

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

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Module No 08

Lecture 37

Gas as Refrigerant(Contd.)

Good morning, my dear friends and students. We have started a new one in the last class that we are handling now with the refrigerant as gas right, gas as refrigerant. And there so far I remember we have said that irreversible COP for irreversible process, COP is less than 0. And for reversible processes the COP is equal to 0 or is the maximum right. So, from there let us start that let us come to that gas as refrigerant continuation the maximum COP is COP of reversible cycle equal to T_L over T_H minus T_L right. This COP is the maximum that can be achieved when the receiver temperature is T_L and the sink temperature where it is rejected is T_H right.

$$COP_{RC} = \frac{T_L}{T_H - T_L}$$

So, it is also clear that the COP is dependent on the temperature only this in earlier cases we have also proved right. And hence for hence independent of working fluid since it is dependent only on temperature and temperature does not tell whether it is from solid from liquid or from gas. So, it is independent of the substance working fluid. So, the second theorem is also proved and all the temperatures are in absolute scale, that is absolute temperature in Kelvin scale, right.

$dQ_{rev} = T ds$. $\therefore Q_L = T_L (s_1 - s_4) = \text{area under line } 4-1 \text{ of Fig. A} = \text{Area } b-4-1-a-b$.
 $Q_H = T_H (s_2 - s_3) = \text{area under line } 2-3 \text{ in Fig A} = \text{Area } a-2-3-b-a$, and $W = Q_H - Q_L = \text{area under line } 2-3 - \text{area under line } 4-1 = (T_H - T_L) (s_1 - s_4)$, since, $s_1 = s_2$ and $s_2 = s_4 = \text{area } 4-1-2-3-4$.

So, we can write that, 0 degree centigrade equal to, 273.16 Kelvin. Now, there is a small input to this that, here we have taken, 273.16 Kelvin. This one may be everywhere, but may be, depending on book, it may vary between 273.16 or 17 or 15.

So, do not get confused there, because, it is book dependent, but we are assuming it to

be 273.16, and this is from the standard book of ASHRAE, right. I hope, you will find in any standard library, ASHRAE, right, American society for heating, refrigeration and air conditioning Engineering. So, this is there, and from there, we have taken it to be 273.16 and this is a society.

So, that is why, I said, many others may differ a little, that is independent, because this is a prime number that is 0 centigrade, is 273.16 Kelvin, ok. From the thermodynamics, for reversible heat transfer, we can write $dQ_{\text{reversible}} = TdS$. This, we have already established. Therefore, we can write Q_L is equal to T_L into S_1 minus S_4 , that is area under the line of 4 to 1. In the last class, we had shown that, we add this, right. So, Q_L was supplied, right, and Q_H was rejected, and W work was done, right, that is how we got that Q_H is equal to Q_L minus W , right.

So, from that, if we look at this that, $dQ_{\text{reversible}} = TdS$, and 4 to 1, if we again go back to this, $T-S$ diagram, where we had like this, right. This was 1, this was 2, this was 3, and this was 4. So, 1, 2, 3, 4. This was our diagram, and which we are referring to figure 1, right. Similarly, that, this is S_1 , this is also S_2 . So, S_1 is equal to S_2 . This is S_3 , and this is S_4 , and S_3 is equal to S_4 , right. Whatever, could be shown in the figure, we have already described. And one more thing, here is that, that area, under the line 4 to 1, 4 to 1 is this.

$$\frac{dCOP_{RC}}{dT_H} = \frac{T_L}{(T_H - T_L)^2}; \text{ and, } \frac{dCOP_{RC}}{dT_L} = \frac{T_H}{(T_H - T_L)^2}$$

So, the area we can write that, this is the area. Let me clear it up, otherwise, it will be over written, yes, that area is, if we put it here, and if we keep the cycle here. So, 1, 2, 3, 4, and this is the area, right, if we write 4 to 1, that is, area under b 4 1 a b, which you remember, in the previous class, we had shown you also, right. So, it is b 4 1 a b. So, it may be a, it may be b. So, b 4 1 a b is the area, right, and Q_H is T_H into S_2 minus S_3 , that is, area under 2 and 3, that is, this area.

$$W = Q_L / COP_{RC}$$

So, area under 2 and 3, is area a 2 3 b a, that is, this a 2 3 b a, this is the area, right, and W can be written as Q_H minus Q_L W is equal to Q_H minus Q_L , that is, area under the line, 2-3 minus area under the line 4-1, right. So, area under the line 4-1, is this. We have shown, area under the line 2-3 is this. We have shown. So, W becomes equal to this area, that is, area under the line 2 to 3 minus area under the line 4 to 1, right, and this is equal to T_H minus T_L into S_1 minus S_4 . This again, S_1 is equal to S_2 and S_2 is equal to S_3 is equal to S_4 , S_2 is this, no, S_3 is equal to S_4 , S_3 is equal to S_4 . Therefore, we can write, area 4 1 2 3 4, that is 4 1 2 3 4, this is the area for the work, W right.

