ENVIRONMENTAL GEOSCIENCES

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Lecture-53

Fossils Fuels - Natural gas

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module ten. In the module ten, we have to discuss about the fossil fuels, conservation of non-renewable resources. We have already discussed lecture one, two and three. Today, we will discuss the lecture four that is fossil fuel comprises of natural gas.

In this lecture, the important concepts will be covered like introduction to natural gas, composition of natural gas, origin of natural gas, natural gas reservoirs, properties of natural gas, natural gas recovery, natural gas storage, natural gas transportation, and production of natural gas in India. Now let us understand first the natural gas. Natural gas also called as marsh gas and swamp gas in older texts and more recently landfill gas. Natural gas is a gaseous fossil fuel found in oil fields, natural gas fields and coal beds. As one of the cleanest, safest and most useful of all energy sources, it is a vital component of world's supply of energy.

While it is commonly grouped in with other fossil fuels and sources of energy, there are many characteristics of natural gas that make it unique. That is, natural gas is the result of the decay of animal remains and plant remains. This is important. Decay of animal remains and plant remains, that is organic debris, that has occurred over millions of years. Over time, the mud and soil that covered the organic debris changed to rock and trapped the debris beneath the newly formed rock sediments.

Pressure and to some extent heat change some of the organic material into coal, some into oil that is petroleum and some into the natural gas. Now composition of natural gas, just see, the natural gas is the flammable, this is important, flammable gaseous mixture that occurs alone or with petroleum in reservoirs and is predominantly methane. It is predominantly methane and some of the higher molecular weight paraffins, that is C_nH_{2n+2}, generally containing up to five carbon atoms. In the table also you can see the

different components are methane, seventy to ninety percent, ethane, then propane, zero to twenty percent, butane, then pentane and higher hydrocarbon, zero to ten percent, carbon dioxide, zero to eight percent, oxygen, zero to zero point two percent, nitrogen, zero to five percent, hydrogen sulfide, carbonyl sulfide zero to five percent. And rare gases like argon, helium, xenon and neon these are in the trace amount. So this table is showing the range of composition of natural gas.

Briefly methane is the simplest member of hydrocarbon series and has one carbon atom and four hydrogen atoms. So, in its purest form, the natural gas delivered to the consumer is almost pure methane and the remaining hydrocarbons and non-hydrocarbons have been removed through the refining process. The non-hydrocarbon constituents include but are not limited to carbon dioxide, then hydrogen sulfide, and nitrogen, and helium. All of the hydrocarbon constituents of natural gas are combustible, but non-flammable non-hydrocarbon components, that is carbon dioxide, hydrogen sulfide, nitrogen, and helium, detract slightly from the heating value of natural gas. However, they are valuable and in certain natural gases where their concentrations are relatively high, they may be extracted commercially.

Now, origin of natural gas. There are many different theories as to the origins of fossil fuels, specifically natural gas and petroleum. The most generally accepted theory is that natural gas and petroleum are formed when organic matter or debris such as remains of plants or animals is compressed under the earth at very high pressure for a long time. So, on this basis, there are three main theories regarding the origin of natural gas. The first is the thermogenic origin, which is most accepted theory.

Second is the biogenic origin and third is the abiogenic origin. Now, regarding thermogenic origin, which is most accepted one. The most widely accepted explanation for the formation of natural gas is the thermogenic theory, which states that natural gas is formed from the remains of ancient plants and animals that were buried under layers of sediment and rock over millions of years. Here are the step-by-step processes. The first step is the formation of organic material.

That is, three hundred to four hundred million years ago, tiny sea plants and animals died and accumulated on the ocean floor. Over time, layers of mud, sand, and other sediments covered this organic material. Second step is the transformation begins. About hundred to three hundred million years ago, as more sediments piled on the top, the pressure increased. Simple chemical reactions started breaking down the organic material.

Then burial and compression take place about fifty to hundred million years ago. The organic material was buried deeper under layers of rock under high pressure and possibly high temperatures accelerated the chemical changes. Then next step is the formation of natural gas and oil that is one to five fifty million years ago. The combination of pressure, heat and time caused the organic matter to break down into hydrocarbons, that is oil and natural gas. The gas and oil migrated through porous rocks until they became trapped in underground reservoirs.

This process mainly produces methane, the primary component of natural gas. Because the transformation occurs under heat and pressure, this type of gas is called the thermogenic methane. Now second theory is the biogenic origin, that is methane from microorganisms. Not all natural gas comes from deep underground processes. Some methane is formed much closer to the earth's surface through the actions of microorganisms known as methanogens.

