Engineering Thermodynamics
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Lecture 23
Energy balance for steady flow devices

Welcome back we were discussing the mass energy analysis of a control volume, now we will take couple of examples we will take some devices and analyze mass energy balances and do some examples based on those devices.

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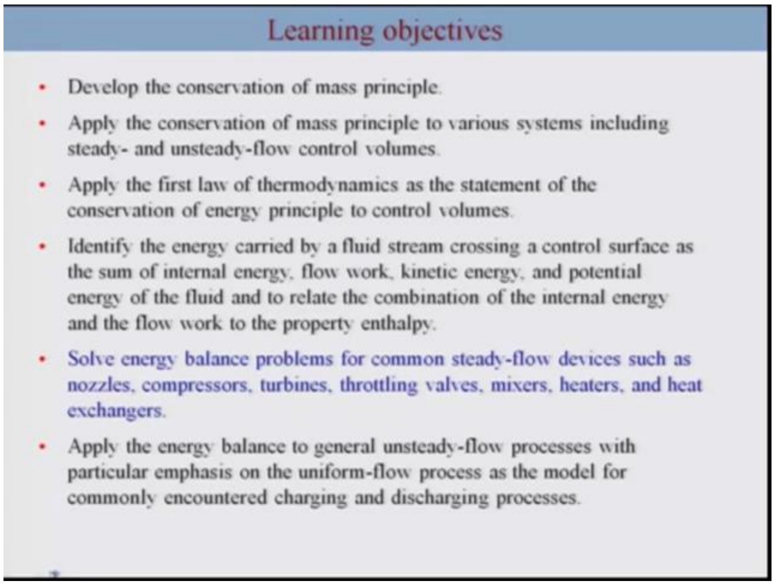

So let me just give you overview what we have done until now, so barely we have applied the conservation of mass principle and energy principle to the control volume. Now in this particular lecture we will solve some energy balanced problem for the common steady state flow devices, okay.

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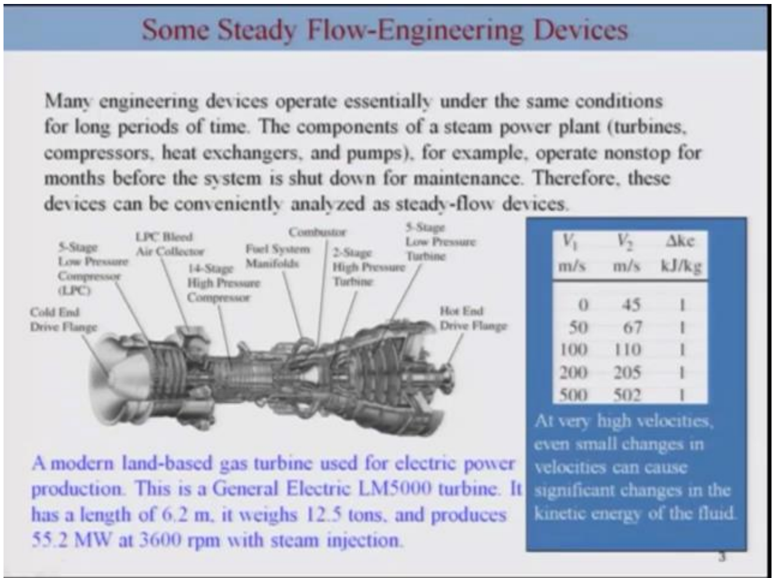

So let me just illustrate the common engineering devices, a typical like power plant such as a steam power plant contains turbine, compressor, heat exchangers and pump and most of the normal conditions they are operative for very very long time and thus you can assume that all these devices which are part of this such a power plant such as turbine, compressor, they operate at a steady flow conditions, okay. So we will be using such an approximation because these devices operate at non-stop for months before the system gets shut down for maintenance.

So for the case of analysis to be convenient if we can make use of steady flow assumptions for such devices. So this is an example general electric turbine okay which has many different aspects of the device. So we will take a these devices one by one and particularly apply a mass balance and energy balance of for this particular devices.

