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

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Module No 06

Lecture 28
Carnot Cycle (Contd.)

Good afternoon my students. We are in the last phase of Carnot cycle right. If you remember we started with Carnot and today it will be the last Carnot cycle plus and we will be recapitulating a little then come to some problem solution. In the previous class we have shown that what is the efficiency Carnot efficiency that is 1 minus Q L by Q H and that is 1 minus T L by T H. We have done one problem also perhaps around 62.5 percent towards the efficiency.

If, I remember, we have done the cycle from point 1, point 2, point 3, point 4. Before that, we had done the state points in psychrometry, all in detail, and all the state points, we have said, are reversible in Carnot cycle, right. All the paths from the state points 1, 2, 3 and 4 back to 1 are reversible. This we have shown and said many times. Apart from this, we have also shown that, if we have the two hot and cold reservoirs, and if we have two engines, one is reversible and another is irreversible, then the reversible engine will have higher efficiency than that of the irreversible, because we showed that the work done or obtained from an irreversible engine is always less than that of the reversible one under the same operating hot and cold reservoirs, right. This you have to keep in mind that, both the hot and cold reservoirs, they are to be identical for both the engines.

If there is a discrepancy, definitely the output also will be different, and we cannot compare. For comparison, it has to be identical. We have also shown that the reversible engine, whatever it is, producing work as work output as W R from the hot reservoir source as Q C quantity of heat supply, Q H quantity of heat supplied, and then Q C quantity of heat is rejected to the cold reservoir, and we reversed and showed that, since it is reversible, then Q C quantity of heat, if it is extracted from the cold reservoir and if W R quantity of work is done on the engine, then Q H quantity of heat is produced, which we had also supplied without a reservoir, as if, this is the reservoir to the irreversible engine and obtain the same W I quantity of work and Q C dot or Q C prime quantity of heat was rejected to the cold reservoir, right, and by this, we had said or we had come to the conclusion that W R is never less than W I because, that violated the Kelvin Planck statement, and W I is never equal to W R, because if W I is equal to W R, then it is converted to a reversible engine only, right. Then, we had also shown that, if there are two reservoirs working under the same two, sorry, if there are two reversible engines working under the same two reversible same two heat and cold reservoirs, then, the work obtained from one engine is W R 1 and work obtained from the other engine is W R 2, and we also, we also showed that W R 1 is equal to W R 2 and that is why, yeeta thermal R 1 is equal to yeeta thermal R 2 right. So, on continuation of that, this being the last on the Carnot, we recapitulate, a little, as we are doing, we have shown that this W R, W I, Q C, Q C dot, that, if they were W I, was more, then that was violating the current Kelvin Planck statement. Then, we made W R equal to W I, then, that becomes equal to Q C equal to Q dot C. That is, it is converting into reversible engine. Then, we also showed that, if W I is less than W R, then, yeeta thermal irreversible, that is, W I over Q H, and yeeta thermal reversible is W R over Q H and yeeta thermal irreversible is less than yeeta thermal reversible, right, and we concluded from there, that, all reversible power cycles, operating between the same two thermal reservers, have the same thermal efficiencies, right. And here also, we showed that, instead of irreversible engine 1, if we substitute to that with reversible engine R 2, and another one is reversible engine, R 1, then, operating between the two same hot and cold reservoir one is giving W R 1 work, and other is giving W R 2 work, and same Q H quantity of heat is supplied to R 1 and Q C quantity of heat is rejected to the cold reservoir, and if, we reverse, then, we got the same Q H as output and Q C as input and W R 1 was done on the system, and when, we supplied it to the R 2, the same quantity, we are getting Q H to the reservoir R 2 to the reversible engine R 2, and W R 2 work was obtained and Q C quantity of heat was rejected. This, we got to the corollary of the Carnot, that both engines receive, Q H, and Q H quantity and Q C quantity of heat is rejected for which, Q cycle becomes 0, and W cycle also becomes 0, for both the engines, with one reversed, because, they are both reversible, right, and here, we can also show, tell, one more thing, let me say that, instead of this, instead of this, that you are supplying Q H and Q H you are obtaining, you could have done the same thing with air, you have done supplied Q H, you had supplied air Q C, and you obtain, the same Q H and that same Q H could have been supplied to this right.

