Engineering Thermodynamics
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Lecture 25
Energy analysis of steady and unsteady flow devices

Welcome back, we were discussing the mass and energy balance of control volume.

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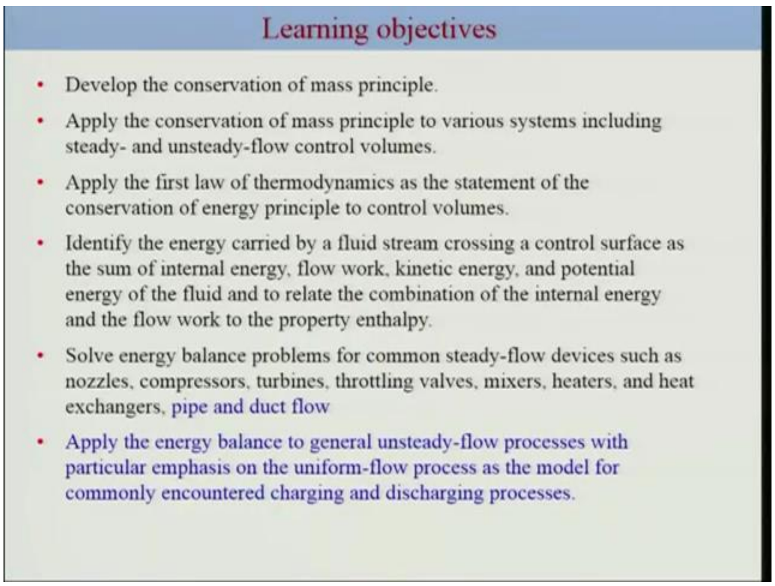

In this lecture we are going to continue our discussion on steady flow devices. So in particular we will discuss Pipe and duct flow and as well as energy balance for general unsteady flow processes.

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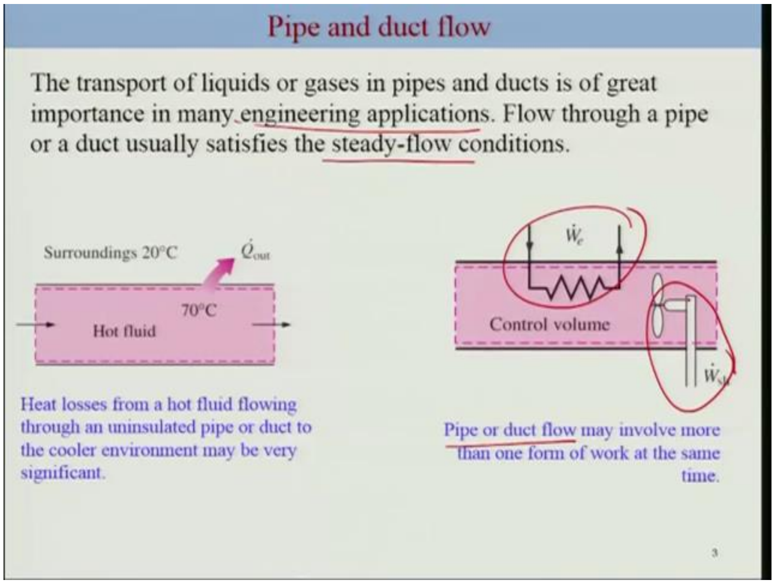

So Pipe and duct flow are very common in our daily usage and is very important in many Engineering applications. So a simple flow through a pipe usually satisfy the steady flow condition. This is an example of a hot flowing through a pipe and the heat transfer in such a condition are quite significant.

A typical pipe or duct flow may involve many form of work. So this is an example of electrical work as well as shaft work in this particular flow. So what is a energy and mass balance for a simple duct flow? We will take one particular example to understand it.

