**Concepts of Thermodynamics**
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**Lecture - 22**
# First Law for Steady State Steady Flow (SSSF) Process

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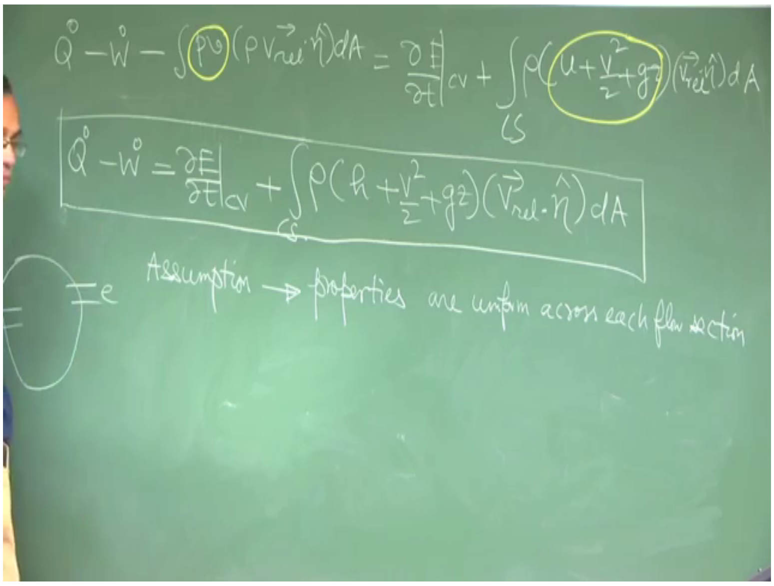

In the previous lecture, we were discussing about writing an expression for the First Law of Thermodynamics for a flow process taking place across a control volume. So, when we were doing all that this is the final expression that we arrived at before we called it a day for the previous lecture.

So, this is the heat transfer, this is the work done rate of heat transfer, rate of work done, this is the rate of change with respect to control volume and this is basically the outflow minus in flow term.

Now, we make certain assumptions properties are uniform across each flow section. So, if you have for example or control volume with this is outflow inflow and this is outflow, then the properties are uniform across each flow section.

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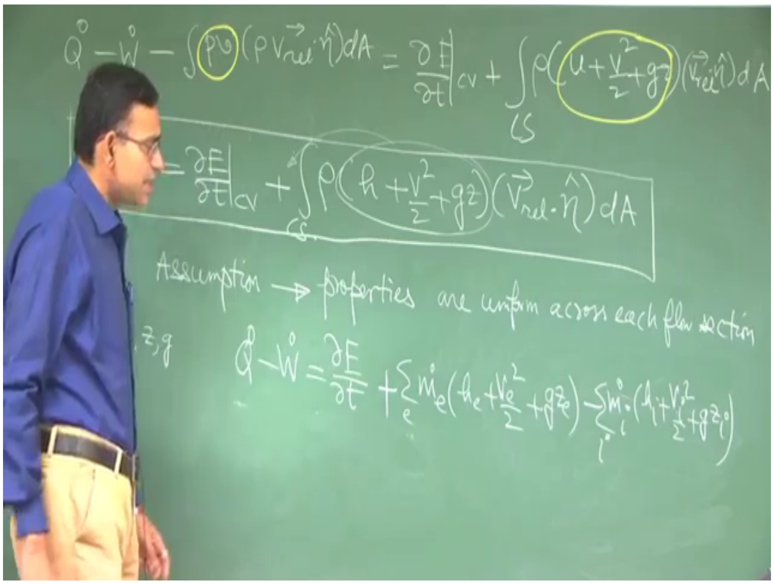


By that what we mean? By that what we mean is that at the outflow or inflow for example h v z all these things or even g, all these parameters these do not vary over the area A. So, if you have this area A, then across this area this properties do not vary. So, if this property do not vary across this area, then this can be taken out of the integral if it is not varying over the area. So, then within the integral you have integral rho v relative dot eta d A. What is that? That is nothing, but the mass flow rate.

So, we can write Q dot minus W dot. Why this is plus and this is minus? Because according to our algebraic calculation, this will come out to be positive for outflow and this will come out to be negative for inflow. We can write a summation over all exit areas and summation over all inlet areas by noting that there can be more than one inflow and there can be more than one outflow, ok. So, this is pretty much the rate equation for the first law of thermodynamics across a control volume assumption. One major assumption that all properties are uniform over the respective sections; based on this background we will now learn a very important type of process which is called as Steady State Steady Flow Process.

