Cooling Technology: Why and How utilized in Food Processing and allied Industries
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Module No 07

Lecture 35
Pure Substance as Refrigerant (Contd.)

Good afternoon. We are continuing that reverse Carnot cycle in the reality, that is, with pure substance as refrigerant right. And in the previous class, we have come to the point, where, it was up to the step point 3. From step point 1 to step point 2, it was isentropic, then, we went to from 2 to 2a, then, from a to 3, we have come. Now from 3 to 4, we will come back right and 3 to 4, and then 4 to back to 1. So, here we said that, we are doing with saturated vapour.

  If we remember that, many a times, we had said that, we have started with the vapour liquid, that is on the saturation curve. From there, we went up to point 2. So from point 2, we went to point a, from point a we went to point 3, and from point 3, now, we will go to point 4, and then back to point 1. So, till now, with the area covered for the point 1 to 2, point 2 to 2a, point a to 3, we have seen or we have shown.

$$-\overset{.}{W}_{isen} = \overset{.}{m}\left(h_2 - h_1\right) \qquad -w_{isen} = \left(h_2 - h_1\right)$$

  Now, let us go to the remaining 1, that, remaining 2, rather, are like this. This was also done. Now, if we, step 1, step 2, step 3, we have already done, and that was shown that, area under 3 b c a 3, right, and 3 b c a 3 was this point, 3 b then, c, then, a, then back to 3. This was our TS diagram. This area, right, that is the area, and that is equal to h a minus h 3. This we have done.

  Now, the step 4, if we look at, and here also, we assume that, both the kinetic and potential energies are negligible, or equal to 0, right, and in this process, it is an isentropic process, and therefore, Q is equal to 0, and if w t is assumed to be, the specific turbine work output, then, from the first law we can say that W t is equal to h 3 minus h 4. So, when we were doing thermodynamics, that time I repeatedly said, please keep in mind that, these relations, and these will be very much useful, because, every now and then, we cannot go back to that. So, we again here take that W t is h 3 minus h 4 from the first law. Then, then, we go from this to step 5. Now step 5 is the process, between 4 to

1 that is evaporation.

Here, we are assuming again that, no kinetic and no potential energies are there, and if they are not there, then it is equal to 0. So, if no work is involved in this process, therefore, first law says that Q e is equal to m dot into h 1 minus h 4, right, h 1 minus h 4, that, if you remember, it was our T s, it was, say vapour, and this was point 1, this was 3 to 4, back to 1. So, 4 to 1, we are going back right. So, that is m dot h 1 minus h 4, therefore, we can write Q e, that is, Q evaporator heat is h 1 minus h 4.

Again, that capital is for the entire mass, m dot and small e is for the per unit mass right. So, we can now write, that this process is also isobaric, and also isothermal. Therefore, from the relation T d s is d h minus V d p, we can write d h is equal to T d s, because, there is no pressure change, so, d p is 0 right. I showed you, I told you many many times that, this in the T s diagram, we have this is, right. This, we go there, we went there, we came back here, came back. So, this was a pressure, this was another pressure, this is another pressure, this is the intermediate pressure, p I, this is the pressure p e, this is the pressure p c, right and this p e is the same as 0.

4, p e. So, there is no delta p, so if there is no delta p, then V d p, d p is 0, that goes out. So, we can write that, it is also under constant temperature isothermal, right, both isobaric, as well as isothermal. Therefore, we can write q e is equal to h 1 minus h 4, that is, equal to in terms of entropy, T e into s 1 minus s 4, and is equal to the area under 4 1 d b back to 4. So, 4 1 d b back to 4, so, this was our point 4, 4 1 d b back to 4, 4 1 here, it is d, here it is b, so, back to 4, this was the area, which, is the equivalent to the refrigeration available, right.

So, if that, we look at, then, if we go back a little, and show it, in the real diagram, because, ultimately, if things are not before, eye, so, many times, it becomes very difficult to visualize, here, we see, right. So, unfortunately, we made it black, it should have been white, it could have been, then, easy to visualize. However, that is why, I am repeatedly saying, so, it is 4 b, or 4 1 d b back to 4. This is the area under refrigeration, or we call it to be that, the refrigeration effect, or refrigeration available is this, right. So, by looking at all the points, we can now come back to this, we can now come back to this point, where, we have said that, yes, it is under area 4 1 d b back to 4. So, the same result could have been obtained if we would have taken dQ reversible is Tds, that also is the other way of finding it out.