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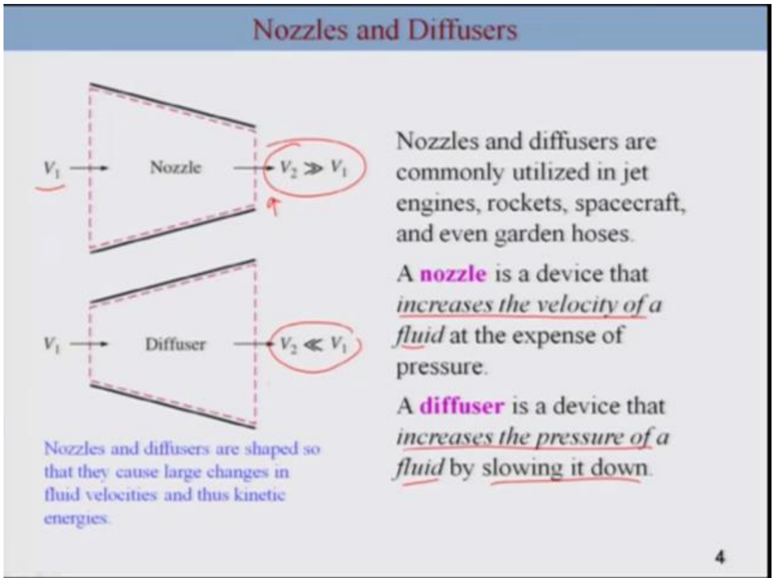

So let me start with nozzles and diffusers, so nozzles and diffusers are commonly used jet, rocket, spacecraft and even in common household purposes such as garden houses, okay. Nozzles and diffusers are kind of completely opposite in case of nozzle which is a device that increases the velocity of a fluid at the expense of pressure, what does it mean is that the velocity at the exit of a nozzle is extremely large compare to the inlet of course in that case there is pressure would be low here at the exit compare to the inlet.

On the other hand diffuser is a device that increases the pressure of a fluid by slowing it down, so it is just opposite of nozzle here of course the velocity at the exit is extremely small compared to the velocity at inlet, okay but the pressure here would be large much larger at the exit here compared to the inlet, okay.

Let me just go through the basic energy and mass balances, so for the case of nozzle and diffuser you can start with again the basic energy balance concept.

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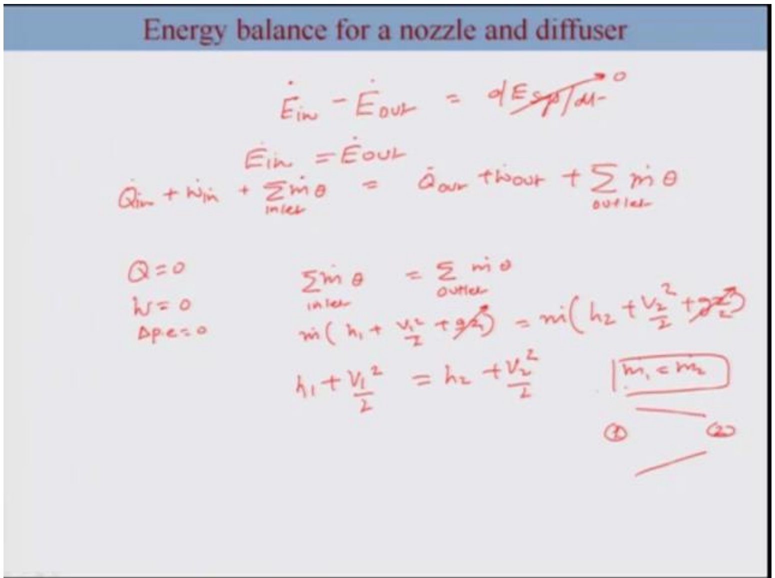

So this is your Ein as Eout okay we are using the rate expressions here dE system by dt and considering a steady flow conditions so you would be making this particular expression 0, okay. So which in this case would mean that Ein minus Eout or Ein is equal to Eout, okay. Now what is Ein here? Ein would be your Qin if there is any heat provided to the system or to the control volume plus Win plus summation of all the flow energies, so this would be your inlet and this should be your equal to Qout plus Wout plus summation m theta outlet, okay.

Okay considering that for the case of nozzle and diffuser you would be having only one inlet and one outlet, so what about the heat Q and W? Now typically what we are going to assume that Q is going to be 0 and W is also 0, okay. The reason for Q to be 0 is because the fluid does not spends a long time within this small you know diffuser or nozzle and hence we would be considering that the significant heat transfer is not there. But there are exceptions such as your liquid propellant rocket where the diffuser itself is quite a large and thus there will be some significant heat transfer but for the sake of our understanding and the problems which we are going to deal with we will be assuming Q to be 0, okay.

