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

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Lecture 26
The Carnot Cycle (Contd.)

Good morning. We have been talking about Carnot cycle, and perhaps, in the previous class, we had gone up to single cycle right. From there, we went to one reversible, and one irreversible cycle, under the same reservoirs, hot reservoir and cold reservoir right. Now, if we analyze them, and subsequently we will see actually, our, now, aim is to show that the Carnot refrigeration, Carnot cycle of course, we are talking about Carnot heat engines, when we will come to refrigeration, then also we will see, but we everywhere, we cannot show the same thing. So, here, our objective is that, we will like to show, reversible cycles have higher efficiency than that of the irreversible cycle, that we will establish, for which, in the previous class, we stopped here, that is, at hot reservoir and cold reservoir with the same reservoir, if reversible engine, and one irreversible engine working under the same two reservoirs, right. Q H quantity of heat is supplied to reservoir, say, reversible engine, and W R quantity of work is done by the engine and Q C quantity of heat is rejected by the reversible engine equivalent to Q H minus W R.

Now, the same reservoir has given Q c rather rather Q H quantity of heat to the irreversible engine and W i quantity of work done by the engine and Q dot c quantity of heat equivalent to Q H minus W I has been rejected by the irreversible engine to the cold reservoir like the reversible engine right. So, this is the place where we stopped in the previous class. Now from there we can say the Carnot's first corollary and that first corollary is saying that each engine receives identical amounts of heat that is Q H and produces W R quantity of work or W I quantity of work right. So, each engine receives identical amounts of heat that is Q H and produces W R quantity of work for the reversible engine and W I quantity of work for the irreversible engine right.

Carnot's first corollary.

Taken together,

$$W_R + W_I = Q_H - Q_C + Q_H - Q_C'$$

Now reverse the reversible engine.

$$-W_R + W_I = -Q_H + Q_C + Q_H - Q_C'$$

Then we can also say that each engine or each of them discharges an amount of Q quantity of heat to the cold reservoir equal to the difference between the heat it receives and the work it produces. If you remember that we had said that Q W sorry Q Q Q Q H is equal to Q H no amount of heat Q this is which is rejected. So, it is Q C, Q C is equal to Q H minus W R, for reversible engine and for irreversible engine we said Q C prime is equal to Q H minus W I, this is Q C prime, right. This W I is for irreversible engine. So, first corollary of Carnot, we have said that each receives, each engine receives identical amounts of heat equivalent to Q H and produces W R quantity of work or W I quantity of work and it rejects the heat to the cold reservoir equivalent to Q H minus W R for reversible engine, and Q dot C equivalent to Q H minus W I right. So, from there, then, we can go to one, where, we have again two identical reservoirs, that is hot reservoir, two identical reservoirs, that is hot reservoir and cold reservoir. These two are identical, and we have same reversible engine and irreversible engine right.

Now, in the first case, as we can see that, Q H quantity of heat is supplied to the reversible engine, and W R quantity of heat, rather work is done by the engine, and Q C quantity of heat rejected to the cold reservoir, and that is equivalent to Q C equal to Q H minus W R, right. this is for the reversible engine. Now, if we do the reverse, if we do the reverse, what is that reverse? Reverse is that, if we supply Q C quantity of heat to the reversible engine and W R quantity of work is done on the reversible engine, then Q H quantity of heat can be rejected to the hot reservoir, right. So, from the cold reservoir, if we draw Q C quantity of heat and supply it to the reversible engine, then W R quantity of work has to be done on the reversible engine, so that, Q H quantity of heat is rejected to the hot reservoir, right. Now, this is again leading us to one, in earlier, if we remember that, we have said the first one, that is, Q H quantity of heat is supplied to the reversible engine, W R quantity of work is done by the engine and Q C quantity of heat is rejected to the cold reservoir.

We also said that Q H quantity of heat is supplied to the reversible engine, W I quantity of work is done by the irreversible engine and Q dot C quantity of heat, equivalent to Q H minus W I is rejected to the cold reservoir. This was in the previous slide, which I showed also right. Now, this says that, then, instead of instead of this path, if we had done this path right and if we reverse it, to this path, then, we are obtaining the same Q H, then this Q H can be supplied to this right. So, this Q H can be supplied to the reversible engine because from the reversible engine we had supplied Q H quantity of heat and W R quantity of work obtained from the engine and Q C quantity of heat was rejected to the cold reservoir equivalent to Q H minus W R. Now, if we supply the reverse way, Q C quantity of heat to the reversible engine, and if W R quantity of work is done on the system, then Q H quantity of heat is rejected to the hot reservoir.

That means, whatever, we had supplied to the reversible engine, that, we had received back, and we are using it, to this irreversible engine, right. In that case, the corollary of the Carnot, that, we can say, under this condition is that, this taken together, that is irreversible and reversible engine work, that is W R plus W I. If we add up to them then, it is Q H minus Q C plus Q H minus Q dot C, right. So, W R plus W I is giving us, 2 Q H, and minus 2 Q C minus Q dot C, right and this is in the normal, which we had showed earlier. Let me go back and show you. In this, we had supplied Q H quantity of heat, W R quantity of work was done by the reversible engine.

Here also, we had supplied Q H quantity of heat, and we received W I quantity of work from the irreversible engine, and in both the cases, reversible engine rejected Q C equivalent to Q H minus W R quantity of heat to the cold reservoir, and Q dot C equal to Q H minus W I quantity of heat was rejected to the cold reservoir by the irreversible engine, right. So, this was our normal. So, and we have added these two and showed you that W R plus W I, if we add up them. So, W R plus W I. So, this is Q H minus Q C plus Q H minus Q dot C right. You refer to the reversible, and irreversible engine, we had just shown.

