Material and Energy Balance Computations

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Lecture –38
Introduction to Energy Balance - IX

Welcome back. We will continue our discussion on the components of energy that we have started to talk essentially in the previous class. We were primarily talking about different forms of work in which work can be done. Of course, we will soon realize that only certain forms out of those for example some of you can understand for example electrical work and stuff like that is not going to be very, very important for us in our context.

But nonetheless we will look to continue our discussion briefly and we will highlight what I will do now is I will pick up a problem which will give you a very clear idea about something I have been telling you for a while and that is work is a path function. So, after we are done with that, we will talk a little bit about heat transfer, the different modes which most of us know all of us know. But I will not take up heat transfer in any detail because that is something there is a full course that typically one is taught in the fourth semester where you learn about different aspects of heat transfer.

Probably, what I will do instead I will spend some time discussing about the different components of internal energy. And, then once we are ready with all the constituent components constitutive components that is the internal energy the external energy the work into the energy in transition and stuff like that then we can probably talk about that then the mathematical form the expression of the first law of thermodynamics becomes very easy for us.

And then we are primarily chemical engineers we are essentially chemical engineers. So, we will be looking at systems which are certainly not going to move at very high velocity or move at all or are going to change elevation. So, we will also see that certain components of energy are not that greatly important for the type of systems we are going to study. So, anyway let us pick up the thread from where we had left in the previous class.

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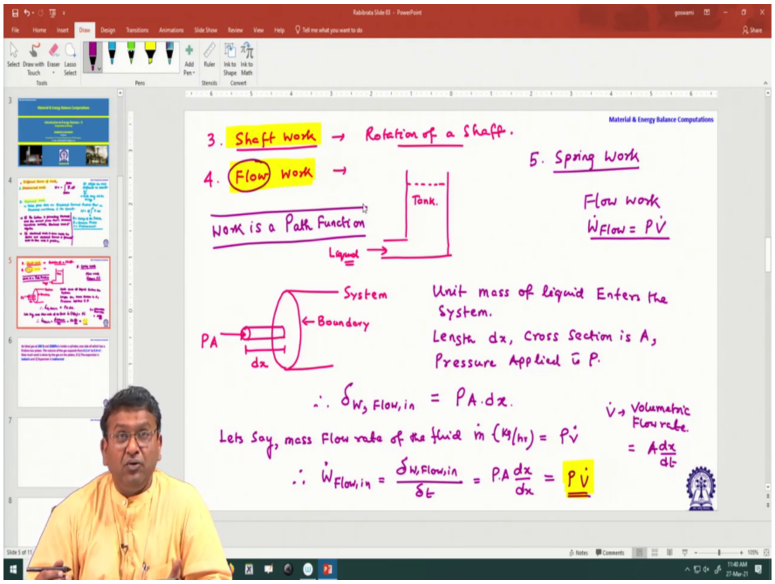

So, I guess this now all of us understand that there are different forms of work the most important being the mechanical work then one can also have electrical work. And then we also discussed in detail why work done by the system is negative and work done on the system is positive it is essentially attributed to change in the internal energy it is related to. So, when the surrounding does work on the system the energy of the system essentially goes up energy the system gains energy and therefore it is considered to be positive work.

And then we also talked about some other forms of work shaft work is nothing but a special form of mechanical work because as you can understand that in order to get large amount of mechanical work done the displacement has to be very, very large. And this problem is circumvented in the form of rotation of a shaft. Then another thing that is going to be pretty important for us is what is known as flow work this is something very specific to open systems and in classical thermodynamics you typically do not talk about an open system you essentially talk about a closed system.

So, you typically all of you have seen that most of the time we talk about a frictionless piston cylinder arrangement. And we rarely talk about mass being exchanged with the surrounding. So, it is actually a closed system and it is actually easier to define or talk about the first law for a closed system. So, essentially you can heat up the cylinder from outside or you can compress the cylinder expand the cylinder. So, the system can do work or what can be done on the system but rarely we talk about transfer of mass.

But for many of the type of system particularly for those of us looking into fluid dynamics for example or any type of flow or flow work is an important aspect and what you should remember that flow work is something that is associated with open systems only because there has to be a flow something must flow in into the system. So, these are some certain things we have talked about. So, one very nice example, also the other thing I will take up probably after a little while is interconversion of work from one form to the other.

