Engineering Thermodynamics

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Lecture – 14
Laws Of Thermodynamics:
1st Law for Control Volume.

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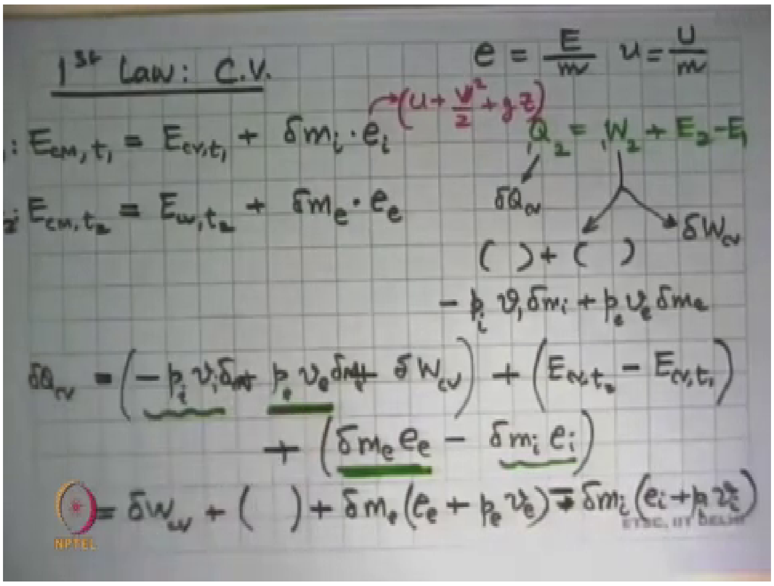

Now, we say that we got the law for close system, what will be the expression of the 1st law for a control volume, so 1st law for a control volume. The logic we will do is very similar to what we did for conservation of mass. At the end of that, but what instead of looking at mass, we will look at energy ok. Before I get, I think there is a question there thus an isolated system have 0 work done or not ok. Isolated system means, it has absolutely no interactions with the surroundings whatsoever, so work will be 0, heat will also be 0 ok. 1st law and now for a control volume, so, we let us go back to the picture that we made for control the mass.

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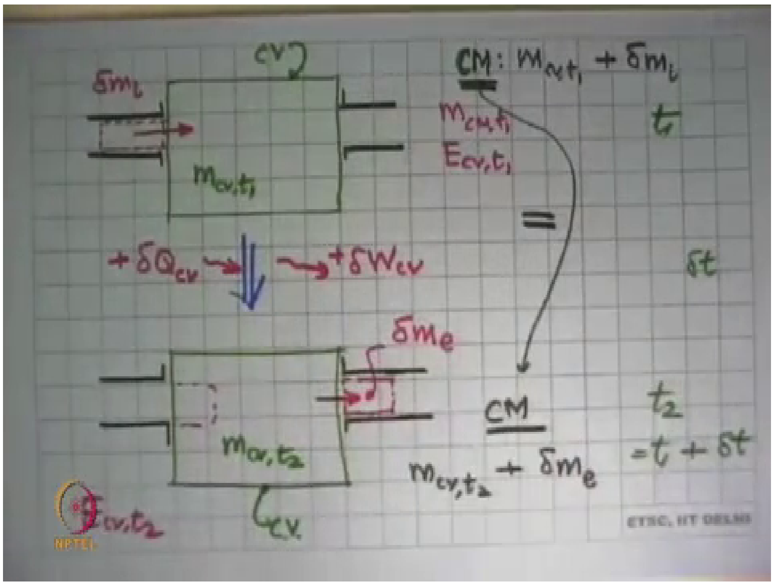

This is what we made, the thing is we will apply the same sort of a arguments, but this time look at energy and at the end of that we will come up with the long expression. And that one of the longest expression you will come across in this course, when it is the most important one for many types of problems, but fortunately we can simplify it in many cases and get a very compact expression from which we can solve problems that part we will do, when we look at specific problems not right now.

Right, now we will say look does not matter what the application is, what the working substance is, what is the law 1st law statement for a control volume ok? So, here is how we do it, we do the same thing here. And now we need to talk about, instead of looking at mass of the control volume of t 1 and t 2. We will look at energy of the control volume at t 1 that means, whatever substance was there, what was its energy at time t 1 and what was the energy at time t 2.

