Upstream LNG Technology
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Lecture – 79
Hydrocarbon recovery in natural gas system – I

Welcome, after learning about the liquefaction refrigeration; now we go on to learn the applications of these processes for the natural gas processing. So, in this particular lecture again we shall be looking into some series of this topic, in the Hydrocarbon recovery in natural gas systems.

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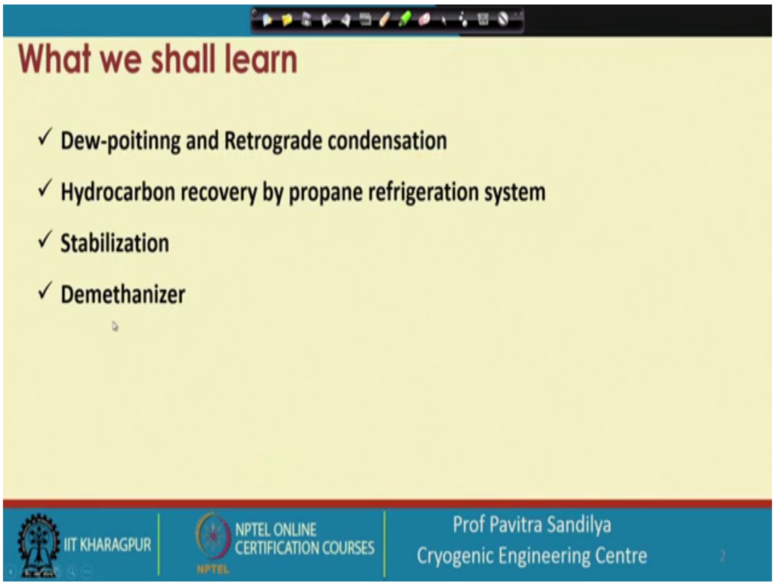

What we shall learn

- ✓ Dew-poitinng and Retrograde condensation
- ✓ Hydrocarbon recovery by propane refrigeration system
- ✓ Stabilization
- ✓ Demethanizer

In this particular lecture we shall be learning about dew pointing, the hydrocarbon recovery by propane, refrigeration, stabilization and demethanizer.

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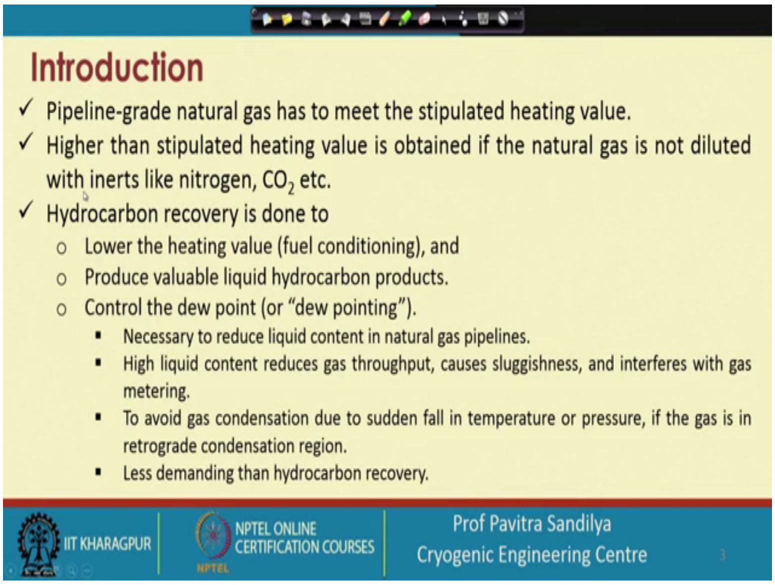

Introduction

- ✓ Pipeline-grade natural gas has to meet the stipulated heating value.
- ✓ Higher than stipulated heating value is obtained if the natural gas is not diluted with inerts like nitrogen, CO_2 etc.
- ✓ Hydrocarbon recovery is done to
    - o Lower the heating value (fuel conditioning), and
    - o Produce valuable liquid hydrocarbon products.
    - o Control the dew point (or "dew pointing").
        - Necessary to reduce liquid content in natural gas pipelines.
        - High liquid content reduces gas throughput, causes sluggishness, and interferes with gas metering.
        - To avoid gas condensation due to sudden fall in temperature or pressure, if the gas is in retrograde condensation region.
        - Less demanding than hydrocarbon recovery.

So, let us first see that why do we need this recovery of the hydrocarbons. Now we know that the pipeline grade, natural gas has to meet the one natural gas we are going to sale the sale gas that has to meet some stipulated heating value. And it has been found that if there is a dilutions by the nitrogen or carbon dioxide the heating value is quite high, then the stipulated value. And what we find that the presence of the various types of hydrocarbons because any kind of hydrocarbons can be burnt and the (Refer Time: 01:26) combustion of this hydrocarbons lots of heat will be generated.

So, we find that the hydrocarbon recovery is done why to lower the heating value and what we call the fuel conditioning the conditioning of fuel. So, we have to take out those other hydrocarbons. So, that we want only natural gas means the methane we want in this. So, that the heating value stayed within the limit and to produce valuable liquid hydrocarbon products means the recovered hydrocarbons are not thrown out they are also used for to make some other products. And we know there are so, many products which are made from the hydrocarbons many kind of polymers are made like for example, PVC which we use in our day to day life that is a hydrocarbon product. So, this sort of many other products are there in our day to day life that we for that we need this hydrocarbons.

So, this natural gas provides a very good source of the hydrocarbons, which are the raw materials for other commercial products. And we also need these recoveries the hydrocarbons for control the dew point or we call it dew pointing, in this way this necessary to reduce the liquid content in the natural gas pipelines. We know that if the hydrocarbons are more than the dew point of the system will also be raised; that means, we will be getting the dew point or the liquid product very easily.

So, and we do not want the liquid product to be too much because otherwise what will happen they will accumulate in the pipelines. So, we have to recover those higher hydrocarbons so, that we can lower the dew point. And you have to be see that the high liquid content reduces gas throughput causes sluggishness and interfaces gas metering. That is what is say that if the amount of if the higher natural gases too many higher hydrocarbons heavier hydrocarbons, then it will liquefy easily. And if it is liquefies easily what will happen, they will start blocking the pipe lines and that is and the gas flow will be hampered; and also we will not be able to measure the flow rates of the gas easily because of presence of the liquid.