And similarly there is no involvement of work in this case for nozzle and diffuser, we will be also considering the change in the potential energy to be 0, okay and in that case for the single stream which will be the case for nozzle and diffuser we can simple write m theta this will be your inlet and this will be your outlet, okay. Now considering single stream you have m has been your steady state flow the m’s of the inlet should be same as outlet this should be equal to h2 plus V2 square plus gz, okay so this would be 1 here and then we would be assuming this delta p0 that is what we said here.

So this would be negligible for most of the cases, okay so what we have is that your h1 plus V1 square by 2 is equal to h2 plus V2 square by 2 and the reason is that m1 is equal to m2 for the streams which we are going to consider that say for the case of nozzles, so you have a1 and you have a2 for the case of steady flow your m1 should be same as m2 here, okay.

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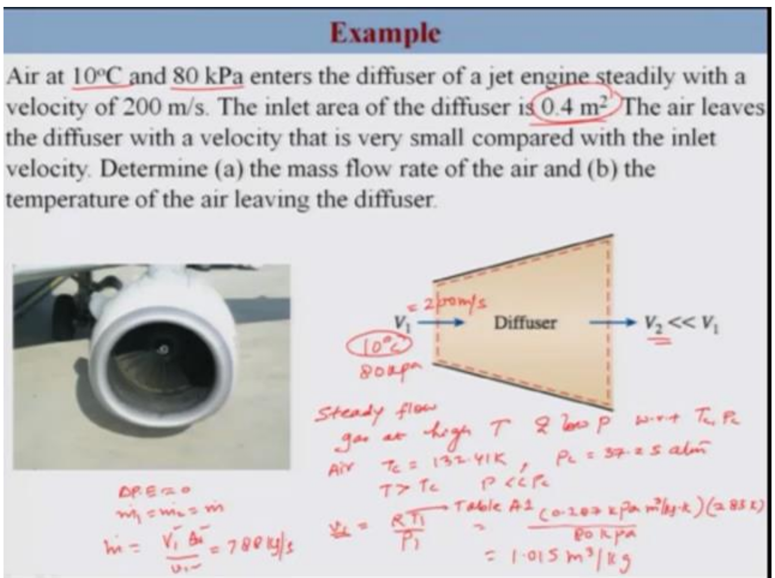

So this is our basic energy balance for nozzle and we can make use this analysis for a specific example, so let us take that example this is a case of a diffuser for jet engine. So what we have is air which is at 10 degree Celsius and 80 kilo Pascal enters a diffuser, okay so this is your 10 degree Celsius and 80 kilo Pascal.

And with velocity of 200 meter per second that is air which enters the diffuser of a jet engine with a velocity of 200 meter per second. The inlet area of the diffuser is given that is this area is given, so which is 0.4 meter square the air leaves the diffuser with velocity that is very small compare to the inlet velocity which essentially means that V2 is negligible. So what we have to determine is the mass flow rate of the air and the temperature of the air leaving the diffuser. So this is the problem for based on the diffuser, so what we are going to do is we are going to make approximation that this is steady flow device.

So this steady flow is an approximation which we are going make the second is that can we model air as ideal gas? typically gas behaves like ideal gas at very high so gas at high T or low P compare to with respect to Tc and Pc can be considered as ideal gas. So for the case of air Tc is around 132.41 kelvin and Pc is 37.25 atmosphere, so considering the current conditions which is 10 degree Celsius is much higher than Tc and the pressure which is 80 kilo Pascal is much lower than Pc, thus we can consider this particular system as an ideal gas so that will make our analysis much easier.

So the other thing which we are going to do is we are going to ignore your change in potential energy and being a steady flow we can say m1 the mass balance will lead to that m1 dot is equal to m2 dot is equal to m dot, okay let us first look at what is specific volume for based on data we have here so let us say we have V1 is nothing but R T1 by P1 this is your of course based on ideal gas. Now this R is gas constant and you can see table A1 based on that you can get the values from there so this turns out to be 287 kilo Pascal meter per cube per kg kelvin and then the temperature is given here which is in kelvin is 283 kelvin and then you have 80 kilo Pascal, okay.

So this turns out to be 1.015 meter cube per kg, we can find out from here the specific volume from ideal gas is now being calculated and we already know the velocity and we know the area of the diffuser the inlet diffuser so we can find out the mass flow rate for the air and that should be your simple m dot is V1 A1 by V1, okay. So this is a velocity here, this is area of the cross section here the inlet and this is the specific volume which we have calculated from ideal gas, okay. So you plug in this information based on this velocity is 200 meter per second A is given as your 0.4 meter square and thus this would come out to be 788 kg per second.