So, the energy at time t 2 here, we will say was E cv at time t 2. And during this process, we say that there was delta Q cv heat transferred to the system that will be a plus and delta W cv work done by the system on the surroundings. So, we are keeping both, so plus sign. So, I am not showing it on this diagram or this diagram, because both are transitory at the system boundary and they occur over the duration of the process, so that is the additional thing that is coming, we defined the energy of this.

Now, we say well what was the energy of the control mass at time t 1? We looked at mass of the control mass at time t 1, now we say my control mass is this whole thing plus this little thing, what is the energy of this control mass and we will equate that with the energy of this control mass plus all these other things that are coming. So, we will write some expressions now, so, I will keep this here you can see that. So, if that energy of the control mass at time t 1 is equal to energy in the control volume which is E cv at t 1 plus energy of this little thing, which is delta m i times its specific energy.

I would not set this, but specific energy e like u is nothing but E upon m like we said small u is U upon m ok. So, specific energy what it has is all three terms u kinetic energy and potential energy all are there in this. Energy of the control volume, then whatever substance was there, then again the same thing its internal energy u plus its potential energy plus its kinetic energy that, but that applied to the control volume. In this case we are applying this to this little mass.

At time t 2, the same story that our mass that little element has gone in, but some element has come out this is E cv at t 2 plus delta m e what exited multiplied by its specific energy. So, now we say I am going to apply this equation for a control mass, what is the equations that I have to finally use? So, what was that equation is Q 1 2 is equal to W 1 2 plus E 2 minus E 1. So, you are going to put some terms into this that are relevant to the control volume.

Q 1 2 is in the process, what was the energy transferred because of temperature difference and that we have already said is delta Q cv. So, this term becomes delta Q cv, this work term has two parts; one part is the work done on the system boundary which is the delta work cv and the two terms which were related to work associated with this fluid going in and this fluid coming out.

So, this going in if you remember in the earlier discussion, this was minus p i v i and this term was plus p e v e. We defined this as the flow one, something being pushed in work done on the system minus p i v i work done by the system in pushing the element out p e v e ok. So, now E 2 minus E 1 that here it is E 2, this is E 1 and now will it all these terms into this equation. So, we start getting a longest type of an equation and we start putting some things more down, we will substitute the small e by u plus v square by 2 plus g z with the appropriate substance; i for the inlet, e for the exit.

And let us now work on this big equation what we get, the left side is delta Q cv, this is equal to minus p i v i plus p e v e plus delta W cv they are all are work terms and the energy terms this minus this. So, we will take these two terms put them together that becomes E cv at t 2 minus E cv at t 1 plus delta m e e e minus delta m i e i. What we will do next is a little combination, we see this p i v i coming here and this thing coming here, and on this side we have this and this.

So, we will combine these and that gives us the delta W cv stage plus this term for the control volume, I will skip that plus, but this include delta m i (Refer Time: 09:19). So, I was missing a term there, this is this into delta m i into delta m e. So, we get delta m e e e plus p e v e plus delta m I, sorry minus here now e i plus p i v i.

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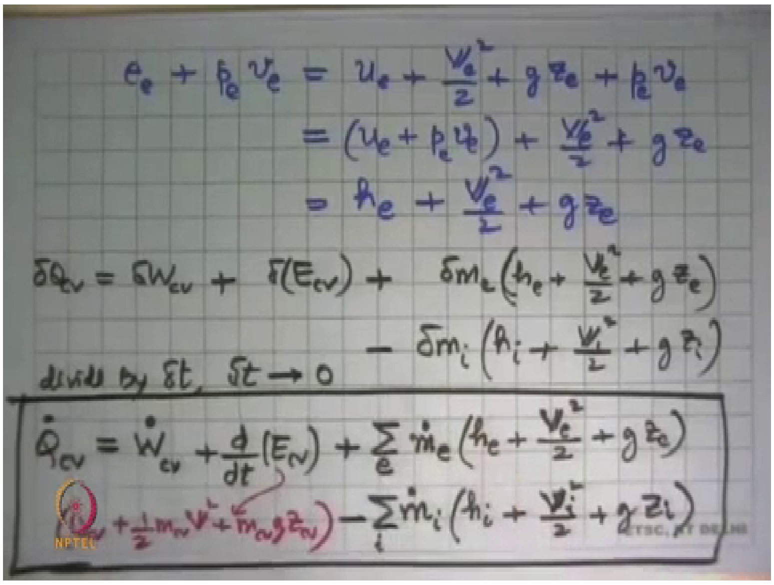

Now, we open up this term and we do a little simplification on this. So, we say that say e e plus p e v e is equal to u e plus V e square by 2 plus g z e plus p e v e. And this gives us the same combination again, u e plus p e v e plus V e square by 2 plus g Z e. And this we have just defined this combination of properties, h e plus V e square by 2 plus g Z e.

