Petroleum Reservoir Engineering

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Lecture 21: Unconventional Natural Gas Production

Hello everyone. Welcome to the class of petroleum reservoir engineering. Today is actually the last class of this MOOCs course on petroleum reservoir engineering. This is lecture number 2 of week 8. We are still in section 3 of this levels and today we will complete this section. In the previous lecture, we discussed about the introduction of the petroleum reservoir simulation.

Briefly we discussed about the basic concept of petroleum reservoir engineering in the simulation model and how commercial software can be classified based on the information available and can be utilized for simulating the complex reservoir process. In today's lecture, we are going to discuss the concept of unconventional natural gas production. Briefly, I will be discussing some of the unconventional natural gas resources. So the production from unconventional petroleum reservoirs include petroleum from Shell, Coal, Tide gas and Oil sand.

So the hydrocarbon that is oil and gas can be produced unconventionally also from various sources. These reservoirs contain enormous amount of oil and gas but the technology applied to recover these resources are not commercially economical. Hence the challenges on the technical side still need to be improved. If we look the total primary energy demand of the world in 2 years 2014 that is already passed and compare it with the projected value of 2040, these data are taken from the IEA that is published in 2017. If we see share from the past 2014 and compare it with 2040, we can see the fossil energy is still going to be the dominating factor.

But the share of other energy like nuclear energy is going to increase from 5% to 11% and similar for the other. If we just look on the fossil energy sources that is coal, oil and the gas, we can see the coal percent is going to be reduced from 29 to 13% only while the oil will also get reduced from 31 to 22% and gas percent is going to increase in the future that is where we need to discuss the future of the natural gas in supplying the energy to the world. If we look the data from United States for oil and gas production, so

this data are classified from unconventional and conventional sources. From year 1980 till the projected value 2035 and of course 2030 is also projected value. Here from this histogram, we can see the share of conventional and unconventional sources of oil and gas in different years.

So if we see the data in 1980, we can see mostly conventional oil and conventional gas are predominantly supplying the energy for the United States. When we move further, we can see the share of the oil and gas shifted but now if we see in the future perspective, we can see the unconventional oil and unconventional gas are going to take significant part of the energy need of the United States. Hence, the unconventional sources of oil and gas are getting exploited, explode to meet the energy demand. So the natural gas to be fossil fuel with substantial growth in the uses in the future production profile, we can see for the United States here. The growth in natural gas production will be because of LNG, liquefied natural gas and fuel cell technology development.

Those require natural gas to be utilized for their technology development. If we look unconventional natural gas production in terms of natural gas resource that is the part of hydrocarbon energy. Hydrocarbon energy means the organic material got converted on geological time scale to fossil fuels. Those are coal, oil and gas. So the fossil energy is natural gas, oil and coal that can be produced in conventional manner and unconventional manner also.

If we see the unconventional natural gas resources, we are having Shell gas, Tide gas, Gas hydrate, Coal-bed methane. These are actually fossil fuel waste things, other sources of the natural gas production could also be there. For example, the pyrolysis of the carbonaceous substance, if we pyrolyze those substance, we will get the oil and gas kind of the substance. The carbonaceous substance could be biomass, plastic, coal itself and the others. Briefly, we can list out what this Tide gas is.

This is the place where the gas is stored relatively very impermeable rock like limestone and sandstone. The permeability is very low, less than 1 milli tar sea. Shell gas is the place where the gas is trapped in fine grade sedimentary rock shell. Coal-bed methane is also one of the source of unconventional natural gas production where the gas is trapped in coal seams. It means it is adsorbed in the solid matrix of the coal or in the micro pores those are present in the coal.

One of the important source of the unconventional natural gas that is gaining lot of attention is gas hydrate. This is crystalline case like structure where the modern molecules stabilized by small gas molecules. It means the gas molecules are trapped within the case structure of the water molecules. The gas that is getting produced from these different sources is not different. Mostly it is methane gas with other constitute like

C2, C3, C4 but the difference in the classification of the unconventional natural gas resources comes by the geological setting and the rock type where the gas is trapped.