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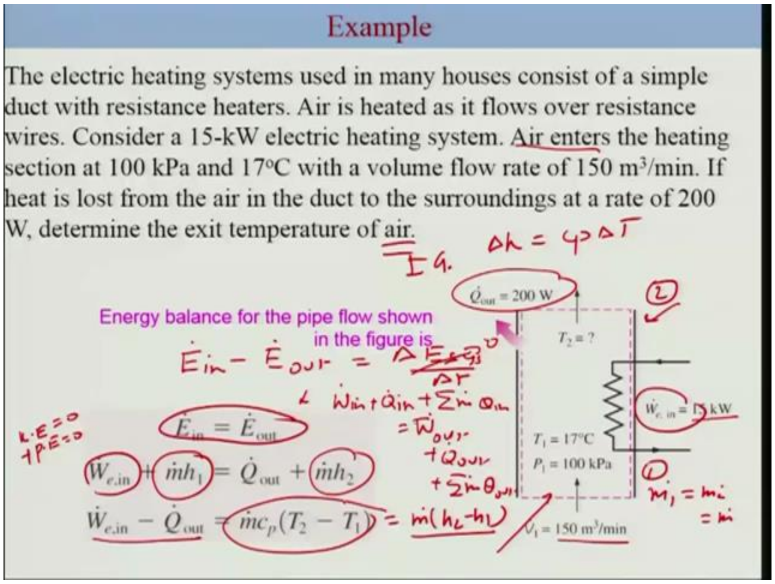

So this is an example of an electrical heating system which is used in many houses, ok? So you have a simple duct with a resistance heater. Ok? and there is a electrical work of power of 15 kW which is supplied to the flowing fluid and this is air which enters here at 150 meter cubed per minute at 17 degree celsius with a certain volume rate which is of course 150 meter cube minute. And there is a heat loss of 200 Watt and what we need to find is the exact temperature of the air.

So we will go with the simple mass balance considering it is a steady flow, of course M 1 here dot should be M 2 dot which is here at 2 and this is 1 and this should be M dot, ok? Considering steady flow conditions the in dot out that is net energy transferred to the system would be zero because this is a steady flow condition. So this is what you get in E in dot is equal to E out dot, Ok? Now what is the E in here?

E in is a work E in and the heat supplied to the system and the work supplied to the system plus the energy of the following fluid which is here that is you have W dot in plus Q dot in plus summation of m Theta in, should be equal to your W out in plus Q out plus summation M theta out, ok? So this should be here. Ok, now since there is no Q in so what you have as far as the E in in concerned is W in so that is W in as you mean your K E plus P E is zero, ok?

You have W in plus only their enthalpy of the flowing fluid as a part of your energy of the flowing fluid that should be equal to the E out which consist of heat out which is this plus the energy of the flowing fluid at the exit condition. So this further can be written in this form, ok? So this apparently is nothing but M dot H 2 minus H 1, considering air as an ideal gas and we know that delta H is nothing but simply delta T, ok?

So this is what we can write this expression in terms of CP. So this is going to be a simple energy and mass balance for a fluid flowing through a duct having a certain energy transfers as well as a work interactions.

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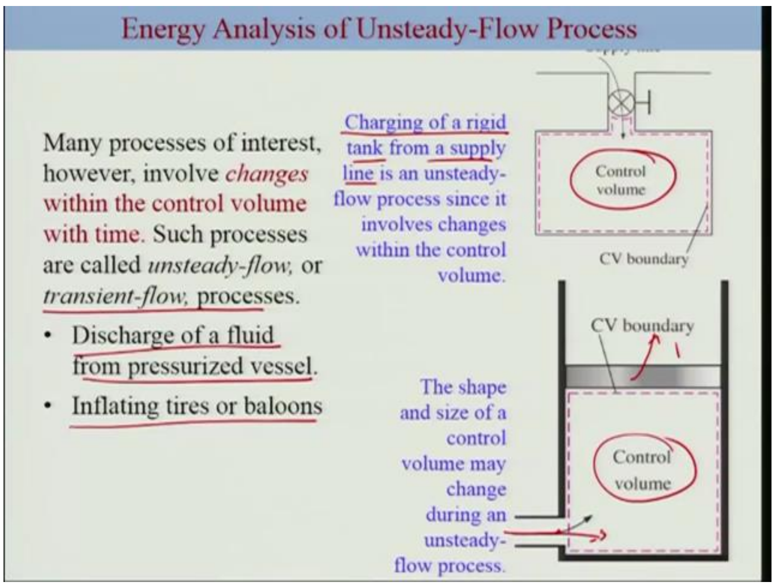

Ok, so now we will look at the systems which are considered as unsteady flow processes because there are many processes of interest which involves changes in the control volume properties. So for example, you have charging of a rigid tank from a supply line unsteady flow condition which essentially means that the control volume properties or the control volume undergoes changes with time and such kind of changes would be a part of unsteady flow process.

