Engineering Thermodynamics
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Lecture 22
Flow work and energy of flowing fluid

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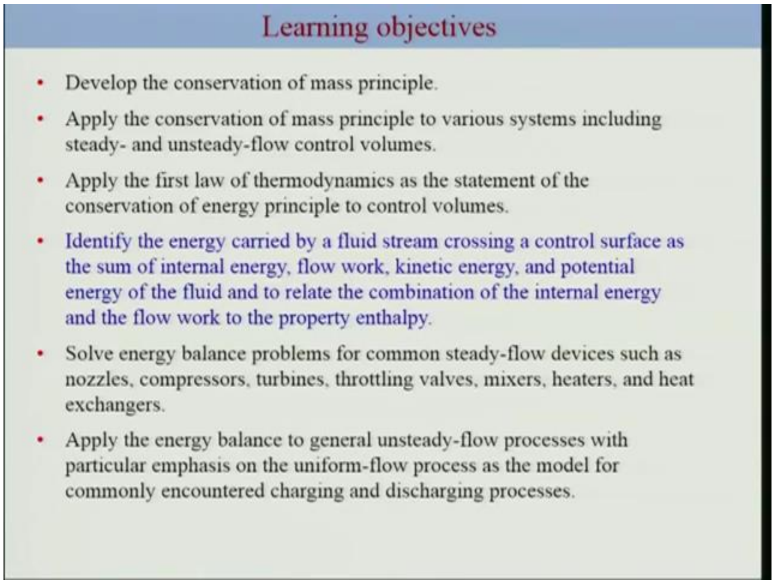

Ok, Welcome back. Let me just go through what we have done. We have done as of now the conservation of mass principle and now we are going to apply this for the case of energy analysis of a open system, ok?

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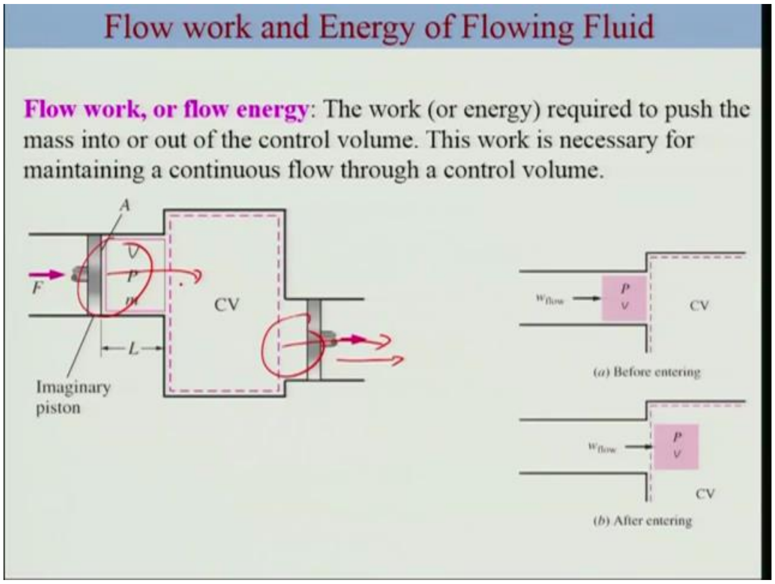

So let us first look at a particular aspect of flow work, ok? So you have a control volume, ok and essentially you there is a specific flow which comes in and there is a outlet from the control volume and thus some amount of fluid gets enter to the control volume and around the same amount of the fluid which gets out in order to attain the steady state. So to maintain a continuous flow, there is a specific work which is necessary, because the work is necessary to push the fluid into the control volume and the work is necessary to push the fluid out of the control volume.

So in other words, the surrounding does some work on the system or the system does some work on the surrounding and this particular type of work is called flow work, ok? Because this is a work which is required to push the mass into and out of the control volume. So this we will refer as flow work or flow energy, ok? So let us assume the case where you have the system attain a steady state.

