Engineering Thermodynamics

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Week-03
Lecture-15
Energy Analysis of Closed System

Welcome to this lecture, which is energy analysis of closed systems. We will discuss this later. This is the third part of this lecture. In this lecture, we will discuss the general energy balance and apply it to some examples of closed systems. If you take any system and it is processing something, then we can write the energy balance in a simplified form. We have already discussed this, and we are writing it ourselves. If you have changes in the total system If you have called it a system So, the total change in the system is called Delta E Systems. This change is internal energy, potential, kinetic energy and whatever is associated with it. This change will be equal to the net energy that we are transferring from heat, work or mass. So, we write it in a generic form, E in minus E out. E is a kind of representation of heat work on mask. And we can also write it in absolute form as it is written here. But if the rate changes with time, then we can also write it in the form of rate. Like if the system is flowing, like the energy is flowing continuously from a rate or the mass is flowing continuously from a rate, or the mass is flowing continuously from a rate, then we can also write it in the form of energy balance. In this way, you use the rate. Rate means change in that amount per unit time, i.e. how that particular property has changed over time. So, this system will Here you have written absolute but if you want to write in rate form then this will happen Rate, we call any rate as x dot which is dx by dt So here we are talking about energy care rate so this will be your de system by dt Here Similarly, this will also come under the rate instead of net energy transfer, rate of net energy transfer by heat, work and mass will be equal to rate of change in internal energy kinetic energy of the system so this is energy balance in rate form this you can also calculate the total quantity if you have given delta t, total time of this process then you will multiply the rate by total time you can also multiply the total quantity by the rate of the process. It is generic but you want to discuss on per unit mass It means that you take the mass as the basis If you have this process in 1 kg, then how much energy balance will be there So many times we use this That's why we change the symbol too We have made E in small e It means that this is per unit mass here is kilo joules per unit kg The rest of the equation is the same E in minus E out is equal to delta E system This is done according to the per unit kg Similarly, you can write differential forms delta E in delta E out is equal to System Now this symbol delta and this two are differential forms this path is dependent and this is exact so in this, this is exact differential and this is inexact differential and this is normally heat work The flow is path dependent, so we distinguish it. We use this symbol to show it separately.

Similarly, if you write per unit mass, then the differential form will come. delta small e in minus delta small e out and d e system. So, this is your per unit mass. So, this is a generic representation of energy balance for closed system. Now let's move forward. So, if you take closed system, then notice that closed system means that mass will not flow. Energy can flow from the boundary, energy can come, work can also happen, but mass will not happen because it is a closed system. This is the meaning of closed system So we have already seen that this is the form of energy balance which is a generic form This will also work in closed system and non-closed system because it is generic Now let's simplify it a little more Because we said that mass will not flow in closed system This means that E is only related to work or heat.

$$E_{in} - E_{out} = \Delta E_{system}$$

Net energy transfer by heat work and mass is equal to change in internal, kinetic and potential etc. energies.

$$Q_{net,in} - W_{net,out} = \Delta E_{system} \; or \; Q - W = \Delta E$$

$$Q = Q_{net,in} = Q_{in} - Q_{out}$$

$$W = W_{net,out} = W_{out} - W_{in}$$

For a cycle $\Delta E = 0 \; thus \; Q = W$

In convention, it is always said that the positive heat is positive if it goes to the system and if the work is done by the system in the surrounding, then it is positive. So, this is a natural convention. If you don't know the direction, you can assume it. If it is negative instead of positive, it means that your assumption is wrong, and you can collect the value and sign. So sometimes when we don't know the direction, we assume that the heat is being transferred and not extracted. If it is transferred, it will be positive. But finally, when we get the answer, if it is negative, it means that the heat is transferred from the system to the surrounding. So, on the basis of assumptions, you can easily do calculations.

After that, positive or negative tells you that your assumption is wrong. Sign assumption is wrong. or correct and you can define the direction of the heat or the work so this is the standard convention and we have used this here now we understand that if this was a cyclic process then what would have happened? that if you are going in a cycle in any process, then the system is coming back to the same place. If the system is in state condition, then delta E will be zero. So, for a cycle, delta E is zero. This means that in the cycle, Q is equal to W. And what is Q? Q is the net in. The energy net, the heat transfer, the heat net in Q. and w is net out both will be same in which condition? in cycle condition we can take it in rate form or dot form is it? So, this is your summary in your science shift you can say that for a cycle Your delta E is equal to 0. Q is equal to, W And these are the conditions This is the graphically Transformation of a cycle Your cycle is coming back from this point and coming back To this point And as we have The rest energy balance. for closed system because it is q and w only and there is no mass, so it is generic for closed system and it is stationary it is closed, but there is no mass flow but it is stationary there is no change in kinetic energy or potential energy so delta u is only related to internal energy you can write per unit mass like this you can bring it in small because per unit mass is there and it can be written in differential form like this This means that this path is dependent and this path is independent.