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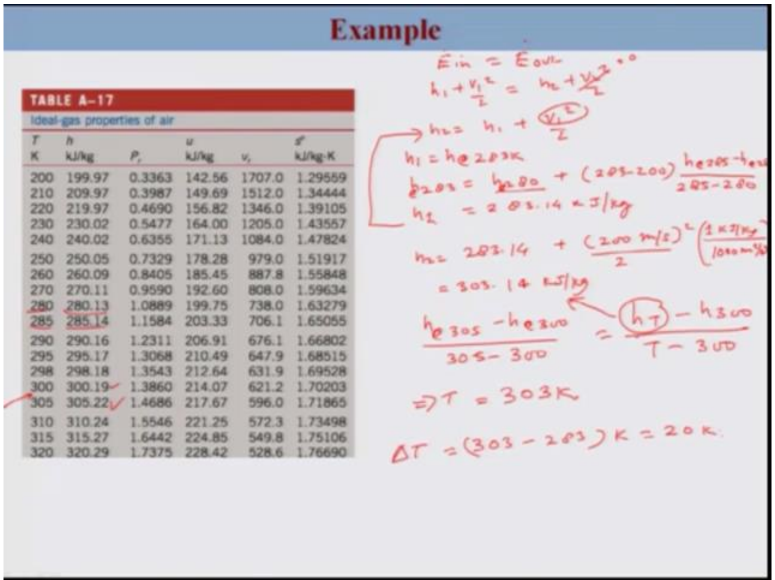

Okay, so the next thing we have to calculate is of course the condition which is your temperature because this the first part was the mass flow rate which we already calculated, now we need to calculate the temperature of air leaving the diffuser, so let us start with again the energy balance we already done that with the previous slide here.

So we will just make use of it so being a steady flow we can simple write Ein is equal to Eout okay and assuming the potential energy is 0 and no heat as well as no work interactions we can straight away write this as h1 plus V1 square is equal to h2 plus V2 square and this we can neglect because we can say this is extremely small thus you can write this simply as h2 is the h1 plus V1 square by 2.

Note that the m has been cancelled out here considering is a single stream system. Now what we need to do is we need to calculate h1, so let us first calculate h1 and then we will calculate h2 and from the tables we will try to find out what is the appropriate temperature for the outlet stream.

So h1 is nothing but h at 10 degree Celsius which is 283 kelvin, okay. So we look at the air table which is given in a17 so just take a look at this table a17, now 283 lies between 280 and 285, okay. So now we need to interpolate this and we can make use of interpolation based on 280 data and 285 data so this is what I am writing here.

So this would be your h of at 285 minus h at 280 and this is 285 minus 280. So now you can plug in this values so 280 values is already given or you can take it from the table and as well as 285 values you plug in the rest of data and the value which you get is 283.14 kilo joules per kg. And now this is the value which is h1 so you plug in h1 here you know the velocity here so this would become, so h2 is 283.14 plus 200 meter per second by 2 and then you can convert it to kilo joules per kg, okay.

So this comes out to be 303.14 kilo joules per kg, okay so the based on the simple energy balance and as well as the table utilization you may have to make use of interpolation quite often because not the tables are discrete points it is not so and the temperature may not be precisely falling on the table data points, so you may have to use interpolation quite regularly. Now the idea is very simple now is that once you have calculated the enthalpy you look back the corresponding temperature from the table. So where does 303.14 lies, okay and then again you make use of interpolation.

So let us try that, so 303 is somewhere here so this is 300.19 and this is 305.22 which essentially means that our temperature somewhere lies between 300 to 305, okay. So we again make use of your interpolation, so let us write it here h305 at 300 kelvin divided by 305 minus 300 this should be h of a specific temperature which we are interested in minus h300 by T minus 300, okay and T hT is nothing but this, okay so you place this hT by 303.14 and thus you can get your T as 303 kelvin, okay so this is the temperature of the outlet temperature of the air which leaves the diffuser. And so what will be your delta T in this case, so delta T would be 303 minus 283 kelvin.

