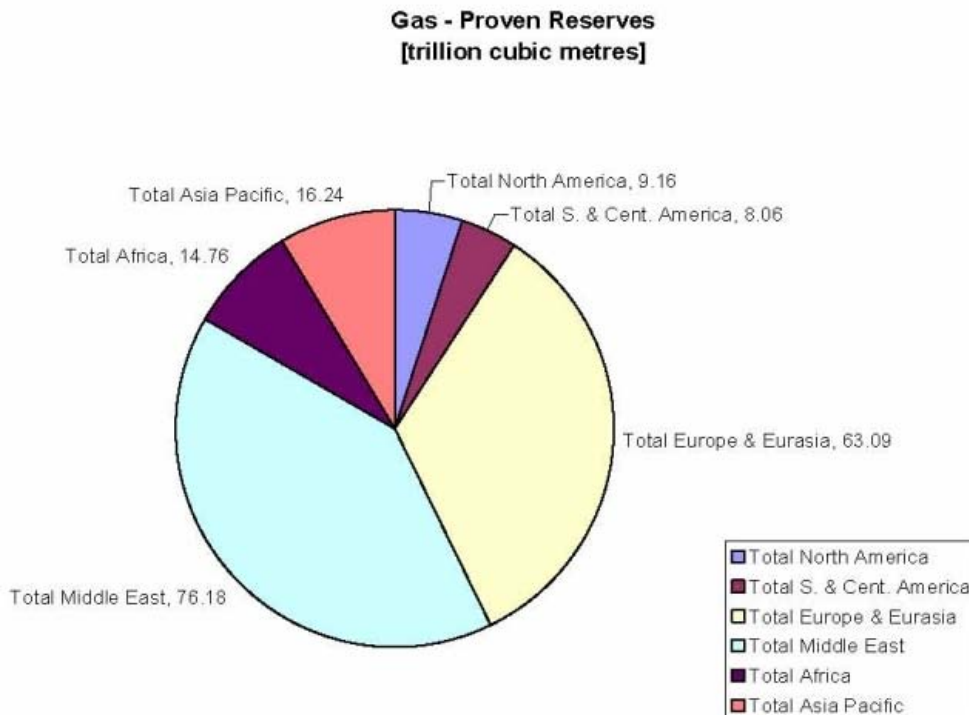


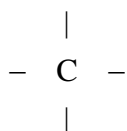
Figure 6. Proven Gas Reserves

3. Chemistry of Petroleum

Chemically, crude oils are complex mixtures of a vast number of individual chemical compounds and the proportions of these compounds differ depending on the source reservoir. Hence, every crude oil is chemically different and even crude oil found within the same oil field can vary depending on its location within the reservoir as not all accumulations of oil are connected due to the rock strata.

The bulk of the chemical compounds found within crude oil consist entirely of carbon and hydrogen known generically as hydrocarbons.

The carbon atom has four valency linkages available for attachment to other atoms:



The main hydrocarbon series present in crude oils consist of saturated chain and ring-like structures known as paraffins (alkanes), naphthenes (cyclo-alkanes) and aromatics.

There are two alkane series composed of chains of linked carbon atoms which both have the general composition C_nH_{n+2} . The normal-alkanes have a straight un-branched chain whereas the iso-alkanes have branched chains. These are illustrated below:

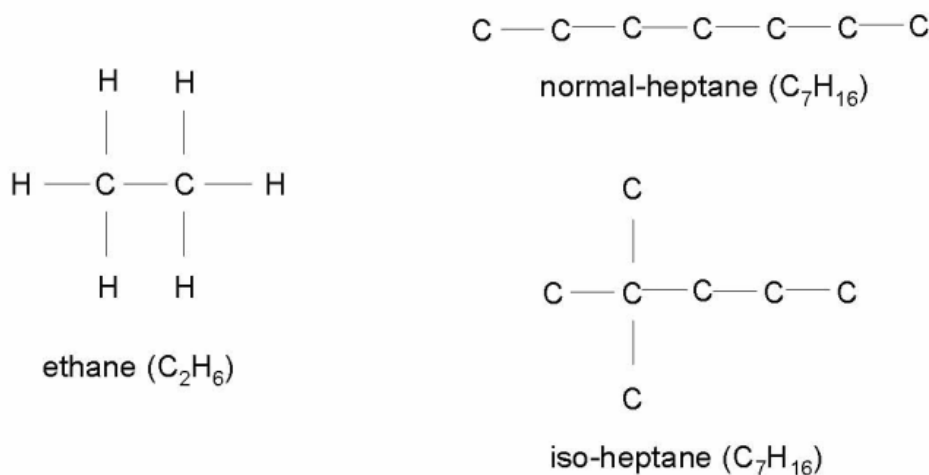


Figure 7. Alkanes

There are two cyclo-alkane series composed of carbon atoms linked in ring-like central structures which both have the general composition C_nH_{2n} . The cyclo-pentane series consists of five carbon atoms in the ring, and the cyclo-hexanes have a six-membered ring. These are illustrated in Figure 8 below:

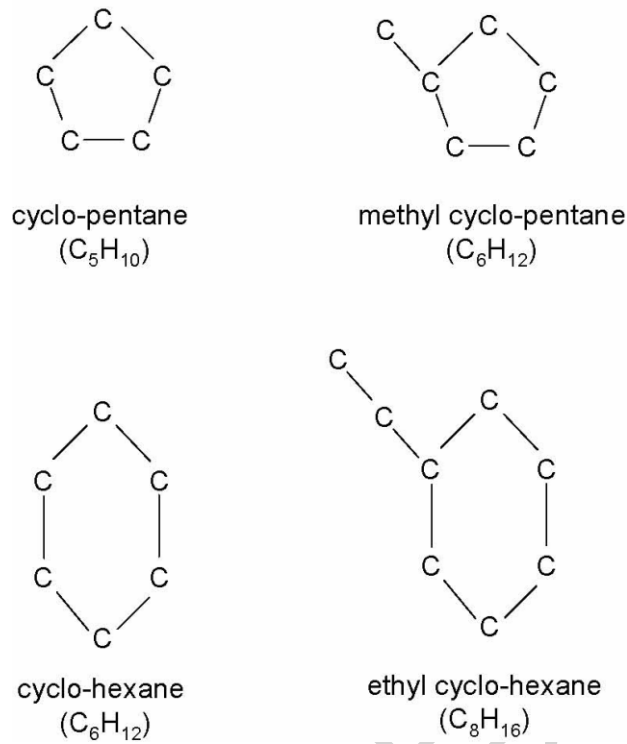


Figure 8. Cyclo-alkanes

The basic building block of the aromatic series is the benzene ring (C_6H_6) as illustrated in Figure 9 below:

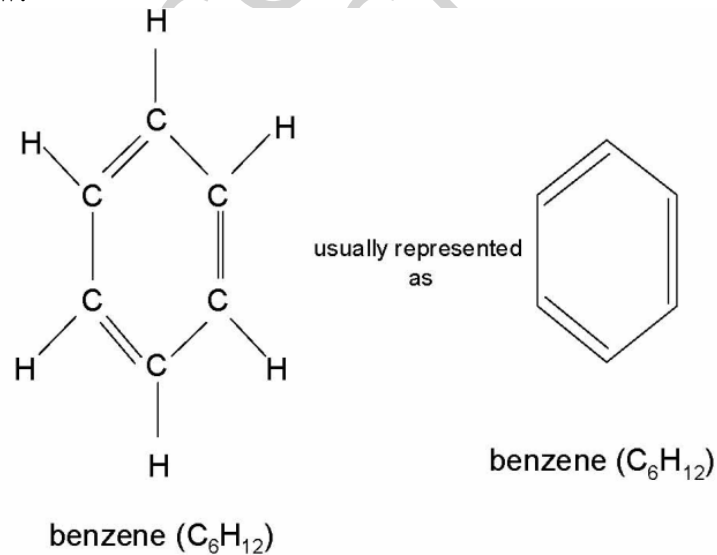


Figure 9. Benzene Ring

Aromatic series are then formed from progressive substitution of hydrogen atoms on the outside of the ring with alkanes or further benzene rings as illustrated in Figure 10 below:

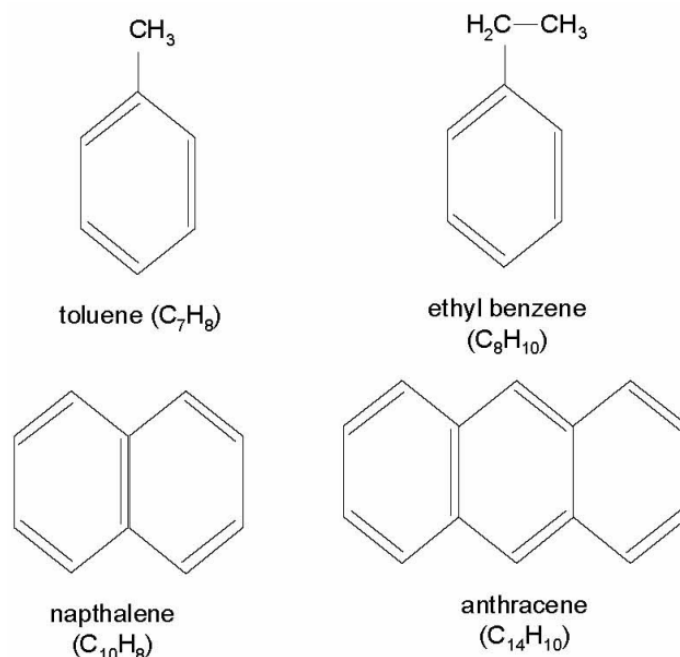


Figure 10. Aromatics

Crude oils also contain relatively small proportions of the elements sulfur, oxygen, nitrogen, vanadium and nickel which are chemically attached to hydrocarbon-like chains and rings.

Refining processes which “crack” larger molecules to produce additional light and middle distillates produce other hydrocarbon series, such as alkenes, which are present in the finished products.

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Biographical Sketch

Colin Deddis is a Chartered Engineer and Fellow of the Institution of Chemical Engineers, with over 20 years experience, predominantly in the oil and gas industry. He began his career with BP in oil refining and gas processing supporting operations and brownfield projects before moving into BP's upstream business where he has held positions supporting offshore production operations and as a lead process engineer on major projects. In the last several years he worked as a lecturer in Chemical Engineering Design at the University of Cambridge before moving back into the oil industry as an engineering consultant prior to rejoining BP in 2007. Colin is currently a Senior Process Engineer working in BP's Exploration and Production Technology Group. In this role he provides internal technical services to major projects and operations and is involved in technology development in the areas of separation and sand management.