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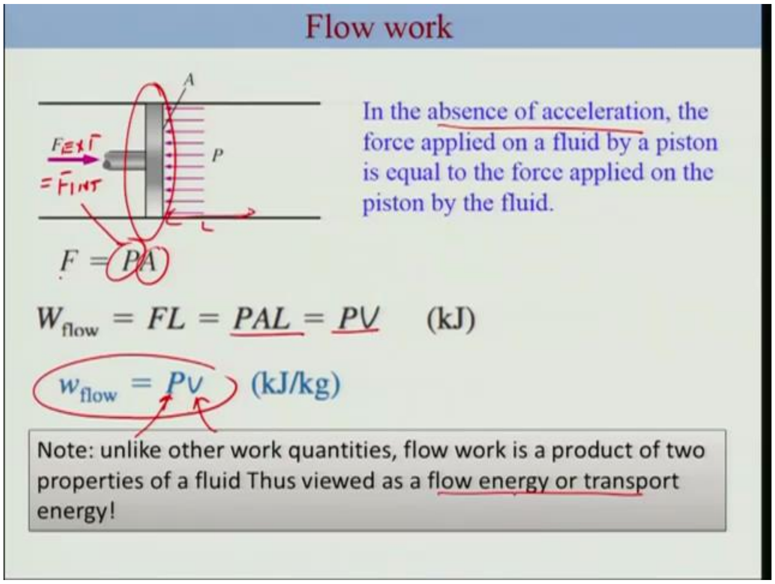

So let us consider a case where you do not have any specific acceleration and you can imagine that this fictitious piston. So which is representative of this particular force required to push this fluid by a distance say L, ok? In case of absence of acceleration your F here will be in equilibrium for infinitesimal small amount of time to the force applied by the fluid.

Your F external, ok? Would be same as F internal which essentially means F here external is can be written as the pressure applied by the fluid to the fictitious piston multiplied with a cross sectional area. And thus you can calculate your workflow as forces just as which can be written as pressure multiplied by cross sectional area multiplied by the distance L and thus it can be written as P multiplied by V.

You can rewrite this in terms on the unit mass basis in this form, ok where this is nothing but P as specific volume. So note that the workflow contains two properties, pressure and specific volume. This is a reason that flow, we assume this kind of work as a part of flow energy or transport energy of the specific fluid here.

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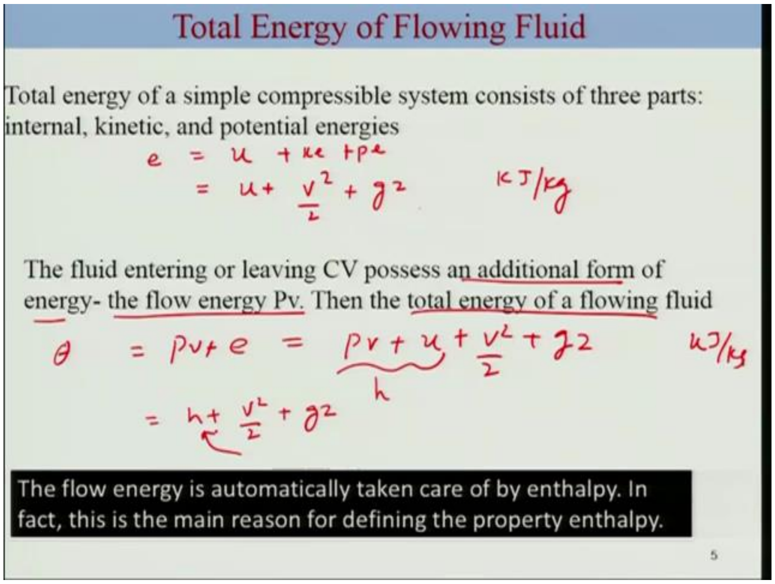

So let us first consider the case where we had developed for the case of closed system for the total energy, where we consider total energy of a simple compressible fluid as a simple summation of the internal energy, kinetic energy and the potential energy.

