Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 16
Control Mass and Control Volume

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Let us start this lecture a thought process from swami Vivekananda says I would call him as a traitor.

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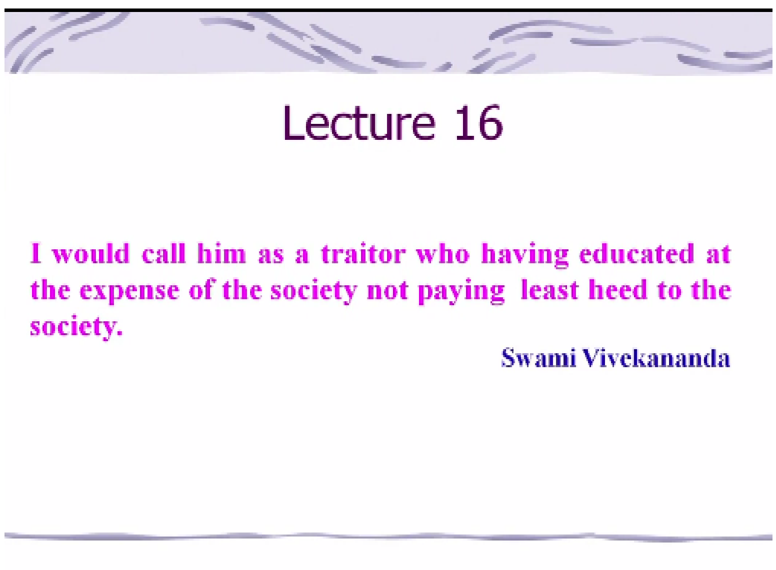

Who having a educated at the expense of the society not paying listed to the society, so what we will do now we will try to recapture or recall what we learnt in the last lecture if you look at last two few lectures we are basically focusing our attention on the first law of thermodynamics, and we have derived that first law of thermodynamics for what you call control mass system right or a non cyclic process for a non cyclic process we have derived the relationship from the actual first law of thermodynamics which is cycle integral of the law is proportional recycled integral of the heat interaction during a process.

So and if you look at like we have taken several examples of course for a simpler systems like where some of the variables will be remaining constant for example isochoric process, isobaric process, isothermal process, adiabatic process right all these processes we have learnt how to apply the first law of thermodynamics for a non cyclic process right, but if you look at the examples whatever we have taken that is valid you know for the control mass system, let me give you example of a control mass system and control volume system okay.

For example you might be knowing the hand pump any of you use hand pump to get the water from the ground hand pump we will be using a hand pump right and if you look at like suppose you have not used that pump for quite some time and even if you press that pump are the actuators right you would not get any water did you observe any time you may not have that experience because I was having when I was a person like you and nowadays people are using pump which is of course they are calling it submerged pump which is there down on the ground.

And they take out the water very easily right, now if you consider this system I want to analyze because some work is being done both are as a matter of fact is a one you call pom-pom means to increase the what you call pressure, so that it will come up and like that now which one will be the control mass system which is the control volume system, I want to analyze this is a problem one is hand pump another the submerged pump you know which is having a motor and impeller you know like water is coming out I do not know whether you have seen those thing or not okay.

Suppose I will take hand pump how I am going to analyze because water is coming out okay and the other one the submerged pump what is also coming out okay should I give answer or you will think about it see I want to analyze now this is the situation and lie allowed to apply the control mass or control volume and then you know there will be some work done and there is a change in velocity also fluid will be in at the steel in the ground and then it will be moving, so there is a change in kinetic energy right.

And it is going at elevation, so from the ground to the some height on your terrace or in some tank which is at a higher elevation, so there is a change in potential energy also right, so this is a beautiful problem for the to you to analyze using the first law of thermodynamics right, now how do unless I choose my control system I cannot go about it okay now see let me just tell you because you are not giving any answer, so let me tell you that you know if we use that hand palm then I can use I can in a control mass system and what you call analyze it very easily as compared to the control volume system.

Let me take another example what you people will be using I think in your hostel there will be Geezer right yes or no yes you are having Geezer like you will get hot water in the summer season sorry in the winter season right and, so that you will get comfortable sour otherwise it is very painful to have a cold water bath in the winter season, so there some heat will be passed through and some water will be coming into the Geezer and some water is taken out by you or the way by the user.

So I want to analyze that can I use a control mass system right I can use as such, okay but it will be little cumbersome to do that and there are several you know system where the flow will be taking place right for example you know fan right you the floor does take place some work being done in your wind turbine in your gas turbine right and your compressors car radiators you know like do you know car radiators right what it will be in the front of the engine right what for it is and palms.

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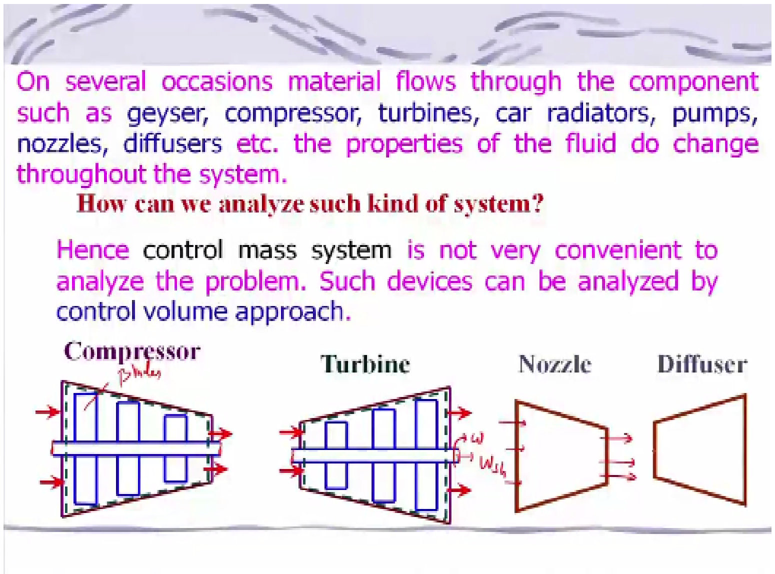

And nozzles and diffusers you know there are several host of you know components are the gas gates what people have developed and so and also several of them in which the properties of the fluid will be changing throughout the system as it moves and you know like questioner arises how it will be you know you will be applying the first law of thermodynamics analyzing it.

