Concepts of Thermodynamics
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Lecture – 20
Control Volume Mass and Energy Balance

In the previous lecture we were discussing about a mathematical way of transforming control mass based approach to control volume based approach and that was essentially achieved by the Reynold's transport theorem. So, let us write it.

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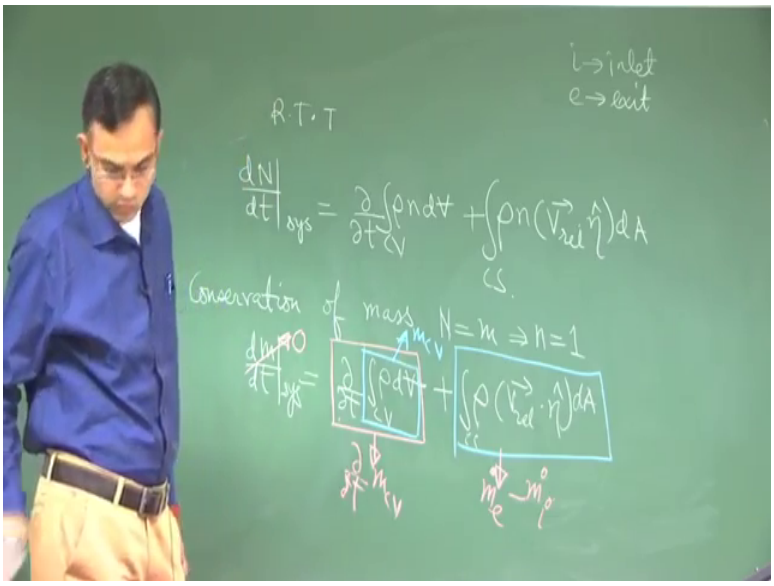

So, to summarize, this is the rate of change with respect to the control mass system, where capital N is the property, extensive property. This is rate of change with respect to the control volume, where small n is the intense corresponding intensive property. And this is the flow across the control volume carrying with it some property n.

So, now we will take an example, rather we will take two examples; one is conservation of mass and another is conservation of energy. So, conservation of mass means capital N is equal to m, which is the total mass of the system. So, when capital N is equal to m you have small n equal to 1 which is capital N per unit mass.

So, you have so, let us now write physically what these terms are, what is dm dt of the system? By definition a control mass system should have a fixed mass. Therefore, dm dt of a control mass system has to be 0. If dm dt of a control mass system has to be 0 then. The next is what is this? This is the rate of change of mass within the control volume, because this is essentially mass within the control volume.

Student: (Refer Time:05:18).

Yes.

So, this is and what is this? So, remember the recall the derivation of the Reynold's Transport Theorem. It was outflow minus inflow of property, here the property is mass. So, this is m dot outflow, m dot is mass flow rate, so unit is kg per second.

So, m dot e minus m dot i, e for exit, i for inlet. So, let me write it somewhere here. So, the conservation of mass for a control volume can be written in this way, this has a rate equation.

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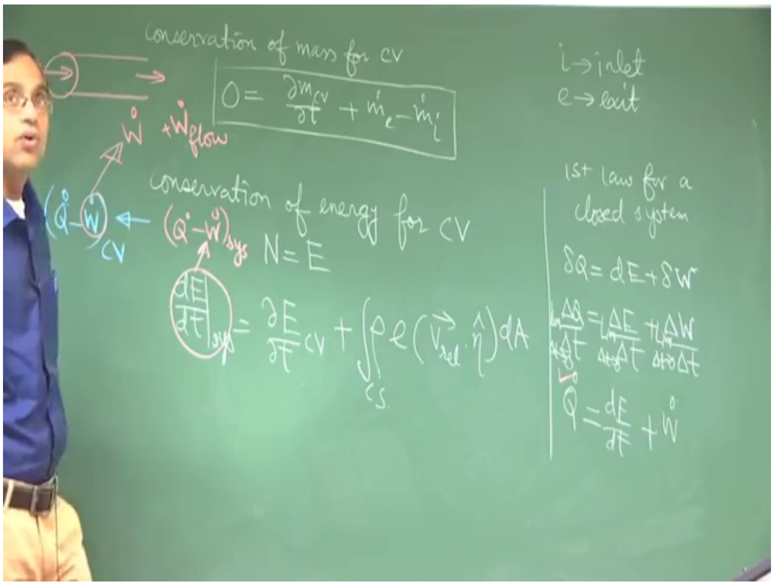