This process is called biogenic methane formation. In this process, methanogens break down organic matter such as decaying plants and waste in environments that lack oxygen. This commonly occurs in places like swamps, wetlands, landfills, and shallow underground reservoirs. The methane gas produced is often released into the atmosphere. However, in some cases, the gas becomes trapped underground and can be collected as a natural gas resource.

A good example of biogenic methane is landfill gas, where decomposing waste generates significant amounts of methane. Third is the abiogenic theory that is methane from deep earth processes. A third theory known as abiogenic, that is inorganic origins, suggests that natural gas can form deep within the earth crust through chemical reactions between hydrogen-rich gases and minerals without the need for buried organic material. In this process, deep within the earth, hydrogen-rich gases rise toward the surface as these gases interact with the minerals under high pressure and in the absence of oxygen, they form hydrocarbons like methane. This process is thought to occur near volcanic regions, mud, ocean ridges, and deep within the Earth's mantle.

While some abiogenic methane gas, it is not considered a major source of natural gas compared to thermogenic and biogenic processes. Now, natural gas reservoirs. Natural gas is found in porous rock reservoirs, that is sandstone, which are sealed by impermeable materials. These reservoirs exist at varying depths from two to five miles

underground and can also be located beneath the ocean floor. The gas forms and rises naturally but impermeable rock traps it in underground formations known as reservoirs.

Here in the diagram also you can see an anticlinal reservoir containing natural gas. This is the sedimentary rock and here the natural gas remains and this is the cap rock. This one is the cap rock. The most common reservoir formations occur when impermeable rock creates a dome-like structure preventing gas from escaping. Fault lines also play a key role in trapping natural gas within porous rock layer.

To extract the gas, drilling must penetrate the impermeable layer allowing the pressurized gas to escape. If a drilled well successfully taps into a reservoir, it becomes a development or productive well. Otherwise, it is classified as a dry well. Once extraction begins, various treatments are applied to remove the impurities like sulfur and water content. Now, what is the properties of natural gas?

The properties of unrefined natural gas vary because its composition is never constant. To understand its behavior, it is essential to analyze the properties of its individual hydrocarbon components. Once natural gas is refined removing impurities such as carbon dioxide and hydrogen sulfide, it primarily consists of methane, which has more consistent properties. Natural gas composition depends on the field formation and the reservoir from which it is extracted. It can be classified as rich, containing five or more gallons of recoverable hydrocarbons per cubic foot or lean, less than one gallon per cubic foot, based on its hydrocarbon content.

Now combustion properties of natural gas. The typical combustion properties of natural gas has been shown in the following table. The properties shown are an overall average of the union gas system. These values can vary from supplier to supplier. Here in this table, you can see the typical combustion properties of natural gas.

The ignition point is five ninety three degree centigrade. Flammability limits four to sixteen percent volume percent in air. Theoretical flame temperature is near about nineteen hundred sixty degree centigrade. Maximum flame velocity is zero point three meter per second. And relative density is specific gravity zero point five eight five and wobbe index is one three two eight. Now natural gas recovery. Natural gas is extracted from underground reservoirs using wells.

This extraction process decreases reservoir pressure which in turn reduces production rates over time. The decision to drill a well depends on economic factors as well as the

geological assessments. Once a drilling site is chosen, legal and logistical preparations are completed before drilling begins. If the well successfully taps into a gas reservoir, it is classified as a development well and prepared for production. However, if no marketable gas is found, it is termed as dry well and abandoned.

Gas wells are similar to oil wells using casing, tubing and a well head to control gas flow. In low permeability reservoirs, horizontal drilling and hydraulic fracturing techniques, such as injecting ceramic beads to maintain fractures, enhance the gas extraction. Some wells use smart technology for real-time monitoring. If gas is extracted from petroleum reservoirs, production methods differ to accommodate oil and gas separation. Pressure naturally pushes gas to the surface, but when pressure declines, artificial lift techniques that is pumps are used.

pumps are used. Production follows a decline curve where output initially rises, peaks and then gradually decreases. To extend a well's productivity, operators may perform workovers to clean the wellbore or fracture or acid-treat the reservoir rock to improve the flow pathways. Natural gas is often mixed with liquid hydrocarbons and water during extraction. These components are separated at processing plants and the purified gas is transported via pipelines or alternative methods depending on the location and market needs.