For example if you look at there is a compression of course the diagram is not that good but however you can see that this you know like it is having a what you call a sap which consisting of several rotated rotating blades you know these are all blades which are rotated and there will be stationary blades also and that makes the fluid to you know compress the air or liquid whatever you will be using and similarly turbine in this case you know there is also a consists of several kinds of blades like as I told rotary blades and stationary blades and it will be what you call gas if it is gas it will be expanded and you will get some work done.

You know like so if you look at this he will be rotating and you will get some shaft work and similarly if you think of some example of nozzle you know some fluid will be going through this and then what will happen this velocity will be increasing right and in case of a diffuser it will be other way around there will be decrease in velocity but question arises how we will apply the first law of thermodynamics and how you are going to analyze this because there will some heat interaction and there is some also the work interaction right is going on.

Now because the mass is coming in case of any of this component let us say for nozzle mass is getting into the fluid you know who it is entering here and it is going out and hence the control mass system is not convenient to analyze this problems this we call it as a flow problem and such devices you know can be analyzed very easily using control volume approach like you know one is control mass other is controllable we call it closed system and this is one the control volume you know kind of things what whenever we use a control volume we call it as an open system right.

And then we will be now basically learning about how to apply the first law of thermodynamics fluff system because these are all flow is taking place right.

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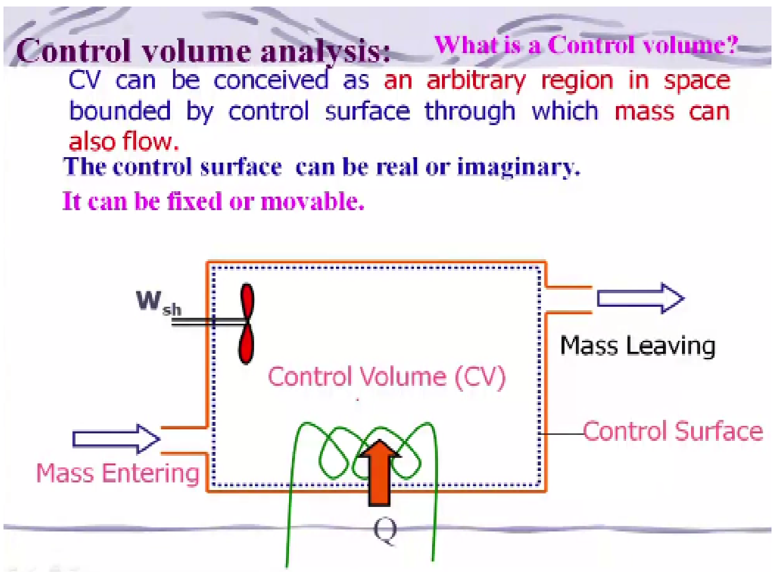

And let us recapitulate what we learned with a control volume and if you look at the control volume is basically a what we call an arbitrary region in space bounded of course by the control surface through which mass will be passing through right and of course if you look at let us consider a system in which the mass is entering here there is some shaft work is you know going on and there is some heat interaction and mass is leaving out and this we can consider that dashed line as basically a control surface and this is the control volume because the control volume is being mark or what you call being bounded by the control surface right.

And this control volume protocol one has to choose properly right and this control surface can be real it can be imaginary it can be fixed or it can be variable right for example in this case if you look at is it is control surface is real or imaginary in this example what I have taken is it what you call control surface is real one or imaginary real one means it will be having some kind of a what we call fixed boundary which is maybe casing incase of your compressor or turbine right you can have a control surface that because that is the boundary.

And that is the imaginary so can you know like whether this what you call these are the control surface is it imaginary or real definitely it is a fixed one it is not moving as the flow is entering right this is a fixed one is not movable right I am I right or wrong is it real or is it imaginary.

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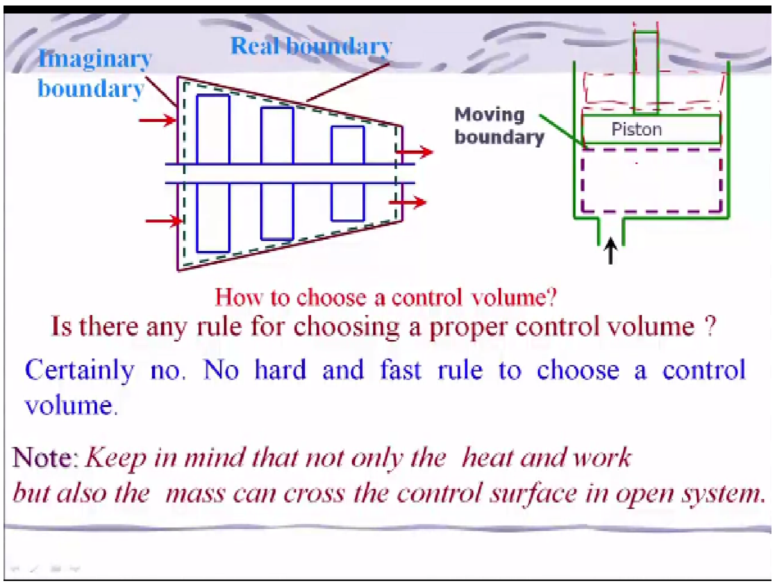

So let us look at I mean like compressor if you look at this boundaries which is corresponding to the casing of the what you call compression right if you consider this as a compressor then this is a real boundary because it is corresponding to the actual boundary of the system but whereas here the flow is entering you know like there is a passage through which flow is not it.