Or we can write on the basis of unit mass and the expression would be your, let us say e which would be your energy per unit Kg and we can write as your internal energy plus kinetic energy plus potential energy, ok? And this further can be expressed as u plus v squared by 2 plus g z. Note that this is your kiloJoules per Kg units, ok? Now in the case of open system there is a fluid which enters in the control volume or there is a continuous flow out of the control volume.

Thus we have to now include this particular flow energy which is a part of the fluid. So we need to add an additional form of the energy, the flow energy in order to obtain the total energy of the flowing fluid. Thus you have e plus P v, that will be your total energy of a flowing fluid per unit mass, ok? So we will represent this by a symbol theta here and so we can now use this expression to use for e and replace it here.

So this will be your P v plus u plus v squared by two plus g h. Note that this will also be in kiloJoules per Kg. Now this expression, we have already defined when we were discussing the tables. So this P v plus u would be defined as enthalpy. So the h essentially is nothing but P v plus u, that is by definition. So we can write this total energy of a flowing fluid in terms of h plus v squared by 2 plus g z, ok.

So note that hh the flow energy which we have added now is automatically accounted within the enthalpy of the fluid, ok? And that is precisely the reason why we have introduced enthalpy make use of the expression in a simpler form.

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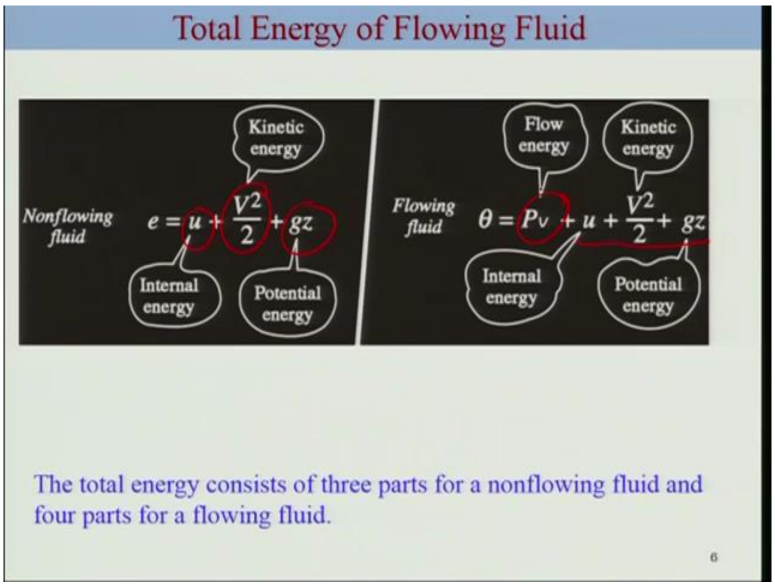

Ok so let me summarise for the two cases. One is a non flowing fluid and other is a flowing fluid so for the case of a non flowing fluid you have three terms, ok? These are all unit mass basis, so you have three terms, you have internal energy, you have kinetic energy and the potential energy, for the case of flowing fluid you have not only these three terms which was there for the case of a (())(5.32) but in addition you have a flow energy, ok? So there are four terms which are part of this particular expressions for the flowing fluid.

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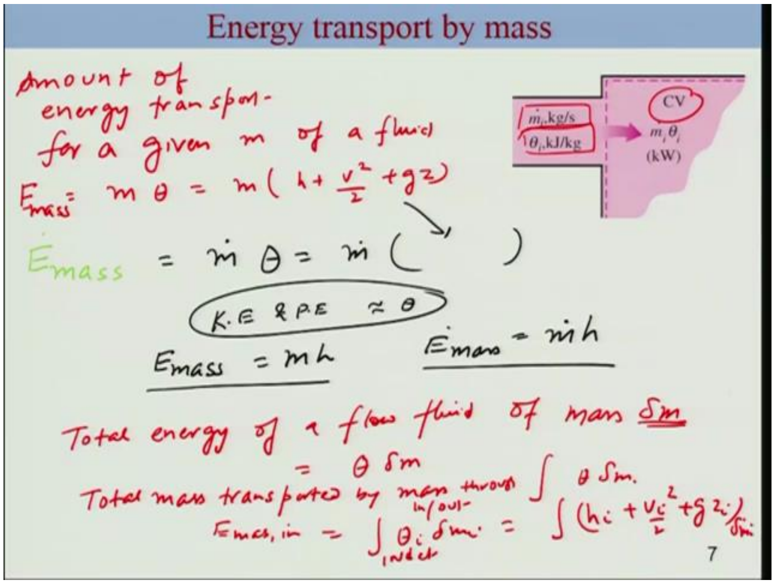

