

Engineering Thermodynamics
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Week-06
Lecture-30
Entropy

Welcome to the last lecture we were discussing about entropy. We introduced entropy and defined it. In the internal reversible case, dq by dt is the differential entropy. Entropy is a state property. So, when there is a reversible process, internal reversible process or total reversible process, ΔS is integral of $\frac{dq}{T}$. We also said that entropy is an extensive property so if you have an isolated system you can divide it in several sub-systems and add entropy to it and you will get total entropy in the system and we also proved that change in entropy of the total system when the system is isolated then it will be greater than or equal to zero ΔS is normal system we also said that $\Delta S = \frac{dq}{T} + S_{\text{generation}}$ in general system and in reversible case of course this $\frac{dq}{T}$ in reversible case $\Delta S = \frac{dq}{T}$ will be integral and $S_{\text{generation}}$ will be 0 and production of $S_{\text{generation}}$ in generation system will be greater than 0 for irreversible process 0 will be for reversible and less than 0 will never be possible We also discussed that the entropy of the system can be reduced. Because if the heat is coming out of the system, then the entropy will be reduced. But wherever the surrounding energy goes, the entropy of the surrounding energy will increase. And the total entropy will be greater than zero. As we have shown in this case through examples.

So, here are some remarks and some tips about entropy which have been written. And the main thing is that process, as we said last time, the second law of thermodynamics tells the direction of the process. That process cannot be in any direction, it is in a certain direction, it has a direction. And that direction is where your energy is conserved but entropy will keep increasing or will remain constant. It means that direction cannot be reversed, and entropy generation cannot be negative. So, there is one direction of every process, it takes the same direction in which its entropy increases or remains equal. Second, entropy is not a conservation property. Like we can conserve energy, entropy is not a concept, it is not a law that your conservation will remain. Only in the case in which your process is reversible, or an ideal system, in such cases, since entropy does not change, then it will be equal. In such cases, you can say that it is conserved, but there is no belief in it. Because... In your process, normally your $S_{\text{generation}}$ production of entropy will continue. Because of the direction in which it is sitting, the direction in which it is sitting, production will continue. And your entropy will not be conserved. If entropy is being produced, then why is it happening? Because it is connected to irreversibility. So, if entropy is generated, it is irreversible. And irreversibility means that the performance of the engineering system is getting worse. So, if you want to improve the engineering system, you will have to reduce the production of entropy as a generation. So, this is a very detailed introduction to entropy. Now we can find out by using an example which process is more irreversible. Take an example where you have two processes in which you transfer 2000 kJ from 800 kJ to the sink. and in the second

case, the heat loss was 2000 kJ, but the temperature of the sink is 750 K in the first case, it is 500 K so if you are asked which process is more irreversible which process?

So, first let's see the case. This is the example which is 500 degrees So how much is the total S generation? As Generation, Delta S will be total, and this will be Delta S source because it is extensive we are adding both the changes in the source entropy and the change with the sink entropy so what is Delta S? Heat transfer divided by temperature is fixed so Delta S is your source 2000 kilo joules was transferred so this is minus 2000 kilo joules and temperature are 800 and in this 2000 received sync kilo joules and temperature is 500 Now if you connect this, it will come out to be 1.5 kJ per Kelvin. Now do say case, as generation. It will come out as before minus delta s source plus delta S sink so Minus 2000 kJ by 800 K plus 2000 kJ by 750 K Minus 2.5 plus 2.7 kJ per Kelvin 0.2 kJ per Kelvin So clearly you can see that S generation is less in the second case.