No such process is also sometimes called transient flow process. So, the example of course is one which we have highlighted here which is a charging of rigid tank from a supply line, other could be a discharge of fluid from a pressurized vessel and as well as the inflating tires for baloons.

Now for unsteady flow conditions the shape and size of the control volume change along with time. So, this is an example, so you have a flow through this opening and the control volume size can undergo change and because this volume or this particular piston can move up as the fluid during the transport of the fluid to the control volume.

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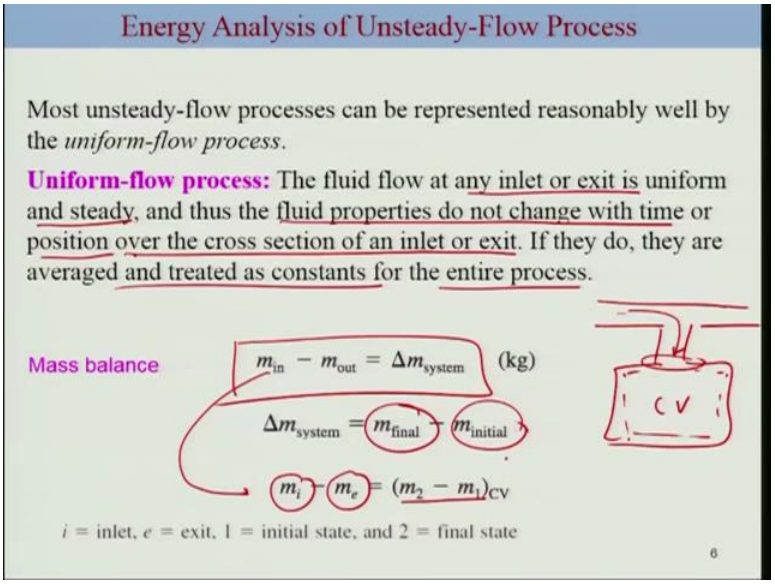

Now most of the unsteady no process can be considered as uniform flow process. The definition of uniform flow process are as following; fluid flow at any inlet or exit is uniform and study, ok for such uniform flow process which essentially means that let us say if you have a charging through pipe, ok? So what we assuming if this is a control volume, ok? The properties here is uniform in steady, ok? And thus we can approximate this unsteady flow process as a uniform flow process.

So, thus the fluid properties do not change with time or position over the cross section of an inlet or exit. Even if you consider, let us say because this is an approximation as far as the uniform flow process, in practice the temperature and other conditions may change across the cross section. So what we are going to consider is we are going to take an average value, ok? For such a condition. So if the properties do change we are going to treat as an average as a constant for the entire process for our analysis.

So this is a simple mass balance for this particular now uniform flow process. So m in minus m out (for) within the control of volume is simply change in the mass of the system in the mass of the system change can be written simply the final value of the mass minus the initial value of the mass, ok? You can write this m in minus m out as simply m inlet minus m exit, this should be m 2 minus m 1 of the control volume. So this is a simple mass balance.