So, we can write, we can write that, the relative influence of the two temperatures, that is, T_H and T_L , on the COP. This can be seen, by differentiating COP with respect to both the temperatures, that is, T_H and T_L right. Both the temperatures, T_H and T_L , if we differentiate, COP with respect to T_H and T_L , then $DCOP_{RC}$, means reversible cycle, $DCOP_{RC}$, DTH , this part $DCOP_{RC} DTH$, this is equal to T_L over T_H minus T_L , whole square, right, and $DCOP_{RC} DTL$ is T_H over T_H minus T_L , whole square, right. So, this is differentiating the COP with respect to high temperature, T_H , and low temperature, T_L . So, the COP of the reversed Carnot cycle is, most strongly, dependent on the low temperature at which the heat is absorbed, than the temperature, at which the heat is rejected right. Because this is from there we have seen that this is T_L over T_H minus T_L whole square, whereas, it is T_H over T_H minus T_L whole square, right.

So, the COP is, in the reversible Carnot cycle is, most strongly dependent on, the low temperature reservoir, temperature at which the heat is absorbed, from which the heat is absorbed, than that from where the heat is rejected, or to where the heat is rejected, right. So, from this expression of the COP, it is also clear that COP reversible cycle, COP reversible cycle decreases as T_H increases, or as T_L decreases, right. This perhaps, we have also said earlier, but since, again, it has come up. So, let us look into that this was our, four points, right, and this was our W , and this was our Q_L , right. So COP is Q_L over W , means how much work you have given, how much refrigeration or cooling effect you have obtained, and this is a $T-S$ diagram, right.

So, the constant temperature was this, as T_H , this as T_H , and this as T_L , right. So, if we increase T_H , that means, this line, if we increase, like this, W is increasing, the moment W is increasing for a given T_H , given Q_L , if W is increasing COP is decreasing, that is, what here, we are saying clear, that the COP decreases as T_H increases, right. This, I have shown you many many times. So, since, again it has come, I am showing you, so that it is embedded into your mind, and another one is if T_L is decreased, that means, if we decrease T_L , so, again, we, sorry, again, we have that, 1 2 3 4, and this is the $T-S$ diagram right.

So, this was our area for Q_L , right. This was Q_L , and this was area for W , right. Now keeping, T_H , this is T_H , and this is, sorry, this was T_L , right. Now, keeping T_L , ok. Now, keeping, we said that, T_H , constant, keeping T_H constant, if we decrease, that means, we are lowering down T_L , then, Q_L decreases, whereas, W is increasing, then, COP, as we said is Q_L over W . So, Q_L is decreasing, W is increasing. So, COP is decreasing, that is, what we also said here, that COP, it is clear that COP RC decreases as T_H increases, or as T_L decreases, T_L is decreasing then COP is also decreasing, right.

Then, we can say that, the work requirement, for the same refrigeration effect is W equal to Q_L by COP_{RC} right. So, W is equal to Q_L over COP_{RC} reversible cycle, that means, the work requirement, for the same refrigeration capacity increases, as T_H increases, or T_L decreases, right. So, of course, this, again, we have said earlier, in different platform, right. So, this is one, which can be further shown, with numeral example. Numerical example, we can say that, if the sink temperature, this is T_H , is equal to 30 degree, 30 degree or 40 degree receiver temperature, that is T_L is minus 10 degree, minus 20 degree or minus 10 degree combination.

