Upstream LNG Technology

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Lecture - 69
Cryogenic refrigeration and liquefaction in natural gas systems – I

Welcome. So, far we have learnt about many processing methods of the natural gas, and in these methods we found what are the various techniques of removing the various types of impurities to get the methane, methane increase the methane fraction. And among these various techniques we have learnt we have seen that many of the techniques many of the ways are based on the low temperature, that is based on the refrigeration or liquefaction. Now, this refrigeration liquefaction have been dealt with in the thermodynamics and in many other subjects like refrigeration itself, but when it comes to natural gas we know that the natural gas consists of methane, nitrogen etcetera helium for example.

So, some of many of these gases are having very low boiling points. And there the ways of their refrigeration or cooling down or the liquefaction need some special treatment, that is why in these a series of lectures we shall be looking into the various ways of cooling and liquefying these gases, and also we will see that how these principles can be applied for the various other processing methods of the natural gas. So, in this particular lecture series this is about Cryogenic refrigeration and liquefaction in natural gas systems.

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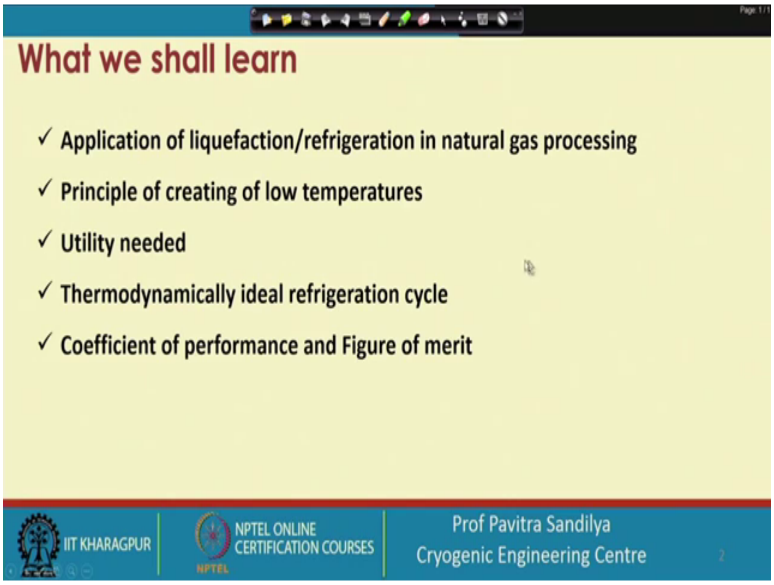

So, in this first of this the series we shall learn about the applications of the liquefaction refrigeration in natural gas processing, then principle of creating creation of the low temperatures, utility needed for carrying out the liquefaction refrigeration, and then what is thermodynamically ideal refrigeration, and then we will see the coefficient of performance and figure of merit.

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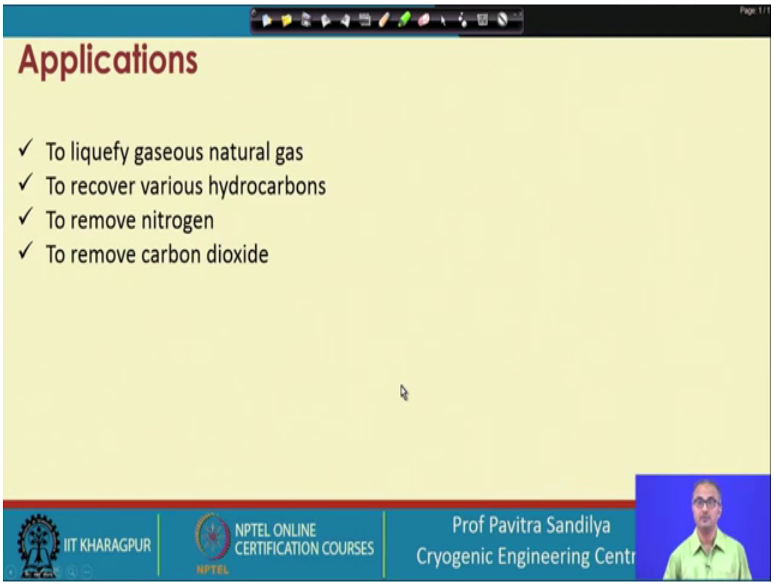

So, first let us come to the applications of this refrigeration and liquefaction in natural gas systems. So, we have learnt already that for example, if we want to store the natural gas and there are various ways of storing natural gas for example, we can compress it and or we can liquefy it. When we liquefy the natural gas for a given mass we occupy the least volume. So, liquefaction of natural gas is one of the very important ways of storing natural gas. So, that is why in that case we need these kind of techniques of liquefaction and refrigeration. So, to liquefy the gaseous natural gas we go for this kind of refrigeration and liquefaction; or we too want to recover the various types of hydrocarbons other than the methane.