Next is conservation of energy. So, for energy capital N is the total energy of the system. So, capital E is the total energy; so capital E is the total energy and small e is the specific energy which is total energy per unit mass.

In the Reynold's transport theorem we have substituted capital N with capital E, which is the total energy of the system. Capital N is abstract right, it could be anything. Now that anything in the case of conservation of energy is substituted by the particular parameter which is energy. Now in the limit as delta t tends to 0, several interesting things occur and why that limit is important? That limit is important, because we derived the Reynold transport theorem by taking a limit as delta t tends to 0, so that the system and the control volume are almost coincident. So, that the common zone of intersection between the two system configurations can be taken as the control volume, if you refer to my last lecture you will understand that more clearly.

Now, let us consider the first law of thermodynamics for a control mass system. See why we have written it in this way? We have written it in this way, because on one side you have a knowledge on the first law of thermodynamics for a system and that knowledge you have that gives you the expression for this term; the change in energy of the system. You do not have a direct expression for change in energy of the control volume. So, you are forced to write this in terms of this and here appears a correction term, because of outflow and inflow.

So, now let us recall the first law for a closed system. So, you have so, now if you are interested to express this in terms of a rate equation likes this. So, you can write delta Q divide by delta t and take the limit as delta t tends to 0.

So, this is Q dot the rate of heat transfer, this is de dt, this is W dot. So, to relate this with whatever we have written in this part of the board this is nothing, but Q dot minus W dot that is from here.

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So, in this differential form is.

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Yes.

Student: (Refer Time: 13:40).

No, the reason is that you know these are differential terms, but these are small terms which are not differential terms.

So, the difference between these is these are differential terms. So, this is exact differential, this is inexact differential. For writing small terms which are not differential, there is no distinctive symbol for exact and inexact, so that is why this delta is written for all. Keeping in mind that when it will be a differential this will be inexact differential, this will be inexact, but this is exact ok.

So, now you write this as Q dot minus W dot. What is this Q dot minus W dot? Q dot minus W dot for the system or Q dot minus W dot for the control volume, which one? So, fundamentally it is Q dot minus W dot for the system right, but you have to keep in mind that Reynold's Transport Theorem was derived under the condition when the system almost converts to the control volume.

So, heat transfer and work done for the system is same as heat transfer and work done for the control volume. So, that is true, because of the derivation which was considered taking the limit as delta t tends to 0. So, this is as good as Q dot minus W dot for the control volume. Now when you say Q dot minus W dot for the control volume you also have to account for an additional form of work which comes into the picture here, because of what? Because the fluid is flowing.

So, this W dot includes the energy that you extract from the control volume or the energy you supply from the control volume whatever plus or minus depending on the algebraic sign. The energy that you give in or the energy that you take out, because of the fluid flow, so question is. So, let us write this as so, instead of just writing that it is the work, so it is the matter of symbol you see. So, this refers to the CV, this refers to the work extracted from the CV. So, just let us write it as W dot without referring to CV. So, this is what? this is the rate of work; that is you know either output or input from the control volume and the work associated with the control volume is another, it involves another expression which involves the work transfer due to flow.

So, if you have a pipe, fluid enters and fluid leaves. So, when you have the work transfer due to flow that work transfer due to flow is associated with what is the work that is entering, what is the or what is the energy that is entering you can call it work or you can call it some energy input. So, I would say that you know it is better to call this as an energy transfer across the control volume.

