Upstream LNG Technology
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Lecture – 06
Phase Behaviour of Natural Gas

Welcome. Today, we are going to see the Phase Behavior of Natural Gas. Now you are aware of the phase behavior of many pure components like water, like carbon dioxide, etcetera and perhaps you know when through our earlier lectures that how we represent the phase diagrams in various manners. So, like pressure temperature, pressure enthalpy, temperature entropy, etcetera.

Now, in case of natural gas, we have to look into phase behavior because it behaves very peculiarly which you will not find in the case of many general gases. So, this needs a special attention and this phase behavior is also important from the point of view of the reservoir engineering because, the type of reservoir like whether the reservoir will be having only gas, whether it will be having liquid oil and gas or only oil this kind of behavior is also represented from the phase behavior of the natural gas.

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So, from these angles, we need to know the phase behavior of natural gas. Now, in this particular lecture, what we shall learn; we shall learn about the phase behavior of natural

gas and the very interesting phenomena that is called retrograde condensation and its prevention.

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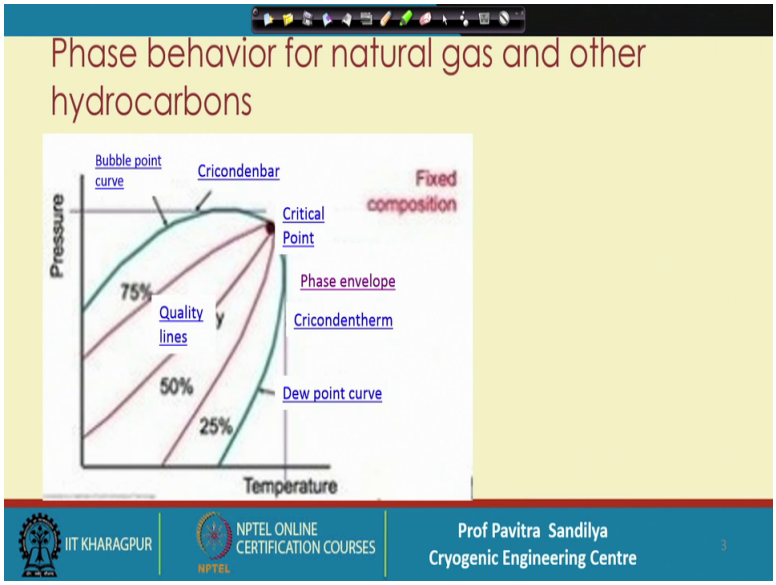

Now, first let us come to the phase behavior of the natural gas. Here, we have drawn a typical diagram with respect to pressure and temperatures. This diagram is not unique, in the sense that depending on the type of natural gas, we will be having different types of this phased diagram, though the overall features which are shown here and discussed will be the same.

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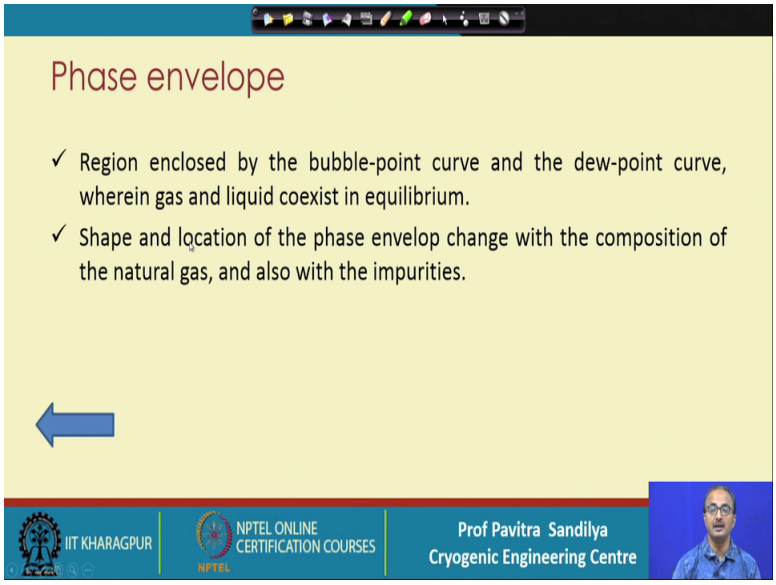

Now first let us see the phase envelope. Now, what is phase envelope? Phase envelope is the region that is enclosed by the bubble point curve and the dew point curve and this bubble point curve and dew point curve; as we learnt earlier are the ones which dictate the pressure and temperature at which the liquid phase may go to vapor phase or the vapor phase may vapor phase will go to the liquid phase.