So that boundary is imaginary boundary and we can think of his piston cylinder arrangement and if the gas is entering here with high pressure the piston can move you know let us say piston is moving and then what will be the let us say it is having this boundary to start with after that what will be boundary will be this one that means this boundary is moving.

So this is a moving boundary kind of things and so question arises how to choose a control volume is there any you know kind of a procedure or the rule for choosing a proper control volume right, so it is actually you will have to use your judgment and those choosing of the proper control volume you will be you know learning in fluid mechanics because that is critical over more as compared to the thermodynamics problems right and there is no hard and fast rule for you know choosing a control volume.

That depends upon the kind of problem it depends upon the what kind of experience you are having rather a try to put other way around it will be depending on how you think right because sometimes it will be convenient for you but for it may not be convenient further for others but however one has to use you know choose the control volume and control surface accordingly diligently it says that it will be easier to handle the problem.

So we should keep in mind that for a open sister or a control volume system not only the heat or the walk but also the mass can cross the control surface and there will be interactions you know like in this case the fluid will be entering and leaving and sometimes entering not leaving you know sometimes leaving not entering you know lot all those things can happen and it may be accumulated also so that you should keep in mind.

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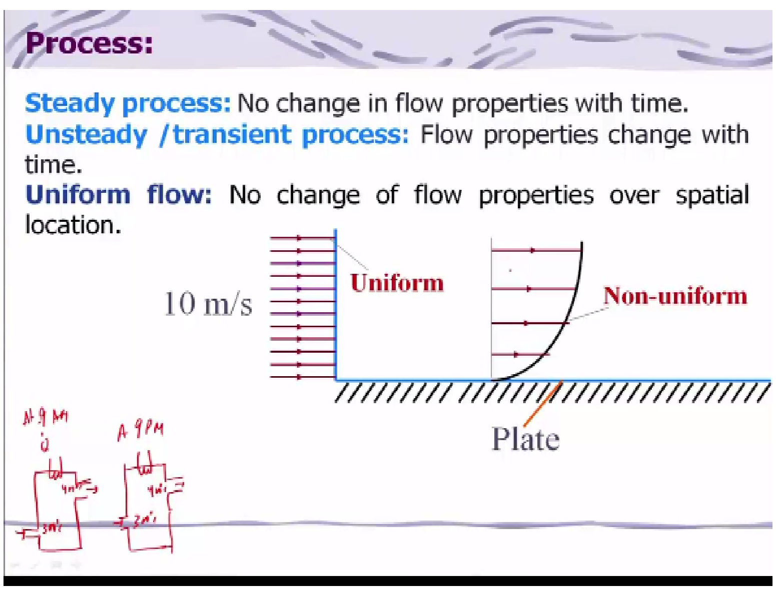

So let us look at what are the processes we can consider right processes can be what you call steady it can be transient process as we are right steady process means no change in flow properties with time, for example like if I take a system here let us say this fluid is entering and through it is going out and let us say this is something what you call 300 degree Celsius and it may be 400 degree Celsius of course there will be heater here like there will be some heat input.

And this is at time let us say 9:00 am and I will consider the same thing like you know same system I am considering same so if it will remain here at 300 degree Celsius for and a same thing at let us say 9:00 p.m. in the night morning till night let us say we are considering that period of time then we call it as a steady but if it is changing you know of course it can change within hour it can change within you know this thing so then we consider this as a unsteady process or standing transient process.

In which the flow properties will be changing with time right but whether there is another process what we call as a uniform flow that means no change of flow properties over a special location right for example I will take a flow over a flat plate you know there is a plate over here and flow is coming let us say it is a uniform velocity 10 meter per second as it moves you know because of boundary layer see this is the boundary so the velocity will be here 0.

So therefore it changes and because of you know viscosity and the flow is not uniform here earlier we have given input you know as a uniform velocity profile but here the velocity has change and this flow in this case you know it will be uniform properties and here it is changing so also the other things will be changing now that we call it as a uniform flow let me just tell you that in case of thermodynamics we will be considering most of the times rather all the times right well most of the times.

Uniform flow like in fluid mechanics when you will analyze you will be using non uniform you know flow kind of things right that you should keep in mind and you might be wondering like you know whether the unsteady process will be occurring all the time or the steady process how to choose and then whether the steady flow process will be really occurring right or the all the process will be unsteady so as you go along we will see that that there are some processes we can happily you know assume to be steady provided steady over the period for which we are analyzing it you know that is important.

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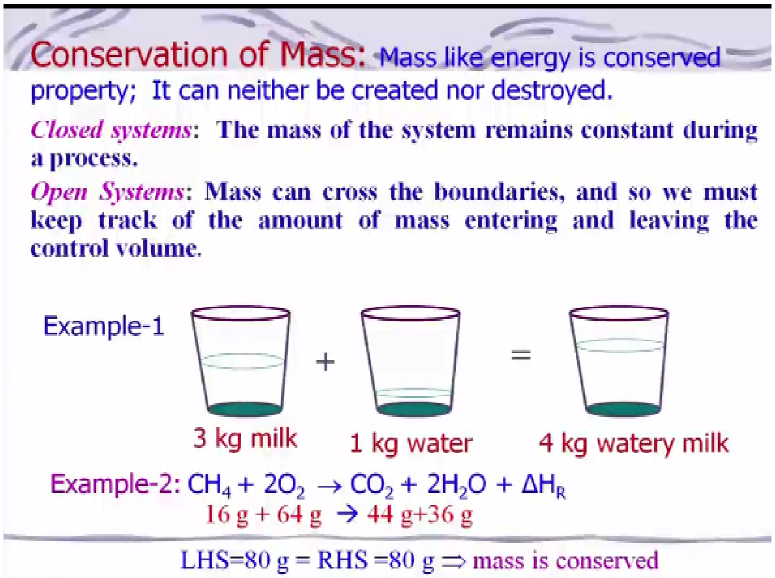

So as I told that the mass of the system remains constant during a process in case of a closed system there is not nothing to worry about it right and whereas the open system mass can cause the boundary so we need to keep track of how much mass is causing the boundary inlet boundary outlet boundary right or there might be several inlets and there might be several outlet we need to have a book keeping of the mass entering and leaving kind of things.