So the second case, the case of B, is the least S generation, which means that B is the least smaller irreversibility. Temperature difference is also a factor. The lower the temperature difference, the less the irreversibility. Irreversibility is due to the increase in temperature difference and the increase in friction. So, in this case, 800 K and 750 K are very close, so the irreversibility is less. Note that when the source changes, the heat transferred inside it is internally reversible. Both reservoirs process internally reversible. This is also an assumption. We talked about entropy as a property. When the state is fixed, the property is fixed. The property of entropy will also be fixed as soon as the state is fixed. To fix the state, you need two variables for a simple compressible system which are the intensity variables like temperature, pressure, temperature density or pressure density type of combination which will fix the state Similarly, to find the entropy and to fix the state you need two variables like all the other properties like enthalpy, internal energy in this way, you will have a T versus S plot T versus V plot In this case, we will show that a typical plot of a compressible liquid in temperature versus entropy will look like the one you have seen before, in which the left-hand region is a compressed liquid. If you use a specific volume, it will look like that. And the right-hand region, the right-hand curve in the right hand is a superheated vapor. and the region between the two phases is called two-phase region where two phases coexist and live in equilibrium so that is the liquid vapor region which is called the saturated region the upper region is superheated it is the same as this region you can also call it supercritical because the critical point is above this region so this is the phase diagram of the previous phase diagram and As we said earlier, in the case of compressed liquid, we can approximate it. For example, we used to approximate enthalpy. If enthalpy is in the case of compressed liquid, like in the case of 1, then we assume enthalpy at the same temperature as the fluid. In the same way, we can assume entropy as well. Superheated vapor cut is a table. For example, common fluids like working fluids, water, refrigerant. We will use the tabulated data of this. And the two-phase region, like if we consider S2 in this particular case, then S2, like you have used for enthalpy, or for internal energy, or for volume, similarly, S2, this is specific entropy, because this is S divided by mass, you can write it like this, which is the quality multiplied by Sfg which is Sg minus Sf As we have done earlier, we have done Intel and Angel for Enthalpy exactly the same There is no such thing in it We will use it exactly the same as you have used table for other properties You will use it exactly the same You will use it in the same way in the example or to solve the problem Now, this is the only thing that is slightly different when you make a tie line. So, tie line is for equilibrium data. If you see from the example, this is your temperature versus entropy. This is your critical point. Normally, if you see the pressure isobar, where the pressure is constant, then this comes out. You have to show it from

the example. P is equal to 10. water example here pressure 10 mega pascal this is your saturated liquid in this particular condition, and this is your specifically T_{sat} which is at 10 mega pascals in this pressure and this is your S of liquid which we will also call as fluid, and this is your S of gas. So, this is your saturated vapor, this is the liquid, and this is the saturated vapor. So, this is how the rest of the pressure will be applied. And this dotted line is the line of specific volume. So, this is a little different. Notice that it is isochoric. So, this line will not be like the line you are seeing where the saturation point is.

Now as we have done the rest of the We will use the same technique as we did for phase diagram. This table is the same as the one I am talking about. As an example, we have used a table of refrigerants. There is a pressure table in which the pressure is the first column. The corresponding temperature will be this. And since this temperature is a saturated refrigerant, the temperature will also change. That will be the T_{sat} . The corresponding T_{sat} of every pressure. This is its liquid specific volume. It is internal energy. This is enthalpy. This is entropy. Notice that this is specific entropy because it is per kg. It is divided by mass. So, like your enthalpy, here you have saturated liquid enthalpy, saturated vapor enthalpy, and the difference between the two is h_{fg} . Similarly, you have the same entropy of saturated liquid entropy, which is called S_f , and the saturated vapor is S_g , and this is ΔS .

So, the change in the operation is that. Now we will use this table for problem solving. So, let's solve a problem. This is a problem using Refrigerant 134A. Initially, it was 20 degrees. And its initial pressure is 140 kilopascals. Now we are cooling it. Along with that We are also stirring the pedal. The pedal is spinning. We are cooling the pedal as well. The heat is also losing. The question is how much entropy change will be there in this process. The final pressure will be 100 kPa. The final pressure is 100 kPa. The initial temperature is 140 kPa. The initial temperature is 20 degrees Celsius. Since there is heat loss, the temperature will also be lost. So, we have to extract entropy. So, to extract entropy, because we have defined entropy, ΔS is ΔQ by T when this is internal reversible. Otherwise, you will have to add this plus S generation. Now, this is a simple term, but ΔS is also a state property. So, you don't need to remove this in this case. You can directly remove it from the state property. You can use the state property reference for the table. And directly remove ΔS from the state property because it will be $S_2 - S_1$. Now the question is what is S_1 and what is S_2 ? So, to remove this, you will have to understand first what the initial condition in its phase diagram is. Is it superheated? Is it saturated or compressed? You should be able to answer this question. For that, you have to see what the corresponding saturation temperature is at 140 kPa. So, this is the table of 140 kPa, A13. Here, the corresponding temperature is T_{sat} , which is minus 18 degrees. And the temperature we have given is 20 degrees. That is, it is above. You should have more than the key set of the pressure. In this case, the initial state is superheated refrigerant. And the temperature is 20 degrees, so this is 20 degrees. Pressure is fixed, so in this pressure, S comes out. So, this is initial S .

