Material and Energy Balance Computations
Prof. Rabibrata Mukherjee
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture –37
Introduction to Energy Balance - VII

Welcome back. I hope all the concepts that we have discussed so far, are clear to all of you. We continue with our discussion on the basic concepts of energy balance and we are now heading towards some very exciting discussions. So, first we have discussed what is a process? and then we have discussed what is a reversible process? This is something that is going to be very important in your future courses when you study thermodynamics. Reversible process is going to be a concept that is very important.

And now we are slowly inching closer to understanding the basic constitutive equation of energy balance that is the first law of thermodynamics. And the functional form whether you have formally studied it or not; you all know energy cannot be created or destroyed until and unless of course you are talking about nuclear energy. What is so special about it? That is where essentially the mass defect gets converted into energy. Anyway, we are not going to cover this in this particular course.

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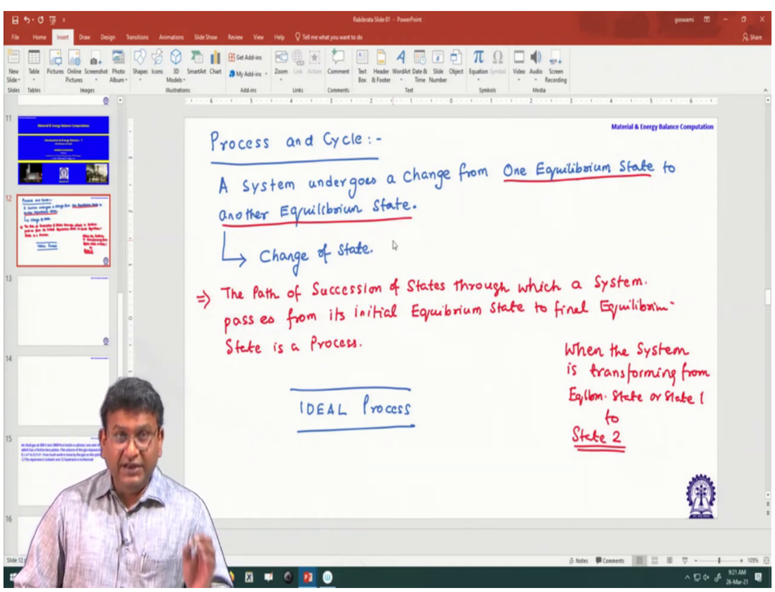

So, let us see what we have in store for us today. So, we started talking about what is a process.

So, essentially process is when a system undergoes a change from one equilibrium state to another. So, when water is heated from let us say 30°C to 50°C; it is a process.

There is a change of state though there is no change of phase there is change in temperature. So, there is a formal definition a path of succession of states. A system passes from its initial equilibrium to the final equilibrium state. Now this is very, very important that you can define the configuration the condition or the state of the system initially because it is at equilibrium and then finally once it attains an equilibrium.

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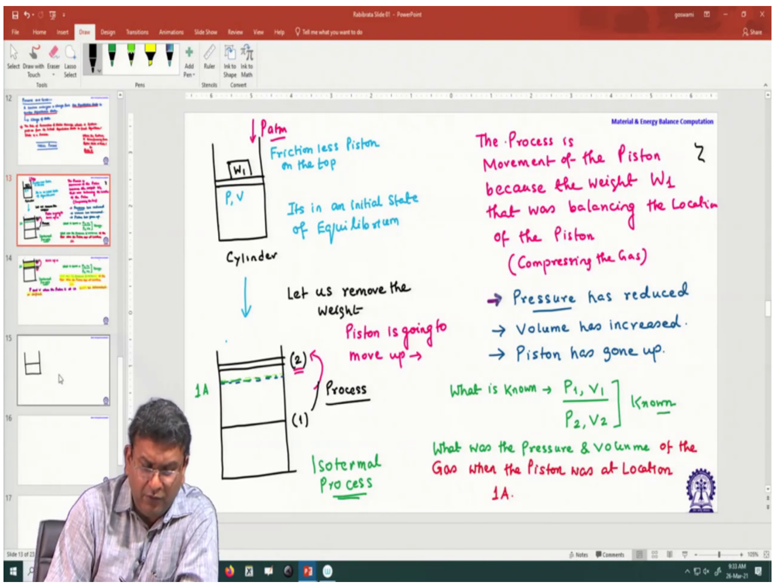

So, let us pick up a very simple and classic example. So, let's say we have a cylinder that has a frictionless piston on the top which is balanced by some weight '1'. So, you understand that whatever is the weight, whatever is the pressure and the corresponding volume that is sort of balanced and there is an initial state of equilibrium. Now, let us remove the weight.