For example, Tide gas, Shell gas, Coal-bed methane and gas hydrate they are geologically different domain where the natural gas is trapped. If we look the recoverable natural gas resources on the resource triangle diagram, this diagram qualitatively showing about the different types of the gases in terms of their share in total natural gas. So on the top we are having the conventional source that is the small amount compared to the large unconventional sources that is Tide gas sands, Coal-bed methane, Shell gas and the gas hydrate. Gas hydrate is at the bottom that is sharing the large part. We will see in the coming slide also the gas hydrate is getting lot of attention because of the massive amount of the gas hydrate that is trapped under the sea level or in the terrestrial domain also under the specified temperature and pressure condition.

So the conventional resource are small volume that are easy to develop while unconventional resources are large volume that are difficult to develop. Technology intervention is still required to recover these resources effectively under the economical condition. If we see the natural gas reserves on the global platform, Russia is having the larger bar which is also including conventional Tide gas, Shell gas and Coal-bed methane. In this diagram that is taken from again EIA is not including the gas hydrate. If we look on the unconventional sources, we see United States and China are having the massive resources of unconventional natural gas.

If we look the data published in 2014, country wise distribution of these unconventional resources like Coal-bed methane, Shell gas and Tide gas, we can say in this reported data United States is dominating compared to other countries in terms of the total unconventional gas production by United States in the form of CBM, Shell gas, Tide gas. In this list you will see India is at the lower side but still the exploration and exploitation of natural gas in the unconventional manner is getting discovered in India and across the globe. Unconventional resources will change significantly with data from other countries. So these data are representative information of different conventional and unconventional resources of the natural gas provided by the agency to the publication agency. But this picture is showing of course the unconventional resources are going to be major player in the future to meet the energy demand.

One of the unconventional resource of natural gas is gas hydrate. Gas hydrate are crystalline case like structure where the water molecules stabilize via small gas molecule. So the water molecule is kind of a host molecules and then the gas molecules is the gas molecules and this molecule is trapped in the cavities under high pressure and low temperature condition. So to get gas hydrate form low temperature and high pressure condition is required along with the water molecules and the gas molecules. Most

commonly the small gas molecules are lighter hydrocarbon methane ethane propane and other gases that may also be present like H2S, CO2, N2.

These gas hydrate are discovered in late 19th century in Siberian permafrost where the solid kind of the structure was found under the conditions of low temperature and high pressure. So the gas hydrates are known to form pipeline blockage for years. So this was the situation is happening when the transportation of natural gas by the pipeline was happening. When the reason of low temperature and high pressure was attained the water molecules are present in the natural gas. They are going to form the case like structure.

In fact a solidified structure where the blockage of the pipeline is happening. So this was considered to be one of the biggest problem in transportation of natural gas through the pipeline. For that purpose as much as water molecules can be separated before sending the natural gas to the pipeline was adopted or making sure the pipeline is not going to hit the reason of low temperature and high pressure. It was rediscovered as oil exploration moved offshore in early 1970s that time it becomes the source of the energy compared to the problem of transporting natural gas through the pipeline. In current time the gas hydrates are gaining the popularity as the fuel for the next century because of their massive amount present.

If we see in this diagram this is how the gas molecules is trapped in the cavity of water molecules structure. This picture is showing the solid kind of the structure that gets formed from the water molecules and gas molecules and we get the gas hydrate. If we show the flame to this structure it start burning because the gas that is combustible in nature is present in this kind of the structure. This is what I was mentioning about the blockage of the pipeline when the gas hydrates are forming in the pipeline. So this kind of the massive solid structure get formed and block the pipeline transportation.

The gas molecules within the water structure are trapped. The gas molecules could be methane, ethane, propane, carbon dioxide and the number showing here the molecules of the water around 7 molecules are required to trap one molecule of the methane. Because of that water gets solidified at a temperature considerably higher than the freezing temperature of the water. Hence to prevent this kind of the formation happening in the pipeline transportation either the water molecules are separated before natural gas is transported. The structure as I mentioned the hydrate number is not fixed for particular formation but the structure those got formed can be classified as a structure 1 gas hydrate crystal that is cubic lattice kind of the structure with the lighter molecules of the hydrocarbon gases.

