Engineering Thermodynamics
Prof. S. R. Kale
Department of Mechanical Engineering
Indian Institute Technology, Delhi

Lecture – 02
Thermodynamic Concepts: System definition. Heat. Work. Mass flow

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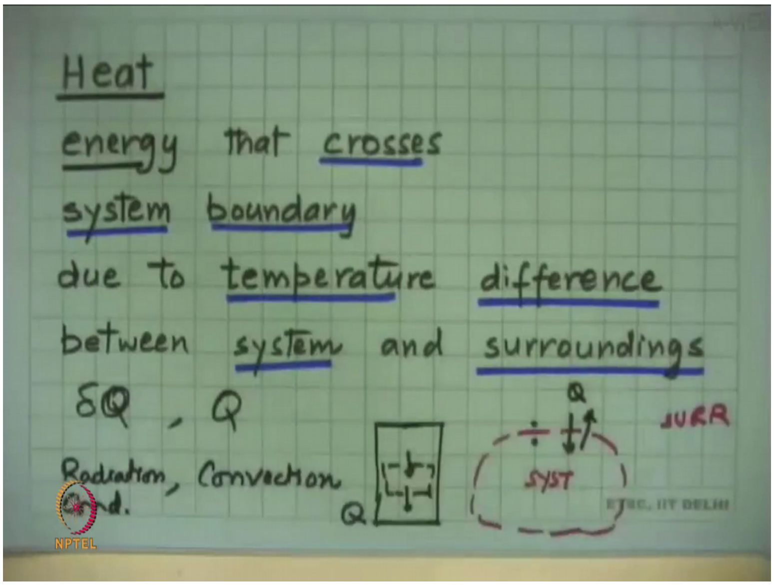

Then what is the basis of analysis and to get you an idea of why it is important to do, what we are doing in this module, which is concepts and definitions I have just put up the thermodynamic definition of heat. Why? For what we are looking at is whether it was power generation, whether it is aircraft engine, whether it is a diesel engine or solar thermal somewhere where this word heat coming in. So, let us see: what is the definition of heat when it comes to thermodynamics.

This is a very fundamental and a very very important thing and one needs to be very clear about it I have listed this here that heat is that form of energy if that crosses a system boundary due to a temperature difference between system and surroundings. And the symbol is either delta Q or Q and it is immediately tells you that only one that I underlined what is they mean. What is the system, what is the system boundary, what do we mean by temperature difference between system and surroundings, what is surroundings and what do we mean by crossing.

So, we first need to develop these concepts only then we can appreciate what heat is. The second thing that we get to is that thermo dynamics is relation between heat and work. So, while we define heat there let us see: what is the definition of work.

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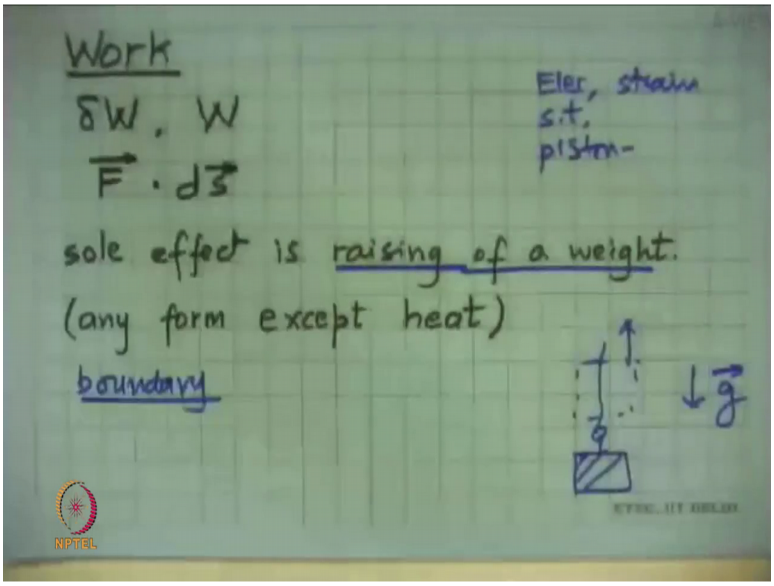

And, this could be called a directly what we get in mechanics as the vector product of the force into a small displacement between the, that much work. In thermo dynamics you will find a definition which says that work is seen at a system boundary, which are the sole effect of raising the weight. That means, we are assuming rising of a weight means we are in a gravity environment we are not in a micro gravity environment that is in a gravity. And that raising of a weight means that there is a weight over there and we have connected it to something and something is lifting it up and brings the weight over there in this process we are assuming that the gravity that is downwards. So, this is the only effect that happens at the system boundary then it is work.

