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

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Module No 03

Lecture 14
Basics of Thermodynamics Contd.

So, good afternoon.If you remember, in the previous class, we have also introduced another thermodynamic property, called entropy. Because, and this is that, in the class, a lecture of 14, basics of thermodynamics is continuing right. Now, after defining entropy, let us consider Carnot heat engine as an example. Because, we said that we have come to one new thermodynamic property, that is entropy.   Now, when entropy is to be established, or is to be understood properly, then it is better to go for Carnot heat engine, right.

And in Carnot heat engine, all the processes are reversible. Earlier, we said about this, a cyclic process unless, it is a reversible process, cannot come back to its original, right, where from you started with. So, here also, we are starting with the point say 1, then we are going to the point, all these are state points, mind it. All these are state points.

So, it is going to state point 2, then it is going to state point 3, then it is going to state point 4, and again coming back to state point 1, right. And, this is only possible if we are considering all the processes under reversible condition. You see, here we have shown the reversibility sign, here we have shown the reversibility   sign, here also we have shown the reversibility sign. So, reversible heat engine, unless it is there, unless, the heat engine is reversible, rather then, this is not possible to come back to state point 1, from state point 2 to 3 to 4 and back to 1, right. So, in all these processes in heat engine, we say the processes which are involved in   the heat engine, through Carnot cycle is that these are the 4 reversible processes in which process 1 to 2 is isentropic compression here.

The one, which we are showing, the graph is PV, right, this is P and this is V. So, PV diagram, we are showing. So, all the processes are reversible process 1 - 2 is isentropic compression right.   Isentropic means that entropy is constant right.   Isentropic compression.

The process 2 to 3 is isothermal heat addition, that is Q - H quantity of heat is added and work is obtained as output and process 3 to 4 is isentropic expansion and process 4 to 1 is isothermal heat rejection, where QC quantity of heat is rejected and work is obtained as input right. So, this is what explicitly is the Carnot engine sorry, this is what is the explicitly Carnot engine, heat engine, rather, where there are 4 reversible steps 1 to 2, 2 to 3, 3 to 4, 4 to back to 1, and all the processes are reversible, as it is shown through, the another figure, that is, that is, this, where all the processes are reversible, right here, here, here, these are all reversible processes and we are following the heat engine through Carnot cycle, and in this cycle there are 4 reversible processes. Process 1 to 2 is isentropic compression process 2 to 3 is isothermal heat addition to the heat quantity of QC and work output is obtained because, you are adding heat, work is obtained as output, and process 3 to 4 is isentropic expansion and process 4 to 1 is isothermal heat rejection, QC, where work is to be done on the system, or work in, as input right. So, then if we analyze and if we assume that the system to have a perfect gas, then if perfect gas is acting as a working fluid along the isothermal process that is 2 to 3 along the isothermal process that is process 2 to 3 here, also, I am drawing may not be exactly that, these are the 4. So, this is 1, this was 2, this was 3 and this was 4, this will keep.

So, that we do not have to go back to the figue every now and then. so in the isothermal process, 2 to 3 that isothermal was this one, right process 2 to 3 and process 4 back to 1, the temperature is constant, as a result the internal energy remains also constant right. We have seen earlier that we had given 10 kg kilo joules of heat and we saw that the internal energy went up, because of that the molecules were moving, remember right. So, if the temperature is constant that means, the internal energy is also constant. So, from the first law we can write that Q 2 to 3 is equal to W 2 to 3, because U 2 to 3, that is this one, is 0 right.

From the first law, we can write

$$Q_{2\text{-}3} = W_{2\text{-}3} \text{ since } U_{2\text{-}3} = 0 \qquad \therefore \quad Q_H = W_{2\text{-}3}$$

Similarly, $\qquad Q_{4\text{-}1} = W_{4\text{-}1} \text{ since } U_{4\text{-}1} = 0 \qquad\qquad \therefore \quad Q_C = W_{4\text{-}1}$