Or in general in a larger perspective after we are done with the different components, we can talk about inter conversion of energy in different forms. So, we will take up and there I will give you a very nice example of what flow work can essentially do. So, one thing I have been highlighting for a while and that is work is a path function that is we talked that just by if you know the initial and final states even let us say for a piston cylinder arrangement you know the pressure and the volume the first state 1 and state 2 you cannot actually draw it on the graph straight away unless the path is fully defined.

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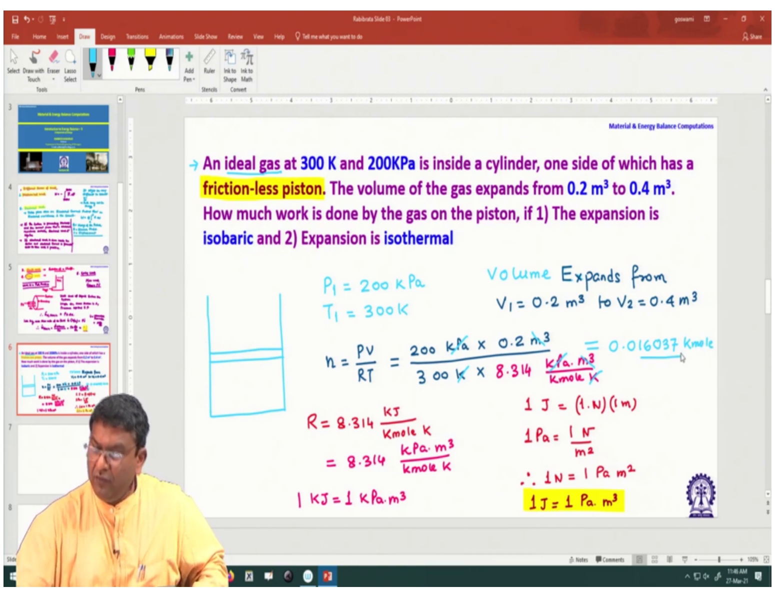

So, let us pick up a problem and then we can probably understand the concept very clearly. So, it is a very simple problem. an ideal gas at 300 k and 200 kilo Pascal pressure is inside a cylinder one side of which has a frictionless piston. So, it is the same piston cylinder arrangement and as I told these is the most fundamental form of problem that you do in most thermodynamic problems.

So, I think the time has also come we talked about why we always use a frictionless piston. maybe I will highlight that as well. So, what it says that initial state is given. So, it is given that P one is equal to 200 kPa and T 1 is equal to 300 kPa it is also clearly mentioned that it is an ideal gas. So, you can straight away apply the ideal gas law and one side of which is a frictionless piston. Now the volume expands from $V_1 = 0.2\ m^3$ to $V_2 = 0.4\ m^3$.

Now what is not given, and we will need it for our calculations is the amount of gas that is present. So, the first thing that we will essentially do is we will try to find out since the P V and T everything is given and mass is going to be conserved because this is a closed system please do understand that. So, we can straight away find out from ideal gas law n equal to PV by RT. now everything is fine.

So, what we have P is 200 kPa and since we are beginners, I am going to be very, very fussy about writing the units. So, it is always good it is good ideas to write the units as well T is 300 K and what value of R do you take do you remember of the shelf any value of R which comes in terms of kilo Pascal? At least I do not remember because the standard values of R that we all remember is 8.314 kilo joule per Kelvin per kilo mole is one standard value or one can talk about this cc atmosphere 0.082 in terms of cc or 82.06 liter or things like that.

So, I will also show you what value of R we will take. So, R this is a standard value. we know is 8.314 kilo joule per kilo mole Kelvin. Now, what we know this is a Gibb's conversion I think professor Otto has been teaching all this. So, it is a good revision for us we know that one joule is equal to 1 Newton into 1 meter. So, if you apply a force of 1 Newton and the displacement is one meter and we also know that 1 Pascal is 1 Newton per meter square.

So, combining these two what we get is 1 Newton is equal to 1 Pascal meter square and therefore, 1 joule is equal to 1 Pascal meter cube. So, this is something you may recall, or it is best that you just do it and. So, if one joule is one Pascal meter cube. So, one kilo joule is going to be one can simply write this that one kilo joule is equal to 1 kilo Pascal into meter cube and therefore, the value of R the unit actually is also kilo Pascal meter cube divided by kilo mole Kelvin.

So, if you now plug in the value of R equal to 8.314 kilo Pascal meter cube divided by kilo mole Kelvin you see that most of the term the units actually cancel out. So, if you do the numerical, I have which I have done it, it turns out to be 0.016037 kilo mole.