Now the second point is, the second state, that is S_1 , 20-degree Celsius Note that this unit is also important because it is a small S , specific entropy. Note that this mass has already been given to you. So, you will multiply the specific entropy to get the total entropy. So, you will get the change in entropy. You will multiply the specific entropy with the mass, so you will get the total change in entropy. Now the question arises that how will you get state 2? So, this is the state property. Now for state 2, notice that 100 kPa is the final pressure. So, what we do is we check 100 kPa. This time instead of checking table A13, we checked table A12. And at 100 kPa, So the final pressure is 100 kPa but the temperature is not given. So, the temperature is not given. But note that the specific volume of this is fixed. It is a constant volume.

So, according to the volume, you can see that the volume. Because this operation is happening on a constant volume, so, you can use it to find out which state it is in. So, this means that first, we should check this too. How much is the volume? So, V is given here. So, this will also become important that this is here. So, this is your situation. Minus 2. this, yes, this is the one. So, the specific volume is 0.16544. So, this will be constant, this means V_2 will be the same. And you have to see that if it is superheated at 100 kPa, then this V_2 should be more than 100 kPa V_g . If V_2 is between V_f and V_g , then it is in 2 phase region. To find out state 2, I took out the 100 kPa saturation table. And noticed that V_f is 0.19255 and V_g is 0.0007. And our V_2 is in between this. Because V_2 defined is 0.16. 0.16544 This means that V_2 is more than V_g but less than V_f This is the 100 kPa saturation table We have not given any temperature so we have only seen 100 kPa saturation table and this shows that this will be in the middle This means that this is the two-phase region The final state is the two-phase region, state 2. Now you know that state 2 is two-phase. So, you can extract its quality from here. To extract the quality, you should know that v_2 is v_f plus x v_g minus v_f . So x is v_2 minus v_f v_g minus v_f . because you already have all the information so it will be 0.859 so state 2 is X_2 state 2 will be quality 0.859 now you will use this so S_2 is your S_f plus X_2 S_{fg} here the information of entropy is already given S_f is also given S_{fg} is also given and S_g is also given when you enter this then it will come out 278 kilo joules per kg per Kelvin So now Δs is small Δs which is 0.8278 minus 1.0625 And if you want to get the total then multiply it. So here comes Δs total This is multiplied by 5 kg, and this is your This is 5 kg. This is your kJ per kg Kelvin. This is minus 1.173 kJ per Kelvin. So, in this problem. This law determined entropy change for this process. Now, this is negative. Total S is negative. So, total S change is negative. This means that this system is getting heat transfer from surrounding. And there is no violation. It just says that entropy is decreasing in this system. It is being processed like this. Now, we say that entropy process will be in the same direction. in which the total entropy or production increases. But you will wonder what is happening in the negative. Actually, we haven't seen the surroundings. When we talk about S generation, then the system plus surrounding is total. Total of the system. Because we are talking about the system only. So, you can be negative in this. There is no problem. So, I hope you understood this. With the help of this example, we will move this stage forward.

Let's take some specific examples. As we said, entropy changes if you fix the mask. Entropy changes due to two reasons. First, if there is a heat transfer, it will happen. Second, irreversibility, from which the term S generation comes out. So, if there are no both, the heat transfer is also zero. and irreversibility is zero, then entropy will not change. That's why entropy is constant when there is an internally reversible system and an adiabatic process. We call such processes isentropic process. There are two things in the isentropic process, one is internally reversible, and the other is adiabatic. We assume that there are two devices in the heat engine where this application can be done. The most common example is the turbine. In the turbine, fluid comes which is normally streamed. It is at high pressure and when it goes here, the low-pressure stream is there. If you consider that there is no heat, it is adiabatic and it is internally reversible, then this entropy will be constant. And normally, when the turbine is reduced, it loses energy and converts it in terms of work. But entropy will be constant because it is an adiabatic process, and your irreversibility is zero. If you plot temperature vs S , you will get a vertical line. It will be a straight line because S_2 is equal to S_1 . So, it is a vertical line. You can understand this in another way. Where S is changing, but internally reversible, we can also see TdS is equal to δQ . This means that you can see the total amount of Q Transformed is simply integration TdS . This is the result of temperature versus entropy plot. This process is internally reversible. From this point to

