# ENVIRONMENTAL GEOSCIENCES

**Prof. Prasoon Kumar Singh**

**Department of Environmental Science and Engineering**

**Indian Institute of Technology (Indian School of Mines), Dhanbad**

**Lecture-52**

## Fossils Fuels - Petroleum

Welcome to the SWAYAM NPTEL course on environmental geosciences. We are discussing the module ten. Module ten consists of fossil fuels, conservation of non-renewable resources. Already we have discussed lecture one and lecture two. Today we will discuss the lecture three, that is fossil fuels, especially the petroleum.

In this lecture, the important concepts we will cover like introduction to petroleum, origin of petroleum, mode of occurrence, migration of oil, reservoir trap, distribution in India, usage of petroleum, oil recovery, oil sands, oil sale, refining of petroleum, crude oil, production of petroleum in India. First of all, let us understand what is petroleum. Petroleum is the term which means rock oil. This is one of the most important mineral fuels and is a complex mixture of hydrocarbon compounds with minor amounts of impurities like nitrogen, sulfur and oxygen. The liquid petroleum is generally called as crude oil.

Petroleum gas is called as natural gas and the semi-solid to solid forms of petroleum are commonly known as asphalt, tar, pitch, bitumen, etc. However, through processing and refining, products derived from petroleum have well-defined properties. Petroleum can be found in reservoirs of varying sizes of heterogeneous composition under high pressure and moderate temperatures, often associated with natural gas and water. Many of the world's largest petroleum reservoirs are very massive in scale and often are made up of carbonate rocks. The voids in these porous rocks are filled by hydrocarbons, water and gases.

It is normally agreed that petroleum was found mainly from marine and animal life deposits over many millions of years under the combined action of time, temperature, pressure and mobility of components. These were aided by bacterial and mineral actions. But if you will see the origin of petroleum, a number of theories have been forwarded for the origin of natural petroleum. And depending upon the primary source materials, the

different theories have been grouped. The first theory is the inorganic theory and the second theory is the organic theories.

Inorganic theories comprises of Brethelot's alkaline-carbide theory, Mendeleef's carbide theory. So, Brethelot's alkaline carbide theory, according to Brethelot, $CO_2$ might react with alkaline metals contained in the interior of the earth at high temperature with the formation of alkaline carbides. These, on contact with water, liberate acetylene, which, through subsequent process of polymerization and condensation, forms the petroleum. Mendeleef's carbide theory explains that iron carbides within the earth on contact with percolating water form acetylene, which escapes through fissures to the overlying porous rocks and there condenses. This theory is based on laboratory experiment but the presence of iron carbide within the earth has not been established definitely.

The third inorganic theory is the Moissan's volcanic theory. He suggests that volcanic eruptions may be caused by the action of water on subterranean carbides and may lead to the formation of petroleum. The fourth is the cosmic theory taking into account the presence of small quantities of hydrocarbons occasionally in meteorites, Sokolov considers petroleum to be an original product resulting from the combination of carbon and hydrogen in the cosmic mass during the consolidation of the earth. Now see the organic theories. This has been put forward by Engler.

His theory is based on the fact that by destructive distillation of fish-blubber, a product similar to natural petroleum could be obtained. According to him, petroleum is formed by a process of putrefaction of animal remains. Nitrogen thus eliminated and residual fats gets converted into petroleum by earth's heat and pressure. Putrefaction is the process of organic matter decaying due to microorganisms resulting in a foul odor. Second organic theory is the vegetable origin theory.

On the basis of certain facts, as deposits of petroleum found in close association with sedimentary deposits containing diatoms, seaweed, peat, lignite, coal, oil-shale of known vegetable origin. This theory has been propounded. Besides the above, the other facts also support the theory that is oil and coal appear to have close relationships indicating a vegetable origin. The large amount of methane in natural gas can be explained as produced by the decay of vegetable matter. Oil's closely resembling petroleum can be distilled from coal, lignite, etc.

Microscopic vegetable remains have been noted in crude oil even though it is rare. The third is the animal origin theory. Since ninety five percent of the oil fields occur in

marine sediments, it is assumed that oil was formed from marine organisms buried in sediments. It has been suggested that bacterial action plays the most effective role in the conversion of organic material into oil. It is now commonly presumed that the primitive forms of life like diatoms algae etc. which were mixed up and enclosed within the sediments in the sea-bed, where the primary source material for petroleum.

