Thermodynamics of Fluid Phase Equilibria
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Lecture – 07
Mass – Energy analysis of open system

Welcome back. In this lecture we are going to summarize mass energy balance for open system.

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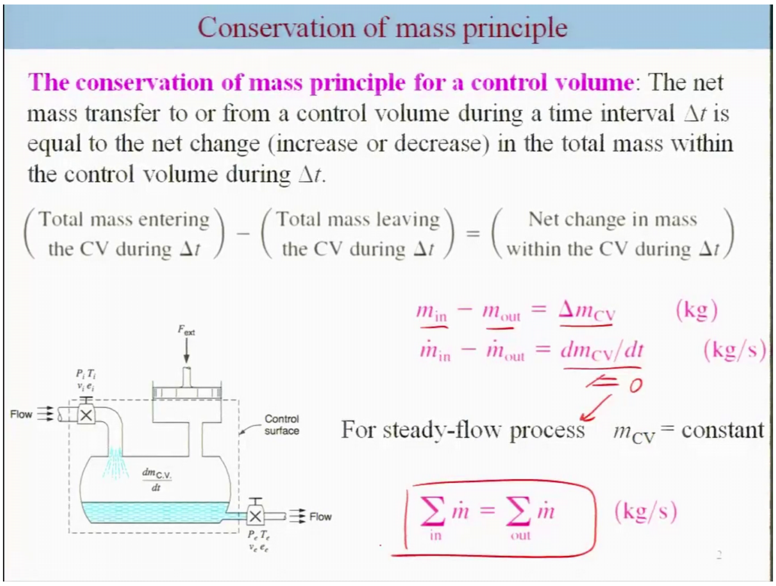

So, we start with the conservation of mass principle. For a simple control volume as depicted here the total or the conservation of mass principle says that the net mass transfer to and from a control volume during a interval time delta t is equal to the net change in the total mass within the control volume during delta t or the time change time interval.

So, in a simpler form one can simply write down in expression the total mass entering the control volume during a certain time interval minus total mass leaving the control volume during delta t and that should be same as or that should be equal to net change in mass within the control volume del delta t. Or, in other word m in minus m out is equal to delta m control volume, for in the case of rate expression you will be considering dots here and this will be your dm by dt.

For a steady-flow process, the mass of the control volume will remain constant and hence this expression this will be 0, this will turned out to be 0 for steady flow process and thus you will have m in minus is equal to m out for a many inlets and outlets this would be a generic expression for the case of steady flow process.

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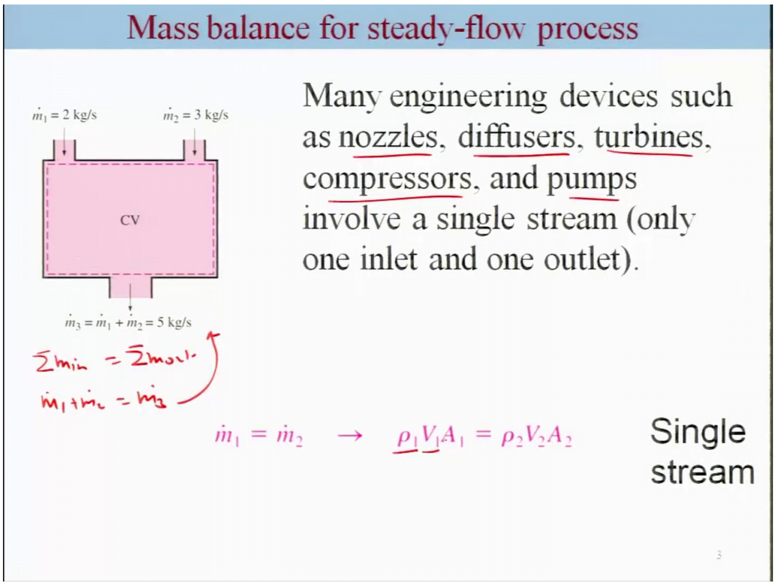

Now, in many systems of course, there are many inlets and outlets. So, one for simple steady flow process an example would be let us say if you have two inlets you have m 1 and m 2 and if this outlet is 1, then based on simple your m in is equal to m out your m in is m 1 plus m 2 and that should be same as m 3 .