For example, ethane, propane, butane, etcetera we need this kind of techniques. And you know that in the LPG that is the liquefied petroleum gas which we use in our day to day life at home that consists of basically butane and propane. So, those things are also coming from the natural gas. So, this also need for their storage they need this kind of low temperature techniques and liquefaction. Then to remove nitrogen we have learnt already that how to remove nitrogen then to remove carbon dioxide and also to remove helium. So, all these things need these kind of technique things.

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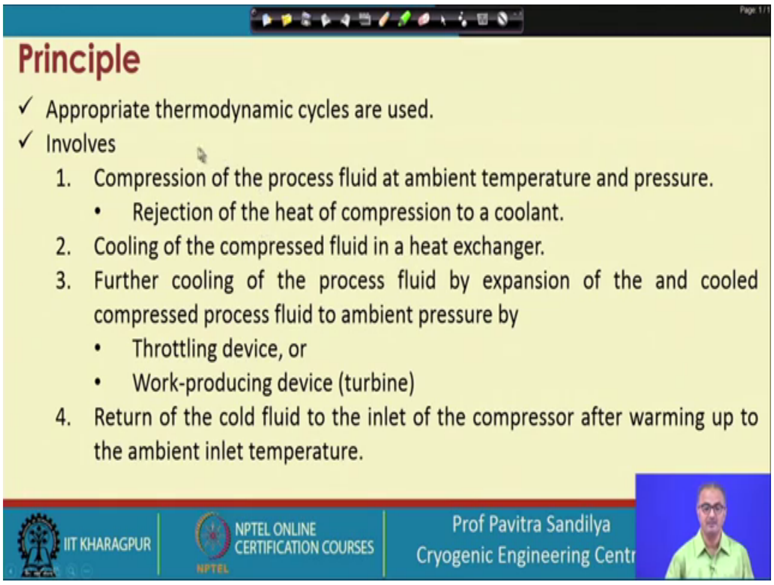

Now, here we have the first principle that appropriate thermodynamic cycles are used. So, all these refrigeration liquefaction are based on some thermodynamic cycles, and if you go in to the thermodynamics book you will find that there are dedicated chapters on the various types of liquefaction and not liquefaction the refrigeration techniques. I shall not be going in to the all those techniques I shall be confining myself only those methods which are used in the cryogenic or the natural gas industries.

So, and these thermodynamic cycles involve that that the basic few processes which are there for refrigeration that is first is that we compress the process fluid at some ambient temperature and pressure. So, what we have process fluid is there it is coming generally coming from the ambient. So, we compress it at from that ambient temperature and pressure and then in during this compression we know that compression involves a heat generation, that heat of compression comes out.

And also we have learnt earlier that the way when we are carrying out this compression the we can carry out is either isothermally or we can carry out either adiabatically and we have found also that if we carry out the compression isothermally then it will be involving least amount of work. So, that is why it is important for us to make the compression process as isothermal as possible. So, that is why in this compression what we do that we reject the heat of compression to a coolant. So, as we learnt earlier that in the compression we use many stages sometimes and in between the two stages we use intercooler. So, intercoolers are used to make to approach the isothermal condition.

Then after we have compressed the process fluid what we do when the cool again we cool the compressed fluid in a heat exchanger. Then after this cooling is done first cooling is done further cooling of the process fluid by expansion, then we carry out the expansion of the cooled and the compress fluid to the ambient pressure and this expansion causes some more temperature drop of the process fluid and this can be done either by some throttling device or by some work producing device for example, turbine. So, this we shall learn about a bit later.

And then what we do that after the cooling has been occur; has occurred then if this be. So, that the cold fluid may get into two phases that means, it can produce liquid and the gas or it can also remain in single phase. So, whatever phase it remains the vapour is again return to the compressor after warming up to the ambient inlet temperature because, the pressure in after the expansion is brought back to the initial pressure or the inlet pressure of the compressor why the temperature still remains very low, but now what we do we simply warm up this process fluid. So, that it can be brought back to the same condition as it entered into the compressor. So, that is how we carry out this compression this liquefaction process or refrigeration process in general. So, in both the cases the basic thermodynamic process remains the same.

