Concepts of Thermodynamics

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Lecture – 01
Introductory Concepts

I welcome you all to this course on Concepts of Thermodynamics. Modern lifestyle has evolved so, much going to great developments which can be traced back to the industrial revolution. It was truly the moment when man really started exploiting nature in order to extract usable work and power. However, the saga of converting something natural into something usable goes back to the dawn of civilization when there was the invention of fire.

Since, then man has been almost obsessed to somehow extract maximum work out of everything. So for example, today all of electricity is generated in a power plant, in some kind of a power plant. In India there are coal powered power plants, there are hydroelectric power plants as well now in Gujarat and all the states there are something called as solar farms. The fundamental understanding of all these lies within the subject of thermodynamics so; typical power plant consists of a big unit known as a boiler.

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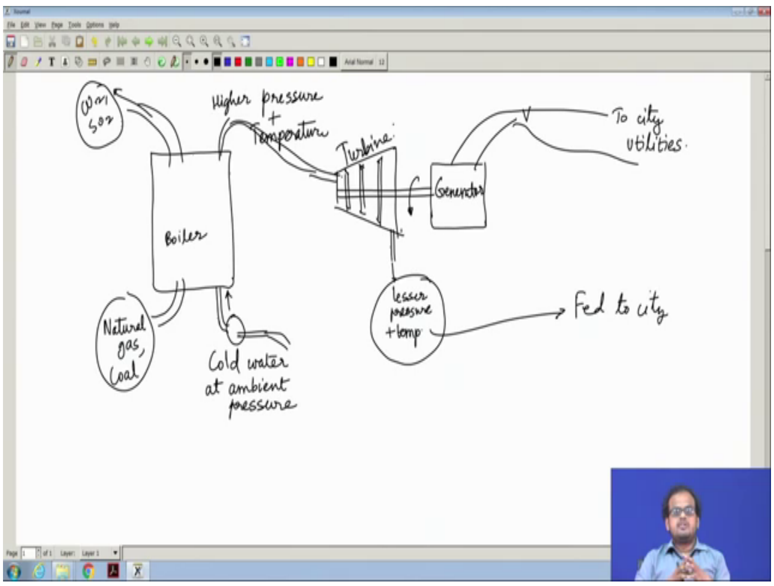

So, inside the boiler there is water inlet by means of a pump and there is lot of fuel fed into the boiler and this fuel could be anything from natural gas or it could be coal or any other source which can deliver a certain calorific value. So, once this is burnt it goes off as an exhaust as C O 2 S O 2 and all these pollutants that we identify nowadays. But, also cold water which is being input into the boiler reaches something at a higher pressure and temperature. So, the inlet is maybe something from a river it is maybe cold water at ambient conditions. So, with the help of the burnt fuel you are able to elevate the pressure and temperature of water and convert it to a steam.

Now, this steam has a higher energy content and this is then driven through a turbine. So, there are various blades attached to the turbine. So, when high pressure steam is passed over the turbine; the turbine blades start to rotate and by virtue of this rotation the shaft starts to rotate. And, the moment the shaft starts to rotate you have essentially extracted a part of energy which the high temperature and pressure steam head. And, you have converted in it into something at a lesser pressure and temperature is cold water may be from a river. So, this loop can be operated in a open cycle. So, this shaft is then coupled to an electric generator. The generator starts rotating and we all know by our knowledge for of electrical machines, that if you have a coil and changing magnetic field then you are able to create a voltage.

These are a consequences of the Faraday's law and thus you are able to create some kind of voltage which we can distribute to the city. In cold countries such as United States of America, Canada or any other European country the lesser temperature and pressure is still high enough to have use in house. So for example, they have 2 taps out of which one has running hot water. So, this is also fed to the city. So, this is how water at one particular condition was raised to another condition and that was then step down to another condition while, the energy content was being extracted by means of a turbine. And, this we were able to harness by means of an electric generator. Similarly, a refrigerator works in an opposite sense.

