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CHM 306

Petroleum Chemistry

Module 1

CHM 306 Petroleum Chemistry Module 1

Course Developer/Writer
Dr A. A. Kasali, Lagos State University, Ojo Lagos

Course Editor
Dr Olusegun Abiola, University of Lagos, Akoka Lagos

Course Coordinator
Dr H. Aliyu & Mr. Adakole Ikpe, National Open University of Nigeria

Programme Leader
Prof Femi Peters, National Open University of Nigeria

Credits of cover-photo: Henry Ude, National Open University of Nigeria

National Open University of Nigeria - 91, Cadastral Zone, Nnamdi Azikiwe Express Way, Jabi, Abuja, Nigeria

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Module 1 Basic Concepts in Petroleum Chemistry

Unit 1 Origin of Crude Oil

1.0 Introduction

This unit will explain petroleum and its origin. It will also introduce you to generation of petroleum (crude oil) and the link between crude oil and photosynthesis. In addition, the importance of carbon cycle in maintaining the carbon balance as well as the fate of organic matter in sediments viz-a-viz the three main stages of transformation of organic matter in sediments will also be discussed.

2.0 Objectives

At the end of this unit, you should be able to:

- define crude oil
- describe the involvement of photosynthesis in production of crude oil
- explain the carbon cycle
- show diagrammatically the carbon cycle
- describe the three main stages of organic matter in sediments: diagenesis, catagenesis and metagenesis.

3.0 Main Content

3.1 Definition of Petroleum (Crude oil)

Petroleum can be broadly defined as the complex mixture of hydrocarbons that occurs in the earth in liquid, gaseous, or solid forms. It is a naturally-occurring brown to black flammable liquid (Fig. 1). Crude oils are principally found in oil reservoirs associated with sedimentary rocks beneath the earth's surface.

Fig.1: A Sample of Medium Heavy Crude Oil

(Source: http//www.wikipedia.org)

3.2 Generation of Petroleum (Crude Oil)

Although exactly how crude oil originated is not established, it is generally agreed that crude oil is derived from marine animal and plant debris subjected to high temperatures and pressures. It is also suspected that the transformation may have been catalysed by rock constituents. Regardless of their origins, crude oil is mainly constituted of hydrocarbons mixed with variable amounts of sulphur, nitrogen, and oxygen compounds. Metals in the forms of inorganic salts or organometallic compounds are present in the crude mixture in trace amounts, the ratio of the different constituents in crude oil, however, varies appreciably from one reservoir to another.

Petroleum generation occurs over long periods of time—millions of years. In order for petroleum generation to occur, organic matter such as dead plants or animals must accumulate in large quantities. The organic matter can be deposited along with sediments and later buried as more sediments accumulate on top. The sediments and organic material that accumulate are called source rock. After burial, chemical activity in the absence of oxygen allows the organic material in the source rock to change into petroleum without the organic matter simply rotting. A good petroleum source rock is a sedimentary rock such as shale or limestone that contains between 1and 5% organic carbon.

Rocks occur in many environments, including lakes, deep areas of the seas and oceans, and swamps. The source rocks must be buried deep enough below the surface of the earth to heat up the organic material, but not so deep that the rocks metamorphose or that the organic material changes to graphite or materials other than hydrocarbons. Temperatures of less than 302°F (150°C) are typical for petroleum generation.

Geologists often refer to the temperature range in which oil forms as an “oil window” below the minimum temperature oil remains trapped in the form of kerogen, and above the maximum temperature the oil is converted to natural gas through the process of thermal cracking. Although this temperature range is found at different depths below the surface throughout the world, a typical depth for the oil window is 4–6 km. Sometimes, oil which is formed at extreme depths may migrate and become trapped at much shallower depths than where it was formed. The Athabasca Oil Sands is an example of this.

According to generally accepted theory, petroleum is derived from ancient biomass. The theory was initially based on the isolation of molecules from petroleum that closely resemble known biomolecules **(**Fig. 2**)**. A number of geologists in Russia adhere to the abiogenic petroleum origin hypothesis and maintain that hydrocarbons of purely inorganic origin exist within Earth’s interior. Astronomer Thomas Gold championed the theory in the Western world by supporting the work done by Nikolai Kudryavtsev in the 1950s. It is currently supported primarily by Kenney and Krayushkin.

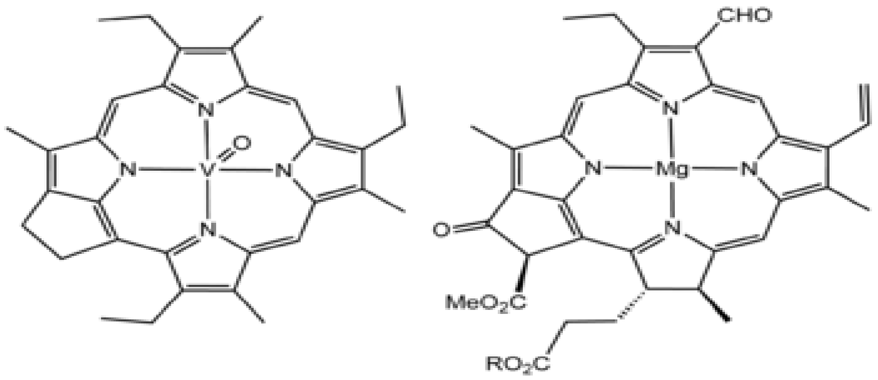

Fig. 2: Structure of Vanadium porphyrin compound (left) extracted from petroleum by Alfred Treibs, father of organic geochemistry. Treibs noted the close structural similarity of this molecule and chlorophyll (right)

Biomass, a renewable energy source, is biological material derived from living, or recently living organisms, such as wood, waste, and alcohol fuels. Biomass is commonly plant matter grown to generate electricity or produce heat. For example, forest residues (such as dead trees, branches and tree stumps), yard clippings and wood chips may be used as biomass. However, biomass also includes plant or animal matter used for production of fibers or chemicals. Biomass may also include biodegradable wastes that can be burnt as fuel. It excludes organic material such as fossil fuels which have been transformed by geological processes into substances such as coal or petroleum. Although fossil fuels have their origin in ancient biomass, they are not considered biomass by the generally accepted definition because they contain carbon that has been "out" of the carbon cycle for a very long time. Their combustion therefore disturbs the carbon dioxide content in the atmosphere.

The abiogenic origin hypothesis lacks scientific support. Extensive research into the chemical structure of kerogen has identified algae as the primary source of oil. The abiogenic origin hypothesis fails to explain the presence of these markers in kerogen and oil, as well as failing to explain how inorganic origin could be achieved at temperatures and pressures sufficient to convert kerogen to graphite. It has not been successfully used in uncovering oil deposits by geologists, as the hypothesis lacks any mechanism for determining where the process may occur.

3.3 Production and Accumulation of Organic Matter

In spite of the common occurrence of petroleum, and the great amount of scientific research on it that has been carried out by many researchers, there remain many unresolved questions regarding its origin. Although it is recognised that the original source of carbon and hydrogen in petroleum was in the original materials that made up the primordial earth, it is generally accepted that these two elements have to pass through an organic phase to be combined into the varying complex molecules recognised as petroleum. There are numerous geochemical and geological reasons for this belief, a few of which are listed below:

- Petroleum is commonly associated with sedimentary rocks, principally those deposited under marine conditions but also including continental sediments. Conversely, there is a complete absence of commercial deposits of petroleum where only igneous or metamorphic rocks are present.

- The optical activity of petroleum (the ability to rotate the plane of polarised light) is almost completely confined to compounds of biogenic origin.
- Most types of petroleum contain complex hydrocarbon compounds termed porphyrins, formed either from the green colouring matter of plants (chlorophyll) or from the red colouring matter of blood (hemin).
- Carbon isotope ratios ($^{12}C/^{13}C$) indicate that petroleum may be derived in large part from the lipid (fats and waxes) fractions of organisms.
- Many petroleum-like hydrocarbons have been found in recent marine sediments as well as in soils in many places throughout the world. This occurrence forms a link between present living organisms and the petroleum found in sediments of older geological ages.

Thus, in order to produce petroleum, organic matter has to be synthesised by living organisms and thereafter deposited and preserved in sediments. Depending on further geological events, part of the sedimentary organic matter may be transformed into petroleum-like compounds called source rock. It is important to realise that during the history of the earth the conditions for synthesis, deposition and preservation of organic matter have changed.

Self-Assessment Exercise

1. What is petroleum?
2. Why it is that crude oil cannot be used directly for the production of chemicals?
3. What are the constituents of crude oil?
4. What are kerogens?

3.4 Organic Source Materials

The organic material that is the source of most petroleum has probably been derived from the single-celled planktonic (free-floating) plants such as diatoms and blue green algae, and single celled planktonic animals such as foraminifers, that live in fresh water. These simple forms were abundant in seas long before the beginning of the Paleozoic Era (The Paleozoic covers the period from the first appearance of abundant, soft-shelled fossils to when the continents were beginning to be dominated by large, relatively sophisticated reptiles and modern plants) 570,000,000 years ago, and could have formed the source organisms of the petroleum found in the Precambrian and early Paleozoic rocks they also may have contributed to much of the petroleum found in younger rocks.

In addition, land plants brought into the lakes and seas by rivers apparently have been the source of some crude oils. The larger, more complex forms of sea life-such as corals, mollusks, crustaceans and shellfish are neither abundant enough nor are their remains adequately preserved from the sea scavengers to constitute a source for crude oil.

All organic matter can be divided into the classes of proteins (amino acids), carbohydrates (sugars, cellulose), lignin, pigments (including porphyrins), and lipids (fats, fatty acids). All but lignin are present in both living plants and animals the source materials for petroleum are among these five building blocks of living organisms.

The proteins and their amino acids are relatively easily decomposed and probably contribute little to the petroleum source material (organic matter). Carbohydrates make up the major portion of both plant and animal matter. They are subject to rapid and nearly total degradation but may provide a logical source material for some petroleum.

Lignins must definitely be considered as a major contributor to organic deposits of land plants, and although these have contributed largely to lignite and coal deposits, many authorities believe that they may constitute a progenitor of petroleum hydrocarbons as well. The pigments, particularly the porphyrins, are known to form a minor but recognisable source of crude oil.

It is lipids, however, that may form the chief and primary source of petroleum. Biochemically the lipids (fats and fatty acids) are insoluble in water but are soluble in ether, benzene, or chloroform. Some of the planktonic plants (phytoplanktons) produce and store fatty oils during photosynthesis. Moreover the $^{13}C/^{12}C$ ratios in petroleum closely resemble the ratios found in the lipid fractions of the various phytoplanktons. Because the lipid fraction, which contains the hydrocarbons most closely resembling petroleum, it is much more stable than the water-soluble proteins and carbohydrates. It could well be the main building block from which petroleum is constructed.

3.5 Photosynthesis: the Basis for Mass Production of Organic Matter

Photosynthesis is the basis for the mass production of organic matter. About two billion years ago in Precambrian time, photosynthesis appeared as a worldwide phenomenon. The emergence of photosynthesis as a worldwide phenomenon is a noteworthy historical event with respect to the formation of potential source rocks. Photosynthetic process converts light energy into chemical energy. It is basically a transfer of hydrogen from the water to carbon dioxide to produce organic matter in the form of glucose and oxygen.

