INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Refrigeration and Air-conditioning

Lecture-14
Multi-evaporator and Cascading

with
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Hello, I welcome you all in the course on refrigeration and air conditioning today we will cover multi evaporator and cascading system in vapor compression system in a multi pressure system for last two lectures we are dealing with multi pressure system.

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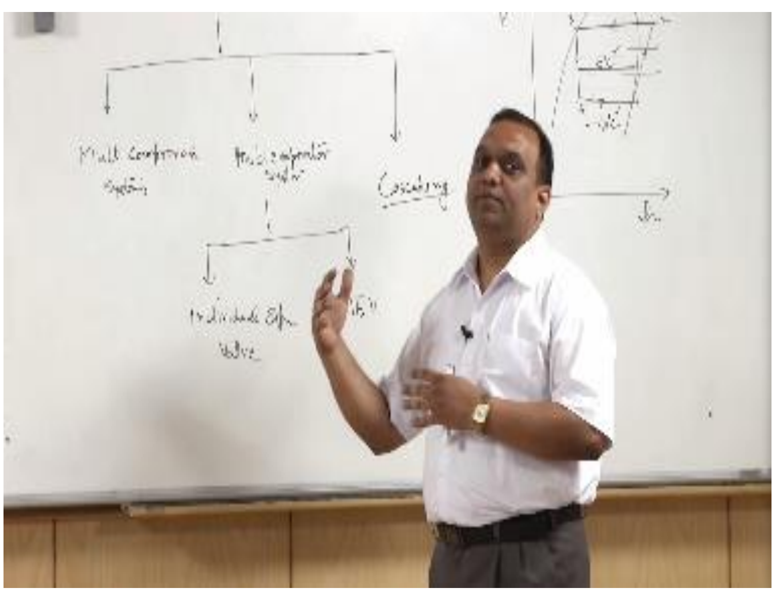

Multi pressure system and multiplier systems we have already covered in the last two lectures multi compression system, now in multi compression system the compression has taken place in more that none stages right and instead of having to pressure system because to pressure means to pressure system is simple vapor compression system this is a two pressure system. So on a pH diagram so this is a two pressure system and we have already done this multi compression system where compression takes place in more than one stages maybe two stages or three stages.

Another multi pressure system is multi evaporator system in multi evaporator system there may be one compressor right compressor compression for compression there may be one compressor but there are number of you operators instead of having one evaporator they are number of evaporators evaporating at different temperatures now the benefit of this system is suppose I want to have a deep freezer to for the preservation let us say is minus 40^0 centigrade I want to have a I mean freezer also at let us say 5^0centigrade to keep the things.

So at these two temperatures if I have a simple system it is difficult to operate I mean I will have to make arrangements but here if I have a multi evaporator system we can expand the compressed liquid sorry not compress liquid this condensed refrigerant at high pressure at state 3 in 2 different evaporators and these way operators are operating at different temperatures or different pressures this type of system is known as multi evaporator system the multi evaporator system is further classified as individual expansion of all system and multiple expansion wall multiple expansion wall system individual expansion wall means every evaporator has its own expansion wall.

So the refrigerant at state 3 is expanding in your printer 1 and evaporator 2 and both the evaporators are having their own expansion mode in multi expansion wall is the refrigerant which is entering the anyway operator is let us say we have little 1 or evaporator 2 it is expected in two stages that is why it is known as multi expansion arrangement and there is third type of system which has number of I mean two compressors or more than two compressors and more than two operators also and this type of system is known as cascade system or the arrangement is known as cascading.

Now in the cascading there are two simple vapor refrigeration or more than two simple vapor compression cycles and different refrigerants are used in different cycles we will discuss this cascading in details first of all will assume you have already covered this and now we will start with multi evaporator system with individual expansion wall, now in this type of arrangement there is one compressor or we are there used to be one evaporator now there is one compressor and one condenser.