So, W 2 to 3 is 0, I said rather, U 2 to 3 is 0. So, Q 2 to 3 is W 2 to 3 and similarly, we can say that Q 4 to 1 is also W 4 to 1, Q 4 to 1 is this one, sorry, Q 4 to 1 is this one, right and W 4 to 1 is also here, right. So, in both the cases, since, U 2 to 3 and W, rather, U 4 to 1 is 0, we can say that Q 2 to 3 is W 2 to 3 and Q 4 to 1 is W 4 to 1. So, we can say that Q h is equals to w 2 to 3 and q c is w 4 to 1 right. Therefore, we can say that work requirement for isothermal process in open system that can be given, by W 2 to 3 is equal to minus integral of 2 to integration of between the 2 to, state points 2 and 3, as v dp, right and this is equal to minus R T h ln of p 3 over p 2 right.

$$W_{2-3} = -\int_2^3 v\,dp = -RT_H \ln\frac{p_3}{p_2} \quad \therefore Q_H = RT_H \ln\frac{p_2}{p_3}$$

$$W_{4-1} = -\int_4^1 v\,dp = -RT_C \ln\frac{p_1}{p_4} \quad \therefore Q_C = RT_C \ln\frac{p_4}{p_1}$$

Similarly,

So, a little thermodynamics, if you know then, it is that v dp, can be replaced from 2 to 3, as minus v dp is minus R th ln p 3 over p 2 right. Therefore, we can write Q H is equal to R T h ln of p 4 over p 1, this is Q C, and that was Q H, right. So, Q H is R T h ln p 2 by p 3, and similarly W 4 to 1 is, minus 4 to 1, v dp is equal to minus R T C ln of p 1 over p 4, and therefore, Q C can be written as R T C ln p 4 is to p 1, or p 4 by p 1 right. Therefore, from these two relations, we can write p 2 by p 1 is equal to T H by T C to the power gamma by gamma minus 1, right. We know that p v gamma is constan,

$$\frac{p_2}{p_1} = \left(\frac{T_H}{T_C}\right)^{\frac{\gamma}{\gamma-1}} = \frac{p_3}{p_4} \qquad\qquad \frac{Q_H}{T_H} = \frac{Q_C}{T_C}$$

Also,

$$\frac{Q_H}{T_H} - \frac{Q_C}{T_C} = 0$$

we know. So, p 1 v 1 gamma is p 2 v 2 gamma therefore, we can write p 2 over p 1 is T H over T C to the power gamma by gamma minus 1, right and this is also is equal to p 3 over p 4. So, we can write that Q H over T H is equal to Q H over T C. So, Q H over T H equal to Q C over T C right. So, from that, we can write, Q H over T H minus Q C over T C. This is equal to 0 right or for a cyclic reversible process this is, that cyclic symbol, the cyclic reversible process d Q over T is equal to 0 right.

So, for a cyclic reversible process d Q over T is equal to 0 therefore, we can write d Q over T reversible, right this does not change in a cyclic process and that means, d Q over T is 0, that Q H over T H minus Q C over T C being equal to 0, we, this is nothing, but, d Q. So, d Q over T, T is constant. So, under reversible condition, this is saying that it does not change in a cyclic process and therefore, in a cyclic process d Q over T is equal to 0 right. So, it is a function of the thermodynamic state points only, right, because, d Q over T in a cyclic process is 0. It is a function of the state points only.

$$\left(\frac{dQ}{T}\right)_{rev} \qquad \oint \frac{dQ}{T} = 0 \quad \therefore \quad dS = \left(\frac{dQ}{T}\right)_{rev} \qquad or, (dQ)_{rev} = T\,dS$$

Hence, it is the change in a thermodynamic property only, and this property is known as entropy, and this is described by the symbol capital S. Capital S is for entropy with total mass, and small s is entropy with per unit mass, right as usual earlier for d Q for d W we have said and for internal energy we also you have said right. So, we can write that d S is equal to d Q over T reversible, right, or we also can write d Q reversible is equal to T d S. So, for a reversible system, d Q is equal to T d S, right where, d S is the change in entropy and T is a constant right. This equation can be written for unit mass of the working fluid as d s small, is equal to d Q over T reversible, this is for unit mass.

$$\therefore \quad ds = \left(\frac{dQ}{T}\right)_{rev} \qquad s_2 - s_1 = \int_1^2 \frac{dQ}{T}$$

As I said that for entire mass it is capital S, entropy, is expressed and for per unit mass it is small s as it is expressed right. So, per unit mass d s is d Q over T reversible right. Now, s is the specific entropy in kilo joules per kg per kelvin. So, mind this unit also, that entropy unit is, let me write here entropy in, so that you do not forget entropy unit, is kilo joules per kg per kelvin, or degree centigrade right, so, that you do not forget kilo joules per kg per degree centigrade as the entropy. For a finite reversible process, between state points 1 and 2, it is also used as criteria for equilibrium.