The oxygen produced in this reaction is from the water molecule and not from the carbon dioxide. Autotrophic organisms (are organisms that produce their own organic compounds using carbon dioxide from the air or water in which they live) can then synthesise polysaccharide, such as cellulose and starch, and all other necessary constituents from the glucose produced during photosynthesis. Primitive autotrophic organisms, such as photosynthetic bacteria and blue-green algae were the first organisms responsible for this mass production. A basic requirement for photosynthesis is the light absorbing green pigment called chlorophyll (Equation 1)

$$6CO_2 + 12H_2O^* \underset{674\text{Kcal}}{\overset{h.v}{\rightleftharpoons}} C_6H_{12}O_6 + 6O_2^* + 6H_2O$$

(Glucose)

$$\downarrow$$

Polysaccaride

Equation 1: Equation of Photosynthesis. Glucose relatively rich in energy is formed by green plants with the help of sunlight (h.v). Oxygen is the by-product of this process

You may be wondering that of what significance is photosynthesis to the production of organic matter which eventually leads to the production of source rocks. However, do not lose sight of the fact that without the production of glucose as a result of photosynthesis there will be nothing for autotrophic organisms to synthesise polysaccharide.

3.6 Carbon Cycle

A closer look at the equation of photosynthesis shows that carbon dioxide is used up in the reaction. Since photosynthesis is a continuous process it will come to a time that all the carbon dioxide in the atmosphere will be used up and photosynthesis will come to a stop and subsequently deposition of organic matter will also stop. However, this does not happen, carbon dioxide is reintroduced into the atmosphere. Thus, reintroduction and mass balance of carbon used in photosynthesis is what is known as carbon cycle.

The carbon cycle is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth. The carbon cycle is usually thought of as four major reservoirs of carbon interconnected by pathways of exchange. These reservoirs are:

- The plants
- The terrestrial biosphere, which is usually defined to include fresh water systems and non-living organic material, such as soil carbon.
- The oceans, including dissolved inorganic carbon and living and non-living marine biota.
- The sediments including fossil fuels.

The annual movements of carbon, the carbon exchanges between reservoirs, occur because of various chemical, physical, geological, and biological processes. The ocean contains the largest active pool of carbon near the surface of the Earth, but the deep ocean part of this pool does not rapidly exchange with the atmosphere. The global carbon budget is the balance of the exchanges (incomes and losses) of carbon between the carbon reservoirs or between one specific loop (e.g., atmosphere ↔ biosphere) of the carbon cycle. An examination of the carbon budget of a pool or reservoir can provide information about whether the pool or reservoir is functioning as a source or sink for carbon dioxide.

Most of the carbon on earth is concentrated in sedimentary rocks of the earth's crust. Part of it is fixed as organic carbon, and a greater part as carbonate carbon i.e. compounds containing carbonate anion. A relationship of course exists between organic carbon and carbonate carbon. The atmospheric carbon dioxide reservoir is in a constant exchange with the hydrospheric carbon dioxide reservoir. From aquatic environments, carbonates may be precipitated or deposited by organisms (shells, skeleton etc.) to form carbonate sediments. Conversely, carbonate rocks may be dissolved to contribute to the equilibrium reaction between CO_3^{2-}, HCO_3^- and CO_2 in waters.

Primary organic matter is formed directly from the atmospheric reservoir by terrestrial plants, or by photosynthesis of marine plants from dissolved CO_2 in the hydrosphere.

Terrestrial and marine organic matter, in turn, is largely destroyed by oxidation. Thus, CO_2 is returned for re-circulation in the system. A simplified sketch showing the main processes and pathways concerning the element carbon in the earth's crust is given in Figure 3. Only an almost negligible portion of the organic carbon in the earth's crust, including the hydrosphere, is found in living organisms and in dissolved state.

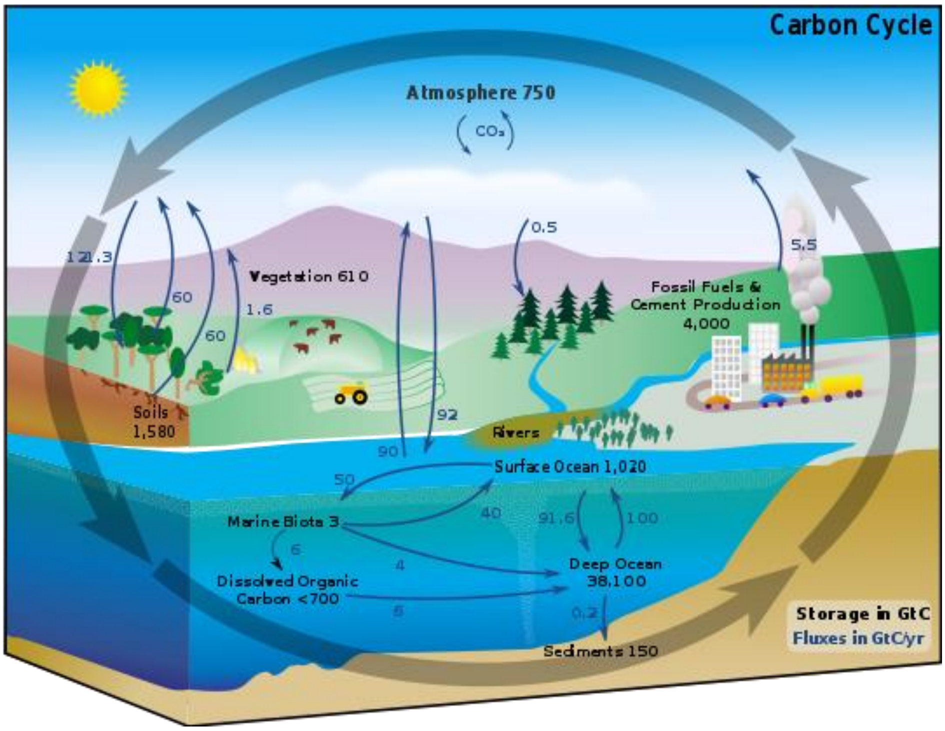

Fig. 3: Diagram of the Carbon Cycle

The black numbers indicate how much carbon is stored in various reservoirs, in billions of tons ("GtC" stands for GigaTons of Carbon and figures are circa 2004). The purple numbers indicate how much carbon moves between reservoirs each year. The sediments, as defined in this diagram, do not include the ~70 million GtC of carbonate rock and kerogen.

(Source: http//www.wikipedia.org)

Self-Assessment Exercise

1. Explain the term autotrophic organism
2. List the four major reservoirs of carbon
3. What information can you obtain by examining the budget of a pool or reservoir

4.0 Conclusion

This unit has examined the origin of petroleum, what crude oil is and its generation. Also, it has showed the link between photosynthesis and crude oil. Photosynthesis as the basis for mass accumulation of organic matter was also discussed. In addition, the role of carbon cycle in reintroducing and maintaining mass balance of carbon dioxide used in photosynthesis was also examined.

5.0 Summary

This unit has introduced you to the origin of crude oil, the prerequisite for the existence of petroleum source rock. Furthermore, it defined organic matter or material as materials comprised of organic molecules in monomeric or polymeric forms, derived directly or indirectly from organic parts of organisms. In addition, it divides all organic matters into five classes namely proteins (amino acids), carbohydrates (sugar, cellulose), lignin, pigments (including porphyrins) and lipids.

Finally, the unit has also introduced you to conditions necessary for the production of petroleum which include synthesis of organic matter by living organisms, deposition and preservation of such organic matter.

6.0 Self-Assessment Exercise

1. What are the facts that support the theory that carbon and hydrogen found in crude oil were in the original materials that made up primordial earth i.e. organic.
2. State why abiogenetic theory / hypothesis failed.
3. Define the following terms:
    a. Oil window
    b. Source rock
    c. Paleozoic era
    d. Precambrian era

7.0 References/Further Reading

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Unit 2 Fate of Organic Matter in Sedimentary Basins

1.0 Introduction

This unit will discuss the transformation of organic matter deposited in sediments. It will also discuss the various geological boundary conditions controlling the accumulations of organic in sediments.

Furthermore, it will discuss the physicochemical transformation of organic matter in sediments, and will also discuss factors that determine the variation of sediments. A general scheme of evolution of organic matter from time of deposition in sediments will also be examine. In order to understand the discussion the following stages of evolution: diagenesis, catagenesis, metagenesis and metamorphism will be considered.

2.0 Objectives

At the end of this unit, you should be able to:

- state the favourable conditions for the deposition of sediments rich in organic matter
- define and discuss diagenesis, catagenesis and metagenesis
- explain transformation of organic matter.

3.0 Main Content

3.1 Accumulation of Organic Matter

Production, accumulation and preservation of undegraded organic matter are prerequisites for the existence of petroleum. It should be noted that the term "organic matter' does not include mineral skeletal parts, such as shells, bones, and teeth. The accumulation of organic matter in sediments is controlled by a number of geological boundary conditions. It is practically restricted to sediment deposited in aquatic environments, which must receive a certain minimum amount of organic matter. This organic matter can be supplied either in the form of dead or living particulate organic matter or as a dissolved organic matter. The organic material may be autochthonous to the environment where it is deposited, that is, it originated in the water column above or within the sediment in which it is buried, or it may be allochthonous, i.e., foreign to its environment of deposition. Both the energy situation in the water body in question and the supply of mineral sedimentary particles must be such as to allow a particular kind of sedimentation. If the energy level in a body of water is too high, either there is erosion of sediment rather than deposition, or deposited sediment is too coarse to retain low-density organic material.

An example is a beach area with strong wave action. Furthermore, in coarse-grained sediment, ample diffusion of oxygen is possible through the wide open pores. On the other hand, if the level of energy is very low, too little sediment is supplied, and there is, like-wise, no appreciable organic sedimentation. Examples of this type occur in certain parts of the deep sea.

Once these boundary conditions are satisfied, the accumulation of organic matter in sediment is dependent on the dualism between processes that conserve and concentrate and those that destroy and dilute organic matter.

3.2 Diagenesis

Sediments deposited in sub-aquatic environments contain large amounts of water (the amount of water is 60% of the total weight of sediment), minerals, dead organic material, and numerous living microorganisms. Such a mixture results from various sedimentary processes and primary components of very different origin it is not in equilibrium and therefore unstable, even if microorganisms are not present. Diagenesis is a process through which the system tends to approach equilibrium under conditions of shallow burial, and through which the sediment normally becomes consolidated. The depth interval concerned is in the order of a few hundred meters, occasionally to a few thousand meters. In the early diagenetic process, the increase in temperature and pressure is small and transformation of the sediments occurs under mild conditions.

During early diagenesis, microbial activity transforms the sediment. Anaerobic organisms reduce sulphates to free oxygen; the oxygen so produced is consumed by aerobic microorganisms that live in the uppermost layer of sediments. The energy required is provided by the decomposition of organic matter, which in the process is converted into carbon dioxide, ammonia and water. The conversion is usually carried out completely in sands and partly in mud. During this period, the Eh decreases abruptly and the pH increases slightly. In addition, certain solids like $CaCO_3$ and SiO_2 dissolve and reach saturation and re-precipitate, together with authigenic minerals such as sulphides of iron, copper, lead and zinc.

Within the sediment, organic material proceeds towards equilibrium. Furthermore, during diagenesis proteins and carbohydrates (known as biogenic polymers or biopolymers) are destroyed by microbial activity. Their constituents become progressively engaged in new polycondensed structures leading to the production of *kerogen.* Kerogen is the organic constituent of sedimentary rocks that is not soluble in aqueous alkaline solvents or in common organic solvents. The part of the sedimentary rock that is soluble in organic solvents is known as bitumen. Kerogen is the most important form of organic carbon on earth, and it is 100 times more abundant than coal plus petroleum in reservoirs, and is 50 times more abundant than bitumen. Kerogens that have a high hydrogen / carbon ratio have potential for oil and gas generation.