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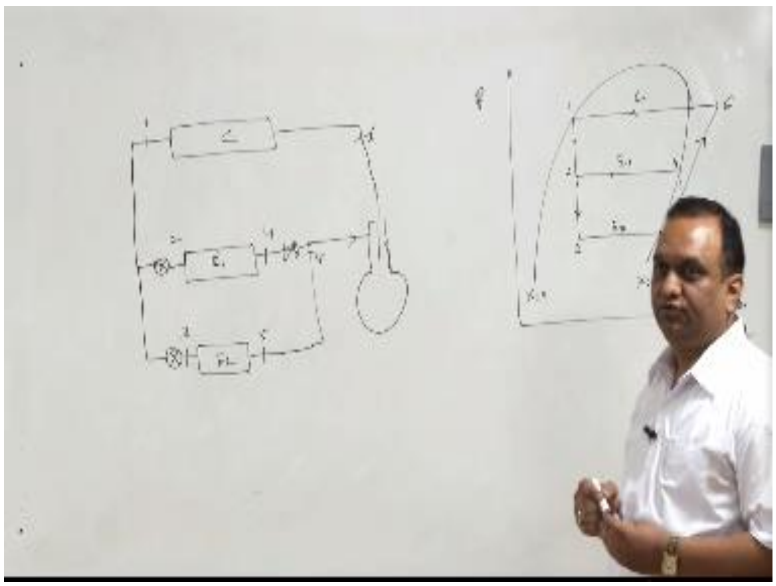

The vapor going from the compressor is getting condensed in the condenser now let us come to the evaporation side the wave part is available here let us start from here one it goes to the evaporator one and before that it gets expanded then again vapor goes to evaporator two and then again it gets expanded in expansion valve one and expansion wall two respectively and this is e2 now vapor is emerging from e 1 and E 2 as well so this is state 1 this is state 2 this is state 3 and this is state 4, let us say state 5.

Now pressure at state 5 4 &5 are not same pressure are different because here expansion is taking place earlier at higher pressure so pressure at state 5 is not same as the pressure in this state for state 5 is not as the pressure in state 4 and we have only one compressor and then it is only one compressor is available for this purpose in this case we have no other choice but to expand this the vapor available at 4to the pressure of 5 and here at pressure 5 it is sent to the compressor.

Now if you I want to depict this process on pressure enthalpy diagram on a pressure enthalpy diagram there is a saturation line X is equal to zero X is equal to 1 this is condenser and at the exit of the condenser this state is 1 expansion is taking place in1 first expansion device and we are getting state 2 and state to the vapor is entering the evaporator and coming out of at state 4, now further in this down the line this vapor continue to expand up to state 3 3so 2 to it is expanded up to state 3 and after a timing state 3 it goes to the evaporator 2 this is e_2 this is e_1 this is condenser.

And after heat exchange in the second evaporator it emerges as the state v and here we have state for what we should do we should here reduce the pressure at the exit of the evaporator one through throttling so in a throttling process and third P remains constraints so through a throttling process the pressure is reduced and mixing takes place here mixing takes place and after mixing the mixture it goes to the compressor and compression takes place and we attain state 6, so this is a this is an arrangement of multi evaporator system it is very useful.

Especially in the shopping area it is very useful we are some of the items in for some of the food products we can preserve at a very low temperature let us say -40^0 centigrade or-30^0 centigrade and some of the items which are to be preserved on high temperature may be -10 or 0^0 centigrade, so we can have this type of arrangement where we have two operators and both the evaporators are operating at different temperatures.

So this is the arrangement for multi evaporator system with individual expansion one we can have another arrangement also where there are multiple expansion valves in this type of arrangement we will start with the compressor because then we have only one compressor.