And this also done to avoid gas condensation due to certain fall in the temperature or pressure; if the gas is in retrograde condensation region. So, this retrograde condensation we are learnt earlier, we shall again see it recapitulate what we learnt earlier to see that that if we to we want to avoid this gas condensation, we do not want to go into the retrograde condensation region so, in that case also we need to adjust the dew point. And it is less demanding then hydrocarbon recovery means, even though it is the many things we are doing to do that, but this is not so, cost costly as the recovery of the hydrocarbon. So, we generally do the dew pointing.

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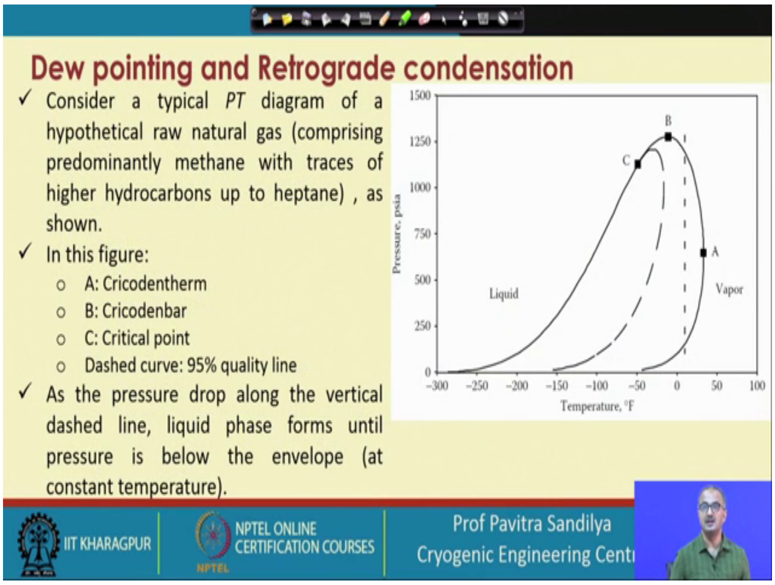

Dew pointing and Retrograde condensation

- ✓ Consider a typical *PT* diagram of a hypothetical raw natural gas (comprising predominantly methane with traces of higher hydrocarbons up to heptane) , as shown.
- ✓ In this figure:
  - A: Cricodentherm
  - B: Cricodenbar
  - C: Critical point
  - Dashed curve: 95% quality line
- ✓ As the pressure drop along the vertical dashed line, liquid phase forms until pressure is below the envelope (at constant temperature).

Now, let us see at the retrograde condensation. This particular curve we saw earlier also and as we said that this curve is very peculiar for the natural gas and this is a typical retrograde, this curve pressure temperature curve, that is the equilibrium curve for natural gas and as we learnt earlier this curve will differ for different types of natural gases depending on the composition. And here we see that here we have three points A B C and this A is the cricodentherm that is the highest temperature below, which we will get the two phase and above which we will not get two phase, whatever we changes you can do with the pressure temperature means in this region even if we keep reducing the temperature or increasing the pressure we will not be able to get two phase.

So, these are cricodentherm and then the B is a cricodenbar this is the highest pressure below which we will have two phase and in above which we will have only single phase ok. And the C this is a critical points we know and we find that or in this particular regions, we will be having single phase either the liquid or the vapor ok. Only within this particular region which is given by this particular envelope, this we are getting the two phase region and this particular dashed line it shows the curve for a given quality that is the amount of vapor in the total mixture ok.

So, as the pressure drop along the vertical dashed line, liquid phase forms until the pressure is below the envelope. So, we find that this particular line this is a this is the suppose at this particular temperature we are reducing the pressure and as we know that when we reduce pressure the what happens the liquid goes into vapor state, but it is very peculiar we find one when we reduce the pressure, the vapor is going into a two phase region that is peculiarity and until when you keep reducing pressure, it is their existing in the two phase region, until it comes out of this envelope and again we shall find this is the vapor we are getting.

So, this is the peculiarity.

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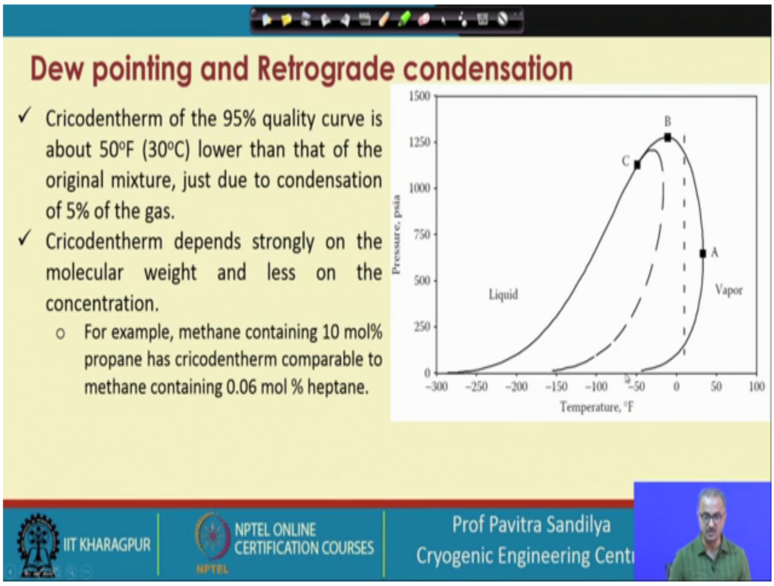

Dew pointing and Retrograde condensation

- ✓ Cricodentherm of the 95% quality curve is about 50ºF (30ºC) lower than that of the original mixture, just due to condensation of 5% of the gas.
- ✓ Cricodentherm depends strongly on the molecular weight and less on the concentration.
  - o For example, methane containing 10 mol% propane has cricodentherm comparable to methane containing 0.06 mol % heptane.