So, if you go to see this particular diagram, here see that this particular curve, this is the this curve is the bubble point curve and this is a dew point curve. And these are kind of enclosing the 2 phase region within which we have 2 phase region and outside this phase envelope we have the single phase region.

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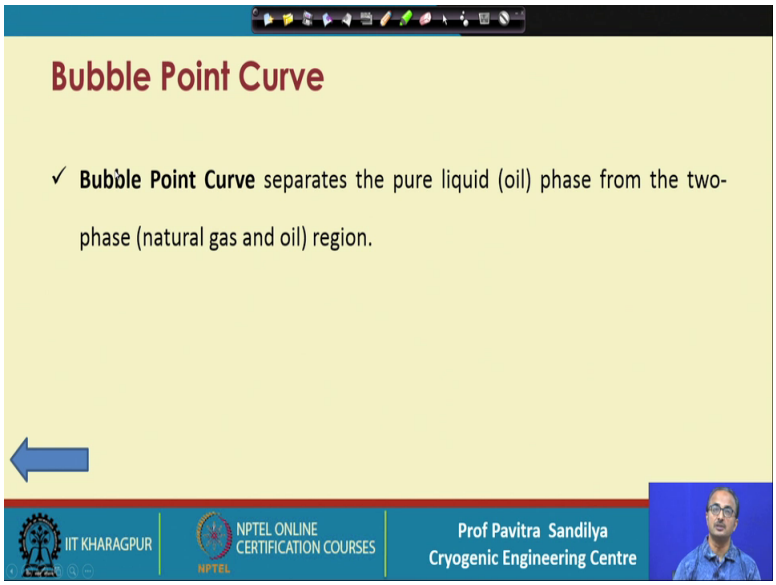

So, we know that what is bubble point curve; bubble point curve as we learnt earlier it; separates the pure liquid and from the two phase region. Now, in case of reservoir engineering or in case of the petroleum reservoirs, the pure liquid means we oil; oil is the liquid and when I say gas it means the natural gas. So, the in case of the natural gas phase behavior, the bubble point curve demarcates the oil from the two phase region that is a mixture of the oil and the natural gas, then we have the dew point curve dew point curve separates the pure phase gas from the two phase region.

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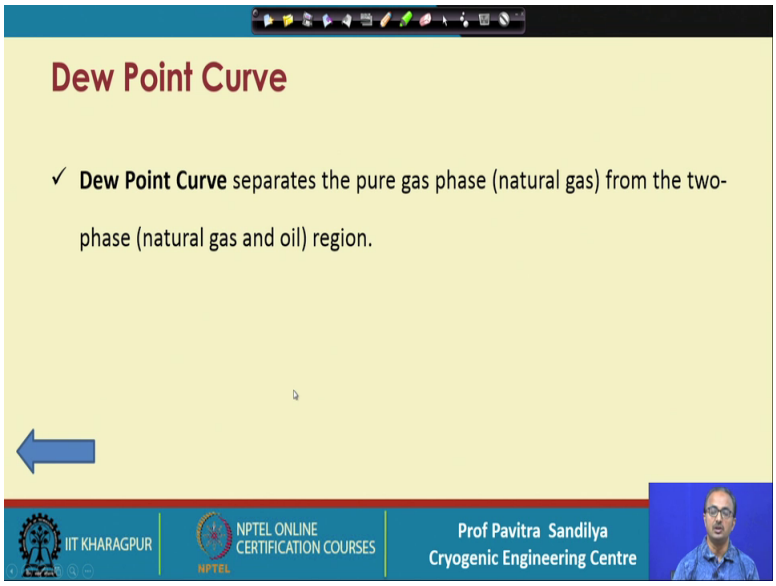

So, as I told you, the pure phase gas means it is a natural gas.