Thus diagenesis begins in recently deposited sediments where microbial activity occurs. At the end of diagenesis, the organic matter consists mainly of a fossilised, insoluble organic residue called kerogen.

3.3 Catagenesis

Continuous deposition of sediments results in the burial of previous bed to a depth reaching several kilometers of overburden in subsiding basins. This leads to a considerable increase in temperature and pressure. Such increase again places the system out of equilibrium and results in new changes. There are some changes in the clay fraction while the mineral phase's composition and texture are conserved. The main inorganic modification at this stage involves the compaction of the rock, water continue to be expelled, porosity and permeability decreases greatly, salinity of the interstitial water increases and may come close to saturation.

On the other hand, liquid petroleum is first produced by the kerogen generated in the diagenesis stage. In a later stage, wet gas and condensate are produced. Both liquid oil and condensate are accompanied by significant amount of methane. These are the major changes that the organic matter experience during catagenesis.

The end of catagenesis is reached when the disappearance of aliphatic carbon chain in kerogen is completed. Catagenesis results from an increase in temperature during burial in sedimentary basins. Thermal breakdown of kerogen is responsible for the generation of most hydrocarbons.

3.4 Metagenesis

The last stage of the evolution of sediments is known as metagenesis. Metagenesis is reached only at great depth, where temperature and pressure are high. At this stage, organic matter is composed only of methane and a carbon residue. The constituents of residual kerogen are converted to graphite carbon. Minerals are severely transformed under this condition, clay mineral lose their interlayer water and gain a higher stage of crystallinity iron oxides containing structural water (goethite) change to oxides without water (hematite) etc. severe pressure dissolution and recrystallisation occur, like the formation of quartizite, and may result in a disappearance of the original rock structure. The rock reaches temperature conditions that lead to the metagenesis of organic matter. At this stage, the organic matter is composed only of methane and a carbon residue, where some crystalline ordering begins to develop. Coals are transformed into anthracite.

Self-Assessment Exercise

1. Explain the following terms:
    a. Autochthonous
    b. Allochthontous

3.5 Transformation of Organic Matter

The time covering sedimentation processes and residence in the young sediment, freshly deposited, represents a very special stage in the carbon cycle. The first few meters of sediment, just below the water-sediment contact, represent the interface through which organic carbon passes from the biosphere to the geosphere. The residence period of organic compounds in this zone of the sedimentary column is long compared to the lifetime of the organisms, but very short compared to the duration of geological cycles e.g. 1-m section often represents 500 to 10000 years.

During sedimentation processes, and later in such young sediments, organic material is subjected to alterations by varying degrees of microbial and chemical actions. As a result, its composition is largely changed and its future fate during the rest of the geological history predetermined within the framework of its subsequent temperature history. When comparing the nature of the organic material in young sediments with that of the living organisms from which it was derived, the striking point is that most of the usual constituents of these organisms, and particularly the biogenic macromolecules, have disappeared.

Proteins, carbohydrates, lipids, and lignin in higher plants amount to nearly the total dry weight, on an ash-free basis, of the biomass living in sub-aquatic or sub-aerial environments. The total amount of the same compounds that can be extracted from very young sediments is usually not more than 20% of the total organic material, and often less. This situation results from degradation of the macromolecules by bacteria into individual amino acids, sugars, etc. As monomers, they are used for nutrition of the microorganisms, and the residue becomes polycondensed, forming large amounts of brown material, partly soluble in dilute sodium hydroxide, and resembling humic acids.

As a result of microbial activity in water and in sub-aquatic soils, biogenic polymers have been degraded, then used as much as possible for the metabolism of microorganisms. Thus, even in fine mud, a part of the organic matter has been consumed and has disappeared through conversion into carbon dioxide and water. Another part has been used to synthesise the constituents of the microbial cell, and thus is reintroduced into the biological cycle. The residue that cannot be incorporated by microorganisms is now incorporated into a new polycondensate, which is insoluble kerogen. This chemical process occurs under mild temperature and pressure conditions. Thus, the influence of the increase of temperature and pressure is likely to be subordinate, compared to the nature of the original organic constituents. This view is confirmed by the results of experimental evolution tests of heating organic matter under inert atmosphere in order to stimulate the transformations at greater depth that is catagenesis and metagenesis but not diagenesis.

At the end of diagenesis, organic matter still comprises minor amount of free hydrocarbons and related compounds. They have been synthesised by living organisms and incorporated in the sediment with no or minor changes. Thus, they can be considered as geochemical fossils, witnessing the depositional environment. As time and sedimentation proceed, the sediment is buried to several hundreds of meters. Most of the organic material becomes progressively insoluble as a result of increasing polycondensation associated with loss of superficial hydrophilic functional groups. This completely insoluble organic matter from sediments has received limited attention until recently. It is called "*humin*" by the few soil scientists who have worked on sub-aquatic soils. In ancient sediments, the insoluble organic matter is called *kerogen* and is obtained by demineralisation of the rock. The terms *humin* and *kerogen* are not strictly equivalent thus, humin, collectively with other insoluble organic matter such as pollen, spores, etc. may be considered as a precursor of kerogen.

Petroleum geochemists consider kerogen as the main source of petroleum compounds. The whole process is referred to as diagenesis and leads from biopolymers synthesised by living organisms to geopolymers (kerogen) through fractionation i.e. by separating the mixture into its components, partial destruction and rearrangement of the building blocks of the macromolecules. The transformation of sediments to kerogen can be assumed to occur or takes place in three steps viz-a-viz biochemical degradation, polycondensation and insolubilisation.

Kerogen is a mixture of organic chemical compounds that make up a portion of the organic matter in sedimentary rocks. It is insoluble in normal organic solvents because of the huge molecular weight (upwards of 1,000 Daltons) of its component compounds. The soluble portion is known as bitumen. When heated to the right temperatures in the Earth's crust, (*oil window* ca. 60°-120°C, *gas window* ca. 120°-150°C) some types of kerogen release crude oil or natural gas, collectively known as hydrocarbons (fossil fuels). When such kerogens are present in high concentration in rocks such as shale they form possible source rocks. Shales rich in kerogens that have not been heated to a sufficient temperature to release their hydrocarbons may form oil shale deposits.

As kerogen is a mixture of organic material, rather than a specific chemical, it cannot be given a chemical formula. Indeed its chemical composition can vary distinctively from sample to sample. Kerogen from the Green River Formation oil shale deposit of western North America contains elements in the proportions C 215 : H 330 : O 12 : N 5 : S 1.

There are three types of kerogen namely labile kerogen, refractory kerogen and inert kerogen. Labile kerogen breaks down to form heavy hydrocarbons (i.e. oils), refractory kerogen breaks down to form light hydrocarbons (i.e. gases), and inert kerogen forms graphite. However, when Van Krevelen diagram is used (Van Krevelen diagrams are a graphical-statistical method that cross-plots the oxygen: carbon and hydrogen: carbon ratios of petroleum) to classify kerogen. The following types of kerogen are arrived at:

Type I

- Containing alginite, amorphous organic matter, cyanobacteria, freshwater algae, and land plant resins
- Hydrogen:Carbon ratio > 1.25
- Oxygen:Carbon ratio < 0.15
- Shows great tendency to readily produce liquid hydrocarbons.
- It derives principally from lacustrine algae and forms only in anoxic lakes and several other unusual marine environments
- Has few cyclic or aromatic structures
- Formed mainly from proteins and lipids

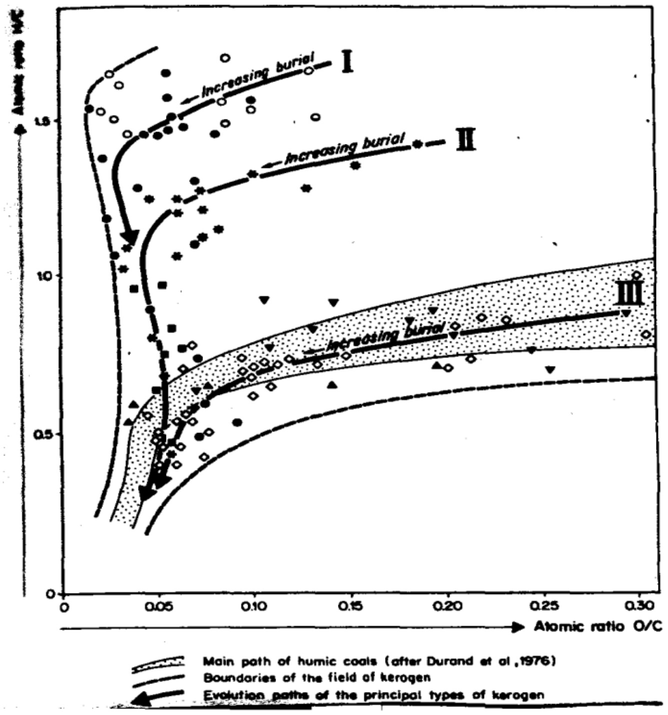

Fig. 1: Van Krevelen diagram (Principal types and evolution path of kerogen: types I, II and III are most frequent. Kerogen of intermediate composition also occurs. Evolution of kerogen composition with increasing burial is marked by an arrow along each evolution path I, II, and III (Source: Petroleum formation and occurrence. B. R. Tissot & D. W. Welte)

Type II

- Hydrogen:Carbon ratio < 1.25
- Oxygen:Carbon ratio 0.03 to 0.18
- Tend to produce a mix of gas and oil.
- Several types: exinite, cutinite, resinite, and liptinite
- Exinite: formed from the casings of pollen and spores
- Cutinite: formed from terrestrial plant cuticle
- Resinite: formed from terrestrial plant resins and animal decomposition resins
- Liptinite: formed from terrestrial plant lipids (hydrophobic molecules that are soluble in organic solvents) and marine algae
- They all have great tendencies to produce petroleum and are all formed from lipids deposited under reducing conditions.

Type II-Sulphur

- Similar to Type II but high in sulphur.

Type III

- Hydrogen:Carbon ratio < 1
- Oxygen:Carbon ratio 0.03 to 0.3
- Material is thick, resembling wood or coal.
- Tends to produce coal and gas (recent research has shown that type III kerogens can actually produce oil under extreme conditions).
- Has very low hydrogen because of the extensive ring and aromatic systems

Kerogen Type III is formed from terrestrial plant matter that is lacking in lipids or waxy matter. It forms from cellulose, the carbohydrate polymer that forms the rigid structure of terrestrial plants, lignin, a non-carbohydrate polymer formed from phenyl-propane units that binds the strings of cellulose together, and terpenes and phenolic compounds in the plant.

Most of the biomass that eventually becomes petroleum is contributed by the bacteria and protists that decompose the primary matter, not the primary matter itself. However, the lignin in this kerogen decomposes to form phenolic compounds that are toxic to bacteria and protists. Without this extra input, it will only become methane and/or coal.

Type IV (Residue)

- Hydrogen:Carbon < 0.5

Type IV kerogen contains mostly decomposed organic matter in the form of polycyclic aromatic hydrocarbons. They have no potential to produce hydrocarbons.