Now, if we reverse the reversible engine, which, we had shown in the previous slide, that if we reverse the reversible engine, then W R plus W I, W R with a negative, because, work was done on the system. So, this was there, work was done on the system. So, that is why, W R is negative, W I was is positive, because we got Q H quantity of heat, right and we produced W I quantity of work by the irreversible engine. So, these two are added, this leads to minus Q H plus Q C, because it was Q C minus W R. If you remember, Q H, sorry Q H minus W R was Q C right. So, the reverse way W R, we can write is equal to Q C minus Q H right, Q C minus Q H, from this relation we can write.

So, that is what we have written, minus Q H plus Q C, and for the irreversible engine the second one, where, we have supplied Q H quantity of heat W I quantity of work obtained and we got Q dot C quantity of heat rejected to the reservoir. So, we can write that, W I is equal to directly Q H minus Q dot C right, because, it was Q dot C equal to Q H minus W, sorry, Q H yeah, minus W I right. If that be true, then we can write, if that be true then we are adding up the reverse of the reversible engine, right This, yeah, this is now clear. So, we have, we have reverse the reversible engine, and that is how we got this W R minus W I plus and if we substituted them, and then, we see, this Q H, this Q H goes out then W I minus W R this becomes equal to Q C minus Q dot C right. So, W I minus W R is Q C minus Q dot C, because Q H quantity of heat is a cancelled out, right.

So, we can again come back to the corollary of the Carnot and that says this we have which I so told earlier I had written. Now, it is being shown here that, Q C quantity of heat we have taken from the cold reservoir W R quantity of work is done on the reversible engine. Therefore, Q H quantity of heat is rejected to the hot reservoir, but instead of heat going to the hot reservoir if you direct it to the irreversible engine, that same quantity of Q H, then, the irreversible engine will do the work W I and we got Q C dot quantity of heat rejected to the cold reservoir equivalent to Q H minus W I, right. So, this means the same reversible engine, we have just reversed, it is reversible. So, we can reverse and in the reverse, we have taken Q C quantity of heat from the cold reservoir supplied to the reversible engine and a W r quantity of work was done on the system, because of that, Q C quantity of heat, we could reject to the hot reservoir, but now instead of hot reservoir we directed it to the irreversible, the same quantity of heat, Q H to the irreversible engine, and W I quantity of work was done by the irreversible engine.

So, we got Q dot C quantity of heat rejected to the cold reservoir equivalent to Q H minus W I right. So, instead of instead of two reservoirs single reservoir that is cold reservoir with a reversible engine and our irreversible engine, we are supplying the heat, same right. Then we can correlate and we can say that Carnot's first corollary as minus W r plus W i is equal to plus Q C minus Q dot C right. So, in that case if W I is greater than W R, if W I is greater than W R, then the system puts out net work and exchanges heat with one reservoir, and this is violating the K P statement, that Kelvin Planck statement, it is violating. So, W I cannot be greater than W R, how we arrived at.

Carnot's first corollary

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

If $W_I > W_R$, the system puts out net work and exchanges heat with one reservoir. This violates KP. So, W_I cannot be $> W_R$.

So, we have taken both the work from the reversible and irreversible, but in the reversible one we took the reversed path. So, W R quantity of heat work was done on the system. So, that is why it minus W R and W I quantity of heat was rather, the work was done by the irreversible engine. So, that is Q C minus Q dot C right. Then, we can say, if W I is greater than W R then, W I minus W R is positive, right, is positive right, which means that the heat exchanges or work and heat network and heat exchanges right with a single reservoir.

Because, we started with, if you remember, we started with, here, right that, the negative work was done, that is work was done on this system. Q C quantity of heat was supplied and the Q H quantity of heat, which was available, was supplied to the irreversible engine and it worked. W I quantity of work obtained from the engine, and Q C dot quantity of heat, right, Q C dot quantity of heat was rejected to the same single reservoir, that is, the primary, that the same single reservoir is used for the exchange of the heat for both the cases of reversible and irreversible engines, which is against, the Carnot, which is against the Kelvin Planck statement. So, we said that, if W I is greater than W R, then it is to be worked from the same reservoir, which is not feasible, according to Kelvin Planck statement. So, we can see, now, that, this is violating the Kelvin Planck statement. Therefore, W I, that is, work from the irreversible engine cannot be greater than that of the reversible engine, otherwise, it will, it will violate the K P statement, which is not desirable, which is, which cannot happen rather. So, we can say that, with this, we can say, we have done with single reservoir, rather, with two reservoirs, and with two engines, reversible and reversible and seen, that, W R and W I quantity of heat was produced by both the engines, and Q C and Q dot C quantity of heat, was rejected to the cold reservoir, from the hot reservoir. Q C quantity of heat was extracted, right. This was first, then, we said, since we have reversible engine, so, if we reverse the path, instead of Q C coming from the hot reservoir, if we take Q H quantity of heat coming from the hot reservoir, if we take Q C dot, Q C quantity of heat from the cold reservoir, and give it to the reversible engine, then W R quantity of work has to be done on the system to get Q H quantity of heat and that quantity of heat, we supplied to the irreversible engine.

So that, heat produces W I quantity of work, and Q C dot quantity of heat right. So, since it is working from the same single reservoir, this is violating the Planck Kelvin Planck statement. So, W I, that is, work from the irreversible engine, cannot be greater than work from the reversible engine.

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.

So, our time is up. So, we stop it here today.

Next, we will proceed in the next class ok. Thank you.