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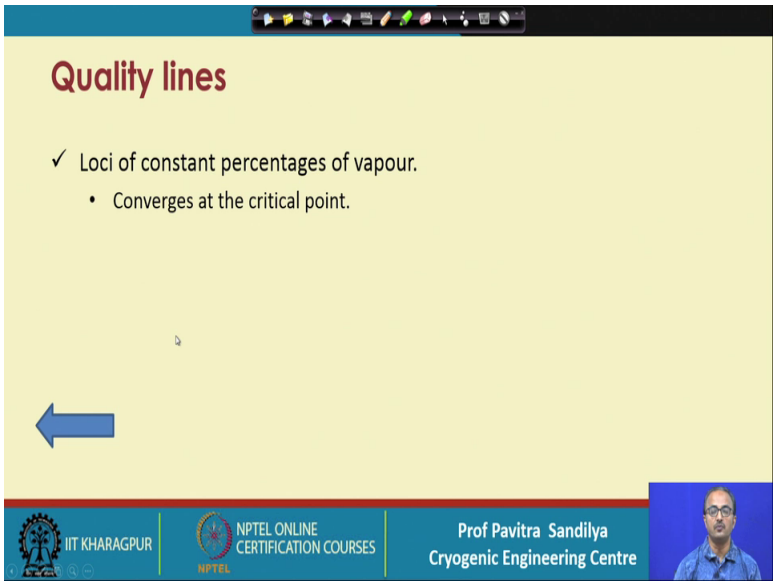

Next comes the quality lines. Now, what are quality lines these quality lines represent the loci of constant percentages of vapor. Now as we know from early our knowledge about the water vapor and water phase diagrams that quality represents the fraction of vapor present in a liquid vapor mixture. So, in the same manner, in case of natural gas also, we might be having both gas and the liquid present together and the quality would represent the fraction of the vapor that is present in the two phase region that is why you find that

the two phase region, within this two phase region, we have the various types of qualities.

And in this case, we find there are various types of lines are there and this here it is this 25 percent shows that this particular curve is representing 25 percent vapor, then this curve representing 50 percent vapor. Similarly, we have a 75 percent vapor and in this manner, if you go here we find that we have the hundred percent vapor ok. So, and then we have a another interesting point which we will not find that is the cricondenbar.

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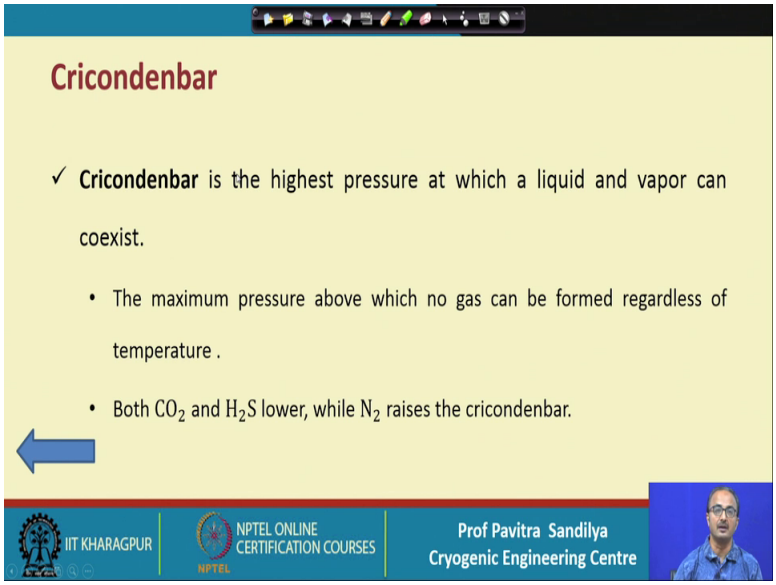

Cricondenbar; you do not find; in case of the other materials this is cricondenbar is the highest pressure at which a liquid or a vapor can coexist. Now, let us see this that this is the pressure. Now this is the highest pressure at which we will find that the liquid and vapor phase will coexist, if you go above this pressure, we will find there will be only a single phase region ok. So, in this case, if I again see that cricondenbar is the maximum pressure above which no gas can be formed regardless of temperature; that means, we know that at a given pressure, if I reduce the temperature many of the gases will liquefy.

However, in when we cross the cricondenbar, then we will find that howsoever reduction, we may do to the temperature the gas will not go into the liquid phase, it will remain a single phase and you know that the natural gas contains many impurities among which we have acid gases like carbon dioxide and hydrogen sulfide. Now, these the presence of these two gases lower the cricondenbar while the presence of the nitrogen

raises the cricondenbar. Similar, manner we have another term what is we call cricondentherm.

