Engineering Thermodynamics

Dr. Jayant Kumar Singh
Department of Chemical Engineering
Indian Institute of Technology Kanpur

Week-04
Lecture-21
Mass Energy Analysis and Control Volume

Welcome to the part 3 of Mass Energy Analysis and Control Volume In this lecture we will try to solve some problems related to Steady 4 devices like Nozzles, Compressors, Turbines Let's start There are many devices that are used practically, like gas turbine There are many components and units that are used It is very complex For example, we have shown here that it is a land-based gas turbine. If you notice, there are different levels of compressors and turbines. There are different turbines with high-pressure, low-pressure turbines and flanges. When this type of engineering starts in a practical sense in a plant, when we start initially, it takes several months to achieve steady state conditions and steady flow conditions. After that, the steady flow devices are made. Our analysis, the control system that we have made, the energy and mass balance that we are applying on the steady flow devices, can't be applied immediately when you start any process plan or any engine. So initially, there can be such an analysis which is non-steady state. So, we will talk about that later. But in this lecture and in this topic, we are mainly going to work on steady-state related. We will definitely try to understand some examples through practice. Unsteady-state behavior. One more thing to notice is that we Maximum time we are neglecting kinetic energy of the system. But where there is flow, kinetic energy comes, and velocity comes. And many times, we cannot neglect kinetic energy. For example, if you see there is a change in kinetic energy, then notice in the difference of velocity, that initially when the velocity is less, then more difference is needed, so that the same change can be achieved. The same change can be achieved in a very low velocity difference of 1 kJ per kg. If there is a difference of only 2 mps in the velocity, then you can get 1 kJ per kg. The same 45 MPs difference is required, so that you get 1 kJ per kg of kinetic energy. So, in higher velocity, which is very high velocity, then even a little change can change the kinetic energy. So, the system becomes so sensitive at high velocity. So, the turbines and engines that work at high velocity, for its design, you need to do the energy balance very correctly. And you assume a lot of things in it, but the assumptions should also be correct, and its error analysis should also be good.

Some common devices that we use are nozzles, diffusers, pumps, compressors, etc. We will understand each device. Nozzles are used to measure the velocity of water. Normally, you will find this in jets, rockets, space crafts, or garden pipes. Nozzles are used in these too. Nozzles and diffusers are available in this type of device or systems. There is only one difference between a nozzle and a diffuser. Nozzle is used to increase the velocity Diffuser is used to increase the pressure Nozzle increases the speed of the pipe hose and the diffuser slows down the pressure That's why if you see the initial velocity V1 In the case of the nozzle, the final velocity will be much higher in comparison to V1 The ratio will be very high And the same diffuser is the opposite V1 will be much higher in comparison to the final velocity Because here the purpose of this is to increase the pressure and the purpose of this is to increase the velocity of the diffuser. Let's start with the energy balance of the nozzle and the diffuser. So, we are simply talking about the control volume of the energy balance. This is a steady flow system, so it will be zero. So, whether it is a nozzle or a diffuser, in your energy balance,

$$\dot{E_{in}} - \dot{E_{out}} = \frac{dE_{ev}}{dt} = 0$$

$$\dot{E_{in}} = \dot{E_{out}}$$

$$\dot{m}(h_1 + \left(\frac{{v_1}^2}{2}\right) + gz_1) = \dot{m}(h_2 + \left(\frac{{v_2}^2}{2}\right) + gz_2)$$