3.6 From Kerogen to Petroleum

As sedimentation and subsidence continue, temperature and pressure increase. In this changing physical environment, the structure of the immature kerogen is no longer in equilibrium with its surroundings. Rearrangements will progressively take place to reach a higher, and thus more stable, degree of ordering. The steric hinderances for higher ordering have to be eliminated. They are, for instance, nonpolar cycles (e.g., saturated cycles) and linkages with or without heteroatoms, preventing the cyclic nuclei from a parallel arrangement.

This constant adjustment of kerogen to increasing temperature and pressure results in a progressive elimination of functional groups and of the linkages between nuclei (including carbon chains). A wide range of compounds is formed, including medium to low molecular weight hydrocarbons, carbon dioxide, water, hydrogen sulphide, etc. Therefore, the petroleum generation seems to be a necessary consequence of the drive of kerogen to adjust to its new surroundings by gaining a higher degree of order with increasing overburden.

Kerogen is a polycondensed structure formed under the mild temperature and pressure conditions of young sediments and metastable under these conditions. Therefore, its characteristics seem to remain rather constant, even in ancient sediments, as long as they are not buried deeply. In most cases, however, as sedimentation and subsidence proceed, kerogen is subjected to a progressive increase of temperature and pressure. It is no longer stable under the new condition. Rearrangements occur during the successive stages of diagenesis, catagenesis, and metagenesis toward thermodynamic equilibrium.

Diagenesis of kerogen is marked by decrease of oxygen and a corresponding increase of carbon content with increasing depth. With reference to van Krevelen diagram (Figure 1), this stage of evolution results in a slight decrease in the ratio of hydrogen / carbon and a marked decrease of oxygen / carbon. Infrared spectroscopy has demonstrated that the decrease of oxygen is due essentially to the progressive elimination of carbonyl (C=O) group. In terms of petroleum exploration, this stage corresponds to an immature kerogen, and little hydrocarbon generation has occurred in the source rock. However, large quantities of carbon dioxide and water and also some heavy heteroatomic (N, S, O) compounds may be produced in relation to oxygen elimination.

Catagenesis, the second stage of kerogen degradation, is marked by an important decrease of the hydrogen content and of the hydrogen to carbon ratio, due to generation and release of hydrocarbons. Again, in terms of petroleum exploration, the stage of catagenesis corresponds to the main zone of oil generation and also to the beginning of the cracking zone, which produces "wet gas" with a rapidly increasing proportion of methane. As temperature continues to increase, the kerogen reaches the stage of catagenesis. More bonds of various types are broken, like esters and also some carbon –carbon bonds, within the kerogen and within the previously generated fragments. The new fragments generated become smaller and devoid of oxygen, therefore, hydrocarbons are relatively enriched. This corresponds first to the principal phase of oil formation, and then to the stage of "wet gas" and condensate generation.

At the same time, the carbon content increases in the remaining kerogen, due to the elimination of hydrogen. Aliphatic and alicyclic groups are partly removed from kerogen, carbonyl and carboxyl groups are completely eliminated, and most of the remaining oxygen is included in either bonds and possibly in heterocyclic.

When the sediment reaches the deepest part of the sedimentary basins, temperatures become quite high. A general cracking of carbon – carbon bond occurs, both in kerogen and bitumen already generated from it. Aliphatic groups that were still present in kerogen almost disappear, correspondingly, low molecular weight compound, especially methane, are released. The remaining sulphur, when present in kerogen, is mostly lost, and H_2S generation may be important. This is the principal phase of dry gas formation.

Once most labile functional groups and chains are eliminated, aromatisation and polycondensation of the residual kerogen increases, as shown by alteration of optical characteristics and by Infra-Red spectra. Parallel arrangement of aromatic nuclei extends over wide areas from 80 to 500Å, forming clusters. Physical properties evolve accordingly (high reflectance, electron diffraction). Such residual kerogen is unable to continue to generate hydrocarbons, as shown by the negative results of thermo-gravimetric assays. This stage is reached only in deep or very old sedimentary basins and it corresponds to metagenesis.

Self-Assessment Exercise

1. What is the effect of too high energy in a body of water on sedimentation?
2. What is the effect of very low energy in a body of water on sedimentation?

4.0 Conclusion

This unit discussed the production, accumulation and preservation of undegraded organic matter in sediments. It also discussed the various geological boundary conditions controlling the accumulation of organic matter in sediments.

In addition, this unit also discussed all the four stages of organic matter evolution in sediments. It further examined the meaning of kerogen and the van Krevelen diagram as a graphical-statistical method used in classifying kerogen. Finally, the different types and the transformation of kerogen to petroleum were discussed.

5.0 Summary

This unit has introduced you to the production, accumulation and preservation of organic matter, the various physico-chemical transformations of organic matter to kerogen, the different types of kerogen and the Van krevelen diagram was also introduced.

Furthermore, the unit classified kerogens into three types. The kerogens were classified by their respective evolution path in the Van krevelen diagram.

6.0 Self-Assessment Exercise

1. List and briefly discuss the three main stages of evolution of organic matter.
2. Kerogen can be classified into three types. Discuss.
3. What are the geological boundary conditions that control the accumulation of organic matter in sediments?
4. Physicochemical transformation of organic matter is controlled by certain factors, list them.
5. What are the prerequisites for the existence of petroleum?

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Unit 3 Gas Origin, Transportation and Uses

1.0 Introduction

Natural gas is a gas consisting primarily of methane. It is found associated with fossil fuels, in coal beds, as methane clathrates, and is created by methanogenic organisms in marshes, bogs, and landfills. It is an important fuel source, a major feedstock for fertilizers, and a potent greenhouse gas. It is often informally referred to as simply gas, especially when compared to other energy sources such as electricity. This unit will examine the origin, generation and migration of natural gas. It will also examine the differences between natural and other gases. Furthermore, processing, uses, environmental effect, energy content, statistics and pricing of natural gas will also be discussed.

2.0 Objectives

At the end of this unit, you should be able to:

- discuss the origin of natural gas
- explain the accumulation of natural gas
- differentiate between natural gas and other gases
- describe the process of natural gas using processing plant
- list uses of natural gas.

3.0 Main Content

3.1 Origin of Natural Gas Accumulations

The decomposition of organic material in an oxygen-poor environment, with the aid of anaerobic bacteria, results in the formation of methane. Since organic matter is present in the younger sediments of the earth, so is methane. If all of the existing methane could be collected, it could provide most of the world's energy for hundreds of years. Unfortunately, most is too diffuse to be commercially recovered. Natural gas, a hydrocarbon mixture consisting primarily of methane and ethane, is derived from both land plant and marine organic matter. Over geologic time, almost all natural gas reaches the earth's surface and is lost to the atmosphere.

When its upward migration is interrupted by a geologic trap (an upwardly convex permeable reservoir rock sealed above by impermeable cap rock) commercial quantities of gas can accumulate. This gas is termed non associated gas. Commercial amounts of gas also can accumulate as a gas cap above an oil pool or, if reservoir pressure is sufficiently high, dissolved in the oil. Such natural gas is termed associated gas.

Natural gas generation and migration occurs over an extensive vertical zone that includes shallow biogenic gas, intermediate dissolved gas of the oil window, and deep thermal gas. The production of biogenic methane requires anaerobic microbial activity, and is confined to poorly drained swamps, some lake bottoms, and marine environments below the zone of active sulphate reduction. Gas of predominantly biogenic origin constitutes more than 20 percent of global gas reserves. The mature stage of petroleum generation occurs at depths between about 6,500 and 16,000 feet, depending upon the geothermal gradient. At these temperatures and pressures, the full range of hydrocarbons is produced within the oil window and significant amounts of thermal methane gas often are generated along with the oil. Below about 9,500 feet, primarily wet gas that contains liquid hydrocarbons is formed. In the post mature stage, beneath about 16,000 feet, oil is no longer stable and the main hydrocarbon product is thermal methane gas that is a product of the cracking of the existing liquid hydrocarbons.

Gas displays an initial low concentration and high dispersibility, making adequate seals very important to conventional gas accumulation. Due to differences in the physical properties of gas and oil, similarly sized oil traps contain more recoverable energy (on a Btu basis) than gas traps, although more than three-quarters of the in-place gas often can be recovered. Less than one percent of the gas fields of the world are of giant size, originally containing at least 3 trillion cubic feet of recoverable gas. These fields, however, along with the associated gas in giant oil fields, account for about 80% of the world's proved and produced gas reserves. Oil is derived mainly from marine or lacustrian source rocks, but, since gas can be derived from land plants as well, all source rocks have the potential for gas generation. Many large gas accumulations appear to be associated with the coal deposits.

3.2 Unconventional Gas Accumulations

The boundary between conventional gas and unconventional gas resources is not well defined, because they result from a continuum of geologic conditions. Coal seam, shale, and tight gas occur in rocks of low permeability and require special treatment for recovery. The process by which vegetation is converted to coal over geologic time generates large amounts of natural gas. Much of this gas becomes concentrated as conventional gas deposits in permeable sediments adjacent to the coal, but some gas remains in the coal as unconventional "continuous" gas deposits. The coal does not form a continuous reservoir over an entire basin, but occurs in individual non-communicating coal seams separated by other strata. Coal seams are compartmentalised gas reservoirs bounded by facies changes or faults and the coal itself yields extremely variable amounts of gas. Coal seams that are deeply buried exhibit significantly reduced permeabilities and, thus, reduced gas recoverability.

Coal seam gas well productivity depends mostly on reservoir pressure and water saturation. Multi-well patterns are necessary to remove water from the coal and to establish a favorable pressure gradient. Since the gas is adsorbed on the surface of the coal and trapped by reservoir pressure, initially there is low gas production and high water production. Therefore, an additional expense relates to the disposal of coal bed water, which may be saline, acidic, or alkaline. As production continues, water production declines and gas production increases, before eventually beginning a long decline. In general, however, coal seam gas recovery rates have been low and unpredictable. Average per-well conventional gas production in a mature gas-rich basin is about five times higher than average per-well coal seam gas production. Thus, several times as many wells have to be drilled in coal seams than in conventional gas accumulations to achieve similar gas recovery levels.

Large continuous gas accumulations are sometimes present in low permeability (tight) sandstones, siltstones, shale, sandy carbonates, limestone, dolomites, and chalk. Such gas deposits are commonly classified as unconventional because their reservoir characteristics differ from conventional reservoirs and they require stimulation to be produced economically. The tight gas is contained in lenticular or blanket reservoirs that are relatively impermeable and can occur downdip from water-saturated rocks and cut across lithologic boundaries. They often contain a large amount of in-place gas, but exhibit low recovery rates. Gas can be economically recovered from the better quality continuous tight reservoirs by creating downhole fractures with explosives or hydraulic pumping. The nearly vertical fractures provide a pressure sink and channel for the gas, creating a larger collecting area so that the gas recovery is at a faster rate. Sometimes massive hydraulic fracturing is required, using a half million gallons of gelled fluid and a million pounds of sand to keep the fractures open after the fluid has been drained away.

In the United States, unconventional gas accumulations account for about 2 trillion cubic feet (tcf) of gas production per year, some 10 per cent of total gas output. In the rest of the world, however, gas is predominantly recovered from conventional accumulations.

3.3 Town Gas

Town gas is a mixture of methane and other gases, mainly the highly toxic carbon monoxide that can be used in a similar way to natural gas and can be produced by treating coal chemically. This is a historic technology, still used as 'best solution' in some local circumstances, although coal gasification is not usually economic at current gas prices. However, depending upon infrastructure considerations, it remains a future possibility.