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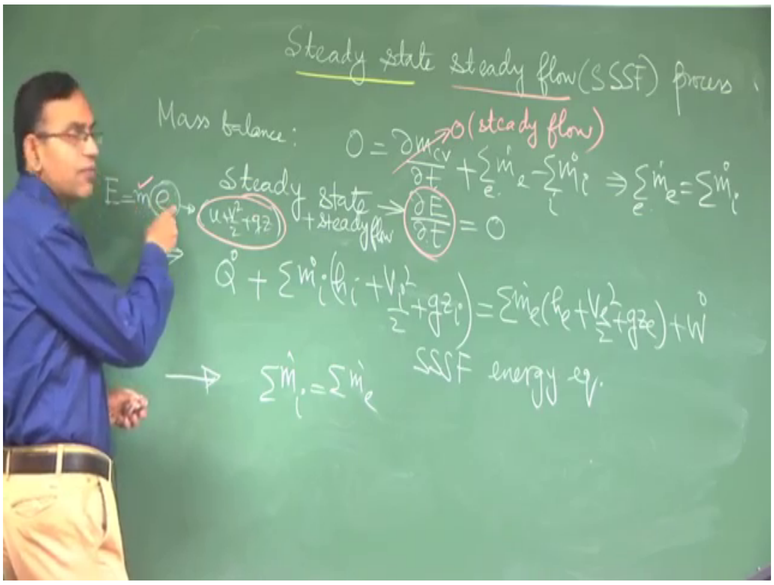


So, first of all you see there are two keywords here. One is steady state I mean coupled keywords; another is steady flow. We will come to the steady flow first. So, let us write the mass balance. So, from the Reynolds Transport Theorem if there are multiple inlets and exits, then it is summation just like this, ok. So, steady flow means that this is equal to 0 ok. So, study means what? At a given location the velocity and fluid properties they do not change with time.

So, at a given location if the fluid properties do not change with time; that means at a given location density also does not change with time. If density at a given location does not change with time, then mass within the control volume does not change with time, right. Therefore, this is 0 for steady flow. So, physically what it means? Physically steady flow is very intuitive. There is a device or say pipe as an example. The rate at which the water is entering is the same rate at which water is leaving. So, that is steady flow.

So, steady flow will essentially mean then comes Steady State. So, for steady state we refer to this energy balance and steady state means that within the control volume, the state, the energy state does not change with time. So, E within the control volume it is the energy, the state of energy within the control volume, that state does not change with time. So, at now you may immediately ask what is the difference between steady state and steady flow, we could have coupled both together and said that it is simply either steady state or steady flow. So, we want to mean something which is very settled here.

What is that settled, what is the energy? Energy is mass into the specific energy. So, this includes the specific properties like say u plus b square by 2 plus g z like that.

So, even if these properties are not changing with time, but mass is changing with time then you can have this term not equal to 0 despite property is not changing with time, right. So, let me elaborate this again. I will give it because this is where books do not right thing that explicitly. So, when you right E, it is a product of mass into the specific property even if the specific properties do not change with time, but mass changes with time, then you will have E change with time. On the other hand, if mass changes with time and E changes with time, but product of m into e does not change with time, then you could have capital E not changing with time. So, you could have an unsteady flow with steady state or unsteady state with steady flow. So, steady state steady flow combination essentially means that both the unsteady terms are 0 both in mass conservation as well as in energy conservation.

So, sometimes you know this is very confusing. There are many books which tends to simplify things and in the process of simplification, they have omitted steady state steady flow process and they just right steady flow energy equation. So, when they right steady flow energy equation essentially what they mean is that this term is 0, but they also have to keep in mind that in this term there is one component which is mass, another component that is specific energy and mass flow is coupled with another term for. So, energy balance is not energy balance just in an isolated manner, energy balance for a control volume has to be coupled with mass balance.

So, energy balance cannot be written in such a way that it violates the mass balances. Therefore, what many books commonly write as steady flow energy equation that should be better termed as steady state steady flow energy equation, where the two terms steady state and steady flow are taken care of by setting this and this equal to 0 in the energy equation and in the mass conservation equation.

So, when you have steady state this is equal to 0 and then, so this is a combined consequence of steady state and steady flow. Why? So, which this term is 0 because this product somehow has not changed. So, one very standard case is the product has not changed is because m has not changed and small e has not changed. So, small e has not changed the steady state and m has not changed is steady flow. So, the combination m into e has not changed is steady state steady flow, but one can argue the example that I had just given that m might change and e might change, but product of m into e also does not change.