Structure 2 that is diamond lattice kind of the structure and structure 3 where the hexagonal lattice structure got formed as shown in this diagram. Generally structure 2 and 3 got formed with a little bigger molecules of the hydrocarbon like ethane, propane,

butane. In this diagram you can see the massive amount of the gas hydrate present across the world. The two colors showing here one for the recoverable and then the other color is showing the infrared gas hydrate condition. It means it is the potential side where the gas hydrates are there but the decision to make them produce is still not at decided.

The condition to get the gas hydrate form is shown on the diagram where the pressure of the hydrate formation is plotted on the y diagram and then the temperature is on the x diagram. Here different lines are drawn there for different gases. For example methane to get the gas hydrate form we requires low temperature and then the high pressure. If we increase the temperature pressure will also increase to get the gas hydrate form. With respect to the composition of the gases we can see here methane is getting formed at a condition where the high pressure and low temperature is there.

If the gas gravity is reducing for example 0.6 gravity even at a low pressure the gas hydrate may get formed. When the gas gravity is around 0.9 and 1.0 even further lower pressure the gas hydrate can get formed.

In the transportation we want to avoid the situation or in terms of exploration we are looking the location where such kind of the gases are present and then the favorable pressure condition and temperature conditions are present. And then these massive gas hydrate amount can be economically exploited and recovered to meet the energy demand in the future. So the diagram that similar to the previous case that is showing here if we want this to be recovered from the sources where it is formed we need to alter the pressure or the temperature condition. So the condition could be to get it formed is the presence of the liquid water. So if liquid water is not present no gas hydrate will be formed.

Low temperature and the high pressure conditions. Presence of the seed crystal of the hydrate is kind of a favorable condition if those small seeds are present the chances of getting the gas hydrate formation is more. Presence of highly soluble gas such as H_2S or CO_2 favor the gas hydrate formation. Now if we know the gas hydrates are formed we want to recover them we have to alter the condition. The first condition that we can alter is or the mechanism through which we can recover the gas from this gas hydrate is depressurization.

In this case what we do we alter this pressure so the high pressure condition can be changed to a lower pressure condition in that case the gas will be liberated out from this case like structure and we can recover that thing. That can be done in a very systematic manner here that is shown in this diagram if by any mean we are able to reduce the pressure of this formation where the gas hydrates are stored or gas is trapped in the hydrate form if we can depressurize this gas will come out water molecules will remain there and that is where we can recover the gas. Second condition with respect to

temperature so we can increase the temperature by the thermal injection of the fluid that fluid could be hot brine or the gas when we are pumping this fluid to the domain of the gas hydrates the dissociated hydrates will remain in the domain while the liberated gas will come out to the surface. This is where the condition where the temperature is increases and then the condition or alter where the hydrate cannot be remain in the gas hydrate form. The third condition could be in vitro injection those could be the chemical injection into the domain for example methane is injected into the formation where the gas hydrates are there that will alter the condition for the hydrate formation condition and the gas will be release out and we can get the gas out of the domain.

So these are the condition through which the gas hydrate can be recovered but the massive amount is there lot of the things are there how to recover those in a technical economical manner is still under the research phase. So the gas hydrate was a problem in the past because of the pipeline chalking was happening now researcher are looking as a future in the gas hydrate to recover the gas from this gas hydrate that can be utilized for the energy need. The other source of unconventional natural gas is coal bed methane where the gas trapped in coal seams adsorbed in the solid matrix of the coal. This is known for several years I mean to say it is as old as the coal mining because when the coal mining started natural gas was getting produced and this natural gas lead to several disaster those happened or can happen in the future also in the coal mining. The conventional methods was to ventilate these mines and let the natural gas go away but this is a pure methane gas and it is having the more energy as it is not having the non hydrocarbon gases in it.

Hence the exploitation of the coal bed methane was considered for recovering the valuable natural gas. Every methane trap is very large and making conventional method uneconomical we cannot just let it go by the venting process. Large quantity of methane can be recovered making it as a potential energy source. So the coal seams that is adsorbing methane on the surface or in a micro porous in it that can be altered by certain means and letting this methane gas come out from this coal seams that can be done by the distortion of the gas from the coal surface that is trapped inside the micro pores then further the diffusion of the gas happens through these micro pores towards the production site or towards the surface Darcy law through the fracture and the clads to the bellwort. So the gas that is adsorbed on the coal seams this is coal bed on the surface of that the gas is adsorbed by any mean for example any mean is we are reducing the pressure here or changing the pressure here the gas will liberated out and then the water will also get produced along with this process.

