Engineering Thermodynamics
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Week-07
Lecture-34
Entropy

Welcome to part 5 of entropy. In this lecture, we will talk about entropy balance. And how to apply it and how to use it. how to use it, like how to find the entropic generation. So, let's start. Entropy balance is not like conservation. Like conservation of energy. We can't say that there is any concept of conservation of entropy. But you can use entropy generation and change in entropy to add the whole system and surroundings. you can create an entropy balance and you can understand how entropy is increasing and decreasing. So, we are trying to explain this concept.

Let's start. If you use the system as shown here. and if there is an energy inlet in the system, then the energy is getting out. Similarly, if there is a flow in the system, then entropy is coming and going. But you know that the principle of entropy is that entropy generation will always be greater than or equal to zero. And total entropy will also be greater than or equal to zero by adding the surrounding system. So, you can balance this, that the total entropy that entered the system, minus the total entropy that came out, plus the total entropy that was generated, that will be the total change in entropy of the system. This means, S in minus S out plus S generation is equal to delta H system. So, it's a simple balance.

$$S_{in} - S_{out} + S_{gen} = \Delta S_{system}$$

Entropy changes of a system ΔS_{system}

$$\Delta S_{system} = S_{final} - S_{initial} = S_2 - S_1$$

When the properties of the system, are not uniform,

$$S_{system} = \int s\delta m = \int s\rho dv$$

1) Heat Transfer

   Entropy transfers by heat transfer

$$S_{heat} = \frac{Q}{T}\ (T = constant)$$

$$S_{heat} = \int_1^2 \frac{\delta Q}{T} \cong \sum \frac{Q_k}{T_k}$$

So, what will be delta H system? S2, which is S final minus S initial. So, this is a simple description of absolute values. But if your property is not uniform, like mass flow or duct, then you can integrate the system of entropy and find out, as it has been said in this case, So, you can multiply delta m and integrate it to get S-System. Or if you are over integrating the volume, then you get delta m and rho dv. You can insert that. Now, entropy transfer is mainly due to heat transfer. It is important to understand that if there is entropy transfer, then it is a simple Q by T. And if it is in the differential form, then it is integral of del Q by T. And if you are getting it from many places, which you can add, then you can take it in the summation form, where K is a part of the boundary. because this is a boundary phenomenon and no entropy is generated by the work, so S of work is zero so heat transfer is always connected to entropy transfer like if heat is transferred, entropy is also transferred in this case, we have given this system and here is the boundary, the dash line and heat is transferred from the surrounding 500 kilo joules. So S is Q by T, the temperature on the boundary. Because the phenomenon of the boundary is the temperature of the system. Which is 400 Kelvin. If you do Q divided by 400, it will come out. That much entropy went inside the system. The second way to increase or decrease entropy is through flow. If there is fluid in the flow, then you will have enthalpy and entropy. And mass flow rate is so much that it is flowing continuously. And entropy associated with mass also increases. So, the transfer of entropy by mass is M into S. And if the properties are changing, then you can take it specifically against cross-sectional, if you take cross-sectional, dSe, then you can also do this through it, that if it is rho, then it is normal velocity, or if it is dSe, then this part is V. So, we have written S rho dV as such, because it is taking cross-sectional area. So, you can also integrate it like this. And this is what is written in this form. If it is varying from time, then you can add that too. So, we have been told that entropy changes in two ways. One is due to heat and the other is due to flow rate. Now, let's talk about entropy generation. Entry and leaving are told in two forms. One is due to heat and the other is due to mass. Now, entropy generation has been done. S generation is in the system. This expression is for the S generation system. S generation is 0 if the system is not irreversible. In this case, we call it an internal reversible process. In this case, S generation is 0. It means that delta S system is only net entropy transfer by heat or mass. If you have adiabatic and mass B-transfer in your closed system, then delta S will be zero. But if S generation is zero in the system, it does not mean that there is no irreversibility. The irreversibility can be in the surrounding outside the system. In the total reversible case, your total S generation will be zero. So, if you want to get the total entropy generation, you will have to take System plus Surrounding. In such cases, we can take System plus Immediate Surrounding by which T is more than let us because it is transferred from the heat transfer system. And here, by changing it gradually, T will be surrounded. So, the T surrounding is outside because if the T surrounding is here, then this change This change will be gradual from here to here and this system will be called System plus Surrounding this will be called Extended System this is called Extended System So if you want to get the total you can get the generation on Extended System and in this system plus the total of the emitted surrounding is added Entropy and total of your generation is added so this concept and we will understand it more through examples.