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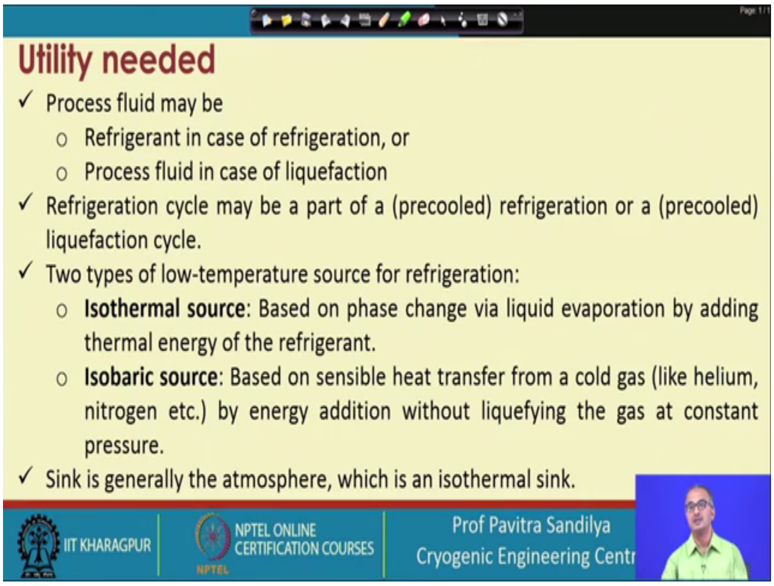

Now, what are the various utility used? In that means what are the various types of fluid and other things which help in carrying out the process. So, first is that the process fluid maybe the refrigerant in case of refrigeration that means, whatever refrigerate whenever we are talking about refrigerator there is some process fluid is undergoing the cycle this cycle. So, there we are using the refrigerant to carry out the refrigeration.

Or, if we want to liquefy the particular gas then the gas itself is the process fluid. So, depending on my purpose the process fluid may be is the refrigerant or the actual process fluid which needs to be liquefied. And refrigeration cycle maybe a part of a refrigeration or liquefaction cycle. Let us find later on that in some of the liquefaction cycles, in some of the refrigerant cycle we again need a secondary refrigeration cycle. So, this refrigerant cycle may be or come as a secondary utility cycle for the actual liquefaction or refrigeration cycles.

Then we have two types of temperature source of a refrigeration, means that you know that whenever this a fluid there is a purpose of this refrigeration is to extract the heat from some cold source, because it is the reverse of the heat pump means that we are trying to take out the heat from a cold source and eject it to a higher temperature. So, for this we need to do some work on the system as per the second law of thermodynamics.

So, we need some temperature source, and these temperature sources may be of two types one may be isothermal source, it means that there is a constant temperature, and how can we maintain constant temperature, it can be maintained if there is some kind of phase change. As we know when there is a phase change means it can be either in terms of liquid to vapour or vapour to liquid, but when it is from liquid to vapour what we need we need to have the energy from the surroundings, and in case of vapour to liquid that is condensation in that case the this heat will be released.

So, we talk of that kind of phase change that due to this phase change, what happens? The temperature will remain the same. So, depending on where we are trying to take the temperature inside the system. So, we will be doing this kind of source. So, when the vapour is coming to the liquid phase it will release the energy and that release that energy will be taken up by the particular heat exchanger. And then we have isobaric source, isobaric means there is no phase change. It is simply that the pressure remains constant pressure remains constant, but there will be a temperature change that that means, there is a sensible heat transfer during this type of isobaric source.

So, with the cycle can run either with an isothermal source or with an isobaric source as we shall see later. And generally the sink they must to be sink that we have talking to stop that source then that has to be sink. So, sink is where the heat is rejected by the particular refrigeration or liquefaction cycle. So, generally the sink is taken to the atmosphere and that we know that that atmosphere provides an isothermal sink. That means the temperature of the atmosphere will not change drastically for moderate amount of refrigeration and liquefaction.