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And when we look at this suppose if you look cricodentherm of the 95 percent quality curve suppose this is 95 percent quality curve, and if this cricodentherm is about 50 degree means pardon a 30 degree centigrade lower than that of the original mixture. So, we find that this cricodentherm for this particular curve, we is lower than the cricodentherm for the 100 percent quality line ok. So, here we find this is the this difference is about 30 degree centigrade, and we find that how its difference coming only 5 percent is condensing. That is a small reduction or small condensation needs to very large difference in the cricodentherm.

And cricodentherm depends strongly on the molecular weight and less on the concentration; that means, when this cricodentherm if we have higher hydrocarbons, that we have some cricodentherm the lower hydrocarbon. It is another cricodentherm. It does not matter how much amount of that hydrocarbons are there, but how heavy the hydrocarbons are and examples are given that methane containing about 10 mole percent of propane has cricodentherm comparable to methane containing 0.06 mole percent of heptane. So, we can easily see, the heptane is much heavier than propane heptane is h 7 sorry c 7 h 16 and propane is c 3 h 8 oh.

So; that means, heptane is a much heavier molecule than propane, and even if it is present a very small amount and propane is at a very large amount, but the cricodentherm seems to be almost close. So, it is the molecular weight which determines the cricodentherm more than the concentration. That is why it is use it is important for us to closely monitor the amount of the heavier hydrocarbons present in the natural gas.

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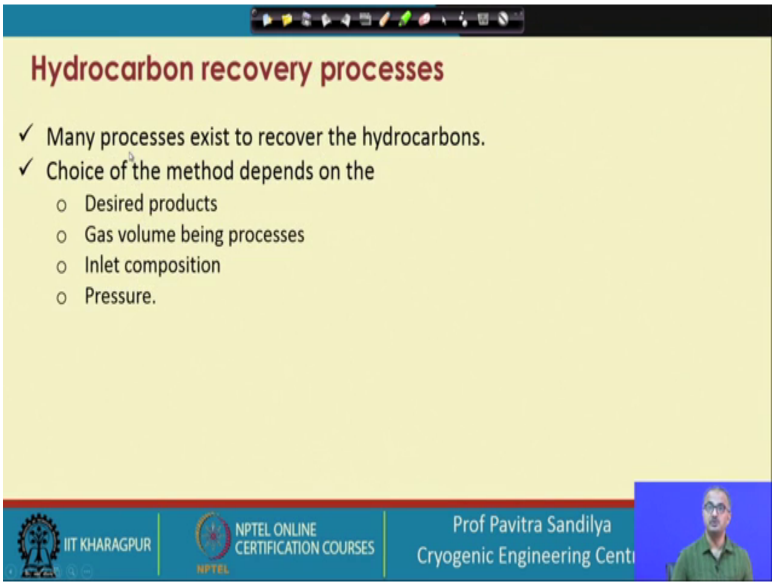

Hydrocarbon recovery processes

- ✓ Many processes exist to recover the hydrocarbons.
- ✓ Choice of the method depends on the
  - o Desired products
  - o Gas volume being processes
  - o Inlet composition
  - o Pressure.

Now, we come to the hydrocarbon recovery processes, there are many processes that exist to recover the hydrocarbon and the choice or the selection of the process would depend on the desired products. What kind of product we want the amount of the gas being processed the inlet composition of the gas and the pressure ok. So, these are the factors we determine the selection of a particular process for recovery of the hydrocarbons.

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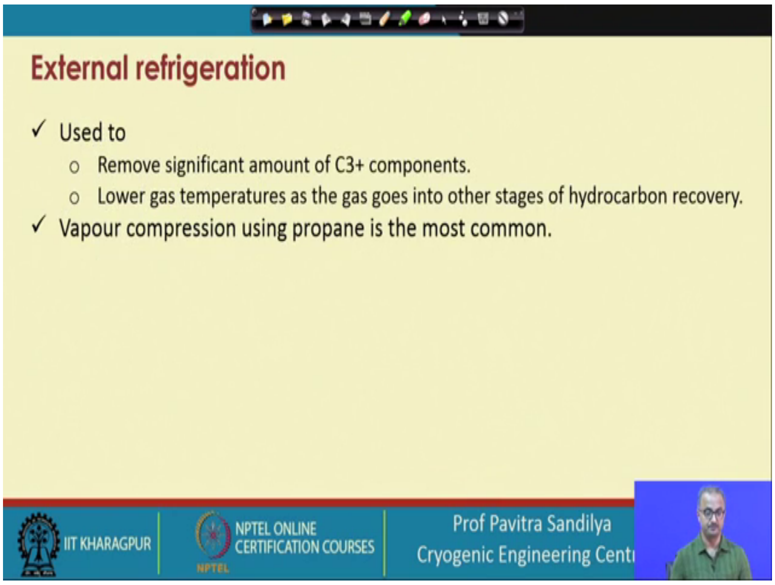

External refrigeration

- ✓ Used to
  - Remove significant amount of C3+ components.
  - Lower gas temperatures as the gas goes into other stages of hydrocarbon recovery.
- ✓ Vapour compression using propane is the most common.

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Now, one is that we do external refrigeration and it is used to remove significant amount of C 3 plus components C 3 plus means propane and higher components ok. So, it is external refrigeration is used for that, and the lower gas temperatures the as the gas goes into the other stages of hydrocarbon recovery. So, this by refrigeration we are loading the gas temperature, which is coming into the system. And the vapor compression is using propane is the most common; we shall be discussing about this vapor compression cycle using propane.