Now, this expression can be written in the rate form by using dots. So, this is the rate of change of entropy. We can write this in the form of per unit kg or we can write it according to the mass. So, this is the general definition. Like we discussed in the last slide too. Due to mass in, due to the S in, it is mass in or due to heat. S out is due to mass out or heat. Total delta S system is S surrounding. So, delta S system is S generation greater than zero. So total delta S system will come out by balancing S. In which S generation is greater than or equal to zero. Now if we talk about closed system, then in process, closed system means that your mass flow is not there, so it will only be possible with heat transfer and heat transfer will be generated which will be from the boundary of the system. So, in such a case, your closed system is, we have said that in this case, S generation is kept, but the term mass is removed, only a heat term has come. So, this is summation heat which is simply Entropy, in, minus, out, whatever changes are there, can be taken in the form of summation. This is delta S, dS due to heat. Plus, S generation and delta S system S2 minus S1. If it is adiabatic, then this part will also be zero. Then S generation is simple, delta S system. The adiabatic system will be there. So, if we take closed system and along with it, boundary, like we took closed system. In this case, we said that it is a closed system. It is a closed system. And we also get immediate surroundings. So, if we add both, then what will be the S generation? System plus surrounding. What will be the S generation? System plus surrounding. And delta S system is always, we can see, mass into S2 minus S1, which is specific entropy. the surrounding, you will write Q surrounding. The surrounding will be divided by T surrounding. So, T will take the temperature of the surrounding. And heat transfer is from the surrounding system. So naturally the same heat will come out or vice versa. So, in this case, you can easily get the Q surrounding from the system. So when you do these questions, it will be clear. This was the thing. In this case, we have to consider the mass flow. In such a case, we do not have to take entropy only due to heat contribution and heat transfer, but we have to take it also due to mass. In this case, we have done Inlet minus Outlet plus S Generation, and this is S2 minus S1, CV control volume. So, this summation is the total heat transfer, delta summation Qk divided by k. It may be that it has come from different forms, but not from the same place. Suppose for example, here the Q is coming from different places, or here the Q is coming from different places. So basically, they are saying that sum up all the heat transfer that is coming from the boundary. Plus, the contribution of the mass inlet and mass exit, plus the S generation, S2-S1, which is the change in the system entropy in the control volume. So now I can also take it in rate form. If it is a steady flow, then this part will be zero in the steady flow. So, what is S generation? For S generation, we can take it in full right-hand side. So, this is S generation. M.E SE minus summation MIE SI minus summation QK dot divided by Q. If it is a single stream, then we remove the summation. So, this is m dot se minus si minus summation. If it is adiabatic, then q is zero, then this is your simple S-generation, which is change in the flow entropy. And normally, if you assume that if adiabatic single stream is there, then your SE will be greater than or equal to SI. If it is reversible, then of course your SE will be equal to SI. But in general, exit entropy is more. Let's move forward with this discussion.

Closed system:

$$\sum \frac{Q_k}{T_k} + S_{gen} = \Delta S_{system} = S_2 - S_1$$

Adiabatic Closed system

$$S_{gen} = \Delta S_{adiabatic\, system}$$

Any Closed system + Surrounding can be consider as adiabatic,

$$S_{gen} = \sum \Delta S = \Delta S_{system} + \Delta S_{surrounding}$$

$$\Delta S_{system} = m(s_2 - s_1)$$

$$\sum \frac{Q_k}{T_k} + \sum m_i s_i - \sum m_e s_e + S_{gen} = (S_2 - S_1)_{CV}$$

$$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{S}_{gen} = \frac{dS_{cv}}{dt}$$

Stedy Flow: $\dot{S}_{gen} = \sum \dot{m}_e s_e - \sum \dot{m}_i s_i - \sum \frac{\dot{Q}_k}{T_k}$