But, in many engineering devices such as nozzles, diffusers, turbine, compressors and pumps they involve only a single stream. In such case you have m 1 is equal to m 2 or the m 1 dot is equal to m 2, and this you can represent in terms of density volumetric flow rate and the cross sectional area as well ok.

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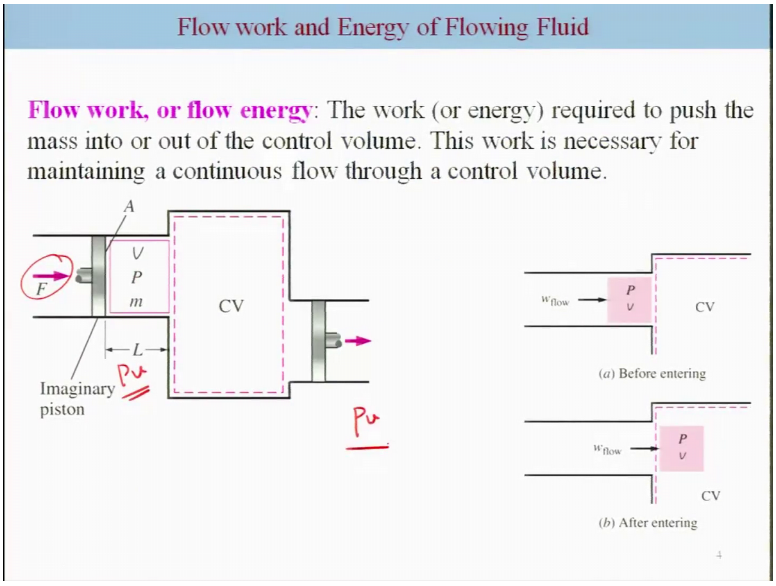

So, since we are talking about energy balance also so and we know that for generic ex expression the net energy balance would be through heat work as well as from us. So, me just talk about component which we have not discussed earlier.

Now, for a flow system and for a steady state system say for a steady-flow system the fluid continuously flows through the inlet and exit through the outlet and in order to maintain the control volume when the steady state there will be work which is needed to continuously flow. Now, there will be work which we need to push the certain mass here before the inlet and similarly, there will be work which will have to be pushed out in order to maintain the continuity.

So, ah, let us consider again ah, so, this is the pressure of volume of the element of the flow which need to be pushed in and this push this work which say is work of or flow work or flow energy. So, be this is before the entering and it is after the entering and so, consider this that this pushing this work is being done by some imaginary piston, ok, there is a certain force which is being applied and this is basically the steady state there is no acceleration and the constant force is being applied and this mass gets in.

So, the question is what is basically the work for such a case, ok. So, me just take a simpler view of it.

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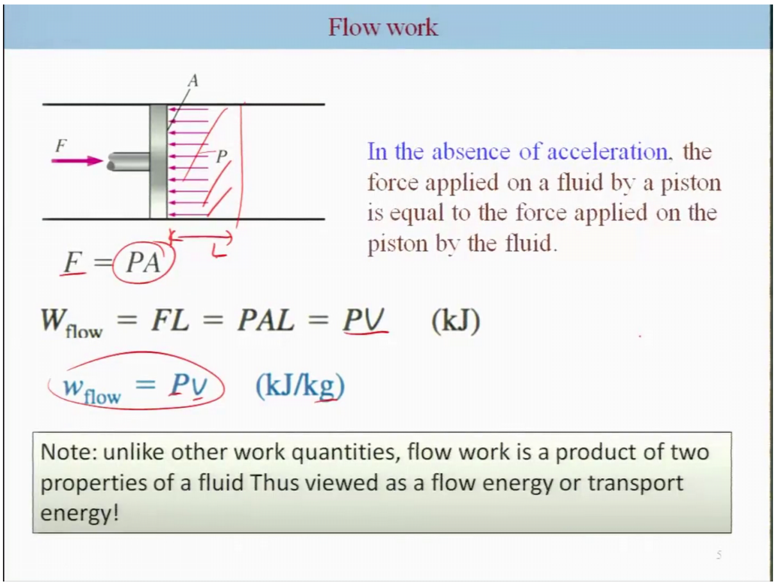

So, this is again the force and this this element here have to be pushed in by a certain distance L and this force in absence of acceleration is equal to the force applied on the piston. So, this would be equal to the opposite force here assuming this to be a strow slow process this P into A is going to be the force, ok. Now, this work would be the force multiplied by that is an L and that would be PAL, that will be P into volume. Now, in terms of a kilo joules this will be P into specific volume.