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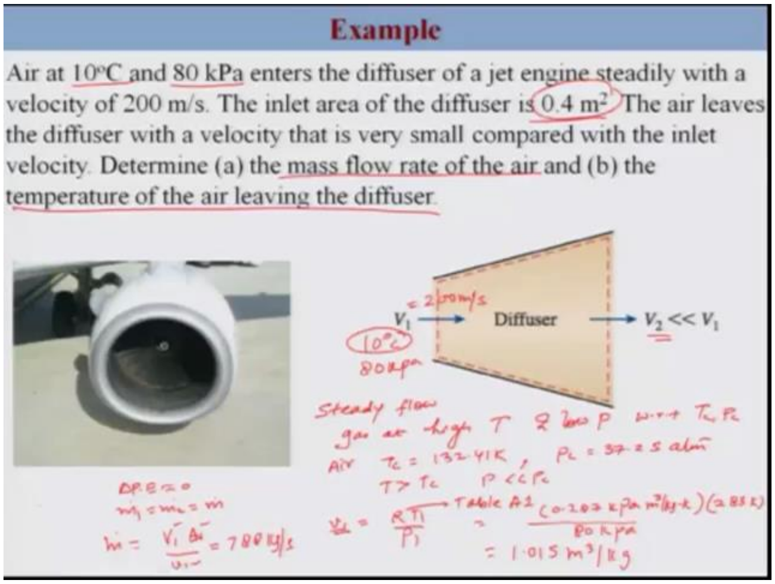

So this is your 20 kelvin or 20 degree Celsius, okay and so there is a increase in the temperature at the outlet condition and the reason being is that your kinetic energy of the air gets converted to the internal energy and raising the temperature of the overall air. So let us now take a look at different device, okay so we have discussed diffuser and nozzles now we are going to discuss turbine and compressor.

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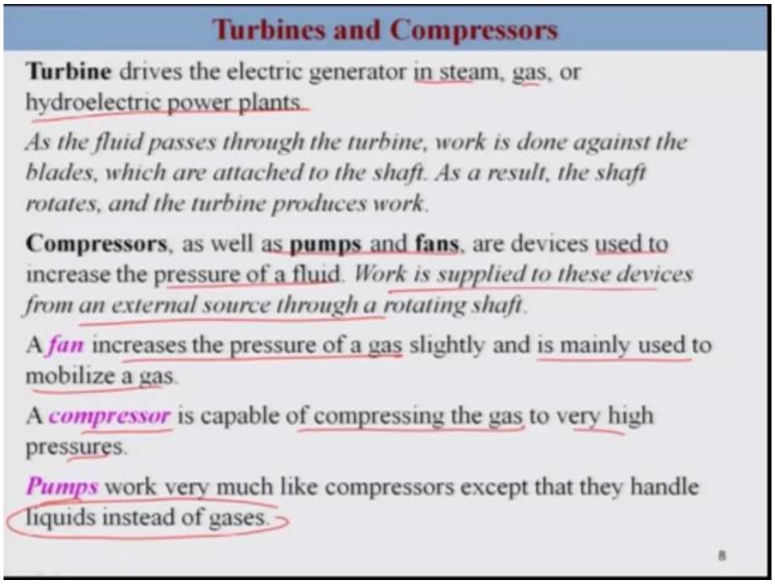

Turbine we have already looked at a bit in early stage of this course basically the purpose of the turbine is it drives the electric generator in steam, gas or hydroelectric power plants. So during in the turbine the fluid pass through the blade of the turbine, okay and it does work against the blade blade is connected to the shaft so it rotates the shaft and thus it produces work. So that is the philosophy or that is the purpose of the turbine in that case.

On the other hand compressor or such as other examples are like pump and fan these are the devices which use to increase the pressure of a fluid, okay. Now turbine produces work on the other hand compressor pump and fan requires work and so this there is a work input for the case of compressors pumps and fan and for the case of turbine there is a work output.

So thus your work is supplied to compressors, pumps and fan from an external source through the rotating shaft. The operational (())(16:34) similar for compressor fan and pumps but the results are different the fan mainly increases the pressure of the gas slightly and is mainly used to mobilize a gas, on the other hand compressor is capable of compressing the gas to high pressure. And a pump works very much like compressors except that they handle liquids instead of gas. So the operational aspects are a slightly different, but in terms of the work required the philosophies are quite similar.

So let us do an energy balance for the case of a compressor, okay so we will just take a compressor and apply the mass and energy balances and then we will try to do some examples later, okay.

