Engineering Thermodynamics
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Week-06
Lecture-28
Entropy

Welcome to the lecture on entropy. In this lecture, we will discuss the classes on inequality, which is related to the second law of thermodynamics and processes. When we talk about the second law of thermodynamics, then usually inequality is associated. Whether we talk about efficiency or heat pump, then we said that if the heat pump is reversible, then its coefficient of Performance you have. will be more than irreversible. Wherever there is irreversibility, the performance decreases. If we talk about heat engine, the reversible of heat engine is That will be more than the irreversible efficiency. Inequality is usually associated with the second law of thermodynamics. And equality occurs only when things are in reversible conditions. So, let's try to understand this. Another special inequality related to the second law of thermodynamics is inequality of Clausius. The inequality of Clausius introduced in this law which we write as this joule clause introduced it in 1865-1865. This is a very important inequality in thermodynamics. And it is connected to the second law of thermodynamics. The term and expression given in the circle integral means cyclic integral. If we talk about a cycle, we use 4 devices. When there is a whole cycle, the term is transferred to every process. If the temperature is T with the boundary, then we will sum it with every device. Then you will get the integral of the whole cycle. the amount will be less than or equal to zero. So, naturally, integral is we can write it like this. Sum of will be the differential term. So, this is on the entire cycle. The entire cycle is part of the cycle. The temperature of the tea is at the boundary. and delta Q is the amount of heat that is being transferred from the boundary K through. Now if you understand how to prove this, then we call this validity. How valid is this expression that we have written? So, for this we will use a reversible device. Use it. And make it as if it is your reversible in which you have Boiler, Turbine, Condenser and here is your pump. This boiler will get heat from the thermal reservoir which is on TR. The heat is losing from the condenser, but this amount will go to the system. The system is a piston cylinder which will work after the heat is applied. So, this is your system. And here is your W which is turbine. But we have said this because this is cyclic, reversible cyclic, this is a heat engine. So, this is W reversible. Now we can apply for this. Energy balance but we will apply this whole. We will take a combined system. So, this is the combined system in which you have combined system, system plus the cyclic device. I have kept the thermal reservoir TR outside. So, this black line is yours, combined system plus cyclic device. Now you can apply for it. So, this energy balance is the W system plus W reversible. This is yours plus the changes if your combined system will be total changes and this will be your dull Qr and you can see it like this system plus del QR minus dEc. And this is your combined total work. of combined system. And DEC is change of total energy. Total energy is a combined system plus cyclic device So we can call this combined system. So, change in total energy of the combined system. So finally, we have del WC is equal to del QR minus dEc. So, this is your total energy balance. Now if you consider this device reversible, we have seen in the last lecture that if we consider reversible device cyclic device in this case, the ratio of heat is the ratio of temperature. So, the system is at temperature T. So, its boundary is at temperature T. In this case, del Qr by del Q will be TR by T. And del Qr by TR will be del Q by T.

Now you can use this equation here. You can write del Q in the form of del Q We will try to do that in the next class, so this is your del This is dr del Q by t minus dEc Because del Qr is tr del Q by T. So, this is what I have used here. So, this expression is coming from total energy, and we are considering reversible device. Now let's consider that the system, which is on T, T is the temperature on the boundary, this is a reversible cycle. We can write this particular system as if this system is in our interests. Assume that this will go on as a cyclic process. Cyclic process means that it can be expanded and then compressed back to its original place. To use this symbol, we can write it as Exactly process Now, consider the system as a cycle. A cycle is the process of this system. And when this system does, then the cyclic device can also do it. So, it will assume that the cyclic device will also work during this time. So, when it has done the cycle, then your system also processes the cycle. So, in any cycle, the total energy change will be zero. The combined energy will also return to the same state as it was in the beginning. Now, because of this, the value of the total energy has become zero. And this total work is not done by this device. Because it is constant and is a reservoir, this is your DelQ.

$$\delta w_{system} + \delta w_{reversible} + dE_c = \delta Qr$$

$$\delta w_{system} + \delta w_{reversible} = \delta Qr - dE_c$$

$$\delta w_c = \delta Qr - dE_c$$

For reversible cyclic engine

$$\frac{\delta QR}{TR} = \frac{\delta Q}{T}$$

$$\delta QR = \frac{\delta Q}{T} TR$$

So, this is the final discussion of this process and this exercise. Now notice that WC is doing totally effective work. Because this is combined total work Now, when you did this particular thing which is your combined system so what is it doing? It takes one energy from TR, and it is doing this work effectively so if we pay attention to this then what is the process? It is the process that your Q is taken and here simple WC is given So this system violates your Kelvin Planck statement. Because it is exchanging heat reservoirs, and it is working completely without any throw. So, this means that this WC cannot be positive. cannot be positive. So, it cannot be positive. Because by using this example, we can see that the total net amount of work is being done by exchanging only one reservoir, which is not possible. And TR is positive, which means that it cannot be positive. So, it will be less than or equal to zero. and this is your Clausius inequality.

