Engineering Thermodynamics
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Week-03
Lecture-13
Energy Analysis of Closed System

Namaskar! Welcome to a new topic in this lecture. This lecture and its parts will be on energy analysis of closed systems. Meaning, where mass is fixed, your system is fixed, there is no flow. So, we will discuss the closed system. The main aim of this project is to know about boundary work or PDV work. This is a very important and common work that you get on many devices like automobile, engine, compressor etc. After this, we will talk about the first law of thermodynamics and how to use it on a closed system where you have fixed mass. and then we will develop a general energy balance on the closed system and formulate it and how it is solved and then we will discuss the specific heat and where it is used and finally we will know about the incompressible substance and we will try to understand some examples of these topics and hope that the concept will become clear after this So first of all we will do the work When we discuss the work, the definition of it is that force acting through a displacement. you can take any displacement of the force so when we discuss the work, so this force multiplied by displacement. This is the force in which the displacement is in. And when you take this small work and take a small displacement like we call it differential, dx then this is delta w. And if you do this a lot of times then you can add small work. and when you add it, the forms are written in an integral form so from here it will come in an integral form so this is integral and this is integral, so this is your work so this is a very simple and very common definition but you can understand it in different ways sometimes you will not see that an object is displaced It means that something has moved. There are many examples of this. If a wire has been stretched, then this also works. Or a charged particle is moving in the magnetic field. Then also it works. There are many examples of this. The definition of your work can be used in this. A generic definition is that if you do any work, like work as they say, which a system does, then it does it on the surrounding, means the external things of the system are surrounding. And if work has been done, then you can understand it as one effect; if there is a weight attached to the system, then that weight It can increase the height of the system. It means that if the work is done, then the sole effect, i.e. the one-time effect could be raising of a weight. It means that any weight that is connected, you can imagine that something is connected with the system and the weight is increasing because the work is being done by the system.

Let me explain it to you as an example. As you have read before, we have discussed that work or heat of work can only be recognized on the boundary of the system. So, let's take an example. This is your battery motor system. So, this is your battery and motor, and this is your system. And you are using the battery to run the fan from the motor. So, if you look carefully, there is a displacement in this too. Because the force of this is kind of rotational. So, this will work like torque. If you understand this statement, then you can replace this with a pulley weight system. If you imagine that you put pulley and weight in place of fan, then the shaft of the fan will rotate slowly. So, this question can be understood that this work is crossing the boundary, means the system is doing it on the surrounding. And as the motor rotates, the weight goes up, so one of its effects is basically raising weight. So, this is kind of a definition of work, which is commonly used in many books, you must have seen it. This means that the system has worked on the surrounding and the effect of the system on the surrounding is only on the weight gain. So, you will get many definitions of this term. Now let's talk about boundary work. So, if you notice the boundary work, then you can understand it easily as an example of piston cylinder. So, this is an example, this is your piston, and there is an area of piston, and this is your force, which is coming from outside, from surrounding, which we have called external. external means outside the system and a gas which is on the cylinder that is also due to the force of the gas so our interest will be what will be on this that this F external that the force that we want So, if we push the piston slowly, the gas will be compressed, and the volume will be half. So, these questions will be important for us. In this case, the external force F is very important.

Secondly, you can also think that if the heat is given from below, then the gas will expand. In this case, how much force is felt by the surrounding area? So, both these things are important for us. Whether it is compressing or expanding, the force on the outside is more important for us. That is why when we write its definition, which is the definition of it in a general way, the mechanical work, which we will call boundary work here, simply f external multiplied by the displacement.

Now if we write f external in terms of volume then it can be written as if we multiply and divide it from the area then it is multiplied and divided so this part because the area is constant This is not changing, it will always remain the same. So, we can write this in the form of V. And this part F divided by area is P external. So, your work, the differential work, that is, the small amount of work, when the displacement is your dL and the volume change is your dV, we can write P external multiplied by dV.