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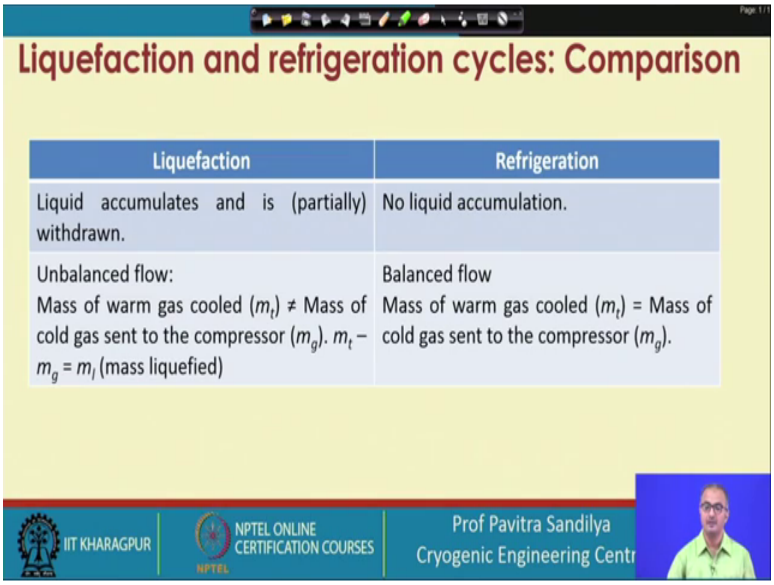

Now, let us compare the difference between the order the compare the liquefaction and refrigeration what are the similarities or dissimilarities. We found so far that the principle of the operation is almost the same with some small changes from the same.

So, we find that liquid accumulates in case of liquefaction and this accumulated liquid is taken out from the system and that makes it a open system whereas, in case of refrigeration there is no liquid accumulation of the liquid, so because nothing has to be taken out of the system. So, it is a closed system and generally it is the unbalanced flow unbalanced means the amount of the gas that has been warmed or cool that same gas is some of it is liquefied and taken out of the system and rest of it is send back for recycling so that means, this two amount that is the amount that is cooled and amount that is recycled are not the same. And the difference between the two is the amount of the liquefied gas. So, this is a unbalanced flow.

On the other hand if we talk refrigeration is a balanced flow means whatever amount is cooled from the compressor the same amount after undergoing a cycle is sent back to the compressor. So, that is how it becomes a closed cycle. So, because we are losing the some amount of the mass in the system in the liquefaction cycle, so we need to provide the makeup fluid from outside to compensate for the fluid taken out of the system. Whereas, in case of refrigeration there is no need of any kind of makeup fluid, provided assume that there is no leakage from the system.

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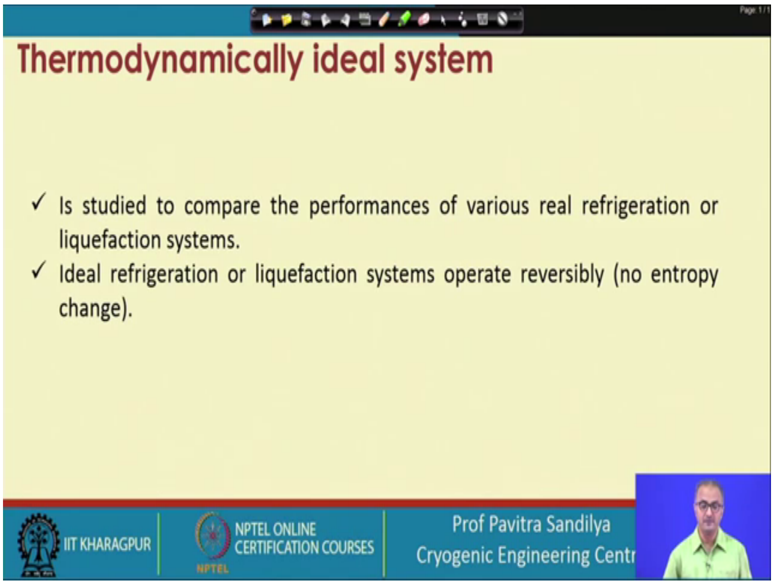

Now, when we talk of thermodynamically ideal cycle; why we need to talk of them? Because they are study to compare the performance of the various types of refrigeration or liquefaction systems which we are using practice. So, to compare this various types of real life refrigeration and the liquefaction system we need to know the performance of an ideal cycle. And this ideal means that they operate reversibly means there is no entropy generation. So, that is how do we define this reversible make the processes as per thermodynamics. So, if there is no generation of entropy we take it to be reversible. And as we know that in our in practice it is almost impossible to obtain the reversible processes