So, for example m has decreased, e has increased, but product of m into e has remained constant. That is very hypothetical. That will not normally occur even it is if it has occurred although it is not individually steady state and steady flow. Its combination is like steady state steady flow. So, steady state steady flow is essentially to make sure that this term is 0. So, this term is 0 for the most common case when m does not change with time and individual properties do not change with time. So, then product of m into individual properties that does not change with time, m does not change with time is steady flow property does not change with time is steady state. So, product of m into property does not change with time, this one is steady state plus steady flow. The only exception is that it might be unsteady state unsteady flow, but the product of properties remains the same, but that is very hypothetical rather than practical.

So, when you have steady state steady flow, you can write q dot. So, this also called as steady state steady flow energy equation coupled with that there is a mass balance for steady flow which is. So, when you couple these two, then the possibility that m changes and e changes, but product of m into e is constant is no more the case because when you are writing this you are ensuring that m within the control volume does not change. Therefore, small e with in the control volume also will not change to make sure that this term is 0, ok.

So, now can you tell what are the assumptions behind this? So, the assumptions behind this first of all properties are uniform over the respective cross-sections over which there is flow properties are uniform. So, if properties are uniform, then you can you know right this h i. So, when we are writing h at the inlet, you can argue that inlet is a collection of large number of points, but at all the points we are assuming the same h same v same z like that. Similarly at the exit same h same v same z, then the other assumptions are steady flow and steady state. What is meaning of steady flow? There is no change of mass within the control volume that is the total weight of inflow is same as the total rate of out flow. What is the meaning of steady state? The state associated with the control volume that is small e, the energy state associated with the control volume that does not change with time.

So, let me now ask you a little bit twisted question. What happens when it is steady state, but not steady flow? When it is steady state, but not steady flow this equation is not valid. The reason is when it is steady state but not steady flow, these does not change with time, but these changes with time. Therefore, e within the control volume will not change with time will change with time, then what happens if it is not steady flow, but steady state when it is not steady flow, but steady state. This equation will not be valid and even this equation will not also not be valid because not steady state and steady flow means if m is sorry not steady flow. But steady state means m is not the same, but e is the same. So, the product of m into e will be different.

So, the key out of all this discussions the take off message is product of m and e small e whether individually m is remaining same or not is important, whether individually small e is remaining same or not is important and if these two individually remain the same, their products their product remains the same which is more important and because that is what is omitted here.

So, to summarise these two equations have the following assumptions. What assumption? Steady flow this one steady state combine with steady flow, this term is 0 and all properties are uniform over their respective sections. So, with this little bit of introduction we come to the final working forms of the equation which we intend to use for many practical devices for engineering applications because many practical engineering devices are essentially steady state steady flow devices that is devices across which mass flow rate in flow same as out flow rate and there is no energy accumulation within the control volume.

So, the rate at which energy is transferred is into the system is same as the rate at which energy leaves the system. No energy is accumulated within the system. So, I will start with a very common example in engineering which is called as Throttling process before we take up any concrete example.

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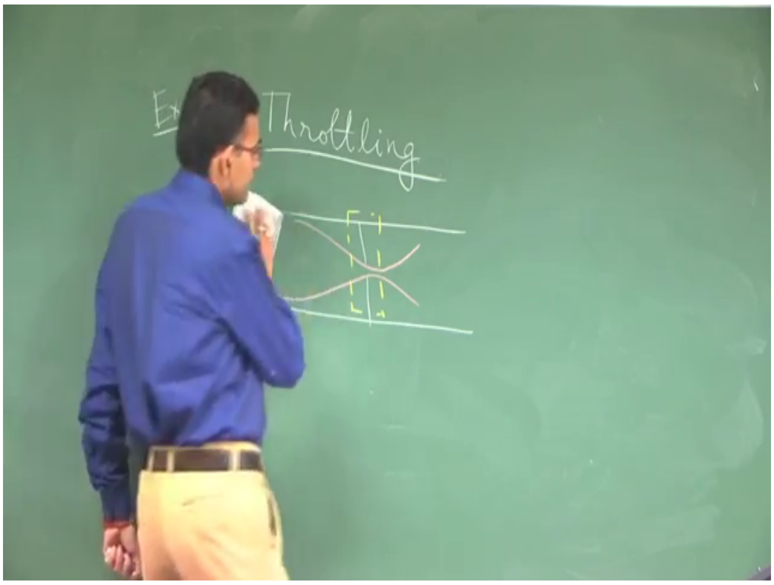


So, throttling is a process which is something like this. So, it can take place across different types of valves in a pipeline. So, you have a pipeline like this, there is a constriction suddenly. So, this will make sure that the fluid in terms of fluid flow the streamlines are constrained, then the streamlines expand again. I am not getting into the fluid mechanics details here. Of course, when the streamlines are constrained, they will come to a minimum separation distance and then, they will again burst out, but the fact is that that there is a sudden blockage in the flow that is what is most important.