There are several CBM extraction technologies have been developed but still this is not economically technically proven hence it also falls in the unconventional energy

resources. The factor affecting the methane content in the coal bed that will vary from coal to coal seams porosity present in the coal seams, adsorption capacity of the coal, fracture permeability present in the reservoir domain means reservoir domain means coal bed and then the other factor like the coal density means rank of the coal, pressure difference and then the thickness of the formation how massive the coal reserve is there accordingly the coal bed methane can be quantified and can be exploited. The recovery rate of the coal bed methane is low and very unpredictable hence the technology could not be advanced to a level of commercialization. Next is shell gas or the tight gas if we see here the diagram showing the comparison of conventional gas, tight gas and shell gas. So the conventional gas is in the reservoir rock, tight gas and the shell gas are also in the reservoir rock.

This can be produced under the conventional manner up to certain extent the tight gas can also be produced under the conventional reservoir but certain features need to be included for example creating the permeability or the porosity or letting the condition where the gas trapped in this tight gas can be liberated out while the shell gas still fall under the unconventional reservoir condition. So in the conventional gas large amount of the gas well connected pores are present so the gas movement can happens while in the case of the tight gas a small amount poorly connected pores are there while in the case of the shell gas very small amount hardly connected pores are there. So the pores are not connected we need to create certain fractures to get the pores connected and then the natural gas trapped in this formation can be flowed from one point to other point. Here in this diagram the shell gas resources across the globe are shown and it is reported that the volume of shell gas or shell oil we will discuss in the next slide what shell oil is. Resources of the world is massive in the amount, advances in economical, bio-world, sustainable extraction technology would enable these resources to provide a platform for new age of the hydrocarbon.

We might have hear the news of like hydrocarbon are going to be depleted very soon we will be on some other source of the energy instead of the fossil energy sources but certain kind of the discovery of the unconventional sources of the hydrocarbon resources both oil and the gas are showing the signal of new age of the hydrocarbon. Still this need to be proven with the economical technology those can be implemented to recover these resources. So the next resource of the unconventional gas production could be oil shell. Actually oil shell is considered for the shell oil production that is unconventional oil production but during the process of producing the shell oil significant amount of the gas also get produced and that is happened by retorting the oil shell material. This picture is showing oil shell structure above the surface.

Similar structure is expected or present underneath the surface but not in very deep reason. This structure shown here is containing organic matter that is primarily carrosan

from 10 to 12% just approximation but in some cases it is 2% to 50% also with a small amount of the bitumen. These organic matter are laminated within the mineral matrix. So mostly the mineral matrix are surrounding these organic materials and a small amount of the free and bound water is also present in this case. So the material can be taken out perform the thermal pyrolysis or retorting process to get the shell oil or the gas out of it.

That can be done in ex situ process or in in situ process condition and then the product we get primarily is shell oil and then the byproduct is gas also there. So what happen in ex situ condition? We take this oil shell solid material that is organic material plus the mineral matrix from its original place to some other place we dig out actually kind of mining process for similar to the coal and then do the thermal treatment that is primarily pyrolysis or retorting and get these material converted into oil and gas. The solid material remains is the spent shell. While in in situ process the original place where the material is present is utilized and instead of mining the material to the retorting facilities we retort the oil shell at the place itself.

The potential of these resources are estimated to be 2.9 trillion barrel of shell oil can be produced from this. United State is the country which is leading in the amount of the oil shell present in the country. Estonia is another country that is using oil shell as the major energy resource for the country's energy need. The process is very simple provide the energy, reduce the time, get converted this corrosion to oil and gas and the remaining amount is the spent shell. Here in this diagram I am showing the temperature time history.

