CHAPTER – 1
INTRODUCTION TO PETROLEUM ENGINEERING

1.1 Petroleum Engineering

Engineering is the profession in which knowledge of mathematical and natural sciences gained by study, experience and practice applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind. Engineers are persons, who, by reason of their special knowledge and the use of mathematical, physical and engineering sciences and the principles and methods of engineering analysis and design, acquired by education and experience, are qualified to practice engineering. However, the most useful approach is to simply regard the engineer as a doer, a problem solver, who applies science and technology to solve the problems and meet the needs of society. The engineer is an innovator and creator of new products and processes aimed at solving problems in a practical and economic fashion.

The engineer's role is to bridge the gap between an idea and its physical reality by solving problems that exist between the two extremes, very often with little to guide him except intuition. This we have called the "creativity gap". The tools of engineer are the scientific principles, that have been formulated about the behavior of universe and its contents. Laws of motion, thermodynamics and matter are among the tools that permit engineer to fashion a workable solution to a problem. The engineer must develop sufficient depth of understanding of the basic principles so that they indeed become like tools. He/she must be able to devote his/her efforts to building a solution to a problem and not concern himself/herself with how the tools are to be used.

Petroleum Engineers combine chemistry, physics and geology with engineering methods in the development, recovery and field processing of petroleum. They are concerned wit finding deposits of oil and gas in quantities suitable for commercial use and with the economic extraction of these materials from the ground. The petroleum engineer will design methods for transporting oil and gas to suitable processing plants or to places where they will be used. The function of petroleum engineering is to provide a basis for the design and implementation of techniques to recover commercial quantities of natural petroleum. It is of necessity to broadly based technology drawing upon the foundations of engineering, geology, mathematics, physics, chemistry, economics and geo-statistics. As an engineering subject, it is a little anomalous in that design is based on observation of production performance and on a representation of the reservoir inferred from very limited sampling.

1.2 History of Petroleum

Petroleum belongs to the minerals that have been used by humanity since the earliest ages, earlier than metals and coal, and for numerous different purposes. The people and tribes who found and used these useful but unusual materials gave them many different names in their languages like “sweat of the devil”, “oil from rocks”, “shining water” and many others. Some of these names have survived thousands of years. For example: “naptha” which is coming from the “Babylonians” and “Assyrians” and **petros** derived from the Greek word “petros” for **rock**, and the Roman word **petroleum** for **oil**.

Reports on petroleum and especially on the use and production of petroleum have been found in Mesopotamian libraries about 4000 years BC. For thousands of years, the only source of petroleum had been surface springs or tar pits. However most of these finds were not very productive. Therefore people began to look for oil under the earth. In Pennsylvania, Colonel

Edwin Drake drilled 69 feet and struck oil in 1859. That day, August 27, 1859 is dated as the birthday of oil industry in USA. Even though, James Williams had completed the first commercially producing oil well one year earlier and oil seekers in Azerbaijan did the same few years earlier. Drake went one step further and he proved that oil could be obtained in sufficient quantities to meet the increasing demand by drilling through rock.

1.3 Definition of Petroleum

Petroleum is a mixture of naturally occurring hydrocarbons that may exist in the solid, liquid or gaseous states, depending upon the conditions of pressure and temperature to which it is subjected. Virtually all petroleum is produced from the reservoir in either liquid or gaseous form, and commonly, these materials are referred to as either crude oil or natural gas, depending upon the state of the hydrocarbon mixture. Petroleum consist of approximately 11-13 wt % hydrogen and 84-87 wt % of carbon. Traces of oxygen, sulphur, nitrogen and helium may be found as impurities in crude oil. Crude oils obtained from different oil reservoirs have widely different characteristics. Some are black, heavy, and thick like tar, and others are brown or nearly clear with low viscosity and low specific gravity. However, nearly all crude oils have elemental analyses within the limits given below.