So, this could take place not just by this geometry, but by various other geometries which puts a constraint to the flow area available. So, to do that, we will consider a control volume.

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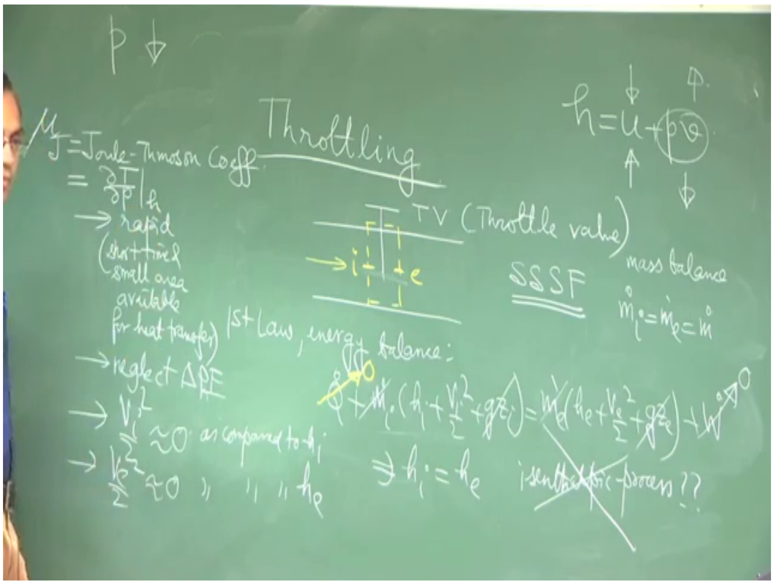


So, imagine that instead of this kind of physical situation we have a valve which we called as Throttle valve. So, these valves is operated by a screw or something like this and that is why this kind of a figure and it can come up and down. When it is screwed like this, it will come down and it will constrict the flow passage just in the way in which I do the previous figure.

So, now we take a control volume where i is the inlet and e is the exit fluid is coming in like this. So, there is one inlet and one exit. Let us assume that this is a steady state steady flow process, this is the assumption and this assumption very close to what happens in practice. So, you have m dot i is equal to m dot e is equal to m dot. So, this is mass balance, then first law energy balance. So, q dot c v oh sorry q dot m plus m dot i h i plus v i square by 2 plus g z i.

When you solve any problem in thermodynamics, you start with an appropriate expression for that particular appropriate law of thermodynamics which you are using to solve the problem. So, we start with this equation. The first assumption is that you know this is a very rapid process. So, if it is rapid then the time available for heat transfer as well as the area available also for heat transfer, both are very small. So, very short time and small area available for heat transfer if that be the case, then you can assume the process to be adiabatic that is heat transfer equal to 0, you can neglect the change in potential energy straight away, so that these two are almost the same even if it is a vertical pipe.

These two sections are so close to each other that you know the difference in z is very small that is the speed also you have what done equal to 0 is not an assumption. This is a reality. So, there is the difference between assumption and reality is that assumption may be very close to reality, but it is an approximation of the reality and reality is it is the exactness. So, adiabatic is not a reality it is an assumption, but work done equal to 0 is a reality here. You have no mechanism by which you can extract work and also you have m dot i is equal to m dot e. The 3rd assumption is that you have v i square by 2 is tending to 0.

So, the kinetic energy, so you can argue that fluid is coming in sometimes the flow is turbulent and then, you are claiming that kinetic energy is 0 is it not a paradox. You have to apply a maturity to understand it is not this as 0. What it says is that this is negligible as compared to thermal energy. So, if you compare the enthalpy with the kinetic energy, so this is a problem where you have maybe a hot fluid or a cold fluid with sufficient thermal energy coming in. So, that part of the energy is much greater than the kinetic energy contribution.

So, this is negligible as compared to h I. This is not a bad assumption. What is a little bit more restrictive assumption is that we also neglect the kinetic energy at e as compared to h e. Can you tell out of v i square by 2 and v e square by 2 which one is more? See because of the restriction in the flow area, the product of flow area into velocity for incompressible flow that is what is remaining constant. So, if you reduce the area if you reduce the area from this much to this much to maintain the same mass flow rate, the velocity will increase right because area into velocity will remain the same assume rho as constant. So, although this is may be much smaller as compared to this, this may become significant, so that you do not know this maybe you know not that much negligible as compared to h e, but we also make an assumption and that assumption is valid for most of the practical processes that v square by 2 is negligible as compared to h e.