So, this will be the work of flow of course, the PV value here and PV value in the outlet may be different, because that will depend also on the pressure of the outlet and the specific volume of the outlet. So, that means, there is a some PV work here which is associated with it and there is also PV associated with the outlet.

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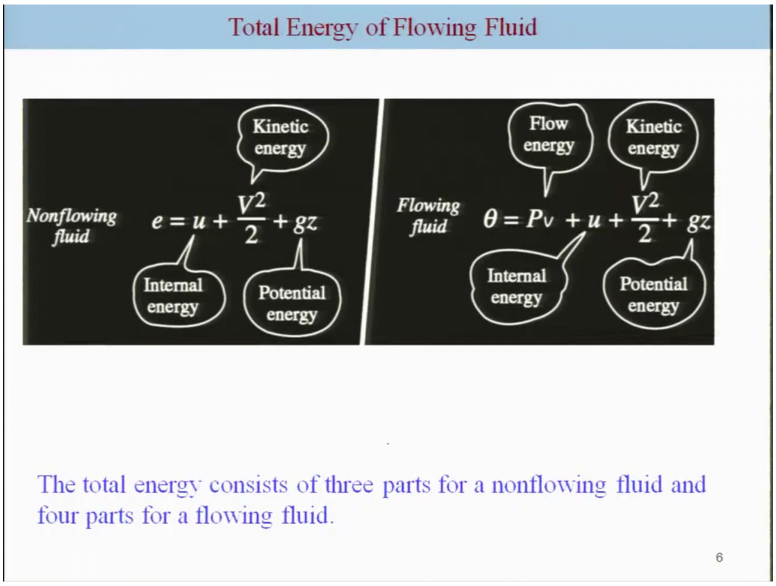

Now, we can summarize this concept in terms of comparing both the case of non flowing and a flowing fluid for the non flowing fluid you have energy of the fluid as internal energy or energy or the fluid contains internal energy kinetic energy potential energy as shown here. So, this internal energy per unit mass the kinetic energy and the potential energy; for the case of a flowing fluid in addition to that internal energy kinetic energy and the potential energy it also poses a flow energy because it moves inside and certainly outside. So, it contains that energy and we use that energy as a part of the energy of the flowing fluid there is PV or in other word we can also make use of the basic definition this u plus PV comes in the flowing case and this can be written as simply h ok.

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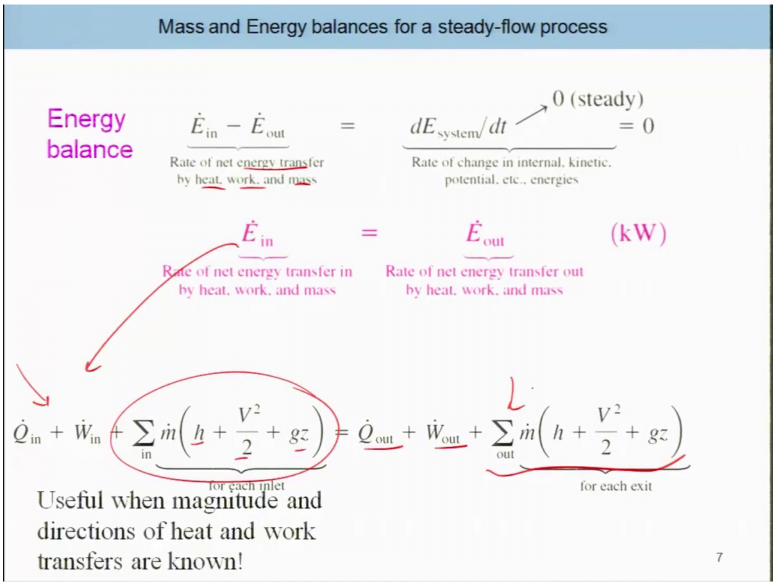

So, again we go back to the generic energy balance that is e in minus e out is equal to e e dE system by dt and we are considering the rate expression considering is a flow process. Now, in this case the net energy transfer is heat work and due to heat work and mass ok; for the case of a steady state of course, the e in is equal to e out , so, if we know the directions of various different interactions we can write this expression where Q in plus Q out this part of E in plus whatever the contribution due to the flow ah, that is, mass that could be your enthalpy plus kinetic energy plus g z potential energy and that should be equal to Q out W out plus the energy contained by the flowing mass. So, that would be m h.