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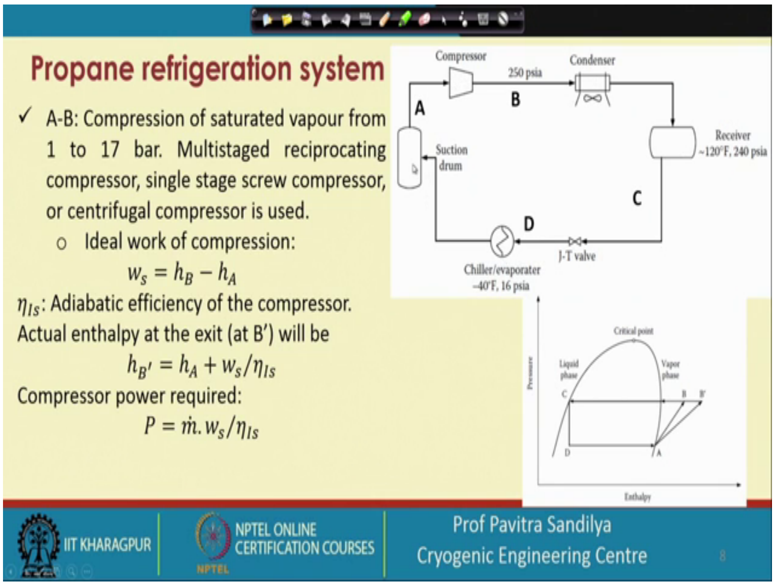

Propane refrigeration system

- ✓ A-B: Compression of saturated vapour from 1 to 17 bar. Multistaged reciprocating compressor, single stage screw compressor, or centrifugal compressor is used.
  - Ideal work of compression:

$$w_s = h_B - h_A$$

η_{Is}: Adiabatic efficiency of the compressor.

Actual enthalpy at the exit (at B') will be

$$h_{B'} = h_A + w_s/\eta_{Is}$$

Compressor power required:

$$P = \dot{m}.w_s/\eta_{Is}$$

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Now, here is the typical system for the propane refrigeration system, here I have shown that we have a compressor and we have a condenser, we have a receiver and the JT valve is your expansion, we have a chiller and the suction drum. So, these are drum typically the main equipment needed to carry out this propane refrigeration, and here also we are given the sum of the values of the various temperature pressures at different parts of the system.

So, let us see this A to B this is a compression of the saturated vapor from about one bar to about 17 bar. So, here we find that from here A to B we are raising the pressure for about one bar to 17 bar and the same thing may be represented on a pressure enthalpy diagram. So, in this diagram also we have this saturated liquid line and the saturated vapor line and this is the A because you are saying this is a saturated vapor. So, it must fall on the saturated vapor line. So, here it is A and what is happening, we are compressing it we are raising the pressure and we want to ideally we want to go for isothermal compression. So, this is the one this A to this B is the we are getting; however, in practice we will not be able to get external condition. So, you find it will deviate from these isothermal lines to these values. So, these B prime this B prime is the one, which will be obtained in practice ok.

So, this is what we are doing and the ideal work of compression as we have learnt earlier this is the hB minus hS. So, the enthalpy over here and the enthalpy over there this difference will be the ideal work of compression and generally such a high pressure ratio is obtained by multi staging the reciprocating compressor or single stage screw compressor or centrifugal compressor.

So, any of these may be used to raise the pressure from 1 to about 17 bar. And as I said that if in eta is the adiabatic efficiency of the compressor then what we get? We get this particular expression; that means, the slope b we shall be reaching b prime and this is the kind of expression, which is again get in obtained from this expression that h B prime is equal to hS plus wS by eta is ok. And then we have the compressor power required, this is we can again obtain the simply by multiplying the flow rate of the gas being processed with the actual work done for ideal compressor this one will be unity.

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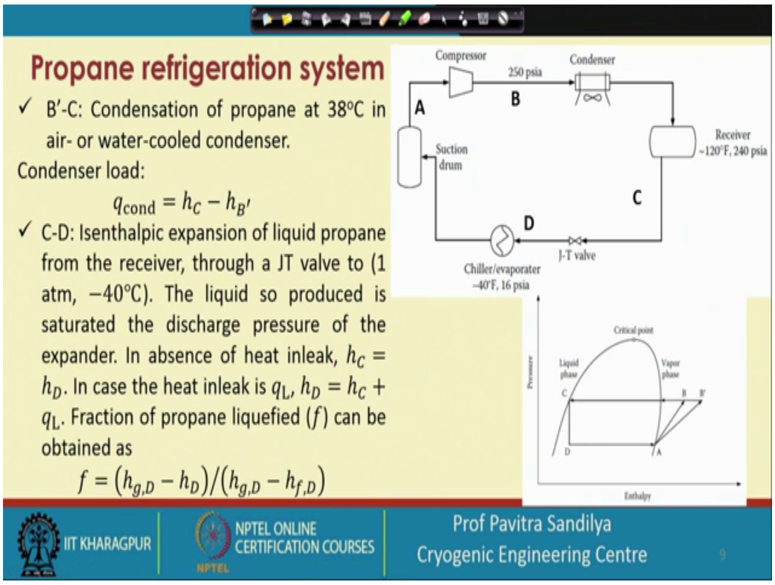

Propane refrigeration system

- ✓ B′-C: Condensation of propane at 38°C in air- or water-cooled condenser.

Condenser load:

$$q_{\text{cond}} = h_C - h_{B'}$$

- ✓ C-D: Isenthalpic expansion of liquid propane from the receiver, through a JT valve to (1 atm, −40°C). The liquid so produced is saturated the discharge pressure of the expander. In absence of heat inleak, $h_C = h_D$. In case the heat inleak is q_L, $h_D = h_C + q_L$. Fraction of propane liquefied (f) can be obtained as

$$f = (h_{g,D} - h_D)/(h_{g,D} - h_{f,D})$$

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Now, coming to from point B to C or B prime to C. Now from B prime to C, what we find that we are this is we are going from here to here we are finding that in this condenser, we are condensing the propane and by condensation what is happening? The heat is being released and this heat is released and it is put into the some suitable sink. So, that is how we are rejecting the heat from the system, and it is happening at around 38 degree centigrade and to take out the heat to whatever heat is being generated due to condensation of the propane, that is taken out either by the air cooled or water cooled condenser.

So, we are simply using air or water to take out the heat of condensation from the this propane. And the condenser load is the difference between the enthalpies this is quite simple then coming from C to D. Now what we are doing after this condensed this condensed liquid is being expanded for JT valve ok. And this expansion is done to about one atmosphere and this JT valve reserve some cooling and this cooling is about minus 40 degree centigrade.