So, this is again happening at the boundary and there are many other forms of work, but easiest thing to say what is work and what is heat is that if energy transfer across the system boundary is by any means others than by heat then it is work. So, this could mean that you are pulling a rubber band that is work; electric power that is work because we can then run a electric motor with it and do this lifting this is what happens in the lift. So, electricity is the form of work.

Then you have stress or strain energy like we are in a strain or a rubber being pulled or a tiring being compressed and expanded all the time then it moves or surface tension extracted a film of something being pulled or as happens in a reciprocating engine or a compressor of piston which is moving inside the cylinder. So, these are all cases which are associated with work.

So, before we proceed further we first get some clarity on systems, system boundary and surroundings. So, system is very simply that portion that we demark it for our analysis.

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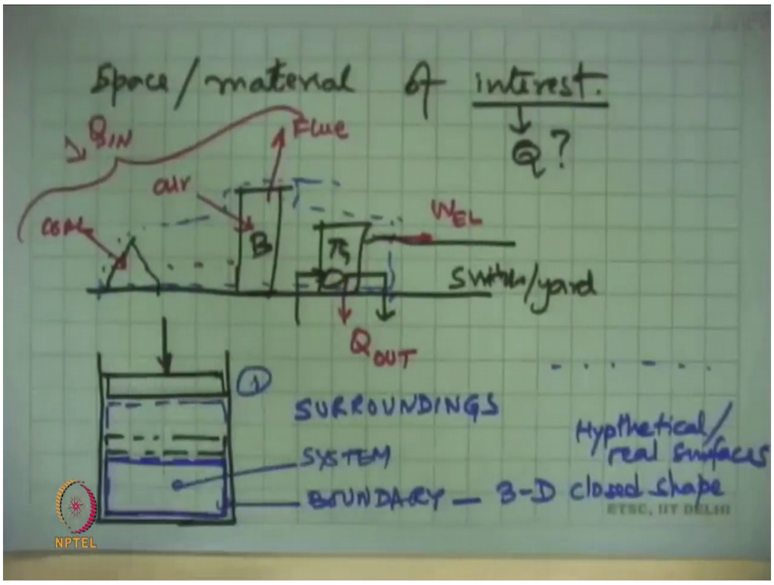

So, what we can say is a space or a material that is of interest to us. So, it is a very simple definition and we are fully free to define a system boundary whichever where we want to do it. Interest means if you are asking certain question or you want to know something about it then you say I want to know about that. So, I must take that as my system. I do not want something whose about whom I not interested to be a part of the system and one can do this at a large number of levels.

The picture of a thermal power plant that you just saw we can say that well here is a thermal power plant in which I saw some pole and then there was a building which was the boiler. And, then there we saw as a turbine and energy generator and then on this side we had wires coming out and we saw the switch yard.

And say it is a work. So, I want to analyze the power plant itself that is a total entity then we will define this entire system say this is my system and then we say that what is happening in this power plant. And, then the things become clear that yes, what happened here for that coal went in railway (Refer Time: 06:26) and it work coal into it and connected over here and then we connected in to the boiler, boiler will burnt it and for burning we need a air.

So, we got air into it and then after burning we through the flue gases out, flue gas is nothing, but the term for exhaust gases which is the combustion products that covered up a boiler. And, we got work out as the form of electricity and what you have not shown here is that there is a condenser in to which we pump in water and warm water goes out. So, together in this we rejected heat in cooling water. So, these three entities together became how much heat went in and this is heat out of the system. So, that is one example of a system boundary.

The cylinder piston arrangement we will see that in many problems all the time say that this is just the cylinder and say there is a piston which has got is moving in it and it is completely leak proof in practical thing that is an idealization only. And we I want to study how much work I need to do on the piston and I need to push this how much work do I need to so that it comes and moves into this position.

So, here our initial system would be say look I want to know what is happening inside the piston so, there was some gas in it when the piston was here we say that my system boundary is this. It is just adjacent to the walls from the cylinder, but does not include the cylinder of the piston material and it is such that it includes all the gas which is contained in this device.

When it gets compressed the system boundary comes over here and we now have this system. What happened? The system changed its shape, the system changed its size that is ok. So, that is another example and what we do is when we have define this we say that this is the material of interest you need. So, this is the system everything and then this thing is the system boundary and everything else outside the system boundary is the surroundings.