Table 1-1 Elemental Analysis of Typical Crude Oils

Element	**% by wt**
Carbon	84 - 87
Hydrogen	11 - 14
Sulphur	0.06 – 2.0
Nitrogen	0.1 – 2.0
Oxygen	0.1 – 2.0

Table 1.2 Typical crude oil fractions

Crude Fractions	Boiling point, °F	Chemical composition	Use
Hydrocarbon gas		$C_1 – C_4$	Natural gas, bottled fuel gas
Petroleum ether	To 160	$C_5 – C_6$	Solvent, paint thinner, cleaner
Gasoline	160 – 400	$C_7 – C_8$	Motor fuel, solvent
Kerosene	400 – 575	$C_{10} – C_{16}$	Illuminating oil, diesel fuel, jet fuel
Light gas oil	575 – 850	$C_{16} – C_{30}$	Lubricating oil, mineral oil, cracking stock
Heavy gas oil	850 – 1100	$C_{30} – C_{50}$	Lubricating oil, bunker fuel
Residue	1200+	C_{80+}	Tars, asphalts, wood preservatives, roofing compounds

1.4 Where Does Petroleum Occur

Rocks forming the earth’s crust are traditionally divided into three groups according to their origin as igneous, sedimentary and metamorphic rocks.

1.4.1 Igneous Rocks

Igneous rocks are formed as a result of cooling and solidifying of molten magma erupted from the earth’s interior. The rocks of this type are thought to make about 95 % of the outermost crust of the earth. They are generally hard, crystalline in structure, and are practically devoid of pore spaces or voids. Granite, basalt, andesite, serpentines, diabases are the typical examples oF this group.

1.4.2 Sedimentary Rocks

Sedimentary rocks are formed from the deposition of organic and inorganic matter. Fine pieces of igneous rock along with plant and animal fossils were deposited by wind or water and gradually settled in layers and strata. Sedimentary rocks are grouped into three categories as clastic, chemical and organic sediments. Clastic sediments were formed by breakdown, transport and deposition of rocks. These are gravels, conglomerates, breccia, sands, sandstone, siltstone, clay, clay-stone and shale. Chemical sediments are mineral salts (chlorides, sulfates, etc..), carbonates (limestone, dolomite and others) and siliceous rocks. These rocks generally have a crystalline structure. Sedimentary rocks are produced by erosion, deposition and compaction. Erosion is the gradual breaking down of larger rocks into smaller stones by the forces of nature-wind, rain, snow, ice, streams, etc.. These eroded rocks are generally carried away from their point of origin and deposited elsewhere, generally and/or ultimately on the ocean floors. As the process of deposition has continued for millions of years, the thickness of the sediment on ocean floor has reached several thousand feet. Compaction occurs as the underlying sections of sediment are compacted by the weight of new layers above.

Sedimentary rocks are of two types: fragmental rocks and precipitated rocks. Fragmental rocks are made up of broken pieces of larger rocks that have been eroded by nature. Such rocks include conglomerates (rock particles, the size of marbles or larger), sandstone (particles the size of sand grains), siltstone (a mixture of very fine sand and clay) and shale (particles of clay size). Precipitated rocks are those which have been affected by chemical action, evaporation or the activity of animals and plants. Precipitated rocks include limestone, gypsum and dolomite. Conditions favoring petroleum formation are found only in sedimentary rocks

1.4.3 Metamorphic Rocks

Tectonic processes, which occur in a high-pressure, high-temperature environment, change the composition and the structure of original igneous and sedimentary rocks and cause the formation of metamorphic rocks. The most common of such rocks includes quartzites, shales and marble. Metamorphic rocks do not contain fossils. They resemble igneous rocks in their crystalline-grain structure and sedimentary rocks in the parallel-linear distribution of mineral grains.

1.5 How Does Petroleum Occur

There are still differences of opinions regarding the origin of oil and gas. Many theories on the origin of petroleum have been proposed and are normally classified into two general groups.

1.5.1 Inorganic Theory

A number of scientists adhere to the concept that inorganic oil and gas have originated in the earth's interior as a result of chemical reactions between hydrogen and carbon under conditions of high temperature and high pressures in the absence of organic matter.

1.5.2 Organic Theory

The organic theory of the origin of oil – the most accepted theory- maintains that the hydrogen and carbon source for petroleum was organic material from decaying plants and animals forming and accumulating in oceanic sediment. The acceptance of the organic theory of the origin of petroleum dictates that the search for oil be directed to areas underlying by thick sections of sedimentary rock.

At the present time most authorities favor the organic approach. Their principal reasons are the followings:

-No inorganic theory can account for the necessary quantities of carbon and hydrogen needed to form large petroleum deposits. The abundance of plant and animal life present in sediments is a sufficient source.