If we remove the weight, we all understand that the piston is going to move up till it attains its new equilibrium position which is at elevation '2'. So, the system was at equilibrium and then from '1' it goes to another state of equilibrium '2'. So, the there is of course a process; the process is movement of the piston.

As shown in the slides, the weight W_1 was initially balancing the location of the piston. What exactly was it doing? This weight was actually compressing the gas. The gas was actually balancing a weight that is corresponding to the atmospheric pressure over here, because atmospheric pressure is always acting along with weight. So, the gas was in a state of compression. Now, once the weight has been removed now the gas present inside the piston only balances the atmospheric pressure.

So, the pressure essentially has reduced. So, if the pressure reduces, we all know that the volume is going to increase and that is exactly what has happened. So, what are the signatures of the process? Signatures are the reduction in pressure, increment of volume. Essentially, to accommodate for this increased volume, the piston has gone up. Right.

So, practically, the movement of the piston from location '1' to location '2' will require some finite amount of time. Let us now ask a question that when the piston was at this particular location let us say at location '1A' which is some intermediate position. (P_1, V_1) and (P_2, V_2) are known and they represent the locations '1' and '2' respectively. Let us assume that it is an isothermal process. So, there is no change in temperature. So, temperature remains constant.

So, for a single component system, we now know degrees of freedom is equal to 2. Therefore, we can define the system with pressure and volume. Now, interesting thing is if we ask a question that when this expansion was taking place at some intermediate position '1A' what was the pressure and volume? What is the volume of the gas when the piston was at location '1A'?
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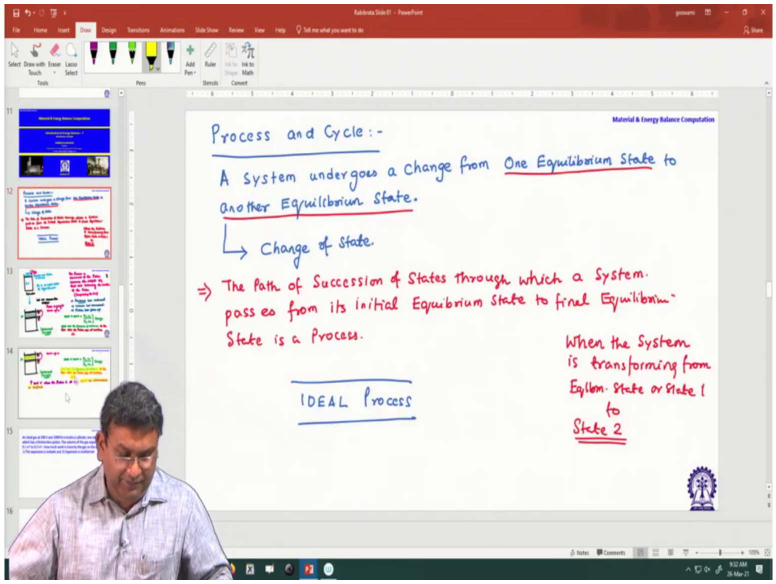

What is the pressure and volume of the gas when the piston was at location '1A'? Can anybody answer? The pressure (P) and volume (V) when the piston is at '1A', can't be determined or defined. At the location '1A' during the movement of the piston from one equilibrium position '1' to the other equilibrium position '2', the piston is not at equilibrium. It is a state between two equilibrium states. And, if a system is not at equilibrium, according to thermodynamics you cannot define its states.

So, therefore you cannot define the state of the system when it is undergoing a process. You can only define the state of a system in the initial condition and the final condition but not in the intermediate stages. And since you cannot define that for a system, you also do not know the path. What I mean to say that if you suddenly withdraw the weight for example in the previous example we have given, we do not know how fast the piston is going to move. We also do not know if the piston shoots up a little bit and then comes back to equilibrium. There may be some oscillation during the process. We do not know anything like this for sure. So, that is the whole crux that of course there can be process and this type of process is fine, but you do not know the path of the process. because you do not know the intermediate states.

Because a regular process if not done under certain specific conditions, the system is not at equilibrium. It leaves the first equilibrium and attains the second equilibrium but in between it is not at equilibrium. And therefore, at these intermediate points it is not possible to define the state because it is not at equilibrium.

