Material and Energy Balance Computations
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Lecture –38
Introduction to Energy Balance - VIII

Welcome back. So, we were talking about processes and we have now understood what cyclic process is. So, we will now quickly try to understand what a reversible process is and then move on to the constituent components of energy, which is very important.

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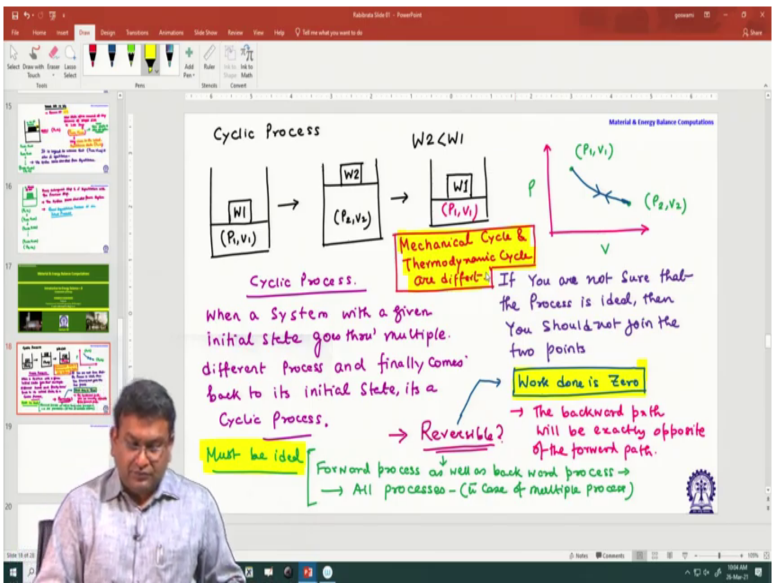

So, here we were talking about the cyclic process. Now, is every cyclic process reversible or not. So, what exactly is a reversible process? Reversible process means that whatever is the forward path of the process is the backward path of the process also. Or, the net work done after a reversible process is actually zero. Why? Because many of you know though we have not formally defined the pressure for a cyclic process you will soon see the work done is the area under the PV curve.

Reversible process is a process which is fully reversible. that is the forward path and the backward path will be identical and exactly opposite. Now, the problem is that in order to traverse the forward path backward, you need to know the forward path. And, for a regular process, if it is not mentioned that is an equilibrium process or a quasi equilibrium process; you do not know the forward path. that is clear to all of you based on our discussion.

Therefore, reversible process is possible only for an ideal process. So, reversible process necessitates that both the forward process as well as backward process or if there are multiple number of process, all processes must be ideal. So, this is a necessary condition for having a reversible process. The work done in a reversible process is zero. this is something we may be talking in detail later.

There is a fundamental difference between a thermodynamic cycle and a mechanical cycle. For example, a two-stroke or a four-stroke engine where a piston traverses back and forth in a combustion chamber is actually a cycle but that is a mechanical cycle. So, what happens here? You have chambers on both sides where fuel and air come in and you compress it. And, you spark it. Therefore, it ignites, and the volume expands. So, the piston moves on the other side and the wheel or the axle is essentially connected to the piston in some way or the other. So, the piston travels back and forth. So, the piston undergoes a cyclic motion. now that is a mechanical cycle. But since the chamber every time after the combustion it opens up and the exhaust gas goes away its not at a thermodynamic cycle.

So, this is an important point of distinction which is not that much important to chemical engineers, but it is important to know nonetheless that mechanical cycle and thermodynamic cycle and thermodynamic cycle are different. I will not drag on any discussion on this. but I recommend you consult some literature or textbook.

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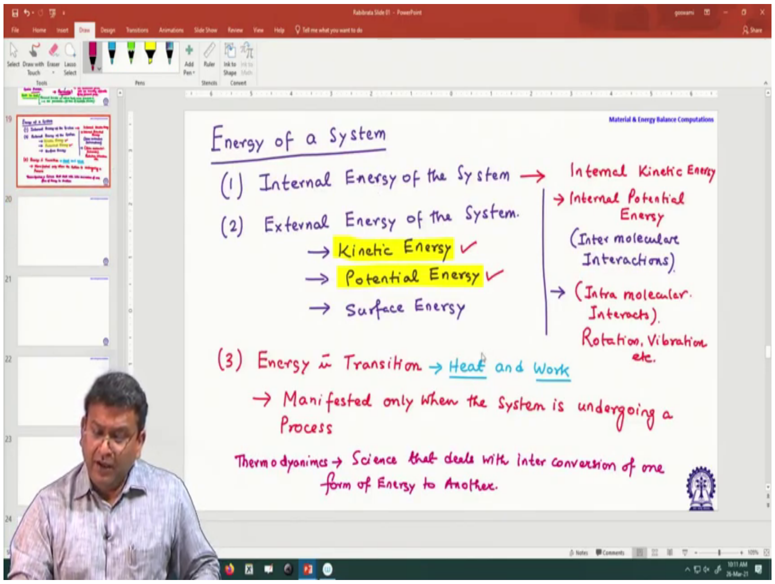