Now this question will come to your mind that what is the difference between the P external and P internal? and it can be different in real application we will understand that this process is happening very slowly so slowly that your force this force is coming from inside and force means that pressure is your Because the area is constant, you can say that it is P internal. There is very little difference between P internal and P external. The difference is almost negligible. There is very little difference. As you can assume, it is the same. As we have written here, it need not be equal. It is not necessary that the P external is outside and the P internal is inside. equilibrium, the process is very slow. The changes that are happening, if the process is expanding, then it is changing very slowly. It is changing so slowly that the P internal and P external are almost equal. Because the area is constant. So, this condition is called Quasi-Static equilibrium because we know that whenever there is an equilibrium thing, forces will be balanced. But Quasi-Static means that the process is taking place slowly as if at any time we can understand that it will be equal. One more thing you have to keep in mind is that this P internal is attached to the surface of the piston, but your pressure is also present in this gas. This can also change. When we call it a quasi-static or quasi-equilibrium system, in such a case, we say that P internal pressure is total pressure. It means that the same pressure will be applied here when it is here. This is called homogeneous. In quasi-equilibrium, we assume that the forces in the gas and the changes in the properties are Homogeneous. So, the first thing to understand is that if any boundary moves, then the work that is connected to it is called boundary work. So, the definition of boundary work is that this boundary is like a piston cylinder. Because the piston is up and down, the work that is connected to it is called boundary work. As we said earlier, in this differential form, the boundary vacuum FDL can be called. If you look at this picture here, so here, Initially, it was like this, here its pressure was P, as shown in this. And the change of displacement is ds. So, the work done for this, the differential amount of work is del V, and that will be the force, which is the external force, and the displacement is ds. So, we can also call the external force P times A, as we wrote earlier. and this is called PDV. And P here is always external LED. So now when we integrate this, this is your total. Total work boundary work is integral of 1 from 1, meaning 1st position, which was the initial position, initial position to final position. This total work will be a process that has happened between 1 and 2. This will be a similar expression for expansion, same expression will be there for compression. Now, the important thing is that you can ask this question that how we will understand when you calculate the expression how we will understand that this work is done by the system or by the surrounding. So, as you are intuition, you will understand that when there is compression, then naturally what will happen in compression is that your surrounding system is working, that's why your gas is compressed. When the gas is expanding, the system is working on the surrounding. The definition of work is that when the system is working on the surrounding, it is called positive and when the surrounding is working on the system, it is called negative.

Expansion means that the system works on the surroundings. So, in this case your WB will be positive. WP will be negative in compression because surrounding It works on the system. So, this is important for basic rules and understanding. Let's move on to the discussion. We will talk about this specifically. We will talk about the Causie equilibrium process. When we define this process, it is that this is the process where your system always It is in equilibrium. Nearly, or you can say it is in equilibrium. It means if you have done a process suppose you have started from 1 and you have to go to 2 Let's understand this piston cylinder which is shown here Initially, this is an expansion this is from 1 and this is a PV diagram and this is your initially volume is on V and from V you have to go to 2 to V2 and this process You are completing this with the help of the And slowly, at every point, it is expanding. And at every point, there is equilibrium. Equilibrium means that the system will be the same in all the properties of the gas. And of course, P internal and P external will be the same. This is the definition and the definition of this. When you do this, so in this case, area under the curve, as we have said that PdV is our work, so area under the curve which you will see here, this will be your total work. As you have noticed earlier, when all these are integrated, in the PdV diagram, in the P versus V diagram, from process 1 to process 2, all the areas inside are related to your work. That is your boundary work. So, if you have done this process, this quasi-equilibrium process, you can graphically also find out how much work is there. Now let's take an example that if you have state 1 and state 2 and by any means you have decided 3 processes A, B, C which are shown in this and its path is different so in such a situation you notice that since you are in quasi equilibrium So you can integrate WA into pdV Similarly, you can integrate WB and WC So in this case, 1 to 2 is the same formula According to the definition According to the definition, you will get pdV in all three But the path is different And this area is different with it This is your WC and on top of this area will be your W and you can understand that WC will be smaller than WC, WB will be bigger than WA because the area under the curve is different.

Now, In such a situation, if you have a system of network, which works on the surrounding and then comes back to the surrounding system, then it is not necessary to have the same path. This is an example of a cycle. We will show you the PV diagram. We started from 1. And the process is B. It is a path. We went from 1 to 2. And after that, if 2 is the initial state of the system, if it comes back from 2 to 1, then it comes through a different path, which we defined as A. In this case, the net Work will be initial work of W122 and W221. So, what will be the net? The Net will be W221-W122. So this is a simple graphically you can understand that this is a network and this is a very important and very simple example but it is an important observation because this type of cycle is usually used in engineering devices so you can understand this example by using this example which is piston cylinder Now, the piston cylinder that went back to 1 to 2, if we say that it has to come back to 1 from 2, then the path will be different. Because now the surrounding gas initially, let's say, was at high temperature pressure, and thus it expanded and stopped somewhere, where the pressure outside the surrounding pressure was equal to that. Finally, you can understand it in another way that it is slowly heating up and slowly it is matching with the pressure of the surrounding You can understand it in a way that the piston initially used 1-2 process in which the gas is expanding and now it has to be compressed from 2 to 1 so the surrounding system and the path of this will be the same as the effective network but the same as the effective network The question is how to optimize the network because the network is more or less depending on the device you are using. But if you are doing this on 2 to 1, then this is your path. your body is coming out. I hope you have understood the concept of boundary work.