Now, once we have analyzed the cycle, then, we can say that, net work, which is obtained, is the total work input to the compressor minus the net work output of the turbine. So, this is equal to the net work of the cycle, you have done some work on the

system for the compressor and you got some output from the turbine. So, the difference of these two is the net work of the cycle right. So, therefore, we can say, we can say, mod W equal to mod W isentropic plus mod of W isothermal, minus W turbine right. So, this is nothing but h 2 minus h 1 plus T c into s 2 minus s a minus h 2 minus h a minus h 3 minus h 4.

$|w_{isen}| = h_2 - h_1.$

So, this, on simplification, can be written that, T c into s 2 minus s a plus h a minus h 3 minus h 1 minus h 4, right, and the process, a to 3, and 4 to 1, are isobaric and isothermal processes, right, which you have seen that, these are isobaric, as well as isothermal, right. Just previously, I had shown you also. Then, we can write h a minus h 3 is equal to T c into s a minus s 3 and h 1 minus h 4 is equal to T c into s 1 minus s 4 right. Therefore, W, we can write to be, T c into s 2 minus s 3 plus T c into s a minus s 3 minus T e into s 1 minus s 4, this is not d this is s 4, right, there was a typing mistake. So s 1 minus s 4.

$$\dot{Q}_{iso} - \dot{W}_{iso} = \dot{m}(h_a - h_2) \qquad \therefore -\dot{Q}_{iso} = \dot{m}T_c(s_2 - s_a) = \dot{m}(area\ 2 - a - c - d - 2)$$

$$\therefore -\dot{W}_{iso} = \dot{m}(h_a - h_2) + \dot{m}T_c(s_2 - s_a) \quad *|w_{iso}| = T_c(s_2 - s_a) - (h_2 - h_a)$$

$$or, \ -W_{iso} = T_c(s_2 - s_a) - (h_2 - h_a)$$

$$\therefore w_{iso} = -\int_2^a v\, dp = \int_2^a T\, ds - \int_2^a dh = T_c(s_a - s_2) - (h_a - h_2)$$

So, therefore, we can write this is T c into s 2 minus s 3 minus T e into s 1 minus again s 4, right. So, we can write that, T c into s 1 minus s 4, this is s 2, is equal to s 1 and s 3 is equal to s 4, if you remember that, if we plot again that T s, right, this was 3 and 4, ok. This was, this was, 3 and 4, that T s right. So, this was 3, and this was 4, right and this is isentropic. So, s 3 is equal to s 4, and this was isentropic.

$$-\dot{Q}_c = \dot{m}(h_a - h_3) - \dot{m}T_c(s_a - s_3) \qquad h_a - h_3 = \int_3^a T_c\, ds = T_c(s_a - s_3) = area\ 3 - b - c - a - 3$$

$w_T = h_3 - h_4$

So, s 1 is equal to s 2, right. So, s 1 is equal to s 2, and we have then, come to the point, that T c into s 1 minus s 4 is W, W is T c into s 1 minus s 4 minus T e into s 1 minus s 4. So, we say that, this is area under 2 to 3 minus area under 4 to 1. So, we can say that, area under 2 to 3 is this one, and area under 4 to 1 is this one, right. These things, we have shown earlier also.

So, then, we can say that, we can say that, yeah, since s 1 is equal to s 2, and s 2 is equal

to s 4, therefore, we can write W is equal to T c minus T e into s 1 minus s 4, that is, the total area under area 1 2 3 4 back to 1. Then, if we plot that, T s, that we had this, we started with point 1, went to point 2, went to a went to 3, came back to 4, and back to 1 right. Perhaps, if I remember correctly, this was b, this was d, right and this was giving a name a, right, and then, as we say, this is area under 1 2 3 4 1, that is 1 2 3 4 back to 1, this area is the W net, right. So, this area is the W net, therefore, we can write that, the COP is Q e by W, the COP is Q e by W, right and that is T e times s 1 minus s 4 over T c times T e minus rather, T e times s 1 minus s 4 over T c minus T e into s 1 minus s 4. So, s 1 minus s 4, cancels out, remains T e by T c minus T e, which we said, many times that, COP under refrigeration is, T e over T c minus T e.

$$Q_e = \dot{m}(h_1 - h_4), \quad or, q_e = (h_1 - h_4)$$

$$\therefore q_e = (h_1 - h_4) = T_e(s_1 - s_4) = area\ 4 - 1 - d - b - 4$$

$dQ_{rev} = T\ \Delta s$.