Now, we essentially move on to the constituents of energy. When we talk about the energy of a system what are the constituents. So, the constituents of energy are (1) internal energy of the system, (2) external energy of the system.

External energy of a system is also classified in 3 categories: (a) kinetic energy {for a dynamic system if the system is moving}, (b) potential energy {identical systems at different elevation actually have different levels of potential energy}, and (c) surface energy. primarily if you go by classical thermodynamics, we are limited to kinetic energy and potential energy. So, a ball resting on the ground floor cannot fall down but a ball that is on the on a 10-story building can actually fall down. So, the ability of the ball which is at a higher floor or a higher elevation to fall down is due to the fact that it has higher potential energy the ball which is already resting on the ground has no additional potential energy and therefore it cannot change its configuration.

Internal energy is also classified in three categories such as: (a) internal kinetic energy, (b) internal potential energy {intermolecular interactions}and (c) intramolecular interactions (rotation, vibration etc.). So, internal energy; says consider a system to be a gas. we all know kinetic theory of gases. So, the gas molecules roam around. So, that they have kinetic energy. So, its internal kinetic energy. then there can be interaction between these molecules or particles. So, they can have that is what is known as internal potential energy. of course, ideal gas molecules the molecules of an ideal gas are not supposed to interact amongst each other.

But from the ideal gas equation, the moment you go to Van Der Waals equation of state you have additional correction factors $(P + A)/ V^2$ and that is actually an attribution of the interaction of the molecules amongst each other due to Van Der Waals forces. let us not get into that now. and then the molecules themselves. So, there can be some energy inside the molecules also. So, those are the intermolecular. So, this internal potential energy is related more to intermolecular interactions.

So, essentially for a system we have internal energy of the system we have external energy of the system. the main manifestation of external energy of the system at the kinetic energy and the potential energy of the system. And then we have energy in transition. what is energy is in transition? this type of energy is manifested this form of energy only when the system is undergoing a process. And, which are these forms. they are heat transfer or heat and work. So, we all know that heat and work are path functions. So, there has to be a path. So, when can you have a path? Only if the system is undergoing a process. Because if the system is at equilibrium there can be no path for heat and work or heat or and both together can be manifested

Or you have supplied some energy like the either heat or you have done some work and as a consequence of that the system is undergoing a change of state change from state ‘1’ to state ‘2’. So, a system at equilibrium which is not undergoing a process, can never release heat or work. We will understand it more when we pick up the discussion.

So, just to highlight the science that deals with the transformation of one form of energy to another form of energy is thermodynamics. probably you all know this because all of you have done some course on thermodynamics or the other. But even if you have not done see your opportunity to learn now. the science that deals with inter conversion of one form of energy to another. in contrast, heat transfer essentially talks about only transfer of heat.

So, it essentially talks about deals with which is very important of course for the process industry, deals with only one form of energy in transition due to temperature difference which we all know. So, let us quickly tell what are the write down certain things.

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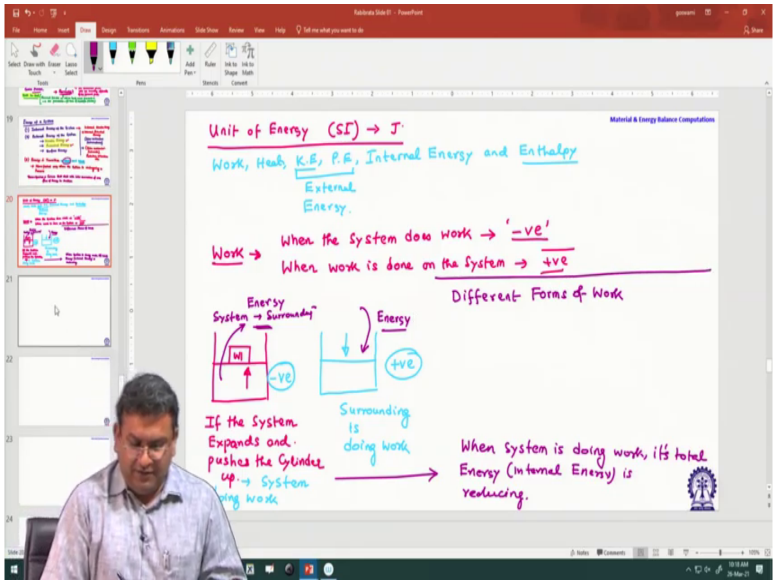