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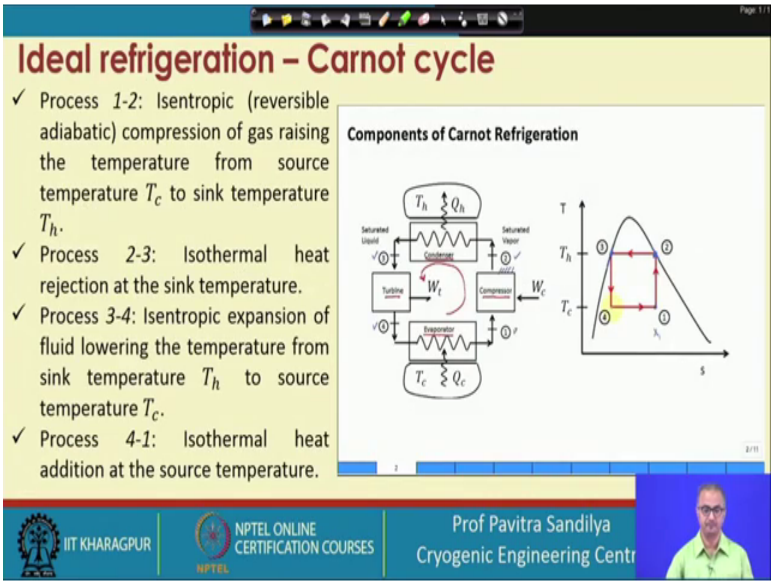

Now, first we come to the ideal refrigeration and that is Carnot cycle. Again I will not going to details of it, I will give you the some basic knowledge about this cycle and Carnot cycle is shown in this particular figure. This is the figure and this here we are represented in the temperature entropy diagram.

So, let us look into whatever and how these things going on. Suppose from the state one I have the particular process fluid at the same ambient condition it will now be compressed. Now, when we are compressing it, to make it ideal we want to put it in a very at (Refer Time: 14:26) way, but Carnot assumed that this is going isentropically. So, in this as whereas, Carnot concerned this is isentropic compression.

So, and when is compression is occurring we have to input the work of compression that is given by the W c. So, after undergoing this compression, what happens? We take it to a condenser and in this condenser what we do that if it is a phase change that is isothermal then there will be some amount of heat rejected, to the sink. And this amount of heat rejected is taken as Q h, the h stands for hot and then T h is the temperature of the hot that means, the higher temperature, ok, hotter higher temperature. And after this when it comes to a turbine or some expansion device where it will be further expanded. And during this expansion what happens again this expansion carried out isentropically as per the Carnot cycle is concerned. So, this particular reaction is isothermal and then this expansion is again isentropic. Isentropic means reversible adiabatic.

And after this expansion it goes to evaporator, where goes to evaporator in this case we are having a constant temperature, and this constant temperature comes only when we have a saturated liquid here. So, this liquid will undergo a phase change and it will go back to a at a constant temperature the heat will be taken out.

So, this is the space from which we are we are main trying to maintain at cool. So, this is the T c representing that space where that; for example, T c maybe our refrigerator, at our home. So, that is a T c we want to maintain cold and from there we are taking this Q c and this is how again this is this is our evaporation. So, we are getting this gas and again just compressed. So, this is how we are operating this Carnot of cycle with isotopic compression, isothermal heat rejection, isentropic expansion and isothermal heat addition, ok. So, these all the (Refer Time: 16:32) this particular dome which shows demarcates the saturated liquid line and saturated vapour line and in between this is happening.

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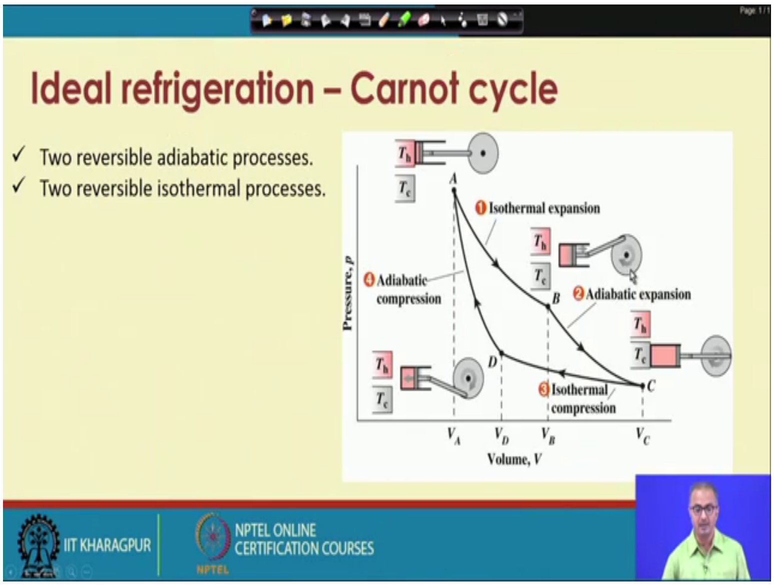