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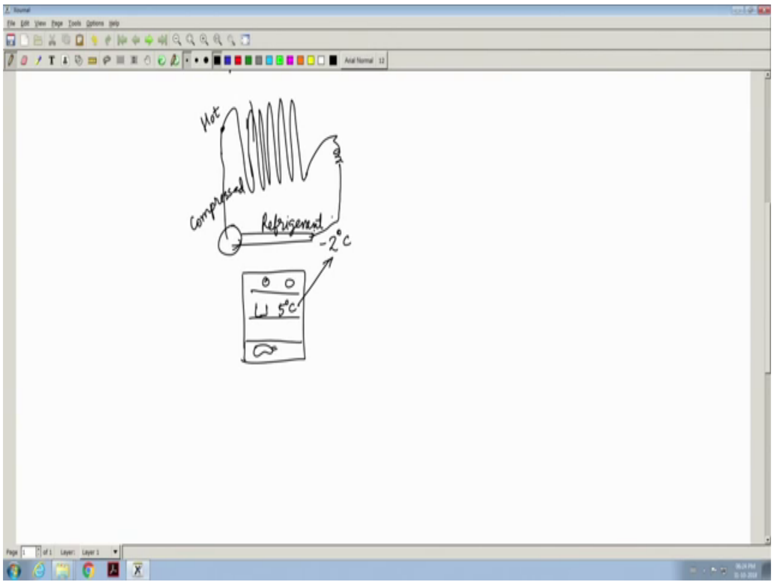

You have your evaporator which is nothing, but the space that you want to refrigerate. You keep some vegetables; some already cooked food, some fruits ok. Essentially you want to maintain a lower temperature inside this chamber; you close it you close the door inside you would ideally want everything to remain at lower temperature to prevent any spoiling of the food safe. So, you have to extract heat from this chamber.

So, you use a refrigerant to extract the heat, while extracting the heat the refrigerant picks up the heat. So, the refrigerant when it picks up the heat it vaporizers after which it is compressed to a highest higher temperature and now the refrigerant has to be brought down again to a temperature lower than the temperature of the chamber. So, if the chamber desired is at 5 degree Celsius; obviously, we need the refrigerant to be at a temperature of say minus 2 degree Celsius. Because, unless the refrigerant it is at some lower temperature there will be no transfer of heat between the chamber that you want to cool and the refrigerant.

So, by virtue of having a lower temperature the refrigerant absorbs heat from the chamber. And thus once it is compressed it becomes hot. So now, the task is to cool the refrigerant and to do this at the back of the refrigerator is the old kind of refrigerators; we could see a black grill it look something like this. So, this is where the heat transfer occurs to the ambient. So, the hot refrigerant is at a temperature higher than the room temperature and thus it is able to reject heat to the ambient. And therefore, you can feel that those parts are bit a hot. Nowadays, nowadays those are built in to the sides of the device and then there is a capillary wall which again reduces the pressure and brings it back into the line.

So, in order to have a clear understanding of how big the compressor should be, how much refrigerant I should use one needs a very thorough knowledge of thermodynamics and the properties of these substances. Unless and until we know exactly what amount of heat needs to be extracted, how much amount of flow rate; we need to have we cannot really have an optimal design. Nowadays, the whole focus is to have minimal energy input to such devices. So, unless we do a proper calculation we will not have an idea how large or how small the compressor, how much refrigerant and all these things need to be used. On a separate note things such as fuel cells.