For let me just take you a control mass system like you are having let us say one jug kind of things right where you are mixing water and milk let us say 3 kg of milk is mixed with 1 kg of water that became 4 kg of water milk you know that what our milkman they do very often what it indicate, indicate that you know mass is conserved right so that means mass like energy is conserved okay property.

Because we know that energy can neither be created nor destroyed of course it can be converted from one form to other right that we have seen for an isolated system and if you look at can I say that also similar way mass can neither be created not be destroyed can I say that way mass can neither be created not be destroyed right it may be converted from one form to other for example water you know what it is converted into liquid water is converted into vapor or also the eyes you know.

Now let us take an example right the one mole of methane is reacting with two moles of oxygen and going to the product one mole of carbon dioxide and two mole of water and of course some amount of heat will be released right so if we do I mean this is this is a balanced equation or not am I right if you look at this basically balance because if you look at carbon this one carbon this side left hand side one carbon right hand side one and this is for H4 this also to h4 basically 4h and similarly oxygen if you look at 4O and this side 212 4 + 4 so it Is balanced.

And if it is balanced what it says is it like if you look at the it is balanced by mole wise like one mole of methane it is reacting with two mole of oxygen and one mole of carbon dioxide back in 2 moles of water so if you look at more wise left hand right hand side is same MRI 3 and this 3 right total but what about mass, mass is also 16 grams right of methane is reacting 64 grams of oxygen and giving rise to the product of 44 gram of carbon dioxide and 36 grams of water right.

If you look at left hand side is basically coming to the 80 grams right hand side 80 grams so we can say mass is conserved in a chemical reaction in chemical reaction you know some heat will be released and then in this case heat being released right so it is happening it is basically so can I say that mass is conserved right, yes or no? But we have taken this example we are saying that mass is conserved right yes or no mass is conserved irate and incase of your fluid mechanics and other thing we will be using the conservation of mass right.

And heat transfer other problems also so but is it really true, right or it is true for some situation, how many of you agree with this mass is conserved? All of you huh yes right how many of you people agree that mass is not conserved mass is changing mass is changing right only two okay so let us look at actually what this Einstein related theory says.

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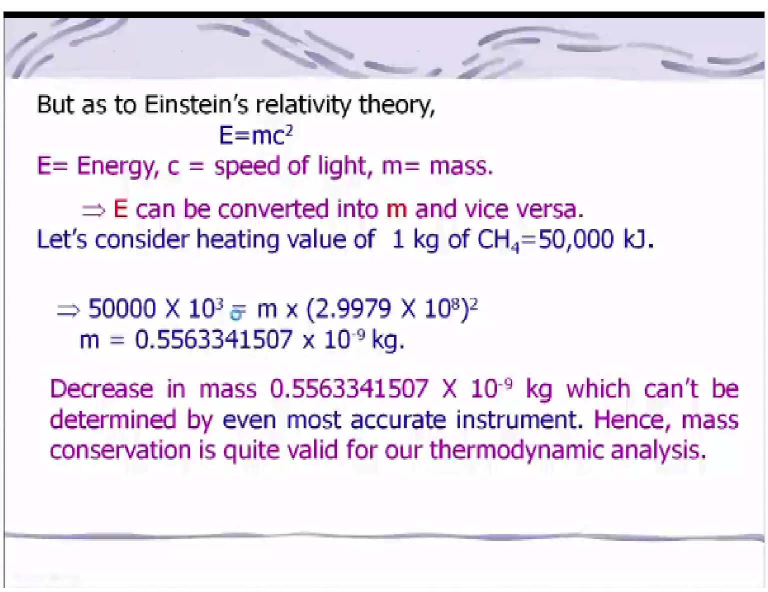

$E = mc^2$ right the E is energy, c is the speed of light mass is the you know m is the mass so if you I will take this example and try to compute how much change in the mass because of heat release right so I mean that we can see that but what this relation says that energy can be converted into mass and vice versa so therefore you know there will be some change if it is changing energy is converted to mass that mass will be consumed you know right and converted into energy.

So let us look at you know considering that example of methane being burnt with a reacted with oxidizer you know convert into carbon dioxide water and that gives rise to something1kg of methane when it burned it gives fifty thousand kilo Joule of energy right and we will substitute these values over this here right and we will also know the speed of sound and you know this sorry the speed of light right and if you do that you will get this mass is very, very small quantities you know.

Like means 0.556×10^{-9} kg right it is a very, very small mass change due to these heat release so which is you know cannot be really measured with the best instrument available at this moment hence the mass conservation is quite valid for our thermodynamic analysis even for queen mechanics heat transfer unless some nuclear you know reactions are you know being taken where the large amount of heat being liberated all are the amount of energy being liberated where there will be some change in the mass there you cannot afford to consider the mass is concerned right. I mean there but rest of the things you can happily assume the mass is conserved right.