So, this is a summary. Another important thing is that mathematically, we can't prove the first law because it's an intuition. But we haven't found a process that can violate the energy balance. It's the standard nature of any system. And that's why it's sufficient proof that it doesn't violate. Let's move forward to Energy balance for constant pressure, expansion or compression process. This type of process in which your constant pressure is there in which there is expansion and compression is there. This is very common in engineering applications. Let's try to derive this. Let's start with a piston cylinder system. Here you can see the piston. This piston will move, so this will be your moving boundary Now that the mass of the piston is fixed, the pressure is fixed. Let's say P2 is equal to P1. That means the pressure is fixed. The final initial state is fixed. We will assume that the quasi-static equilibrium is there. constant pressure process. Now we will assume that there is heat, and some work is happening. So, if there is work in this. There are two types of work. One is the boundary work of the piston. The boundary of the piston has been changed. The other type of work can be done by connecting the electrical cable. So, this will be done in the other work. So, we will start with the general energy balance.

$$E_{in} - E_{out} = \Delta E_{system}$$

$$Q - W = \Delta E_{system} = \Delta U + \Delta KE + \Delta PE = \Delta U$$

$$Q - W = \Delta(W_b + W_{other}) = \Delta U$$

$$Q - W_{other} = \Delta U + W_b$$

$$= (U_2 - U_1) + P_0(V_2 - V_1)$$

$$Q - W_{other} = (H_2 - H_1) = \Delta H$$

Let's start with this example. In this example, your piston cylinder device is 25 gm saturated water vapor, and it is maintained at constant pressure of 300 kPa. Here is a resistor heater which is on the cylinder. Let's turn it on and it is passing a current of 0.2 ampere which is 5 minutes. and 120V source and in this process, your heat loss is 3.7 kJ so we have to find the final temperature so first of all, since it is a constant pressure and a closed system we will assume that this is a slow process i.e. quasi-equilibrium process in this case, you can say that the energy balance By convention, if we apply sign convention, then you know why it is positive when it is applied and transferred to the system. and w is positive if the system works on the surrounding in this way, we can rearrange this expression because we can see that the Q is out so the Q derived is done according to the convention Q net in Now since the system is transferring the surrounding, so Q is minus Q out Minus is like Qin is actually zero. And V will be negative because W is doing the electrical work on the system. So W, E Let's rearrange the work W in minus q out is equal to delta H This is your energy value If you don't do this then you should realize that if you can go back E in minus E out is equal to delta E system you can go back and from this feed properly and you will get the same expression again. Let's go because we have derived it from the convention. So, we have come here from here. Now we will find out what We in is. How will we find it out? Because we have been given voltage, current and time. And this We in will be Vi x delta t. Which we will find out like this. 120V, 0.2A and 300 seconds. It will come in voltage ampere seconds. We can convert this to kilo joules per second. Kilo joules per second is 1000 V. You can see its conversion in any textbook. To convert this to kilo joules per second, we need voltage ampere. This K is small. Now we have 7.2 kilo joules Now we have to find out the final temperature We know the q out Now we can represent this 7.2 kilo joules minus 3.7 kilo joules and delta h will be equal to h2-h1 so h1 and h2 can be taken out of the table so let's see this expression has been obtained because this is a saturated vapor so initially you have to see a specific table if you draw this is your PV diagram and this is 300 KPa here, since the vapor is this line so from here, this line is more straight because it is more in superheated vapor than saturated vapor so this is 1 and this is 2 so we will see the initial 1 point from the saturated vapor table and 2 point, state 2 we will see it in superheated vapor we have to extract the data from the S2 table so let's try first notice that this is the saturated water table which is your A5 table here in 300 kPa this is your saturated vapor Hg so this is basically H1 now if we want to extract S2 then we have to find out first we have to extract S2 After this, we will find out which column of the Superheated Table fits with the temperature. First of all, we already know the data of H1. Because we know the temperature, pressure, condition and state. That is your saturated vapor. So, H1 is found on 300 kPa of saturated vapor. So if you get H1, you will put it back in this equation which we have put 37.2 kJ. we know it your mass is 0.25 kg and this is H2-2724.9 and this is your kilo joules per kg because you have multiplied it with mass so it will cancel so it will come in kilo joules from here you will get S2 is your 2869.4 kilo joules per kg Now, what is the temperature? What is T2? T1 is already given here, the saturation temperature is 133.52 degree Celsius but T2 is not asked so to get T2, you have this information given that because it is constant pressure so essentially in your PV diagram this will continue to run Now, we have to remove the enthalpy. It is superheated but we have to remove the enthalpy. The pressure is 300 kPa which is 0.3 MPa. We have removed the table. Now notice that this is your first saturation column. This is 150 on the table, this is 200 degrees Celsius and this is 250 degrees Celsius and this value H2 this will come, look carefully, so this is around 2865.9 we can take out the exact value, but let's approximate it that this is 200 degrees Celsius We can do linear interpolation between these two points But we have approximated T2 because there is very little difference Here the difference is more than 100 kilojoules per kg in 50 degrees And since there is only a difference of 4 in 2865.9 and 2869.9 So we have approximated it We can also interpolate it and get the exact results to apply this understanding. We have taken a simple example.