So, we got three important things coming out here that we define the boundary and what is the boundary this is actually a 3-dimensional closed shape and this could be real or hypothetical surfaces and is the picture does not convey the full meaning, it is we can always write down the few words and say the system contains this and it does not contain this. So, we have the see to write that. So, we are absolutely clear what is in it, what is not in it.

This is a first step in analyzing anything and we take a few more examples to illustrate this point. This is not this is related to thermodynamics, but to many other things as well.

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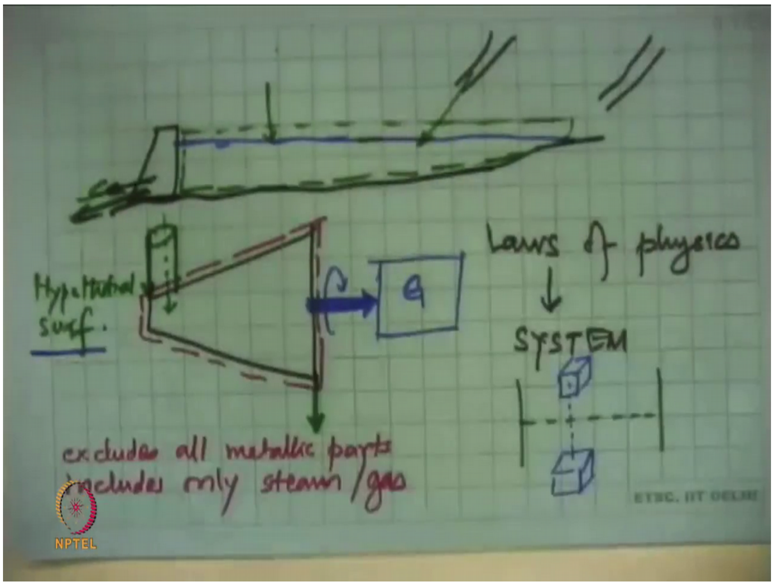

Say we will take a hydro electric system we have build a dam and this is the ground and there are various rivers coming into this and water being let out of the dam or being put out by the hydrogen electrons. So, that is the level in the river and right now everybody is monitoring the progress of the monsoon. So, everybodys first thing is how are our reservoirs doing (Refer Time: 11:16) any such information in the newspapers and say look what is happening in my reservoir that is well I will take my reservoir as my system and I define the system boundary like this and rainfall is coming that is falling into it rivers are draining into it that is and what will going out is here and here.

So, with that we can then do a balance on this and say with this level go up or level go down. So, that is a analysis that one does and this is pretty much similar to the analysis that you would do which are own bank account; there are how much money in that put, how much balance we have how many how much have I explained it.

So, the system and it this way its analysis you have to clearly define what is it that we want to study, what is included in it, what is not included in it. And, then we can proceed to do all the other things that we will learn in the next modules answering the different questions related to the performances of the system. So, this is what also means is when we show the system boundary you need to make a sketch; sketch does not have to be a very very good thing is that make a free hand sketch say look this is what it is. And, the picture shows you actually convey some sense of what that device is all about.

Some typical pictures that are symbols that are used the turbines that we saw in those photographs are shown with this picture, this is the symbol because steam goes in at one side expands and gets bigger whether it is over gas turbine or the steam turbine the same thing happens there and what happens in this is that we are steam or gas entering over there and the steam or gas exhausting there at a lower pressure and the lower temperature. And, you say look I need to analyze this system, I want to know how much power it produce. So, when this turbine the water got power and it produce work which came out from the shaft as work out.

So, if you want to analyze this we want to write the various laws for it and then put properties on it and then do a calculation. The first thing is which says what is my system that I want to study and what one can do is that look this is my system boundary and this system boundary includes the complete turbine PC the photograph that you saw, but excludes all the metal inside the turbine. So, my working so, only thing in my system includes is steam. So, we say here system is this, but excludes all metallic parts.

And, includes only the working substance in it weight remove is in the steel turbine it could be steam or if it is a gas turbine the evaluation engine that you saw that would be gas. So now, it become very clear that look what is it that I am doing whose properties do I need which laws do I need to apply then becomes clear. The need for system arises from very very fundamental thing about all study. If that the laws of nature say laws of physics which could be the laws of thermodynamics, the laws of motion, electromagnetics all the laws are applicable only to a system. If you are not clear what the system is we are very likely to be make mistakes in applying the law and get some fairly erroneous results.