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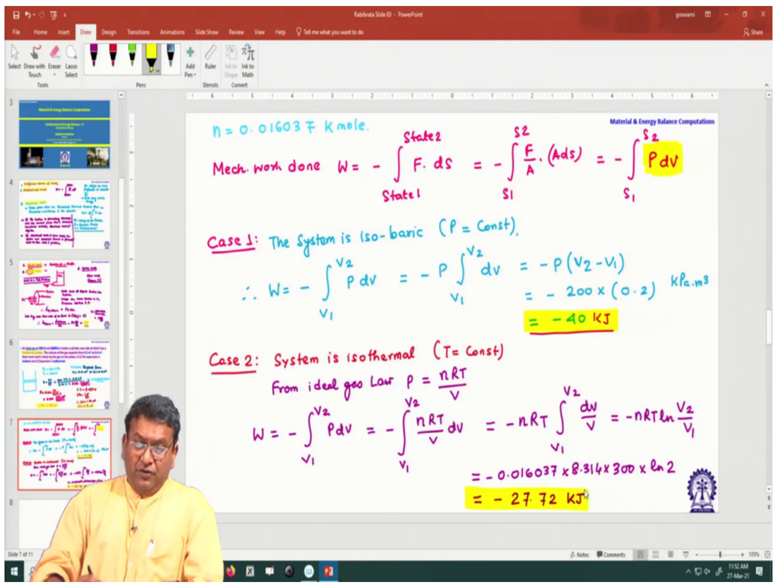

So, we now know that n is equal to 0.016037 kilo mole. So, now what is given? So, mechanical work done what we know it is actually F ds and many of us. So, I do pay attention to this nitty gritty detail and many of us actually write it is A minus integral of P dv. So, why do we write that because mechanical work is F ds we all know that integral from state one to state 2. So, the reason we write it as P dv is its actually F by A into A ds A is the cross-sectional area.

Now we know force per cross sectional unit area is pressure and area into displacement is nothing but the change in volume. So, you should always know why things are happening like that. So, its S 1 to S 2 P dv I think you will never forget in your life because if you go by the classical definition of mechanical work done it is always F into F dot ds and what you always take is P dv why do you take it actually you divide and multiply by the cross sectional area.

So, now let us look into the problem. So, the first case, it is given its isobaric. I should not write it is the system isobaric that is P equal to constant. Therefore, work done is equal to minus integral V 1 to V 2, both of which are given, P dv and now we know P is constant. So, minus P comes out integral V 1 to V 2 dv and we are left with minus P into V 2 - V 1 which is the pressure that is given is 200 kPa. So, its minus two hundred into change in volume is zero point I think it changes from 0.2 to 0.4. So, it is 0.2 m^3.

And therefore, the unit I am very fussy about unit; kilo Pascal into meter cube and it turns out to be minus 40 kilo Pascal into meter cube but then here you have essentially shown that kilo Pascal into meter cube is nothing but kilo joule. So, you get minus 40 kilo joules. I hope this is clear to all of you. I request all of you to kindly solve this problem or solve similar problems. I will provide you some problems.

Now, in case 2, what we have the system is isothermal so that means T equal to constant. So, what we should do? we actually in order to why we need all these condition we actually need please understand that also that is also very important in order to perform this integral we actually need the functional dependence of P and V because you are integrating over PV and P is a function of V. So, if it is given T is equal to constant.

So, here it is given P is constant. So, therefore P comes out and you only have an integral of delta V, but now it now it is told P is equal to constant. So, what do you get from ideal gas law? what you get from ideal gas law is, this all of you know, is nRT by V and now it is given. So, therefore the integral changes to minus integral V 1 to V 2 P d V which is sorry we can write capital P also the way we are writing minus integral nRT by V into dv V 1 to V 2. when you are learning it is it is a good practice to write down the steps very clearly.

So, that you understand every step. So, n, R and T are constants and you are left with V 1 to V 2 dv by V which is a standard integral. So, the answer is nRT ln V 2 by V 1 and if you plug in the numbers everything is known. So, its minus 0.016037 into 8.314 into temperature is 300 Kelvin into ln 2. I would request all of you to do the calculation yourself and the answer that I have got is minus 27.72 kilo joule.

So, right in front of your eyes you can see that the same system is transforming from the same initial state to the same final state same initial state to the same final state and what we are getting or what we are seeing is that the work done in the 2 cases are different. So, that is why in the first case this is for minus 40 kilo joule; in the second case it is minus 27.72 kilo joule. So, you can clearly see that work done is actually a path function.