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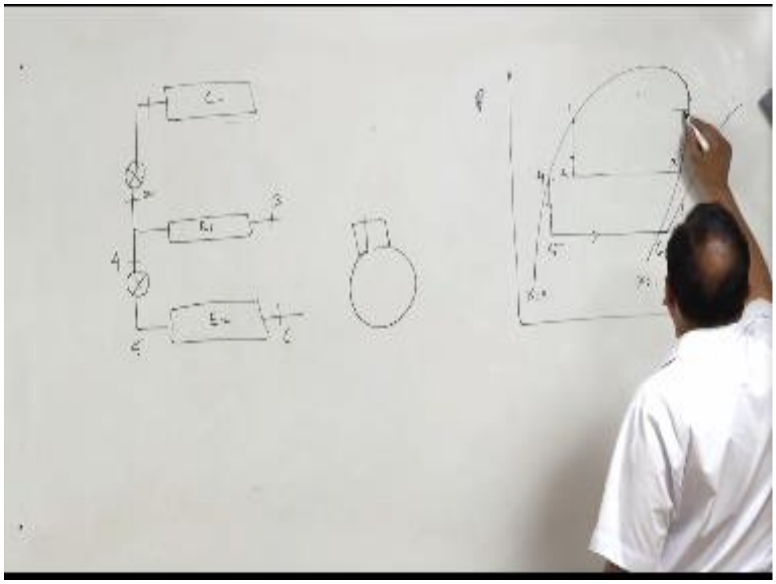

So we will start with the compressor so there is a compressor and there are two operators again this is a e_2 and this is e_1 and there is a condenser and vapor is of a condensation again the vapor is emerging from condenser vapor is emerging from sorry the liquid refrigerant is emerging from the condenser state 1 and the entire liquid is expanded in one expansion wall and that we get the state 2, so state 1 to state 2 we get this expansion we get in one expansion wall this is state 2and after the attaining state to the vapor enters the evaporator one part of the vapor.

And the process then it picks up heat in the evaporator and we get state 3 here now remaining part of the expanded vapor remaining part of expanded paper which is available at this pressure is again expanded and a flash gas type of removal arrangement is also provided here, so that only liquid enters here only liquid enters here and we get these processes so liquid enters here means that is state 4 that is state 4 after expansion is state 5 and then we get state 6, now after restraining attaining state six again these two have to be mixed and for mixing again there is same issue that this pressure has to be reduced to this one okay.

So again third link takes place here and mixing of both the refrigerants and then compression in a compressor, so this is how the multi expansion system multi expansion multi evaporator system works it is called multi expansion because refrigerant is expanded in to stage four evaporator two and now these are connected yes these are connected and it goes to seven state seven and then it is compressed and get state eight, now one arrangement we can make here in this type of system instead of having one compressor if we provide two compressors.

Now we have variety of components with us we have flash gas removal system we have multi compression system we are reverse with multi evaporation system evaporator system evaporator system with individual expansion valve a power system with multiple expansion wall, so we can have combination of all these arrangements to find to develop a system which can give the best performance so instead of it is also recommended that instead of expanding vapor from state 3 to state this state and then again compressing it.

Instead of that if we are able to make use of two compressors instead of using one compressor there are two compressors and one compressor for this and both the compressors are compressing gas up to state eight, so this type of arrangement I want to make here then definitely the, in fact they are not paralyzed the diverging line so instead of writing them like this I would like to draw them like this, so we will get this type of pH diagram for multi expansion original.

Now the problem with these type of multi compression systems the pressure ratio is high these systems are used where the pressure ratio is high but the problem with the multi expansion system says that a refrigerant suppose I will give you some numerical values then things will become clear to you because sometimes it is not possible to see you same refrigerant at a wide range for example in chemical applications the temp we required temperature of the order of let us say 100^0 centigrade.

Or in some of the applications we require temperature as -80^0 centigrade or -60^0 centigrade condenser temperature is 50^0 centigrade or 40^0centigrade so this temperature difference temperature variations is very high this temperature variation is very high similarly corresponding pressure ratio PK / PU or p2 / p1 or pH / PL pressure and condenser and pressure in evaporator this ratio becomes very high for certain range we can go for this multi compression system but for pressure ratio it is okay, multi compression system can be accepted but for this wide variation in temperature same refrigerant may not be recommended for the use.