So, it is, yes, I mean irrespective, whether, you are getting it from R 1 by reversing, or you are getting it from R 2 by reversing, because, both are reversible, right. So, that we have not specially or categorically, differently, we had shown, but here, we are saying that, instead of R 1 reversing, we can also reverse R 2 and obtain the same, right. This we have to keep in mind that instead of reversing R 1, if we reverse R 2. the same Q C quantity of heat, we extract from the cold reservoir, then, we obtain the same Q H quantity of heat, given to the hot reservoir, and the same will be, then, coming back to the R 1, and there will be no change. So, there also you will get W R 1 equals to W R 2 and here also we will get W R 1 equals to W R 2 right. So, that, what, corollaries, we are saying in the cycles that becomes then reality. So, that, if we have reversed, and now we said that reversing can be done, by either R 1 or by R 2, the same result will be obtained, right.

So, Q cycle in both the cases becomes 0 and W cycle also in both the cases becomes 0, because both the engines with one reversed are obtaining the same result, because, both are reversible. So, with one engine reversed, we got, and we got this relation, that W cycle is 0 is equal to W R 1 minus W R 2 and that is why we said W R 1 is equal to W R 2, if both are reversible. That obviously, has to be kept in mind, all the time, that this is true, if both are reversible. And if you remember, in the beginning, when we are starting with cycle Carnot, or even earlier, that, we were always, say, I was always saying that, if it is reversible, all the, all the cycles, if they are reversible, then, only it is possible to achieve the Carnot cycle. We also will say, afterwards, the defects or difficulties of the Carnot cycle, but not now, because we are now with the Carnot cycle and that Carnot cycle, all possibilities, all corollaries, we have stated, and we are recapitulating in the last class of the Carnot cycle. Now, yeeta thermal R 1 and yeeta thermal R 2 were also shown to be same, where yeeta thermal R 2 was equal to W R 2 over Q H and yeeta thermal R 1 is equal to W R 1 over Q H and W R 2 over Q H was equal to W R 1 over Q H and that is why, we can say, or we said, rather, yeeta thermal R 2 is equal to yeeta thermal R 1, that is, what we have shown right. Yeeta thermal R 2 is equal to yeeta thermal R 1 because, W R 1 by Q H is equal to W R 2 by Q H, which are equal to yeeta thermal R 1 and yeeta thermal R 2 respectively, and so, yeeta thermal R 2 is equal to yeeta thermal R 1 right, and this is one corollary of the Carnot and that is called second corollary of the Carnot cycle.

Carnot's second corollary

Both engines receive Q_H, and $Q_{cycle} = 0$ and $W_{cycle} = 0$ for both engines with one reversed because they are both reversible.
Now, with engine 1 reversed.

$$W_{cycle} = 0 = W_{R,1} - W_{R,2}$$
$$\text{and } W_{R,1} = W_{R,2}$$

Carnot's second corollary

And
$$\eta_{th,R2} = \frac{W_{R,2}}{Q_H} = \frac{W_{R,1}}{Q_H} = \eta_{th,R1}$$

So,

$$\eta_{th,R2} = \eta_{th,R1}$$

Now, from there we came to the principles of Carnot cycle, and we had said, as here we have seen that, the yeeta thermal reversible A and yeeta thermal reversible B, both are identical, right, and if that be true, we also said that yeeta thermal irreversible is less than yeeta thermal reversible, right, and all reversible cycles have the same thermal efficiency, that also we have said. Now, also we said that, the thermal efficiency of reversible in Carnot engines are yeeta thermal is equal to W net over Q H and that was equal to 1 minus Q L over Q H, and this is a function of temperature only, that is, T L and T H, T L, is the low temperature, and T H is the high temperature, right. So, that low whatever it be, high, whatever, it be, depending on that the efficiency will be found out. Now, we also found out one efficiency with 800 Kelvin as the boiler temperature and 300 Kelvin as the cooling tower temperature. So, we find found out the efficiency to be 62.5. Now, if we say, some other, high very high temperature, say, T H is equal to say, 1200 degree centigrade, right and T L is equal to say, 400 or 500 degree centigrade, T L is say 500, or for simplicity of the calculation say, 600-degree centigrade right. Then, yeeta thermal we can write to be equal to 1200 minus 600 divided by 1200, right that was, that, 1 minus T L over T H, that is T H minus T L by T H. So, T H minus T L by T H. So, 1200 minus 600 is 600 by 1200 right. So, this two goes out.