Now, what happens that in this cooling here we find that, we are getting this particular cooling from C to D, and we are within this particular dome and here we find we are getting two phases; that means, we are liquid as well as vapor ok. And we are getting good amount of cooling this is isenthalpic ideally. And this is what we are writing that the in the absence of heat inleak, hC is equal to hD; that means, this enthalpy over here is equal to this enthalpy. But if it is not isenthalpic if there is any kind of heat inleak suppose there is a qL amount of heat inleak, then we find hD gets raised it this the enthalpy will be more than hc and this extra amount of energy is coming from the heat inleak. And if you want to find out the fraction of the more liquefied, we can use this particular thing this is very simple this is coming from the expression of the overall enthalpy of the system, which is obtained from the enthalpies of the saturated vapor and the saturated liquid.

So, from that expression, which we often use in thermodynamics we are getting the amount of propane liquefied.

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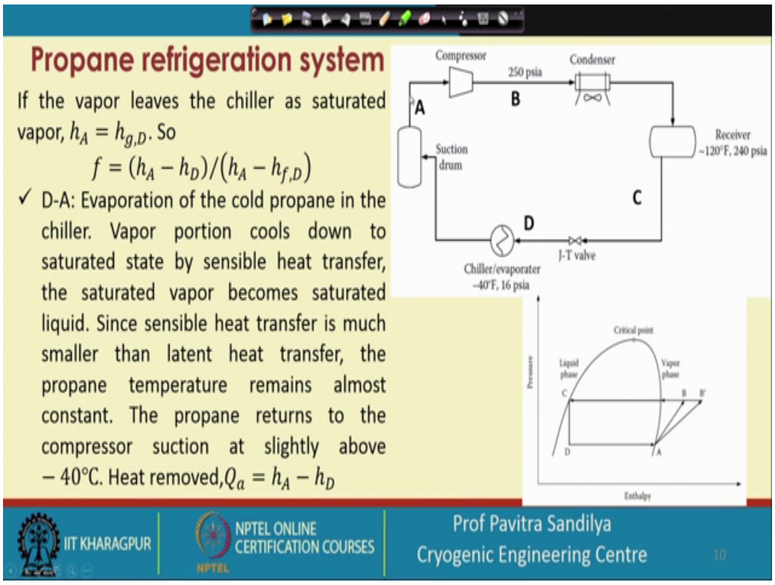

Propane refrigeration system

If the vapor leaves the chiller as saturated vapor, $h_A = h_{g,D}$. So

$$f = (h_A - h_D)/(h_A - h_{f,D})$$

- ✓ D-A: Evaporation of the cold propane in the chiller. Vapor portion cools down to saturated state by sensible heat transfer, the saturated vapor becomes saturated liquid. Since sensible heat transfer is much smaller than latent heat transfer, the propane temperature remains almost constant. The propane returns to the compressor suction at slightly above $-40°C$. Heat removed, $Q_a = h_A - h_D$

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So, as I said because it is there are two phases. So, the general the vapor leaves the chiller; that means, we are doing is using a chiller or evaporator; now what happens that this particular thing is this vapor leaves the chiller as assuming that this saturated vapor. So, h A because we are going to compress the vapor;so, we if you assume it is saturated vapor then h A will be replacing this h g D and we are getting the fraction of the fraction liquefied.

Now, from D to A what we are doing this is, we are evaporating the cold propane in the chiller and what is happening that vapor portion cools down to saturated state by the sensible heat transfer, the saturated vapor becomes saturated liquid and since sensibility transfer is much smaller latent heat transfer what we find the propane temperature remains almost constant.

So, even if the this two phase region was there, but even though the vapor will come first come to the saturated vapor state from a superheated, then it will be transforming to saturated liquid and because sensible transfer is generally less than the latent heat transfer its quite high value. So, we find that we can neglect the sensible it part and if you neglect that we will for practical purposes, we take the temperature to be constant because it is happening at this is a simple phase change. And we find the propane returns to the compressor suction at slightly above minus 40 degree centigrade and heat removed is this h A minus hD

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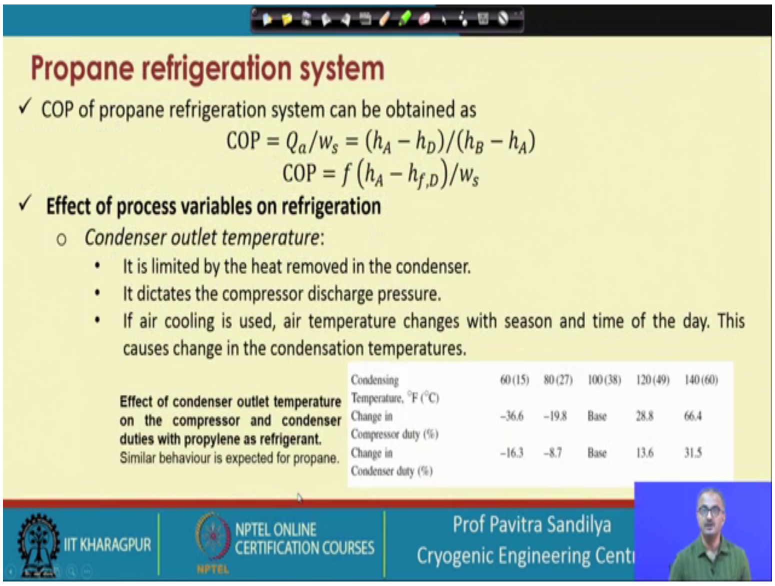

Propane refrigeration system

- ✓ COP of propane refrigeration system can be obtained as

$$COP = Q_a/W_s = (h_A - h_D)/(h_B - h_A)$$

$$COP = f\,(h_A - h_{f,D})/W_s$$

- ✓ **Effect of process variables on refrigeration**
  - *Condenser outlet temperature*:
    - It is limited by the heat removed in the condenser.
    - It dictates the compressor discharge pressure.
    - If air cooling is used, air temperature changes with season and time of the day. This causes change in the condensation temperatures.

Effect of condenser outlet temperature on the compressor and condenser duties with propylene as refrigerant. Similar behaviour is expected for propane.