And now same thing may be represented in a PV diagram. Here we see this is the isothermal compression and then it is isentropic heat rejection in, and it is getting further compressed and isothermal expansion and adiabatic expansion, this is how, this is we are representing this on a pressure volume diagram and this can also be found in any of the thermodynamic books. So, we can represent all these systems in various manners, ok. So, this another way of putting the Carnot cycle.

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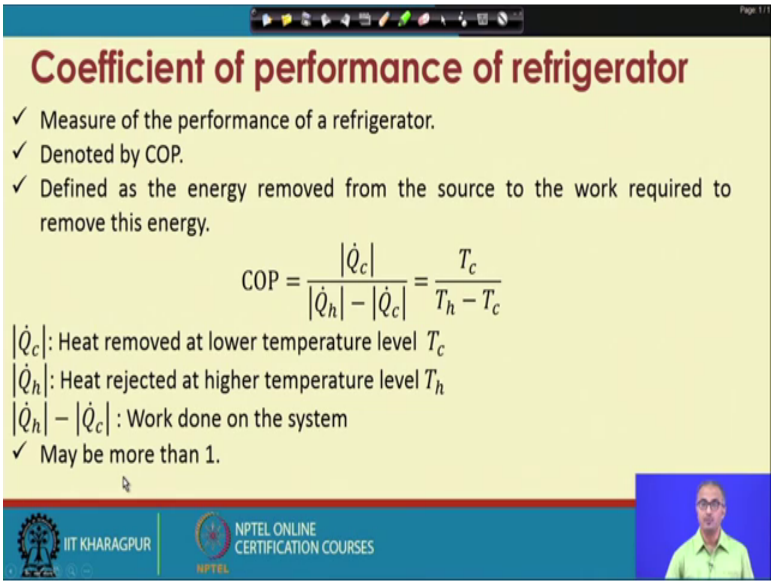

Now, here without any derivation I shall be giving you the final expressions here we have first the coefficient of performance of refrigerator. And what is this? It measures the performance of a refrigerator and denoted by COP and this is the way it is defined that it is equal to the amount of heat that has been taken up from the cold space and this amount of fluid that has been rejected.

So, this is this here to the absolute values of these things and this we are writing the fashion and this again can be written in terms of the temperature of the source and the sink. So, these are the various notations used in this particular equation and this COP may be more than one.

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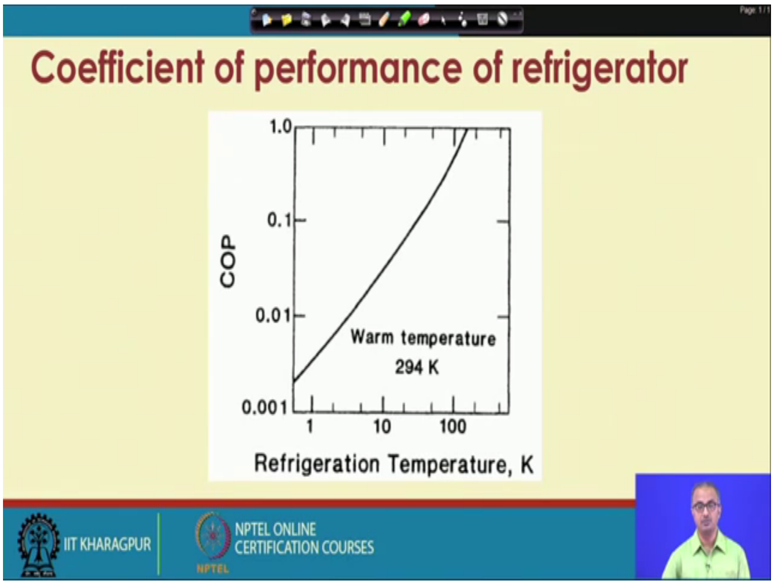

And here we see that how the COP changes with the temperature of the source. And here you be for the warm temperature suppose we take 294 K, we find that as the refrigeration temperature increases the COP also increases. So that means, the COP is dependent both on the T h and T c. This is for a given T h how the COP changes with T c.