So, this is a sort of confusion that I want to fix here. You may not call this as a part of the control volume work. This is actually some energy that is being supplied to the system and the energy that is leaving the system along with the flow. So, not the total energy, but that part of energy which is required to maintain the flow in presence of pressure, so that work is called as flow work.

So, next we will try to look into an expression for what is the flow work. So, let me clarify it once again, because it may create confusion. So, when we are considering the total work associated with the control volume. So, we have one work which is a work which you directly give as input to the control volume or you take away the work from the control volume. Another part of the work is associated intrinsically with the fluid flow and that work is by virtue of the fact that the fluid needs some additional energy to maintain the flow in presence of pressure; otherwise the flow cannot be sustained and that work is called as flow work.

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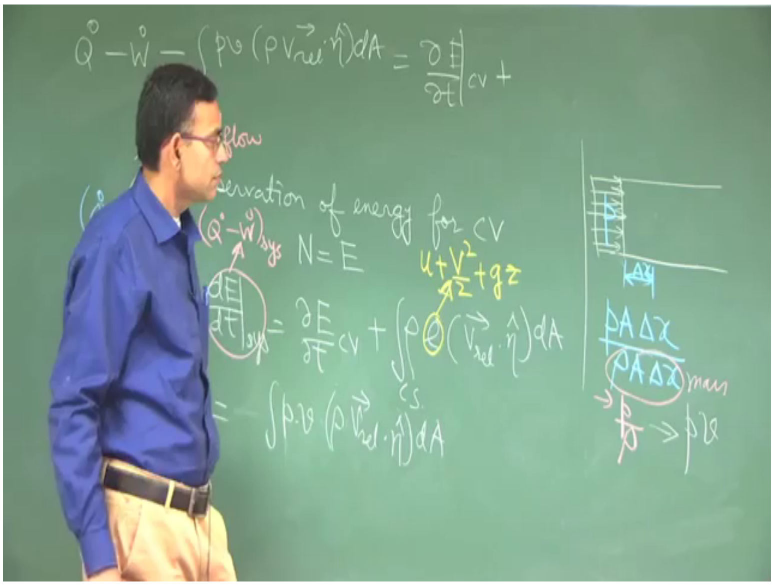

So, then for flow work we have to develop an expression. So, to understand that let us say there is a pipe and fluid is entering the pipe here with a uniform velocity, but you know after entering the pipe the velocity changes. Let us say that there is a small length delta x over which this fluid gets displaced. Why we are considering a small length dx? We are considering a small length dx, because pressure over this small length maybe assume to remain the same and we are considering that the pressure is uniform throughout the cross section.

We will make an assumption later on that all properties, not just pressure are uniform over the cross section, but for the time being we considered pressure as uniform over the cross section. So, let us call that as p. So, what is the work done here, this is pdv p A delta x. this is the work done or energy input, better to say to maintain the flow in presence of pressure.

So, the key is that you can express, you can put this mathematical expression either in work or in energy, but not both ok. So, this is the work done or energy input into the flow system to maintain the flow. So, this work done per unit mass so, this is mass this is nothing, but the flow energy or flow work. So, this rho is what? Rho is the density. So, this is p by rho. You must have seen the corresponding p by rho in Bernoulli's equation, when you have started your first lessons in fluid mechanics. So, the same thing, here it is p by rho.

In thermodynamics we have discussed earlier that instead of the density we commonly used specific volume. The reason is that we can use linear interpolation laws for properties for specific volume. So, this is p into v. So, now the flow work, what is this? The flow work what is the flow work that is output from the system; that is the outflow and what is the flow work that is input to the system; that is the inflow. Remember any work input to the system is negative, any work output which is coming out is positive.

So, minus so this is per unit mass then you have to multiply it by. So, mass flow rate means, so this is per unit mass right and just similarly here, so what we have multiplied it. So, you need a V relative here dot instead of this and instead of the mass so, rate of mass.