Now, this is summation is for each inlet and summation here is for each outlet. So, this is for the case where we know the direction here.

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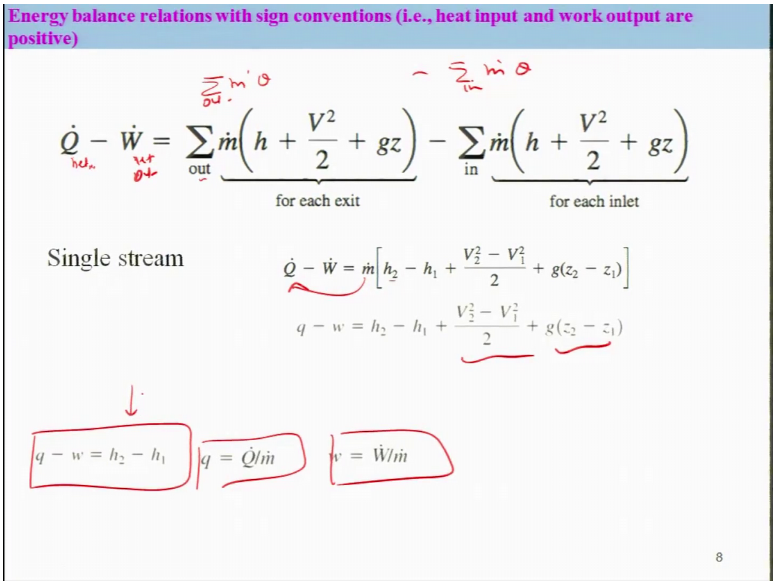

We can write also in terms of very generic expression that would be Q net in this will be Q net in and Q net W net out this is equal to the summation for the case of outlet, that means, it is summation of m dot theta minus summation of m dot theta this is for in and this will be out ok. The change in the energy due to the mass flowing mass for a single stream of course, you are going to consider only h 2 minus h 1, most of the time we will be ignoring this velocity and kinetic energy kinetic energy and potential energy and only for some cases we have to use that.

So, for the case of where we ignore this two terms will have q minus w in terms of per unit mass q where if you divide this q here is going to be small q is q dot divided by m dot and thus you can write a very simpler case here which is q minus w is equal to h 2 minus h 1,. So, a very simple expressions for energy balances, you can apply this for many devi defice devices. I am not going to go through in detail for all the devices and I expect that some of the exercises you have done that in earlier, but we will just recap how to do this for few cases.

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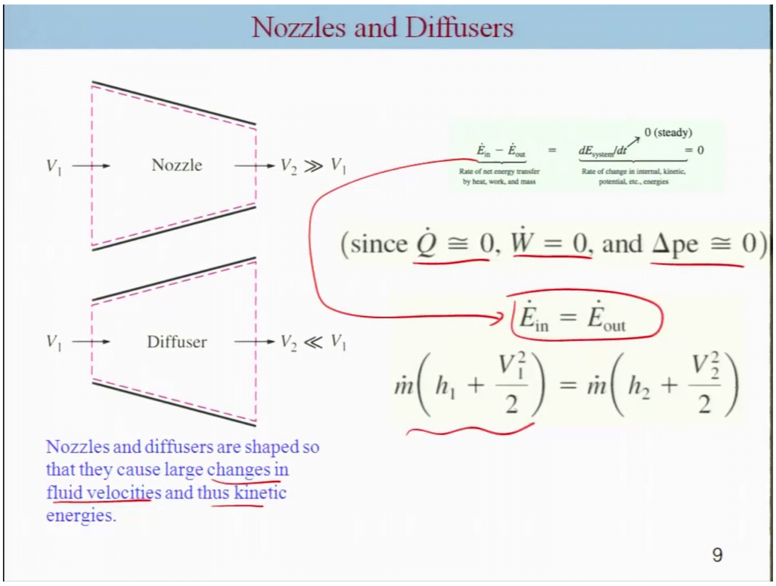

