Engineering Thermodynamics
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Week-01
Lecture-5
Energy and Energy Transfer

Namaskar! Welcome to the second part of Energy and Energy Transfer. Welcome to the second lecture on Energy and Energy Transfer. Last time we discussed the types of energy. And also discussed internal energy and heat and work. Today specifically we will discuss work in this lecture. Work is also a form of energy transfer. Work is a form of energy transfer. Like we said, when a system is transferred from one system to another, it is either in the form of work or heat. Work is like heat.

Heat is caused by temperature difference and work is caused by displacement. force acting through a distance is So, in any particular work, a force will be associated, and the energy transfer will be in the form of a force which travels through a distance. That is why it is said that work is the energy transfer associated with a force acting through a distance. You have a force and a distance that is traveling. And because of this, your work is associated. So, we can also see the work as such that delta w is F, your force and any specific distance that is traveling, called dx. There are many forms of this. There are many examples of this. You can see the example of rising piston. The piston rises or the shaft rotates like this. And then what is not visible specifically. There are many things visible like rising piston and shaft. But like the electrical wire that crosses the boundary system. The current flows in it. This is also a kind of work. So all these examples that we have told here are all examples of work. And its unit is similar to the one in heat, kilojoules. So, in the same way, joules will be a unit. And normally we write in the form of kilo joules. So, if a system is working or the system is working, then naturally your energy is transferred from the system. in the surrounding or other system so the state of the system will change in this process the initial system and after that the changes in the system will happen in different states that's why we say that work done during a process between state 1 and 2 these two systems The two states of this system were initially there when your work started. When the process was completed, the state changed.

The energy transfer between the two states was W12. We can simply call it W. When you divide the mass, it will become w. As we have discussed earlier, we can identify heat and work only when it crosses the boundary. So, in general, the kind of work that is transferred is called boundary interactions. Okay, so we have studied about heat earlier, which is due to temperature difference. And work is your acting through a distance. And sometimes we describe work per unit time. In this case, we often use power. So, the second smaller symbol of this is the W dot. W dot means your work per unit time. Okay. So like delta W by something like DT. Okay, so now we will talk about convention, which normally we use sign convention in thermodynamics.

Many books are presented in different ways, but it is only important to simplify the calculation that you solve. And as long as it is uniform, that is, you always use the same sign convention in any form, it is easy for you not to make mistakes. But there is no specific rule for this. But in this course, we are specifying this. If you don't have a direction, then using a sign convention will be beneficial for you. So if heat transfer is happening on the system, we will give it a positive sign. Okay? And if the work is done.If the work done by the system is working, then we will call it positive. But if the work is being done on the system, then we will call it negative. And heat transfer on the system, then we will call it positive. So, this is a generic science convention. But if you already know the directions, then you can directly use it. After that, we will try to do a couple of things from the example, if you know the direction of the energy, you can easily show it. Similarly, work in work out. This direction is shown, but if you don't know the direction, the heat is transferring energy from the system to the surrounding. You can apply a convention and say that this is a positive heat transfer. And then you can do the calculation. So, as I said, this is an important element. We will do this with the example. So, this heat transfer to a system is positive. And the work done on a system will be negative. So, if the work done on the system is happening, then it is negative. And if the heat transfer is happening on the system, then it is positive. Both forms are boundary phenomena. As I said, it is boundary work. Until they cross the boundary, it is not recognized. When they are connected to the system or surrounded, they will be in the form of energy. In the form of internal energy or any other form. That's why they say that the system possesses energy. That is, the energy of the system. It does not have heat or work. The difference is how we convert that energy into heat or work. This is a different topic. This is the second law that we will discuss. But in any system, you have energy. But we do not say that it is heat or work. Until it is not on the boundary, between two systems or in the surrounding system, the form of energy remains internal energy or system energy. Both types of boundary interactions depend on the process. It means that they do not depend on the final state.