So, this is a very very crucial thing both on the requirement here as well as a scientific requirement that one can apply a laws of physics only to a well defined system when you say what is in it and what is not in it. So, that of the first part about system, system boundary and the surroundings. So, the system boundary we show by dotted lines as I shown here or here. We write on what is in, what is not in then the question is what happens to the system here and here.

So, what is happening here? In reality there is a pipe and there is a pipe connected here through which something is moving and entering the system boundary. So, this is a bulk material steam or gas or say even water. This is moving and we made a system boundary here which is a hypothetical surface the surface which cuts the pipe, but really there is no surface inside the pipe. So, is an imaginary surface that we have created and across that we have seen things moving through in and forth.

So, it is like saying that this is my hypothetical surface, this is my pipe and through this whatever if the substance that was throwing that has move. So, this was a little of or say the steam or the gas this element moved in and cross this thing and came to be here. So, that is the hypothetical surface at this point whatever the work output. This is a solid shaft metal in shaft which is turning and calling a torque to work against the magnetic fuel in the generator. So, this is the generator.

So, it now done the same thing, but instead of for hypothetical surface in a gas we are now going to say I am going to have a hypothetical surface which cuts the shaft at this point. So, it is a imaginary surface across which you can then see this particular part turning and producing a torque. So, there again we have a hypothetical surface there and that completes the 3-dimensional rows system. We are not showing the other two dimensions in this much too complicated, but suppose I say that what we mean is that this is a completely a axis symmetric machine and we have put our system boundary all around that machine, ok. So, now how what happens if it do not follow this?

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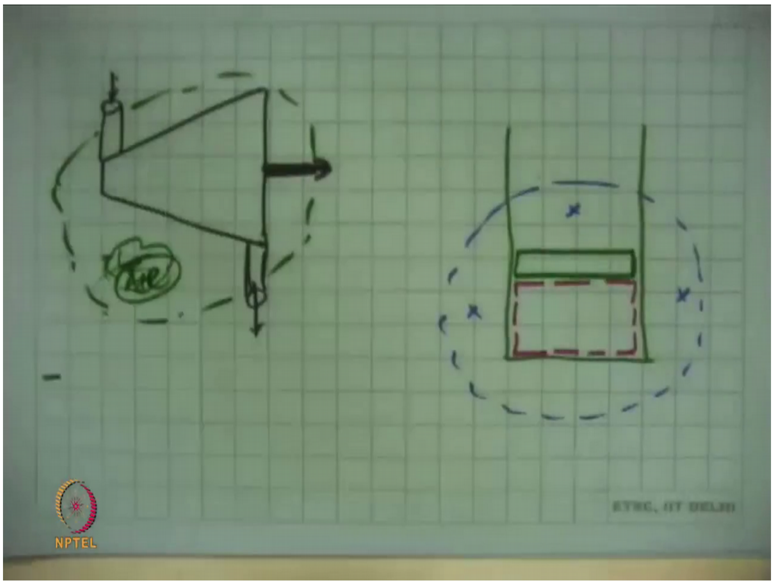

We take the same example or say the turbine, there is power there is steam or gas going in and steam or gas coming out. So, what I explained here about going into the system element if it is moving out same thing we did out of the system you have a minute we will come back and re look at this again. So, this is now say look I want to understand what the steam is going in and how much power it is producing or the gas how much of the gas is taking and what much it produces the electricity from that.

Somebody says fine I need to draw the system boundary I will make a system boundary and I make the system boundary. So, problem is you have unnecessary conveyed the meaning which does not intuitively say that look I am looking at the steam inside this steam turbine or the gas inside the gas turbine. This depiction shows that this material over here is also included in the system and what is this material? This is the surrounding air and what is this metal is there.

So, we have to now write that it excludes not only the metal, but also excludes all the air around it all that we have done is we have added unnecessary complication to this. So, it is best practice that we be very tight in defining what the system boundary is and avoid such a thing; same thing with the cylinder piston arrangement, because this will keep coming back in the work many times. If the piston is here and you want to study what is happening to this and somebody draws a system boundary which is like that again the same problem.

We want to know what happens inside here just let us restrict to that only and not worry about this air or this air or something over there. These are of no use to us we do not want to study that. So, we go back and select the right system for this is this one and system boundary we always will show by dash lines and what this dash line makes it is that this boundary is right of the real surface or a hypothetical surface just a few nanometres outside the surface does not include the surface, but includes every molecule which is there inside the system. That is how it is.