Now, we will talk about units of energy. SI unit of energy is joule. So, work, heat, kinetic energy, potential energy, internal energy and enthalpy are related to the external energy of the system. So, let us start with work; we all know what is work. What is transfer of energy between a system and a surrounding. It cannot be stored. Now, most important thing is work is a form of transfer of energy between the system and the surrounding. the convention that we follow when now it you will realize very soon.

Now that it is not exactly a convention. So, when the system does work, and I am rushing through because as a chemical engineer you will actually find that we will be more bothered about the change of enthalpy and change of internal energy due to heat transfer. Mechanical engineers or electrical engineers are much more bothered about the work done component when the system does work it is considered to be negative and this might be a surprise for all of you many of you all of you know this convention in most cases this is the convention.

And when work is done on the system work is considered to be positive. Now quick examples of what is system doing work and work done on the system, so, you have again had this piston cylinder with some W_1. Now due to whatever reason if the system expands, if the system expands and pushes the cylinder up, the system is doing work. On the other hand, if the surrounding due to whatever reason pushes the piston down, surrounding is doing work. The logic behind that is when the system is doing work, its total energy, you will realize internal energy or whatever is reducing. So, you all know in order to do work you have to spend energy. So, your own energy is reducing. So, work is negative. When the system is doing work, it has to consume part of its energy. So, its total energy comes down. because it is transferring energy. So, what is the direction of energy transfer? Energy transfer from system to surrounding. So, this happens because the system is doing work and therefore the total energy of the system comes down. Therefore, work done is negative.

On the other hand, when the surrounding is doing work it is actually adding energy to the system. and therefore work done is positive. Those of you who thought this is a convention and somehow remembered this please remember this logic and you will never have to consider this to be a convention. it is based on very strong logic of the internal energy of the system. So, what is more important for us is different forms of work.

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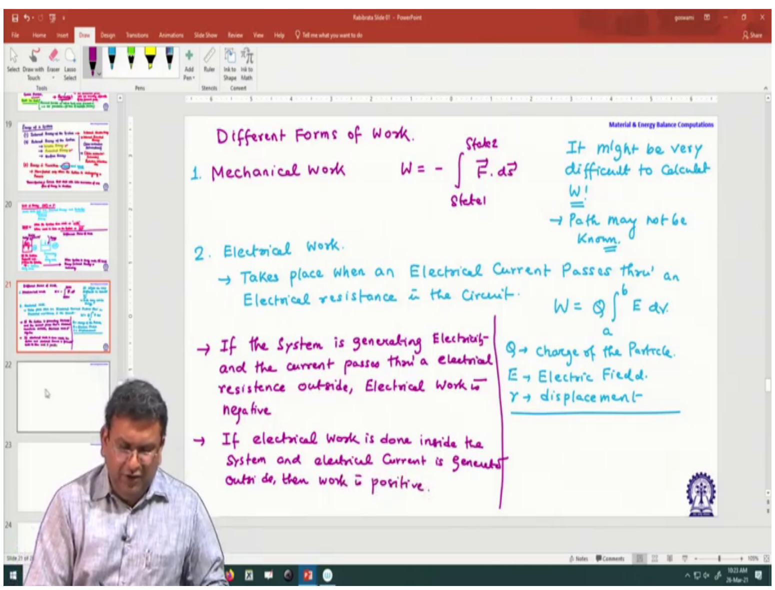

So, the most well-known form of work is mechanical work (expressed as shown in the above slide). Here F is the force applied and ds is the displacement and power is work done per unit time etcetera. So, as we know it might be actually very difficult to calculate W. why? because of the fact that the path may not be known.

What does that mean? how F is related to S? because in order to perform the integral though it is a dot product you write it F ds and you do the integral. reality is if you want to have the integration done if the functionality of F the force applied or how that force remains constant or changes as a function of the spatial coordinates. this functionality or dependence needs to be known. work is a path function we will pick up a problem which will demonstrate that let us first talk about the different forms of work. then of course, we have electrical work not that it will greatly we will require this understanding much, but we know.