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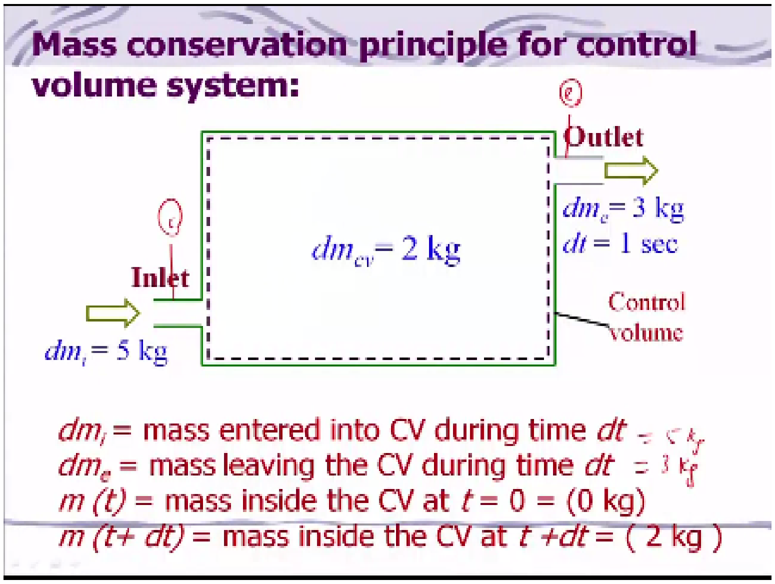

So let us consider how we will handle this mass conservation principle for control volume system because we are considering for thermodynamic you know system mass is conserved so we will take this example in which if you look at let us say there is a Inlet here in this chamber and there is outlet and 5 kg of mass is entering I am enduring a one second and then it is leaving with 3kg of mass and this is something accumulated 2kg kind of mass that we can write down mathematically as let us say DMI is the mass enter into control volume at during time dt and dme is the mass leaving the control volume during time DT and mt is the mass inside the control volume at time = 0

That is we can in this example we can consider as a 0 kg in this example and the mass inside the control at time T plus BT is 2 kg right and if you look at mass entering the control volume during time is basically if you look at this is 5 kg and this is 3 kg. Right now we will what you call look at this how it is happening and derive an expression for that and if I will just do a balance between the inlet and the exit

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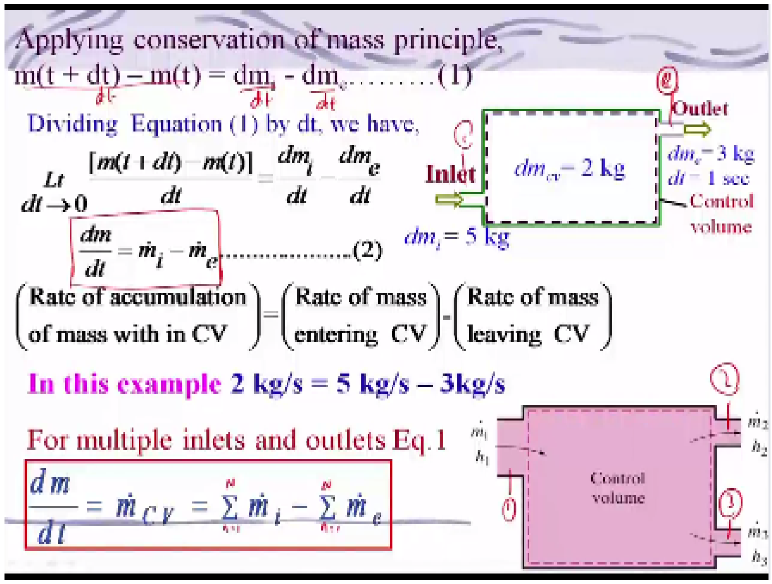

If you look at mass is you know at time T = DT minus the mass at time is equal to DMI – DME the mass he is going to the inlet you know this is your Inlet and this is your exit. So if i will divide this by DT and this is by DT right time and this time is very small and distending to 0 what you will write down and you will write down that you know it will be like this and then we can write down that when DT tending to zero is nothing but DM /DT =MOT I this dot is basically per unit time right minus the mass leaving at the exit mass flow rate leaving at the exit Right and this is what you call the mass conservation equation what it indicates.

If you look at the left hand side this term is basically mass being a cool accumulated in this control volume and this mass is entering into the control volume that is M.I and mass is leaving the control volume right. So and this will be basically taking care of mass balance we call it mass balance how much is you know the mass being accumulated in the control volume and mass being leaving in the control volume and rate of the mass entering into the controller

In this example I am again repeating that the accumulation will be 2 kg per second and mass which is entering into this control volume here is basically 5kg per second and mass leaving is 3 kg per second so this basically you are taking a mass balance it is like you know like in your bank account you know your father will be sending some money and you will be spending and whatever the difference is accumulated and sometimes it will be negative as such you know right.

So of course you know in this situation it will be you know if it is then kind of things so and now this is this equation is mean for a you know one a single inlet and exit right but there might be a situation where there will be several inlet and several exit. For example I do not know whether in your hostel it is like that from the one either you can have several connections right one is inlet pipe or several things are going.

For example in the houses we do let us say we are having two bathrooms so we will put a one greaser and give a connection to the other bathroom right or washroom whatever you call nowadays you know people are calling bathroom as washroom ok the new terminology for me also so it is fine and then there will multiple inlet will be there and multiple exit will be there but how to handle that.

For example in this case you know there is a one what I give like you know let us say mass flow rate you know m dot one at the station one if I consider this as a one station and this is your station two and this is your three kind of things. So how-to handle this then mass balance on this and what you can do you can just rewrite the equation 2 as DM by DT is equal to mass flow rate accumulated in the control room is equal to summation of m.i – me right.

So in this case in this example this you know in the inlet if you look at inlet is only one right but there is there are two exit you know exit are the outlets right so therefore to mass has to be considered it may be n number of things right. If you look at like this can be n = 12 whatever n may be right I can say number of exit you know lv m n is the number it can be n number. I can be 10 it can be 5 it can be 12 it can be one it can be to anything.