this point. So, this differential amount is done. If you integrate this, the total area that will come out will be the total amount of Q that we have transferred. So, in the graphical form, heat transfer amount for internally reversible processes. So, this is what we have said through expression that $\delta Q_{\text{internal reversible}} = T dS$ and integration of this is this. This is what you can consider in graphical form. You can also do the upper unit mass in small amounts. If the temperature is constant, then you can write it as T_0 comes out. So, in such cases, you can write it in a straight line. Whether it is a point mass or a total amount. So, this is a property diagram. You can use it to draw a graphical form. Another specific diagram that is very popular and important in the industry is the Mollier diagram. And that is enthalpy versus entropy. And it looks like this. The horizontal difference is ΔS and vertical is ΔH . And it has a different importance. So, if adiabatic is steady, adiabatic means where there are no changes or heat transfer. And in steady flow condition, ΔH represents your work. So, this is called major work. It represents how much work has been done. And this measures irreversibility. This measures irreversibility. So, if the plot, the molecular diagram is very important, of course, you want the more straight it is, the more your work will be done. So, the less ΔS is, the more your loss of energy will be less and you can convert more energy to work or heat to work. This diagram is also very useful to understand the efficiency of any process. Let's understand the relationship between entropy loss and gain through the example. The best example to understand this is turbine. enters 5 Mpa at 450 degrees Celsius and it comes out at 1.4 Mpa there will be less pressure because of pressure loss and conversion is done in workout and we have been asked how much the workout is so the important thing is that we assume that this is steady flow There is no change in it, the control volume is fixed, the Δm_{CM} is fixed. So, we have to take a lot of assumptions. So, we will say that this is a steady flow. Then we will say that there are no changes in the control volume of Δm . There is no change in energy either. Because control volume steady flow means that all these changes are zero. There is no change in the control volume. There will be no change in the entropy of the control volume. So, there will be no change in the entropy of the control volume. Δs , C_v will also be zero. And mass of course $m_1 \dot{}$ is equal to $m_2 \dot{}$ will be your constant.

So, first of all, we will put energy balance in it. So, $E_{\text{in}} - \dot{e}_{\text{out}}$ is equal to Δe_{system} by dt . This is zero because it is steady. so, this is E_{in} is equal to E_{out} in this part is more which is flow so $M \dot{H}_1$ will be there and in E_{out} there is W_{out} , and this is this part which comes out W_{out} plus $M \dot{H}_2$ and we can directly call W_{out} change in and talk. The second thing we say is that it is adiabatic. And we are saying that it is internally reversible. This is the constant of entropy. So, it is said that S_2 is equal to S_1 . So, this is important. S_2 is equal to S_1 . Now if we want to get $W \dot{}$ out, we will have to get first. So, 5 MPa of 450 degrees Celsius. Because this is steam, it comes directly in superheated. So, we will consider it superheated. If you see the table of superheated, then state 1 will be superheated. You see the table of 5 Mpa, and the corresponding temperature of 450 degrees Celsius. Here you will get H_1 and S_1 . So, already the data will come. I am not deriving it completely, because it will take time, but I am telling you a procedure about how it will be. We have already received this information. So, we will review the state 2 as we did in the refrigerant case. In state 2, P_2 is given, S_2 is given, S_1 is given. Here you will see the two-phase table. State 1 is a superheated case, which we can see clearly. At 5 Mpa. State 2 is at isotropic expansions. Here it is drawn that it is at 1.4 Mpa. But it may not be here, it is two-phase. So, we don't have any option to check this. We have to check the table. At 450 mPa, we had shown that S is 6.8210. Now we have to check the superheated table at 1.4 mPa. This is the superheated table at 1.4 mPa. This is the entropy of its saturation

condition. And what we have shown that S_2 should be equal to 1. S_1 should be equal to S_1 which is 6.8 something it lies between these two 6.7488 which means that S_2 is here, and this is in this condition this is also superheated the diagram shown is correct that it is lying somewhere in the TS diagram, so this is in superheated condition Now to remove it, you have to interpolate it. Interpolate it in such a way that you have to remove H_2 . So, you can assume linear interpolation and do this. Since the temperature is given, you can remove the interpolation here. So normally interpolate it, Because S_2 is given, you can do linear interpolation. So, S_2 will come out which is 2967.4 kJ per kg. Now, S_2 has come out so your work is done. So, this will be H_1 minus S_2 . Work per unit kg. So, this comes out as 3317.2 which was the initial H_1 . And this is the initial value of 331 which we did earlier. H_1 is coming out from here 3317.2 minus S_2 2967 which is somewhere in between 0.4 kJ per kg, so it comes out 349.8 So, we have done a table-based exercise. We have not extracted the entropy from it. So, we have used the table only. So, in this way, because the process is isentropic, due to this, we have extracted the entropy from the table using the entropy constant. And then, we have directly written the workout change in enthalpy through the energy balance. And we have done the interpolation from the table values I hope you got this in time. What is entropy principle? How have we connected it with Clausius inequality? What is the meaning of S-generation in the internal reversible case? What is the production of entropy? And in what condition do we call the isentropic process? We will continue this discussion in the next lecture. Till then bye.