Condensing Temperature, °F (°C)	60 (15)	80 (27)	100 (38)	120 (49)	140 (60)
Change in Compressor duty (%)	–36.6	–19.8	Base	28.8	66.4
Change in Condenser duty (%)	–16.3	–8.7	Base	13.6	31.5

Now, after figuring out all these values, we can easily find out the coefficient of performance of this system and we find this is Qa by W s we put the values of Qa Ws and we find this is a COP and this can also be put in terms of the amount of fractions liquefied.

Now, let us see the effect of process variables from refrigeration. First let us see at the condenser outlet temperature. Now we find that this condenser outlet is limited by the heat removed in the condenser. How much heat can be removed that will determine, because we are using either water or air to remove the heat in the condenser. So, it will depend on what means a at what temperature the water is coming or the air is coming.

And we know that that this particular temperature will dictate the compressor discharge, pressure because it will be the enthalpy will be dictated by this amount the how much heat is being recovered.

And we know that the temperature of the ambient changes from season to season and also at different point in the day. So, if there are changes and so, will be the temperature of the air will also change, and if they change then what will happen it will also change the condensation temperature.

So, all these things will be finding that they will ultimately effect the performance of the refrigeration system. And here in this particular table we are showing a typical values for the condensation temperature the change in the compressor duty and change in condenser duty. So, we find that if the temperature of condensation is changing, we find that how this is the compressor duty and the condenser duty are changing ok. And this is the base value we have considered 30 degree centigrade, the and beyond this is less 36 degree centigrade and this is a higher degree centigrade.

Now, we find that with the change, that we finding that the condenser duty is changing less than the compressor duty ok. So that means, that this is say its clearly shows that the work requirement changes more than the condenser duty. That is how much heat is rejected that is why it is important for because ultimately we are concerned with the work requirement. So, it is important for us to know the temperature of condensation.

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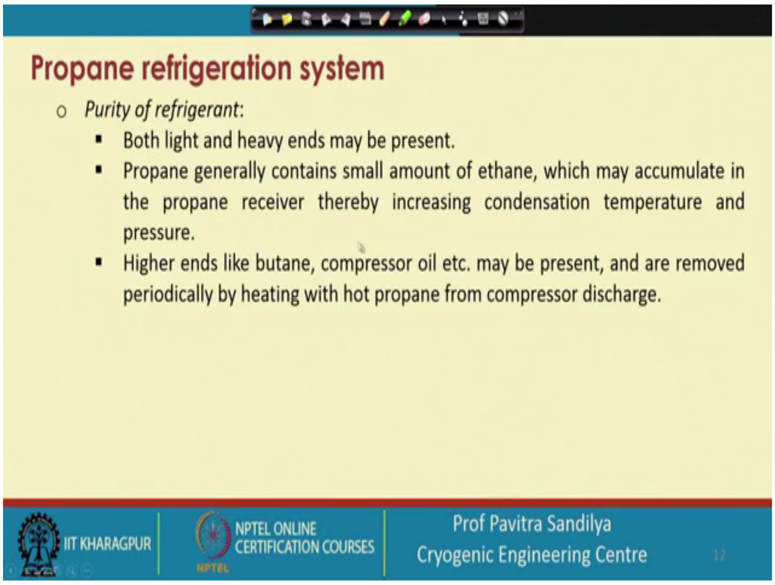

Propane refrigeration system

- *Purity of refrigerant:*
  - Both light and heavy ends may be present.
  - Propane generally contains small amount of ethane, which may accumulate in the propane receiver thereby increasing condensation temperature and pressure.
  - Higher ends like butane, compressor oil etc. may be present, and are removed periodically by heating with hot propane from compressor discharge.

And next is the purity of the refrigerant and because we see that both light and heavy ends may be present and propane generally contains, small amount of ethane and which they accumulate in the propane receiver thereby increasing the condensation temperature. Because propane the ethane will not be condensing at the temperature at which propane will be condensing because ethane has a lower boiling point. And if it does not condenses its keep accumulating and it will be as non-condensable, then what will happen it will slowly raise the pressure inside the system. And if pressure is getting raised what will happen the temperature of condensation will also get affected at will also get it will also rise.

The higher ends like butane compressor oil etcetera may be present and are removed periodically by heating with hot propane from the compressor discharge ok. So, we are talking about only the propane refrigerant, and the propane is generated internally from this system only. So, that is why it is in it will be contain it will not be pure propane, it will be having some kind of impurities. So, those impurities should be removed before means ideal it should be removed before we carry on this kind of process.

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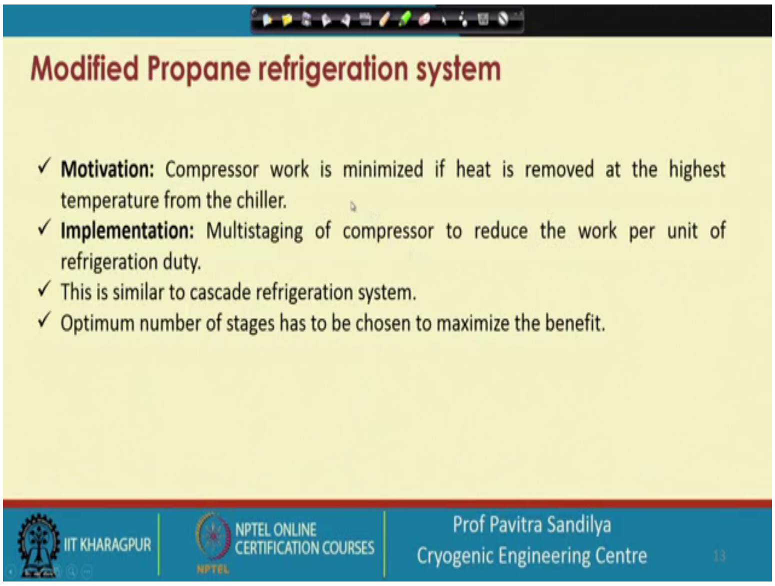

Modified Propane refrigeration system

- ✓ **Motivation:** Compressor work is minimized if heat is removed at the highest temperature from the chiller.
- ✓ **Implementation:** Multistaging of compressor to reduce the work per unit of refrigeration duty.
- ✓ This is similar to cascade refrigeration system.
- ✓ Optimum number of stages has to be chosen to maximize the benefit.