Now let's take 2-3 examples of how it can affect you and how you can solve problems. First of all, we will take a boundary. work for volume processing. Take a tank, it has a closed system, its mass is fixed, it is air, P1 is 500 kPa and temperature is 150 degrees Celsius. Now we cool this air, the pressure and temperature will be reduced. I don't get the upper. So, what will be the boundary work in this process? So, this is the question. If you notice, this is a closed container. It is rigid. It is in a simple box or container. If you understand it in this way, that it is pressure and volume, initially, the pressure was 500 kPa. This is 400 kPa. and this is how it looks between 1 and 2 because the volume is fixed and volume is fixed means area under the curve is 0 so if we see WP So this is zero, this is zero. W is always zero for a constant process. So, this is a simple example. Similarly, you can take another example. And that is the constant pressure process. Let's take another example. We will consider a piston cylinder as a device. So this is your piston, this is your P-atmosphere and this can be any mass you can take anything this is not important what is inside this system? That is 5 kg steam 400 kPa pressure 200-degree Celsius temperature Now consider that heat is applied to it by which your final temperature will be So this is T2, this is P1 and this is T1. Now the question is that in this process, what is the work boundary of Wb? So, the first question is whether the pressure is constant or not. the pressure applied to the outer surface is fixed we assume that this is a quasi-static equilibrium process meaning that when heat is applied, the changes are slow and the volume changes, but the pressure is fixed So, P acting which is applied to the system, there is no change in that. Because the external atmospheric pressure and mass of the piston is the same. That is why the pressure applied to the system is the same. So, Wb is PdV. I can write this as PdV. and since its mass is fixed, I will remove the mass from the system and in the specific volume this is your PM Specific volume 1 to 2 and this is your V2-V1 I will write it again Pressure constant mass of the steam and this specific volume of steam which is at the second state and this is V1 So this will be your WB Now let's solve it to see what value it will get So the first question is that we are dealing with steam, if it was air, we could have assumed that it is an ideal gas and solved it. Because we are dealing with steam. So, we have to understand in what state it is saturated, superheated or not. So, first of all, let's see the saturated table and 400 kPa which is your table A5. Let's see the T-Sat of the 400 kPa saturation pressure table. T-Sat is 143.61 degree Celsius, and temperature is 200 degree Celsius The T-Sat is the line of the isotherm. So, this is the T-Sat on which this is a two-phase system. This means that all the superheated will come out on top of this. Because the temperature of this pressure is 143. and this is above your T-sat so this comes out superheated That's why you have to see table A6 and you should see table 400 kPa which is 0.4 MPa.

Now, when you see this table at 200 degrees Celsius specific volume is 0.53434-meter cube per kg 250 is 0.59520 m3 kg This is your initial specific volume which is V1 and this is your final specific volume which is V2 Now you have all the information Now you have all the information and you can solve it by putting it in the equation. Let's try that too. So, what was your Wb? Wb is your V2-V1, and your pressure is 400 kPa. Mass is 5 kg V1 is 0.5952 V2 0.53434-meter cube per kg This is meter cube per kg If you want to convert this into kilo joules 1 kilo joule is 1 kilo pascal meter cube. Now you can cancel this. Like kg has gone from kilo pascal, kg and here meter cube has come. So, this will be cancelled. Kg has been cancelled from here and meter cube has been cancelled from here and kilo pascal has been cancelled from here. So, this comes out. 121.7 kilo joules. So, this is a positive cube. This is positive. What does this mean? Basically, you can say that this system is working on the surroundings. This means that it is expanding and expanding means that the system is working on the surrounding. That's why it is positive. System. doing work means working in the surroundings. Now if we show this in the PV diagram, then we show it like this. PV, so this came 1 to 2. And this is your area under the curve, which came out as WB. So, this is your boundary work for a constant pressure process. Now let's take one more example. This is your piston cylinder which has air. The initial volume is 0.4 m3 and the pressure is 100 kPa. It is compressing from 1 to 2. And the final V2 is 0.1 m3. in this process temperature is constant so we have to find Wb now Wb is PdV we are assuming that this is a quasi-equilibrium process and it is an idle gas so we can say that Pdv is equal to mass is constant and gas constant is also fixed and the temperature of air in the air is constant so I can write P as C by V so when I wrote C by V dV 1 to 2 because C is constant so C ln V2 by V1 and we can write C as P1V1 because C is constant so P2V2 is also constant so this is P1V1 I know P1, I know V1, I know ln2 So now we can put its value The value we are putting is 100 kPa Volume is your initial point 0.4 m3 and Ln is 0.1 by 0.5 and we can also put it in kilo joules 1 kilo joules by 1 kilo pascal meter cube so it finally comes out as minus 55.5 kilo joules And this is negative, It is working on the surrounding system. This means that this is your Wb. It is working on the surrounding system. And this is a compressive system. And this is a compressive process. It means that it always works on the surrounding system in compression. That's why your work by definition always comes negative. So, compression work is always negative. Because it works on the system, the value is always negative. So, you can understand this. As the expansion happened, the expansive work happened, the positive and the compressive work happened, your negative. So, this was the main topic of this lecture, how to describe PdV and understand it. And we have explained different processes through many examples. We will continue this in the next lecture. So, we will meet again in the next lecture. See you soon.