Similarly, we can do for the inflow term and then go back to writing this long equation once again that tells us that delta Q cv is equal to delta W cv plus what I will do now for this little term, we will say that this is delta E of cv and then we got these two terms coming in here plus delta m e into h e plus V e square by 2 plus g Z e minus delta m i h i plus V i square by 2 plus g Z i.

And that is the chain two steps has earlier now, divided by delta t and that delta t go to 0. And when you do that this is heat transfer in a little time interval divided by the time, this is rate of heat transfer into the control volume, which we will call Q dot cv. So, this is the rate at which heat is transferred to the system due to a temperature difference, this is equal to work rate of the system plus rate of change of energy of the control volume plus this term, which is delta m e over delta t like before becomes m dot e, but inside we have h e plus V e square by 2 plus g Z e minus m dot i h i plus V i square by 2 plus g Z i.

So, this is the energy including the flow work associated with each mass flow into the system existing of the system and minus inflows. If there are more than one inflows more than one outflows, we will generalize this equation and put that this is summation for every mass outflow, summation of every mass inflow. And this becomes our equation for the 1st law for a control volume. The only thing left that was that what was this E cv this is U cv plus half m cv V square by V square plus m cv g Z cv.

So, if this expression we get the mass out, it will become specific internal energy of the control volume plus its kinetic energy half V square plus g Z, this is remaining as that internal energy term whereas, on the flow terms this became specific enthalpy. We have to keep that in mind that the control volume its energy remains as U whereas, the flow terms got h i, because they included the internal energy of the substance and the flow work associated with that, so that is why this is h here. And so you have any problem that we have of flow rate we promptly will get down to h ok, so that is a big long equation, which we will have to again remember all the time.

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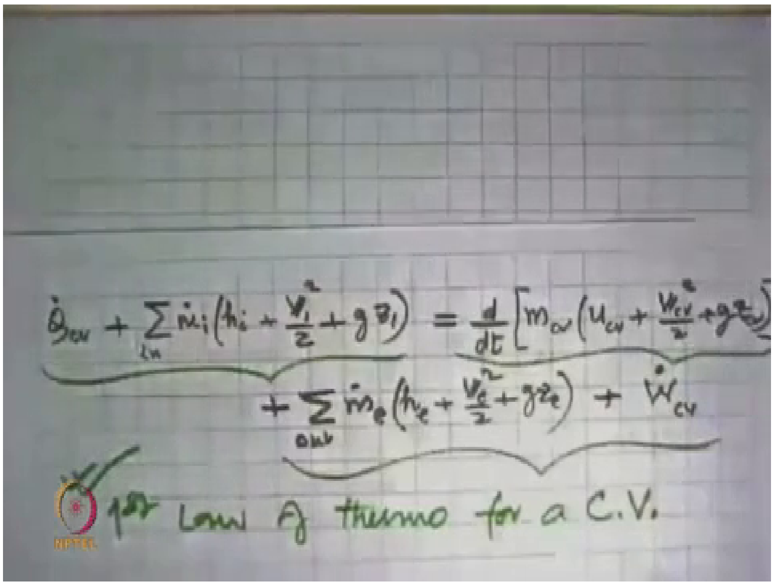

We can rearrange the term by saying that this is inflow, you can get this term to the right side and say that is also an inflow. So, if you want to recast this equation, this becomes Q dot cv plus summation of all inflows m dot i h i plus V i square by 2 plus g Z i, this is equal to d dt mass of the control volume u cv plus V cv square by 2 plus g Z cv plus outflow m dot e h e plus V e square by 2 plus g Z e plus W dot cv that is your complete equation, I have substituted everything now in this, nothing is left for guessing now.

And what is this equation, tell you is that this is energy inflow rate, energy outflow rate, rate of storage of energy in the control volume is equal to rate of creation of energy which is 0 ok. So, this is our most general form of the 1st law of thermodynamics for a control volume.