Now natural gas storage. In the past, excess natural gas extracted alongside petroleum was wasted through flaring-burning it off at oil fields. This practice is now largely illegal due to environmental concerns and companies now store natural gas for future use or transport it via liquefied natural gas or compressed natural gas . Natural gas demand is seasonal with higher consumption in winter for heating. However, as natural gas is increasingly used for electricity generation, summer demand has also risen.

Storage ensures supply availability during peak demand periods and provides a buffer against unforeseen disruptions such as natural disasters. The role of storage. Historically, the natural gas storage was controlled by regulated pipelines to supply utilities. However, after the nineteen ninety two FERC order six three six deregulation allowed companies to store gas for commercial purposes buying when prices are low and selling when prices rise. There are two main storage functions, first is the base load storage, used to meet seasonal demand and these large reservoirs hold gas long term typically cycling gas once per year. Depleted gas reservoirs are the most common type.

Second is the peak load storage designed for short-term demand spikes. These facilities have high deliverability, quick withdrawal rates and faster replenishment cycles. Types of underground storage. There are three main types of underground storage. The first is the depleted gas reservoirs, second is the aquifers and third is the salt caverns.

Depleted gas reservoirs, former natural gas fields repurposed for storage, the most common and cost-effective method. Aquifers, underground water-bearing formations converted for gas storage requiring more preparation and monitoring. And third, salt caverns, man-made cavities in salt formations that allows for rapid injection and withdrawal of gas. Additionally, natural gas can be stored in liquefied form that is LNG, which allows for efficient transport and storage. Natural Gas Transportation. The efficient and effective movement of natural gas from production wells regions to the consumer requires a transportation system.

In many cases, natural gas produced from a particular well must be transported a considerable distance to reach the consumer. In addition, transportation of natural gas is linked to gas storage because if natural gas is not required immediately storage provides a viable option until the gas is required. Natural gas, when extracted from the reservoir, is not suitable for pipeline transportation. Pipelines set their specifications for the quality of natural gas, and the natural gas must be processed to remove unwanted water vapor, solids or other contaminants as well as the hydrocarbons that have a higher value and can be sold as separate products. This being done, there are several options for transporting natural gas energy from oil and gas fields to market. These include pipelines, liquefied natural gas LNG, compressed natural gas CNG, gas to solid GTS that is hydrates, gas to power that is electricity, gas to liquids that is GTL with a wide range of possible products including clean fuels, plastic percursors or methanol and gas to commodity GTC such as aluminium, glass, cement or iron.

Transportation of natural gas as hydrate or compressed natural gas is believed feasible at costs less than for liquefied natural gas and where pipelines are not possible. The competitive advantage of gas to solids and compressed natural gas over the other non-pipeline transport processes is that they are intrinsically simple, so they should be much easier to implement at lower capital cost, provided that economically attractive market opportunities can be negotiated to the gas seller. Now first is the natural gas pipelines. Pipelines are a highly efficient but inflexible method for transporting natural gas, as they deliver gas from a single source to a fixed destination. Their capacity is determined by

diameter and pressure, though enhancements like additional compressors or looping can increase throughput.

Pipelines operate under high pressure seven to eleven hundred psi onshore and fourteen hundred to twenty one hundred psi offshore, which comprises the gas up to six hundred times its original volume, enabling long distance transport. Installation costs vary significantly with subsea pipelines historically being expensive and complex to maintain. To maintain pressure, compressor stations are placed at forty to hundred mile intervals along the pipeline using turbines, motors, or engines to propel the gas forward. The three major pipeline types in transportation network are gathering system, interstate pipelines, and distribution system. Gathering system, low pressure, small diameter pipelines transporting raw gas from wells to processing plants.

Special pipelines handle corrosive sour gas with high sulfur and CO_2 content. Interstate pipelines, large pipelines moving gas across state lines to major markets. And distribution system, it is the networks delivering processed gas to consumers. While pipelines remain the primary mode of natural gas transport, advances in technology are improving their efficiency, reach, and economic viability. Second is the liquefied natural gas.

Natural gas liquefies at about minus one sixty two degrees centigrade and has a volume of about one by six hundred that of the gas at room temperature. However, facilities for liquefying natural gas require complex machinery with moving parts and special refrigerated ships for transporting the liquefied natural gas to market. The cost of building liquefied natural gas plant have lowered over the past twenty five years because of greatly improved thermodynamic efficiencies so that liquefied natural gas is becoming a major gas export method worldwide and many plants being extracted or new ones built in the world. Now, second is the liquefied petroleum gas. Liquefied petroleum gas LPG refers to hydrocarbons like propane and butane, which are gases at atmospheric conditions, but can be liquefied under moderate pressure at ambient temperature.