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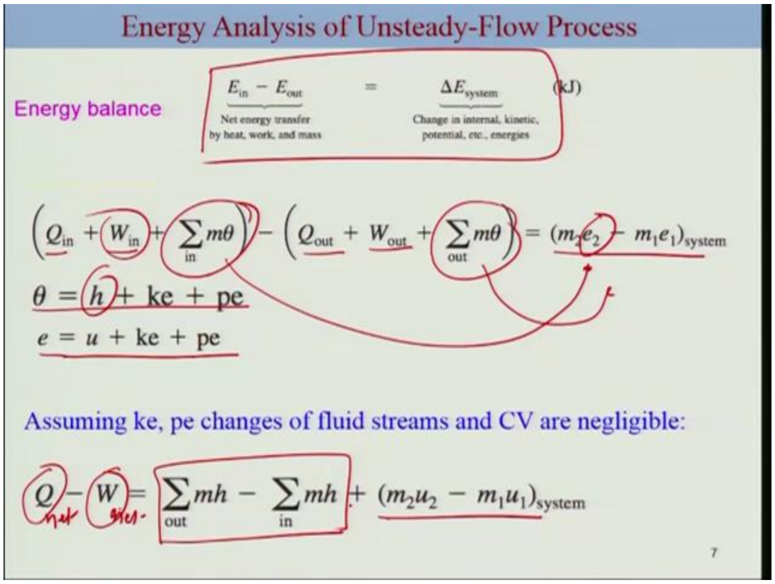

OK what about the energy balance? We will start again by the general energy balance which is nothing but the transfer of energy to the system due to the work, heat and the mass flow should be equal to the net changes in the energy of the control volume. Ok and that that would be change in the internal energy, potential energy of the control volume of the system.

So here this is our basic definition of the energy balance and this E in in this case we are going to consider Q in plus W any work interaction if the inlet condition or the heat transfer to control volume or system and the work done on the system plus the energy of the flowing fluid inlet at the inlet condition minus Q out plus W out plus the energy of the flowing fluid.

This should be equal to change in the energy of the system which includes your internal energy potential energy and other energies. We can go back to the earlier definitions of theta here. So theta was the energy of the flowing fluid per unit mass, which is given here. So this is enthalpy ke plus pe and e was the energy of the non flowing fluid which is defined here by unit mass, ok?

Now assuming ke plus ke and potential energy to be negligible if we assume that and not only for the fluid but as well as for the controlled volume then we can write this has the net energy and net heat supplied to the system minus the net work done by the system is equal to the change in the flowing energy plus that of the system or change in the energy of the system.

So essentially what we have obtained is Q in minus Q out becomes the net heat in and w out minus w in becomes net work done, ok? That should be equal to the change in the flowing energy, ok which means we are taking this to this side and this to this side and then we got this expression, ok? So this is your final energy analysis of unsteady flow process.

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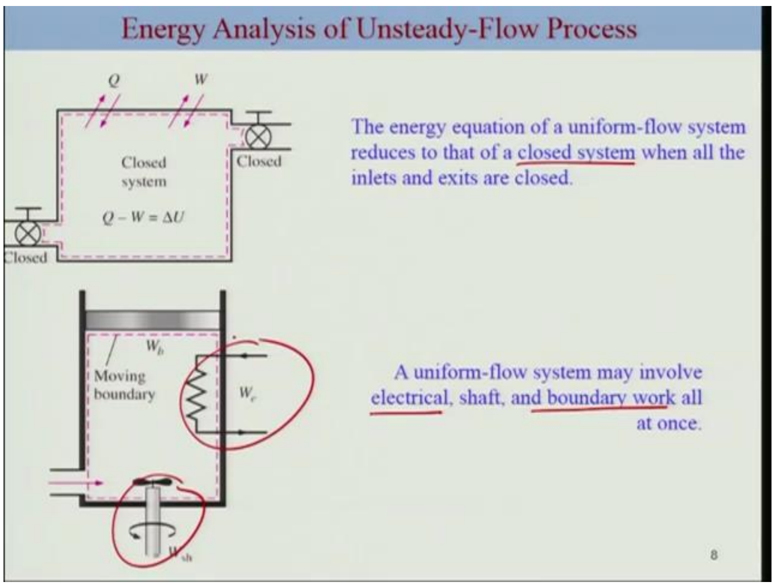

Now just take a specific case here. In case of the exit and inlet conditions are closed, this energy balance would turn out to be energy balance for a closed system, ok? A typical unsteady flow process may involve different work not just shaft work but it can also include electrical work as well as boundary work so that we have to keep in mind, ok? This is a example here illustration here. Ok we will end this particular lecture with an example.