So, this is that depiction of the system boundary the next thing we will do is something we look at in this example of the turbine ok. But, before that let us go back and say look what did we write about the definition of heat that form of energy that crosses system boundary due to temperature deference between the system in the surroundings. So, now we know that I am defined my system based on what I am interested in; we made a boundary, we showed a symbolic way, what the boundary is what is included in the system what is not included in the system. So, that give us clarity on what is surroundings.

So, now we are clear that these words I have understood. The question is now what do we mean by temperature difference. So, here now that we know that there is a system boundary what we can say is if this is a system boundary and this going in general for something this is the system, this is the surroundings then if there is some temperature here and a different temperature over there energy transfer takes place over there that you see it. And, that we will denote as crossing the system boundary and call it Q or delta Q. We are not worried: what is a mode by which this heat transfer takes place. It can be radiation, which does not require medium which means that say like the solar vectors we make the solar crater or a system boundary then sun light enters that system and it radiates.

It could be convection say you have a hot material sitting in the table and it is losing heat to the surrounding air the air is coming and flowing fast heat and by combination of conduction and conjunction in the air energy is transported across the system boundary that is also happen. Or it could be by conduction, for instance we are we have a large body and you say I want to know what happens in this part of the body. So, this is the system boundary and there is conduction taking place may be there and there. So, that is also Q.

So, these are the only three ways in which if energy transfer takes place across the system boundary we call it heat. What it means? The body never contains heat that is one implication that has come out come what we are now argued.

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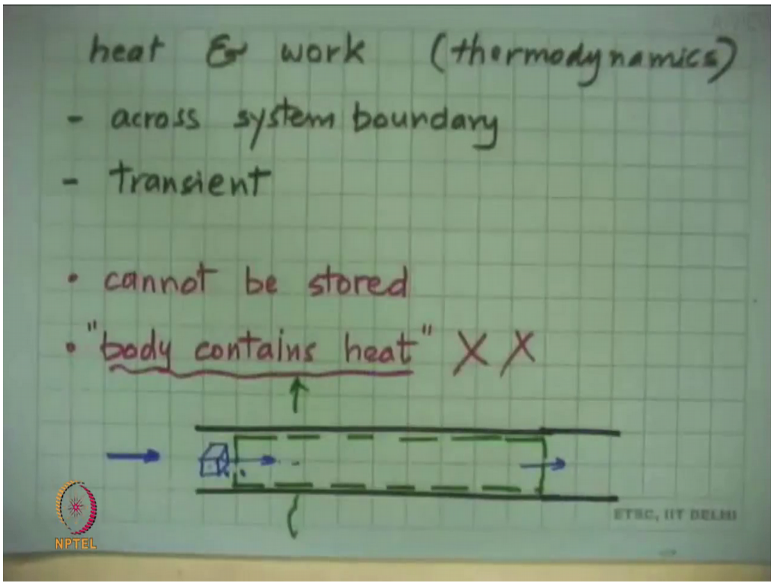

So, heat cannot be stored same way we can see it that work cannot be stored. These are properties that occur at the system boundary only when the system and surrounding interact with another. To say that a body contains heat or the heat energy of the body changes either ground statements. We will never say this type of a thing that boundary contains heat or heat energy will never contains. So, in thermo dynamics heat is a transitory transient phenomena observed only at the system boundary and that is what this definition is so important ok.

Now, ok so, let us check one more example and say is that heat. Say we have a pipe and in this say we have pumping in hot water and outside the pipe we are blowing air. So, it could even cold air cold water and that is how your central air conditioning systems work. Like in a pipe you have cold water flowing it and outside you are warm air coming in, in your window AC or your have split air conditioners you have a very cold gas that is flowing through this and air goes over it the air gets cooled, the temperature of the gas as it goes throw it increases.

And, we say well this is my system boundary and I want to study what is the amount of energy transfer in that takes place and somebody says where we know because this work water or the gas is going in there always be an element here say this element which got pushed in because it is flowing and it cross the system boundary and enter the system and at the other end this element exit at the system. This could be the element 1 millimetre on the cube or it is very big system even could be 10 millimetres or even in a very small system only say 1 micron by 1 micron by 1 micron. So, put that we have number on it.

So, somebody says you know this thing had it is own energy and it went in. So, there is energy transfer across the system and that is heat. Now, that is neither of those are correct because heat as we have seen it happens only because of temperature difference between this and this there are this is not because of temperature difference and we will see later on whether it is work this is a slightly different definition here that if we define the system in a different way.

So, that it include this element and there we push the element we change the system boundary then there is work done on the element otherwise not. So, this is not heat transfer into a system. But, when I said that we now get a more another important definition coming up which is that is this does go in how do we what do we call it.