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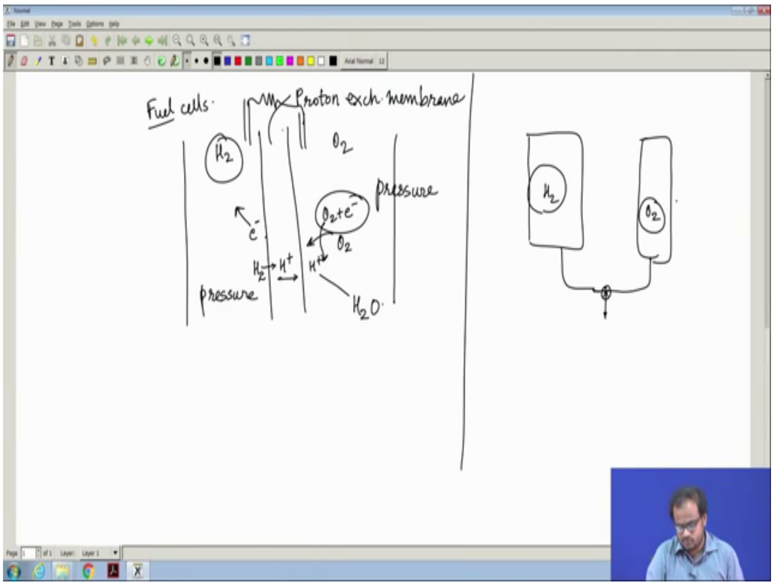

Fuel cells are the hot topic nowadays. So, let us consider how a hydrogen fuel cell works. See you have hydrogen gas on one side, then you have a proton exchange membrane and then you have oxygen on the other side. So, because of the proton exchange membrane, if hydrogen is at a higher pressure on this chamber then hydrogen iron gets generated at this end. One election is released on this end because, the chamber is proton selective it allows the hydrogen and to go over here where it combines with O 2.

So, O 2 combines with an with an electron and combines with this to give H 2 O. Of course, the equation is not stoichiometrically balance, but for now we just bother about the physical process involved. So, in order for this process to happen what is the pressure of hydrogen required, what is the pressure of oxygen required, what is the sizing of the membrane. So, because the electron is released here if you have electrodes kept over here, you can drive a current through a certain load and thus you generate power; you can sort of charger batteries and all these things.

So, this is how fuel cells having this is one of many kinds of fuel cells that can happen. There are nowadays certain kinds of bacterial fuel cells in which bacteria does the work of the proton exchange membrane all this things, it helps in catalyzing the reaction at the surface. But, this is how chemical potential something known as the chemical potential of hydrogen, and the chemical potential of oxygen all these things are required to be known in order to design such kinds of fuel cells. Unless and until one as the thorough and solid understanding of thermodynamics is not possible.

Also nowadays, ISRO is in the news for development of cryengines. So, a crude cryengine can be thought of as liquefied H 2 and liquefied O 2. And of course, they are sort of mixed and combusted and the products of combustion create a lot of thrust. So, because of this thrust there is a very the initial boost that we required to have the escape velocity is generated. So, the reason why we want to have liquid fuels is that they occupy much smaller space as compared to gaseous fuels. So, liquefying hydrogen and liquefying oxygen is by no means a mean task. It requires lot of energy; it requires a lot of stages.

One cannot simply have a single shot compression of hydrogen, one has to do it in multiple stages, one has to cascade it. And, one has to understand that there are certain pressures below which only hydrogen will liquefy. There pressures are called as the critical pressures. So, if you always operating above the critical pressure you will never obtain liquefied hydrogen. So, all these one must know when designing such kind of systems. So, let us begin by considering; what is the most preliminary definition in thermodynamics that of a control mass.

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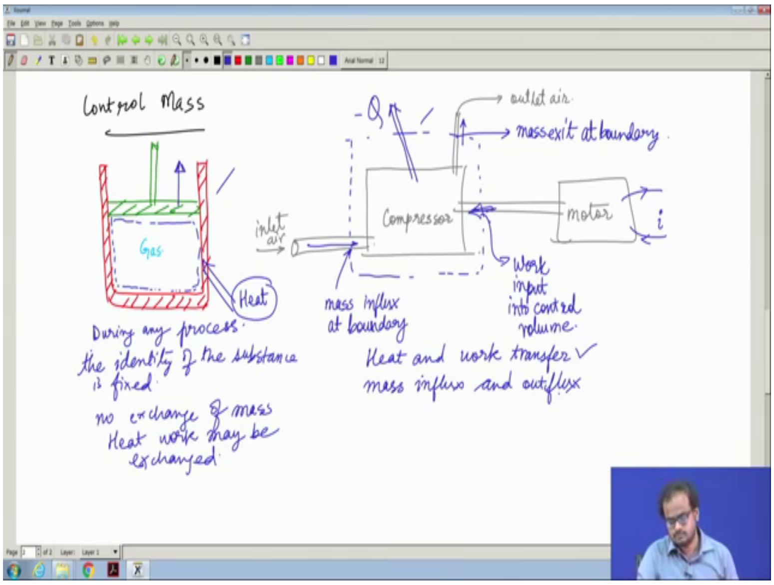