$$h_1 + \left(\frac{{v_1}^2}{2}\right) = h_2 + \left(\frac{{v_2}^2}{2}\right)$$

$$z_1 = z_2$$

Nozzle

$$h_2 - h_1 = \left(\frac{{v_1}^2}{2}\right) - \left(\frac{{v_2}^2}{2}\right)$$

So, this is your equation. You can derive it from the Sth. Let's try to understand it with the help of examples. Here is the air which is at 10 degrees and 80 kPa. Its velocity is 200 meters in the beginning. Inlet area of diffuser A is 0.4 m2 Air is leaving with a velocity that is very small compared to the inlet velocity Which means V2 is very less than V1 This is the statement And this diffuser is of jet engine So we have to calculate mass flow rate How much is M dot of this? and temperature which is T2 so these are two things so we have diffuser so if we see the energy balance we can directly put this in the second question but first of all we have to find the mass flow rate so for mass flow rate we have M dot, I'm going to mass is rho of velocity into A. This is your definition, A is given to you, velocity is given to you, you have to find the density, so you can also take it out like this. Specific volume. And for specific volume, you can consider air as the ideal gas. air as the ideal gas. So, what is the normal condition of the ideal gas? When we consider air as the ideal gas, the ideal gas condition is when the temperature is too high or the pressure is too low so you can assume high temperature or low pressure so you can ask this question how do you know that the condition is high temperature or low pressure so the air If you look at the NIST table or google it, NIST data is considered a standard data for thermodynamics. The temperature of air, Tc, is minus 40.52 degrees Celsius and Pc is 37.05 bar. Naturally, the temperature here is 10 degrees which is very high from minus 40. And the pressure is 80 kilopascal which is below 1 bar. So, the pressure is very low. Because of this, we can consider this air as an ideal gas. If you consider it as an ideal gas, then we can take out its value. You can take out the Pv RT by P R is 0.287 kPa per kg temperature is 283 K pressure is 80 kPa If you do the same V mass, Rho V1 A1 then this is your 200 or you can call it V1 A1 by 200 meter per second 4.4 meter square and this is your RT1 P1 which we can insert from here and put these values Finally, the value of this will come out after calculation 78.8 kg per second Notice the velocity This is the first part First we defined it m dot is equal to rho va We have given the velocity and area to calculate it We have to calculate the specific volume We have explained the ideal gas for the specific volume and then we inserted the expression of idle gas and measured the data 78.8 kg per second Now the second part is to measure the temperature so for the temperature we have to first balance the energy so we are assuming that there is no energy loss in it Q dot is zero, W is zero, and of course delta P is zero. So this is just E in, E out. And normally these assumptions are that Q dot is equal to W dot, you can apply this in nozzle or diffuser. Because it is adiabatic. Let's consider it enclosed or insulated. Since the volume is not changing and external is not working, we can consider it. So, E in will be M.H1 plus V1 squared by 2 plus M.H2 plus is equal to M.H2 plus V2 squared by 2. As we said earlier. And since V2 is too much from V1, we will neglect V2. V2 is too less than V1, so we will neglect V2. So, this will be your h2 is equal to h1 plus v1 square by 2. So what is H1? H1 is given by your conditions here, 283. So H1 is here. If we interpolate it, linear interpolation, then H1 will come at 283 Kelvin. 283.14 comes out. and you know the velocity so you can insert the velocity so first notice that the velocity is 200 V1 is 200 mps So this unit will come here because we will insert here so this will come here H1 value will be in kilo joules per kg plus this value V1 square will be meter square per second square this will be meter square per second square right? so we have to convert this to kilo joules per kg so note that joules per kg Newton meter per kg This is your kg per meter square This is your Newton unit Then meter per kg So this is your meter This is cancelled This is meter square Therefore Kilo joules per kg is 1000 meter square per second square Now you have to use this The value of msqa per sec square is divided by 1000 which gives you kilo joules per kg So H2 is 283.14 kJ per kg plus 200 m2 of air pressure Square second multiplied by 1 by 1000 This is your kilo joules per kg And this is how the value comes out 303.14 kilo joules per kg Now 303 is in between this This means that its temperature will be somewhere here So you will have to do linear interpolation to get the temperature And this T2 will come 303 kilo joules per kg This is linear interpolation Okay, so I hope you know that there is no linear interpolation. So, we will try to explain it in some examples. I hope you understand how to use it. I have given an example of this in the test book. You can also see that. I hope you have understood how to use the diffuser in this case. You can also use the example of the nozzle in the same way. Except that you have to separate the conditions of the velocity. V2 will be more than V1 in the case of the nozzle. This was the diffuser. So, we considered the diffuser.