So, it essentially takes place. So, electrical work you all know takes place when an electrical current pass through an electrical resistance in the circuit. Electrical work can be calculated using the equation shown in the above slide. Here Q is the charge of the particle, E is the electric field and r is the displacement. So, more important here is for us to understand qualitatively what exactly is happening.

So, if the system and we will talk about some beautiful examples of inter conversion of different forms of energy. If the system is generating electricity, electrical current and the current passes through a circuit or a resistance sorry not circuit through an electrical resistance outside then electrical work is negative, same logic. On the other hand, if the electrical work is done inside the system like this generator.

If electrical work inside the system and electrical current is generated outside. then work is positive. we will not go into details of the other type of work.

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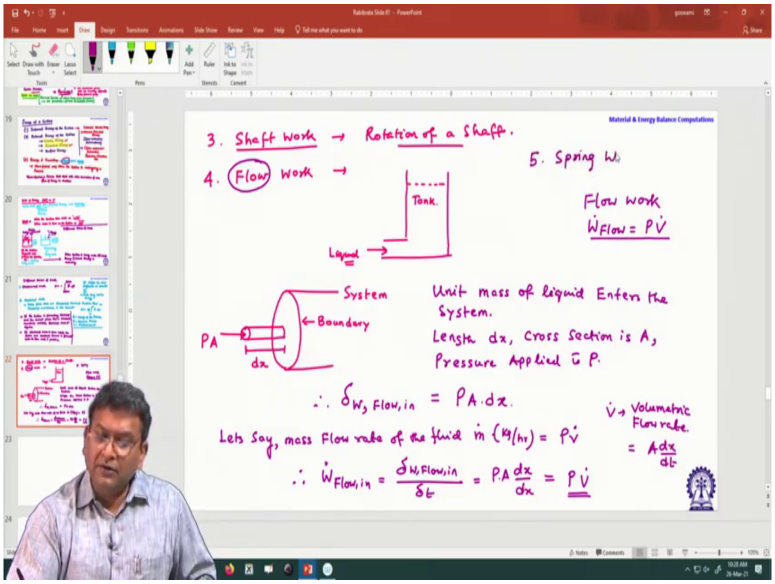

So, the other work can be shaft work; this is a nice way of rotating a shaft to harvest large amount of mechanical work; because as you can see in order to harvest large mechanical work F ds. So, S has to be very, very large. so, it is not possible. So, what you do is you just convert that translation into a rotation. So, that it essentially becomes a function of 2πr into n the number of times you rotate and that becomes the shaft work.

So, we I can quickly write down the expressions or maybe I will see I will share it in the supporting information. So, there is another very con. So, it is associated with the rotation of a shaft, again something we will not need that much. So, you can refer to the textbook there is another interesting concept which is the flow work. Now, flow work is essentially I will again give you the concept not get into the mathematical detail.

So, suppose you have a tank, which is full of liquid and then you have to push some more liquid here from the bottom. So, you actually have to do some additional work to overcome the pre-existing resistance now this is actually called the flow work may be flow work is something that is important for us. So, let me just spend a minute on this flow work. So, we have a system here. So, this is the system, and this is the boundary.

So, let us say a unit mass of liquid. So, unit mass liquid. So, as the work term suggests flow, flow means its associated with liquids. unit mass of liquid enters the system now we do something hypothetical. So, let us say the length of that element is d x, cross section is A. So, we understand liquid does not have a defined geometry. But let us but say it has a defined geometry. So, you can find out the volume A dx and the pressure applied is P.

So, therefore, the work done we write it delta w flow in, because you are pushing the liquid in is equal to force applied. So, what is the force applied? P A is the force applied into the displacement which is dx. So, that is the expression essentially of flow work. Now, what we can do is; now let us say mass flow rate of the fluid is m dot which let's say can be kg per hour or whatever and this can be converted into rho into V dot where V dot is the volumetric flow rate.

Therefore, one can calculate the flow work done as shown in the above slide. Here w dot is inlet flow. Actually flow work per unit time is related to the pressure into the volumetric flow rate.

So, this is flow work. you can also have other components of work like spring work and all that. So, we will not talk about these we will just pick up one problem. So, we are again running out of time as you can see that the classes sort of move faster than 30 minutes. So, what we will do in the next class is that we will pick up a problem first to show that work is indeed a path function something that we have been telling for a while.

Then have a quick discussion on these other components. So, heat we do not have much of discussion kinetic energy potential energy is also easy. I would like to spend some time on internal energy and enthalpy in the next class and I assure it is going to be a very, very exciting class. So, with that I thank you and finish today's lecture. and I will see you in the next lecture, thank you very much.