That means, the lower temperature divided by the difference of temperature, lower temperature, divided by difference of temperature, and COP is only defined by the temperatures. This, we have to keep in mind, that, if the two temperatures are known, that is, the evaporator temperature and the condenser temperature, if these two are known, then, evaporator temperature, right, and the T evaporator and T condenser, if we know, then, we can find out the COP very easily, as T evaporator over T condenser minus T evaporator right. So, for a system, if we are given the pressure, the temperatures of the working fluid at the evaporator, and at the condenser, then the COP of the system, we can find out very easily, from the ratio of the temperatures, right. So, low temperature again is playing an important role, right. Again from here, you see as earlier, we have said many times that, COP being T evaporator over T condenser minus T evaporator.

$$\therefore |w| = |w_{isen}| + |w_{iso}| - w_T = (h_2 - h_1) + T_c(s_2 - s_a) - (h_2 - h_a) - (h_3 - h_4)$$
$$= T_c(s_2 - s_a) + (h_a - h_3) - (h_1 - h_4)$$

So, $(h_a - h_3) = T_c(s_a - s_3)$ and $(h_1 - h_4) = T_c(s_1 - s_4)$.

$$\therefore w = T_c \left(s_2 - s_a \right) + T_c \left(s_a - s_3 \right) - T_e \left(s_1 - d_4 \right)$$
$$= T_c \left(s_2 - s_3 \right) - T_e \left(s_1 - d_4 \right)$$
$$= T_c \left(s_1 - s_4 \right) - T_e \left(s_1 - s_4 \right)$$
$$= area \, under \, 2 - 3 - area \, under \, 4 - 1$$

Now, for a given condenser, if the T evaporator is increased, then this value is increased and the difference is decreased, right. So, if the difference is increased that means, COP is decreased, this is again corroborating, what we said earlier. We, earlier also, we said, that if the evaporator temperature is increased, that, if you remember. So far I remember, we had said that, T s diagram, in that, there was one like, this, ok. And we had in the Carnot, this kind of thing, that is 1, 2, 3 and 4, right and this was under constant temperature T c, and this was under constant temperature T e, right. We had shown that, this is the evaporator temperature, this is the condenser temperature, right, and we said, the work is here and down below, this was the refrigeration effect.

If you remember, we had given, this kind of two areas, right. So, there we said that, if condenser temperature, for a given condenser temperature, rather T c, if the evaporator temperature, this one is increased, so, it was increased to this, so the area, now, is rather, area now is more like this. So, the refrigeration effect available that is Q e divided by W net is the COP, and this Q e being high, COP is increased, right. So, from here also, we are seeing the same thing, because, it cannot change.

See, here also, we have to have the same, because, otherwise, the entire thing will be jeopardized. Entire thing will be non-conclusive, right. So, here, we see that, if we increase the T e, that is evaporator temperature, then COP is increased for a given condenser temperature. The other way, if we decrease the evaporator temperature, then what will happen, this, you are decreasing, for a given T c, right. So, this delta T, is increased, this value also decreased. So, COP is decreased, right, and this was also shown in that figure, which I had shown repeatedly, that, here we had 1, 2, 3, 4.
$s_1 = s_2$ and, $s_2 = s_4$

$$w = (T_c - T_e)(s_1 - s_4) = area \, 1 - 2 - 3 - 4 - 1$$

$$\therefore COP = \frac{q_e}{w} = \frac{T_e \left(s_1 - s_4 \right)}{\left(T_c - T_e \right)\left(s_1 - s_4 \right)} = \frac{T_e}{T_c - T_e}$$

So, this was the net work and this is T c, and this was T e. Now, we are lowering down that T e. So, if we do this, whatever was our area under earlier, this was also under that,

now this has reduced whereas, this has increased. So, W net increased, Q_e got decreased, right. So, that means COP is decreased, right. So, this is for a given condenser temperature. So if we look at the other one, that, for a given evaporator temperature, what is the effect of T_c. For a given evaporator temperature, what is the effect of T_c, either you can increase or decrease.

So, again we go back to that, so, we had this, right and we had, say, this is the work right, and we had, this is the refrigeration effect right. So, this was our T_e and this was our T_c right. Now for a given T_e, if we increase T_c, that is this, what is happening? W is increasing, right. This remains same, W is increasing, this remains same, so Q_e by W, W is increasing, so, COP is decreasing, that means, if we increase the condenser temperature, from here also, you can see the same thing, from here, you can see that, if we keep the T_e same, if we increase T_c then, this part, denominator is increasing, for that given T_e. So the ratio is decreasing, so COP is decreasing if we increase T_c, right.

The reverse, if we decrease T_c, then what will happen? For that, given T_e, and this T_e the same thing, we can show in figure, because, our time is not there, I cannot again and again draw that. So, for a given T_e, if the T_c is decreased, that means, this delta T_e is decreased, for this, so, the ratio is increased, so COP is also increased. So again it is converting, whatever, we have said, till date, right. So, with this, perhaps, today's class is over, and we thank you all for careful listening, and, I, now believe that, you have really started working with the problem, and the cycles, right. Understanding the cycles is very very important, ok. So, thank you very much, we will meet again in the next class. Thank you.