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

Prof. Tridib Kumar Goswami
Department of Agriculture Engineering
Indian Institute of Technology, Kharagpur

Module No 06

Lecture 27
Carnot Cycle (Contd.)

Good afternoon my dear boys and girls, rather my dear students. Of course, I wish all of you happy Diwali, and we had done in the previous class and came to the conclusion that W irreversible cannot be or work done by the irreversible engine cannot be greater than work done by the reversible engine right. This we have established right.

Now as the continuation of the Carnot cycle, we come to this that Carnot first corollary was minus plus equal to minus right and we have shown that cannot be greater than right cannot be greater than.

Carnot's first corollary

$$-W_R + W_I = +Q_C - Q'_C$$

If $W_I = W_R$, $Q_C = Q'_C$

And the irreversible engine is identical to the reversible engine, i.e., it is just the reversible engine.

Carnot's first corollary

So, $W_I < W_R$, and

$$\eta_{th,I} \equiv \frac{W_I}{Q_H} \qquad \eta_{th,R} \equiv \frac{W_R}{Q_H}$$

So, $\eta_{th,I} < \eta_{th,R}$

So, we come to this next possible, if is equals to right, if, sorry, it is equals to then, that means, irreversible work is equal to reversible work. So, under that situation, here you see, has to become, it is equal to, then, has to be equal to, and the irreversible engine is identical to the reversible engine, it is no longer irreversible engine. It is equivalent to, that is, it is just the one reversible engine, it is becoming .

Then it is nothing, but obtaining another reversible engine in place of irreversible engine right, because, it is equal to then, has to be equal to, and it is same as, or rather, is same as, then, it is coming the same reversible engine. So, we get only another reversible one. We can say that Carnot's first corollary is this is less than and yeeta thermal irreversible is over right, and yeeta thermal reversible is over, right. Therefore, yeeta thermal irreversible has to be less than yeeta thermal reversible right, yeeta thermal yeetata is the efficiency, efficiency is yeeta. So, yeeta thermal irreversible is less than yeeta thermal reversible why? Yeeta thermal reversible is equal to, over, right and we have shown that, W I is not greater than,

We have also shown, that is not equal to, because, then, it becomes a reversible engine. So, what we have come to the conclusion that, yeeta thermal irreversible is less than yeeta thermal reversible, right. I hope, you have understood with the logic, why it is, because we started with greater than which, we saw that from the same single reservoir, it is perating the two engines, and this is violating the Carnot Planck, sorry, Planck Kelvin Planck statement. If it is violating then, cannot be, sorry, cannot be greater than that, we have established. We also established that is not equal to, because if becomes equal to, then it is nothing, but another reversible engine, right.

So, we now are saying that, it is less than, there is only option left, because, both, we have shown, it is not possible, the third one is less than . If it is less than, then yeeta thermal efficiency, which, is work by, rather, how much quantity, sorry, how much quantity of heat you have supplied, and how much quantity of work you have obtained, right. That is the efficiency. So, that is for yeeta thermal irreversible and this is also for yeeta thermal reversible, how much quantity of heat you have supplied and how much work you have obtained, that is the efficiency, and since is less than, so, this is less than this term. So, yeeta thermal irreversible is less than yeeta thermal reversible right.

So, this is established that, yeeta thermal irreversible is less than yeeta thermal reversible. Then, we can say that the **second corollary of the Carnot**, as all reversible power cycles, operating between the same two thermal reservers, have the same thermal efficiencies. All reversible power cycles operating between the same two thermal reservers have the same thermal efficiencies. That means, yeeta thermal will be equal to another yeeta thermal only or R 1 is R 2 right. So, this is the corollary of the, second corollary of Carnot, and we can say in that, all reversible power cycles operating between the same two thermal reservers have the same thermal efficiency. Right.