Stedy flow, single stream: $\dot{S}_{gen} = \dot{m}(s_e - s_i) - \sum \frac{\dot{Q}_k}{T_k}$

Stedy flow, single-stream.adiabatic: $\dot{S}_{gen} = \dot{m}(s_e - s_i)$

Let's understand it through examples. This is your brick wall where the heat is transferring from one side to the other side. On the left-hand side, on the left-hand side, it is 27 degrees Celsius and on the right-hand side, it is 0 degrees Celsius. The surrounding temperature but the temperature on the boundary is 20 degrees Celsius on the left-hand side and this is 5 degrees Celsius. The thickness given to you is 30 centimeters. Now you can find out how much entropy generation is there. If this is in the form of steady state, then the right-hand side will be zero. So, your S in minus S out plus S generation will be equal to zero.

$$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = \frac{dS_{system}}{dt}$$

$$\left(\frac{\dot{Q}}{T}\right)_{in} - \left(\frac{\dot{Q}}{T}\right)_{out} + \dot{S}_{gen} = 0$$

Entropy balance for a throttling process

$$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = \frac{dS_{system}}{dt}$$

$$\dot{m}s_1 - \dot{m}s_2 + \dot{S}_{gen} = 0$$

$$\dot{S}_{gen} = \dot{m}(s_1 - s_2)$$

Now what we do is We take an example and with this example We try to apply this concept Which we have learned now in this case, your question is that 50 kg of iron cast is added to the lake and the temperature is 285 K and the initial temperature of the iron cast is 500 K Of course, the island cast temperature will also be 285. Since this lake is very big, its final temperature will not change. It will also be 285. Now we have to find out how much is the entropy changes of the island block; how much is the entropy changes of the lake and how much is the total entropy generated in this process. So, this is the question that comes to you. If you understand this, then you can answer the rest of the questions. So, first of all we will take out entropy change of iron block So the final temperature of iron block will be 285 So if we want to take out delta S iron So this will come out M dot S2 minus S1 And you can get the simple heat capacity of the solid. In this case, remember how we connected the dS with the heat capacity. In this case, the expression will come out. m dot cp average, which is the change from 500 to 285 Kelvin. Which is considered to be 0.445. And ln T2 by T1. T2 is 285 Kelvin T1 is 500 Kelvin Cp average is 0.45 M is 50 kg Cp average is 0.45 kJ per kg and your is 285 by 500 ok if you solve this then you get 12.65 kJ per kV so this is your entropy change of the iron block if you want to remove the entropy change of the lake then we will balance the energy first so if we balance the energy So, this will contain E in minus E out, this is delta A system. What is E in? First of all, you have to consider the balance of this on which you are doing it. Let's say you do it on iron. So, this will come out as E in minus E delta A system. Now, what is E in? E in is nothing, what is E out? Q out. This is the delta E system which will be obtained as mCp Average This Cp Average will be taken and this is t2minus t1 This is what will be obtained Note that I had written cp in it but actually it is hard It is solid mass so Cp Average is Cp Average in fact Because Cp and Cv are the same for iron So from here you will get the expression M is the average, T2 is 285, T1 is 500 So you will get Q from here So Qout will come out Qout, this heat will transfer to your lake So McAverageT1-T2 If you put this, then 50 kg 0.45 kilo joules per kg Kelvin and this is 500 minus 285 Kelvin and this is 4838 kilo joules so entropy of change of lake will come out as Q of lake which is receiving and T lake ok so this will come out as positive because it is receiving kilo joules and temperature 285 so what is 16.97 So this is specifically of delta S lake. Now we have to find out the question that was there. That was entropy change of the lake. So, we found out entropy generation. Now there are two types in this generation. One is in your system and the other is connected to the lake. So, we can do this in two ways. One is we said that 285 and if the temperature changes, we extend it so that 285 comes to the boundary so this is the extended system of system plus surrounding so if we put entropy balance in the extended system then the total generation of the system will be once 285 is here so naturally your total generation because after this the heat transfer The heat transfer will be absorbed by the extended system. If we look at it like this. We can do this in Extended System. So, if we take it in Extended System. Entropy balance is applied So, S in minus S out plus S generation is equal to delta S system.