The solution of every problem should begin from here and we see that by the conservation of mass which was the other equation that you have. So, those are the two equations which get of going in solving any problem. So, in the time we have we will take questions and also if there will be a few examples I will take ok. Let us look at the example and take we have to take a flow system.

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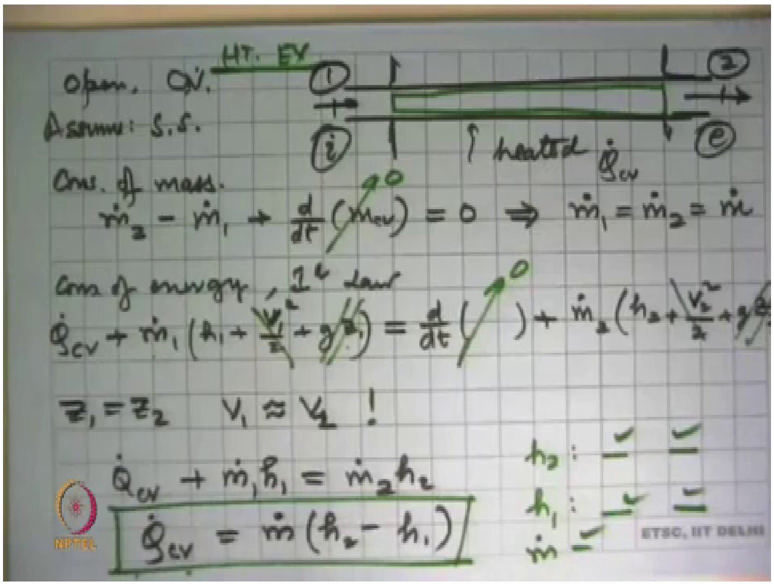

So, we will take a say a pipe through which something is flowing over this portion and here it is say we heated. So, this is what happens inside the evaporator of an air conditioner. So, how can I analyze this and thing we say let us see, what is the application? My application is the tube over a certain portion, there is heat transfer taking place through the other portions there is no heat transfer taking place.

The next thing we do is define the system as boundary which is this and so now I will write the conservation of mass for this and conversation of energy for this. So, the thing do is define the state points; this is 1, this is 2; we can also call this inlet i and exit e that as long as there is only one inlet, one exit this works more than one it (Refer Time: 18:25) and we take the conservation of mass and that full equation that we had there, I will just this put it up for in this place.

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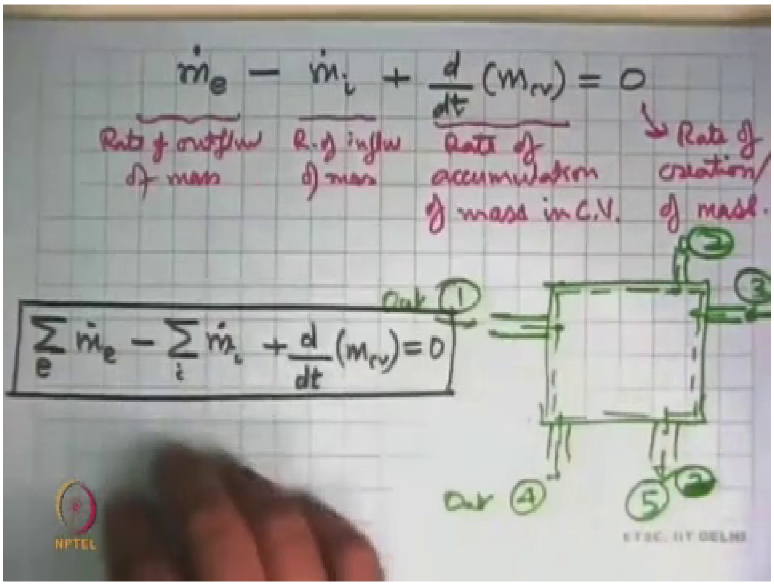

This is what we have, m dot e minus m dot i summation plus d dt m cv equal to 0. For this case, this will become m dot 2 minus m dot 1 plus d dt m cv equal to 0. And we now write that huge long equation, we will say what is the conservation of energy? What is the 1st law? You already said that this is an open system, so we will use the control volume approach, so that is why we use this equation.