Most town “gas houses” located in the eastern United States in the late nineteenth and early twentieth centuries were simple by-product of coke ovens which heated bituminous coal in air-tight chambers. The gas driven off from the coal was collected and distributed through town-wide networks of pipes to residences and other buildings where it was used for cooking and lighting purposes. (Gas heating did not come into widespread use until the last half of the twentieth century.) The coal tar that collected in the bottoms of the gas house ovens was often used for roofing and other water-proofing purposes, and also, when mixed with sand and gravel, was used for creating Bitumen for the surfacing of local streets.

3.4 Bio Gas

When methane-rich gases are produced by the anaerobic decay of non-fossil organic matter (biomass), these are referred to as biogas (or natural biogas). Sources of biogas include swamps, marshes, and landfills (see landfill gas), as well as sewage sludge and manure by way of anaerobic digesters, in addition to enteric fermentation particularly in cattle.

Methanogenic archaea are responsible for all biological sources of methane, some in symbiotic relationships with other life forms, including termites, ruminants, and cultivated crops. Methane released directly into the atmosphere would be considered as a pollutant, however, methane in the atmosphere is oxidised, producing carbon dioxide and water. Methane in the atmosphere has a half-life of seven years, meaning that every seven years, half of the methane present is converted to carbon dioxide and water.

Future sources of methane, the principal component of natural gas include landfill gas, biogas and methane hydrate. Biogases, and especially landfill gas, are already in used in some areas, but their use could be greatly expanded. Landfill gas is a type of biogas, but biogas usually refers to gas produced from organic material that has not been mixed with other waste.

Landfill gas is created from the decomposition of waste in landfills. If the gas is not removed, the pressure may get so high that it works its way to the surface, causing damage to the landfill structure, unpleasant odour, vegetation die-off and an explosion hazard. The gas can be vented to the atmosphere, flared or burned to produce electricity or heat.

Once water vapour is removed, about half of landfill gas is methane. Almost all of the rest is carbon dioxide, but there are also small amounts of nitrogen, oxygen and hydrogen. There are usually trace amounts of hydrogen sulphide and siloxanes, but their concentration varies widely. Landfill gas cannot be distributed through natural gas pipelines unless it is cleaned up to the same quality. It is usually more economical to combust the gas on site or within a short distance of the landfill using a dedicated pipeline. Water vapour is often removed, even if the gas is combusted on site. Other non-methane components may also be removed in order to meet emission standards, to prevent fouling of the equipment or for environmental considerations. Co-firing landfill gas with natural gas improves combustion, which lowers emissions.

Biogas is usually produced using agricultural waste materials, such as unusable parts of plants and manure. Biogas can also be produced by separating organic materials from waste that otherwise goes to landfills. This is more efficient than just capturing the landfill gas it produces. The use of materials that would otherwise generate no income or even cost money to get rid of, improves the profitability and energy balance of biogas production.

Anaerobic lagoons produce biogas from manure, while biogas reactors can be used for manure or plant parts. Like landfill gas, biogas is mostly methane and carbon dioxide, with small amounts of nitrogen, oxygen and hydrogen. However, with the exception of pesticides, there are usually lower levels of contaminants.

3.5 Hydrates

Huge quantities of natural gas (primarily methane) exist in the form of hydrates under sediment on offshore continental shelves and on land in arctic regions that experience permafrost such as those in Siberia (hydrates require a combination of high pressure and low temperature to form). However, as at 2009, no technology has been developed to produce natural gas economically from hydrates.

3.6 Natural Gas Production

The image below (Fig. 1) is a schematic block flow diagram of a typical natural gas processing plant. It shows the various unit processes used to convert raw natural gas into sales gas pipelined to the end user markets.

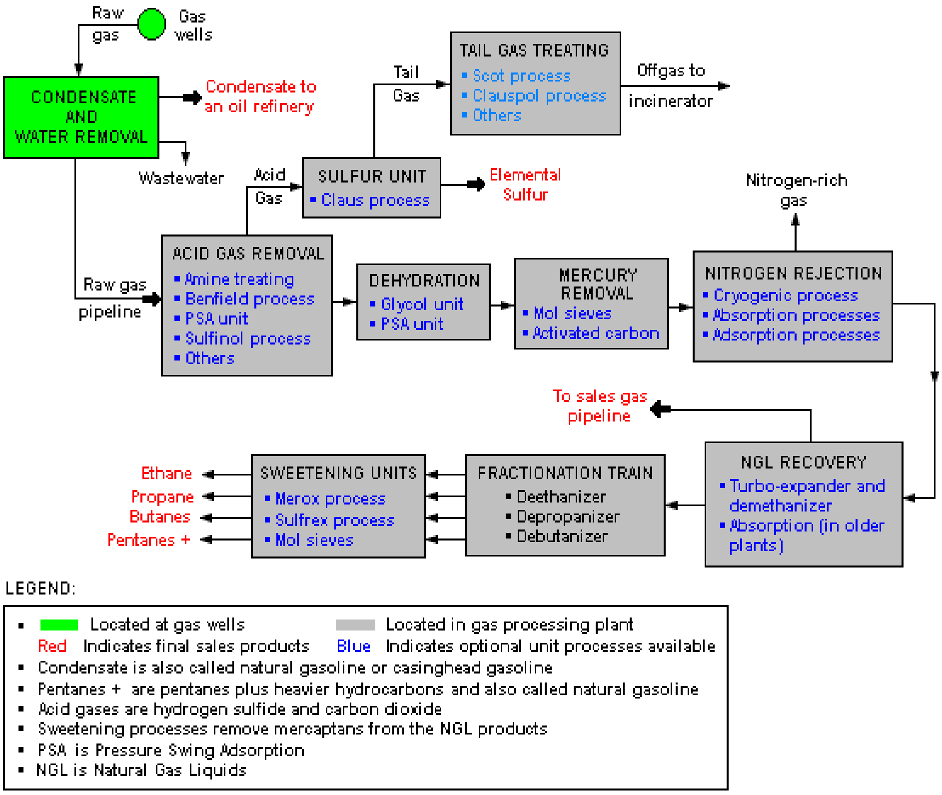

Fig. 1: Schematic Flow Diagram of a Typical Natural Gas Processing Plant

(Source: http//en.wikipedia.org/wiki/file)

The block flow diagram also shows how processing of the raw natural gas yields by product sulphur, by product ethane, and natural gas liquids (NGL) propane, butane and natural gasoline (denoted as pentanes +).

3.7 Uses of Natural Gas

3.7.1 Power Generation

Natural gas is a major source of electricity generation through the use of gas turbines and steam turbines. Most grid peaking power plants and some off-grid engine-generators use natural gas. This is because high efficiencies can be achieved through combining gas turbines with a steam turbine in combined cycle mode. Natural gas burns more cleanly than other fossil fuels, such as oil and coal, and produces less carbon dioxide per unit energy released.

For an equivalent amount of heat, burning natural gas produces about 30% less carbon dioxide than burning petroleum and about 45% less than burning coal. Combined cycle power generation using natural gas is thus the cleanest source of power available using fossil fuels, and this technology is widely used wherever gas can be obtained at a reasonable cost. Fuel cell technology may eventually provide cleaner options for converting natural gas into electricity, but it is not price-competitive.

3.7.2 Domestic Use

Natural gas is supplied to homes, where it is used for such purposes as cooking in natural gas-powered engines and/or ovens, natural gas-heated clothes dryers, heating/cooling and central heating. Home or other building heating may include boilers, furnaces, and water heaters. Methane also known as compressed natural gas (CNG) is used in rural homes without connections to piped-in public utility services, or with portable grills. However, due to CNG being less economical than liquified natural gas, LPG (Propane) is the dominant source of rural gas.

3.7.3 Transportation Fuel

Compressed natural gas (CNG) is a cleaner alternative to other automobile fuels such as gasoline (petrol) and diesel. The energy efficiency is generally equal to that of gasoline engines, but lower compared with modern diesel engines. Gasoline/petrol vehicles converted to run on natural gas suffer because of the low compression ratio of their engines, resulting in a cropping of delivered power while running on natural gas (10-15%). CNG-specific engines, however, use a higher compression ratio due to its fuel's higher octane number of 120–130.

3.7.4 Fertilizer

Natural gas is a major feedstock for the production of ammonia, via the Haber process, for use in fertilizer production.

3.7.5 Aviation

Russian aircraft manufacturer, Tupolev claims that at current market prices, an LNG-powered aircraft would cost 5,000 rubles (~ $218/ £112) less to operate per ton, roughly equivalent to 60%, with considerable reductions to carbon monoxide, hydrocarbon and nitrogen oxide emissions.

The advantages of liquid methane as a jet engine fuel are that it has more specific energy than the standard kerosene mixes and that its low temperature can help cool the air which the engine compresses for greater volumetric efficiency, in effect replacing an intercooler. Alternatively, it can be used to lower the temperature of the exhaust.

3.7.6 Hydrogen

Natural gas can be used to produce hydrogen, with one common method being the hydrogen reformer. Hydrogen has various applications: it is a primary feedstock for the chemical industry, a hydrogenating agent, an important commodity for oil refineries, and a fuel source in hydrogen vehicles.

3.7.7 Others

Natural gas is also used in the manufacture of fabrics, glass, steel, plastics, paint, and other products.

Self-Assessment Exercise

1. What are the by-products of processing raw natural gas?
2. What is the full meaning of NGL?
3. What is the full meaning of CNG?
4. What is the full meaning of LPG?

3.8 Storage and Transport

The major difficulty in the use of natural gas is transportation and storage because of its low density. Natural gas pipelines are economical, but are impractical across oceans.

LNG carriers can be used to transport liquefied natural gas (LNG) across oceans, while tank trucks can carry liquefied or compressed natural gas (CNG) over shorter distances. Sea transport using CNG carrier ships that are now under development may be competitive with LNG transport in specific conditions.

For LNG transport, a liquefaction plant is needed at the exporting end and regasification equipment at the receiving terminal. Shipborne regasification equipment is also practicable. LNG transportation is established as the preferred technology for long distance, high volume transportation of natural gas, whereas pipeline transport is preferred for transport for distances up to 4.000 km overland and approximately half that distance overseas. However, for CNG transport, high pressure, typically above 200 bars, is used. Compressors and decompression equipment are less capital intensive and may be economical in smaller unit sizes than liquefaction/regasification plants. For CNG mode, the crucial problem is the investment and operating cost of carriers. Natural gas trucks and carriers may transport natural gas directly to end-users, or to distribution points such as pipelines for further transport.

In the past, the natural gas which was recovered in the course of recovering petroleum could not be profitably sold, and was simply burned at the oil field (known as flaring). This wasteful practice is now illegal in many countries. Additionally, companies now recognise that value for the gas may be achieved with LNG, CNG, or other transportation methods to end-users in the future. The gas is now re-injected back into the formation for later recovery. This also assists oil pumping by keeping underground pressures higher. The natural gas is used to generate electricity and heat for desalination. Similarly, some landfills that also discharge methane gases have been set up to capture the methane and generate electricity.

Natural gas is often stored underground inside depleted gas reservoirs from previous gas wells, salt domes, or in tanks as liquefied natural gas. The gas is injected during periods of low demand and extracted during periods of higher demand. Storage near the ultimate end-users helps to best meet volatile demands, but this may not always be practicable.