Okay so by these will do basically mass balance what we call keeping of the mass flow rate into the control volume and living out of the control volume and also the how much being accumulated in the control volume. So now we will have to learn how to apply
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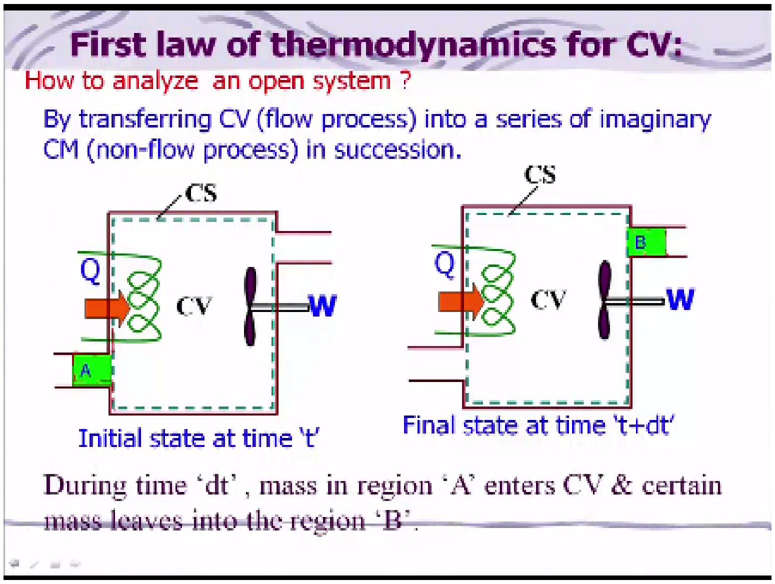

The first law of thermodynamics for analyzing an open system right how will do that because we whatever we have done that where you know mass is not coming in and going out to the control vertical surface in a control mass system right. Now can I apply that equation that is what is that de = D-TW that is the first law of thermodynamics control mass system right and there if you look at if you just you know think about there is no rate term.

Can I really rate in the sense mass flow rate per unit time it is not there right but I can apply that equation for the rate term as well as i right yes or no I can you know divide the time you know all the denominator and then becomes that is all I can say but how will apply? What we will do now you know we will be considering basically a control volume system consists of several control mass system right and then we will apply this control mass system equation and then derive a relationship which will be hold good for the open system or a control volume system.

How it is for example if you consider the video right then video will be consists of several still photographs MRI you might have taken several videos and convert into steel photography am I right you have done or not in the similar way what we will be doing that will be transferring the flow process into a series of imaginary non flow processes in succession like the way we convert the video into several steel photographs right.

For example if I am moving this hand like this you know the hand can go one step to another but it can go several places so I can consider one state and then go another and another and analyze similar way we are going to do that is that clear this is a very important concept you must you know try to visualize then only you can otherwise no right you are you people getting what I am is trying to say that means this flow process will be converted into series of you know non flow processes in succession.

Let us do that what will be considering that this process you know like let us say this is the your control you know system control mass system in which you are having and this is of course initial state at time it is having a shaft work it is having a heat input and then you assume that this fluid a is about to enter into this system at time is equal to T and let us consider at the final state at time is equal to T+DT then if you look at this is my now control protocol system mass system here that means this portion will be my system.

Right in the time T what will my system my system is this one I am considering this right that means coming from here and going this is my control system and at time T plus DT this is my including this fluid which is about to leave from this volume this what you call is that clear. That means the fluid is coming in and going out coming in and going out that we are considering so with this mean that means at time T this is basically we can say it is a control mass system here at time T and I time T + DT again this is the control mass system.

But its boundary of the system is change the boundary becomes like this right and here it is considered the inlet fluid which is about to enter and in case of time plus DT the it is also contains whole boundary but the what you call the mass which is about to leave this you know chamber is that are you people getting at the that is very important point and you should you know try to visualize and keep in mind this is the thing what we are considering.

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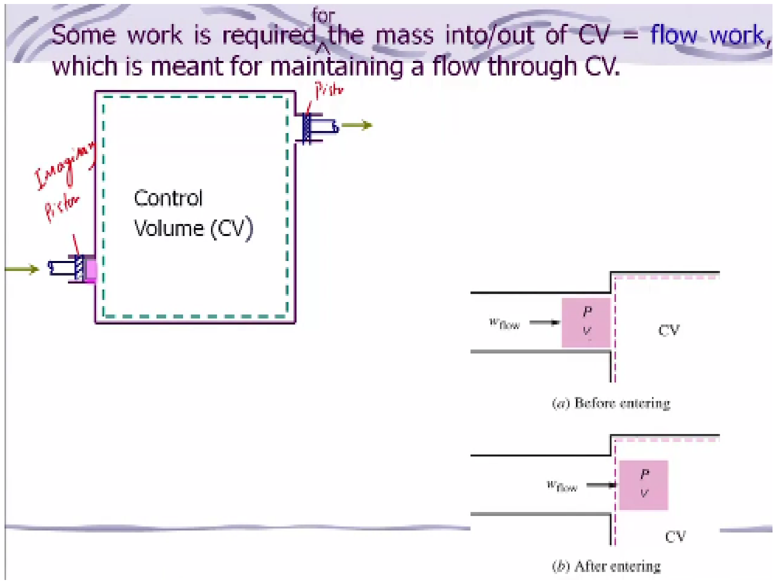

Now during this time DT mass in the region a enters the control volume and certain mass leaves into the region be that we are considering it in to instant of time that is so and some of the work is required for the mass to put into the control volume and that of course we call it as a flow work and also some work is required that by which the fluid will be moving what you call moving out from the control column.

Right are you getting for example that means I need to push this fluid to enter into here right at some work and that we call it as a flow work and similarly this fluid as to go out and then we will have to push some out so that it will be what you call some flow work is required to be given. So for you can think of imagine that this is an imaginary piston right this is a piston kind of thing we stick which is imaginary. It is not there I am just assuming that there is something pushing.