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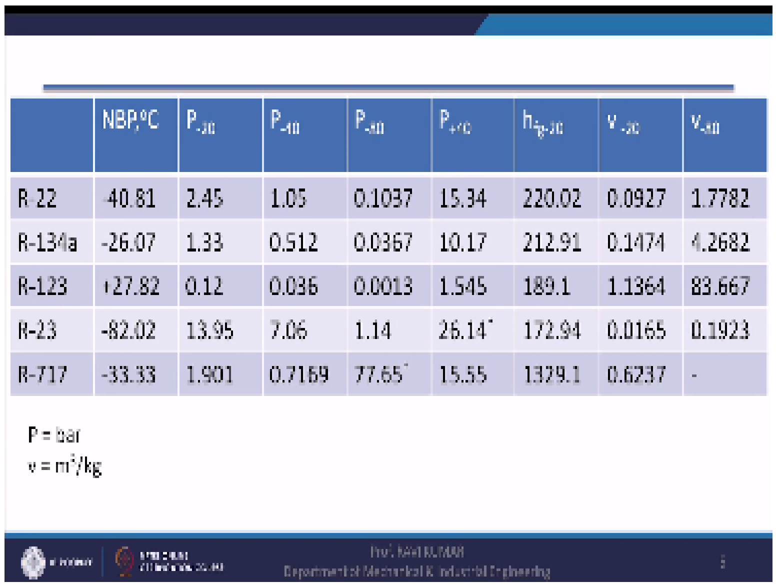

	NBP,°C	P_{-20}	P_{-40}	P_{-80}	P_{+40}	h_{fg-20}	v_{-20}	v_{-80}
R-22	-40.81	2.45	1.05	0.1037	15.34	220.02	0.0927	1.7782
R-134a	-26.07	1.33	0.512	0.0367	10.17	212.91	0.1474	4.2682
R-123	+27.82	0.12	0.036	0.0013	1.545	189.1	1.1364	83.667
R-23	-82.02	13.95	7.06	1.14	26.14*	172.94	0.0165	0.1923
R-717	-33.33	1.901	0.7169	77.65*	15.55	1329.1	0.6237	-

P = bar
$v = m^3/kg$

Let us look at the properties of some of the refrigerants for example r22 so r22 has normal boiling point - 40.81^{0}centigrade right, so if I am using this r22 8 - 20 the pressure is 2.45 bar and if I were using r20 t at -80 it is 0.1037/, remember the moment we reduce the pressure specific volume increases.

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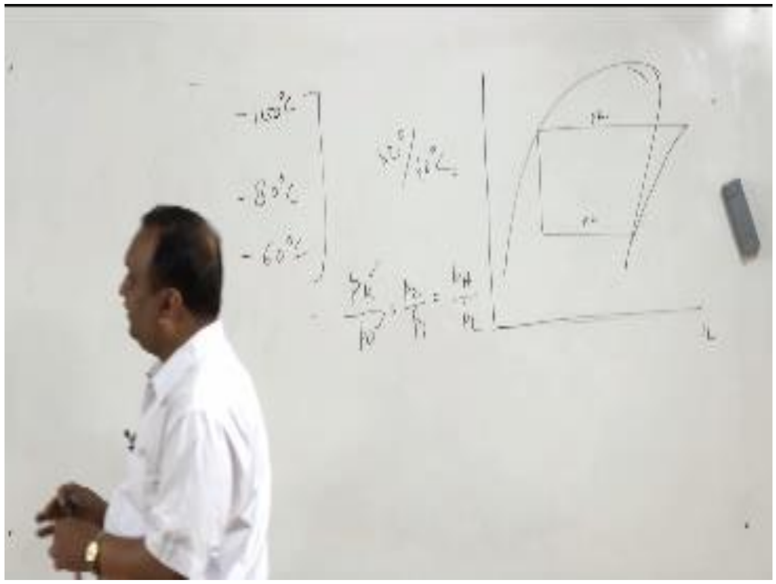