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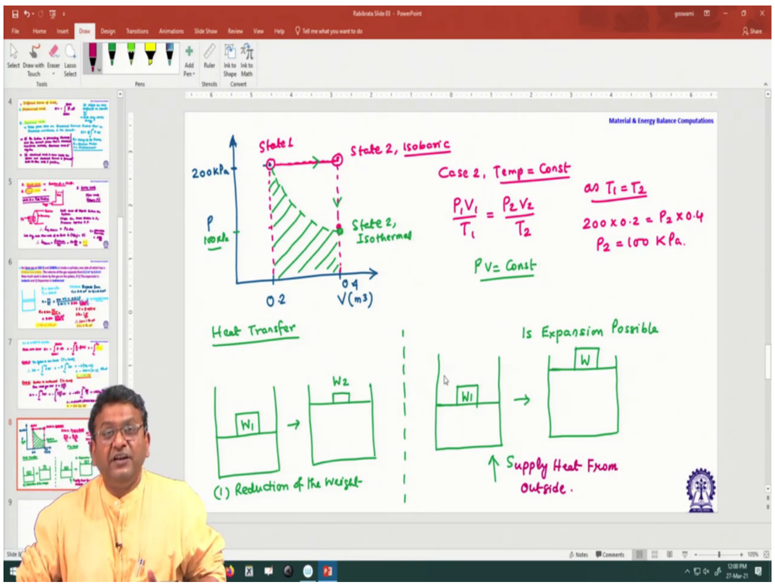

So, if I would like to just plot it on the on a graph. So, how would it look like. So, you see this is a PV plot. So, what is given is the first state is given. So, this is 0.2 m^3 and; let us say this is 0.4, the initial condition is what is the condition it is given as 200 kPa. So, here is the first point and now what it says that it is expanding from in the first case its isobaric. So, pressure is constant. So, this is the volume and so, this is essentially the path. it expands and this is the path.

And this is the; I had I made a small mistake while uttering the final states are not same, but the final volumes are same the volume expanded is same certainly the pressure is going to be different whatever. So, this is state one. And what is the work done. work done is essentially the area under this particular curve. Now in the second case what is given is temperature is constant in case 2, temperature is constant, isothermal it is it is driven.

So, therefore what one can do is PV by T and T 1 is equal to T 2 this you can cancel out. So, P V

P 1 V 1 equal to P 2 V 2. So, 200 into 0.2 you can essentially find out the P 2 also and P 2 turns out to be 100 kPa. So, here is the point, let us say I should not put this arrow. So this is let us say 100 kPa and as PV temperature is constant. So, the functional form of the dependence is PV equal to constant which is similar to xy equal to constant and therefore it is a rectangular hyperbola.

So, this is now a rectangular hyperbola and therefore this is the path the process follows in the second case this is the state 2 isothermal and the work done in the latter case is this much, which you have already seen the amount is lower than the previous case. So, I guess this we understand this is a very clear example where the work done is essentially a path function. So, you could have also the why I say that the work done is a path function is you can would have also followed.

So, this is a simple problem, but one can stretch this a little bit by saying first the system undergoes an isobaric process with the pressure keeping constant then we increase the volume from P 1 to P 2 or V 1 to V 2 and then by keeping the volume constant we somehow reduce the pressure. how can you do that by manipulating the temperature. So, essentially one could have said that the system has gone from here to here and then from here to here. But what is the total work done work done would have still remained 40 k Kelvin.

Because in the second case since there is dv is equal to 0 there is no change in work that is going to be possible. So, this shows it is a clear example of work done is a function is a path function you can say the other energy the component of energy in transition what is transition that all of you know is when a system is undergoing or transforming from changing from or undergoing a change from state 1 to state 2.

And the other form of energy that is manifested only when the system is in a dynamic condition is heat transfer in many cases what can what can actually be done for example for a piston cylinder arrangement. So, you can actually think of the practical settings. So, under what conditions this will expand. So, every time we talk about this expands. So, one of the ways, one of the reasons it can expand is that you have some weight W 1 and you reduce the weight. either you remove the weight, or you reduce the weight to some W 2.

So, there it can expand. So, this is one reason why one way it can expand is reduction of the weight. the other option can always be or let me ask a question that if the weight remains same as W 1 is expansion possible? and the answer to that is yes indeed it is possible all you have to do is you supply some heat from outside and the volume will increase. So, in this particular case what is actually happening the system is essentially doing work in this particular case because of the fact that the opposing force that was being balanced is reducing.