Ok, so let me describe this more for the case of energy transport. So let me consider this particular control volume. So this is your control volume and this is our flowing fluid with a mass flow rate and this is a corresponding total energy of this flowing fluid per unit mass. So what would be the amount of energy transport for a given let us say mass m of fluid? Ok. If you have been given the energy of the total flowing fluid as theta and you have been asked the question that what is the amount of energy transfer for a given m of a fluid then it would be simply m theta. Ok?

So this would be your E mass, ok; and what is your theta? Theta is nothing but h plus v squared by two plus g z, right? Now in the case of the rate there is the rate of transport so you have to look into or you have to express in the form of rate. This we are going to write as E dot mass and this would be your m dot theta, so which essentially is nothing but m dot this expression, ok?

Now in many case your kinetic energy and the potential energy are negligible, ok? And because the major change for the system which we typically consider is due to the change in the enthalpy so in that case, when you consider your kinetic energy and potential energy negligible compared to the enthalpy, your E mass can be written as m h or your rate of energy transport due to this flow of mass in the system is m dot h, ok?

So this is the expression we are going to use for the case when we can consider kinetic energy and the potential energy negligible, ok? Many times, your mass keeps changing with time ok? And so what you what we can do in such case when it changes with time in and the cross sectional locations, you can consider for small amount of mass and write down the expression for the total energy.

This would be your total energy of a flowing fluid, let us say of a mass delta m, ok? So this is a specific mass because we are considering a small mass and asking the question what is a total energy of this specific small mass which is flowing. So in such case we can simply multiply theta assuming theta is a total energy of this flowing fluid for the specific mass which we have considered.

So the theta we can make use of it and multiply by del m, ok? And thus we can integrate in order to find the total mass transport transported by this mass would be simply the integral of theta delta. So for the case of let us say inlet, if you are calculating this energy of mass transported by the mass flow, ok? Through inlet or outlet, this would be your simple theta i del m i for a specific inlet condition.

So this is the case when your theta and mass specifically varies with time or cross section, ok? So you need to make use of the differential change and thus you have to use the integral form. So you have to make use of the small amount of mass and calculate this local total energy and then you integrate over the whole particular cross section of a particular specific inlet or outlet.

That would be the energy due to the mass flow particularly in the case of inlet and outlet. So this would be can be written further as h i z i, ok? Multiplied by d m i.

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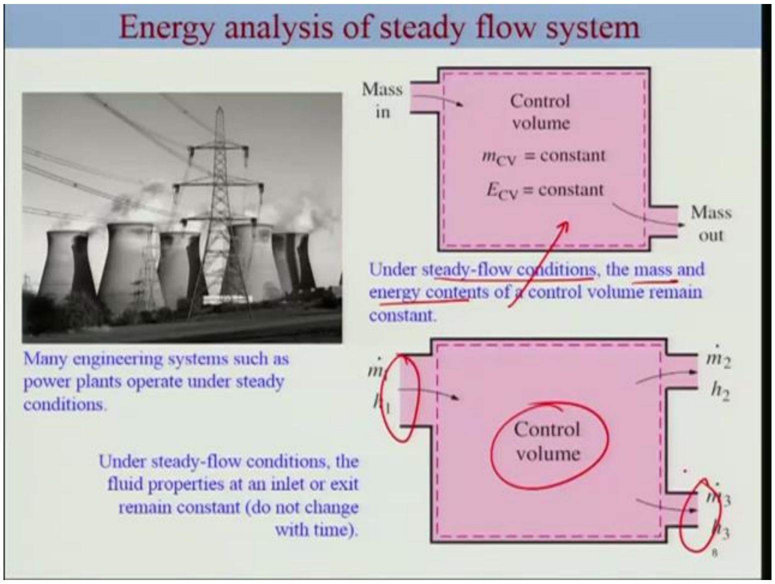

So we will go over to the next case where we will consider the steady flow system and this is very commonly common conditions because many engineering systems are operated for days, and in such case the system or device achieves a steady state conditions and when you have steady flow conditions, your mass and energy content of this particular control volume will remain same. Ok?