Now, we will pay attention to this delta S system. S out is Q out plus Tb. So, we have to pay attention to this. As you can see, this is Q. So, here also Q is coming out. Correct? So here the boundary is Tb, and the boundary is Tb. Since we are doing system plus surrounding, so we are doing system plus immediate surrounding here. We have considered this as an extended system. So, we are considering this as total. And in this, pay attention to Sin and S out. Sin will be 0. Plus, S out boundary, the boundary of the extended system, will come out as Q. So, Q minus Tb will be 285. This is your Delta S system. Now, you have to remember that this Delta S system This system, this system We will consider 12.65 minus What we did here in this one Which is 1 So this is 12.65 kJ per Kelvin and the values that come out are your Qout is taken by us so what is S generation? 4838 kJ, 285 K, minus 12.65 kJ per Kelvin. So, this is 4.32 kJ per Kelvin. So, this is one way in which you took the extended system which is an iron block and immediately has a surrounding. And then you fixed the boundary of the extended system to 285 kJ because it was the surrounding. and when you apply it, your Sin minus Sout plus S generation is equal to delta A system delta A system is already out which is the system so you can do it in one way or another the second method is a little bit more you can understand it in this too that if you took entropy generation in which you considered the iron block and the entire lake as a system means you considered the entire system okay if you took total iron block plus lake if you have isolated system S generation is an isolated system and S generation is delta S total because if we consider it as isolated, then outside of it neither heat transfer nor mass transfer so S generation is delta S total in which you have to calculate delta S system plus delta S lake so this is your minus 12.65 and lake you have calculated is plus 16.97 which is 4.32 So, in this case, you have done it in two ways. In the first case, you gave an extended system and then you solved it. In the second case, you made a simple isolator and made the surrounding oscillator. And the total generation will add the entropy change of the individual subsystem which you can see here. But we will see it and try to understand it through examples.

Let's take one more example. It has been done in this. This is your frictionless piston cylinder device which is a saturated liquid vapor mixture. And when it is processing constant pressure, then the heat of 600 kJ is transferred to the surrounding which is at 25 degrees. And now the question is that the entropy change of water and total entropy generation in heat transfer and if heat is transferred then water will condense so to get delta S system you have to take this red dash so your heat divided by T system so delta S system is simple minus 1.6 because Q is given to you this is your Q and this is your T system ok Now if we want to generate entropy of the system, there are two ways to do it. The first one is simple. We are doing entropy balance in system plus immediate surrounding. Immediate surrounding means that the TB here is the T surrounding. So, this is the immediate surrounding. So, in this, Sin minus Sout plus S generation is equal to delta S system. We are saying that whatever changes are happening in the system, plus whatever generation is there, everything is involved in it and Sin minus Sout is there. So, Sin is of course zero, Sout is this. But in this, we will say that TB is used in this. Q out is fixed, 600 kilojoules, but Tb is 25 degrees. Because it is on the extended boundary, so this boundary is here. not system, but extended TV plus S generation total generation system plus immediate surrounding and this is delta S system from final edge to delta S system delta S system is the ability that we have shown minus 1.61 kJ now you can show that this will be same if you consider this and isolate the surrounding so your value will be delta s generation so delta s total means delta s system plus delta s surrounding and this delta s system is already given so this is 600 plus 25 plus 273 This is the same term that you will get. Notice what we have done. We have shown that it is an extended system. But the term that comes in the extended system is the corresponding term for the delta S around. So, this is your Q, this is your D surrounding, so what is this actually? This is delta S surrounding. So, delta S surrounding plus delta S system is your total generation. So, in a way, it is an extended system, but you can understand that they are doing exactly the same. Like you are removing delta S system plus delta S surrounding. Delta S surrounding is Q out plus B surrounding boundary. The solution of extended system is the same as the solution of the term Sout minus Sin. This will correspond to the term of immediate surroundings where the generations are. So that is the result of Q by T boundary and what is the boundary? The temperature of surrounding and extended system. So, this is a simple method. If you are confused by this So, you simply isolate the system plus surrounding isolate system plus surrounding and then you extract deltaS system plus deltaS surrounding and this will be your S generation I hope you got the time to understand the concepts of entropy. If you want to make it more complicated, you can take another example.