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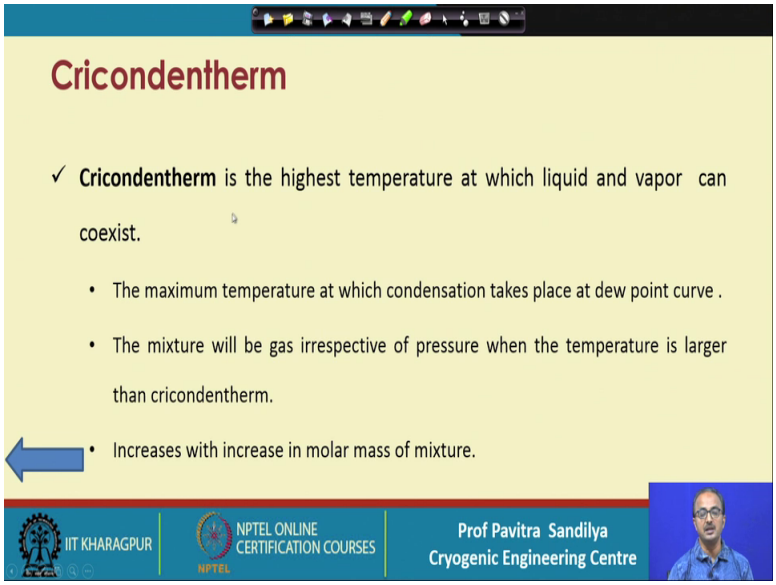

Now, as we see the cricondentherm is the highest temperature at which liquid and vapor can coexist going back to the diagram, we find this; this is the temperature the highest temperature above which we have only gas and below which we have the two phase region. So, this cricondentherm gives the maximum temperature at which condensation can takes place at dew point curve; that means, if we go above this temperature, then howsoever increase in pressure, we may brought bring about there will not be any change of the phase from the vapor to the liquid.

The mixture will be gas irrespective of pressure when the temperature is larger than the cricondentherm and it generally increases with increase in the molar mass of the mixture; that means, if the natural gas contains more and more of the higher hydrocarbons, this cricondentherm will keep on increasing next we come to another point that is the critical point.

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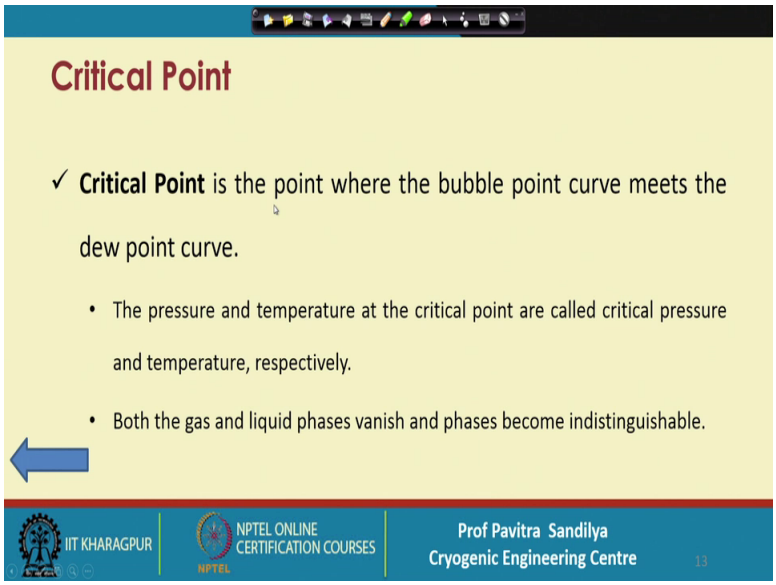

Now, what is critical point as we know from our knowledge form of the pure component phase behavior at the critical point what we found the saturated liquid curve and the saturated vapor curve merged. And what we found that at critical point, the there will not be any clear demarcation between the liquid and the vapor phases. Similar is the case, in case of natural gas their critical point is the point, where the bubble point curve meets the dew point curve as we know in case of mixture of gases we do not talk about the boiling points in this case we talk about the bubble point and dew points. So, critical point is the point where the bubble point curve meets the dew point curve.

The pressure and temperature at the critical point are called the critical pressure and temperature respectively both the gas and liquid phases vanish and phases become indistinguishable. That means, we cannot distinguish that whether we have a gas or whether we have a liquid or a two phase region which is not the case when we are below the critical point in below the below critical point the phase behavior is like that liquid, then liquid phase vapor, then vapor or vice versa.