So, here there is only one assumption. The assumption is that these properties I have not yet written the full expression only the inflow I have written. The assumption is that this property is p i and V i they are uniform over the section i right. So, that being the case.

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So let me come to that so, this is p i V i, so now, you see I am not writing this minus or plus. So, when you write V relative dot eta, so p i into V i this is inflow flow energy. For inflow V relative dot eta is negative; that means, this will come out as negative. So, when you substitute instead of p i v i p e v e, then V relative dot eta is positive. So, that means, this is the flow energy or flow work associated with the outflow which is positive. Therefore, instead of writing separate p e v e and p i v i we are just writing p into V ok.

So, p into V with, p into V for inflow V relative dot eta is negative, p into V for outflow V relative dot eta is positive. So, the actual work, flow work is like sort of minus p i V i into mass flow rate at i plus p e V e into mass flow rate at i ok.

So, now with this you have Q dot minus W dot minus W dot flow minus. See here there is a minus, so minus integral of. So, only one point that remains is what is this e, e is the energy per unit mass. So, what is this internal energy plus kinetic energy plus potential energy right. So, then you can write rho u plus V square by 2 plus g z right, V relative d A ok.

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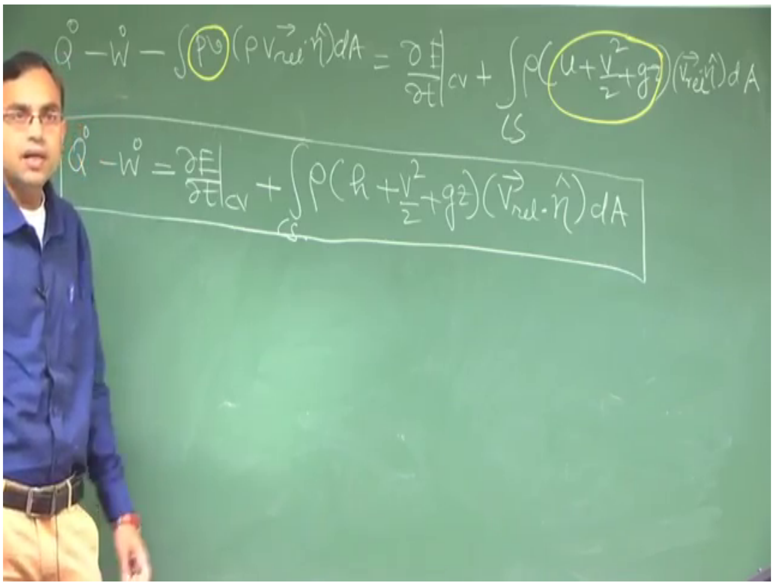

So, Q dot now you see you have a pv term added with this term. So, these two terms that we have circled, this minus will go to the right hand side and it will become plus. So, u will become u plus p v which is nothing, but the enthalpy small h. So, this will be sometimes it may be legitimate to forget about the flow energy and dump the entire thing here, to recognize that when the fluid is flowing its thermal energy is not internal energy, but its thermal energy is internal energy plus flow energy. So, that is another view or another way of looking into it, but why we have started with the flow energy separately is because that we have learned the basic definition that the total energy is internal plus kinetic plus potential right, in terms of thermodynamic definition.

So, if we straight away write enthalpy here that will not be physically meaningful, until and unless we justify that this is the internal energy plus the energy that the fluid requires to maintain the flow in presence of pressure. So, that is internal energy plus pressure into specific volume that makes it enthalpy.

So, a key difference between a flow process and a non flow process is that the thermal energy for a non flow process is internal energy, whereas, the thermal energy for a flow process is enthalpy. We have to keep in mind that both are thermodynamic properties, so they cannot be defined by processes, but for processes the properties can be defined according to whether it is a flow or a non flow.

If it is a non flow then it will be internal energy, if it is a flow then it is the enthalpy. So, that is the basic way of looking into it. So, we stop here today with this expression of the first law of thermodynamics for a control volume process which is pretty generic and we will take it up from here in the next lecture.

Thank you.