With 15 nations accounting for 84% of the worldwide production, access to natural gas has become a significant factor in international economics and politics. In this respect, control over the pipelines is a major strategic factor.

3.9 Environmental Effect

3.9.1 Climate Change

Natural gas is often described as the cleanest fossil fuel, producing less carbon dioxide per joule delivered than either coal or oil, and far fewer pollutants than other fossil fuels. However, in absolute terms it does contribute substantially to global carbon emissions, and this contribution is projected to grow. According to the IPCC Fourth Assessment Report (Working Group III Report, Chapter 4), in 2004 natural gas produced about 5,300 Mt/yr of CO_2 emissions, while coal and oil produced 10,600 and 10,200 respectively but by 2030, according to an updated version of the SRES B2 emissions scenario, natural gas would be the source of 11,000 Mt/yr, with coal and oil now 8,400 and 17,200 respectively. (Total global emissions for 2004 were estimated at over 27,200 Mt).

In addition, natural gas itself is a greenhouse gas far more potent than carbon dioxide when released into the atmosphere but is not of major concern due to the small amounts in which this occurs. Natural gas is generally comprised of methane, which has a radioactive forcing twenty times greater than carbon dioxide. This means, however, a ton of methane in the atmosphere traps in as much radiation as 20 tons of carbon dioxide. Carbon dioxide still receives the lion's share of attention over greenhouse gases because it is in much higher concentration.

3.9.2 Pollutants

Natural gas produces far lower amounts of sulphur dioxide and nitrous oxides than any other fossil fuel.

3.10 Safety

In any form, a minute amount of odourant such as t-butyl mercaptan, with a rotting-cabbage-like smell, is added to the otherwise colourless and almost odourless gas, so that leaks can be detected before a fire or explosion occurs. Sometimes a related compound, thiophane is used, with a rotten-egg smell. Adding odourant to natural gas began in the United States after the 1937 New London School explosion. The buildup of gas in the school went unnoticed, killing three hundred students in a faculty when it ignited. Odourants are considered non-toxic in the extremely low concentrations occurring in natural gas delivered to the end user.

In mines, where methane seeping from rock formations has no odour, sensors are used, and mining apparatus have been specifically developed to avoid ignition sources, e.g., the Davy lamp.

Explosions caused by natural gas leaks occur a few times each year. Individual homes, small businesses and boats are most frequently affected when an internal leak builds up gas inside the structure. Frequently, the blast will be enough to significantly damage a building but leave it standing. In these cases, the people inside tend to have minor to moderate injuries. Occasionally, the gas can collect in high enough quantities to cause a deadly explosion, disintegrating one or more buildings in the process. The gas usually dissipates readily outdoors, but can sometimes collect in dangerous quantities if weather conditions are right. However, considering the tens of millions of structures that use the fuel, the individual risk of using natural gas is very low.

Some gas fields yield sour gas containing hydrogen sulphide (H_2S). This untreated gas is toxic. Amine gas treating, an industrial scale process which removes acidic gaseous components, is often used to remove hydrogen sulphide from natural gas.

Extraction of natural gas (or oil) leads to decrease in pressure in the reservoir. This in turn may lead to subsidence at ground level. Subsidence may affect ecosystems, waterways, sewer and water supply systems, foundations, etc.

Natural gas heating systems are a minor source of carbon monoxide deaths in the United States. According to the US Consumer Product Safety Commission (2008), 56% of unintentional deaths from non-fire CO poisoning were associated with engine-driven tools like gas-powered generators and lawn mowers. Natural gas heating systems accounted for 4% of these deaths. Improvements in natural gas furnace designs have greatly reduced CO poisoning concerns. Detectors are also available that warn of carbon monoxide and/or explosive gas (methane, propane, etc.).

3.10.1 Energy Content, Statistics and Pricing

Quantities of natural gas are measured in normal cubic meters (corresponding to 0°C at 101.325 kPa) or in standard cubic feet (corresponding to 60 °F (16 °C) and 14.73 psi). The gross heat of combustion of one normal cubic meter of commercial quality natural gas is around 39 megajoules (≈10.8 kWh), but this can vary by several per cent.

The price of natural gas varies greatly depending on location and type of consumer. In 2007, a price of $7 per 1,000 cubic feet (28 m^3) was typical in the United States. The typical caloric value of natural gas is roughly 1,000 British Thermal Units (BTU) per cubic foot, depending on gas composition. This corresponds to around $7 per million BTU, or around $7 per gigajoule. In April 2008, the wholesale price was $10 per 1,000 cubic feet (28 m^3) ($10/MMBTU). The residential price varies from 50 to 300 % more than the wholesale price. At the end of 2007, this was $12-$16 per 1,000 cu ft (28 m^3). Natural gas in the United States is traded as a futures contract on the New York Mercantile Exchange. Each contract is for 10,000 MMBTU (gigajoules), or 10 billion BTU. Thus, if the price of gas is $10 per million BTUs on the NYMEX, the contract is worth $100,000.

Natural gas is also traded as a commodity in Europe, principally at the United Kingdom NBP and related European hubs, such as the TTF in the Netherlands. In US units, one standard cubic foot of natural gas produces around 1,028 British Thermal Units (BTU). The actual heating value when the water formed does not condense is the net heat of combustion and can be as much as 10% less.

In the United States, retail sales are often in units of therms (th); 1 therm = 100,000 BTU. Gas meters measure the volume of gas used, and this is converted to therms by multiplying the volume by the energy content of the gas used during that period, which varies slightly over time. Wholesale transactions are generally done in decatherms (Dth), or in thousand decatherms (MDth), or in million decatherms (MMDth). A million decatherms is roughly a billion cubic feet of natural gas.

In the rest of the world, LNG (liquified natural gas) and LPG (liquified petroleum gas) is traded in metric tons or mmBTU as spot deliveries. Long term contracts are signed in metric tons. The LNG and LPG are transported by specialised transport ships, as the gas is liquified at cryogenic temperatures. The specification of each LNG/LPG cargo will usually contain the energy content, but this information is in general not available to the public.

Self-Assessment Exercise

1. What is biogas?
2. What is the meaning of BTU?
3. Why is LPG the dominant source of rural gas over CNG?

4.0 Conclusion

Photosynthesis is the basis for mass production of organic matter. About 2 billion years ago in the Precambrian, photosynthesis emerged as a worldwide phenomenon thus laying the foundation for the food chain and the evolution of higher forms of life. With the emergence of photosynthesis the atmospheric oxygen was enrich which also lead to the mass production of organic matter.

The deposition of sediments rich in organic matter, i.e., such as contain more than about 0.5% by weight or organic carbon, is restricted to certain boundary conditions. Such sediments are deposited in aquatic environments receiving a certain minimum amount of organic matter.

5.0 Summary

The origin, accumulation and migration of natural gas were examined in this unit. The difference between natural gas and other gases, processing of natural gas and uses was also examined. Problems associated with the storage and transportation of natural gas as a result of its low density was also discussed. In addition, the environmental effect, energy content, statistics and pricing was also examined.

6.0 Self-Assessment Exercise

1. Accumulation of gas can be conventional or unconventional discuss?
2. What are the problems associated with the storage and transportation of the various gas product?
3. Tertiary butyl mercaptan (tert-butyl mercaptan) and related compounds such as thiophene are added to gas why?
4. Discuss briefly the various uses of natural gas

7.0 References/Further Reading

Background Note: Qatar,http://en.wikipedia.org/wiki/natural

Benefits of Integrating NGL Extraction and LNG Liquefaction

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Unit 4 Oil Well, Oil Field and Reservoir

1.0 Introduction

An oil well is a general term for any boring through the earth's surface that is designed to find and produce petroleum oil. Usually some natural gas is produced along with the oil. A well designed to produce mainly or only gas may be termed a gas well. Thus, in this unit we will examine what an oil well is, different types of well, and various terms associated with oil well such as completion, production, and abandonment. Reservoir, traps including different types of trap and estimation of reservoir will also be considered.

2.0 Objectives

At the end of this unit, you should be able to:

- describe an oil field
- define an oil well and the various terms associated with oil well such as completion, production, and abandonment
- state the different types of well
- explain what is meant by reservoir in petroleum chemistry
- define traps and enumerate different types of traps
- discuss an estimation of a reservoir.

3.0 Main Content

3.1 Oil Field

Oil field is a region with an abundance of oil wells extracting petroleum (crude oil) from below ground. Because the oil reservoirs typically extend over a large area, possibly several hundred kilometres across, full exploitation entails multiple wells scattered across the area. In addition, there may be exploratory wells probing the edges, pipelines to transport the oil elsewhere, and support facilities. Because an oil field may be remote from civilisation, establishing a field is often an extremely complicated exercise in logistics. For instance, workers have to work there for months or years and require housing. In turn, housing and equipment require electricity and water. Pipelines in cold areas may need to be heated. Excess natural gas needs to be burned off if there is no way to make use of it, requiring a furnace and stacks, and pipes to carry it from well to furnace.

Thus, the typical oil field resembles a small self-contained city in the midst of a landscape dotted with drilling rigs and/or the pump jacks known as "nodding donkeys" because of their bobbing arm. Several companies, such as BJ Services, Bechtel, Esso, Schlumberger Limited, Baker Hughes and Halliburton, have organisations that specialise in the large-scale construction of the infrastructure and providing specialised services required to operate a field profitably.

More than 40,000 **oil fields** are scattered around the globe, on land and offshore. The largest are the Ghawar Field in Saudi Arabia and the Burgan Field in Kuwait, with more than 60 billion barrels (9.5×10^9 m^3) estimated in each. Most oil fields are much smaller. According to the US Department of Energy (Energy Information Administration), as of 2003 the US alone had over 30,000 oil fields.

In the modern age, the location of oil fields with proven oil reserves is a key underlying factor in many geopolitical conflicts. The term oil field is also used as shorthand to refer to the entire petroleum industry.

3.2 Oil Well

An oil well is a general term for any boring through the earth's surface that is designed to find and produce petroleum oil hydrocarbons. Usually some natural gas is produced along with the oil. A well designed to produce mainly or only gas may be termed a gas well.

The well is created by drilling a hole of about 5 to 36 inches (127.0 mm to 914.4 mm) diameter into the earth with a drilling rig which rotates a drill string with a bit attached. After the hole is drilled, sections of steel pipe (casing), slightly smaller in diameter than the borehole, are placed in the hole. Cement may be placed between the outside of the casing and the borehole. The casing provides structural integrity to the newly drilled wellbore in addition to isolating potentially dangerous high pressure zones from each other and from the surface.

With these zones safely isolated and the formation protected by the casing, the well can be drilled deeper (into potentially more-unstable and violent formations) with a smaller bit, and also cased with a smaller size casing. Modern wells often have 2–5 sets of subsequently smaller hole sizes drilled inside one another, each cemented with casing.

To drill the well:

- The drill bit, aided by the weight of thick walled pipes called "drill collars" above it, cuts into the rock. There are different types of drillbit, some cause the rock to fail by compressive failure. Others shear slices off the rock as the bit turns.

- Drilling fluid (mud) is pumped down the inside of the drill pipe and exits at the drill bit. Drilling mud is a complex mixture of fluids, solids and chemicals which must be carefully tailored to provide the correct physical and chemical characteristics required to safely drill the well. Particular functions of the drilling mud include cooling the bit, lifting rock cuttings to the surface, preventing destabilisation of the rock in the wellbore walls and overcoming the pressure of fluids inside the rock so that these fluids don't enter the wellbore.