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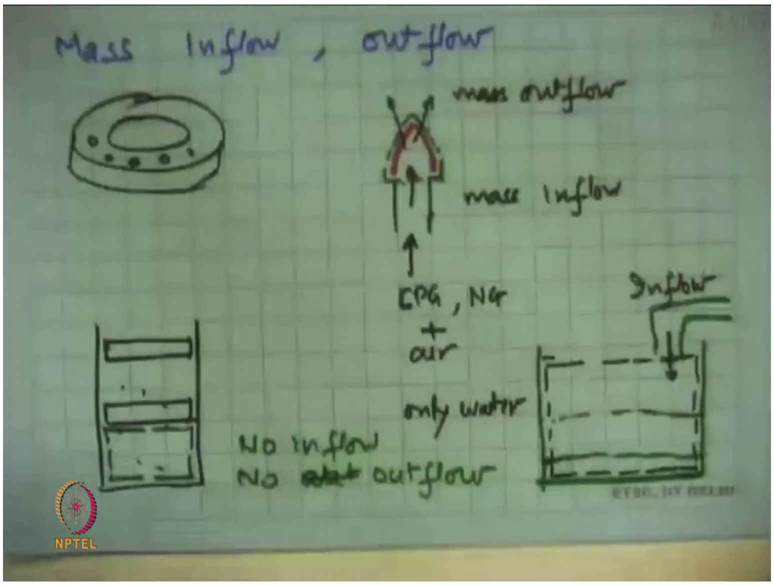

And, that brings us to the idea of a mass inflow and mass outflow. So, have you first thing we do define the system and the system boundary the second thing we got to do is before see where is heat where is work. Next thing we do where is mass inflow, where is mass outflow. So, what we do for this is what we have seen just now in the example of the pipe a bulk material moved across the system boundary this is mass inflow and if another element or something this water continues to flow across the system boundary that is mass outflow.

So, we need to look at the system and the way we define the system what we define what is mass in flow and what is mass outflow. So, let us take the example of an LPG stove. So, you have a burner in which there is a hole there are many holes there if you look at a burner it looks something like that lot of holes there and other side there are more holes and what have been said if I take one hole there and make a section here we are pumping in the gas fuel which is other LPG or natural gas plus air.

And, what it establishes on top is something that looks bluish white that is a flame and we ask you know what are the what are the mass inflows out flows in this flame and so the things to do is what we are done so far. So, I am just take my flame as well system and define my system boundary say, ok.

So, the visible portion of the flame is my system boundary and this is now what is happening in this then you got dash coming in cutting this hypothetical surface of the system boundary and entering into this, exiting the hole. So, for us this gas plus air coming in is mass inflow and after it comes in it burns and all the gases that are leaving out here this is mass out here.

So, that way we can look at every system and say is there mass inflow, is there a mass out flow. In the in the case of cylinder piston arrangement we just took that say air in this and move the piston there and what is there. So, in the first case if you say or in the second case we define the system boundary there. So, in this system boundary there is no mass inflow, no outflow.

In another case say a tank into it water is being poured in say water is inside in to this, the level of water initially about there and it keeps on rising here there and we say that I want to study how much water level is there in the tank and how is it changing. So, we can say well my system is the space inside the tank includes only the water not the air. So, we have to write that there only water and there is water been thrown through this. So, there is a mass inflow into this, but there is no mass outflow. So, there is inflow no outflow.

So, that is another example where here you are no inflow, no outflow; here we have inflow, but no outflow. You can modify this one to remove this and say that water is draining out of this and so, here out flow, but no inflow and we saw this example of water flowing in a pipe or now as we are seeing this turbine or in aircraft engine, we have both inflows and outflows.

So, that is the next step system boundary, surroundings, system, work, heat, mass inflow and mass outflow.