You know that max systems similar here it is having x and this is also a imaginary which is moving out so that way it will go out it is not there in actual system okay but we are just thinking and now what I was trying to say that the fluid which will be you know before entering it will be like that with pressure P and specific volume V.

And is entering and after entering it becomes goes there you know that is the flow work what it if you think that way that you know piston is here and when the force is applied you know then it moves with a distance L so then what will be work done on this that means I am taking this imaginary system which is this fluid which will be entering into that by the imaginary piston so how much work has to be done then what will be work done we know that you know that will bop TV right.

And that is nothing but what call flow war p into a into L write this portion is you change in one right and that of course I can say this change in volume v pv kilo joule right per unit mass what it would be this will be P into specific volume that is kilo joule per kg this is your pressure and this is fluid pressure and v is your specific volume right so that means we can evaluate how much work is done.

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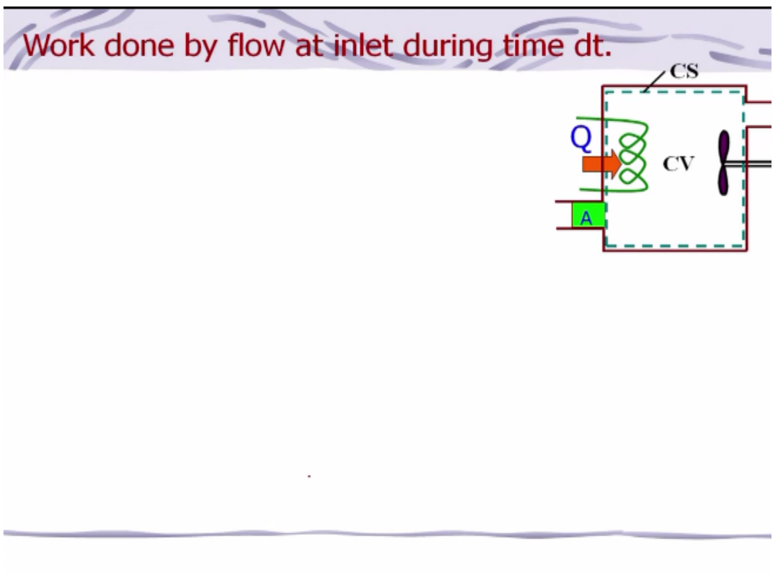

I am like of course if how much work is done during the time e and so let us consider that the work done will be at the inlets basically p I we are into mass flow rate what is entering so this you know whatever entering is m . i, right into DT and during time TDT so that will be work done at the inlet and this is your Inlet and this is your pure exit right and negative sine Negative.

Sign is coming because if you look at the surrounding is doing the walk you know on that so therefore it is not by the system it is on the system so it is negative in the similar way we can find out was done by the flow at the exit during time DT will be w/e p e ve most e into DT right in the similar way only the sign became positive because the work done by the system whatever it is and by the fluid rather fluid in this case is a system.

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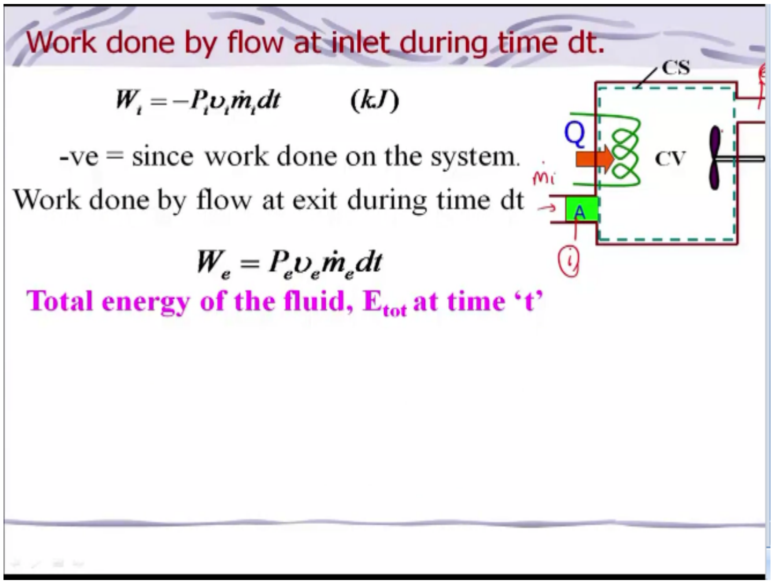

So the total energy of the fluid e total at time Twill be what it will be basically energy of the fluid at time T plus some amount of fluid you know energy the fluid with certain energy of e I is entering during time T at the inlet right are you getting that means this because of this mass flow rate is entering it will be having certain amount of energy right and it is occurring during time DT of course DT we are considering to be very small that will be doing so what is that e is consisting of what e stands for what total energy.

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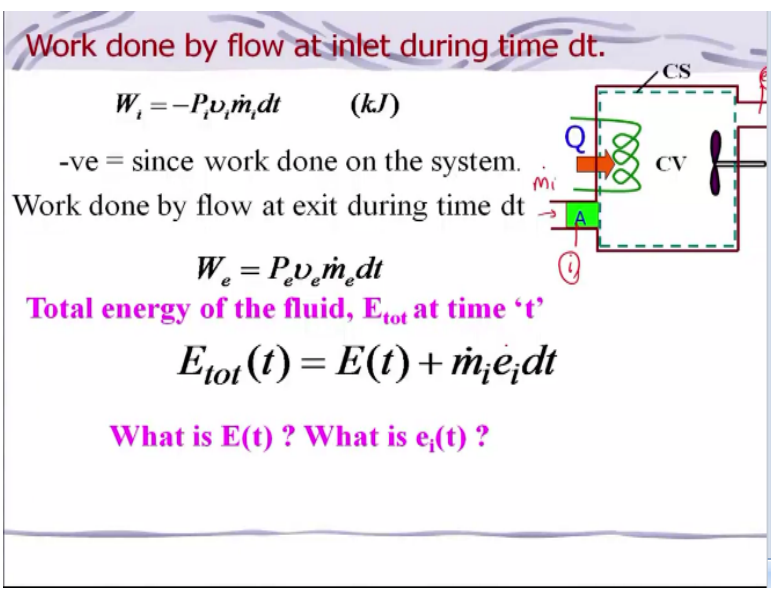

Total energy means twill be having internal energy kinetic energy and potential energy right so that together so that is basically you plus MV square by 2 plus mg jade is elevation right and of course the if we just divide this with the mass you know that became total specific energy atilt okay so similarly at time T plus DT would be e is equal to e that energy in the control volume whatever it will be there at P plus DT plus whatever thundery about to leave from the control that is m.e into DP right.