Now let's move forward. Now let's pick up the second question. This is your unrestrained expansion. So unrestrained expansion. What is in it is that you have a rigid tank, that is, the volume is fixed to your total rank, which is divided into two parts. In the beginning, it is empty. And there is a partition inside which there is water. There is a mass of water, pressure and temperature. When the experiment starts, we remove the partition. The partition is removed, and the water vapor can fill it. After that, it can fill and expand. Along with that, we also give heat so that the temperature of the tank reaches the initial temperature. So, it means that you removed the partition and expanded it. When you normally expand it, the temperature will be a little less. So, we also heated it up so that the temperature comes back to normal. So now the question is, first we have to know the volume of the tank, final pressure and total amount of heat transfer. So, this is the question. So, first of all, since the mass is fixed, we can get it out of the table. 200 kPa First we will check the table. Was it in saturated condition or superheated? Or is everything cool? So, let's see table 4. Here we have 25-degree Saturation pressure is this and our pressure is very high In this condition, this is our compressed liquid. So, this is the compressed liquid. We can also approximate it by assuming that the initial volume of V of this part, this solid region, is the volume of your fluid at 25 degrees. So, we take the specific volume of liquid which is here T K.

This is the specific volume, small v. What is the water volume? V1 is equal to mV1 Do you know the mass? Do you know the specific volume? So, 5 into 0.001 So, this is your 0.005-meter cube So, how much is the total tank? Because it was split, half of the tank So, this is 2 times So this is the first part, volume is out Now we will see the second part In which we are told to remove the final pressure and heat transfer Final temperature is 25 degree Celsius and final volume is V by M so this is V2 by M so this is 0.002 meter cube per kg If you look at table 25, the volume is between VF and VG and the specific volume of the final tank is between these two. VF is at 25 degrees Celsius and VF is at 0.001. and VG is 43.34 V2 is in the middle of VF What does this mean? It means that because it is in the middle of specific volume of the fluid and specific volume of the gas in this condition that's why it is a saturated liquid vapor mixture It means, if you look carefully So this was the initial one, one compressed liquid. This was the initial compressed liquid. And from here, when the expansion happened, it reached 3.17 kPa. Why? Because when the saturated liquid vapor is done, The pressure is P sat. What will be P2? P sat. Because it is 3.168. So, this is the first one because the final state is 2. Now the third part is about the heat transfer. Since this is heat, we have to get heat transfer. So, we will get simple E in minus E out. This is delta E system. And in this we will take simple delta U because delta Ke and delta Pe system is stationary. So, there are no changes in the height of the system. So we will effectively neglect the system of Delta P and Delta K So we will have Delta U And E in minus E out Because it is Net Energy Transfer by Heat Mass Work So because it is Q in So it is Q in So the same energy is transferred from outside And there is no work here Because the boundary of the system is fixed this is internal Because it is not in the system So it is free expansion So there is no work Qin-0 is equal to delta u which is mu2-u1 and u1 is equal to u1 and we will approximate u fluid at 25 degree Celsius of compressed liquid now we have to find out u2 what is u2? uf plus x ufg x you should know which is quality now we have to find out x What do we need to remove the XM? v2-vf-vfg we know v2 is given here vf is given in table so this is 0.002-0.001 vfg is And here I have EFG. 43.340 minus 0.00 So this is 2.3 x 10-5 So we apply this here This is your 1 And we will take out the internal energy This is your uf And this is your ufg Ok So this is your uf 104.83 kJ k g plus 2.3 into 10 to the power minus 5 multiplied by 2304 multiply it with this and simplify it because it is very less, so the changes will be very less so it comes out 88 kJ per kg this is your U2 now we will put it in this and we will multiply the mass given by 5 so what is Q? Q means 5 x 104.88-104.83 so this is 0.25 kJ this is the minimum amount of heat we will have to transfer to water so that we can bring the final temperature to 25 degrees Celsius. I hope you have understood these steps. You will get to practice a lot through the exam assignment. You can practice these questions. There are many problems in the test book that you can practice. In the next lecture, we will talk about specific heat. So, let's close this particular lecture. See you in the next lecture. Till then, bye.