So, what is a control mass? So, very prototypical system which is used in thermodynamics is that of a piston cylinder arrangement. This is the cross section of a piston. So, this is the cylinder, this is not the piston and this is the cross section of the piston and there is some gas which is trap inside and it is assume that the piston is ideal. So, that there is no leakage ok.

So, control mass is defined as that identified set of molecules which are not changing. So, if during any process the identity of the substance is fixed. So, in this case if I focus on the mass contained inside the cylinder piston arrangement and say if I pull out the piston; the volume will increase, but I still analyze the same amount of mass that was there in the piston. So, that is said to be in my control mass, it is that mass which able analyze whatever changes have occurred in that mass that is what which I will analyze. So, there can also be an idea of a control volume.

So, let us say this is a compressor. A compressor requires some amount of work input by means of a motor. There is some inlet air into the compressor and there is some outlet. So, the purpose of a compressor is to compress air, the outlet is at a higher pressure. So, we can define a control volume in such a manner; so, there is mass going in and out of the control volume. So, mass comes in through this boundary. There is some mass exit at this boundary and naturally the electrical work fed into the motor, some current is flowing through the motor and the electrical work is also entering into the compressors.

So, there is also some work input into the control volume. Through the course of these lectures, you will learn how to identify cases where you should analyze a control mass or you should analyze a control volume. In the case where there are multiple mass flows is more expedient to calculate everything in terms of control volumes. So, that mass comes in at with some inlet conditions, it goes out at some inlet conditions, you have some input you can do a net balance. But, whenever we have close systems where some amount of mass is being cycled or it is being compressed expanded heated.

So for example, in this piston I lifted the piston. So, I had to do some work, but alternately I could have also supplied an amount of heat. I could have alternately supplied some amount of heat. The piston whatever reason because, if you heat a substance naturally the volume tends to increase. So, the same amount of mass I would have analyzed which is the control mass, but now the volume is increased. So, this is how I remain fixed, I remain confined to the amount of mass that I have chosen and then I analyze its properties ok. So, in the case of control mass there is no exchange of mass with the surrounding.

So, whatever we have defined as the system. So, these two are the kinds of system that we can have, whatever is not a part of the system is known as the surrounding. The system and the surrounding comprise of the universe. So, for a control mass there is no exchange of mass, but heat and work may be exchanged. Now, here in this case suppose the compressor becomes hot during running, it will also radiate or convect some amount of heat. So, it is also losing an amount of heat and this even for the compressor you can have heat and work transfer across the boundary.

But, additional there can be mass influx and out flux. If you do not allow mass to come in and go out of the control volume, it will reduces to a control mass it is as easy as that. Systems in which there is no exchange of mass are known as isolated systems. Systems in which there is no exchange of energy are called as insulated systems ok. It is a small definition which we will require now and then to solve some problems, but there can be many systems which are like this. For example, your thermos flask once you fill your hot tea into the flask you do not want the tea to become cold.

So, you want to isolate it from the surrounding ok, also you do not want to lose vapor. And thus it is also so, it is insulated and isolated ok. So, now let us go deeper into the idea of how all these properties actually come into being. See whatever we are studying is called as microscopic thermodynamics engineering thermodynamics, but the whole idea is there are atoms and molecules which are wheezing around random directions.