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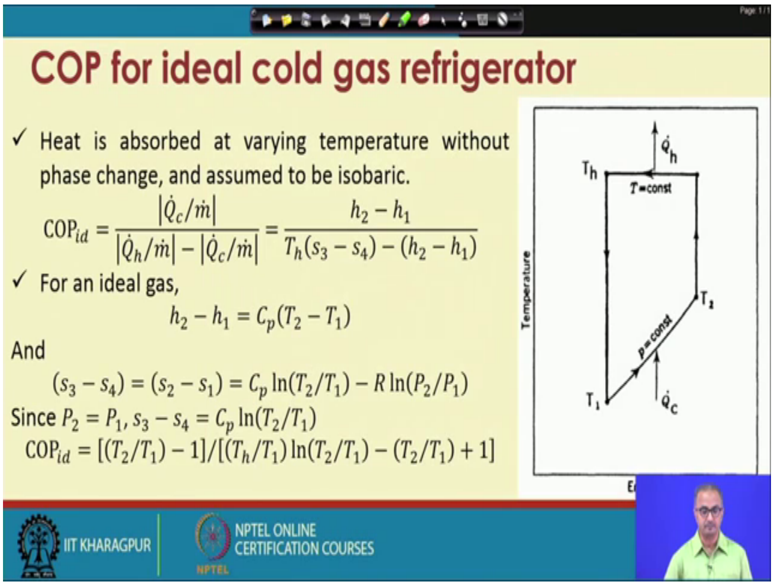

Next we come to COP for an ideal cold gas refrigerator. This is also many a times used. In this case it means heat is absorbed at varying temperature without phase change and assume to the isobaric that means, it is not happening at a constant temperature what is happening here you can see, that Q c is taken up it is not happening at constant temperature as earlier, but it is changing from T 1 to T 2 the temperature is increasing that is there is a sensible heat transfer. But otherwise the heat is rejected at the constant temperature.

So, if that means, it is not now Carnot it is deviating from the Carnot. So, it will have a different COP from Carnot. So, if we take this particular system which is more common in practice, in this case the ideal COP, ideal COP means that we are assuming that there is no heat leakage there is no friction in the pipelines etcetera and all the compressors all the if expanders all they are 100 percent efficient. And the heat exchanger is 100 efficient. So, assuming all those things whatever COP we are getting that is the ideal COP and if we make a energy balance we will get this particular expression for the COP.

And here we are this h 1, h 2 are corresponding to this two states and s 3, s 4 are the corresponding to the other. So, you will send it here s 1 in 1, 2, 3 4. So, these are the various states we are knowing the enthalpy and the entropies and if we consider an ideal gas then h 2 minus h 1 is given by C p delta t, ok.

And this is s 3 minus s 4 will become to s 2 minus s 1 and is given by this particular expressions from the thermodynamic book you can find this expressions. And since p 1 equal to p 2 then s 3 minus s 4 will be equal to this will be 0. So, you get in terms of purely in terms of temperature. And so we can see that for the ideal COP, if I now put all these things in this expression we find this is given in terms of this T 2 by T 1 that is this T 2 by T 1 and this in terms of the T h. So, this how this is how we represent the ideal COP for the cold gas refrigerator.

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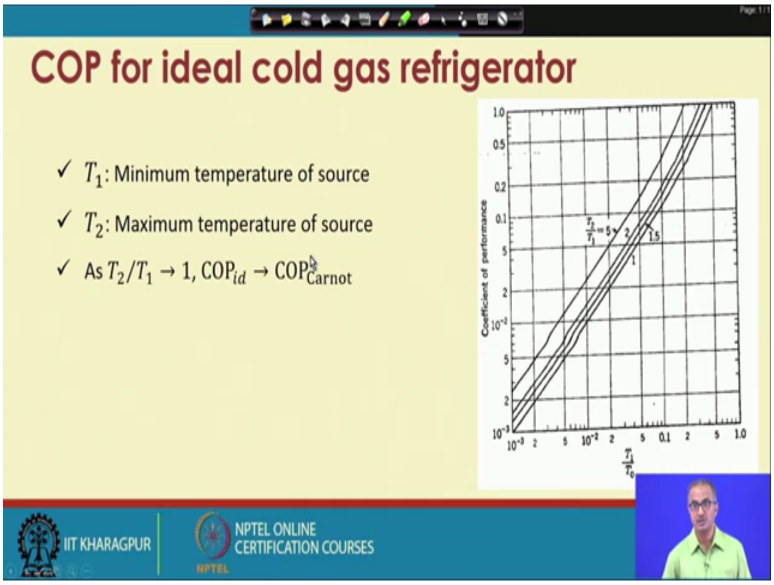

And here in this particular figure what we show that how the coefficient of performance changes with this particular T 1 by T 0 for various value of T 2 by T 1. And this T 2 by T 1 must be find out that when T 2 by T 1 is the 5 here, 2 here and as it goes towards 1 that means, we are going towards the Carnot. So, when T 2 by T 1 is there for whatever COP we are getting that COP will be corresponding to the Carnot COP. So, that is why I say that as T 2 by T 1 approaches unity the ideal COP approaches the Carnot COP, ok.