But above critical point there is no two phase region of liquid and vapor; one more thing should be noted here is that the critical pressure critical temperature; generally, we call for the pure components. But in case of any mixture like natural gas we do not talk of critical pressure, we slightly modify it, we call it pseudo critical pressure and pseudo critical temperature because this represents the overall behavior of the gas mixture, we

shall learn in a separate lecture, how to estimate this pseudo critical temperature and pseudo critical pressure. Now, with this we find that what are the various important points in case of the natural gas there is another interesting phenomenon.

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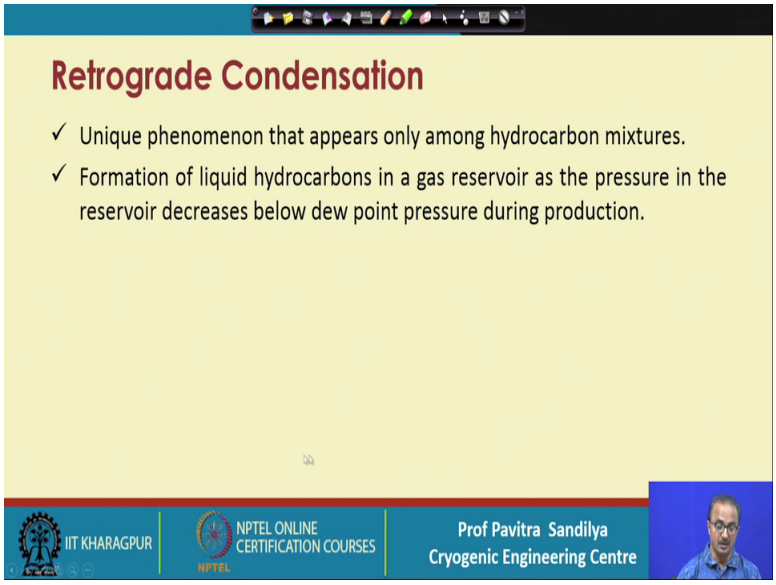

For natural gas and petroleum this is for both petroleum reservoirs as well as well as from natural gas because we learnt earlier that natural gas comes out from the reservoirs which may also contain the petroleum. So, there is a very interesting phenomena that is called the retrograde condensation and what is this retrograde condensation and why it is called. So, let us see.

Now, condensation as we know is the formation of a liquid from a vapor now what is retrograde about it retrograde because that in general we know that at a given temperature, if we increase the pressure, then the vapor will tend to go to the liquid phase on the other hand at a given temperature. If you reduce the pressure the liquid will go to the vapor phase, but this particular observation is not sometimes found in case of the natural gas and let us see why does not happen.

So, this is a unique phenomenon that appears only among hydrocarbon mixtures that is we cannot find this kind of phenomenon in case of other pure components and we find that the formation of liquid hydrocarbons in a gas reservoir as the pressure in the reservoir decreases below the dew point pressure during production, if we go back to our phase diagram, we see that suppose we are here in this region. If you are here, if we are

coming back, if you are going down from this there suppose, we are at this pressure. And as we reduce the pressure this vapor region and we as reduce the pressure we find we enter a two phase region because we are between the dew point and the critical point.

So, during between the dew critical point and the dew point curve wherever we are trying to reduce the pressure, we find that the vapor goes into the liquid phase this is not the general observation for other substances non hydrocarbon substances. So, this particular phenomenon is called the retrograde condensation and if we look at this particular curve there is a region that as I was telling that there is a point B.