Now mode of occurrence of petroleum. Four prerequisites are necessary for petroleum to accumulate in commercial quantity in an area. The first is the oil originates in a source bed and a marine sail, once be a black mud rich in organic compound, is thought to a common source rock. Second, the oil then migrates to permeable reservoir rocks and to do this, it may travel for long distances, both vertically or horizontally. The source beds tend to lack the permeability necessary for profitable extraction of the oil. Third is the non-permeable layer must occur above the reservoir bed. And the fourth is a favorable structure must exist.

Now migration of oil. Oil is found to occur in porous and permeable rocks like grits, sandstones, limestones and carbonate rocks which have served as reservoirs for oil and are called as reservoir rocks. The migration of oil is thought to be caused due to compaction of the sediments during diagnesis due to which currents of water are set up in the source rocks and the oil is squeezed along with water and enters into the porous and permeable rocks in the immediate vicinity. Since oil is lighter than water, the oil tends to float on top of the water. If the sandstone unit was formed under marine water, it already contains salt water in its pore spaces.

The oil slowly moves up around the soil grains until it reaches the top of the sandstone unit. Gases that have been produced are lighter than the oil and tend to move to the top of the oil accumulation. The greater the porosity, the greater the amount of oil that a reservoir rock can contain. And the larger the pore space, the greater the amount of oil. Now reservoir trap.

It holds the oil and gas in place so that they do not escape until it is released by drilling. It is also known as cap rock which may be an impervious shale, clay, dense limestone, well-cemented fine-grained or shaly-sandstones that are effective cap-rocks and they seal the reservoir trap. The occurrences of petroleum deposits are classified into two broad categories, surface occurrences and subsurface occurrences. Surface occurrences. Petroleum occurs at the surface of the ground in the following ways. That is, first is the seepages, spring and bitumen.

Second is the mud flows and mud volcanoes. Third is the oil shales or kerogen shales. Subsurface occurrences. Petroleum mostly occurs under the impermeable cap rock of a reservoir. The barrier which helps in the accumulation of petroleum is called an oil trap. Oil traps are classified into the following three types, that is structural traps, stratigraphic traps, and combination of stratigraphic and structural traps.

First is the structural traps. These are caused by folding or rupture and displacement of the rock units. They include closed anticlines, domes, monoclines, terraces, synclines, faults, fissures, salt domes, igneous intrusion, etc. The process of strata deformation may be compressional, gravitational, intrusional, or rejuvenated uplifting. Stratigraphic traps, these are formed by conditions of sedimentation in which lateral and vertical variations in thickness, texture, and porosity of beds result.

They include unconformities, that is angular unconformities are more effective, ancient shore-line sands, shoe-string sands, sandstone lenses and bars, etc., And third is the combination of stratigraphic and structural traps. Here are included those reservoirs where structural, stratigraphic, and lithological features are significant in controlling the accumulation, migration, and retention of oil and gas. They include both deformational as well as erosional features, for example, bald-headed structure, traps with buried hills, etc. Now, distribution in India.

In India, deposits of petroleum and natural gas are associated with the belt of tertiary rocks in Assam, Gujarat, as well as in the offshore regions of Bombay High and the Cauvery and Godavari deltaic areas. Now, first is the Assam. Here we are getting Digboi oil-field where the Tipam sandstone of Miopliocene age is the oil-bearing formation. Second is the Nahorkatiya oil-field. In the Brahmputra valley, where the oil bearing formation is the Barail series of Oligocene age. Besides the above, the other important oil-fields of Assam are 'Moran oil-field', 'Rudrasagar oil-field' and 'Lakwa oil-field'.

In Gujarat, we are getting the Cambay basin where the main oil-bearing sand is of Oligocene age. Here a majority of the wells are only gas producers. The other oil fields of importance are Kalol oil field, Nawagam and Sanand oil field. Oil field of Gujarat is the Ankleshwar oil-field. This is the most important oil field discovered so far in Gujarat.

The producing sands are of 'Eocene-age'. Third is the Bombay high. About one hundred fifteen miles off from Bombay, in the Arabian Sea, a huge oil-deposit has been struck in limestone rocks of miocene age. This has proved to be the richest oil deposit in the country. The deposit is estimated to be around four billion tonnes.

