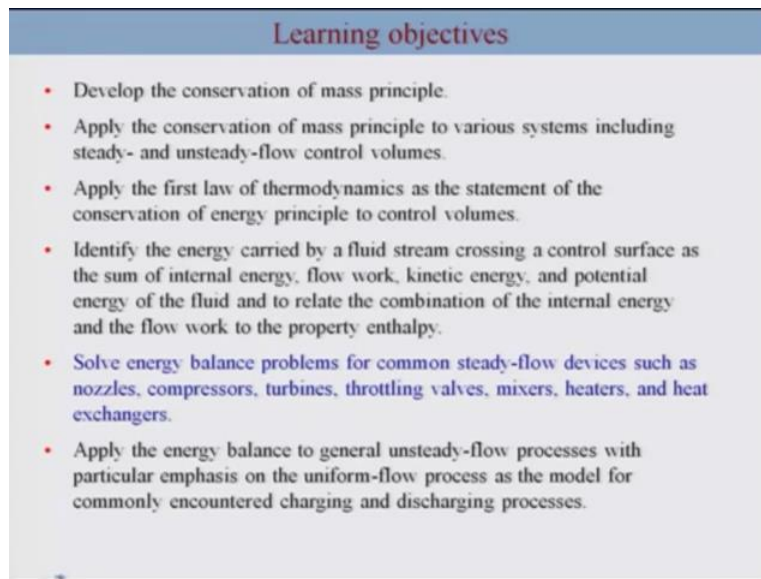


**Engineering Thermodynamics**  
**Professor Jayant K Singh**  
**Department of Chemical Engineering**  
**Indian Institute of Technology Kanpur**  
**Lecture 23**  
**Energy balance for steady flow devices**

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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**Learning objectives**

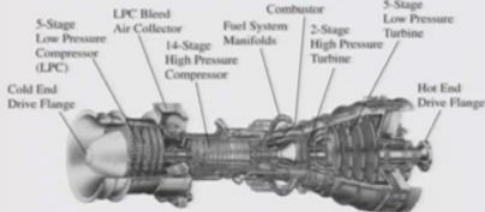
- Develop the conservation of mass principle.
- Apply the conservation of mass principle to various systems including steady- and unsteady-flow control volumes.
- Apply the first law of thermodynamics as the statement of the conservation of energy principle to control volumes.
- Identify the energy carried by a fluid stream crossing a control surface as the sum of internal energy, flow work, kinetic energy, and potential energy of the fluid and to relate the combination of the internal energy and the flow work to the property enthalpy.
- Solve energy balance problems for common steady-flow devices such as nozzles, compressors, turbines, throttling valves, mixers, heaters, and heat exchangers.
- Apply the energy balance to general unsteady-flow processes with particular emphasis on the uniform-flow process as the model for commonly encountered charging and discharging processes.

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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### Some Steady Flow-Engineering Devices

Many engineering devices operate essentially under the same conditions for long periods of time. The components of a steam power plant (turbines, compressors, heat exchangers, and pumps), for example, operate nonstop for months before the system is shut down for maintenance. Therefore, these devices can be conveniently analyzed as steady-flow devices.



$V_1$ m/s	$V_2$ m/s	$\Delta ke$ kJ/kg
0	45	1
50	67	1
100	110	1
200	205	1
500	502	1

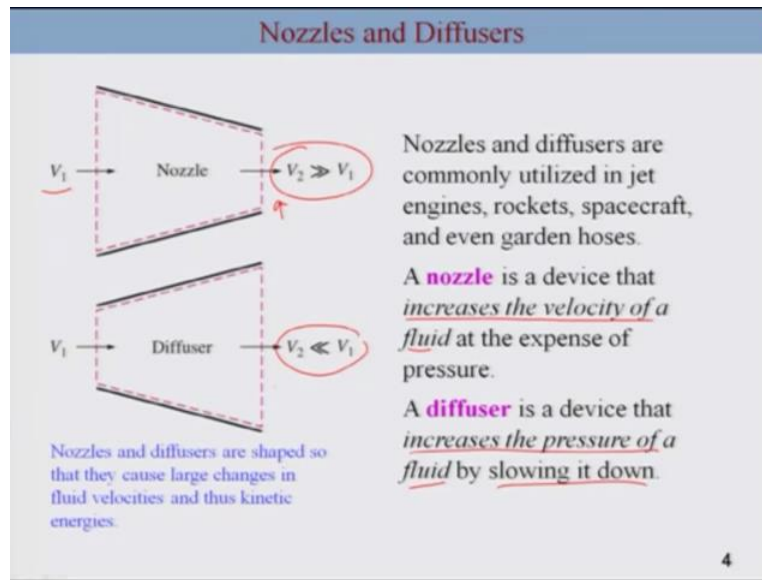
A modern land-based gas turbine used for electric power production. This is a General Electric LM5000 turbine. It has a length of 6.2 m, it weighs 12.5 tons, and produces 55.2 MW at 3600 rpm with steam injection.