So, 6 by 12 is equal to 1 by 2 that is 0.5, that means, 50 percent efficiency, right. Similarly, any such problem, you can find out the efficiency, whatever be the temperature, depending on that, you can determine the efficiency. Then, one more we can take, smaller one, that one, we had taken very high say, one is 100 degree centigrade that is T H equals to 100 degree centigrade and T L is say 10 degree centigrade, right. Then what will be the efficiency? I hope you can do it very well.

So, yeeta thermal is equal to 100 minus 10 over 100, that is 90 over 100 that is 9 by 10, so that means, 0.9. So, that is 90 percent efficiency right, sorry, there is 90 percent efficiency. So, if these be 90 percent efficiency, that means, if the temperature is lower, efficiency goes up, if the temperature is higher, efficiency goes down, also the difference of the temperature, that is also a factor, because, here we have taken only 90 degree as the difference. In earlier cases it was, maybe 500, 600 degree centigrade difference.

$\eta_{th}=W_{net}/Q_H=1-(Q_L/Q_H)=f(T_L,T_H)$

$\eta_{th}=1-(Q_L/Q_H)=1-(T_L/T_H)$.

So, that is also one subsequent classes, not in the Carnot cycle, but maybe some other will show that yes, this is because ultimately this Q L and Q H, that will correspond to that will correspond to the condenser and the evaporator, right. So, this gradually will come across. So, at this very moment we are not there. So, we should not say, but we have already shown that, if the difference is low then your efficiency is high. Say, another one if T H is equal to say 200 degree centigrade and T L is equal to say, 40 degree centigrade, right.

Now, the difference, we have taken moderate one, right. So, yeeta thermal we can write as equal to 200 minus 40 divided by 200. So, 200 minus 40 means,160 divided by 200. So, it is 0. So, 16 means 4 and this is 5 right.

So, that means, we have got 4 over 5 that is 0.8. That means, 80 percent is the efficiency right. So, we are going high right. Again, we come back to one more because, this is giving us practice, also that if T H if T H is equal to say 60 degree right, and T L equal to, it is not possible theoretically, saying say, 0 degree then we got 60 minus 0 over 60.

That means, 60 by 60 that means, 1 that means, 100 percent, which is not yeah, it is possible, if it is reversible Carnot engine right, but because it is becoming 100 right. Another problem if we take, T H to be equal to say 300 degree and T L to be say 30 degree then yeeta thermal, that becomes equal to 300 minus 30 over 300 that means, 270 divided by 300 and that becomes, so, it can be divided by 3. So, 10 and it can be divided by 3, 9.

So, 9 over 10. So, again 0.9. So, again 90 percent. So, depending on your temperatures you can get the efficiencies, right.

This we have done. Now, the last one if we do is that, this is a problem, say let us analyze an ideal gas undergoing a Carnot cycle between two temperatures T H and T L right. So, 1 to 2 is isothermal expansion, that is U 1 to 2 is 0, that is isenthalpic and Q H is equal to Q 1 to 2 that is, W 1 to 2 which is, integral of P Dv, is equal to EMR T H ln of V 2 by V 1. So, T L over T H is V 2 by V 3 to the power k minus 1. So, 3 to 4 is isothermal compression, that is delta U, 3 this is delta U 3 to 4 is 0. So, Q L is equal to Q 3-4 is W 3-4 is minus EMR T L ln of V 4 over V 3.

Therefore, the other one 4 to 1 is adiabatic compression, that is Q 4 to 1 is 0. Therefore, we can write T L over T H is equal to V 1 minus, V 1 over V 4 to the power k minus 1 right. So, from equation 1 and 2, that is this and that, we can write, V 2 over V 3 is equal to V 1 over V 4. Therefore, V 2 over V 1 is V 3 over V 4. Therefore, yeeta thermal is 1 minus Q L over Q H and that is equal to 1 minus T L over T H, since ln V 2 over V 1 is equal to ln V 4 over V 3.

It has been proven that eta thermal is 1 minus Q L over Q H that is, 1 minus T L over T H for all Carnot engines, since the Carnot efficiency is independent of the working substance right. So, with this, let us conclude, our Carnot cycles. Now, we will obviously go to, this was for Carnot engine, right, will may be going to the Carnot refrigeration, or many others ok. So, our time is up today.

Thank you for your listening. Thank you.