So, for example, nozzles and diffusers are typically used to change the fluid velocity and kinetic energy where is there is no heat interaction and the work there the body does not change. So, that is your Q and W's are zeros, delta p e are going to be also considered to be 0. So, you can apply this basic definition and you get E in minus is equal to E out or in the other word m h 1 plus V 1, V 2, V 1 square by 2 is equal to m h 2 plus V 2 square by 2. Now, you can do this analysis knowing that inlet and outlet conditions and the ones un unknown variables you can find out by using simple algebra ok.

So, the this is the final expression of that and you can do the analysis subsequently.

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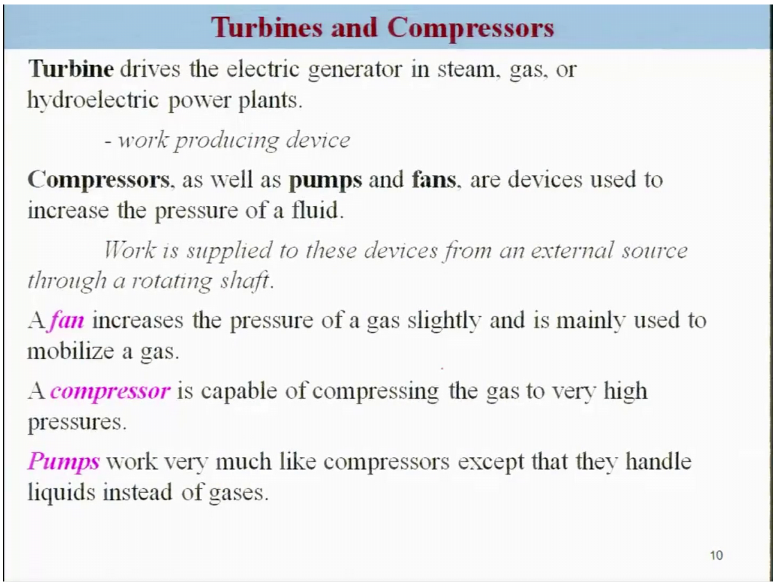

Now, the similar kind of exercises you can do for turbine which is a work producing device for compressor fans and pumps again where the work is needed in order to change the pressures. So, you can do this exercises again based on very simple logics ok.

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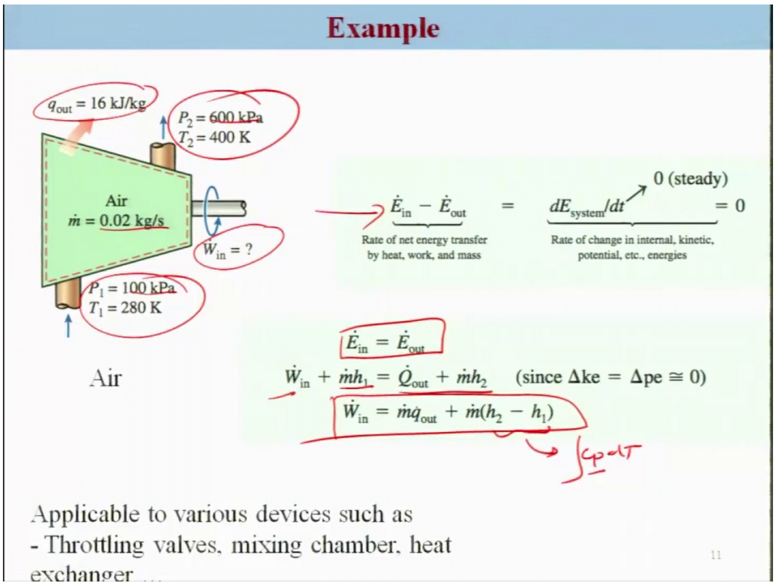

For example, this is the case for compressor where air is being compressed from 100 kilopascal to 600 kilo Pascal whereas, the flow rate of mass is given here 0.02 kg per second and what we need to find out is the work which is required the rate of work which is required and in this process the heat also lost.