- The generated rock "cuttings" are swept up by the drilling fluid as it circulates back to surface outside the drill pipe. The fluid then goes through "shakers" which strain the cuttings from the good fluid which is returned to the pit. Watching for abnormalities in the returning cuttings and monitoring pit volume or rate of returning fluid are imperative to catch "kicks" (when the formation pressure at the depth of the bit is more than the hydrostatic head of the mud above, which if not controlled temporarily by closing the blowout preventers and ultimately by increasing the density of the drilling fluid would allow formation fluids and mud to come up uncontrollably) early.

- The pipe or drill string to which the bit is attached is gradually lengthened as the well gets deeper by screwing in additional 30-foot (10 m) joints (i.e., sections) of pipe under the kelly or top drive at the surface. This process is called making a connection. Usually joints are combined into 3 joints equaling 1 stand. Some smaller rigs only use 2 joints and some rigs can handle stands of 4 joints.

This process is all facilitated by a drilling rig which contains all necessary equipment to circulate the drilling fluid, hoist and turn the pipe, control down hole pressures, remove cuttings from the drilling fluid, and generate onsite power for these operations.

3.2.1 Completion

After drilling and casing the well, it must be 'completed'. Completion is the process in which the well is enabled to produce oil or gas.

In a cased-hole completion, small holes called perforations are made in the portion of the casing which passed through the production zone, to provide a path for the oil to flow from the surrounding rock into the production tubing. In open hole completion, often 'sand screens' or a 'gravel pack' is installed in the last drilled, uncased reservoir section. These maintain structural integrity of the wellbore in the absence of casing, while still allowing flow from the reservoir into the wellbore. Screens also control the migration of formation sands into production tubulars and surface equipment, which can cause washouts and other problems, particularly from unconsolidated sand formations in offshore fields.

After a flow path is made, acids and fracturing fluids are pumped into the well to fracture, clean, or otherwise prepare and stimulate the reservoir rock to optimally produce hydrocarbons into the wellbore. Finally, the area above the reservoir section of the well is packed off inside the casing, and connected to the surface via a smaller diameter pipe called tubing. This arrangement provides a redundant barrier to leaks of hydrocarbons as well as allowing damaged sections to be replaced. Also, the smaller diameter of the tubing produces hydrocarbons at an increased velocity in order to overcome the hydrostatic effects of heavy fluids such as water.

In many wells, the natural pressure of the subsurface reservoir is high enough for the oil or gas to flow to the surface. However, this is not always the case, especially in depleted fields where the pressures have been lowered by other producing wells, or in low permeability oil reservoirs. Installing smaller diameter tubing may be enough to help the production, but artificial lift methods may also be needed. Common solutions include down hole pumps, gas lift, or surface pump jacks. Many new systems in the last ten years have been introduced for well completion. Multiple packer systems with frac ports or port collars in an all in one system have cut completion costs and improved production, especially in the case of horizontal wells. These new systems allow casings to run into the lateral zone with proper packer/frac port placement for optimal hydrocarbon recovery.

Self-Assessment Exercise

1. Define oil field
2. What do you understand by completion?
3. Define / explain what is meant by production tree.
4. What are oil wells?
5. What is the importance of casing in drilling of bore well?

3.2.2 Production

The production stage is the most important stage of a well's life, when the oil and gas are produced. By this time, the oil rigs and work over rigs used to drill and complete the well have moved off the wellbore, and the top is usually outfitted with a collection of valves called a production tree. These valves regulate pressures, control flows, and allow access to the wellbore in case further completion work is needed. From the outlet valve of the production tree, the flow can be connected to a distribution network of pipelines and tanks to supply the product to refineries, natural gas compressor stations, or oil export terminals.

As long as the pressure in the reservoir remains high enough, the production tree is all that is required to produce the well. If the pressure depletes and it is considered economically viable, an artificial lift method mentioned in the completions section can be employed.

Workovers are often necessary in older wells, which may need smaller diameter tubing, scale or paraffin removal, acid matrix jobs, or completing new zones of interest in a shallower reservoir. Such remedial work can be performed using workover rigs – also known as *pulling units* or *completion rigs* – to pull and replace tubing, or by the use of well intervention techniques utilising coiled tubing. Depending on the type of lift system and wellhead a rod rig or flushby can be used to change a pump without pulling the tubing.

Enhanced recovery methods such as water flooding, steam flooding, or CO_2 flooding may be used to increase reservoir pressure and provide a “sweep” effect to push hydrocarbons out of the reservoir. Such methods require the use of injection wells (often chosen from old production wells in a carefully determined pattern), and are used when facing problems with reservoir pressure depletion, high oil viscosity, or can even be employed early in a field's life. In certain cases, depending on the reservoir’s geomechanics, reservoir engineers may determine that ultimate recoverable oil may be increased by applying a water flooding strategy early in the field's development rather than later. Such enhanced recovery techniques are often called “tertiary recovery”.

3.2.3 Abandonment

As a well ages and the reservoir is depleted, the oil produced begins to fall. The production rate at which the well's revenue is so low that it no longer makes a profit is called the "economic limit." The equation to determine the economic limit includes taxes, operating cost, oil price, and royalty. When oil taxes are raised, the economic limit is raised. When oil price is increased, the economic limit is lowered. When the economic limit is raised, the life of the well is shortened and proven oil reserves are lost. Conversely, when the economic limit is lowered, the life of the well is lengthened.

When the economic limit is reached, the well becomes a liability and it is abandoned. In this process, tubing is removed from the well and sections of well bore are filled with cement to isolate the flow path between gas and water zones from each other, as well as the surface. Completely filling the well bore with cement is costly and unnecessary. The surface around the wellhead is then excavated, and the wellhead and casing are cut off, a cap is welded in place and then buried.

At the economic limit, there often is still a significant amount of unrecoverable oil left in the reservoir. It might be tempting to defer physical abandonment for an extended period of time; hoping that the oil price will go up or those new supplemental recovery technique will be perfected. However, lease provisions and governmental regulations usually require quick abandonment, liability and tax concerns also may favour abandonment.

In theory, an abandoned well can be reentered and restored to production (or converted to injection service for supplemental recovery or for downhole hydrocarbons storage), but reentry often proves to be difficult mechanically and not cost effective.

3.2.4 Types of Wells

Oil wells come in many varieties. There can be wells that produce oil, wells that produce oil *and* natural gas, or wells that *only* produce natural gas. Natural gas is almost always a by-product of producing oil, since the small, light gas carbon chains come out of solution as it undergoes pressure reduction from the reservoir to the surface, similar to uncapping a bottle of soda pop where the carbon dioxide effervesces. Unwanted natural gas can be a disposal problem at the well site. If there is not a market for natural gas near the wellhead it is virtually valueless since it must be piped to the end user. Until recently, such unwanted gas was burned off at the well site, but due to environmental concerns this practice is becoming less common. Often, unwanted (or 'stranded' gas without a market) gas is pumped back into the reservoir with an 'injection' well for disposal or repressurising the producing formation. Another solution is to export the natural gas as a liquid. Gas-to-Liquid, (GTL) is a developing technology that converts stranded natural gas into synthetic gasoline, diesel or jet fuel through the Fischer-Tropsch process. Such fuels can be transported through conventional pipelines and tankers to users. Proponents claim GTL fuels burn cleaner than comparable petroleum fuels. Another obvious way to classify oil wells is by land or offshore wells. There is very little difference in the well itself. An offshore well targets a reservoir that happens to be underneath an ocean. Due to logistics, drilling an offshore well is far more costly than an onshore well. By far the most common type is the onshore well.

Another way to classify oil wells is by their purpose in contributing to the development of a resource. They can be characterised as:

- *production wells* are drilled primarily for producing oil or gas, once the producing structure and characteristics are determined
- *appraisal wells* are used to assess characteristics (such as flow rate) of a proven hydrocarbon accumulation

- *exploration wells* are drilled purely for exploratory (information gathering) purposes in a new area
- *wildcat wells* are those drilled outside of and not in the vicinity of known oil or gas fields.

At a producing well site, active wells may be further categorised as:

- *oil producers,* producing predominantly liquid hydrocarbons, but mostly with some associated gas.
- *gas producers,* producing almost entirely gaseous hydrocarbons.
- *water injectors,* injecting water into the formation to maintain reservoir pressure or simply to dispose of water produced with the hydrocarbons because even after treatment, it would be too oily and too saline to be considered clean for dumping overboard, let alone into a fresh water source, in the case of onshore wells. Frequently water injection has an element of reservoir management and produced water disposal.
- *aquifer producers,* intentionally producing reservoir water for re-injection to manage pressure. This is in effect moving reservoir water from where it is not as useful to where it is more useful. These wells will generally only be used if produced water from the oil or gas producers is insufficient for reservoir management purposes. Using aquifer produced water rather than sea water is due to the chemistry.
- *gas injectors,* injecting gas into the reservoir often as a means of disposal or sequestering for later production, but also to maintain reservoir pressure.

Lahee classification

New Field Wildcat (NFW) – far from other producing fields and on a structure that has not previously produced.

- *New Pool Wildcat* (NPW) – new pools on already producing structure.
- *Deeper Pool Test* (DPT) – on already producing structure and pool, but on a deeper pay zone.
- *Shallower Pool Test* (SPT) – on already producing structure and pool, but on a shallower pay zone.
- *Outpost* (OUT) – usually two or more locations from nearest productive area.
- *Development Well* (DEV) – can be on the extension of a pay zone, or between existing wells (*Infill*).

3.3 Oil Reservoir

A petroleum reservoir or an oil and gas reservoir is a subsurface pool of hydrocarbons contained in porous or fractured rock formations. The naturally occurring hydrocarbons are trapped by overlying rock formations with lower permeability.

Once a source rock generates and expels petroleum, the petroleum migrates from the source rock to a rock that can store the petroleum. A rock capable of storing petroleum in its pore spaces, the void spaces between the grains of sediment in a rock, is known as a reservoir rock. Rocks that have sufficient pore space through which petroleum can move include sandstone, limestone, and rocks that have many fractures. A good reservoir rock might have pore space that exceeds 30% of the rock volume. Poor quality reservoir rocks have less than 10% void space capable of storing petroleum. Rocks that lack pore space tend to lack permeability, the property of rock that allows fluid to pass through the pore spaces of the rock. With very few pores, it is not likely that the pores are connected and less likely that fluid will flow through the rock than in a rock with larger or more abundant pore spaces. Highly porous rocks tend to have better permeability because of the greater number of pores and larger pore sizes that tend to allow fluids to move through the reservoir more easily. The property of permeability is critical to producing petroleum: If fluids cannot migrate through a reservoir rock to a petroleum production well, the well will not produce much petroleum and the money spent to drill the well has been wasted.

In order for a reservoir to contain petroleum, the reservoir must be shaped and sealed like a container. Good petroleum reservoirs are sealed by a less porous and permeable rock known as a seal or cap rock. The seal prevents the petroleum from migrating further. Rocks like shale and salt provide excellent seals for reservoir rocks because they do not allow fluids to pass through them easily. Seal-forming rocks tend to be made of small particles of sediment that fit closely together so that pore spaces are small and poorly connected. The permeability of a seal must be virtually zero in order to retain petroleum in a reservoir rock for millions to hundreds of millions of years, the time span between formation of petroleum to the discovery and production of many petroleum fields. Likewise, the seal must not be subject to forces within the earth that might cause fractures or other breaks in the seal to form.