So the moment we reduce the pressure the specific volume increases the specific volume increases here also you can see for this r22 if the evaporator temperature is 80^0 by necessity the pressure is only 0.1 bar and specific volume is also very high it is 1.7782mc per kg and if you look at the refrigerant r23it is normal boiling point is -82^0 centigrade so at one atmospheric pressure it will boil at -82.2^0centigrade and specific volume is our only 0.1923 specific volume is important because a specific volume at the exit of the evaporator decides the size of the compressor.

So specific volume of the vapor at the exit of the evaporator should be as low as possible that is one thing second thing is if you look at pressure at 40 suppose I choose23 okay for -80 it is okay it is giving -82^0 centigrade at normal boiling point is normal 8 82^0centigrade, so it will boil suppose I want temperature minus 80^0 centigrade our 23 will boil below the atmospheric pressure it is okay, I can use it for minus hundred also but the problem is when it is taken at 40^0 centigrade it is critical temperature is 26.47, so I will be operating the system above the critical temperature and the COP of the system will reduce.

So I cannot use this refrigerant for this purpose and similarly if I use low pressure refrigerant that is R 123 R123 is okay when the pressure is 40^0 centigrade pressure is 1.5/ times approximately atmospheric pressure it is okay, but when I use R 123 at -80 the pressure is 0.0013/, so very low right and in that case the specific volume is also very high -80 the specific volume is 83.667 huge amount of vapor has to be handled by the compressor, so now we have two option we have to trade off.

We have low pressure refrigerant low pressure refrigerant Is like R 123 which are at high temperature at condenser temperature the pressure is 1.5 it is okay but on the evaporator side they have very high specific volume, so if I use this refrigerant and the size of the compressor will be very large that is do not recommend it if I use high pressure refrigerant like R23 in that case evaporator side is okay the refrigerant will evaporate at - 82^0centigrade it is its normal boiling point specific volume is also good 0.1923 very small specific volume.

But when it comes to the condenser it is become it becomes supercritical see this case with the ammonia so you take any refrigerants, so we can see that any of the refrigerant which we have to deal in a very high range of your operator and condenser let us say -100 to 50^0 centigrade the difference is approximately 150^0 centigrade one refrigerant cannot work and there are many other reasons for going for cascading system I am just justifying why we should use a cascading system.

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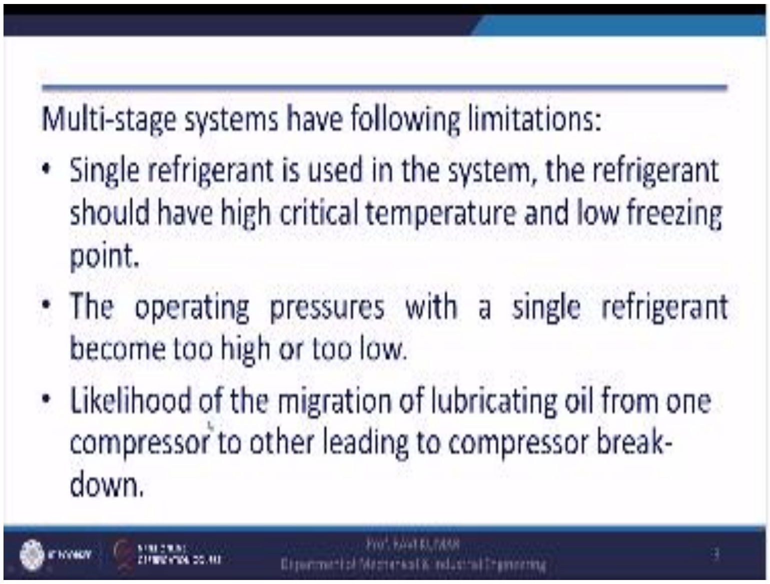

The single reference system is used in the system the reference should have high critical temperature and low freezing point further we operate from critical temperature more we are close to the CUP of a Carnot cycle so CUP of the system of CUP of the cycle increases when it operates far away from critical temperature, so that will not be possible when we use a single refrigerant for a such a wide range the operating pressure with the single refrigerants become - I or to low that I have just now I have explained to you.