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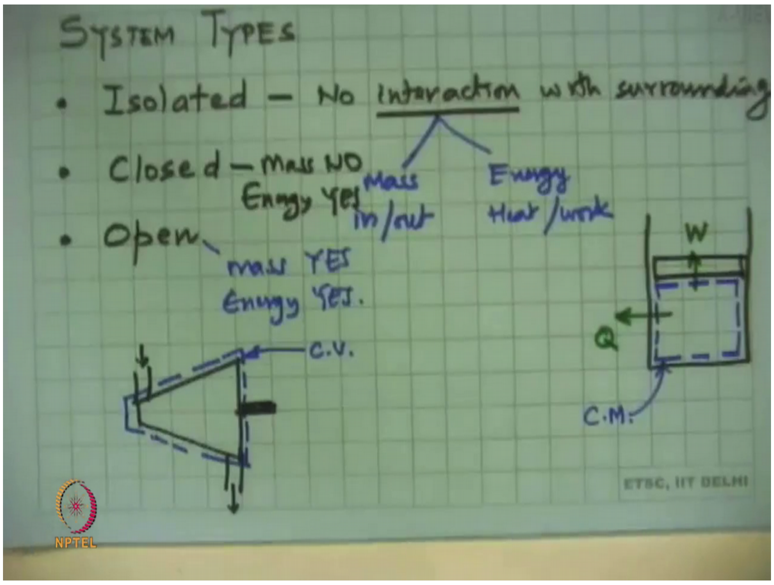

Now, based on this we broadly classify systems into three types and in a way this will also give us the foundation to decide on what strategy to use to write the equations of this problem. So, we define a system as isolated if it has no interactions with the surroundings.

When we say interaction we are included both the terms that we have so far defined that across the system boundary we have interaction in the form of mass outflow, inflow and energy as heat and water. So, that is the system that we draw when we say there is there mass inflow yes or no? If yes there. Mass outflow, yes or no? And if yes, then there; is there heat that is energy transferred due to a temperature difference yes or no you put that.

Work, that means, the system boundary is moving against a straining force between distance that we work that could also include electricity say yes and no and (Refer Time: 34:56). If the system has none of these treated as isolated system. The system is closed system if it has mass outflow is no, but energy is yes.

The example was the cylinder piston arrangement again comes back. You need to see that. So, the system say this is gas, say in the diesel engine, this is hot around this you have water going around it. So, it is cooling it and say the gas is pushing the piston back. So, we want to know: what is the relation between the position and the work done by this the first thing of becomes that we defined our system over there.

This is the system boundary and then we say well, what is happening? There is no mass inflow, there is no mass outflow, but there is water here which is cooling it, across this there is heat transfer and as this system boundary is being displaced against a driving force this site there is work. So, this system is classified as a closed system.

And, the third type of the system is open system which has both mass inflow, outflow either of them and energy in it. When we say that closed system has energy transfer across the system boundary it could either be heat alone, it could either be work alone or it could be both or it would be heat at multiple places also. So, that is fun, only one of that condition is met that is.

In open systems, there has to be either mass inflow or mass outflow or both or more than one of each. If any of those conditions are met then we say yes there is mass flow across the system boundary. The same thing with energy the way we looked as a closed that is about either heat or work or multiple things of that across the system boundary then there is energy transfer then it becomes an open system, ok.

So, that brings us to the next most important thing that have been classified systems in this way. It now gives us a basis for using two terms which are fundamental to deciding which situation to that for the conservation parts.

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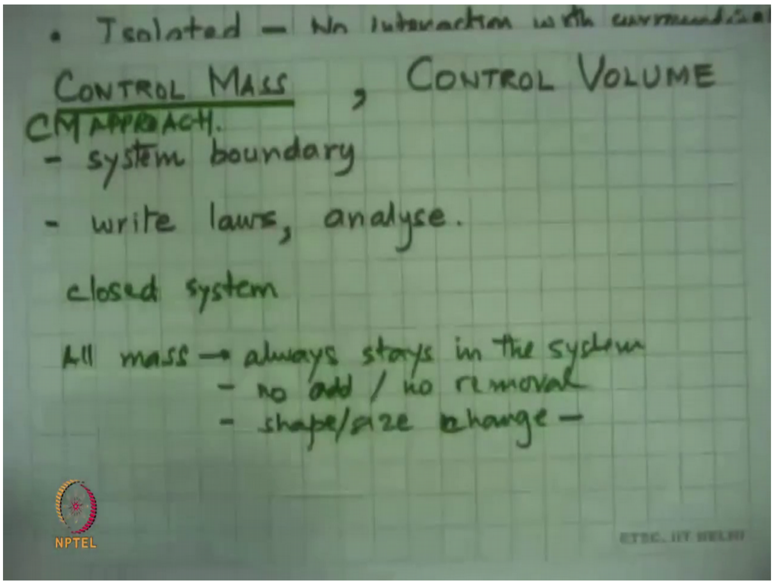

And, that is here isolated system there is nothing to understand about it unless there are internal changes taking place for example, but that is the different thing. If it is a closed system there is no mass transfer across the system boundary and set of a which equation should I write then we say that we will define the system boundary such that the system includes all the material or the mass which is of the interest to us it is not nothing is being added, nothing is being removed.

