Engineering Thermodynamics

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

Week-04
Lecture-20
Mass Energy Analysis of Control Volume

Welcome to part 2 of the Mass Energy Analysis of Control volume. In the previous lecture, we did mass analysis on control volume. In this lecture, we will do energy analysis on control volume. And we will try to understand it through some examples. One most important property that we will introduce A particular term is flow work. We will introduce it. Because it will be useful in control volume and energy analysis. We will try to understand it first. And how it is connected to enthalpy and how it is included in enthalpy. We will discuss about that first. This is called flow work.

So, let's start! If this is the control volume that you are seeing in the dash line, naturally when the fluid flows, some mass will come continuously and will flow out from here. If it is a steady state, then the mass of the control volume will be fixed, the energy will be fixed, and this part will continuously flow out. But to move it, to make it move continuously, we will have to push this mass. That's why it has an imaginary force. And this part, the work that we do to push the mass, or to push in or to push out, that means to put it inside the control column and to take it out, this work is called flow work. And sometimes it is also called flow energy. So, this is the part that from here and this work is taking the mass inside. So, this is before entering, the mass is before entering and this is after entering. And in the same way, this is in inlet condition, you can see it in outlet condition too. Now let's try to understand how to describe it. Suppose this mass is here, and in this amount of length, Push the piston to go inside the control volume. Imagine that this is a piston which is an imaginary piston which has force applied. So, the pressure applied to it has to be overcome by this. So, we have to work against it. If we move ahead with this concept, then we can remove this term. So, this is the pressure volume and this is the mass amount to be pushed. If we see this force, it is almost at a balance, at an instantaneous, I mean momentarily at a balance, so if this force is in mechanical equilibrium and we can push it slightly by giving a little more, then the value of this force will be the pressure times cross-sectional area. This is an imaginary piston. This is not an actual piston. To remove this term, we are assuming that the force applied against it, if we want to remove it, we have to understand how much pressure is applied to it. And the area of this is A. So how much force will be applied? A times pressure Now if we want to get this much length then we have to cover this much length and travel this much distance So how much total work will be done?

$$F = PA$$

$$W = FL$$

$$W = (PA)L = PV$$

So, pay attention, this is your flow work. This is also called flow energy. So, we can call it flow energy because it is in the energy unit. But if you look at it carefully, pay attention, this is pressure, this is also property. And this is your volume, this is also property. So, this is the work of two properties in combination. So, as I have already introduced, enthalpy is also a combination of two properties, like internal energy and PV. So, this part PV, we call it flow energy. or converted. Energy or Transport Energy. We need this much energy to transport the mask. Sometimes we call it Transport Energy. The commonly used term is Flow Work or Flow Energy. So, we will commonly call it Flow Work. Now notice that this PV Term If we look at the definition of Enthalpy, it is U plus PV. If it is specific. So, we can put this work in a specific work. If we divide it by mass, then W by mass is equal to PV by mass. And P is here, and this is your small w. So, this is the definition of H. You can also write like this. Normally when your flow works, we can write it in enthalpy. For example, if you see here, the internal energy is also connected to it. Now, PV and UB are there. And if you see with this, HB is there. So, by definition, HB will be there. But with H, you can add flow work too. H includes flow work. If you are using H as information, then flow work is part of H. It is your flow work inside H. We will try to understand this through examples. But we were looking at its definition first. What does flow work mean? Flow work simply means that your flow work is a PV term which is used to bring in or out the mass. So that's why the mass or flow in inlet and outlet is part of the property. And we usually represent it through enthalpy. We will try to understand it later using examples. Now talking about energy, what kind of energy can be included in it? As we have seen, if there is a system, it will have internal energy It will also have kinetic energy and potential energy So this is by definition that you will have this This is one that we have already read That will be U plus KE plus PE So if you take a simple compressible system gas, etc. Whatever fluid we are considering now So You have these three forms of energy Let's write it in per unit mass If we consider it in per unit mass, we can write E is equal to U plus small kE or P which will be V square by 2 and G of H. So this is your per unit mass energy of simple system. But if we are talking about flow, then we have to add additional energy with this energy. flow energy. This is the energy that is already in your system but the work that is happening on it will also have to be added for the total energy of the flow system. If it does not flow, then this energy is sufficient. This energy is your complete total energy. But because it is flowing, the flowing part of your fluid that is flowing, the flow of you will have to add additional workflow to it. So that will be your basic internal energy, kinetic energy and potential energy which is connected to your system. And apart from that, you will have a flow energy which is PV term. So as the statement is written, the fluid that goes inside the control arm and goes out, that is an additional energy. possesses flow energy. So, total energy is total energy by net mass of flow system of flow system of the flow, flowing fluid. PV plus E this small V is called specific volume plus E so we have to add this part with this E and this term is called theta we will represent the total energy per unit mass of flowing fluid as theta as we have said small e is the total energy of a compressible system which is not flowing, it is its energy this part and this is flowing So we are adding PV to E. Now pay attention to how we introduce enthalpy. How valuable is enthalpy as a term because it captures the flowing fluid. So, if we are writing PV plus E, then we expand it.