Reservoir rocks and seals work together to form a trap for petroleum. Typical traps for petroleum include hills shaped like upside-down bowls below the surface of the earth, known as anticlines, or traps formed by faults. Abrupt changes in rock type can form good traps, such as sandstone deposits next to shale deposits, especially if a sand deposit is encased in a rock that is sufficiently rich in organic matter to act as a petroleum source and endowed with the properties of a good seal. An important aspect of the formation of petroleum accumulations is timing. The reservoir must have been deposited prior to petroleum migrating from the source rock to the reservoir rock. The seal and trap must have been developed prior to petroleum accumulating in the reservoir, or else the petroleum would have migrated farther. The source rock must have been exposed to the appropriate temperature and pressure conditions over long periods of time to change the organic matter to petroleum. The necessary coincidence of several conditions is difficult to achieve in nature.

Petroleum is typically found beneath the surface of the earth in accumulations known as fields. Fields can contain oil, gas, tar, water, and other substances, but oil, gas, and water are the most common. In order for a field to form, there must be some sort of structure to trap the petroleum, a seal on the trap that prohibits leakage of the petroleum, and a reservoir rock that has adequate pore space, or void space, to hold the petroleum.

To find these features together in an area in which petroleum has been generated by chemical reactions affecting organic remains requires many coincidences of timing of natural processes. Rocks occur in many environments, including lakes, deep areas of the seas and oceans, and swamps. The source rocks must be buried deep enough below the surface of the earth to heat up the organic material, but not so deep that the rocks metamorphose or that the organic material changes to graphite or materials other than hydrocarbons. Temperatures less than 302° F (150°C) are typical for petroleum generation.

3.3.1 Traps

The traps required in the last step of the reservoir formation process have been classified by petroleum geologists into two types: **structural** and **stratigraphic**. A reservoir can be formed by one kind of trap or a combination of both.

3.3.2 Structural Traps

Structural traps are formed by a deformation in the rock layer that contains the hydrocarbons. Domes, anticlines, and folds are common structures. Fault-related features also may be classified as structural traps if closure is present. Structural traps are the easiest to locate by surface and subsurface geological and geophysical studies. They are the most numerous among traps and have received a greater amount of attention in the search for oil than all other types of traps. An example of this kind of trap starts when salt is deposited by shallow seas. Later, a sinking seafloor deposits organic-rich shale over the salt, which is in turn covered with layers of sandstone and shale. Deeply buried salt tends to rise unevenly in swells or salt domes, and any oil generated within the sediments is trapped where the sandstones are pushed up over or adjacent to the salt dome.

3.3.3 Stratigraphic Traps

Stratigraphic traps are formed when other beds seal a reservoir bed or when the permeability changes (facies change) within the reservoir bed itself. Stratigraphic traps can form against either younger or older time surfaces.

3.4 Estimating Reserves

After the discovery of a reservoir, a programme of appraisal will seek to build a better picture of the accumulation. In the simple text book example of a uniform reservoir, the first stage is to use seismic to determine the possible size of the trap. Appraisal wells can be used to determine the location of oil-water contact and with it, the height of the oil-bearing sands. Often coupled with seismic data, it is possible to estimate the volume of oil bearing reservoir. The next step is to use information from appraisal wells to estimate the porosity of the rock. This is commonly 20-35% or less (the percentage of the total volume that contains fluids rather than solid rock). This can give a picture of the actual capacity. Laboratory testing can determine the characteristics of the reservoir fluids, particularly the expansion factor of the oil (how much the oil will expand when brought from the high pressure, high temperature environment of the reservoir to "stock tank" conditions at the surface.

With this knowledge, it is then possible to estimate how many "stock tank" barrels of oil are located in the reservoir. This is called the Stock Tank Oil Initially In Place (STOIIP). As a result of studying properties such as the permeability of the rock (how easily fluids can flow through the rock) and possible drive mechanisms, it is possible to then estimate the recovery factor (what proportion of the oil in place can be reasonably expected to be produced). This is commonly between 30-35%. This finally gives a value for the recoverable reserves. The difficulty in practice is that reservoirs are not uniform. They have a variable porosities and permeabilities and may be compartmentalised, with fractures and faults breaking them up and complicating fluid flow.

3.5 Production

To obtain the contents of the oil reservoir, it is usually necessary to drill into the Earth's crust, although surface oil seeps exist in some parts of the world. A virgin reservoir may be under sufficient pressure to initially push hydrocarbons to surface. However, as the fluids are produced, the pressure will often decline, and production will falter with it. However, the reservoir may respond to fluid withdrawal in a way that will tend to maintain the pressure. Artificial drive methods may be necessary. This mechanism (also known as depletion drive) depends on the associated gas of the oil. The virgin reservoir may be entirely liquid, but will be expected to have gaseous hydrocarbons in solution due to the pressure. As the reservoir depletes, the pressure falls below the bubble point and the gas comes out of solution to form a gas cap at the top. This gas cap pushes down on the liquid helping to maintain pressure.

In reservoirs already having a gas cap (the virgin pressure is already below bubble point), the gas cap expands with the depletion of the reservoir, pushing down on the liquid sections applying extra pressure.

Below the hydrocarbons may be a ground water aquifer. Water, as with all liquids, is compressible to a small degree. As the hydrocarbons are depleted, the reduction in pressure in the reservoir causes the water to expand slightly. Although this expansion is minute, if the aquifer is large enough, this will translate into a large increase in volume, which will push up on the hydrocarbons, maintaining pressure. If the natural drives are insufficient, as they very often are, then the pressure can be artificially maintained by injecting water into the aquifer or gas into the gas cap.

3.6 Oil in Place

Oil in place is the total hydrocarbon content of an oil reservoir and is often abbreviated STOOIP, which stands for Stock Tank Original Oil In Place, or STOIIP for Stock Tank Oil Initially In Place, referring to the oil in place before the commencement of production. In this case, *stock tank* refers to the storage vessel (often purely notional) containing the oil after production.

Oil in place must not be confused with oil reserves that are the technically and economically recoverable portion of oil volume in the reservoir. Current recovery factors for oil fields around the world typically range between 10 and 60%; some are over 80%. The wide variance is due largely to the diversity of fluid and reservoir characteristics for different deposits. Accurate calculation of the value of STOOIP requires knowledge of:

- volume of rock containing oil (bulk rock volume, in the USA this is usually in acre-feet)
- percentage porosity of the rock in the reservoir
- percentage water content of that porosity
- amount of shrinkage that the oil undergoes when brought to the earth's surface
- and is achieved using the formula

$$N = \frac{7758\, V_b\, \phi\, (1 - S_w)}{B_{oi}} \quad \text{[stb]}$$

Or

$$N = \frac{V_b\, \phi\, (1 - S_w)}{B_{oi}} \quad [\text{m}^3]$$

Where

- N = STOIIP (barrels)
- V_b = Bulk (rock) volume (acre-feet or cubic metres)
- ϕ = Fluid-filled porosity of the rock (fraction)
- S_w = Water saturation - water-filled portion of this porosity (fraction)
- B_{oi} = Formation volume factor (dimensionless factor for the change in volume between reservoir and standard conditions at surface)

Gas saturation S_g is traditionally omitted from this equation.

The constant value 7758 converts acre-feet to stock tank barrels. An acre of reservoir 1 foot thick would contain 7758 barrels of oil in the limiting case of 100% porosity, zero water saturation and no oil shrinkage. If the metric system is being used, a conversion factor of 6.289808 can be used to convert cubic metres to stock tank barrels. A one-cubic metre container would hold 6.289808 barrels of oil.

3.7 Formation Volume Factor

When oil is produced, the high reservoir temperature and pressure decreases to surface conditions and gas bubbles out of the oil. As the gas bubbles out of the oil, the volume of the oil decreases. Stabilised oil under surface conditions (either 60° F and 14.7 psi or 15° C and 101.325 kPa) is called stock tank oil. Oil reserves are calculated in terms of stock tank oil volumes rather than reservoir oil volumes. The ratio of stock tank volume to oil volume under reservoir conditions is called the formation volume factor (FVF). It usually varies from 1.0 to 1.7. A formation volume factor of 1.4 is characteristic of high-shrinkage oil and 1.2 of low-shrinkage oil.

3.8 Reservoir Engineering

Reservoir engineering is a branch of petroleum engineering, which applies scientific principles to the drainage problems arising during the development and production of oil and gas reservoirs so as to obtain a high economic recovery. The working tools of the reservoir engineer are subsurface geology, applied mathematics, and the basic laws of physics and chemistry governing the behaviour of liquid and vapor phases of crude oil, natural gas, and water in reservoir rock.

Of particular interest to reservoir engineers is generating accurate reserves estimates for use in financial reporting to the SEC and other regulatory bodies. Other job responsibilities include numerical reservoir modeling, production forecasting, well testing, well drilling and workover planning, economic modeling, and PVT analysis of reservoir fluids.

Reservoir engineers also play a central role in field development planning, recommending appropriate and cost effective reservoir depletion schemes such as water flooding or gas injection to maximize hydrocarbon recovery.

Reservoir engineers often specialise in two areas:

- Surveillance (or production) engineering, i.e. monitoring of existing fields and optimisation of production and injection rates. Surveillance engineers typically use analytical and empirical techniques to perform their work, including decline curve analysis, material balance modeling, and inflow/outflow analysis.
- Simulation modeling, i.e. the conduct of reservoir simulation studies to determine optimal development plans for oil and gas reservoirs.

Self-Assessment Exercise

1. Mention the two types of traps that you know.
2. What is the full meaning of STOOIP?
3. Define oil reservoir.
4. What is responsible for the deviation of well from true vertical position?
5. What are the two areas of specialisation of reservoir engineers?

4.0 Conclusion

In this unit, we have been able to know that oil and natural gas are produced by the same geological process by anaerobic digestion / decay of organic matter deep under the earth's surface. As a consequence, oil and natural gas are often found together. Because both oil and natural gas are lighter than water, they tend to rise from their sources until they either seep to the surface or are trapped by a non-permeable layer of rock. Like oil, natural gas is often found underwater in offshore gas fields.

In addition, we have also been able to know that the technology utilised to extract and transport offshore natural gas is different from land-based fields in that a few, very large rigs are usually used.

5.0 Summary

In this unit, you have learnt that:

- Oil field is a region with an abundance of oil wells extracting petroleum (crude oil) from below ground.
- An oil well is a general term for any boring through the earth's surface that is designed to find and produce petroleum oil (crude oil). Usually some natural gas is produced along with the oil. A well designed to produce mainly gas may be termed gas well.
- A petroleum reservoir or an oil and gas reservoir is a subsurface pool of hydrocarbons contained in porous or fractured rock formations.
- Oil in place is the total hydrocarbon content of an oil reservoir known as Stock Tank Original Oil In Place and is often abbreviated STOOIP.
- Reservoir engineering is a branch of petroleum engineering, which applies scientific principles to the drainage problems arising during the development and production of oil and gas reservoirs so as to obtain a high economic recovery.

6.0 Self-Assessment Exercise

1. Briefly discuss stock tank oil
2. How will you estimate how many stock tank barrels of oil located in a reservoir?
3. Discuss in details Oil in Place.
4. Explain the usefulness of a gas cap reservoir.
5. What are the attributes of a good reservoir?
6. There are different ways of classifying a well. Discuss the classification based on their purpose in contributing to developing a resource.
7. What are the problems associated with establishing a field?

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