In that case if the control volume property is not changing then the fluid properties at here and here will also be considered to be constant, ok? That means they do not change with time, ok. So let us try to express the mass and energy balance for such steady flow systems.

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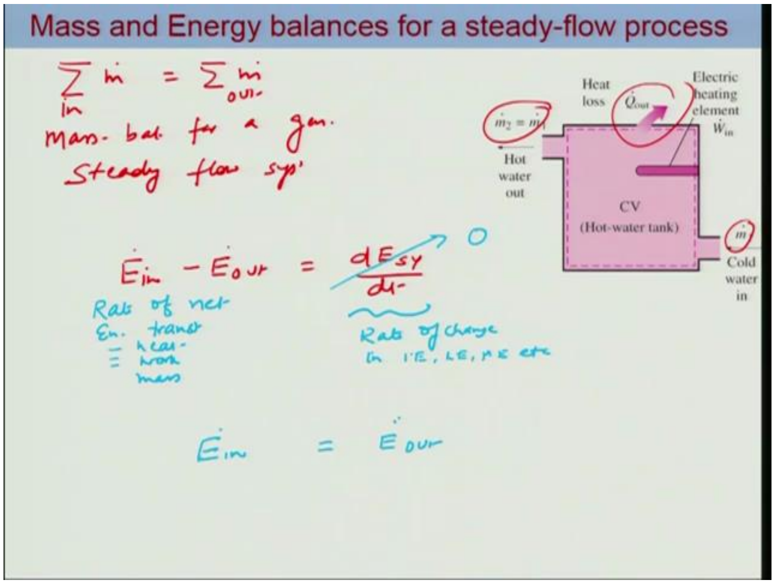

So in this case, we will be making use of this control volume. So you have certain work done by the electrical because you do not considering that you the control volume properties are fixed that means you need to provide work through some other means because of boundary work is zero.

So this is electrical heating element in this case there is a heat loss to the surrounding and you have a m in and m out considering it is a steady flow. The m and m in and m out should be same. So this we have already developed that m in should be equal to m out for the case of, this is a mass balance, ok? For general steady flow system, ok? So we can write a generic first energy balance. So the energy balance will start with the basic definition that E in minus E out should be equal to the change in E system.

The rate of the change in the E system here. So this E is nothing but your rate of net energy transfer ok? And now you have three possible contribution which one is heat, work, and mass and this is nothing but rate of change in internal energy, kinetic energy, potential energy, etc. ok? Now for the case of steady flow process with being a steady flow, this is going to be zero. Ok?

So what you have left is that E in is equal to E out. Ok? So you will consider this now and try to express E in in different forms. So E in is nothing but your contribution to heat transferred in the system, work done on the system and as well as due to the mass energy or the energy of the mass flow.

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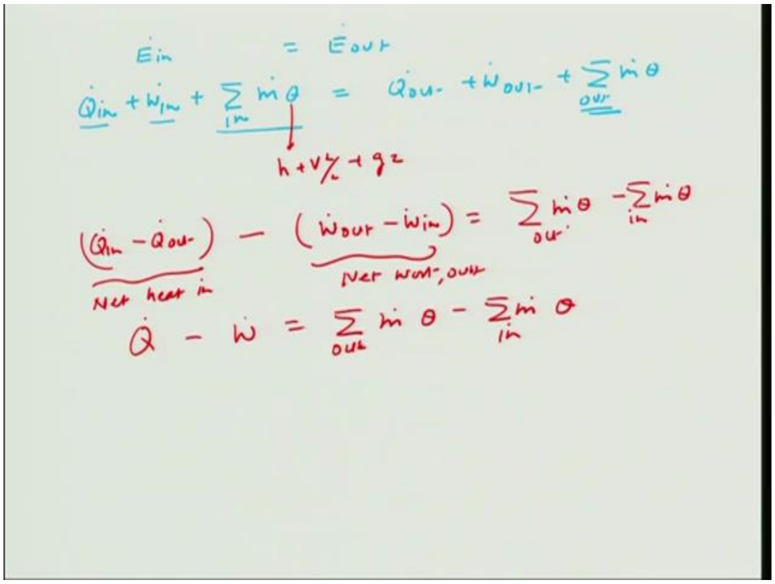