So, remember that this is not a very restrictive assumption, but this is little bit more restrictive, but this is you know obeyed in practice, so that for practical throttling processes you have h i equal to h e [vvocalized-noise. So, sometimes in books and in other places this is written as isenthalpic process. I put a question mark here because we will critically analyse whether it is an isenthalpic process or not. So, ise English wise ise means same, enthalpic means enthalpy remain same. So, thermodynamically this means that it is a constant enthalpy process, but now you see the enthalpy at i is same as enthalpy at e approximately with all these assumptions, but where is the guarantee that the enthalpy has remained everywhere same in between. No guarantee.

So, what it is inferring is that the enthalpy before throttling is same as enthalpy after throttling, but that does not mean that enthalpy has remained constant throughout the process and therefore, this isenthalpic process is not correct. Please keep this thing in mind because this is a very common conceptual mistake made by students that throttling is considered to be an isenthalpic process. Isenthalpic would have meant that enthalpy during the entire process would have remain the same. Here that is not the case. It, simply says that under these assumptions enthalpy before throttling is same as enthalpy after throttling.

Now, what happens to temperature what happens to pressure in this process? So, across this valve there is a pressure drop. So, as a consequence of the throttling the pressure decreases. So, does the temperature increase or decrease there are several possibilities temperature may increase, temperature may decrease or temperature may remain constant why see what has not changed before and after throttling is h is equal to u plus p v, right.

So, h has not changed. If p v has increased, then u will decrease. If p v has decreased, then u will increase. You really do not have a separate control over p v. There if p v has increased u, will decrease. If p v has decreased, u will increase. If p v have not changed, u will not change. So, three possibilities are there u may increase, decrease or remain constant and u being a good representative of temperature, it is there for intuitive that t might increase, decrease or remain constant. So, what will signify whether t will increase, decrease or remain constant that is signified by a property called as Joule Thomson coefficient mu j

So, this is defined as partial derivative of temperature with respect to pressure at the same h. So, here h is the same. So, if mu j is positive I am erasing the assumptions from here.

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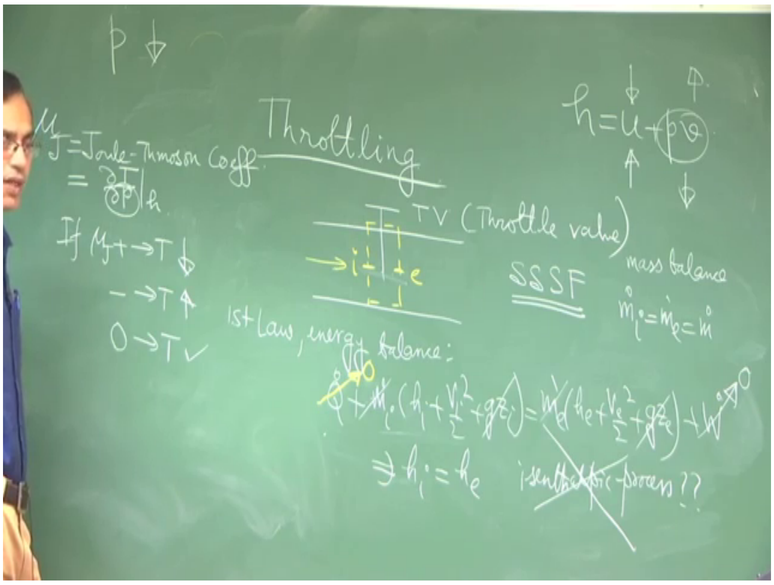


So, if mu j is positive, then temperature decreases because pressure always decrease across the throttle valve. If mu j is negative, then temperature increases and if mu j is 0, then temperature remains the same. We will show later on in one of the chapters that mu j is equal to 0 for an ideal gas and for an ideal gas therefore this corresponds to a situation where temperature before throttling is same as the temperature after throttling.

So, to summarise in today's lecture we have discussed about a special type of process across a control volume called as steady state steady flow process. We have given throttling as a very practical example. This kind of example is very common in industries, also in refrigerators and we will see later on several other practical engineering examples concerning the use of the concept of steady state steady flow processes and these devices in engineering devices are called as steady state steady flow devices, we will take up that in the next lecture.

Thank you.