$$\theta = u + \left(\frac{v^2}{2}\right) + gz + pv$$

$$\theta = u + pv + \left(\frac{v^2}{2}\right) + gz = h + \left(\frac{v^2}{2}\right) + gz$$

$$non\ flowing\ fluid\ e = u + \left(\frac{v^2}{2}\right) + gz$$

$$flowing\ fluid\ \theta = u + pv + \left(\frac{v^2}{2}\right) + gz = h + \left(\frac{v^2}{2}\right) + gz$$

Its unit and other things are all the same. We have written the symbol in the form of theta. So, enthalpy itself This thing considers flow work and flow energy. That's why its main purpose was to introduce it in the thermodynamic system of enthalpy. Because it can capture the energy of flow fluid. It can include flow work. That's why its main purpose was. So, in engineering thermodynamics. Let's move ahead. So, this is your summary. If it is a non-flowing fluid. So, your energy is E per unit mass. In this, your total internal energy is done. Kinetic energy is done. Potential energy is done. And if your flow is fluid, then this is your flow work. This is your internal energy. So, this is your part, enthalpy. And this is your kinetic energy and potential energy. So, this is your summary of the total energy of the flowing fluid. If you see the presentation, we have written it in the form of a PV. Now we do similar exercises. The question is how much will be the total energy transport? By mass, how much energy is mass transporting? Through the inlet or through the outlet. How much energy does it bring to the control volume and how much energy does it take? To understand this, we will write mass and if it is in the rate form, then it is mass dot. And we are introducing theta now because now we represent theta as the total energy of flowing fluid per unit mass. As we said, what is theta? Theta is the total energy of the flowing fluid. So, total energy is 5 minutes. If you want to get the total energy, you can do it from M to 30 Tau. Now The important thing is that if it is in rate form Then if your unit changes, then you have to put m. in rate form m theta will be in rate form rate of energy transfer. Theta is equal to H plus V square by 2 plus g of z of the system. If we consider kinetic energy and potential energy as negligible, Z is negligible in reference to its enthalpy. So, we can also call your E mass. and we can call it as E mass will be simply mH and E mass will be mH which neglects kinetic energy and potential energy but sometimes, if the mass here if it is varying from time, you will face problems because you are considering it as M constant. If time varying is there, then you will have to do summation in small elements according to any particular reference, t0 to t time or from small m0 to m. So, in such a situation If the mass is changing the input time So suppose we talk about the inlet, then the mass will be fixed, but the energy property is fixed. But if the mass is changing, then it becomes dmi and you will integrate it on mi. So, we will always go with a basic concept. And whenever changes come from this way, we call it the first principle, that you understand the basic definition before applying the formula directly. What are the conditions? And according to that, if you start with the basic definition, you can get new expressions if conditions and the formulation is made separately. But we have simplified our problem statements. We are not complicating them. The main purpose is to understand that sometimes we take assumptions, sometimes we assume. And if there are some changes in the statement, like we said that if the mass is changing, then we will consider it. Otherwise, more or less, what will happen in most of the problems is that you must have been given a fix about the mass. for example, or the mass is not changing. Let's move forward with this discussion. So far, we have talked about generic energy transport. We introduced theta, why did we introduce it? Because we wanted to get the energy of flowing fluid. For that we introduced flow work. And then we told how enthalpy becomes important in flowing fluid. In normal stationary fluid, in non-flowing fluid, you have internal energy plus kinetic energy plus potential energy. But in flowing fluid, you have enthalpy plus kinetic energy plus potential energy. Now let's talk about steady state. Steady flow devices are used a lot in our engineering applications. Usually, your initial unsteady state time domain will be you stabilize any device and then the steady state operation starts. In such cases, steady flow occurs. In such cases, if you have considered the control volume, like if this dash line is represented here, then the mass of it will remain constant throughout because the mass that is coming is going because there is steady flow. Because of this, the energy of the control volume will also be constant. Because the mass energy that is coming is the same mass energy that is going. Unless you are told in a proper way. So normally in a steady flow system, we call energy and mass constant. Now, since it is steady, mass will also be balanced. So, as we said, this mass is mi in is equal to mi out.