So if you can reduce the time by increasing the temperature that is similar to what is happening on the geological time scale. So geological time scale it happens at a temperature around 70 to 80 degree Celsius. But if we take this material out or even at the place itself in the in situ process we can heat the material to high temperature let us say 300, 400 degree Celsius this corrosion will get converted into oil and gas. There are several processes at the industrial scale have been developed to get the shell oil from this oil shell. The process is called the shell ICP process, in situ conversion process.

ExxonMobil developed a process that called the electrophrag process. AMSO developed a process that they call it CCR, conduction, convection and the reflux process. And a company called Redleaf they developed a process called the EcoShell process. These processes listed here including the in situ conversion of the oil shell to shell oil and the gas. Except this Redleaf process, this Redleaf process actually use the modified in situ concept.

But the company Redleaf developed a process called EcoShell where the capsule kind of the massive structure are designed where the oil shell is dig out from its original place and placed inside this capsule and heated through this pipeline at the temperature.

And this is done by placing the oil shell and then closing this capsule making this capsule as a reactor, big reactor where the heat is supplied through this hot pipeline and then the amount of the corrosion got converted to oil and gas is recovered out of this capsule through the pipelines. So let us say here is the production pipeline through which we can get oil and gas. Now later on what they did, they considered this as a modified process. A capsule is designed kind of a pool area where the system is heated.

Once the hydrocarbons are recovered in the form of oil and gas, spent shell will remain there, they close it and just leave it there. It means they buried this capsule at the place where the process of retorting was performed. That is why this process is called the modified in situ process. Although mining of oil shell is done, that is the part of ex situ process, but that is placed in a condition kind of the in situ condition. While in in situ process, shell developed this technology, they called it ICP process, that is in situ conversion process, where the heaters are inserted into the domain where the oil shell reserves are there.

Different kind of the structure were studied, but they proposed to have the hexagonal pattern of the heaters and then the production well. So for example, the area where the oil shell is present, hexagonally they put the heaters and one well at the center that is the production well. By heating at the in situ condition, the corrosion got converted into oil and gas that is getting produced through these producer wells. Good results were reported by shell through this process, but this process is also could not produce economically and the operation could not be taken further. So in summary of unconventional hydrocarbon resources, we discussed several options.

Oil as a part of the unconventional oil resource. Similarly, we are having the oil shunt that is massively present in Canada, where the heavy oil is laminated with the shunt. By applying of the heat, we can get that hydrocarbon oil recovered from the oil shunt. In summary of the natural gas as unconventional resources, I would like to emphasize the utilization of the natural gas that is shown here. So several phases of the energy requirement are getting natural gas utilization. These are very old data, 2000 to 2002 and for the United States only where the residential need of the natural gas is large.

So the utilization of natural gas that is used as both feedstock for the petrochemical industry and could be used as a fuel. Natural gas liquids consumption became double or it is expected to be double from 2016 to 2040. So it is expected by 2040, the LGL utilization will be double. Hence, we need more natural gas that can be converted into NGL and then the utilization can be done.

Electrical electricity demand grown by 60%. Natural gas grows significantly with growing demand from the OECD countries. OECD is Organization for Economic Cooperation and Development. So the energy demand is increasing that is why the

utilization of the natural gas is expected to grow. The world shifts to lower carbon sources for electricity generation and led by natural gas and the others. So, coal are utilized for the electricity generation but those are very dirty kind of the fuels.

Hence, the natural gas could be a good substitute for the lower carbon source for producing the electricity. When we look the natural gas industry, it is a gaseous fuel that can be produced from the oil field, from the gas field and from the coal beds. So all these fossil sources of hydrocarbon energy is having the natural gas present in it. Discovered in the United States in 1821, gas was often produced from the oil well and it is often flared in huge quantity because the idea was not there what to do with this natural gas where it to be utilized. So when the oil production was happening along with the oil, natural gas was getting produced.

This is either the gas is present in free condition or in the dissolved condition. The gas used to get produced and this gas used to be flared in the atmosphere. Natural gas has been used as fuel in the area immediately surrounding the gas field. So when it was utilized, the natural gas is also combustible in nature.