So, as we have studied about nozzles and diffusers, likewise, turbine, compressor, fan, all these are part of the devices in which steady flow is processed. Turbine usually drives to generate electrical. You will normally get this in steam, gas or hydroelectric power plants. In a device, when the fluid passes, it works against a blade that is connected to the shaft. And because it works against the blade, the shaft starts rotating and produces the work. And then the fluid comes out at low pressure. The compressor, like a pump or fan, increases the pressure. Normally, the compressor means compressing. This supplies the work through the external source and the rotating shaft is also in this. The work of the fan is that it increases the pressure a little. Usually, the fan mobilizes the gas and the pressure increases a little but not much. But the compressor increases the pressure a lot. Pump also works on the compressor, but it handles the liquid and the compressor uses more gas. We call it liquid because we can't pressurize the compressor too much. But the pump works on increasing the height and taking the high height from low height. It mainly works on liquid. The compressor simply pressurizes the compressor and tries to release the gas on the compressor. Every process of the device is different, and it is important to understand it. When you want to pump liquid, you will not use a pump. When you want to compress gas, you will use a compressor instead of a pump. Let's try to understand the energy balance of the compressor.

Nozzle and diffuser,

$$\dot{Q} = 0, \dot{W} = 0$$

$$\Delta Ke = 0$$

$$\frac{dE_{sys}}{dt} = 0$$

Compressor,

$$\dot{Q} \neq 0, \dot{W} \neq 0$$

$$\Delta Ke = 0, \Delta Pe = 0$$

$$\dot{E_{in}} - \dot{E_{out}} = \frac{dE_{sys}}{dt}$$

$$\dot{W_{in}} - \dot{Q_{in}} + \dot{m}\theta_{in} = \dot{W_{out}} - \dot{Q_{out}} + \dot{m}\theta_{out}$$

$$\dot{W_{in}} + \dot{m}h_1 = \dot{m}h_2$$

So, let's take this as an example. Here is your example. This is gas. Which is given by air. Inlet condition is this. This is your control volume. The flow rate given by air is mass 0.0 kg per second. mass flow rate will be constant in this process, heat loss is given Q out is given per unit mass assuming the change in the kinetic energy is negligible, delta k and delta p is zero so how much is the necessary power input? W in notice that temperature and pressure are increased in this case, the same will be applied that in this case, we will apply E in dot is equal to E out I'll use it again Win plus m dot h1 m dot h2 So Win is your power, so this will be your m dot h2-h1 m dot is already given, 0.02 kg per second But this is only till your heat loss is not there. Here is the heat loss, so the key out is given. So, for the key out, So, we have to put it here. So, this is done. keyout is also missed. So, this is your keyout. But what is your keyout? Your keyout is m. So, mH2H1 plus m dot keyout. Because this is per kg, the total mass flow rate is 0.02 kg per second. So, we multiplied it. Now you have to remove the edge of the If we consider air as an ideal gas, which is a condition that we can assume, because it is at a very high temperature and at a low pressure. It is a little higher, but still, we can assume, because it is still much less than your critical pressure. So, if air is an ideal gas, then we know that enthalpy depends only on temperature. So, we can give it a table. so we can give it here also so initial temperature is 280 Kelvin 280.13 is our enthalpy then final temperature is 400 I have not shown 400 table here but 400 table is given in A17 so according to A17 H1 at 280 Kelvin H2 at 280 Kelvin Air value is 280.13 kJ per kg 400.98 kJ per kg This is given in AA 17 Remember that H is a function of Hg for Idle Gas Hintalpi is for temperature treatment Hg for Idle Gas So you can plug in this value from the palm Do you know the mass? Why? so from this way your W will come which is power

0.02 kg per second and your 400 minus 280. 400.98 minus 280.13 this is your kilo joules per kg plus your Q dot, which is 16 kJ per kg so Win is 2.74 kW which is 1 kJ per second so you have to work this much 2.74 kW and take the pressure from 100 kPa to 600 kPa and in steady flow because of this the corresponding temperature becomes 400 Kelvin so because of this the final temperature also increases so you have to work this much in the compressor so here your 400 was given as 400.98 I hope you understood how to solve this problem. In the same way, we will move forward with throttling wall mixer, heater and heat exchanger. We will keep this project going. This application is very generic. You have to do basic fundamental energy balance. You have to understand the assumptions in that device. As we said, how the velocity changes. It won't make much difference in the divine. the pressure changes in the compressor. But in the case of nozzle and diffuser, the kinetic energy changes very fast. That is why the relation of the inlet and outlet velocity is different. So, you will simplify the equation and solve the problem according to it. So, I hope you have got some time. We will see this project in the next lecture. Till then, bye-bye.