$$E_{in} - E_{out} = \Delta E_{SYS(CV)} = \Delta E_{CV}$$

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

$$E_{in} = E_{out}$$

So,

$$Q_{in} + W_{in} + \sum_{in} m\theta = Q_{out} + W_{out} + \sum_{out} m\theta \ldots\ldots.. at\ stedy\ state$$

$$\theta = h + \left(\frac{v^2}{2}\right) + gz$$

$$Q_{in} + W_{in} + \sum_{in} m\theta = Q_{out} + W_{out} + \sum_{out} m\theta$$

$$(Q_{in} - Q_{out}) - (W_{out} - W_{in}) = \sum_{out} m\theta - \sum_{in} m\theta$$

For single stream,

$$\dot{Q} - \dot{W} = \dot{m}\,(\theta_2 - \theta_1)$$

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

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) + (\left(\frac{{v_2}^2}{2}\right) - \left(\frac{{v_1}^2}{2}\right)) + g(z_2 - z_1)$$

$$\Delta K.E. = 0\ and\ \Delta P.E. = 0$$

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1)$$

So, in this we have the small unit, net energy in. So, the heat will reduce the net work out and change in enthalpy. So, this is the total energy balance we did in the steady flow devices. This is very commonly used. because of the steady flow, the volume is not changing so the question is what forms can be formed because boundary work is not done, because the volume is not changing so what forms are there? there are two types of mainly used one is shaft work which is done by turbines and other devices The devices that it uses are Turbine, compressor or pump ok in all these devices your work is shaft work and electrical work like your electrical work will be used in heater so in water heater water heater is an example so this work water heater electrical work will come in water heater and turbine compressor pump will come in shaft so this work this work this work is kind of other work because the mass we are bringing that work is already captured in Dharpi and that work is included in Dharpi The work that is already included in enthalpy is flow work, which is to bring the mass into the control volume. So, this particular work, because boundary work is not included, because it is a control steady flow device, so your boundary work will not be there. And flow work will not be there because it is in enthalpy. So, what is said in other work? It is shaft work and electrical work. And if we talk about the Q key, then Q is your normal hit in or out. So, there are not many examples of any difference. So, this was the last part. In this particular lecture, we tried to understand the energy balance flow device. We derived it and we understood how Enthalpy is introduced. And we hope that when we do many examples, you will understand its value. And we also understood what W means in this. when you do steady flow, it is related to other works because other works are already whether they are included in enthalpy or bond to work for example it will remain zero because your flow the system, your control volume in steady flow, mass is fixed, energy is fixed, so there will be no changes. I hope you understood this, and we will move forward in the next lecture and will try to understand some common devices. Till then discuss new topics.