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 05

Lecture 25
The Carnot Cycle

Good morning. Hopefully, you are all right and you are very much enthusiastic, because, we are almost, not almost, a little less than half of the total course work. We said that, this is a cooling technology, that means, we will first, we have said, why we need cooling, second we are saying, is on the way that, how to produce the cooling? and third part will be application of the cooling right. So, all three put together is the cooling technology course. Now, just in the previous class, we have finished psychrometrics, and hopefully, you have come across a lot of problems, and hopefully you are using your forum, and you are getting the answers of those. However, now we go to the real cycles of the refrigeration.

The ideal cycle is the Carnot cycle right. So we are dealing with now Carnot cycle. If you remember, we had told you, Carnot heat engine, right. So from there, if we take the queue, that ideal thermodynamic cycles for Carnot.

There are four reversible processes, and this is independent of substance, any substance, whether, it is vapour, liquid, anything will have the same effect right and in that, we have two isothermal, and two adiabatic processes right. In this figure, we have given that, a pictorial view. rather, of the four processes, and these four processes are: isothermal expansion, that is, you are supplying Q H quantity of heat from the heat reservoir to, this is, of course, the, as it is appearing, that it is a reciprocating kind of compressor, or whatever compressor, right piston. The similar one which you use, as the, during holy, period right. So you have one washer and pump and then you blow.

So, you are forcing liquid to go out. It is not that, it is, whatever is inside, that is being compressed, right or expanded, the first one is isothermal expansion. The second one is adiabatic expansion, right second one is adiabatic expansion. So, in the reversible isothermal expansion, from the state point 1 to 2, under constant temperature, T H, it is the first process. The second process is reversible adiabatic expansion between 2 to 3, since it is adiabatic so Q is 0, and the temperature from T H is proceeding towards T L rather, T H is of course, T high and T L is of course, T low right.

Third one is reversible isothermal compression, and it is between 3 to 4 and the temperature T L is constant. Fourth one is reversible adiabatic compression, that is between 4 back to 1. So all processes, are reversible. So, under this equilibrium sign, it is, that it is reversible right. So, all processes are reversible, and we have 4 processes, out of which 2 are isothermal and 2 are adiabatic processes right.

This, we have shown also with the help of this pictorial view right, with the help of this pictorial view we have shown. Now, if we go back to the diagram, then, we see that the Carnot cycle in a PV diagram looks like this right. It looks like this. You have, sorry, you have this point 1 to point 2 where Q H quantity of heat is being supplied at a temperature of T H, that is constant, then from 2 to 3, it is T H is coming to 2 L, this is not, H, it was current phase, mistake, right, where it is, we said, 2 isothermal, and 2 adiabatic. So this was isothermal expansion, this is adiabatic expansion, this is isothermal compression, and this is adiabatic compression, right back to 1.

So, if we look at this, over again PV diagram, then, the area, we said the earlier also that if you remember, in some of the previous classes, we said, say point 3 to 4 the area under this is the net. So that concept again we are bringing here ok. And work done by the gas, if it is a gas, whatever be the substance, we said, see, if it is a gas then, work done by the gas is integral of p dV, which comes under the area 1, 2, 3, during the process, right, dV is greater than 0. So we get p dV is greater than 0 and this is the area, which encompasses process 1, 2, 2 to 3 right. So that we call work done by the gas, that is, integral of p dV, that is area under the process of the curve 1, 2, 3, and dV being greater than 0, from 1, 2, 3 we can say integral of p dV is also greater than 0.

The other one, back, that is from process 3 to 4 to 1, right, process 3 to 4 to 1, that we can say that, this is 3, this is 4 and this is 1. So, work done, that was work done by the gas, this is work done on the gas, right, and that is also integral of p dV, which is encompassing the area under the process curve that is 3, 4, 1 right. Then, it is dV is less than 0. So p dV is less than 0. Then, by subtracting these two, that is, area under 1, 2, 3 and area under 3, 4, 1, if we subtract then, the net work done, that can be written as this, that is 1 to 2, 2 to 3, 3 to 4 and 4 to 1, and this is the net area available, right.

We, said p dV is for 1 to 3, dV being greater than 0, is positive, greater than 0, and process 3 to 4 to 1, dV is less than 0. So, p dV is less than 0 right. So, the resultant will be subtracting this to that and that comes to 1, 2, 3, 4, 3, 4, 1, that area, which is covered under this in the p V diagram, right. So, this is what is the Carnot cycle. Now, if we analyze it, then, here, one thing is that, we have assumed that, all the processes are reversible right.

All the processes are reversible, that we have assumed. So, if we analyze this, then we get this is the actual process, where we have a turbine, we have one pump, we have one boiler, and we have one condenser. So, boiler is supplying the heat, that is Q H at a temperature of T H, then it is from point 1 to point 2, it is a turbine,which is doing the work and coming to the condenser leaving Q C quantity of heat, at the constant temperature T L, and then it is going to the pump, on which, some work is being done, and it is going back to the point 4, and then again it is cycling through the boiler right. So, this is called a Carnot cycle, involving two phases, that is, it is still two adiabatic and still two isothermal process right. So, two adiabatic and two isothermal processes.

So, if we look at the P V diagram, right it looks like this, this is the dome, and point 1 to point 2, point 2 to point 3, point 3 to point 4, and back to point 1 right this is under P V diagram. So, it is always reversible. A Carnot cycle is reversible by its definition. So, we have considered, the cycle to be reversible, because, Carnot cycle is always reversible by definition. Then, if we look at the Carnot refrigeration cycle, for a gas, it is the reverse of that of the Carnot heat engine right.

