Cooling Technology: Why and How utilized in Food Processing and allied Industries

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Module No 06

Lecture 30
Carnot Refrigeration Cycles (Contd.)

Good morning, my dear friends and students. We have started with Carnot Refrigeration Cycle, right and in the last class, we have shown the COP of Carnot Refrigeration Cycle, right. So, this is a Carnot Refrigeration Cycle continuation class, and we have done the COP of Carnot Refrigeration Cycle, which is a function of evaporator and condenser temperatures only, and is independent of the nature of the working substance. The Carnot COP sets an upper limit for refrigeration systems operating between two constant temperature thermal reservoirs, that is, heat source and heat sink. From Carnot's theorems, for the same heat source and sink temperatures, no irreversible cycle can have COP higher than that of the Carnot COP right. This we have also seen in the Carnot heat engine, if you remember.

Now, we come back to schematic diagram of the refrigeration cycle represented by a TS plane, right. So, this is the TS plane, this is temperature, and this is entropy, right and this was our dome right. We started with point 1, then we went up to point 2, then point 3, and then point 4, right. So, if you remember some classes back, we had shown that curve like this, that was 1, 2, 3, and we said, the area under this curve, is either the work or whatever.

So, here also, we are looking at the area under the curves, 1, 2, 3, and 4 right. So, we see that, 1 to 2 to 2 to 3, 3 to 4, to 4 to back to 1. This was our Carnot cycle right. And if we say now that, in this TS plane that, the COP of a Carnot refrigeration system increases as the evaporator temperature increases, right and condenser temperature decreases, right, and this can be explained very easily with the help of the TS diagram, as we have shown in the previous diagram, right. So, we can go back, perhaps, back and forth, we can do and if we see that, this was which, we are referring to, that, this figure says in the TS diagram that 1, 2, 3 and 4. So, the area under the curve will let us know that how much work, how much heat has been given, or work has been obtained or done, whatever.

So, COP is the ratio of the area 1 to 4, A 1 to 4 to B. So, let us look into that area, A 1 to 4 to B back to A right. So, this is the refrigeration part right. So, this is 1 to area A 1, A 1 4 B that is Q e, this increases, and the area 1, 2, 3, 4, that is, W net, this decreases. As a result COP increases rapidly. So let us go back to that, so, we said that area A 1 4 B A.

So, this area, which is shown, that is, equal to Q e, as it is written, right, and the area 1, 2, 3, 4 that is this area, is the W net right. So, COP, as we know, is equal to Q e over W net right. So, if it is Q e over W net is the COP, then, we can say that, our evaporator temperature is T e, our evaporator temperature is T e, and condenser temperature is T c, right. So, as we increase T e, if we increase T e, so, this line then comes here. So Q e goes up whereas, W net goes down.

So, COP, which was Q e over W net, that becomes increasing, right. Q e is more W net is less. So, COP goes up, and the reverse, if you do the reverse, that is, if we decrease T e, if we decrease T c, keeping T e constant, keeping T e constant, if we decrease T c, that means, now, this is like this. So, W net decreases, right, but, Q e remains same. So COP is equal to Q e over W net, W net is decreasing. So, if we decrease T c, COP increases.

So, if we increase T e, keeping T c constant, COP increases. If we decrease T c, keeping T e constant, COP increases. The reverse, again, other way round. If we look at, what is that, other way round? If we, in place of increasing T e, keeping T c constant, if we decrease T e, right, then, Q e decreases and W net increases. So, Q e decreases, and W net increases, right. So, if that be true, then, COP is Q e divided by W net. So, W net is increasing, and Q e is decreasing, right. So, that means, COP is decreasing. Isn't it? This becomes more, this becomes less.

So, the value of COP is decreasing right, when, we have reduced the evaporator temperature, keeping the condenser temperature same, right. Now, if we do the other one also, that is, if we keep the T e constant, right, if we keep T e constant, if we increase T c, then, W net increases, but, Q e remains same, right. W net is increasing, but Q e remains same. So, Q e over W net is COP, and W net being increased, denominator is increased. So, in that case, if we increase the condenser temperature, then also, COP is decreasing, right.

So, increase in COP is by increasing the evaporator temperature, evaporator temperature, or T e, evaporator temperature increasing ,or second is condenser temperature, that is, T c, condenser, if we decrease, then we get increase in COP, right. And the other one, if we look at the other one, that is, if we look at the other one, that is, what we are saying, decrease in COP is because, one, we said that, if the T e is decreased, that is, T e, evaporator decreasing, number 1, and number 2, we said if we increase the condenser temperature, right. So T c, condenser, if we increase, then also COP is decreasing. So, four cases, we have said, one COP increase will happen keeping the condenser temperature same, if we increase the evaporator temperature, then, COP will increase, keeping the evaporator temperature same, if we increase the condenser temperature, then, if we decrease the condenser temperature, then, COP will increase whereas, COP will decrease, if we, keeping the condenser temperature same, if we decrease the evaporator temperature, then, it will decrease as well. If the evaporator temperature is same, but, if we increase the condenser temperature, then also COP will decrease, right. So, this we have understood from the figure 2, explicitly, right ok.

Then, this is what, we have written here, elaborately, that, as shown in the figure 2, COP is the ratio of the area A 1, 4 B 2, the area A 1 to the area 1 2 3 4, for a fixed condenser temperature, T c, as the evaporator temperature, T e increases, area, A 1 4 B that is Q e increases, and area 1 2 3 4, that is, W net decreases, as a result, COP increases rapidly. Similarly, for a fixed evaporator temperature, T e, as the condensing temperature, T c increases, the net work input, that is area under 1 2 3 4, increases, even though cooling output remains constant. As a result, COP decreases, right. This was also observed, from our figure 2, which we have shown right. Now, for figure 3, that shows variation of Carnot COP with evaporator temperature, for different condenser temperatures. It can be seen that the COP increases shortly, with evaporator temperatures, particularly at high condensing temperatures.