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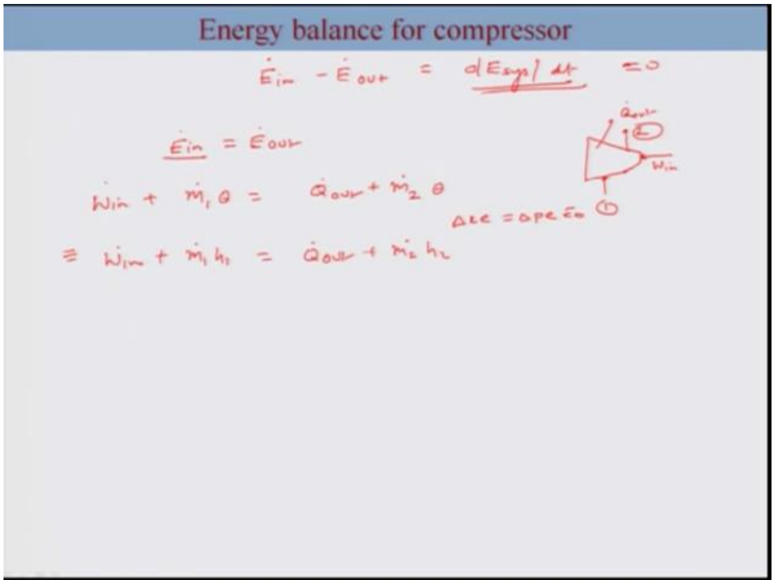

So let us start with this a generalize energy balance here, okay so we will consider this to be 0 because again the compressor will be considered as a steady flow device, let us say you have this inlet fluid and this is outlet and there is a work which is supplied let us say a shaft work, okay and there is some heat loss. So this could be your out, okay so we can write this generalized energy balance for the control volume for the steady flow condition as follows, okay.

Now Ein in this case would be your Win considering single fluid we will consider simple m1 theta here that this is 1, this is 2, okay and this would be your Qout m2 theta, okay. So this is your expression for the case of this this compressor or engine we will be considering that the change here in the kinetic energy and the potential energy would be 0 approximating as to be 0 here and considering that this can rewritten as Win plus m1 h1 is Q plus m2 h2, okay.

So this is in general will be writing such an expression for a compressor, now though we are mentioning that your change in the kinetic energy for the case of compressor to be 0 but the fan you may have to consider that, so based on the specific device you may have to look into the contributions for the case of compressor of course the change in the kinetic energy and the potential energy would be 0.

But overall this energy analysis the way we are doing here will be similar for the turbine and fan and as well as pump. So you just have to write and then you have to make a note of the different interactions and then put the variables accordingly, okay.

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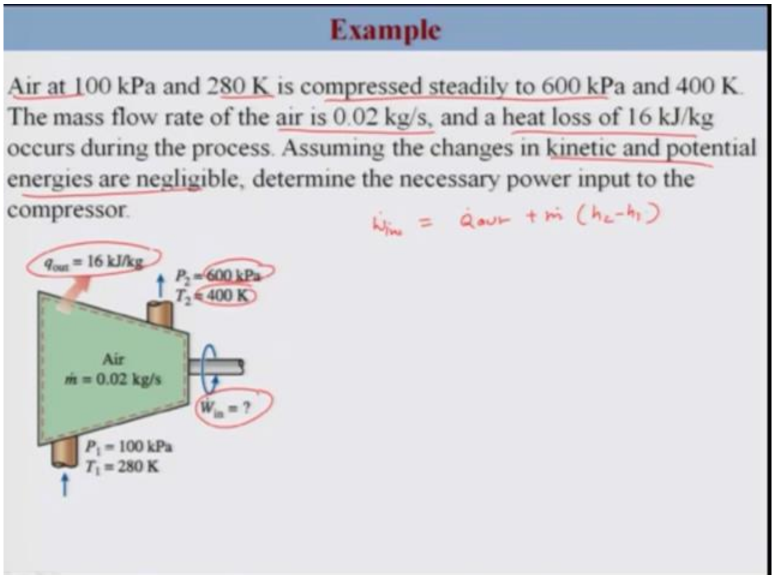

So let us try the exercise for the compressor and apply to this particular example, okay so this example is again making use of air which is at 100 kilo Pascal and 280 kelvin and is compressed steadily to 600 kilo Pascal and the temperature is increased to 400 kelvin. The mass flow rate of the air is already given to you and there is a heat loss okay which we know in terms in unit mass in 16 kilo joules per kg.

So we have to determine the necessary power input to the compressor that means what is your Win dot, we are going to assume the kinetic energy and changes in the kinetic energy potential energy to be negligible. So we will start with our energy balance expression, so this is your Win is Qout plus m dot h2 minus h1, okay this was exactly what we did here okay.