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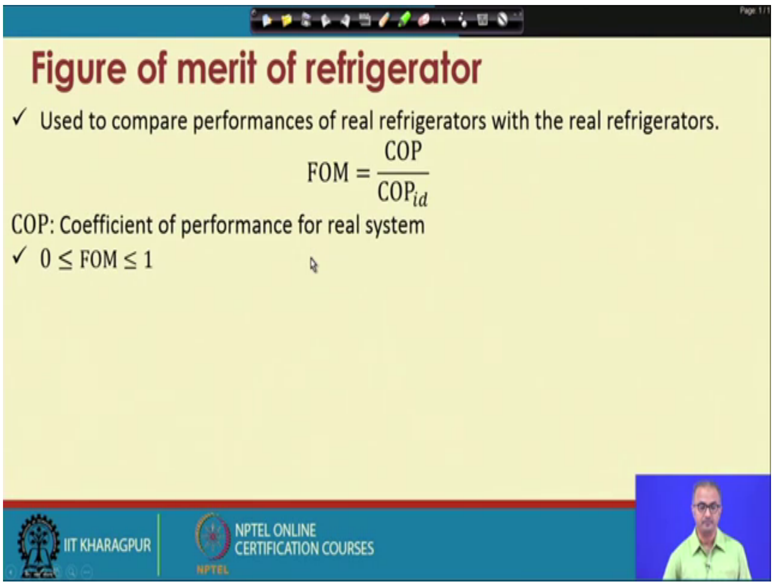

Now, next we come to figure of merit. And what is figure of merit? This is another performance measure for the actual refrigerators. So, far we have seen the COP, COP is talking about only one given refrigerator, but when we want to compare the various refrigerators available with us again we need some datum, and for that we need another parameter that is the figure of merit.

And this figure of merit is defined in terms of a ratio of the COPs. So, this is the COP of the actual system and this is the COP of the ideal system, and if we compare this we get the value of FOM. And FOM is similar to not same, but is similar to the efficiency, so we find that a FOM will be always the between 0 and 1, and it cannot go beyond 1 unlike COP. So, where 0 means it is no good the COP is 0 and FOM, FOM is one means is the ideal cycle, ok. So, that is how we can we compare the various types of liquefaction and refrigeration systems in sums of COP and FOM.

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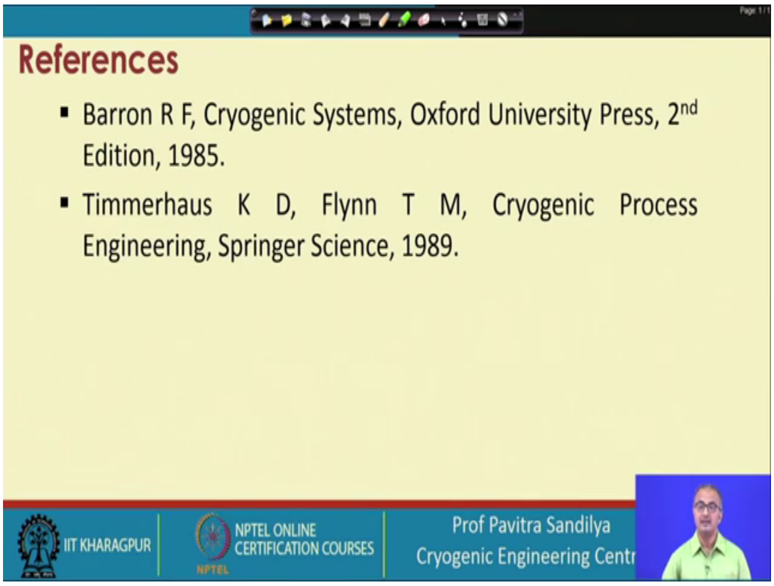

And these are the some references where you can get more detailing about these principles.

Thank you.