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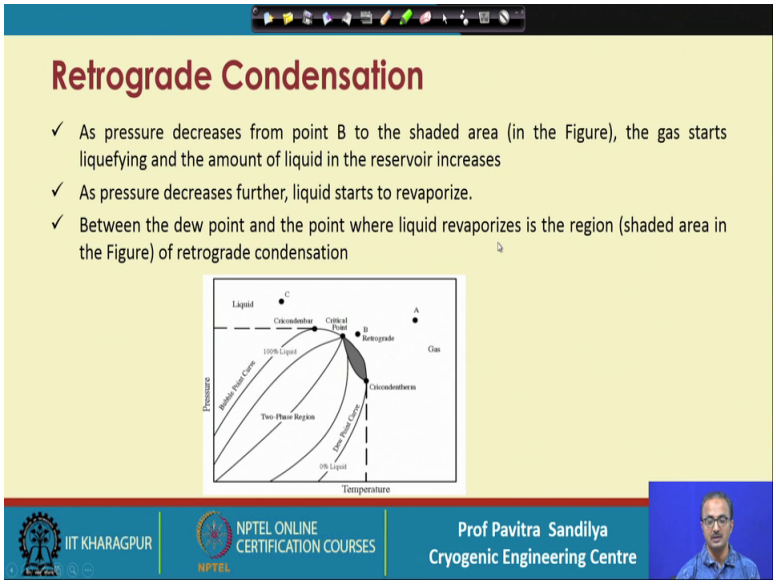

And in this point B, we are just reducing the pressure and there, we find that we have this particular region, this is shaded region this shaded region shows that there is a retrograde condensation. And this point is shows that this is above the cricondentherm. So, even if I reduce the pressure, here, it will remain gas, whereas, this is a C point represents a pressure which is above the cricondenbar; that means, in this case even if you reduce the temperature as constant pressure the there will be only liquid there will not be any gas ok.

Now, as the pressure decreases further liquid starts to revaporize; that means, as I; first it will be coming to the vapor will be get converted to the liquid and if I still decrease this further then after certain point, we will find the liquid will start revaporizing and between

the dew point and the point where liquid revaporizes, this particular zone this particular zone is called the retrograde condensation zone.

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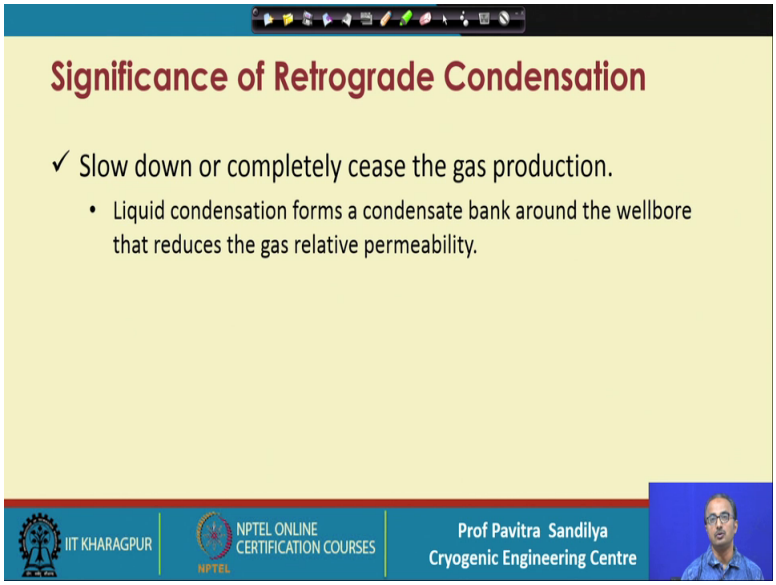

Now, what is the significance of the retrograde condensation? Now what happens that if there is this condensation, it will slow down or completely cease the gas production why because what will happen that the liquid will form and if the liquid forms, what will it will settle in the reservoir and it settle reservoir means it will put a hindrance to the natural flow of the gas. So, gas will face a bigger resistance to its flow through the pipe lines which have been drilled into the reservoir and because of this, we will find the gas production will be either slowed down or if there is plenty of accumulation of the liquid, it may cease the production may cease to occur.

So, that is why we have to know that at what point there could be a retrograde condensation and this as I told you, the relative permeability of the gas this permeability is nothing, but the extent to which the particular reservoir has the pores or the space through which the gas can flow. So, these spaces these void spaces gets filled up by the liquid due to which the gas is unable to move efficiently smoothly that is why we find retrograde condensation needs to be avoided.