In Andhra Pradesh, in the offshore regions of Tamil Nadu and Andhra Pradesh, a number of oil deposits have been discovered by ONGC, recently. Among them, the deposits of 'Nagapatinam' is the most important one, from the commercial view-point. Besides their work, a number of discoveries have already been made in the states of Tripura, Gujarat, West Bengal, etc. Now, usage of Petroleum, the chief use of petroleum are as fuel particularly in the transport operations. The petro-chemical derivatives of petroleum have a wide range of uses in agricultural, industrial and medicinal industries.

It is also used for the purpose of generation of heat and power. Now oil recovery. Production of oil reservoirs using conventional methods remains largely inefficient, leaving significant methods of unrecovered oil underground. The displacement of the oil from the reservoir rock is governed largely by overcoming the local viscous and capillary forces. In recent years, various methods have been developed and are being applied increasingly to enhance the recovery of oil and improve the overall yield.

Primary production methods produce oil via the action of the natural high pressure of the reservoir. It is usually associated with very low recovery effectiveness, typically less than twenty percent. The figure is also showing about the pumping oil out of the reservoir using an externally driven pump. Secondary production methods include water flooding and natural gas injection, mainly to maintain the reservoir pressure as it gets depleted with production and time to help continued removal of the oil from the rock. The recovery rate in these methods can be quite high for light crude but remains relatively low for heavy oil reservoirs.

Tertiary production methods involve the thermal, miscible, and chemical approaches, which are usually applied for certain reservoirs after the exhaustive application of primary and secondary methods. Now, oil sands. Oil or tar sands are mainly made up of sand with around ten percent or less by mass, bitumen and additionally water as shown in the figure. In the figure you can see the typical structure of oil sands showing sand grains surrounded by water and bitumen with some clay and mineral particles in between. The quality of oil sands varies widely with location and depth

Bitumen is a highly viscous fluid made up of complex, huge molecules with enormously large molecular weights of largely hydrocarbon material. It contains also a wide range of elements such as sulfur that is four point five to five point five percent by mass and metallic compounds that is vanadium and nickel equal near about four hundred to five hundred ppm. A schematic representation of an oil sand fragment is shown in figure a

and the extracted bitumen has been shown in figure b. Typically, oil sand deposits, when found up to around fifty meter below the surface, are harvested by surface mining. Deposits below hundred meter deep require thermal in situ bitumen methods where steam injection is used to soften and render less viscous the bitumen that is later pumped with water upward. In recent years, the steam assisted gravity drainage process has become increasingly used for bitumen thermal recovery.

Figure a and figure b is showing the schematically how the SAGD process works. Here you can see the representation of the SAGD process in which you are seeing the discharge stream is coming down and the returning oil and hot water is going up. So and in the figure b you can see the schematic of the clean view of the SAGD process showing the inlet high pressure stream and the return stream to the production well of oil and water. They show two horizontally drilled small-diameter underground long channels with drilled slots pointing upward. Steam is injected continuously in the upper channel to emerge through the slots into the surrounding bed. The steam condenses along the interface and releases its latent heat of condensation to its immediate oil sand surroundings. This will help to heat and reduce the viscosity of the bitumen in the neighborhood and make it mobile.

The oil and the condensed water will then drain via the action of gravity into the lower channels containing similar slots but pointing downward, where they will be withdrawn to the surface. In time, the chamber grows upward and sideways, leaving mainly sand behind. Other in situ methods involving combustion have been tried, but they still require further research and development to render them fully controllable and commercially and environmentally viable for extraction of the bitumen from the huge oil sand deposits. controllable and commercially and environmentally viable for extraction of the bitumen from the huge oil sand deposits. The extraction and processing of oil sands are very energy intensive with a serious environmental impact.

Now, oil shale. Oil shale is a tar-like substance contained in a laminated shale rock. When the rock is fractured, crushed and heated, vapors are released that can be converted by condensation to raw shale oil that can be refined subsequently. In the figure also you can see the fracturing of reservoir through the action of injected fluids and sand to improve the mobility of the resource through the bed. In some instances, the oil can be removed rather expensively by the action of solvents.