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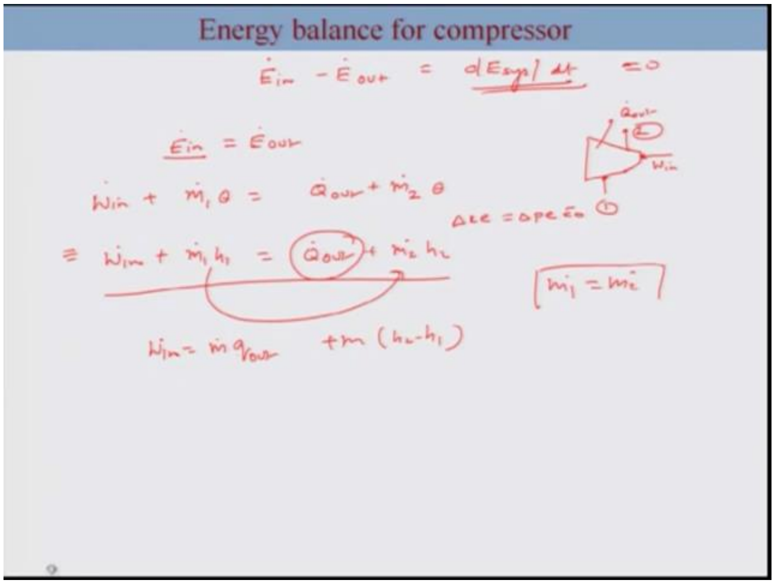

So this can be written by taking it here okay and then you can write it Win as simply m h2 minus h1 considering that m1 dot is equal to m2 dot okay because of the single stream, you can also further simplify this and or use Q in terms in the units of kilo joules per kg by considering m dot multiply by Q dot, okay.

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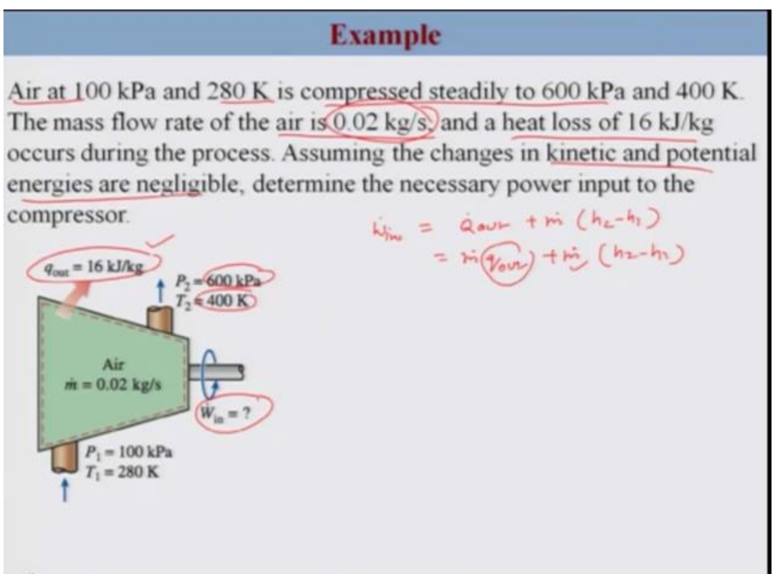

So this is what we are going to write here m dot Qout which is already given here because this is given to you plus m dot h2 minus h1. Now so what we have is we have been given m dot which is of course 0.02 kg per second. Qout is given to you we have to find h2 minus h1.

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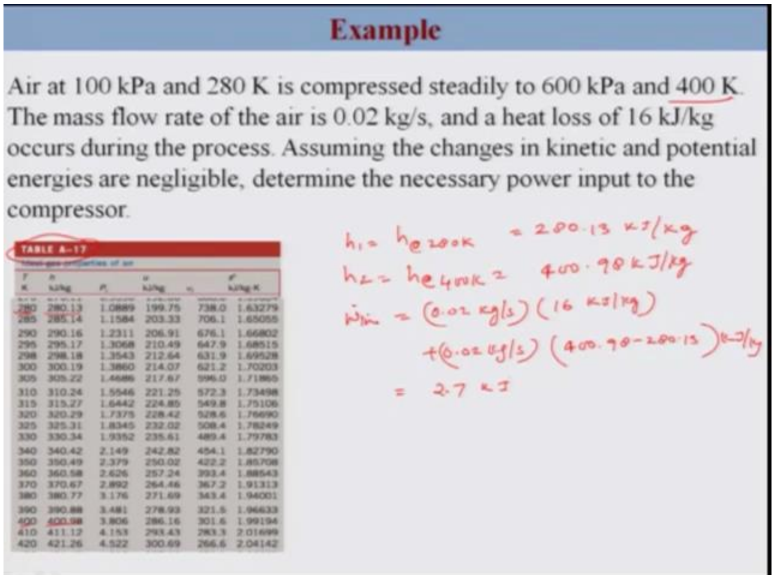

So let us look at h1 so what is your h1? h1 is your inlet condition which is at 280 kelvin, again look at your table which is a17 here is a 280 kelvin, what is h? h is 280.13 kilo joules per kg, okay.