We have done for the inlet we are doing for the exit you know considering that that is all nothing more so now what we will do so how much heat is transferred to the control volume during time p that is basically q dot you know into straight is equal to energy transfer as it into the system that is also work interaction right so how much work is being done during time DT that is w dot into DT.

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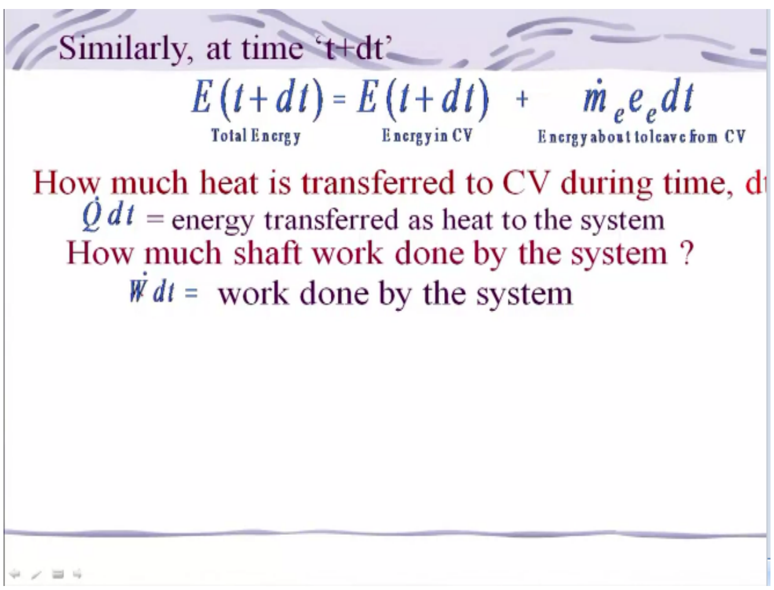

The basically this is you know kilo joule per second kind of thing you can think of unit into DT this is a kilojoules and work done by the system and according to the first law of thermodynamics that we know d is equal to DQ minus DW and DQ minus DW + VW and this is the flow work right and this is what you call any SAP to work one can think of you know like so therefore we can say that e.

By T plods right and this is the energy right this is this term at t minus at the what you call at the t is equal to 0 this amount of energy ET plus m dot I aid tend this is your heat interaction minus the work interaction and this is your flow work right we have already seen emote p EV minus m dot I PIV I into DT during that time you know DT what is happening right you are getting that each term is for basically what you call you know is where control if elected at TDT.

Is one control mass system and T is another control mass system you are combining it and then looking at it right and what we will do we will divide this term you know by DT so if you look at I will divide this and will divide by DT here VP here and aloft here and when DT is tending towards zero so I will get an expression de bid is equal to m.e you know in the bracket if you look at you e I am just expanding that II right and v square divided by 2 plus GJ d and this flow work.

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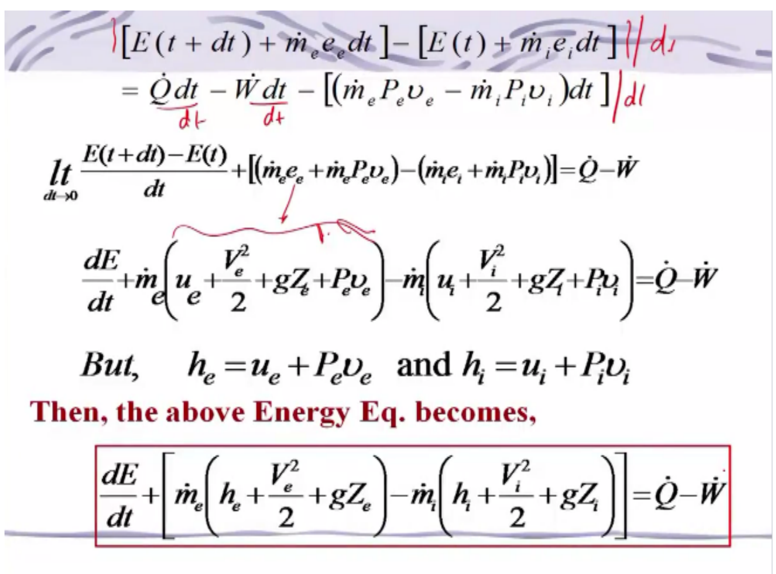

Flow work I have taken over here you know if you look at this kind of things I have already taken here flow work and this I am expanding you know this is expanding version or till this right till this is the e and this is your flow work and this is at the inlets equal to Q . W and where H E is equal to u plus PV that is enthalpy right and similarly I can write down hiss equal to u YP

I VI and then above equation becomes you know de by DT is it plus m dot e h e plus the kinetic energy term v square divided two plus z.

And this is at the exit you know minus the inlet total you know energy right m dot e into h i plus bi square divided by 2 plus GJ i is equal to Q dot minus the work done so this is the energy equation for a flow process or an open system so which is quite complex as compared to the first law of thermodynamics for a control mass systems so we will stop over here and we will discuss in the next lecture how to apply and what are the things and other things.

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