So, you can start with again the basic definition of energy balance here , where is it this is a steady state then you can consider this and then you can write this E m i is equal to E out. Now, knowing the direction here already we can simply write W in plus the flow contribution m h 1, this is going to be equal to Q out plus m h 2 ok. So, Q out is here this part plus m h 2 is due to this. So, you can rewrite this expression in this form.

Now, this you can find it from the tables or you can use C p dT this if you know the expression in terms of C p in terms of temperature and Q out also of course, we know that. Now, this kind of analysis is of course, applicable to other cases throttling valves, mixing, heat exchanger and so forth. So, I am not again going to in details of that you can apply and revisit some of the example to hone your skills again.

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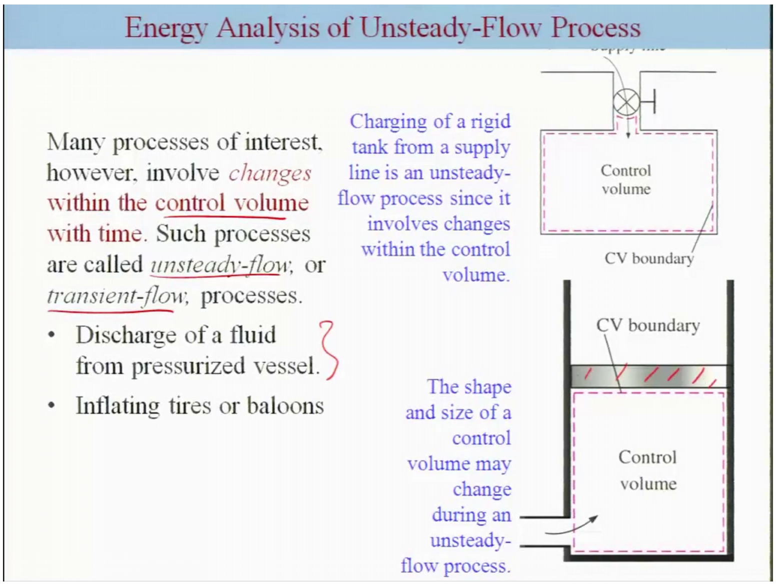

Now, I will just talk about the case where we have unsteady flow process which is also very common. These are the processes where the changes in the within the control volume with time such processes are called a transient flow process or as I said unsteady flow, ok. The examples are discharge of the fluid from pressurized vessel, inflating tires or the balloon. So, for example, here in this case during this process of the filling of the control volume this piston can also move ok.

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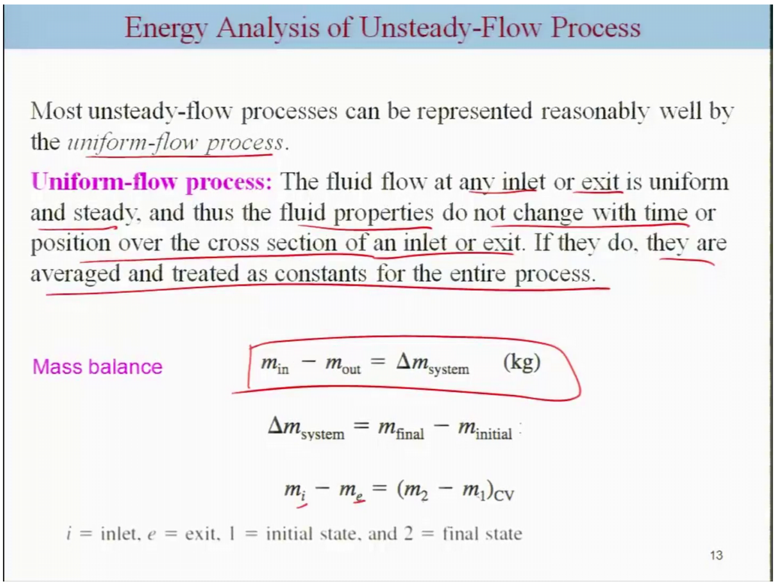

So, let me just quickly explain how to work with this kind of system. So, most steady flow processes can be represented by uniform flow process where we assume that the fluid flow at any inlet or exit is uniform and steady and thus the fluid properties do not change with time or position over the cross section of an int inlet or exit and if they do they are averaged and treated as constant for the entire process.