Conservation of energy tells us all this, Q cv yes there is some heating taking place, so this Q cv exists. There is one inflow, so we have Q dot cv plus m dot 1 into h 1 plus V 1 square by 2 plus g Z 1 this is equal to the energy of the control volume, which we will just put for the time being as d dt or something.

There is no work transferred you can see here and this work is system boundary work and not flow work. So, we are quite happy to say that there is no work transferred in this system, so W dot cv is equal to 0. And the only term left on the other side is m dot 2 h 2 plus V 2 square by 2 plus g Z 2 ok and now we say that what else can I do to make life simple.

And say I will assume that this system is in steady state that help us in that this term will disappear, this term will disappear. And if this term disappears, the conservation of mass equation tells us m dot 1 is equal to m dot 2 and this we will say well whatever it was 5 kg per second, 1 kg per second whatever now you can put generic in that m dot.

And then we come to this equation and suppose this is a tube, this is a horizontal tube. So, I will I am quite to say that Z 1 is equal to Z 2, because it is a horizontal tube and if I had know nothing about the velocity of this, I will say velocities are very much comparable. So, V 1 is of the order of V 2 and so with this m dot 1, g Z 1 and m dot 2, g Z 2 these two terms will disappear and these two velocity terms are of comparable magnitude, this is something we could check later on or see the application and see what happens. So, this and this will go and in the end what we are left is Q dot cv on this side plus m dot 1 h 1 is equal to m dot 2 h 2 or heat transfer rate is equal to m dot into h 2 minus h 1.

We have got a very very nice simple compact equation coming of here from here we can get the properties if I know a state at 2, we can get h 2. State at 1 is to be needed, so for h 2 I need two independent properties at state 2, for h 1 we need two independents at state 1, m dot needs to be given. If these are given, then Q dot cv can be calculated, so that is the illustration of how we proceed in solving problems which are of a flow type of a system, where we need to calculate energy and work transfer.

There are many more such application that we will look at this is a example of what one may call heat transfer or heat exchanger, there will be many more things coming up like turbines and compressors. And then instead of a flow if we had a reciprocating system like one example we took that will not have these questions, but have those equations for a control mass ok.

So, there are some more questions here. Why are we not talking small d instead of del in the expression of a 1st law? this is the thing coming up again ok, I will (Refer Time: 23:29). The question is this, I wrote the 1st law as delta Q is equal to delta W plus dE.

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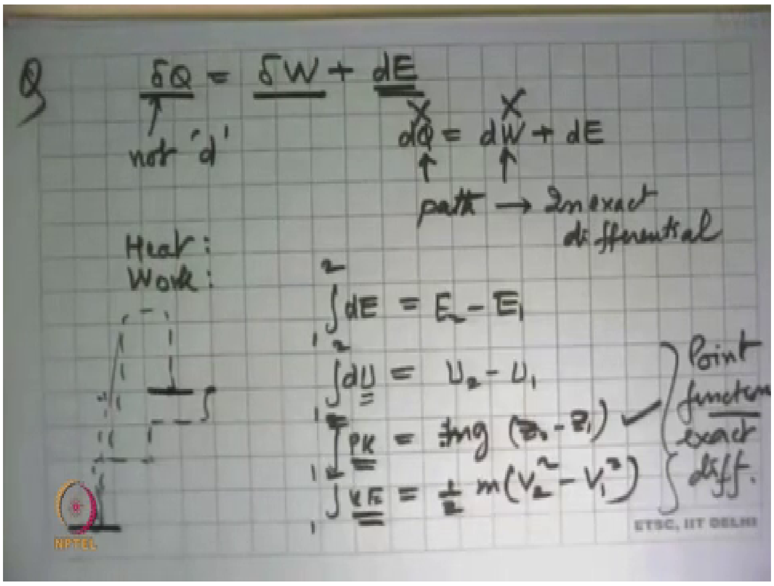

And the question is, why are we using delta and not d? It is wrong, if I write the equation of the 1st law as dQ is equal to dW plus dE, this is the question. And the answer is heat and work are not properties of a substance, they depend on the path which means that they are inexact differentials. DQ means this is a exact differential and I can say that heat is Q 2 minus Q 1 by integrating it, but we do not define Q for a system that is another way of looking at it.

Let Q of a system is not defined, our definition of heat is that form of energy which crosses a system boundary due to a temperature difference, a system does not contain heat. And similarly, work is work done at the system boundary which are the sole effect of lifting a weight of which is force into a distance. So, the two good reasons why we cannot write dQ and this is wrong and this is also wrong and that is why we have the equation in this way.