Likelihood of migration of lubricant oil from one compressor to another leading to a compressor program yes this happens in multi staging compressors when refrigerant from one compressor enters to the other compressor in that case the lubricating oil also shift to the another compressor and the lower pressure compressor becomes the short of lubricating oil. So that is another problem in multistage and very low temperature in vibrator and large suction volume for high boiling refrigerant that I have already explained you.

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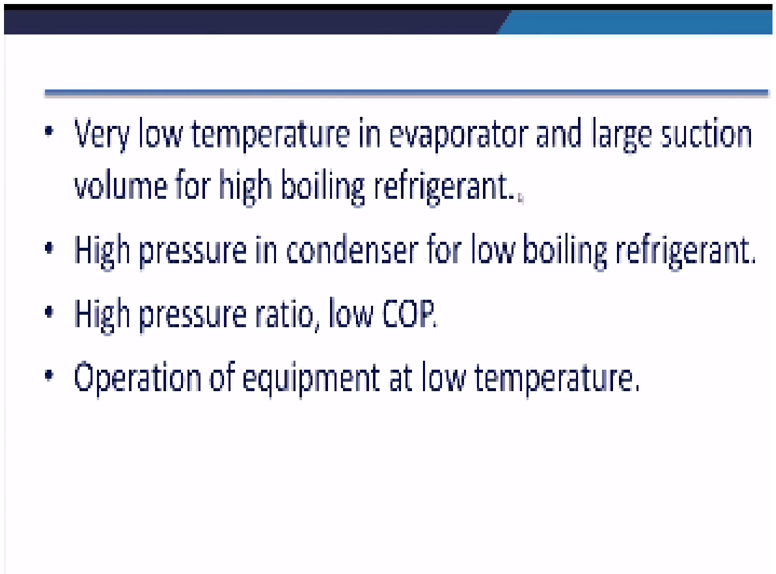

If the high boiling refrigerant means normal boiling point is high in that case if we take therefore every end for the application of very low temperature the specific volume will be high and that is also not acceptable the high pressure in condenser for low boiling refrigerant high pressure ratio low CUP, so if we go for a single if we take a single stage simple cycle for vapor compression cycle so definitely the moment the pressure ratio increases the CUP of the cycle goes down and operation of equipment on low temperature.

I am talking about – 100 -120 or - 150^0 centigrade that also becomes difficult so in order to avoid this a cascading system is recommended, now in cascading system is nothing but a combination of two simple vapor compression cycle or two or more vapor compression cycles it means we have one a vapor compression cycle which has a condenser.

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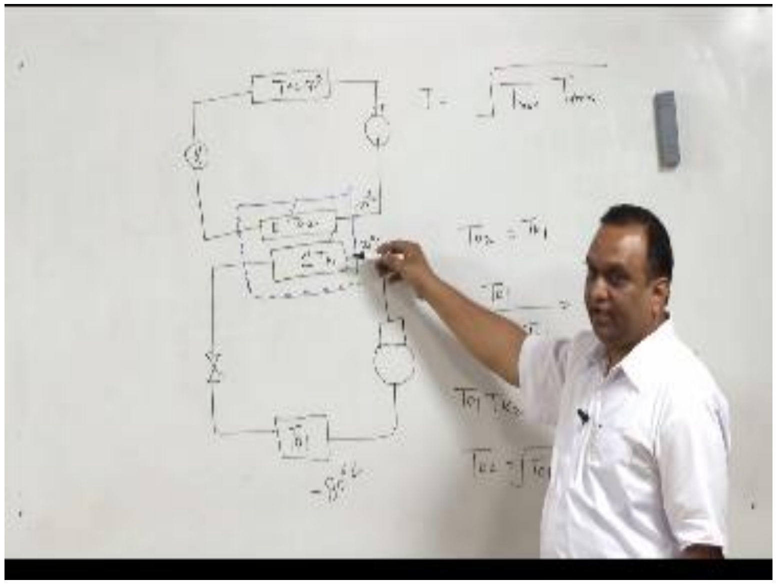