This is an example of a heat exchanger. The thing is that the air is going to be It heats up the steam and then it exchanges heat. This is a heat exchanger. This is steam, which is a saturated vapor. Its quality is 1. It is coming out at 35 degrees Celsius. At 10,000 kg per hour. It is coming out on the saturated liquid. X is equal to zero at 32 degrees Celsius. In this process, the heat is transferring the air which is coming from 20 degrees Celsius to 30 degrees Celsius. Imagine that the building is heating up like this. The same air goes into the building in this particular example. Now the question is how much entropy is generated in this process. So, you can see the balance of entropy in the rate form So we will write in the rate form S in dot minus S out dot plus S generation This will come as dS system dt Which is your steady state So it will become zero Now S in So, the mass of steam is S1 plus the mass of air is S3. So, this is your in. equal to zero. So, if you rearrange this, you will get S generation, rate of generation, M steam. S2 minus S1 plus ma S4 minus S3. So, now the main task you have left is that you don't know about ma so, you don't know about this. You know this. And you can remove S1 and S2 from the table. So, S1 and S2 from the table, because the condition of S1 is that it is steam and at 35 degrees Celsius and x is equal to 1. means this is a saturated water vapor so you can directly remove the table and remove it so if you check table A4 then you can easily get T1 35 degrees Celsius and X1 is 1 means this is a saturated vapor so you can easily get h1 and S1 from here similarly, you can get T2 X2 is 0 means it is a saturated liquid. Here you will also get H2 as well. So, this is the data you have. You can get the heat transfer from this data. M of steam which you know. And this is h1 minus h2. So, you know that this comes out as 6751 kW. You know that this is the heat transfer. and the heat transfer will be same as the heat transfer of the air so if we balance the energy then we get m dot air cp t4 minus t3 this is q which is given by q so from here you will get m dot air because you can get the cp value from the table which will be displayed on the table. If you look at the table, you will see the Cp value on the A table. And T4 and T3 are given. T4 is 30 degrees and T2 is 20 degrees. So, from here you will get m-Air. This means that you know m-Air now.

In general, you know S2 and S1. because you have got the whole table from this condition. Now what is left is S4 and S3. Now, if you consider air as an ideal gas, then here the expression of entropy can be written easily between T4 and T3. As we have already written the DS code in this thing. So if we use that expression, then here it will come out S4 minus S3 and T4 by T3. So, now you know this, we did not talk about the total generation of the surrounding, we just talked about entropy generation related to this process. So, we have to solve a simple equation in which you have to remove all the variables from the table, or you have to use expressions. If you have air, always use the ideal gas form and use the table as much as possible. You will get expressions from the maximum table. And the relation of ds is T of temperature, which we use Cp lnT2 by T1 or T4 by T3, you can use this expression like this. And I hope that you have understood how the basic process is when you talk about entropy generation. And you can practice this thing. We can practice more with the example. If you know the generation, you can also see in the engineering form what you can do to reduce your generation. So, this practice is very valuable. I hope that you will be able to practice the example that we will give in the assignment. And you will understand more about the different forms and how to solve this problem. So, it is a very interesting subject, particularly when entropy comes. I hope you are enjoying. In this particular lecture, we started with entropy. We defined the clauses of inequality. And then we put a condition in a reversible case of entropy. How we said that entropy is a property. And then in general process, if there is an increase of entropy, whether it will be equal or increase, then the entropy principle comes out of that. We discussed about pure substance and entropy change in which we discussed about solid liquid Then we discussed about isentropic processes and how to represent them in property diagram in general, what is the meaning of entropy and how to get the relations of entropy from tedious relations particularly for gas liquid We also used idle gas and as I have done in the previous example entropy and temperature. Then we talked about reversible steady flow. How we can minimize the compressor work. Or in general, how we can understand efficiency. For example, we use Carnot cycle for cyclic devices. which are the ideal conditions for steady flow work, which we can make it a model. We have come out of that, of isentropic efficiency. And finally, we tried to understand the entropy balance so that we can get entropy generation out of any process. So, this was the entropy lecture in the details. We will start a new topic in the next lecture. Till then, goodbye-bye, bye-bye, we will meet again.