At very high velocities, even small changes in velocities can cause significant changes in the kinetic energy of the fluid.

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 hoses, 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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**Energy balance for a nozzle and diffuser**

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{system}}{dt} = 0$$


$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{inlet} \dot{m}_i \theta_i = \dot{Q}_{out} + \dot{W}_{out} + \sum_{outlet} \dot{m}_j \theta_j$$

$Q=0$   
 $W=0$   
 $\Delta p_e=0$

$$\sum_{inlet} \dot{m}_i \theta_i = \sum_{outlet} \dot{m}_j \theta_j$$

$$\dot{m} \left( h_1 + \frac{V_1^2}{2} + gz_1 \right) = \dot{m} \left( h_2 + \frac{V_2^2}{2} + gz_2 \right)$$

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2} \quad \boxed{m_1 = m_2}$$


So this is your  $E_{in}$  as  $E_{out}$  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  $E_{in}$  minus  $E_{out}$  or  $E_{in}$  is equal to  $E_{out}$ , okay. Now what is  $E_{in}$  here?  $E_{in}$  would be your  $Q_{in}$  if there is any heat provided to the system or to the control volume plus  $W_{in}$  plus summation of all the flow energies, so this would be your inlet and this should be your equal to  $Q_{out}$  plus  $W_{out}$  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 spend 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 simply write  $m \theta$  this will be your inlet and this will be your outlet, okay. Now considering single stream you have  $m$  has been


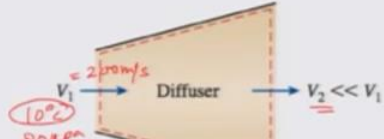
your steady state flow the  $m$ 's of the inlet should be same as outlet this should be equal to  $h_2$  plus  $V_2$  square plus  $gz$ , okay so this would be 1 here and then we would be assuming this  $\Delta p_0$  that is what we said here.

So this would be negligible for most of the cases, okay so what we have is that your  $h_1$  plus  $V_1$  square by 2 is equal to  $h_2$  plus  $V_2$  square by 2 and the reason is that  $m_1$  is equal to  $m_2$  for the streams which we are going to consider that say for the case of nozzles, so you have  $a_1$  and you have  $a_2$  for the case of steady flow your  $m_1$  should be same as  $m_2$  here, okay.

(Refer Slide Time: 6:30)

**Example**

Air at  $10^\circ\text{C}$  and  $80\text{ kPa}$  enters the diffuser of a jet engine steadily with a velocity of  $200\text{ m/s}$ . The inlet area of the diffuser is  $0.4\text{ m}^2$ . The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. Determine (a) the mass flow rate of the air and (b) the temperature of the air leaving the diffuser.

Steady flow  
 gas air high  $T$   $Q$  low  $P$   $w \rightarrow T_2, P_2$   
 Air  $T_2 = 132.4\text{ K}$ ,  $P_2 = 37.25\text{ atm}$   
 $T > T_c$   $P \ll P_c$   
 $\rho_2 = \frac{RT_2}{P_2} \rightarrow \text{Table A2 } \frac{(0.202\text{ kPa m}^3/\text{kg}) (0.881)}{80\text{ kPa}} = 1.015\text{ m}^3/\text{kg}$

$\Delta PE = 0$   
 $\dot{m}_1 = \dot{m}_2 = \dot{m}$   
 $\dot{m} = \frac{V_1 \dot{m}}{V_1} = 780\text{ kg/s}$