-Many crude oil contain –porphyrins- and nearly all contain nitrogen. The presence of these materials strongly suggests organic origin as they are present in all organic matter. Also porphyrins of vegetable origin have been found to be more plentiful than those of animal origin.

-Petroleum rotates the plane of polarized light. This property is restricted primarily to organic materials known as optical isomers and further suggests organic matter as the source of petroleum.

1.6 Formation of Petroleum

The complete process of alteration whereby organic materials are transformed into petroleum is not known. The main factor, which prohibits complete laboratory verification of the theory, is the inability to reproduce the million or so years, during which the process occurs. The role of "anerobic" bacteria in promoting this alteration may be considerable. The evidence from studies of oil fields has led most geologists to the following general conclusions.

-Petroleum originates from organic material, primarily vegetable, which has been altered by heat, bacterial action, pressure and other agents overlying periods of time.

-Conditions favoring petroleum formation are found only in sedimentary rocks.

-The principal sediments generally considered as probable source rocks are shales and limestones that were originally mud under saline water.

In shallow, stagnant water basins host of blue green algae, arthropodal and planktonic organisms develop. On dying, they fall to the bottom of bodies of water along with the dust of plants and entrained fine mineral substances, and form soft, sometimes rather thick layers of organic ooze, or sapropel. The strata of sapropel and humus sediments gradually accumulate at the bottom of water basins. In these strata, the reactions of hydrolysis of fat may take place depending on the pressure, temperature, amount of oxygen and salinity of water. These reactions yield fatty acids, glycerin, and other products, which then transform into hydrocarbons (methane, napthene and aromatic types) and oxygen compounds (ketones). All these compounds dissolve in fatty acids to give a homogeneous tar like mass that remains at the bottom together with mineral matter (sand, clay) and is gradually covered with mineral sediments. Such a tar like accumulation can be called primary oil (protopetroleum). The conversion of organic matter into oil in a reducing medium involves chemical reactions, which tend to raise the carbon and hydrogen content and to decrease the oxygen content.

It is now believed that combination of factors is necessary to transform primary organic matter into oil, such as elevated temperatures and pressures, the activity of bacteria and the action of radioactive substances.

1.7 The Migration of Petroleum Hydrocarbons

The main reason for the migration and the trapping of petroleum hydrocarbon in reservoirs is the existing system of static and dynamic pressures existing in the pores (such as overburden pressure - pressure due to the weight of overlying sediments an the average of 1 psi/ft-). The main result of overburden pressure is the compaction of rock that will reduce the pore space and pushing the liquid content out of the core. Liquid will try to find the way out to the upper low pressure sections. During compaction water surplus of sediments will be expelled and move to zones of lower pressure carrying with it droplets of oil and gas bubbles. Under normal conditions water shows higher affinity to rock surface, the pore space then is water wet and will always retain a fine film of water covering the rock surface called “connate water”. Compaction of sediments will remain a permanent process over geologic time. The squeezed out water is kept moving for the same time even longer and the path of its migration may cover hundred of kilometers. Many of these migration paths may lead into open and the oil droplets will be lost by migration. Others will be ended by so called traps or reservoirs forming oil or gas fields. It may take million of years to fill such a reservoir with a considerable amount of hydrocarbons.

1.8 Oil and Gas Migration

After its formation, petroleum may migrate from the source rock into porous and permeable beds where it accumulates and continues its migration until finally trapped. Petroleum created from the decomposed remains of animals and plants (which were deposited and accumulated in deep sedimentary strata) finds its way to natural storage basins by traveling through porous rocks or layers of rocks. The tiny spaces or pores of sandstone or the ores or cracks of limestone, dolomite or other sedimentary rocks, form the "avenues" by which the petroleum products wind their way upward, carried by their original salt water environment. The oil, gas and water eventually stop when they reach a structure or trap, having a cap rock seal, that forms a reservoir to hold them; that is what the oil and gas industry took for in exploration operations.

The capacity of rock to contain petroleum is termed **porosity**. The ability of the rock to permit petroleum flow is known as **permeability**. The forces causing the oil migration are:

-compaction of sediments as depth of burial increases.