So, for such a case we can simply write mass balance as m in minus m out is equal to delta m system, where delta m system is m final minus m initial sometimes also we write m i inlet and exit is equal to m 2 minus m 1 of the control volume ok. So, this is our mass balance.

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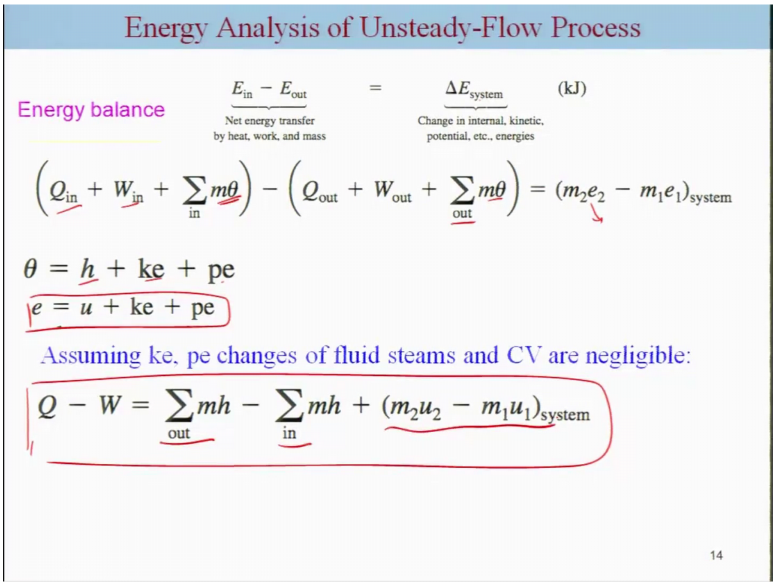

What about the energy balance? so, we will write again here energy balance E in minus E out is equal to delta E system. Now, delta E system is not going to be 0, in this case delta E system is m 2 e 2 minus m 1 e 1, where this contains only the internal energy, potential energy, kinetic energy as shown here whereas, E in is Q in plus Q w in plus summation of m theta where theta contains h because it is a flowing fluid and k e plus p e, whereas for the case of outlet is Q out plus W out plus summation m theta for the outlet.

Now, assuming p e and k e changes are negligible, you can write down this generic expression in this form , ok, q where q is net heat minus W is net work out and this equal to summation m h m h summation, this equal to the contribution due to the changes in the enthalpy from the outlet and inlet and as well as the changes due to the internal energy of the system.

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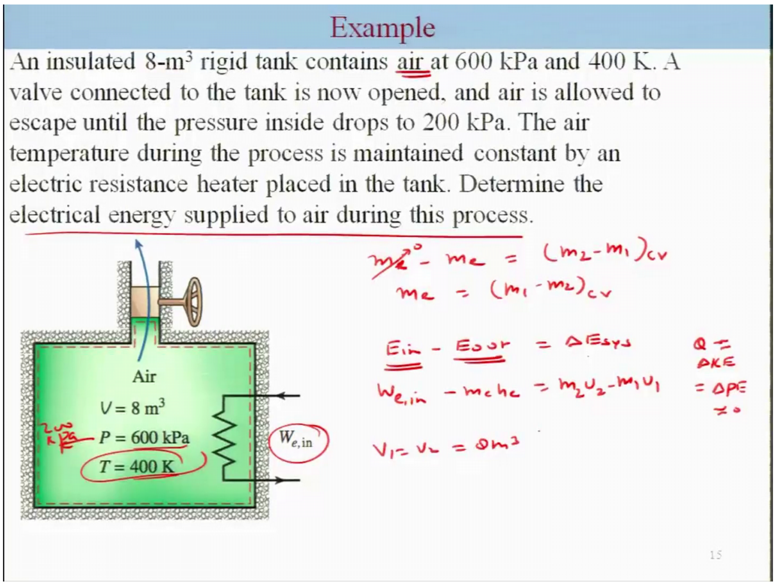

Now, the question is how do you apply this? So, we will take up one example and this we will end the lecture with this example. This is an example where you have an insulated 8 meter cube rigid tank which contains air at 600 kilo Pascal, 400 at 4 400 Kelvin and the wall is connected to the tank which is now opened. Air is allowed to escape until the pressure inside the draw inside the drops to 200 kilo Pascal.