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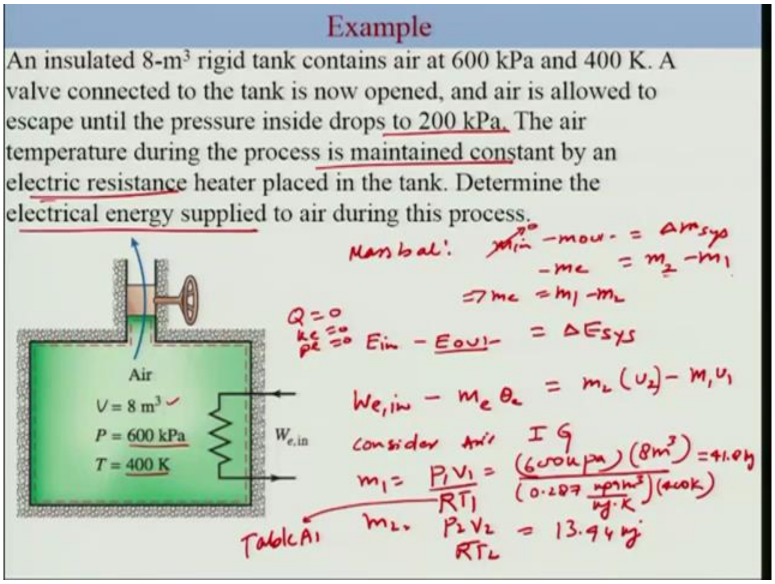

So this is an example of insulated 8 metre cube volume, ok which contains air at 600 kilo Pascal at a temperature of 400 Kelvin and there is a discharge value open the specific valve and there is a discharge in the pressure starts dropping drops to 200 kilo Pascal. The temperature of this particular air is maintained constant by an electrical resistor and what we have to determine is electrical energy supplied to air during this process.

So let us start with simple mass balance here. So mass balance would be m in minus m out is equal to delta m system, ok? So now this m in is zero and this is nothing but m e, e stands for exit and this will be m 2 minus m 1 so m 2 and 1 defined as a state, initial state and the final state of the system. Thus you m e is nothing but m 1 minus m 2, ok? Now what is energy balance here, energy balance would be is E in minus E out.

So this is that energy transfer to the system and that will be delta E system, ok? So E in in this case is nothing but W e in, ok? There is no specific heat transfer to the system minus what about E out? Now E out there is no Q, there is no K e there is no P e, so this will be considered zero. So the exit E out would be only due to the energy of flowing fluid which essentially means this is nothing but m e Theta e. Ok?

And this would be simply their internal energy of the system at 2 minus 1. So this since mass is varying is initial in a mass be different, so this has to be written as m 1 v 1. So this our energy balance, ok? Now we need to find out first of all what is m 2 m 1 and m e, ok? So what are going to do is we will consider air as ideal gas and hence m 1 should be simply p 1 v 1 by R T 1 and m 2 is nothing but p 2 v 2 R T 2.

So let us see what is p 1, p 1 is of course 600 kilo Pascal. The volume is already given to you okay? We can get R from table A 1. So this is 0. 287 kiloPascal meter cube by kg Kelvin and 400 Kelvin. So this comes out to be 1.8 Kg, ok? And this similarly you can also calculate m 2 or the m 2 the only change is p 2 which is 200 kiloPascal, ok? Here and thus you (())(12.15) simply 13.94 Kg.

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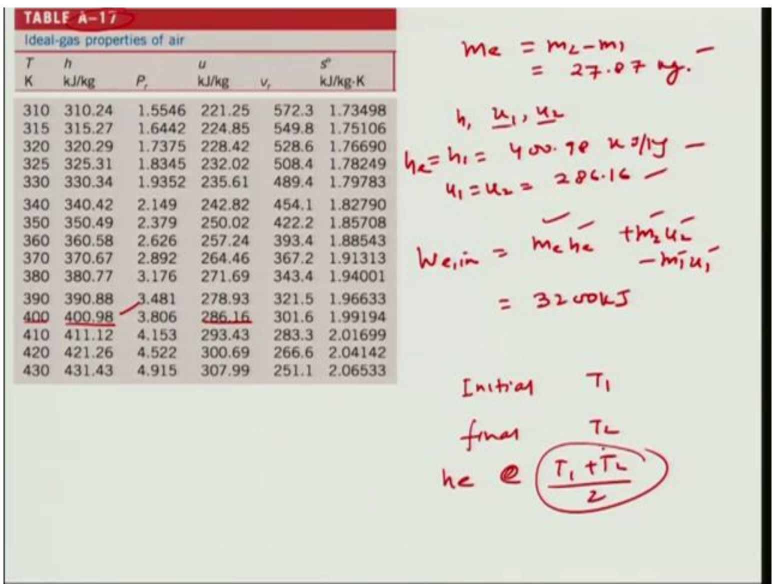