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  $V_2$  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  $T_c$  and  $P_c$  can be considered as ideal gas. So for the case of air  $T_c$  is around 132.41 kelvin and  $P_c$  is 37.25 atmosphere, so considering the current conditions which is 10 degree Celsius is much higher than  $T_c$  and the pressure which is 80 kilo Pascal is much lower than  $P_c$ , 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  $m_1$  the mass balance will lead to that  $m_1 \dot{m}$  is equal to  $m_2 \dot{m}$  is equal to  $m \dot{m}$ , okay let us first look at what is specific volume for based on data we have here so let us say we have  $V_1$  is nothing but  $R T_1$  by  $P_1$  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  $m \dot{m}$  is  $V_1 A_1$  by  $V_1$ , 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.

(Refer Slide Time: 10:22)

**Example**

T K	h kJ/kg	P <sub>r</sub>	u kJ/kg	v <sub>r</sub>	s <sup>o</sup> kJ/kg·K
200	199.97	0.3363	142.56	1707.0	1.29559
210	209.97	0.3987	149.69	1512.0	1.34444
220	219.97	0.4690	156.82	1346.0	1.39105
230	230.02	0.5477	164.00	1205.0	1.43557
240	240.02	0.6355	171.13	1084.0	1.47824
250	250.05	0.7329	178.28	979.0	1.51917
260	260.09	0.8405	185.45	887.8	1.55848
270	270.11	0.9590	192.60	808.0	1.59634
280	280.13	1.0889	199.75	738.0	1.63279
285	285.14	1.1584	203.33	706.1	1.65055
290	290.16	1.2311	206.91	676.1	1.66802
295	295.17	1.3068	210.49	647.9	1.68515
298	298.18	1.3543	212.64	631.9	1.69528
300	300.19	1.3860	214.07	621.2	1.70203
305	305.22	1.4686	217.67	596.0	1.71865
310	310.24	1.5546	221.25	572.3	1.73498
315	315.27	1.6442	224.85	549.8	1.75106
320	320.29	1.7375	228.42	528.6	1.76690

$E_{in} = E_{out}$   
 $h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$   
 $h_2 = h_1 + \frac{V_1^2}{2}$   
 $h_1 = h_{e 283K}$   
 $h_{283} = h_{e 280} + (283-280) \frac{h_{e 285} - h_{e 280}}{285-280}$   
 $h_2 = 283.14 \text{ kJ/kg}$   
 $h_2 = 283.14 + \frac{(200 \text{ m/s})^2}{2} \left( \frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right)$   
 $= 303.14 \text{ kJ/kg}$   
 $\frac{h_{e 305} - h_{e 300}}{305-300} = \frac{h_T - h_{e 300}}{T-300}$   
 $\Rightarrow T = 303 \text{ K}$   
 $\Delta T = (303 - 283) \text{ K} = 20 \text{ K}$

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  $E_{in}$  is equal to  $E_{out}$  okay and assuming the potential energy is 0 and no heat as well as no work interactions we can straight away write this as  $h_1$  plus  $V_1$  square is equal to  $h_2$  plus  $V_2$  square and this we can neglect because we can say this is extremely small thus you can write this simply as  $h_2$  is the  $h_1$  plus  $V_1$  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  $h_1$ , so let us first calculate  $h_1$  and then we will calculate  $h_2$  and from the tables we will try to find out what is the appropriate temperature for the outlet stream.

So  $h_1$  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  $h_1$  so you plug in  $h_1$  here you know the velocity here so this would become, so  $h_2$  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.

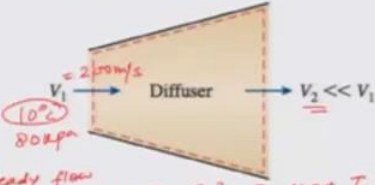

So let us try that, so 303 is somewhere here so this is 300.19 and this is 305.22 which essentially means that our temperature somewhere lies between 300 to 305, okay. So we again make use of your interpolation, so let us write it here  $h_{305}$  at 300 kelvin divided by 305 minus 300 this should be  $h$  of a specific temperature which we are interested in minus  $h_{300}$  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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**Example**

Air at  $10^\circ\text{C}$  and  $80\text{ kPa}$  enters the diffuser of a jet engine steadily with a velocity of  $200\text{ m/s}$ . The inlet area of the diffuser is  $0.4\text{ m}^2$ . The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. Determine (a) the mass flow rate of the air and (b) the temperature of the air leaving the diffuser.