That means, again we are putting back, we have two reservers, one is hot reservoir, another is cold reservoir, right. In other, this is hot reservoir, and this is cold reservoir, right. We have two engines, one the R 1, and one R 2, right, instead of irreversible engine, which, one was here, we are now putting one reversible engine as R 2, right. Then in the former case, which, we started with that Q H quantity of heat is given to the reversible, say R 1 engine, and Q H quantity of heat, we have given, and W R quantity of work was obtained and Q C quantity of heat was rejected to the cold reservoir. This was, the first, when, we have, instead of R as I, right this I am reminding you. Then, we also had shown that, when it was I, when, instead of R, when it was I, this Q C quantity, or Q H quantity of heat is supplied right, Q C quantity of heat is rejected, W R quantity of work was done.

Now, we reversed,, since it is a reversible engine, we reversed, we supplied Q C quantity of heat to the reversible engine, and obtained Q H quantity of heat and that we supplied to the I, that is irreversible engine, right. Since, we have already established that, irreversible engine has less thermal efficiency than that of the reversible thermal efficiency. Now, we have taken, the same thing instead of irreversible one, reversible engine R 1 and another reversible engine R 2 right, and the same Q H quantity of heat we have supplied to the reversible engine R 1, Q C quantity of heat is rejected to the cold reservoir and W R quantity of, or W R 1 quantity of work obtained from the engine. Now, we reversed again, and Q C quantity of heat is supplied from the cold reservoir to the reversible engine R 1, then W R 1 quantity of work done on the reversible engine, then Q H quantity of heat is rejected to the reservoir. Now instead of this reservoir, now if we reverse and supplied to the another engine R 2 then, Q H quantity, we obtained from the reverse of the reversible engine, that Q H quantity of heat is coming to the R 2 engine.

Q dot C quantity of heat is rejected, or Q C, rather, Q C quantity of heat is rejected and W R 2 quantity of work was done by the reversible engine, right. So, instead of irreversible one, we have now done the same thing with the another one more reversible engine, a reversible engine R 1 and reversible engine R 2, right. Then we can say as **Carnot second corollary** that, both engines receive Q H quantity of heat and Q cycle is becoming 0 because, it was producing, Q H was supplied to the engine reversible, Q C quantity was rejected to the cold reservoir. Now Q C quantity of heat is taken from the cold reservoir, supplied to the reversible engine R 1 for to whom W R 1 quantity of work was done and Q H quantity of heat was obtained, which was supplied to the reversible engine R 2, right. That means, in the cycle we are not changing anything.

So, Q cycle becomes equal to 0 right. So, for both the engines, receive Q H quantity of heat and Q cycle therefore, becomes equal to 0, and W cycle also becomes equal to 0, for both the engines with one reservoir, and because, they are both reversible, right. So, one is reversed from both R 1 and R 2, what we did this was there, and then, we reversed this. So, this was there, this was there, for which we got the same Q H right, and ultimately same Q, sorry, same yeah, same Q C and the same W R, right. So, if this be same for the two reversible engines, we can say that W cycle is 0, and Q cycle is also 0, for both reversible engines, if one is reversed right.

So, we can say with engine 1, as reversed, we can say, W cycle is 0 is equal to W R 1 minus W R 2 and therefore, W R 1 is nothing, but equal to W R 2, right. So, we say that, W cycle being 0, W, and that is equal to W R 1 minus W R 2, and this leads to the fact that W R 1 becomes equal to W R 2, right. Then, we can say as **Carnot second corollary** that is, W yeeta thermal R 2, is equal to W R 2, by Q H and which, is also equal to W R 1 by Q H and is equal to yeeta thermal R 1, which I just said, sometime back, right. So, yeeta thermal R 2 is equal to yeeta thermal R 1. That means, all reversible engines have the same thermal efficiencies, all reversible engines working under the same reservoir, that is, that, hot and cold reservoir, they have the same thermal efficiency right.

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.