COP reduces, as the condenser temperature increases, but, the effect becomes marginal at low evaporator temperatures. It will be shown later, that, actual vapour compression refrigeration systems also behave in a manner similar to that of Carnot refrigeration systems, as far as the performance trends are concerned. Now, let us look into that figure. This figure says that, COP versus T e, that is evaporator temperature. COP versus evaporator temperature, for different condenser temperatures. This is, say condenser temperature 1, this is say, condenser temperature 2, and this is say, condenser temperature 3,, right.

What is the effect of COP for different T e right? So, obviously, this T c 1 is higher than T c 2, is higher than T c 3, right. So, no, the T c's are increasing like this, right. So, this T c 1 is lowest, T c 2, is moderate, T c 3, is the higher, as it is seen right. So, for a given T e, this is the given T e, right, as the condenser temperature increases, COP decreases, right. COP decreases, as the condenser temperature increases. For a given T e, the other way, as the condenser temperature decreases, COP increases right.

So, this is what we have seen from the figure 2 also, where for a given evaporator temperature, like for a given evaporator temperature, like this, this is the, say, given evaporator temperature, and if we go vertical, right. So, it could not have been proper, if we go vertical right. So, for a given T e, so, this is a temperature T e 1, for a given temperature T e, what we said, and condenser temperature is increasing, this way, as it is shown. So, this is T c 1, this is T c 2, this is T c 3, and T c 1 is less than T c 2, is less than T c 3, right. So, the COP of T c 3, is like this COP of T 2, is like this and COP of T c 1 is like this, right.

As we can see that, we said, this is the highest T c 3, temperature, this is moderate, and this is the lowest, right. So, as the condenser temperature is lowering, the evaporator temperature, keeping same COP is increasing and the reverse, keeping the same T e, as the condenser temperature is increasing, the COP is decreasing, which, is true in our earlier figure 2. I will confirm from there, so that, there is no confusion, and if we go back to that, then we get this that this is the one which you are referring to right. We said that if we had if we draw the plot again, here, this was COP, right these were the 3 condenser temperatures, this is the evaporator temperature. So, T evaporator, we said for a given T e, right, if this is the given temperature, COP is here 1, this is 2 and this is 3.

What we said, condenser temperature was increasing, like this, that means, this T c 1, is less than T c 2, is less than T c 3, right. So, if this be true, then, we are also getting it from here, that, what did we say? That, for a given T e, so, this is the given T e, we are decreasing, this way, it is decreasing, we are decreasing the condenser temperature, that means, we are lowering down the condenser temperature, that means, W net is decreasing, whereas, Q e is same. So, COP is Q e divided by W net, and W net is low. So, COP is increased, right the reverse T c is increasing, right.

So, T c is increasing, that means, we are increasing here. So, W net is increasing, Q e remains identical. So, W net is increasing. So, COP is decreasing, right. COP is decreasing, this is, what exactly, we have shown from that figure. So, we have now shown that the effect of the condenser and the evaporator temperature.

Similarly, this was a plot, for this was a plot for constant temperature versus, COP against, COP, against different condenser temperatures. Similarly, if we have, a plot of COP, which at this moment, we do not have here, that this is T c. If we look at, then also, we will see the same, that if we lower down the evaporator temperature, for a given condenser temperature, this Q e lowers down, W net increases. So, COP decreases, whereas, the other one, if we increase the evaporator temperature, giving the same condenser temperature, then Q e increases, W net decreases. So, COP increases. This also can be shown, and that, if we have, COP versus T c plot against different evaporator temperature, we can say that, right. So, this is our, we have to keep in mind that, how the COP is getting increased or decreased with the increase or decrease of the condenser, or evaporator temperatures, right.

So, if we go back to that point, then, we say, this. So, we say that, the condenser temperature and evaporator temperature has a specific role to the COP of the refrigeration cycle. This, you keep in mind, because, subsequently, when we are in real, or actual refrigeration cycle, this thing will be very much needed, that, for a given T c, if the T e is increased, then, COP is increased. If the evaporator temperature is decreased, then COP is decreased, for a given condenser temperature, and for a given evaporator temperature, if the condenser temperature is decreased, COP is increased, and if the condenser temperature is increased then, COP is decreased. This is what explicitly we have to keep in mind, and we have shown, one COP versus temperature, that is evaporator temperature plot for different condenser temperatures. Similarly, if we have plots for COP versus condenser temperatures, for different evaporator temperatures, then also we can show whatever we are claiming right.

So, hopefully, you are able to understand, the T-S diagram, from where it is more evident, and we can really look into the effect, and I repeatedly, I am showing you that, this figure, we should keep in mind, right. This figure, we should keep in mind, that, what is the Q e, that is the quantum of heat or refrigeration, we obtain, this is Q e, is equivalent to the quantum of refrigeration we are obtaining for a given net work input right. This COP, we are, we can again say, alternatively, I hope, this proverb, you know, how many paddy how many rice? This proverb, perhaps, you may know that, how much rice you are obtaining, from how much paddy. So, that is what is the COP, that may be from 100 kg of paddy, you if you are getting 70 kg of rice, then your performance is 70 kg of rice you are getting. 75 kg of rice then, you are getting 75 percent. If you are giving, 65 kg of rice, you are getting 65 percent, that is what exactly, that same proverb that how many paddy how many rice right.

So, how much you have given input as work, how much you have obtained as refrigeration effect, as output? This is the COP, right. So, with this we thank you all for careful listening, hopefully, you will go through the class notes, or class records for your betterment of understanding. Thank you.