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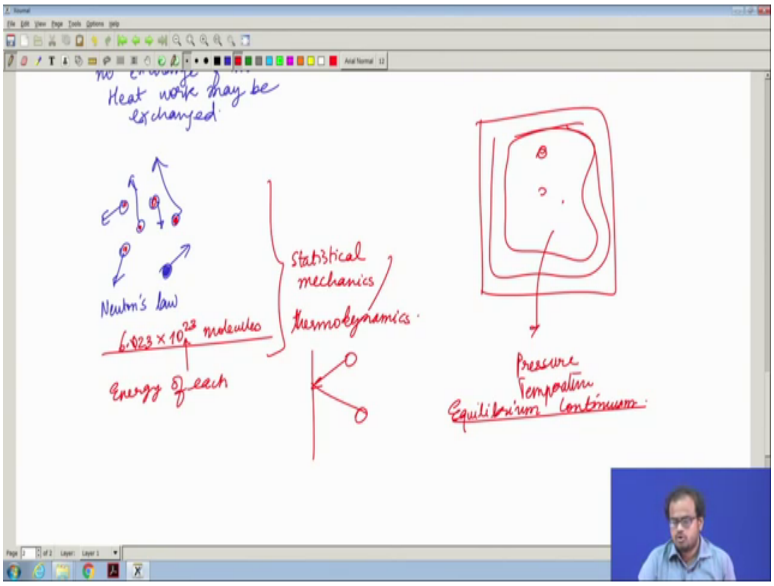

For example, if you take nitrogen it is going around everywhere. And so, if you focus on one particular molecule, one is bound to run into very very massive problem. Ideally you can solve for the Newton's laws for each molecule there is, you can find out the force acting on this particular molecule. Because of this molecule, this molecule, this molecule, this molecule and this molecule; however, you have to do it for all the molecules and very quickly things become not so feasible.

So for example, if you have very I mean suppose it have 22.4 litre of a can; so, that is the volume occupied by 1 mole of an ideal gas. So, 1 mole is 6.023 10 raise to 23 number of molecules. So, quite naturally you have to do so many calculations to solve for the Newton's law. Once you have the Newton's law you can solve for the trajectory, once you have the trajectory you can have the velocities. After having the velocities you can have the energy of each particle and then you can do an average of each particle. So, it is not feasible.

So, then all this is taken care by a statistical mechanics. So, these topics were developed early 20th century by Boltzmann all these people. Actually it had been going on for quite a while, but the Boltzmann formulation is what really set of all these ideas; it was later taken up by Einstein and all these people. So, statistical mechanics give us around on an average, if the particle has this kind of distribution of the velocities this is how it will behave. Based on the net energy it possesses you can interpret what the temperature will be, based on what the collisions with a wall will be you can interpret what the pressure will be ok. So, all these fall within the ambit of statistical thermodynamics which we are not so much interested in this course that is a very specialized course and that will be a part of some other course.

So, here we work with averaged quantities. We assume that the system, if we have a system then the system is homogeneous in its properties. So, if if I say that the system is at same temperature and pressure, then it means I am talking about the system on an whole and not talking about any molecule in particular ok. So, that brings us to the idea of a continuum. So, we are working in the equilibrium continuum situation. So obviously, when you start reducing the pressure, reducing the pressure means you are evacuating a system. The more evacuate the system, the lesser molecules there are and when the number of molecules reduces we can no longer draw statistical inferences from anything. And, thus all this continue hypothesis are not valid anymore.

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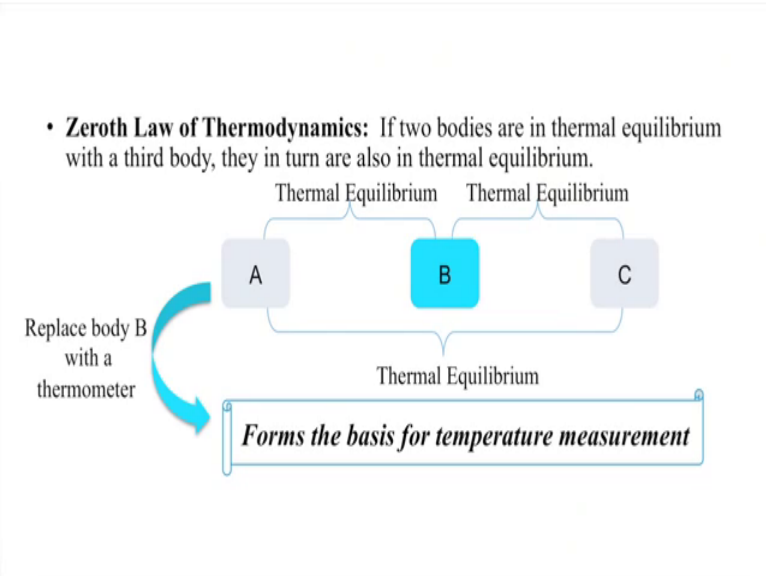