So, here in this case the system was balancing a total force that corresponds to the external pressure plus the weight that was placed. here what is happening the external pressure remains same that the weight has reduced. So, the total force that was applied by surrounding on the system is essentially reduced and therefore the system is expanding. what is happening here the force that the surrounding is exerting on the system remains same there is no change, but you have supplied some energy.

So, you have supplied some energy and that energy is leading to expansion of the system. So, essentially what is happening is that the energy that you are supplying a part of that energy is getting manifested in the form of work done, something that we will understand even better subsequently. What you must remember that all the amount of heat that you are transferring may not get converted to work its not getting converted to work.

Because part of the heat that you are transferring is also consumed in increasing the temperature of the system. In fact, this is something or as the temperature of the system increases it essentially means the internal energy of the system is increasing which we will understand. And this is a very good example to explain why we talk about another very well-known term that is enthalpy.

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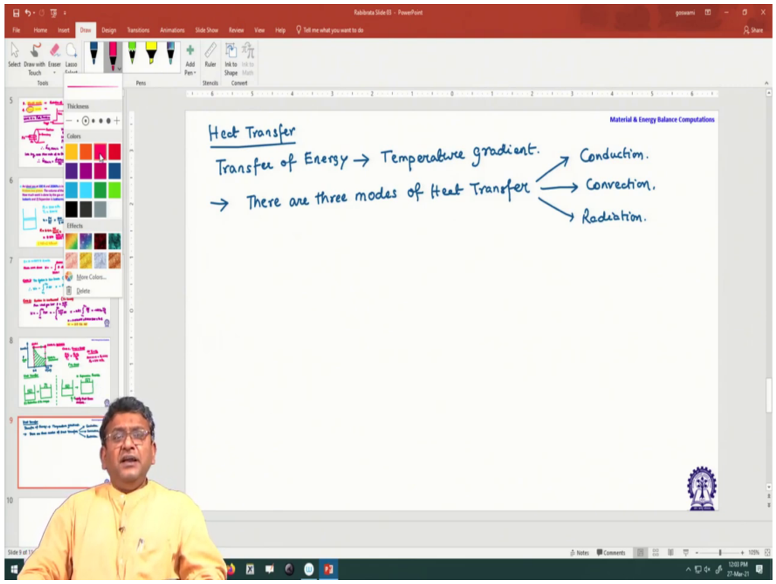

So, regarding heat transfer I guess we do not have much to discuss except the fact that heat transfer takes place or transfer of energy of course there has to be a system is undergoing some transition, but heat transfer takes place only when there is a temperature gradient. So, unless there is a temperature gradient heat transfer will not take place. So, we all know that temperature or heat flows from a high temperature body to a low temperature body.

The only other thing that I may want to highlight at this point of time regarding heat transfer is that there are three modes of heat transfer which are which probably most of you know conduction, convection and radiation. There are lot of things that one can talk about each one of these components; but I will probably skip that this is not the time to talk about it. most of us know that conduction takes place through solid.

So, it is a depending on again the nature of the solid it can either be direct transfer of electrons or it can be through vibration of the lattice; convection most of us know that it takes in vapors in gaseous form or in liquids. But reality is conduction convection also takes place or sorry the other way conduction also takes place in liquids. But one typically talks about convection in liquids only because the amount of heat transfer in a liquid by convection is actually much much higher than that that means that means that heat transfer in a liquid by conduction.

So, everybody thinks that the predominant mode of heat transfer in a liquid is convection at this point of time if you know that that is good enough. But remember maybe in some time you will all realize and learn that conduction takes place everywhere in fact in liquids also. it is an important parameter. Radiation we all know that we survive essentially because of radiation because radiation is transfer of energy or heat without any medium.

And therefore, the heat that comes from the sun to the earth which is fundamental basis of life one can say is through radiation. So, these are the basic modes of heat transfer. And, we will be looking into systems like this where we supply some heat from outside. So, we are not going to be bothered essentially what exactly is the mode of heat transfer etcetera. We will talk about it but there is a completely different course on heat transfer which all chemical engineering students and all mechanical engineering students have to do.

So, you need to understand the fundamental difference between the between the between thermodynamics and heat transfer. So, thermodynamics essentially is the subject which talks about inter conversion of different forms of energy. And heat transfer talks about only one specific form of transfer of energy that is due to temperature gradient. So, I think we are running out of time.

So, we will close this lecture here and in the next lecture that is going to be the last lecture of the eighth week we are essentially going to talk about the other remaining forms of the energy of a system. So, thank you very much.