Ok so the next thing is that m e. m e is nothing but m 2 minus m 1. So this is straight away because we have already calculated m 2 and m 1 so this comes out to be 27.87 Kg, ok? So now we need to find out h and u, ok? The particularly h e and u 1 and u 2 and this we need to make use of the table A 17. Now what is given here is always at 400 Kelvin and as we know for an ideal gas, enthalpy is only dependant on temperature.

So for this particular system, u 1 and u 2 should be same. So 400 kelvin, h is given here and u is already here so h 1 is nothing but 400.9 which is this kiloJoules per Kg and u 1 is nothing but just same as u 2 which is 2 it is 6.16 ok? Now you can make use of this data ok, in your energy balance which was nothing but this which I am writing again here, plus m 2 u 2 minus m1 u 1.

So you know this information you know h e, ok? You know this m 2 u 1 and m 1. So thus you can calculate your electrical work which is nothing but 200 kiloJoules, Ok?

So this is how we solve the problem making use of the table for the case of unsteady flow process. If for example in this case we have maintained the temperature at 400 Kelvin. If there was a case where the temperature was changing then the, so let us say initial temperature could have been T 1 and final temperature could have been let us say T 2 then what we could have done is at the exit condition, we could have calculated h e at T 1 plus T 2 by 2.

So to evaluate the property and this would have given presumably accurate calculations in terms of the values.

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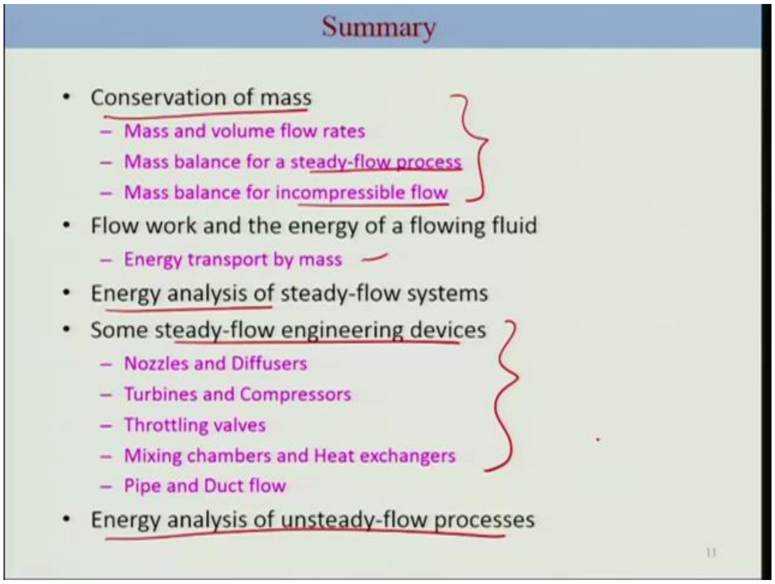

Ok so that would be the the end of this particular module which was on the energy and mass balance of a control volume, ok? So what we have done in this five parts, we have looked into the conservation of mass, ok where we considered the mass and volume flow rates. Mass balance of a steady flow process incompressible flow and flow work energy of a flowing fluid, ok?

We have also looked into the energy analysis of steady flow systems and we have taken examples of various steady flow engineering devices, ok? And in this particular lecture e looked into the energy analysis on steady flow process. So that would be the end of this particular lecture. In the next lecture, we will start a new topic which will be second law of thermodynamics. So I will see you in the next lecture.