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

This is again we have established, with taking two engines reversible, as R 1 and R 2 right. Then the Carnot principles, we can say, what are those? The Carnot principles are, there are the efficiency of an irreversible heat engine is always less than the efficiency of a reversible one operating between the same two reservoirs. Therefore, we can say, yeeta thermal irreversible is always less than yeeta thermal reversible, right. Then, from the things, we have already said, can be taken as the Carnot principle. The efficiencies of all reversible heat engines operating between the same two reservoirs, are the same, that is, yeeta thermal reversible 'A' must be yeeta thermal reversible 'B'.

Carnot's second corollary

And

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

So,

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

So, all the efficiencies of all reversible heat engines, operating between the same two reservoirs, are same, that is yeeta thermal reversible A must be equals to yeeta thermal reversible B, right. So, as many reversible, you take A, B, C, D, if all are reversible, then, they will have the same thermal efficiency, provided, that also has to be, said, provided they are working under the same two reservoirs, that is hot reservoir, and cold reservoir. If your hot reservoir and cold reservoir are same, for the two reversible engines their efficiency also will be same, but if one is this, hot reservoir and if this is the cold reservoir, another hot reservoir is this and cold reservoir is this, then, obviously, if this is R 1, and if this be R 2, they will not be same, right. So, they have to be operating under the same two identical reservoirs, that is, hot and cold, then only, we can say that, the thermal efficiency of the reversible engines will have the same efficiencies, right, as here, we have showed as, A and B right. Then third principle we can say, so, both can be determined using the second law right.

Therefore, we cannot, therefore, both, rather, both the, both can be demonstrated using the second law and we can say, the Carnot heat engine defines the maximum efficiency and practical heat engine can reach up to that. So, Carnot heat engine has given you one maximum efficiency, that is yeeta Carnot is max. You cannot go beyond that, at least at the most, you can reach up to that, but you cannot go beyond that, that is, all practical engines, whatever engine you have, that will have less thermal efficiency than that of the Carnot. So, we can see that, both this can be demonstrated with the second law, and therefore, the Carnot heat engine defines, the maximum efficiency, any particular heat engine can reach up to, or any practical heat engine can reach up to that limit right. Now the another principle we can say that, thermal efficiency that is, yeeta thermal is equal to W net over Q H, that is, 1 minus Q L over Q H, or Q C over Q H, whatever you call, Q C or Q L, there is, no, Q H is hot. So, 1 minus Q L over Q H is a function of T L and T H, and it can be shown that yeeta thermal is equal to 1 minus Q L over Q H and that is equal to 1 minus T L over T H, and this is called Carnot efficiency.

So, Carnot efficiency, we can say that, it is 1 minus Q L over Q H, and that means, it is 1 minus T L over T H and that means, it is T H minus T L over T H, right this is the Carnot heat engine efficiency, right this is called Carnot heat engine efficiency. Now the last one, as the principle of Carnot, we can say, for a typical, for a typical steam power plant operating between say T H is equal to 800 Kelvin, that is boiler, and T L is equal to say, 300 Kelvin for say, cooling tower, 300 Kelvin, means somewhere 27 degree centigrade, right. That is 300 Kelvin. So, it is reasonable. Now the maximum achievable efficiency that you can have is how much? we have said, yeeta thermal is equal to 1 minus Q L over Q H, right, then we can also write that yeeta thermal is equals to 1 minus T L over sorry T this should be written this way that yeeta thermal is equal to 1 minus T L over T H. So, this means, it is T H minus T L over T H, now our T H given, is 800 Kelvin and T L given is 300 Kelvin.

So, we can write yeeta thermal is equal to 800 minus 300 divided by 800 right. So, this becomes equal to 500 divided by 800. So, it is 5 by 8. So, 5 by 8 means, it is equal 0.6

and 2 that means, 2 right. So, it is 62.5 right, it is 6.625, rather it should be said.

So, it is 0.625 means 62.5 percent. So, the efficiency has come to 62.5 percent. So, we can now say that, we have shown how the efficiency of Carnot reversible engine can be found out, right, that is, 1 minus T L over T H, and that is equal to T H minus T L by T H, and one such example we have shown right.

With this, we, our time is up. So, we can conclude today that, Carnot efficiency is 1 minus T L over T H ok. Thank you.