So we can write this in our generic form here, this is nothing but can be written as Q in dot because it is all in the rate expression. This plus due to mass flow in and you have different systems. So this I can write it in this form. So this is your heat, work, and your mass transfer, mass energy of the flowing mass in the system. And this would be your Q out plus W out plus your m dot theta for the out stream. Ok, so now, of course we know that this theta is nothing but your h plus v squared by two plus g z.

Now this is useful when you know specific direction of the heat and work. You can generalize this when you are not aware of the specific direction, ok? And in that case what you can do is you can consider this Q in minus Q out and your minus of W out minus W in and this will be your m dot theta out minus m in theta. Now this will be network out which essentially means done by the system and this will be your net heat in, ok?

And you know why convention we have used the sign in this way that the Q is positive energy supplied to the system and work is positive and it is done by the system. And thus you this can be written as Q dot, ok? Minus W which is effectively Q means that is net heat in and W means net work done or out or from the system in, this can be written as m dot theta out minus m dot theta in, ok?

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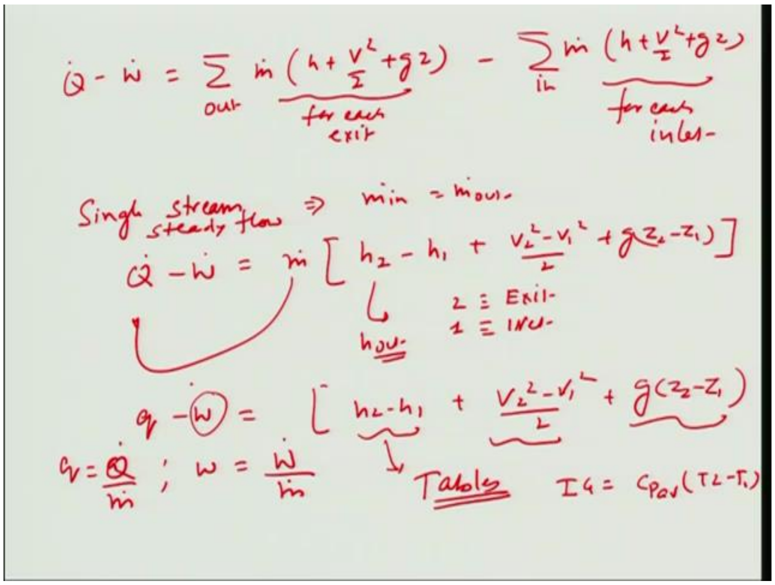

Now this further we can try to simplify by considering this expand the expression of theta here h plus v squared by 2 plus g z minus. So this is out that means this is for each exit and this would be your m h plus v square by 2by g h inlet. So this would be for each inlet streams, ok? Now you can consider a specific case here where we will consider only the single stream because this is most common in the operations.

Hence in that case you can write Q dot minus W dot as simply your m considering single stream and as well as steady state, so this which essentially means your m in is your m out. Single stream steady flow, ok? Then you can write this as m dot h 2 minus h 1 plus v 2 minus v 1 squared by 2 plus g z 2 minus z 1. Where h 2 is your h out that is outlet stream one stands for inlet and two stands for exit, ok?