However, mineral matter in the deposits typically constitutes more than ninety percent by mass. In general, the technology for extracting oil from the shale is simpler than that of the liquefaction of coal and less developed than that of the production of oil from oil sands. There are serious problems facing the commercial exploitation of oil shale deposits. Some of these relate to the high financial and energy costs of oil removal from such type of oil sale deposits and the serious environmental disruption associated with the extraction process of oil from shale. Typically, more than a ton of rock may need to be removed per barrel of oil produced.

Thus, an extraction plant may have to deal with the disposal of millions of tons of spent rock. The plant may need to carry out necessary remedial measures for preserving the environment while possibly producing nearly a million tons of spent rock to dispose per day. Now refining of petroleum or crude oil. Crude oil must be refined in order to produce finished products. There are four basic operations that all the refineries perform for production of a variety of products.

These are distillation, catalytic reforming, cracking and treating. Distillation, this is the first and most fundamental process in refining crude oil. It involves heating the crude oil to separate its components based on their boiling points. The process takes place in a distillation column where lighter fractions such as gasoline and diesel rise to the top while heavier fractions such as fuel oil and bitumen remain at the bottom. Second is the catalytic reforming.

This process is used to improve the quality of gasoline by increasing its octane number. It involves the use of catalysts such as platinum or rhenium to rearrange hydrocarbon molecules, converting low-octane naphtha into high-octane gasoline and producing valuable byproducts like hydrogen. Tracking this process breaks down large, heavy hydrocarbon molecules into smaller, more valuable ones. There are two main types, thermal cracking and catalytic cracking. Thermal cracking uses high temperature to break the molecules, whereas catalytic cracking uses catalysts to speed up the reaction and produce more gasoline and diesel.

The fourth is the treating. This process removes impurities such as sulfur, nitrogen and metals from crude oil products to improve fuel quality and reduce the environmental pollution. Common treating methods include hydro-desulfurization that is removing sulfur and sweetening that is removing unpleasant odors from fuel. Here you can see in the diagram the early stages in the refining of petroleum separating the crude into bulk

output streams mainly through fractioning distillation processes. Fractioning tower you are seeing.

This is the refinery storage. This is the fractioning tower. And then one condition remains. And this gives the different processes of refining of petroleum. The main products of refining petroleum are refinery fuel gas, liquefied petroleum gas that is LPG, regular and premium gasolines, Kerosene, Solvents, Aviation Fuels, Diesel Fuels, Heating Oils, Lube Oils, Greases, Asphalt, Industrial Fuels, and Coke.

Now production of Petroleum in India. You can see in the diagram the production of Petroleum products by type during two zero two two to two three, in the year two zero two two to two three, the production of petroleum products in the country was two hundred sixty six point five four Mega ton as against two five four point three one Mega ton during two zero two one to two zero two two that is an increase of four point eight one percent. In the total production of petroleum products during two thousand twenty two to two thousand twenty three, high-speed diesel oil accounted for the maximum share, that is forty three percent, followed by motor gasoline. Now let us summarize the chapter.

First of all, we have discussed the introduction to petroleum. We have seen that petroleum is a term which means rock-oil. This is one of the most important mineral fuels and is a complex mixture of hydrocarbon compounds with minor amounts of impurities like nitrogen, sulfur and oxygen. Then we have discussed about the origin of petroleum. A number of theories have been forwarded for the origin of natural petroleum and depending upon the primary source materials, the theories may be grouped as inorganic theories and organic theories.

Thirdly, we have discussed the reservoir trap. The occurrence of petroleum deposits are classified into two broad categories, that is, surface occurrences and subsurface occurrences. Fourth, distribution in India. In India, deposits of petroleum and natural gas are associated with the belt of tertiary rocks in Assam, Gujarat, as well as in the offshore region of Bombay High and in the Cauvery and Godavari Deltaic areas. Fifth, oil recovery.

In recent years, various methods have been developed for recovery of the oil, that is primary production methods, secondary production methods, tertiary production methods. Then we have discussed about the refining of petroleum crude oil. There are four basic operations for this. The first is the distillation, second is the catalytic reforming, third is

the cracking, and fourth is the treating. Lastly, we have discussed about the production of petroleum in India in the year two zero two two to two zero two three.

We have seen the production of petroleum products in the country was two sixty six point five four Mega Ton as against the two fifty four point three one Mega Ton during two zero two one to two zero two two, that is showing an increase of four point eight one percent. Thank you very much to all.