The air temperature during the process is maintained constant. So, this is maintained and by how it is maintained by providing this electrical resistance. So, there is a work electrical work is applied to the system. What we need to find is basically the electrical energy supplied to the air during this process ok. During the process, where the pressure is changed from 600 to 200 Kelvin, keeping the temperature constant.

So, the first thing is since the valve is opened certain mass has escaped. So, we will be applying the mass energy mass balance first followed by energy balance. So, m in or m in minus m exit is equal to m 2 minus m 1 of control volume. Now, this there is no inlet, so, this m exit is nothing, but m 1 minus m 2, of control volume.

Now, E in minus E out is delta E system ok. What is E in W e in here and what is E out because only the mass flow then we can simply write m e h e ignoring the kinetic energy and potential energy. So, and as well as since it is insulated, so, q delta e delta K E and delta P E are going to be 0, and this is m 2 u 2 minus m 1 u 1.

Now, V 1 is constant ok. P 1 we know P 2 we know, now the thing is it is air ok.

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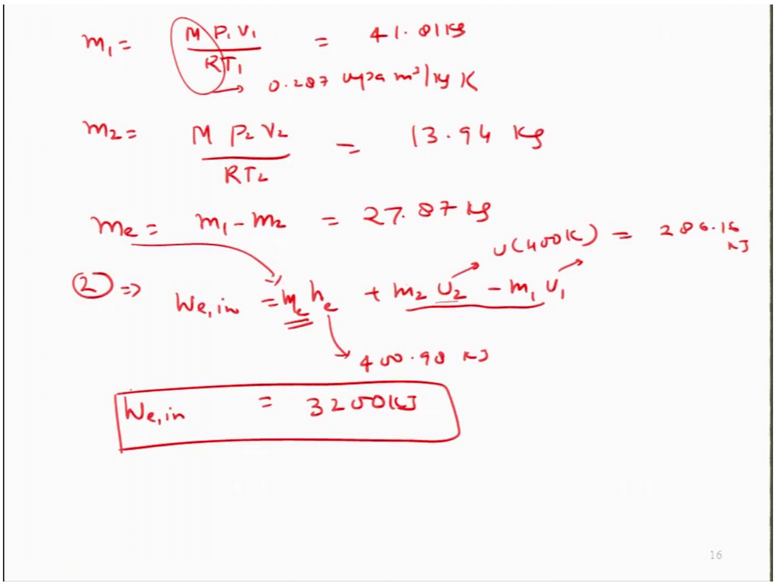

So, we can consider air to be idle gas and thus we can make use of the equation idle gas equation to obtain m 1 which will be your ma molar mass P 1 V 1 by RT 1 and this itself is 0.287 kilo Pascal meter cube per kg Kelvin and if you plug in the P 1 and V 1, P 1 is 600 kilo Pascal, T 1 is and T 1 and T 2 is constant, V 1 and V 2 is also constant is V 41.81 kg ok.

Similarly, you can get m 2 M P 2 V 2 by RT 2 you get 13.94 kg. Thus, you can obtain m e which is m 1 minus m 2 27.87 kg. So, now knowing this m e we can now plug in in this equation ok. So, so, you can plug in this information m e and what about h e?.

So, you can plug in 2; 2 will become W in and you can rearrange here this is m e h e plus m 2 u 2 minus m 1 u 1 ok. The reason where you have taken again this is because this is the delta E of the system which is non flowing is only of the control volume and this u since this idle gas is your only depends on the temperature which is 400 Kelvin you can use the table given in any book and this comes out to be 286.16 kilojoules.

Similarly, h e which h e is basically the enthalpy , which can be approximate because this can be enthalpy of the air at 400 Kelvin, ok, because enthalpy is the temperatures is a fixed over there and this from the table also we can get there. So, with this information and with the value m e which we have calculated we know m 2 m 1 as well this value W in comes out to be 3200 kilojoules ok.

So, with this we complete this lecture and we have just covered the energy balance for the open system. So, we will continue our reviewing process of basic engineering thermodynamics first. So, with that I will end this lecture and I will see you in the next lecture.