In a final state, your properties will depend on the state of the system. But the work you did in this state will depend on the path you took and the form you tried to transfer. process state in path and it depends on the path and the magnitude of the work not on the final end point so let's try to understand this more heat vs work as we said let's take any other property for example, you consider that you have a particular system in state 1 and state 2 the volume difference is delta V ok so initially let's say you can say that initially when it started the initial volume of this system was 2 m3 and when we process it any process which is changing the volume it becomes 5 m3 ok so The process you have done, which you are changing the system, its volume, you can say that we have 2-3 processes, we said that we will try to do it on 2 processes. Let's consider that you have a process in which you are changing the system from state 1 to state 2. And this PV diagram shows pressure versus volume. State 1 is 2m3 and State 2 is 5m3 You have changed from 1 to 2 by 2 processes Process A In this, your work is less Area under the curve is less and in the second, your work is more Process B So this is your typical work kind of behavior It means that this is path dependent You have to understand that work depends on the path And the most important thing is that this is not the exact differential. Like any other property that depends on the state, like you have considered volume here. So, this volume is a state property. So, you have taken out the exact differential. So, when the integral is 1,2,2, then V2-V1 and delta V. But you can't do this with work. That's why we write work in delta v and not in d And its integral is simply work 1,2 not capital delta w They can't do it like this because work and heat are not system properties When we cross the boundary you have transferred from one system to another it depends on that and it also depends on the path that's why it is not exact and changes can occur that's why you can't write this as delta w similarly, your heat is also like this heat is also your path function So let's consider some examples of path-based work and specifically different kinds of work that we know about.

Let's try to understand it through examples. First is electrical work. Here you have seen that there is a circuit in which there is a resistance, and this is your current, V is your voltage and it is against it, which is dropping. And we have defined this work. So, it is a typical force and this is your specific distance this is your coulomb of electric charge So, electric charge is the same charge when your per unit time is over then this current is generated and if your per unit time is over then this is your power from here So, basically your work As I said, this is a form of force into distance or force applied to a distance. So, there is a force in this also and this is your kind of a distance. the amount of charge the more amount you have the more your work will be done and if you do it for a period of time it will come in power you can convert it V, I and then V into I R current into resistance and it can be written in this form ok so as I said this is in power form if you you have to find the total work in between t1 and t2 you can integrate it also but from t1 to t2 t1 to t2 is the variable t1 to t2 and you can find the total amount of electrical work between t1 and t2 as we have written in this case so this is your example in electrical work unit of this is kilo joules so this is your example Okay. It is not moving mechanically.

The mechanism of the electric current is different. But still, it is moving. That is why we call it work form. But here it is a mechanical form in which your boundary is moving. In the electric current you will not see the boundary moving. But yes, your charge is moving in a distance. If there is no movement, then your work cannot happen. So, if you are sleeping, lying down, and you haven't moved anything, then imagine that there won't be any work in this. So, this is an example that you will have to move to get work done. So, the basic definition of work is force into distance. As we said, this is mechanical work. In general, you can define work in such a way that force is a generalized force. Meaning, any type of force. And distance There is a kind of a distance which is different in every form. Here the distance is the boundary distance, the boundary which is moving. If the force is not constant, then we cannot write like this. Then we have to integrate. Okay. And then the number of ds, the very small amount of movement, we will call it ds. And then we will integrate it with f ds. This will also be in kilojoules. So, work done is definitely. You can say that the work done is proportional to the applied force. The applied force's diaclip is proportional and the distance traveled is SM. The second is shaft work. So, in shaft work, we can consider the example of a boat. In many practical examples, the shaft work is done. In many mechanical equipment, the shafts are connected. But you can understand it like this, if you have a rotating device, like here we said that there is an engine, this is a shaft, this is rotating, then if you take its cross sectional, then it will come out like this.

You have this surface, and this is a kind of shaft, like a rod, and it is rotating N dot, means the number of rotations per unit time. How many times it is rotating in a unit time. Okay, that's why it is called N dot. force is acting on it you can see here radius of this disc is r so if we understand it as torque force is acting on it its moment arm is r so torque is force multiplied by the moment arm which is your distance which is your radius force times radius, your moment arm will generate torque. So, force, torque divided by moment arm, which is radius of this particular disc, is yours. Now the question arises how we will typically remove force. If you have torque, then the force will be removed from it. But then how will we remove the work? To find the time, you have to know how much distance you have travelled. This is the rotating device. How much you have rotated in the rotating process. Rotation will depend on the number of rotations per unit time. You can also find the time like this. First, you have to understand that when you rotated once, how much distance you travelled. So, the distance is nothing but the length. This is the circumference. So, this is your distance. So, this is your $2\pi r$. Okay? And If it rotates once then it becomes $2\pi r$ If it rotates n times then it becomes $2\pi r$ multiplied by n So this is distance So the shaft is working force into distance Force is T by r multiplied by distance S is 2πr N is the distance you have taken from here And this r is cut 2πnT which is torque Usually torque is defined, torque is part of the specification. So, torque you know, the total number of rotations is 2π. Total is connected to the circumference.