-diastrophism (crustal movement causing pressure differentials and consequent subsurface fluid movement)

-capillary forces (causing oil to be expelled from fine pores by preferential entry of water)

-gravity (promotes fluid segregation according to density differences)

Commercial crude oil and gas reserves are found mainly in sedimentary rocks (sands, sandstone, limestone and conglomerate). In igneous and metamorphic rocks oil occurs rarely and as a rule, has no commercial significance. Natural accumulations of oil and gas in the earth's interior are called oil and gas reservoirs. An oil bearing reservoir (also called formation) is usually bound at the top and the bottom by impermeable rocks (clays) that do not allow oil and gas to penetrate into other strata.

1.9 Traps

In order for petroleum to accumulate in commercial quantities, it must, in its migration process, encounter a subsurface rock condition that halts further migration and causes the accumulation to take place. These subsurface conditions are numerous in type ranging from very simple to extremely complex forms. Numerous systems of tap classification exists where the following is an example.

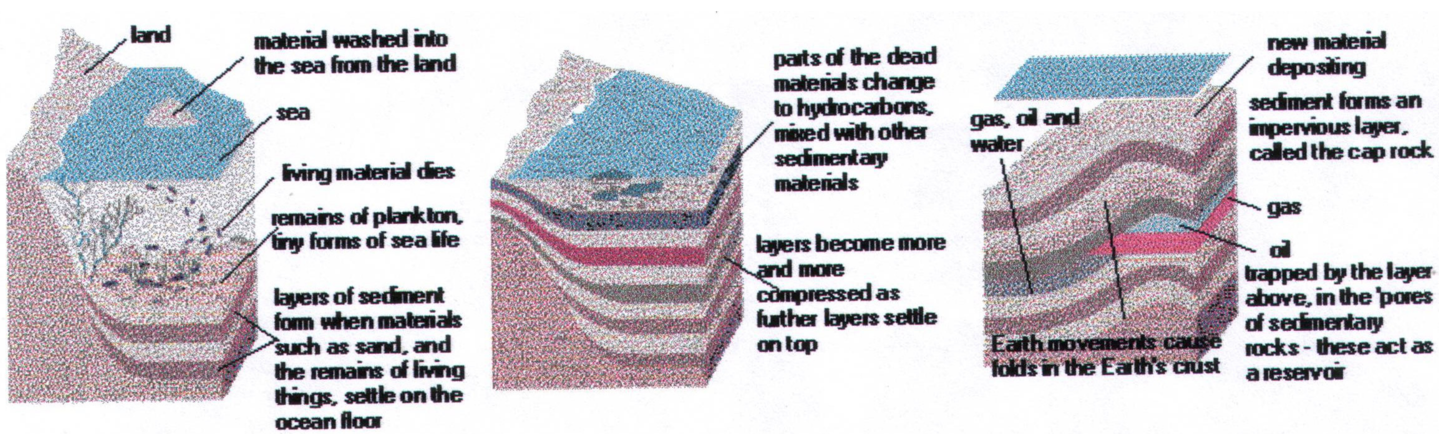

Figure 1-1 Sequence of Oil Deposits

1.9.1 Anticline Trap: An anticline is formed when the crust folds to form a dome-shaped layer like an upside-down bowl. The dome can be a rock which will not let the oil or gas pass upwards or sideways (impervious). This is called the ‘cap rock’. It can also be a layer of clay. Notice the order of the layers in the trap. Gas is the least dense, so it rises above the oil.

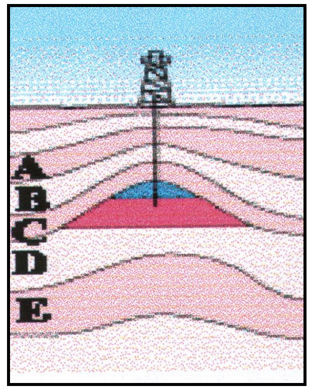

Figure 1-2 Anticline Trap

<u>1.9.2 Fault Trap:</u> When rocks move, they may slide past each other. This changes the layers next to each other. The oil trapped in the sedimentary rock can be forced next to a layer, which will not let the oil and gas move any further.

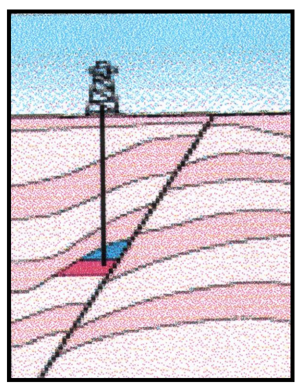

Figure 1-3 Fault Trap

<u>1.9.3 Combination Trap:</u> An example of this type of trap is the ‘salt dome’. When a sea dried up a layer of salt was formed. Eventually, this layer became rock salt, which is impervious. Through a combination of rock movements, the salt can be forced through the layers around it to form a plug. This trapped the oil, gas and water.