$$\delta W_c = TR\frac{\delta Q}{T} - dE_c$$

$$\oint \delta W_c = \oint TR\ \frac{\delta Q}{T} - \oint dE_c$$

$$W_c = TR\oint \frac{\delta Q}{T}$$

This relation of Clausius inequality is valid for the thermodynamic cycle. Whether it is reversible or irreversible or whether it is a refraction cycle. Notice that if the system we have created is also reversible, then the combined system will be reversible. So, if the system is reversible, it means combined system is reversible So if we reverse the combined system, i.e. change the direction of the cycle, then it becomes a reverse cycle. In the case of reverse cycle, the quantity we use The magnitude is same as in normal case But the sign is opposite it will be opposite it will be positive of negative and negative of positive and when reverse cycle happens in such cases as we said in regular cases that Wc that cannot be greater than zero In reverse case Wc less than 0 for reverse case This means that if your system is reversible, then the combined system inside the dotted line is reversible. In this case, WC will be valid only when WC is internally reversible. This means that this will be 0. In regular case, we will reverse it. So, this is the condition. This means that if your system plus device combined system is reversible. So, this is your condition. This means that the condition you used, del cube by t, your Clausius inequality, finally this expression will be zero. So, when this becomes internal reversible, then this becomes zero. So, this means that equality, equality means that Clausius expression the equality sign in it is totally reversible Yeah, internal reversible. in your irreversible cases. Inequality will be totally reversible and internal reversible will be in the case.

Now, let's understand the inequality of clauses through an example. How can we use it to check and find out whether the process we have shown violates or not. So, this is a process diagram that we have shown. This is the proper process. Just make it have a turbine, boiler, pump and condenser. It means it is a heat engine. It has been given the conditions that the turbine that comes out of the pump is at 15 kPa at 90% quality, and 10% condenser at 15 kPa. And the pump is saturated liquid. and from here it boiled and became a vapor went into the turbine Now this cycle of the heat engine Does it do the wallet? The second law of thermodynamics means that does this equality inequality. to check if the device is following the instructions or not to check this you have to note two things first, which devices are getting heat transfer Boiler which will have a dull cube in the boiler and condenser So this del Q specifically which is connected to the boiler This is the difference between this and this. Which will be approximately the same If you say there is no loss, then it will be equal Because this amount will be delta H Which means this will be delta H Similarly, you can also say that this will also be delta H Between this and this Rest of the devices are like adiabatic devices, there is no heat interaction. So, there are only two heat interaction devices in these four devices. So, you can write properly that this is your delQ by T, this is your boiler, and this is your condenser. Now, I can write delQ as the boiler part.

$$\oint \frac{\delta Q}{T} = \int (\frac{\delta Q}{T})_{boiler} + \int (\frac{\delta Q}{T})_{condencer}$$

$$\delta Q = \frac{1}{T_1}\int \delta Q + \frac{1}{T_3}\int \delta Q$$

$$\delta Q = \frac{\int \delta q}{T_1} + \frac{\int \delta q}{T_3}$$

$$\delta Q = \frac{h_2 - h_1}{T_1} + \frac{h_3 - h_4}{T_3}$$

The boiler is here, so this part of the boiler. integration which is temperature fix so we can write it as 1 by T del Q plus 1 by T this is the boiler temperature because it is 1 and 1 or 2 will be same so this will be the constant temperature which will boil in this condition and T1 will be Tsat T1 del q plus t3 integral del q. So, we can write it as well that the integral total amount of boiler is done. So, this is your integral. Q, which is the total, effectively, this We can also assume that the amount is per unit mass. Assume that 1 kg of working fluid is working in the cycle. We can use this per kg. So, this can be small q. 1 by T1 or. dq plus dq by 3 integral and this is your dq total amount heat is equal to h2 minus h2 minus h1 by t1 plus loss y is equal to h3 minus h4 Note that writing like this is not correct. This del Q does not have a sign by default. We are not saying how much loss is there and how much is there. So, it needs a sign convention. If I have taken this as h2-h1, then here I have used this as your direction. Final minus initial. So, if you see from this side, this is the final H4 and H3. H4 minus H3, this will be your del Q. So of course, assuming that your condenser is going to hit. So here, either write minus here, or you can write it as H2 minus H1 plus T1 plus H4 minus H1 plus T3. Now H4 minus H1 will be negative anyway. So, this way you can automatically check the sign that this part is heat loss, and this part is hit gain. So, this expression came out. This part. Now, this deltaH T1. T1 is Tsat. This will come at 0.7. and T3 will come at 15 kPa Now the main thing is that you have to find out the values So you have to see the table You will get the table in A5 If you see the table in A5 You will get Tsat You will get T1 is equal to Tsat You will get 160 4.95 degree Celsius And you will get 53.97 H4 and H1 are also available from table A5 H2 minus H1 is superheated so you will get it from table A5 from your steam table If you put the value of H4 H2 minus H1 is 2066.3 kJ per kg H4 minus H1 is equal to minus 1898.4 kJ per kg If you plug in this You get If you plug in and add values here You get Minus 1.087 kJ per kg per Kelvin So this is negative means that your process is correct. I have not shown you this table. As you have seen before, you should know how to remove the table. First of all, in the case of boiler, the saturated liquid has gone from the saturated vapor. You can also see table A5, the table of 0.7 kPa. From there you will get delta H. Hfg and use it directly In this case, since it is 90% quality then you will get H3 which is Hf plus xHfg and H4 which is Hf plus xHfg x is your quality So if we see it like this H4 minus Hf will be your minus 0.8 hfg because x is equal to 0.9 and 0.1 and hfg at 15 kPa you will get table A5 and when you multiply it you will get this value so you can calculate it easily I hope you got this time so we will do this much in this lecture Now we will connect entropy with this inequality and classical inequality and we will discuss it in the next lecture. Till then, bye. Goodbye.