Next we do some modifications done, this modification is in what is modification that compressor work is minimized if heat is removed at the highest temperature from the chiller. This is the these are these are thermodynamics, that the higher the temperature for removing the heat the more less using the compressor works. And how its implemented it is implemented by multi staging of the compressor to reduce the work per unit amount of refrigerant duty. And this is similar to cascade refrigeration and this cascade refrigeration we learnt earlier, and the optimum number of stages has to be chosen to maximize the benefit.

So, how many stages because we know that this kind of working compressor compression is done in multi staging and the there will be an optimum number of stages to maximize the benefit of the reduction in the overall this work done.

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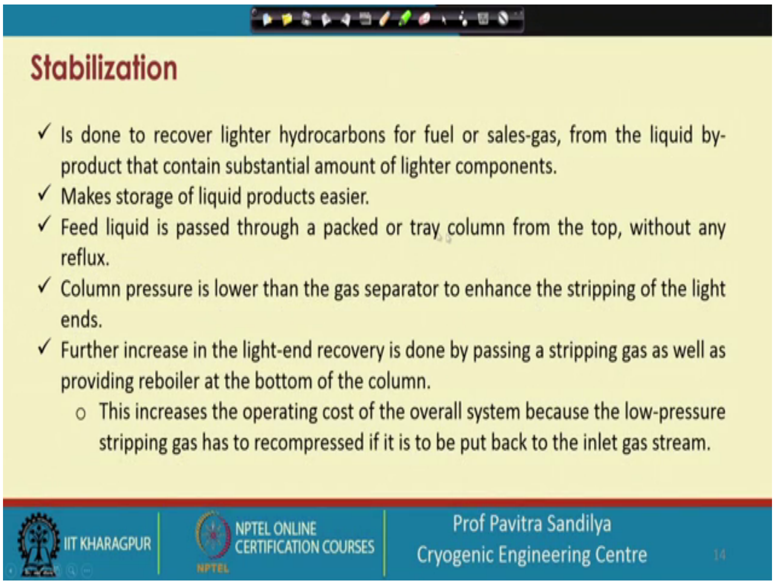

Stabilization

- ✓ Is done to recover lighter hydrocarbons for fuel or sales-gas, from the liquid by-product that contain substantial amount of lighter components.
- ✓ Makes storage of liquid products easier.
- ✓ Feed liquid is passed through a packed or tray column from the top, without any reflux.
- ✓ Column pressure is lower than the gas separator to enhance the stripping of the light ends.
- ✓ Further increase in the light-end recovery is done by passing a stripping gas as well as providing reboiler at the bottom of the column.
  - o This increases the operating cost of the overall system because the low-pressure stripping gas has to recompressed if it is to be put back to the inlet gas stream.

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Next we can to stabilization and why it is done it is done to recover the lighter hydrocarbons for fuel or sales gas from the liquid by product that contain substantial amount of the lighter components. That means, whenever we are having the heavier components coming out with that some lighter components like methane ethane will also be there. So, we do not want to pass this methane with the higher hydrocarbons, because methane will be used as a in the called natural gas.

So, whatever last amount of methane or ethane is remaining we want to take it out of this higher hydrocarbons so, that is why we what we call it stabilization. And this will also make the storage of liquid easier why because if you have the lower hydrocarbons it is difficult to liquefy them ok. So, that is why because there is the lighter hydrocarbons will lower the dew point ok. So, it will be difficult to liquefy them. So, that is why we also need to take out this lighter hydrocarbons to raise the dew point. And its need not by liquefying it we can reduce the storage space for a given mass.

And in this case what happens feed liquid is passed through a packed bed or a tray column from the top without any reflux. So, it is not exactly like distillation it is more like the stripping section, in which the feed comes from the top and goes out from the bottom and there is we are not using any kind of reflux usually. And column pressure is lower than the gas separator to enhance the stripping of the light ends we know that if we lower the pressure at kind of flash happens. So, that the vapor which is generated by the loading the pressure whatever the vapor will contain the lighter components.

So, the pressure inside the column escaped somewhat lower than the pressure in the in the gas separator. And if we want to increase the recovery of the light and hydrocarbons, then what you have done it is passed stripping gas as well as providing reboiler at the bottom of the column ok.

So, we have we can put some another stripping gas to the column, which will be again taking out the lighter hydrocarbons from this liquid feed from the top it is somewhat like distillation, again we are not using any kind of reflux here. So, that this kind of stripping gas may be used or we can also provide a reboiler so, that we can boil off the liquid and by boiling of we shall be the vapor will be getting will be enriched with the lighter hydrocarbons.

But what happens by doing this doing this we increase the operating cost of the overall system because the low pressure stripping gas has to be recompressed. If it is to be put back to the inlet gas stream, because once the stripping gas comes out of the system it will be at a lower pressure and this stream will not be thrown out, it will be again taken out and it is sent back to the suction side feed side. So, which has to be recompressed to a pressure, which is the same as the pressure of the feed ok. So, this will again increase the operating cost of the system.

So, one has to weigh all these things at whether to whether we are going to increase operating costs or whether we are going to increase the recovery of the lighter hydrocarbons. So, all these things are [waid/wait] wait before design this kind of system.

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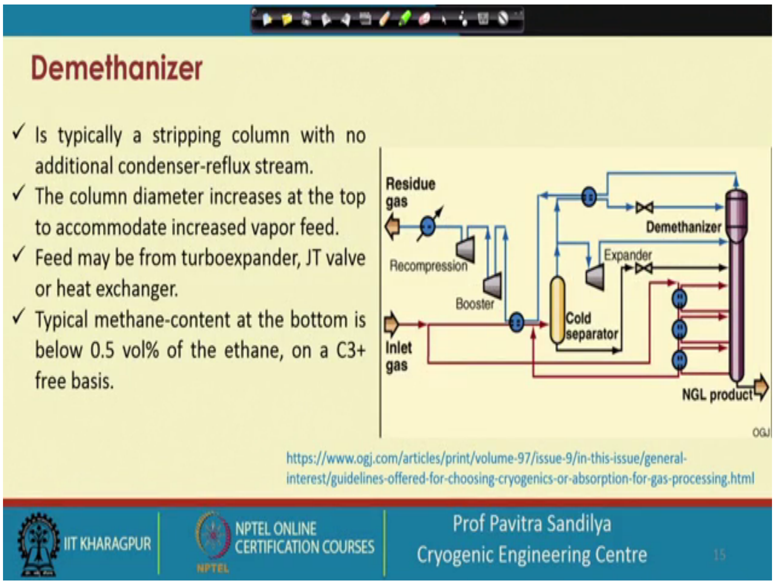