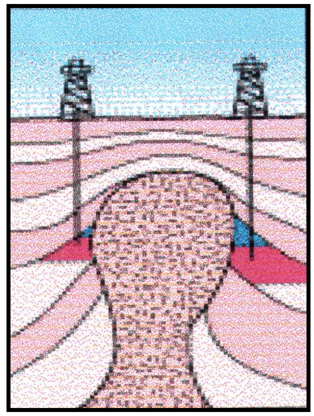

Figure 1-4 Combination Trap

1.10 Unconformities

An unconformity is a surface of non-depositional rock that separates the newer layers of rock from the older. Angular unconformity is the lower, older strata dip at different angle from the layer above them. Disconformities are an unconformity between the parallel strata. Non-conformity is unconformity where the older, lower layer is of plutonic or solidified molten rock origin. Petroleum is trapped in unconformities by the solid cap rock, laid across it by the cut-off surfaces of the lower beds.

1.11 Measuring the properties of rocks

Geologists and geophysicist work closely together using a variety of methods. All the information is carefully considered, with the help of computer analysis, before any decisions to drill are made. A geologist collects small samples of rock. Sometimes the samples of rock are dug out by hand or cylindrical cores are drilled to give samples, which can be cut and studied under a microscope. These help them to find out:

-where the rocks have come from (their origin)

-what they are made of (their composition)

-how the rocks are arranged in strata.

Geologists also find out about the physical and chemical properties of the rocks (mineralogy) and the fossil record from ancient times (paleontology). All these clues give information to build up a picture of the area being surveyed.

A geophysicist adds to the information of a geologist by studying the physics of the earth. Surveys are made of the magnetic field, the gravity and how waves travel through the layers.

1.11.1 Magnetism

Magnetometers measure very small changes in the strength of the Earth's magnetic field. Sedimentary rocks are nearly non-magnetic and igneous rocks have a stronger magnetic effect. Because of these different effects on the magnetic field, measurements can be made to work out the thickness of the sedimentary layers, which may contain oil.

1.11.2 Gravity

Gravimeters measure the strength of the Earth's gravitational pull. This is not the same all over the Earth because of the different densities of the rocks. Igneous rocks like granite is denser than sedimentary rocks. Granite near the surface will have a stronger pull than the same lump deeper down, so measurements help to build up more information about the layers of rock.

1.11.3 Seismic waves

Shock waves or seismic waves are used to help give a picture of deep rock structures. The idea is to make artificial shock waves and record how they travel through the earth. The shock wave travels through the water and strikes the sea bed Some of the energy of the wave is reflected back to the hydrophones. The rest of the wave carries on until it reaches another rock layer. The time taken for the waves to travel from the source to the hydrophones is used to calculate the distance traveled - hence the thickness of the rock layers. The amplitude of the wave gives information about the density of the reflecting rock. A survey using artificial shock waves is called a seismic survey. The data from a survey is recorded and displayed by computer as a pattern of lines, called a seismograph..

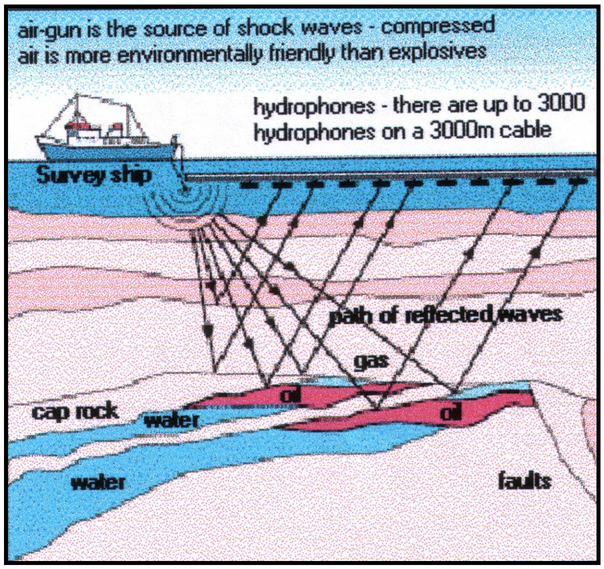

Figure 1-5 Seismic Waves

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