Here, it starts from point 1, sorry, it starts from point 1, right and Q H quantity of heat is dissipated, that is 4. So, it starts from point 1, aonend W quantity of heat whereas, work is done and then Q L quantity of heat is added to the system at constant temperature of T L and again some work is done by, or on the system, reaches to the point 4, where, at a constant temperature T H, Q H quantity of heat is rejected. This is the refrigeration cycle, for Carnot system, and earlier it was the heat or what we say that it is, that was a heat engine, right. So, if we analyze, we can say, the analytical form of the Carnot statement is like this, that, constant that conservation of energy for a cycle, this says that, delta E is 0 that is, no internal energy, and is equals to Q cycle minus W cycle. If that be true, then we can say, that Q cycle is equal to W cycle, right quantity of Q supplied to a cycle, total summation of total Q that is equal to summation of total W of the cycle right.

So, if this be true, then, what we can say, we have not limited the number of heat reservoirs or work interactions, for that we have not limited to number of heat reservoirs or work interactions. Therefore, Q cycle could be Q H minus Q C right, Q cycle could be Q H minus Q C for example, this is what. Now, if we look at the analytical form of the K P statement, if you remember, during our thermodynamic class, we had said K P statement, and I repeatedly told that this will be using subsequently.

$$\Delta E = 0 = Q_{cycle} - W_{cycle}, \text{ or}$$

$$Q_{cycle} = W_{cycle}$$

So, please listen, and understand it, right. So, it is Kelvin Planck statement, and it is saying that, let us limit ourselves to the special case of one thermal energy reservoir, T E R.

So, if you have one thermal energy reservoir, like this, then if Q, quantity of heat is supplied to a heat exchanger, this is that, heat exchanger, then W quantity of heat work will be done by the system because you are supplying Q. So, the energy of the heat exchanger is increasing, so, it will do some work. So, it is done by the system, if it is a single reservoir, as a special case, if we limit to that, and W quantity of heat, rather W quantity of work will be done. Now, if we look at again, the Kelvin Planck statement, that, however, it would not violate the K P statement, if work were done on the system, during the cycle, or, if work were 0. That means, W cycle can be less than, or equal to, if it is work done on the system or it could be equal to 0, then, W cycle is less than equal to 0, and this is for a single reservoir.

$$W_{cycle} \leq 0 \qquad (\sin gle \quad reservoir)$$

$$Also, \quad Q_{cycle} \leq 0 \quad (\sin gle \quad reservoir)$$

So, Q cycle, then, would be less than equal to 0. Again, for a single reservoir. So, these are known as analytical forms of the K P statement, and if we analyze further, this is for single reservoir right. If we analyze further, with say, the K P statement analytical form which can be said like this that both the equations may be regarded as analytical form of the K P statement, which are the equations, this that, W cycle is less than equal to 0, or Q cycle is also less than equal to 0. So, both, these may be regarded as the analytical forms of the K P statement.

It can be also shown that the equality applies to only reversible processes. Less than, could be the irreversible, but, the equality is applied to the reversible processes, and the inequality applies to irreversible processes, then which, we consider a cycle, for which, the equality, applies, then, we can say, that, sorry, you can say that Q cycle is equal to W cycle, right, Q cycle is equal to W cycle then, Carnot fast corollary, we can write the thermal efficiency of an irreversible power cycle is always less than the thermal efficiency of a reversible power cycle, when each operates between the same two reservoirs right. The thermal efficiency, we repeat, the thermal efficiency of an irreversible power cycle is always less than the thermal efficiency of a reversible power cycle, when each operates between the same two reservoirs right. So, what we can, we have said that, the thermal efficiency of reversible power cycle, when it operates between the same two reservoirs, is always less than the thermal efficiency of, if it is a reversible, then the irreversible one is always less than the reversible one. So, here we show that, we have one reservoir like this, and hot reservoir, and another is cold reservoir right, but, both the reservoirs, under which, the two engines are working, one is reversible and the other one is irreversible.

$Q_C=Q_H-W_R$; $Q_C^{'}=Q_H-W_I$;

If Q H quantity of heat is supplied to the reversible one, then, W R quantity of work will be available, then the Q C quantity, which is rejected, can be written as Q C equal to Q H minus W R right. Q C is that left over, where W R was done, and Q H was supplied, right. So, Q C is Q H minus W R right. Then, we can say for the same irreversible one, the same Q H quantity of heat is supplied, sorry, is supplied and same W I quantity of work is done, then the quantity of heat that is Q dot C, which is rejected is Q H minus W I, right.

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

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

So, it is Q H minus W I. So, we are operating in the same heat reservoir, one reversible and another irreversible engines, and the same Q H quantity of heat is applied to both the engines, R and I, that is reversible and irreversible, and in one case W R quantity of heat work is done by the reversible one and it is rejecting Q C quantity of heat equivalent to Q H minus W R right. Whereas, for the irreversible one, this Q H quantity of heat is being supplied and W I quantity of work is obtained, or is being done, the quantity of heat, which is rejected is Q C dot and which is equal to Q H minus W I, right. So, perhaps, today, we have come to the end of the time. So, we will do it next time, next day. So, till that time you please take care and do practice. Thank you.