You can divide this, Q and W by m dot and you can write this expression as this. Ok? Where Q is nothing but, and small w is nothing but your capital W divided by m dot. This your three terms, ok? So most of the time you will be ignoring the kinetic energy and the potential energy because these are typically very less or has low contribution in this equation compared to the change in enthalpy. Ok?

So you can calculate this for example delta h from the tables, ok? Or if it is an ideal gas, so you can consider it to be as simple c P average, t 2 minus t 1, ok? Now for the case of a adiabatic system, if it is insulated your Q is going to be zero, ok? And the work here considering it steady state flow system. Since steady state, the control volume properties are going to be constant and thus our contribution due to boundary work will be zero. So there would be other kind of work such as shaft work or electrical work, ok?

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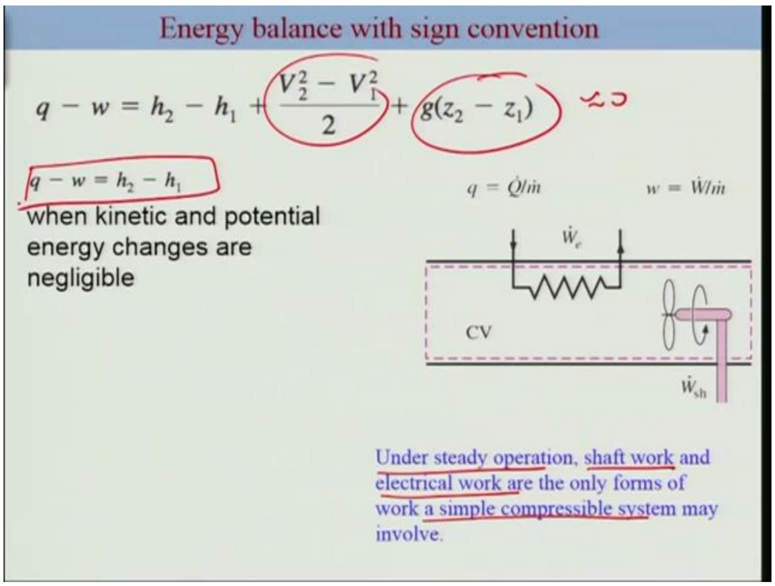

So this is general expression we are going to make use of it and this is what I summarise it here, ok? So under steady operation only the shaft work and the electrical work are the only form of work which will be involved for a simple compressible systems for the case of your steady state flow system. So considering your kinetic energy and potential energy is zero, negligible then this would be a final expression for their systems and energy balance.

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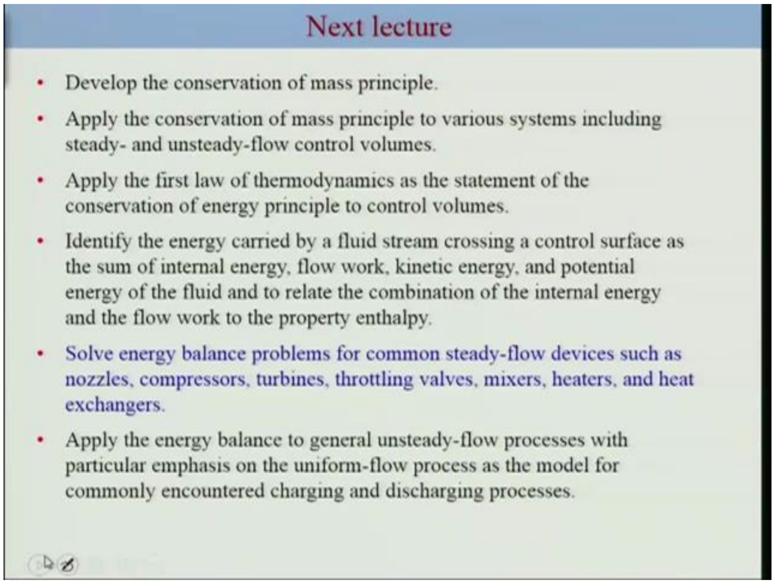

Ok so with that I would end this lecture, in the next lecture we are going to solve some common energy balance problem for some specific devices, ok? And we will do some example. So I will see you in the next lecture.