So, COP_{RC} is T_L over T_H minus T_L , if the combination is 30 degree T_H and T_L minus 10, it is 6.579, right and work requirement is W over Q_L , by COP_{RC} is 0.52 over 0.152 Q_L , right. Now, if it is 30 degree and T_L is minus 20 degree, then COP_{RC} becomes equal to 5.063 and the work requirement is 0.198. And now if the T_H is 40 degree centigrade, and T_L is minus 10 degree centigrade then COP is 5.263 that is work requirement is 0.189 Q_L right. So, from there, as we see, from these two, as we see, from these two data that both T_H is rather, both T_H is constant, T_L is decreasing, right then COP is also decreasing, right. And the work requirement is increasing, right and if we keep the other one, that is, if we keep this 10, and this 10, that is, T_L constant, for 30 degrees, this is 6.579, whereas, for 40 degrees, it is 5.263, right. So, for a given T_L , with the increase of T_H , the COP_{RC} is also decreasing, and the work requirement is also increasing.

Sink Temperature	Receiver temperature	$COP_{RC} = \frac{T_L}{(T_H - T_L)}$
$T_H = 30\text{ }^\circ\text{C}$	$T_L = -10\text{ }^\circ\text{C}$	6.579
$T_H = 30\text{ }^\circ\text{C}$	$T_L = -20\text{ }^\circ\text{C}$	5.063
$T_H = 40\text{ }^\circ\text{C}$	$T_L = -10\text{ }^\circ\text{C}$	5.263

So, this, with this, we have confirmed, whatever we said that, the effect of T_H and T_L

on the COP right. So, this table tells that, a decrease of 10 degrees centigrade of low temperature source, decreases COP reversible cycle by 23 percent, whereas, an increase of 10 degrees centigrade in high temperature source, decreases the COP R C by 20 percent. So, T L is more important. This shows that, low temperature source has more dominant effect on the COP R C right. Then, we come to analysis of this cycle, right, maybe it will be requiring for the next class also, because, it may not be over in this, class right, if it is fine. Now, first law of thermodynamics says that for an open system in steady state with one as inlet and two as outlet state.

The first law states that $\dot{m} \left(h_2 + \frac{v_2^2}{2} + gz_2 \right) - \dot{m} \left(h_1 + \frac{v_1^2}{2} + gz_1 \right) = Q - W$. I hope, you could understand the equation, right. So, as convention, the heat transfer to the system is considered to be positive and the work done by the system is also considered to be positive. While applying first law to the components of the system, we can say that the specific potential energy change, that is $\Delta P e$ is $g(z_2 - z_1)$ is considered to be negligible. Since, the height difference is very very negligible, right the specific potential energy for the pipe work, connecting to the components, may not be there, also negligible.

$$\dot{m} \left(h_2 + \frac{v_2^2}{2} + gz_2 \right) - \dot{m} \left(h_1 + \frac{v_1^2}{2} + gz_1 \right) = Q - W$$

Then, we can say that, the change in specific kinetic energy, $\Delta K e$ is $\frac{v_2^2}{2} - \frac{v_1^2}{2}$, that is, it can also be taken as negligible. Applying first law of thermodynamics in all components, that leads to, for the first one, that is, 1 to 2, isentropic compression, there, for 1 to 2 process, $S_1 = S_2$, and $Q_{1-2} = 0$. And assuming that changes in kinetic and potential energies to be 0, for steady flow right this positive sign indicates that work done on the, negative sign indicates here, there should have been a negative that has gone here ok. That negative sign has come here. So, it should have been here. Negative sign indicates that the work has been done on the system for a flow in the open system for the isentropic process.

$$\Delta pE = g(z_2 - z_1)$$

$$\Delta KE = \left(\frac{v_2^2 - v_1^2}{2} \right)$$

$$-W_{1-2} = h_2 - h_1 = c_p(T_2 - T_1)$$

$$p_1 v_1^\gamma = p_2 v_2^\gamma$$

$$-W_{1-2} = \int_1^2 v dp = \frac{\gamma}{\gamma-1} (p_2 v_2 - p_1 v_1) = \frac{\gamma}{\gamma-1} R (T_2 - T_1)$$

$$-W_{1-2} = \frac{\gamma}{\gamma-1} R T_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

This means that minus W_{1-2} is integral of $v dp$, is equal to $\frac{\gamma}{\gamma-1} (p_2 v_2 - p_1 v_1)$ and that is equal to $\frac{\gamma}{\gamma-1} R (T_2 - T_1)$. So, we can write minus W_{1-2} is equal to $\frac{\gamma}{\gamma-1} R T_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$. So, we can write that minus W_{1-2} , as $\frac{\gamma}{\gamma-1} R T_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$. So, with this the time is over, we leave it that 1 to 2 is the isentropic compression, and their work done, we have related in terms of $p v$ that, how much work a $p v$ rather how much work is done on the system that is minus right.

So, with this let us stop today. Thank you.