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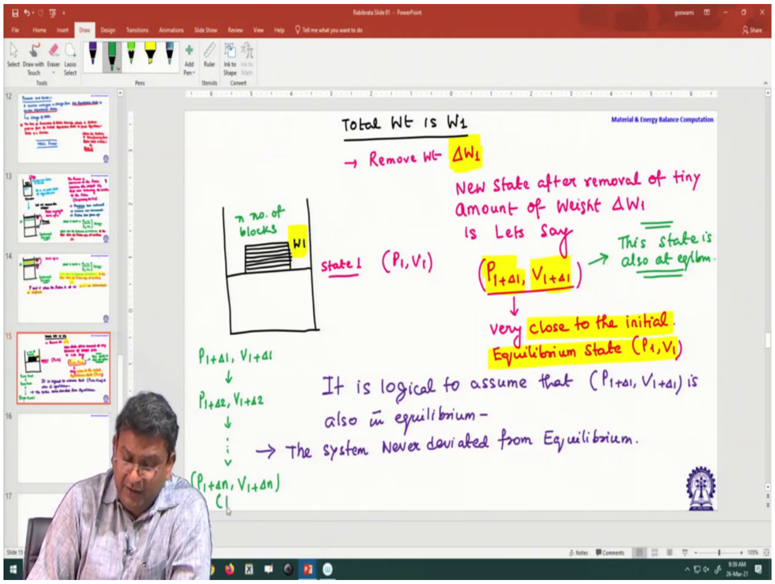

So, can anything be done to circumvent this problem? So, this is a problem we will take up later. So, now you imagine that we are again looking at this same piston cylinder which I am sure in your high school you have been doing or maybe from your first year you have been doing.

So, if we move the piston from the first position as shown in the slides. Now, let us think of the same piston and what do you do? You again place the same total weight W_1 but now instead of one block you have a number of small blocks consisting of a total weight of W_1. Now, it is not important to ask what is small? whether one gram is small, or one milligram is small enough. but you let us say you have these small blocks which you can keep on removing. So, initially it is at the first state '1', now if you remove some very tiny amount of weight ΔW_1, the piston will move to some new state which is in the vicinity of that initial equilibrium. So, the new state after removal of tiny weight is let us say ($P_{1+\Delta 1}$, $V_{1+\Delta 1}$) is very close to the initial equilibrium state (P_1, V_1).

Now to assume that ($P_{1+\Delta 1}$, $V_{1+\Delta 1}$) is also in equilibrium or the system never deviated from equilibrium. And therefore, we now assume, or it is logical to conclude that this state is also at equilibrium. This is a hypothetical concept. It means that if you instead of suddenly removing the weight if you now slowly reduce the weight; the system of course progresses to its new states slowly. But as the deviation from the initial state is very less it is now logical to assume that the system never deviates from the equilibrium. Or, this is called a quasi equilibrium process. So, essentially now keeping on doing this, so, now if you remove another weight and you move on to $(P_{1+\Delta 2}, V_{1+\Delta 2})$. Let us say there are 'n' number of blocks. So, eventually when all these blocks have been removed the system has again transformed from state one to state 2; but through this tiny step and the logic is every is every subsequent step is in equilibrium with the previous step.

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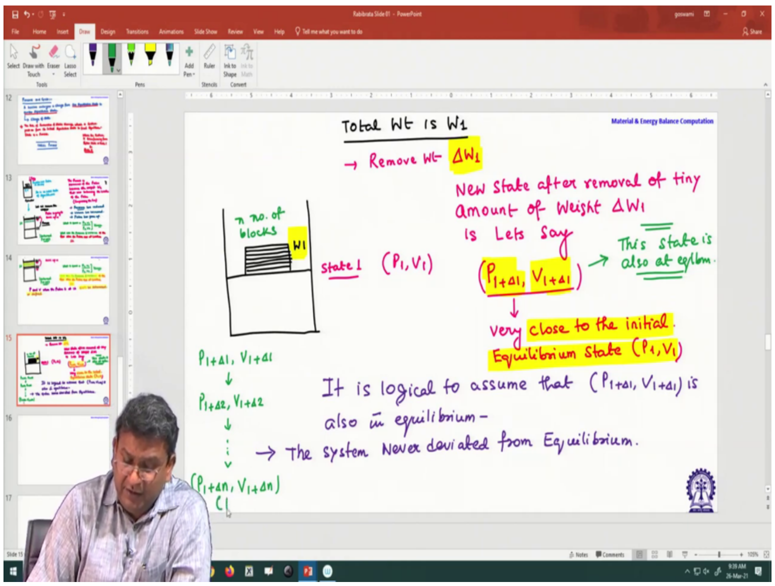