*Steady flow*  
gas air high  $T$   $Q$  low  $P$   $w \rightarrow T_c, P_c$   
AIR  $T_c = 132.41\text{ K}$   $P_c = 37.25\text{ atm}$   
 $T > T_c$   $P < P_c$   
 $\rho_c = \frac{RT_c}{P_c} \rightarrow \text{Table A2 } (0.202\text{ kg/m}^3)(2.852)$   
 $\rho_c = \frac{0.202 \times 2.852}{80\text{ kPa}}$   
 $= 1.015\text{ m}^3/\text{kg}$

$DPE = 0$   
 $m_1 = m_2 = \dot{m}$   
 $\dot{m} = \frac{\dot{V}_1 A_1}{v_1} = 780\text{ kg/s}$

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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**Turbines and Compressors**

**Turbine** drives the electric generator in steam, gas, or hydroelectric power plants.  
*As the fluid passes through the turbine, work is done against the blades, which are attached to the shaft. As a result, the shaft rotates, and the turbine produces work.*

**Compressors**, as well as pumps and fans, are devices used to increase the pressure of a fluid. Work is supplied to these devices from an external source through a rotating shaft.

A fan increases the pressure of a gas slightly and is mainly used to mobilize a gas.

A compressor is capable of compressing the gas to very high pressures.

Pumps work very much like compressors except that they handle liquids instead of gases.

8

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.

(Refer Slide Time: 17:20)

**Energy balance for compressor**

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{sys}}{dt} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$W_{in} + \dot{m}_1 \theta = \dot{Q}_{out} + \dot{m}_2 \theta$$

$$\equiv W_{in} + \dot{m}_1 h_1 = \dot{Q}_{out} + \dot{m}_2 h_2$$

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  $E_{in}$  in this case would be your  $W_{in}$  considering single fluid we will consider simple  $m_1 \theta$  here that this is 1, this is 2, okay and this would be your  $Q_{out} m_2 \theta$ , 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  $W_{in} + m_1 h_1 = Q + m_2 h_2$ , 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.

(Refer Slide Time: 19:45)

**Example**

Air at 100 kPa and 280 K is compressed steadily to 600 kPa and 400 K. The mass flow rate of the air is 0.02 kg/s, and a heat loss of 16 kJ/kg occurs during the process. Assuming the changes in kinetic and potential energies are negligible, determine the necessary power input to the compressor.

$$\dot{W}_{in} = \dot{Q}_{out} + \dot{m} (h_2 - h_1)$$

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  $\dot{W}_{in}$ , 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  $\dot{W}_{in}$  is  $\dot{Q}_{out}$  plus  $\dot{m} (h_2 - h_1)$ , okay this was exactly what we did here okay.

(Refer Slide Time: 20:30)

**Energy balance for compressor**


$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{sys}}{dt} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{in} + \dot{m}_1 \theta = \dot{Q}_{out} + \dot{m}_2 \theta$$

$$\dot{W}_{in} + \dot{m}_1 h_1 = \dot{Q}_{out} + \dot{m}_2 h_2$$

$$\dot{W}_{in} = \dot{m} q_{loss} + \dot{m} (h_2 - h_1)$$


  
 $\dot{m}_1 = \dot{m}_2$

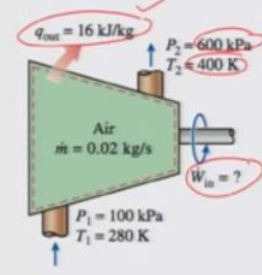
So this can be written by taking it here okay and then you can write it  $\dot{W}_{in}$  as simply  $\dot{m} h_2$  minus  $h_1$  considering that  $\dot{m}_1$  dot is equal to  $\dot{m}_2$  dot okay because of the single stream, you can also further simplify this and or use  $Q$  in terms in the units of kilo joules per kg by considering  $\dot{m}$  dot multiply by  $Q$  dot, okay.

(Refer Slide Time: 21:01)

**Example**

Air at 100 kPa and 280 K is compressed steadily to 600 kPa and 400 K. The mass flow rate of the air is 0.02 kg/s, and a heat loss of 16 kJ/kg occurs during the process. Assuming the changes in kinetic and potential energies are negligible, determine the necessary power input to the compressor.