And then you have h2, now what is h2? h2 is at 400 kelvin so h 400 kelvin now 400 kelvin is here this is your 400.98, okay. So now you can directly plug in these values to the energy balanced expression we already know all these values we have h, you have already Q so and as well as your mass flow rate, okay. So this is a first term 16 kg per kg. Okay so now this should be h2 minus h1 this is 400.98 minus 280.13 kilo joules per kg and this turns out to be 2.7 kilo watt.

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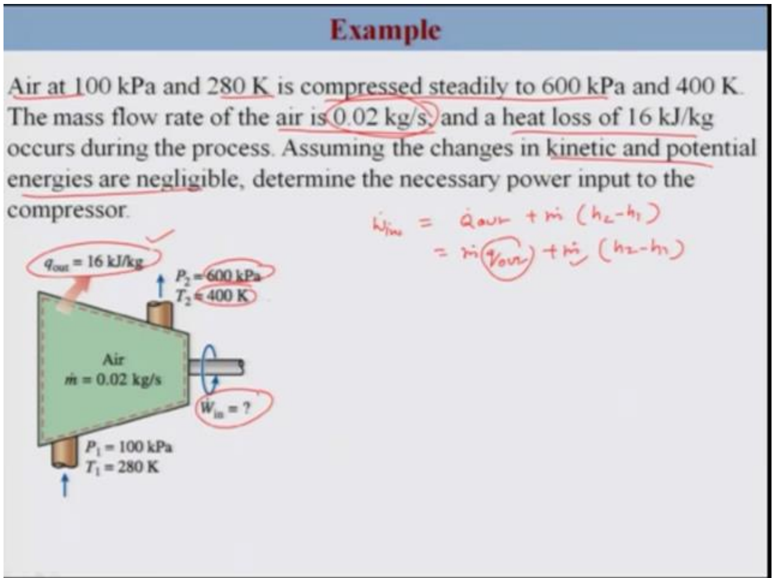

So this is how you are going to solve such a problem for the case of compressor, so what is important here is that if you look at carefully the work here which is being supplied to the compressor or to the control volume has raised the temperature in and essentially it also as increased the enthalpy where enthalpy at the outlet condition is much higher than the inlet condition, okay. So this is your increase in enthalpy due to mechanical energy input, okay.

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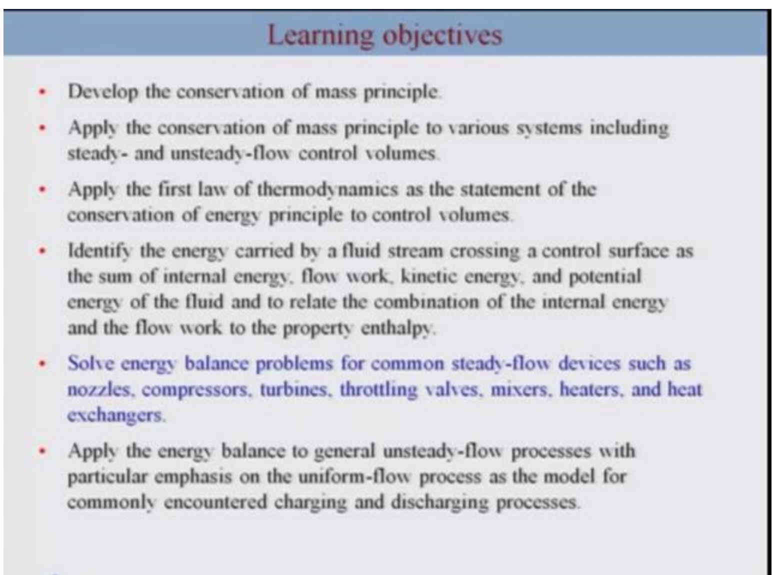

So let me end this lecture and the next lecture we will consider couple of more devices such as throttling valves, mixer heaters and heater exchangers, okay so that will be the end of this lecture, see you in the next lecture.