And so, we say that we have controlled by mass on which my analysis will be done and that gives us the control mass approach. So, essentially control mass is studying with that we are dealing with closed system and all the mass that is there in the system for the material or the substance always stays in the system. So, there is no addition, no removal and the shape and size may change, shape size or both may change, but the mass that was there that does not change the same amount of material is always been trapped.

So, that is that gives us the idea of a control mass approach. And, when we saw the problems straight around I will define the system we come to this point instead look this is a closed system, this is my mass of interest, we got to use the approach this is the control mass approach or CM. What that does is it gives us equations in a particular form and we can solve those equations quite easily.

The other case where there is an open system, what we do is we fix the volume in space, the fixed system in space. So, it was the example of the turbine, there is a pipe here through which steam was flowing in, say steam going out and work been produced over there we define the system boundary by this and now, we say that there is mass entering from the system boundary here, mass inflow here, mass out flow there and work outflow there.

So, what has been done in the system you say look my system in this case is going to be fixed in this space. This system will not change its shape; will not change its size no matter what happens. This fast flow rate can be increased or decreased or even becomes 0 does not matter, but my system is going to be this. What you have done is define the volume a 3-dimensional space closed space by the way which will not change with whatever happens across it.

So, this system boundary is denoted as the control volume CV and this should be the CV approach and so, in solving problems we will make this and instead of writing this as say system boundary we will then say that this is my CV and in this case this is say this is the CM. Once we reach this point we will have enough clarity on which the equation we use, ok. So, that is how much I will cover today I will stop now and just give summary of what we have done.

We started off by looking at some applications and in every lecture I will keep showing some more application of the real world and we got a feel of what is the connection between thermodynamics and those things around us. Very very crucial things like, electricity, generating electricity for our use and you cannot escape the fact that these have environmental impact and we have that is now driving our concern on what we need to invent, what need to develop and how we need to use for come over energy.

So, we saw some examples from deviation, from desalination and all of these produced for tangible benefits for society.

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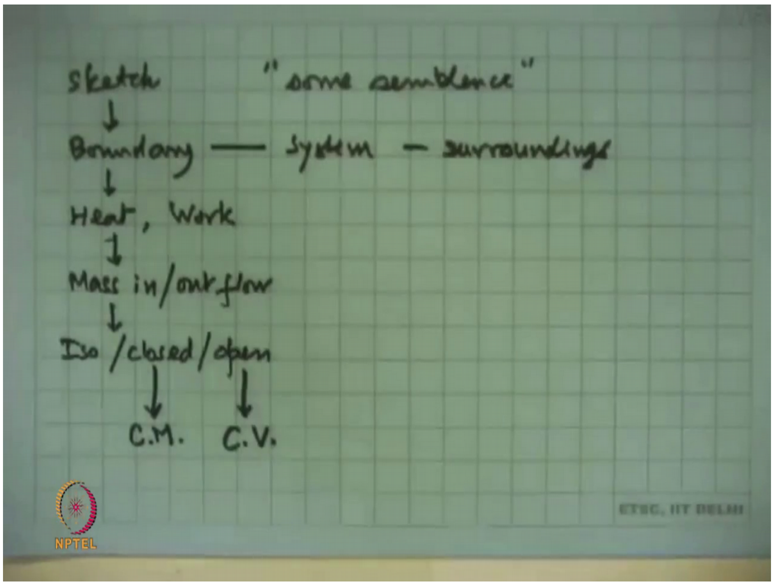

Then we asked ourselves the question how can I analyze this, how can I study this and we said look first make a sketch, try to make it as well as you can try to replicate what the real thing was some simplest to reality you can call it that way. Then draw the system boundary that will tell us: what is the system if you need to write a few words write that. It will also tell you what is surroundings then we decide then we defined what is heat is that form of energy that crosses the system boundary because, of temperature difference only and it will be defined work as energy across the system boundary that always force into displacement or lifting of a weight or any other form of energy, but not heat.

Then we said what is mass inflow, what is mass outflow based on that we defined systems as isolated closed or open. And finally, we said that if it closed system we fix the mass and the approach that we will use for the equations in the control mass approach. And, for open system we define the fixed volume as the system boundary and use the control volume approach.

So, we have come up to this point and we will continue the discussion in next as to what is the system, how do we characterize it, how can I put numbers on it all those things. And we take it normal tomorrow; we will come back on this.