A simple vapor compression cycle compressor expansion device evaporator, so this is a To1and this is PK 1 temperature of condenser one temperature of evaporator one now this is one simple cycle a particular refrigerant for use this cycle may be here temperature - 80^0 centigrade here temperature maybe 0^0 or - 40^0 centigrade, now this condenser is used to take away now how the condensation will take place here suppose the temperature here is - 80^0 centigrade and temperature here is -20^0 centigrade.

Now how the condensation will take this here for the condensation of vapor at -20^0 centigrade we need to have fluid which has temperature lower than this right, so we cannot use air we cannot used stet water, water cooling is avoided it is not possible air cooling is not possible the possibility is that we have another vapor compression system we have another vapor compression system which has evaporator temperature less than this one.

So there is another vapor compression system this is T k2 and it has also its own expansion wall and it has evaporator To2 and then it has its own compressor both the systems are working with different working fluids now these systems are they are made as one heat exchanger or this is known as cascading so the heat of the heat of this condenser is taken by away by this evaporator, so this evaporator maybe at let us say -25^0 centigrade operating between - 25 to35^0 centigrade I am just taking some values.

So that you can have clear cut inside of the phenomena so I am repeating in a cascading system we can have two or more simple vapor compression refrigeration cycles each cycle has its own compressor evaporator and condenser let us take one cycle of suppose we have to maintain minus 80^0 centigrade and one cycle will operate - 82 -20^0 for example I am just giving an example and here the condensation of vapor is taking place at -20^0 centigrade.

Now in order to condense this vapor we need a fluid which has temperature lower than the -20^0 centigrade right, so the air can normally the air cannot be used water cannot be used deaf water cannot be used so we what we have done we have introduced another cycle which has evaporated temperature let us say -25 or -30^0 centigrade and these two are clubbed or a heat exchange is arranged between evaporate of higher pressure to the operator at lower pressure or condenser at lower pressure and in this case the condensation of vapor will take place in this condenser and this heat will be taken away by this evaporator and it will go to the cycle.

So and we can have similar type of arrangement two or three similar type of arrangement and this is known as cascading of vapor compression system we assume that the CUP of this definition cycle is equal to CUP of these definitions cycle so if the CUP Carnot cycle so Carnot cycle working between this temperature between these temperature is equal to CUP of the Carnot cycle working between this temperature. So To1 / T sorry Tk1- To1 = To2/Tk2-To2, now in idle case we assume that To2 =Tk1if you assume To2= tk1 the To1 /To2 this Tk1 is replaced by T.

This temperature we assume is equal to this temperature, so TK 1 = To2 - To1=To2/Tk2- To2, now we cross-multiply To1 TK 2 – To1 To2 =To2 To1 To 2^2 – To1 To2 we have just simply cross multiplied this and you can see on the left hand side To1To 2 here this will be cancelled out and we will be getting To2 = √To1Tk2, it means approximately this is not exact value but approximate value at temperature this is a frog approximate absolute temperatureTo2 is equal to under root of multiplication of maximum temperature and minimum temperature.

So in a cycle if I want to develop a cascading system for a temperature range of T 1 and T 2 T Max and minimum so T max multiplied by T minimum of the cycle if we take under all of this is going to be the temperature of evaporator or condenser of high pressure or low pressure cycle for the sake of heat transfer we can have some adjustment in the in the in the temperature values so that we can attain a design of a realistic system, so that is all for today's lecture now in last lecture we will solve atypical example on vapor compression system. Thank you.

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