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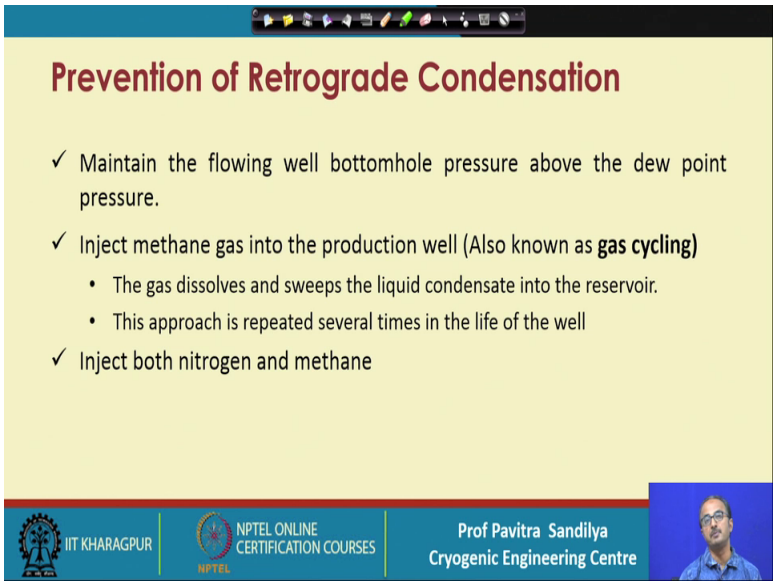

So, for preventing the retrograde condensation, mainly measures may be taken one of them is maintaining the flowing well bottom hole pressure above the dew point pressure. If we always maintain the pressure above the dew point pressure, we will find that we will not be encountering the retrograde condensation and then sometimes inject methane gas methane gas comes from where because natural gas is primarily methane. So, this methane gas can be also injected into the wellbore and what how; it works the gas dissolves and sweeps the liquid condensate into the reservoir it dissolves with the liquid and sweeps it into the um in the reservoir.

And this approach is repeated several times in the life of the well every well has some fixed life this life is decided by the amount of the gas and the oil in the well. So, during this life period of a well this injection of the methane to dissolve the liquid is done several times. Another way is to inject both nitrogen and methane because sometimes methane may not be used because it has a very good calorific value we do not want to waste methanol times and also separating it may be a problem and I am not economical.

So, sometimes we use nitrogen which is much cheaper than methane this, but nitrogen also adds to the impurity of the natural gas. So, case by case basis, we have to decide that whether, we want only methane or whether we want to have a mixture of natural methane, but any of these methods may be used to reduce the retrograde condensation.

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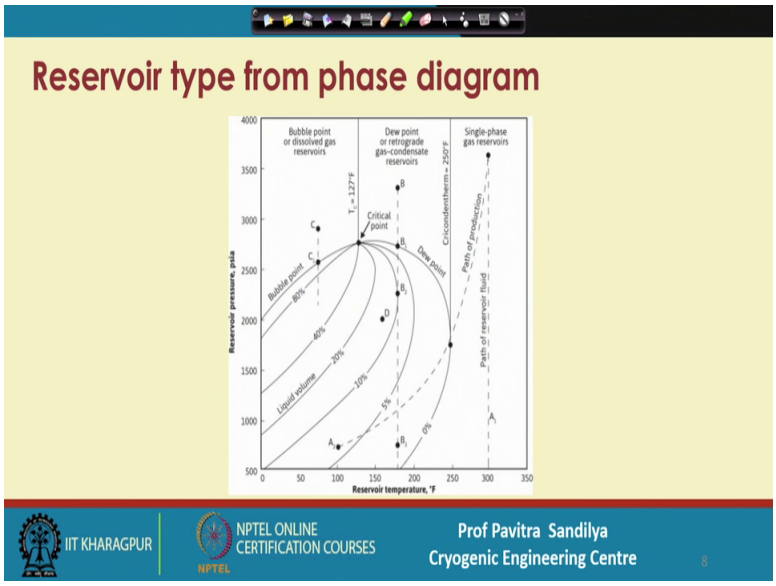

And next we find that what is the significance of this phase diagram on the reservoir type and this is very much important from the point of view of petroleum engineers who are into the exploration business. They need to know this phase envelopes and as shown in this figure what we find that there are several regions into which this phase diagram has been divided, this first would let us see that if suppose, we are at this point at this point that we are above the cricondentherm; that means, we know there will only be gas.

Now, if we are in this particular region; that means, if we find in the reservoir we have such a high pressure and this kind of say 300 degree Fahrenheit temperature. And suppose above say 3500 psia pressure, then we find at this point, we have the reservoir will be having only gas, there will not be any oil in the reservoir.