Energy though is a property of the system, it does not depends how to system got there and that is why we are justified in writing this dE. And when we integrate it from 1 to 2, this we can write as E 2 minus E 1 and the same thing is integral of dU, while U is also a property this can be written as U 2 minus U 1. And same thing with your potential energy and kinetic energy, that is why we got the terms here potential energy was m g Z 2 minus Z 1 and this was half m V 2 square minus V 1 square, so these are properties.

And you can physically if you want to see, you can see these two that if you lifted a weight from this height to this height, whether you just lifted it straight or whether you lifted it high up and then brought it down or whether you lifted it up. And then went up like this and then came here, the change in energy is always going to be the same, it does not it is not dependent on that these are the paths, this is path 1, this is path 2, this is path 3, it does not depend on the path; it is only the initial. And final points where it depends on, so that is why kinetic energy, potential energy and internal energy all these are point functions and so exact differentials ok. Another one which is can we say, dW is equal to U 2 minus U 1 in an isolated system.

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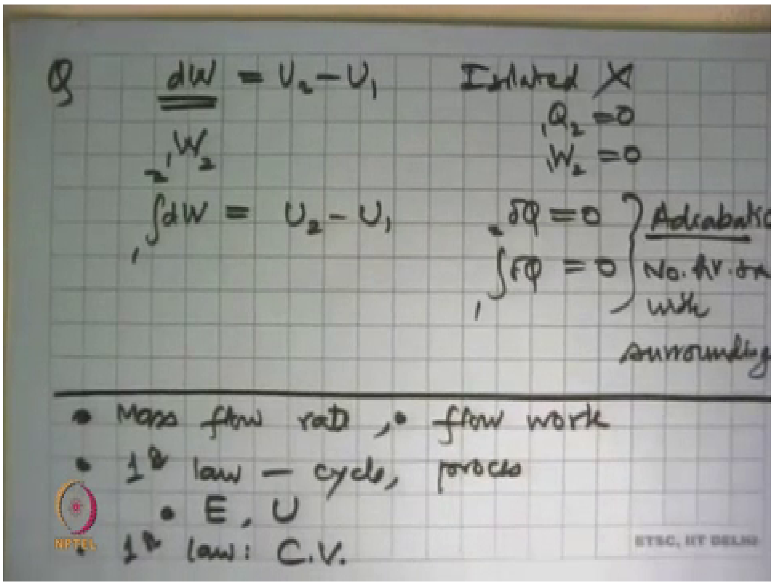

One more question, we have taken 3 d control volume. So, there should be partial derivative in all equations which (Refer Time: 26:56). Now ok so, let us take this one the question is, because the 3 D system why are we taking d dt as this and not as a you know partial derivative, well it is we have said that everything in the system is included in the mass. So, the dimensional dependency is gone, so we do not need to worry about that we are only saying whatever the total mass in this system, what is it that we are looking at.

We are saying that m cv does not depend on anything else either so, but if you want to express this in terms of volume and space coordinates, then you are right the space coordinates will come here, those will be partial differentials in space xy here ok, so that is a reason for that.

Here is a question, isolated system 0 work done or not ok, that is been answered ok. Can we say dW is equal to U 2 minus U 1? That this will be the case, not when it is an isolated system, isolated system means it has no interaction with the surroundings that Q 1 2 0, W 1 2 is 0. So, U 2 will be U 1 nothing will change. Anyway dW writing is wrong, the correct word should have been W 1 2 or integral dW 1 to 2 if this has to be equal to U 2 minus U 1, it means that delta Q should be 0 or integral delta Q 1 to 2 should be 0, which implies that the system should be adiabatic. Adiabatic system means, it has no heat transfer with surroundings that is the case under which this will be true adiabatic system not an isolated system.

So, what we have learnt is we came across some new concepts today. Let me just summarize and then we will quit further. Now, we got the idea of what is the mass flow rate and the idea of flow work. Then we derived the 1st law statement for a cycle and then for a process and during that we came across a new property which is energy and a new property internal energy.

And then we applied this 1st law, got a long equation for a control volume. So, we have now all the two of the most important things in doing all types of problems, which is this and this. What we will do in tomorrow's lecture is to look at a few more examples and applications before we move onto the second law of thermodynamics.

So, thank you.