Demethanizer

- ✓ Is typically a stripping column with no additional condenser-reflux stream.
- ✓ The column diameter increases at the top to accommodate increased vapor feed.
- ✓ Feed may be from turboexpander, JT valve or heat exchanger.
- ✓ Typical methane-content at the bottom is below 0.5 vol% of the ethane, on a C3+ free basis.

https://www.ogj.com/articles/print/volume-97/issue-9/in-this-issue/general-interest/guidelines-offered-for-choosing-cryogenics-or-absorption-for-gas-processing.html

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And here I have shown a demethanizer which is the part of the stabilizer, here you can see its a this is the demethanizer column, actual column and here we have the inlet gas feed and here we have the residue feeds residue gas is coming from the top of the column and this inlet gas is going inside a cold separator and we it maybe using some kind of turbo expander or a JT valve or some kind of heat exchanger, to cool it down and sending it from the top ok. So, it is typically a stripping column with no additional condenser reflux stream, the column diameter increases at the top to accommodate increased vapor feed you can see the column diameter is more than the rest of this column.

Now, why because as the vapor is going to be generated it will need more and more there is a after more and more volume and if you restrict the diameter what will happen the pressure drop will rise and if you pressure drop rises we need a compressor to push the gas through. So, to keep the pressure drop lower what we do that we increase the diameter of the column, where to handle the higher amount of vapor which is generated during this process.

The typical methane content at the bottom is about 0.5 volume percent of ethane on a C 3 plus three bases. So, this is the way we report it is per as a fraction of the ethane that is present in the gas in the bottom product. And feed may be from turbo expander JT valve or heat exchanger this turbo expander JT valve of the heat exchanger I was telling you.

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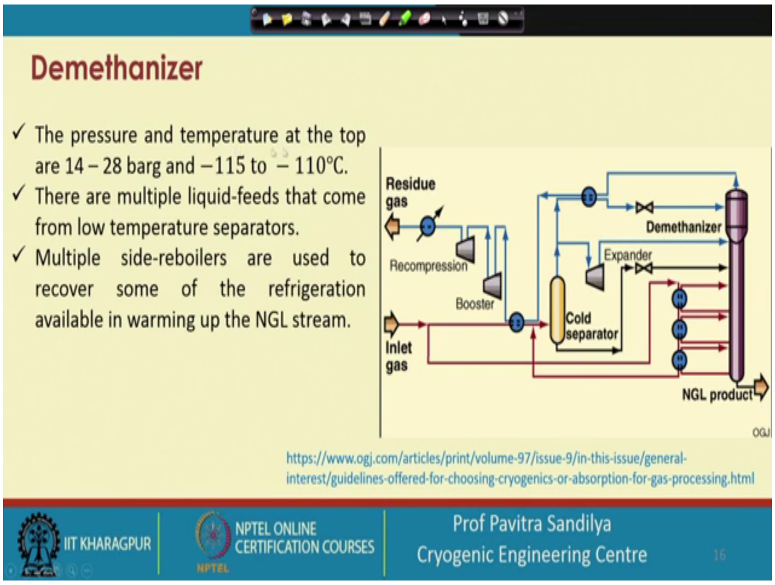

Demethanizer

- ✓ The pressure and temperature at the top are 14 – 28 barg and –115 to – 110°C.
- ✓ There are multiple liquid-feeds that come from low temperature separators.
- ✓ Multiple side-reboilers are used to recover some of the refrigeration available in warming up the NGL stream.

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The pressure and temperature at the top is about 14 to 28 bar gauge and about 100 minus 115 to minus 110 degree centigrade. So, you can see it is quite low pressure and there are multiple liquid feeds that come from low temperature separator. So, there are multiple feeds beyond these ones feed second feed and third feed. So, we have multiple feeds they are coming to the system and multiple side boilers are used like here we have the multiple side boilers and why they are used so, that we can recover some of the refrigeration available in warming up the NGL system.

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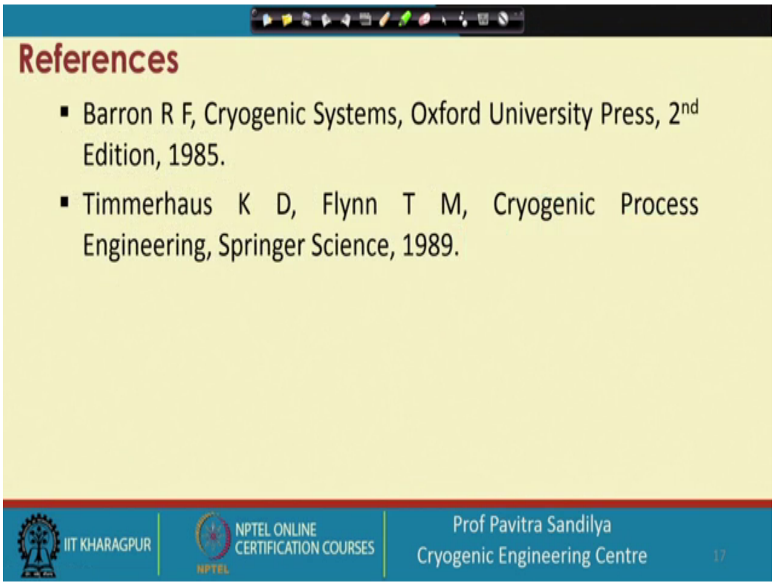

References

- Barron R F, Cryogenic Systems, Oxford University Press, 2nd Edition, 1985.
- Timmerhaus K D, Flynn T M, Cryogenic Process Engineering, Springer Science, 1989.

And here are the some books which you can refer to for further clarifications.

Thank you.