So, this is a gas reservoir, now at this point if we reduce the pressure we find that it is if it is pressure at the same temperature isothermally, then there will be only gas, there will not be any oil. However, what happens this is the reservoir condition, but one thing we must understand that as the gas is coming out of the bore into the pipeline into the pipeline it will so happen; it takes a different path line this; this is showing this curve which is showing the path of the production.

So, when the gas flows to the pipeline there will be some pressure drop and there may be some changes in the temperature also. So, this kind of path line may be followed and if we follow this path line of production, we find that ultimately, it may go into the two

phase region; that means, a gas phase reservoir may give rise to a two phase region when as the gas is flowing through the pipeline. However, we must remember the reservoir still remains with gas only into the pipeline, we find there is a two phase zone form; two phase mixture form in the pipeline not in reservoir.

Now, let us look into this. So, here we see that the critical point is somewhere different it is not the same as I showed you in my the first phase diagram, here, we see there in the critical point the bubble point curve the dew point curve and all the quality lines are merging at the critical point. Now, in this case, a critical point is shifted on to the left and between the critical point and the dew point curve suppose, I am choosing some kind of it a condition of the reservoir that is B.

Now, in this in this particular thing, we find that this is it is only gas. Now, in this when I am reducing the pressure we find that as it goes down as at a constant temperature then as we reach the point B 1, this gas now starts going into a two phase behavior. That means, that when the reservoir pressure falls during the production initially the reservoir contained only gas. But as I am producing the gas what happens the pressure falls and the when the pressure falls, we find in the reservoir there could be a two phase formation mixture now, the reservoir will now contain initially, it was having only gas now it will have both gas and the liquid.

So, that is how this reservoir is different from this reservoir this reservoir will always be having only gas, but this reservoir will be having gas and liquid after sometime when the pressure in the reservoir falls. So, this that is why it is called dew point and or retrograde gas condensate reservoir. Now, the on the left hand side of the critical point, you have another interesting thing this is the in this case, we have only liquid ok. Now, again if we start from some point C, we find we have liquid; that means we have only oil. So, with this oil reservoir, as I keep decreasing the pressure we find that this goes into a two phase region ok.

So, these are not interesting that here these two phases are occurring due to decreasing the pressure due to retrograde condensation. But in this case, it is not there is a retro condensation, but it is simply the pressure is falling from the from the liquid and liquid is going into a two phase region; that means, for this kind of reservoir which is initially

containing oil as the production goes on pressure falls and we will land up with both gas and oil.

And in this case, we find that there are several points where there are several curves again shown for the liquid volume and suppose initially we have a point D. Now, what is D point; that means, this D point represents a reservoir which is already having a two phase region ok? So, when we if I start with a reservoir with this initial condition, we will find even if the pressure is falling; the two phase thing will always remain in the two phase.

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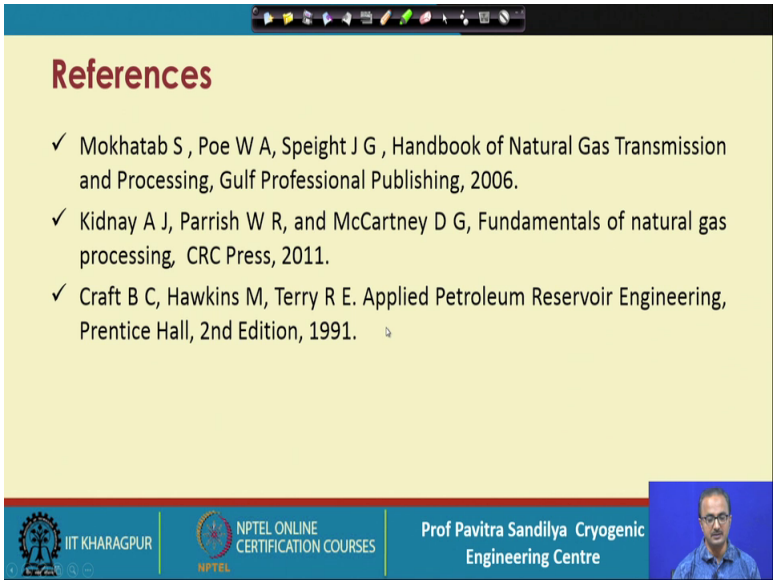

So, there will not be any kind of single phase, in this kind of reservoir. With this, we come to the end and these are a few references from which you can study further about the phase behavior of the natural gas as well as their effect on the type of reservoirs and the hence the type of production.

Thank you.