It is having the energy but it was not having any market. So the natural gas produced from the reservoir was utilized at the immediate place where it gets produced or just nearby places it was utilized as an energy source. Natural gas was once a byproduct of crude oil production. As mentioned it was having no utilization either it is just flared or used for the domestic or local uses. But now the natural gas is seeing the future, it becomes from byproduct to the fuel of the choice in the future.

It is one of the most cleanest, safest useful form for the energy. Hence it is gaining lot of attention. In this diagram you can see the natural gas production by the region. So these are the four countries those utilizing lot of energy or in future they are expected to utilize lot of energy. So in the summary of future for the natural gas industry I can conclude that 19th century was a century for coal that supported the initiation of industrial revolution in Europe. 20th century became the century of the oil that was the primary energy source to support the growth of the global economy.

At the end of the last century natural gas took over the position of coal, became the number two energy source behind the oil. Since the natural gas is now becoming the premier fuel of choice for the world economy and the natural gas is having very potential application in the future. Natural gas is superior to other sources not only in economic attractiveness but also in environmental concern. The utilization of the natural gas or the future of the natural gas will depend on the production of the natural gas as well as its demand in the market. So if we look the data or fact the primary producer of natural gas are the United States and the Australia.

So in summary the future of the natural gas will depends on the technology those are getting developed to exploit the natural gas through the unconventional sources as well as the Recovered natural gas should have the market value and that will depends how the technology for the utilization of natural gas are getting advanced. That will make sure the natural gas is having a good future as the clean energy source. With this I would like to end my today's lecture. Let me quickly summarize what we discussed so far in this course of petroleum reservoir engineering as this is the last class.

So I would like to go through these slavers that we planned in section 1, 2, 3. We also planned this to be completed in 8 weeks time around 20 hours lecture. So in the first week we discussed about the introduction of the petroleum reservoir engineering with the basics of the petroleum reservoir engineering how flow through porous media happens. Some numerical methods like the Newton Raphson methods and the trapezoidal rule those are needed to solve some of the problems are discussed in this lecture. Second we move to petroleum reserves how the petroleum reserves are formed what is the potential of those reserves what is the market value we discussed in that lecture. In lecture 3 we discussed about the petroleum geology where the petroleum bearing rock like the sedimentary rocks were discussed the migration of the petroleum from its source rocks to the reservoir rock were discussed and in the last lecture of week 1 we discussed briefly about the well drilling methods.

In next week we discussed about the hydrodynamics of the hydrocarbons followed by natural gas properties and the properties of the crude oil. In week 3 we discussed about the reservoir rock properties and then further extend the concept of relative permeability when multi-phase system is present in the reservoir domain followed by the natural dry mechanism also called the primary dry mechanism those are present in the reservoir domain. In week 4 we discussed the concept of tank model that is the zero dimension model we discussed this in general and then in the next lecture of week 4 we discussed for particular reservoir like the oil reservoir and the gas reservoir. In week 5 we started including the flow equation so the fundamental of reservoir fluid flow discussed in lecture 1 of week 5 followed by setting up of the IPR equation and then the general radial diffusivity equation for flow through radial direction in the reservoir domain. We solved this equation for different cases of different types of the fluid and different flow regime.

In week 6 we discussed the assessment of the well testing and the performance of the well. In week 7 we discussed about the processes those are implemented in the reservoir domain after the primary recovery process those are secondary recovery process like the water and the gas injection and then followed by enhanced soil recovery method. In the last lecture we discussed about the reservoir simulation briefly about the conservation law of 3D and 3 phase system, commercial software, discretization of the equation and

then the boundary condition. In today's lecture we briefly discuss about the unconventional sources of the hydrocarbons, gas hydrate, coal bed methane, oil shell and then the utilization of the natural gas considering this as a fuel for the future. In this course development I used the material specifically the tare camera that I can recommend you as a text book for this course other book could be good reference material to understand the concept of this petroleum reservoir engine course.

I also took some material from other sources hence I acknowledge all of these books and the material from where it is taken in my lecture preparation. With this I would like to end my today's lecture as I mentioned this is the last lecture of petroleum reservoir engine. Hence I wish you enjoyed this course and the course content was up to the expectation you were planning with this petroleum reservoir engine course and good luck for your exam. Thank you, thank you very much.