$\dot{W}_{in} = \dot{Q}_{out} + \dot{m} (h_2 - h_1)$   
 $= \dot{m} (q_{loss}) + \dot{m} (h_2 - h_1)$



So this is what we are going to write here  $\dot{m} \cdot Q_{out}$  which is already given here because this is given to you plus  $\dot{m} \cdot h_2$  minus  $h_1$ . Now so what we have is we have been given  $\dot{m}$  which is of course 0.02 kg per second.  $Q_{out}$  is given to you we have to find  $h_2$  minus  $h_1$ .

(Refer Slide Time: 21:25)

**Example**

Air at 100 kPa and 280 K is compressed steadily to 600 kPa and 400 K. The mass flow rate of the air is 0.02 kg/s, and a heat loss of 16 kJ/kg occurs during the process. Assuming the changes in kinetic and potential energies are negligible, determine the necessary power input to the compressor.

T K	h kJ/kg	h <sub>f</sub> kJ/kg	u kJ/kg	v <sub>f</sub> m <sup>3</sup> /kg	v <sub>g</sub> m <sup>3</sup> /kg
280	280.13	1.0889	199.75	738.0	1.63279
285	285.14	1.1584	203.33	706.1	1.65050
290	290.16	1.2311	206.91	676.1	1.66802
295	295.17	1.3068	210.49	647.9	1.68515
298	298.18	1.3543	212.54	631.9	1.69528
300	300.19	1.3860	214.07	621.2	1.70203
305	305.22	1.4686	217.67	596.0	1.71865
310	310.24	1.5546	221.25	572.3	1.73498
315	315.27	1.6442	224.80	549.8	1.75106
320	320.29	1.7373	228.42	528.6	1.76690
325	325.31	1.8340	232.02	508.4	1.78249
330	330.34	1.9352	235.61	489.4	1.79783
340	340.42	2.149	242.82	454.1	1.82790
350	350.49	2.379	250.02	422.2	1.85708
360	360.58	2.626	257.24	393.4	1.88543
370	370.67	2.892	264.48	367.2	1.91313
380	380.77	3.176	271.69	343.4	1.94021
390	390.88	3.481	278.93	321.8	1.96633
400	400.98	3.806	286.16	301.8	1.99194
410	411.12	4.153	293.43	283.3	2.01699
420	421.26	4.522	300.69	266.6	2.04142

$h_1 = h_{@280K} = 280.13 \text{ kJ/kg}$   
 $h_2 = h_{@400K} = 400.98 \text{ kJ/kg}$   
 $\dot{W}_{in} = (0.02 \text{ kg/s}) (16 \text{ kJ/kg})$   
 $+ (0.02 \text{ kg/s}) (400.98 - 280.13) \text{ kJ/kg}$   
 $= 2.7 \text{ kW}$

So let us look at  $h_1$  so what is your  $h_1$ ?  $h_1$  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  $h_2$ , now what is  $h_2$ ?  $h_2$  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  $h_2$  minus  $h_1$  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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**Example**

Air at 100 kPa and 280 K is compressed steadily to 600 kPa and 400 K. The mass flow rate of the air is 0.02 kg/s, and a heat loss of 16 kJ/kg occurs during the process. Assuming the changes in kinetic and potential energies are negligible, determine the necessary power input to the compressor.

$W_{in} = q_{out} + m_i (h_2 - h_1)$   
 $= m_i q_{out} + m_i (h_2 - h_1)$

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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**Learning objectives**

- Develop the conservation of mass principle.
- Apply the conservation of mass principle to various systems including steady- and unsteady-flow control volumes.
- Apply the first law of thermodynamics as the statement of the conservation of energy principle to control volumes.
- Identify the energy carried by a fluid stream crossing a control surface as the sum of internal energy, flow work, kinetic energy, and potential energy of the fluid and to relate the combination of the internal energy and the flow work to the property enthalpy.
- Solve energy balance problems for common steady-flow devices such as nozzles, compressors, turbines, throttling valves, mixers, heaters, and heat exchangers.
- Apply the energy balance to general unsteady-flow processes with particular emphasis on the uniform-flow process as the model for commonly encountered charging and discharging processes.

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.