$dQ_{rev} = T\,dS$; and, $dW_{rev} = p\,dV$ From first law, $dU = dQ - dW$, substituting, we get,

$dU = T\,dS - p\,dV$, or, $T\,dS = dU + p\,dV$,

we also know that

$H = U + p\,V$; or, $dH = p\,dV + V\,dp$; $\therefore$ $T\,dS = dH - V\,dp$

For an actual process, which is not reversible then, what happens to d S? d S is always greater than d Q over T for irreversible process. For irreversible process d S is always greater than d Qover T right. Then another very important statement, or situation comes up, that is called Clausius inequality. Now, Clausius inequality can be said that one of the mathematical form of the second law of thermodynamics. For a closed system undergoing cyclic process is the Clausius inequality, which states that cyclic integration that is d Q over T is equal to 0 and can be used to derive maximum efficiency and COP of the engine and also refrigerating systems.

$T\,ds = du + p\,dv$; $T\,ds = dh - v\,dp$

For real processes that is irreversible process, the entropy always increases and that is why you might have heard that entropy of the universe is increasing. Obviously, the

more entropy is increasing, the more it becomes chaotic, and the more it be, leads to be destroyed right. So, for real processes that is irreversible process the entropy always increases. This is proved for an isolated system that is one which does not, in which does not involve any heat transfer, any mass transfer and any work transfer. Any system along with its surroundings that is the universe can also be considered as isolated system.

The corollary of second law states that the entropy of an isolated system either increases or remains constant. It does not go negative, either increases or remains constant. So, the corollary of second law states that the entropy of an isolated system either increases or remains constant right. So, you can say that the second law is known as limit law or limiting law. It gives the upper limit of efficiency of heat engine and the COP of refrigeration systems and also gives the direction that process can flow.

Now, there are some fundamental relations, which are also required in thermodynamics, that from the measured data on a few properties, determination of several thermodynamic properties can be made, using some general relationships. From the definition of entropy and the first law of thermodynamics, it can be written that dQ reversible is T ds. So, dQ reversible is T ds and dW reversible is pdv right. So, from first law, we know, dU, here you see we have written capital U, that is for entire mass. So, dU is equal to dQ minus dW.

Now, substituting this, we get dU is equal to T ds, because, dQ is T dS that we know. So, dU is T dS minus pdv because dW is pdv or we can write T ds is equal to dU plus pdv and we also know earlier we have seen that h is equal to U plus pv. Therefore, we can write dh is equal to pdv plus vdp. Then we can say that T dS equal to dh minus vdp.

T dS equal to dh minus vdp. On per unit mass first fundamental relation on thermodynamics can be written as T ds is equal to du plus pdv and second fundamental relation of thermodynamics that can be written as T ds is equal to dh minus vdp right. T ds equal to dh minus vdp. Two things we have said one is T ds is du plus pdv and another is T ds is dh minus vdp. So, this we have to keep in mind because, subsequently, they will be utilized. Now, third law of thermodynamics says that it gives the definition of absolute value of entropy and also states that absolute 0 cannot be reached.

It states that the entropy of perfect crystals is 0 at absolute 0. This law also states that entropy is a measure of disorder of the system. So, another form of this law states that absolute 0 cannot be achieved right. So, if we look back to third law it says that absolute value of entropy is and also states that absolute 0 cannot be reached. It states also that the entropy of the perfect crystals is 0 at absolute 0.

Since absolute 0 is not reachable so, entropy of perfect crystal becoming absolute 0 is

also impractical. This law states that the entropy is measure of disorder which we said, I said earlier, that the universe entropy is increasing. So, the disorder of the universe is increasing, right. So, another form of this third law can be said that the absolute 0 cannot be achieved right. So, we have learnt all laws of thermodynamics along with a new function called entropy and also the Carnot heat engine cycle right.

We have analyzed a little in detail we will be analyzing afterwards when we go to Carnot system right. So, with this we conclude today's class and next day let us see we will look into the further details. Thank you.