So, the system never deviates from equilibrium. So, this is what is called a quasi equilibrium process or an ideal process. Of course, in both the cases the system transforms from one equilibrium state to the other but if it is an ideal process then the transition from the first equilibrium state to the subsequent equilibrium, equilibrium state is through tiny deviations from the initial equilibrium state and we assume that the system is never actually leaving equilibrium.

So, all along it maintains equilibrium. now. So, there are certain things you need to understand this is a concept and therefore, please do not ask questions like how small weight is actually enough to maintain equilibrium or how much time we should actually give at every step for the system to equilibrate. everything is infinitesimal. I think all of you understand what the meaning of the word infinitesimal is. Now, what is a cyclic process? Now, cyclic process is very simple. So, it is like a slightly I mean. So, what happens is I am giving you an example maybe I will use a fresh.

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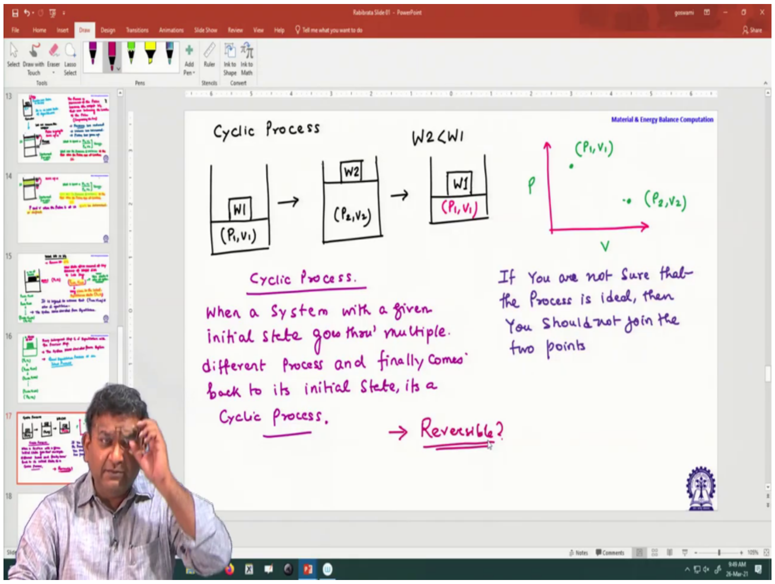

So, let us say one can understand it with the example of this this example itself. So, you have a piston cylinder assembly which initially has weight W_1 now it is the weight is let us say I will now slightly modify it weight is let us say reduced to W_2. And, now again the weight is increased to W_1. Right. So, essentially you know that if let us say temperature is constant or even if whatever if there is a change.

So, since here the weight is W 1 in this particular both the cases. So, let us say the pressure if it was here (P_1, V_1) it changed to (P_2, V_2) in this particular case and once you reintroduce back the same amount of weight it is logical to conclude the pressure and volume are again back to P_1 and V_1. So, what actually happened? Can you join them up on this P-V graph? The answer is you can. The moment you join them up, you actually are defining each of the intermediate points between these two states. So, therefore you can join states with a line only to indicate that this is an equilibrium process, or you know the exact path through which the process took place. In reality, the path is known only for an equilibrium process. So, if you have a quasi equilibrium process, of course you are entitled to join the pathway.

Now, there is another concept that I would like to discuss which we will continue in the next class. So, when a system starts from an initial state moves to a second state and comes back to its initial state; this is called a cyclic process. And, this is indeed a cyclic process. So, there can be some classical definitions for that when a system in a given initial state goes through a single or number of different changes of state or process.

And finally comes back to its initial state the system can be considered to have undergone a cycle. So, when a system, let me write it down, with a given initial state goes through multiple. So, it has to be multiple different process. Here, also there are two processes: one is expansion one is compression and finally comes back to its initial state. It is a cyclic process. Now another question comes in. So, are all cyclic processes reversible? So, you might have heard about reversible process and all. So, in the next class I will start from what is the reversible cyclic process and also there is a very important distinction between a thermodynamic cycle and a mechanical cycle. So, with that I finish this lecture and see you with the next class.