Now if you want to get power out of it, you have to say per unit time. So, when you did per unit time, it became W dot. It came in your power form. And this N is N dot. Rate of rotation, i.e. how fast it rotates in each unit, this is the end dot. So now you can see that the shaft work is proportional to the torque. It is proportional to the torque. And this is proportional to the number of rotations. So, this number of rotations is also proportional to this. So, this is a form of mechanical form. Let's see spring work.

Spring work

$$\delta W_{spring} = F\ dx$$

$$F\ = kx$$

For linear elastic springs, the displacement x is proportional to applied force.

$$W_{spring} = \left(\frac{1}{2}\right) k({x_2}^2 -\ {x_1}^2)$$

Work done in elastic solid bar.

$$W_{spring} =\ \int_1^2 \sigma_n\ A\ dx$$

The unit of normal stress is the unit of pressure. This is applied to solids. We use normal stress for solids or general word stress So in force x distance we replace this Normal stress x a x dx, so this is related to one kind of elastic solid bar So a is your surface area which is the surface area of solid bar Okay so second One of the most interesting mechanical forms of work is surface tension work. Surface tension work is when the surface tension is applied to the area of the surface. the surface tension is applied to the area of the liquid surface. If you extend or compress the area, it will work against that particular force. For example, if you take any film, it can be your soap film, and if you put it in a wire mesh, it has two surfaces. One that you can't see, which is on the opposite side. And one that is this surface. So, these are your two specific surfaces. And if you have this wire mesh, if this particular wire is movable, then if you try to pull it a little bit, then it will try to increase your surface. And this will work against surface force. So, what will be the surface force applied to this? So 2 is your specific area which will work on it So specifically the force which is applied Because force is The definition of surface tension is Force per unit length And if you work on it So basically your surface tension will be multiplied by area So if you force you have to overcome the force that is working against it so you have to understand that the force that is equivalent to the surface which is the balance before pulling it almost imagine that you are slowing down so much that the force that is applied is matching the force of surface tension or equivalent so that will be your σs let's assume this is your surface tension There are two particular surfaces, one on this side and one on that side. The length of both surfaces will be 2 times p. So, this is the actual force that you are pulling. Now it depends on how much you have to pull. Delta W will be there Let's assume the differential work F into R del X And this is your Sigma S into 2B del X Now if we integrate this Then your total work will come Which will come in the case Now, we can also call this thing That your Sigma S is DA

Because DA What is this? This is nothing but DA And here DA will be on both surfaces Which is on this side and the other side as well. We will capture both the surfaces. As the DA says here, 2bx is the change in the surface area of the film. There are two surfaces in it, so 2x2 is applied. So, this is a mechanical form of work. You can understand it that eventually you have to find out the force that how much force is there, what type of force is there. In general, if your force is not mechanical, then you can say that it is a generalized force and a generalized displacement. So, this is your generalized displacement, that is, a form of displacement. This is a very common definition, whether it is mechanical or non-mechanical, whether it is electrical or magnetic. and different forms of work. In all these forms, this definition will work. This works. This is a basic fundamental definition. And it is important to understand that it takes a type of force, and it works in any direction. And this direction is generalized displacement. Displacement does not mean that a boundary will always move. When the boundary moves, it is mechanical.

Now let's discuss that if you raise your body in a gravitational field, then naturally its potential energy increases. Similarly, if you accelerate anybody, then its kinetic energy increases. If there is no temperature difference between these two things, then definitely the change will be due to work. For example, if you have an elevator, like a lift, and its height is increasing, then the energy that we transferred basically went into its body. Because we worked, its potential energy changed, so the potential energy changed, which means its system energy increased. So, if the system energy increased, then the question is, what form is it in? Is it through work or heat? There is no temperature difference in this, so we will understand that this is due to work. So, these are two statements. The first statement says that work transfer needed to raise a body is equal to the change in the potential energy of the body. Means that the amount you spent on raising the body, the amount you spent on changing the potential energy of the body. or equivalent to potential energy change. Meaning, the work transferred has been transferred to potential energy change. This energy conservation concept is required. Second, the work needed, the second statement is, the work transferred needed to accelerate a body is equal to the change in the kinetic energy of the body. to accelerate the body will be equal to the change in kinetic energy of the body These are two statements of the concept of energy conservation It is said that there are no temperature differences So whatever you did, whether it is mechanical or non-mechanical work or the whole system either changed in kinetic energy or in potential energy Hope you understood the concepts of work and different forms of work. In the next lecture, we will talk about the first law of thermodynamics. See you in the next lecture. Thank you.