It is primarily extracted from natural gas or crude petroleum and is commonly used for heating, cooking and as a fuel. LPG has defined flammability limits, the minimum and maximum gas concentration in the air for combustion to occur. Here you can see the properties of propane and butane. The formula is C_3H_8 and C_4H_{10}, boiling point minus forty four of propane and thirty two degree Fahrenheit, specific gravity one point five three two, flash point in degree Fahrenheit minus one five six, minus seventy six for butane and ignition temperature in here in degree Fahrenheit you can see here nine

hundred twenty, one thousand twenty and in the case of n-butane, it is nine hundred to thousand. CNG gas can be transported in containers at high temperatures, typically eighteen hundred psi for a rich gas, that is significant amounts of ethane, propane will be there, to roughly thirty six hundred psi for a lean gas, which consists mainly of methane.

Gas at these pressures is termed compressed natural gas, CNG. It is primarily composed of methane and is used as clean and efficient fuel for vehicles and power generation. CNG is produced through a three-step process. First, natural gas is extracted from underground reservoirs. Next, it undergoes processing to remove impurities such as water vapor, sulfur, and heavier hydrocarbons.

Finally, the purified gas is compressed, reducing its volume by about three hundred times for efficient storage and transportation. Advantages of CNG. Economically friendly It produces less carbon dioxide, nitrogen oxides, and particulate matter compared to diesel and gasoline. CNG is generally cheaper than gasoline or diesel in many countries. CNG is lighter than air and dissipates quickly in case of a leak, reducing explosion rates. And it is efficient and reliable.

It provides a high energy yield and consistent performance. Production of natural gas in India, net production of natural gas for consumption increased from thirty three point one two billion cubic meters in two zero twenty one to two zero twenty two to thirty three point six five billion cubic meters in two thousand twenty one to two thousand twenty three, registering an increase of one point six one percent. The net production for sale has also experienced a growth of over two point eighty eight percent in comparison to the last financial year. After having a steady decline from the financial year two zero one three to one four to two zero one six to one seven, the net production for sale of natural gas has increased to twenty eight point one four billion cubic meters during the financial year two zero two two to two zero two three as compared to twenty seven point three five billion cubic meters during financial year two zero two one two zero two two. Here in the figure also, you can see the net production of natural gas in India during the financial year two zero one three to two zero one four, two zero one four to two zero one five, two zero one five to two zero one six, two zero one six to two zero one seven, two zero one seven to two zero one eight, two zero one eight to two zero one nine, two zero one nine to two zero two zero.

and two zero two zero to two zero two one, two zero two one to two zero two two, and two zero two two to two zero two three. So this table is showing the trend of net

production of natural gas in India from financial year two zero one three to two zero one four to two zero two two to two zero two three. Now let us summarize the chapter what we have discussed. Firstly we have discussed about the natural gas. We have seen that natural gas which is also called as mass gas and swamp gas in older texts and more recently it is called as landfill gas.

It is a gaseous fossil fuel found in oil fields, natural gas fields and coal beds. Then we have discussed about the composition of natural gas. Natural gas is the flammable gaseous mixture that occurs alone or with petroleum in reservoirs and is predominantly methane, ethane, propane and butane. Thirdly, we have discussed about the origin of natural gas. There are three main theories regarding the origin of natural gas.

That is, first is the thermogenic origin, which is the most accepted theory, then the biogenic origin, and then the abiogenic origin. Then we have discussed about the natural gas reservoirs. Natural gas is found in porous rock reservoirs, often sandstone, which are sealed by impermeable materials. The most common reservoir formations occur when impermeable rock creates a dome-like structure preventing the gas from escaping. Then we have discussed about the properties of natural gas.

Once natural gas is refined, removing impurities such as carbon dioxide and hydrogen sulfide, it primarily consists of methane which has more consistent properties. We have also discussed the natural gas transportation, which includes pipelines, LNG, that is liquefied natural gas, then compressed natural gas, CNG, gas to solid, GTS, that is hydrates, gas to power, GTP, that is electricity, and gas to liquids, that is GTL. And at the last, we have discussed about the production of natural gas in India. We have seen that net production of natural gas for consumption increased from thirty three point one two billion cubic meters in two zero two one to two zero two two to thirty three point six five billion cubic meters in two zero two two to two zero two three, registering an increase of one point six one percent. Thank you very much to all.