Temperature is a very familiar property of defining it is not exactly very easy. We can sense whether a object is hot or cold by the feel of it. However, the feel is not a very quantitative judgment of what you want to convey. So, now for that purpose we now know that we make use of a thermometer. In a thermometer we connect or we touch the bulb of thermometer to the object of which you want to measure the temperature of. So, then eventually the level of mercury or alcohol in the thermometer rises or falls upon till the point it is able to indicate the temperature of the object. This is because the mercury or alcohol in the thermometer comes into equilibrium with the temperature of the body essentially the thermometer comes in thermal equilibrium with the object.

Now, let us consider two different objects object A and object B. If we touch the thermometer on object A and let the thermometer come to equilibrium with the object A. Now, if we connect the thermometer to object B and we observed at the level of mercury on alcohol in the thermometer does not change, then it implies there are objects A and B are both in thermal equilibrium. This is called as Zeroth law of thermodynamics and it cannot be obtained from any other principle. It is a basis of measurement of temperatures.

So, the different temperature scales are Celsius, Fahrenheit, Rankine and all these things. So, the most commonly used temperature scale is Celsius or the as a more convenient unit Fahrenheit is also used; for example, to determine or to state the temperature of the body. So, we will see what how the absolute temperature scale is defined because, absolute scale of temperature comes more from the second law of thermodynamics. So, the Zeroth law logically precedes the first and second laws which are essentially conservation in equalities. And, hence it follows first in the presentation. Let us define what a phase is, let us proceed and define what a phase is.

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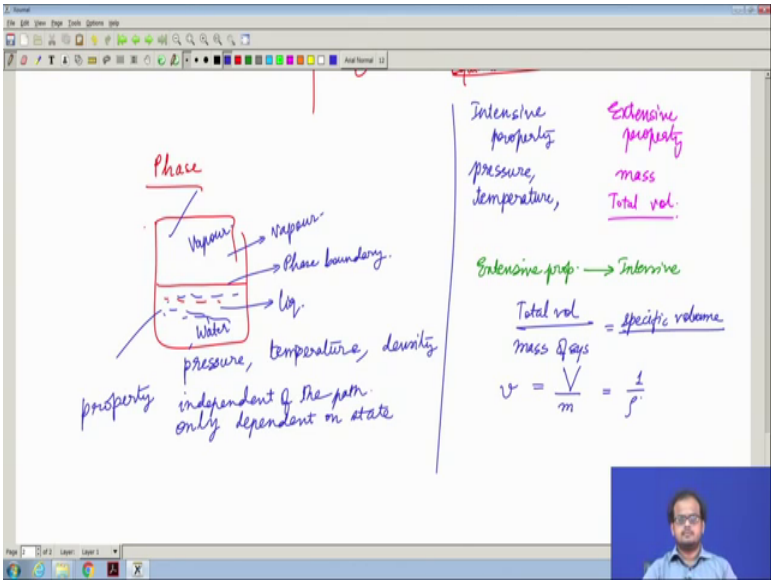

So, phase is something which has a uniform property. Let us say there is some a closed container and there is some water which is a liquid and some vapour. So, this is called to be the liquid phase, this is called to be the vapour phase ok. And, this boundary which demarcates the two is called as a phase boundary. If I heat the water the phase boundary will shift there will be more generation of vapour, the all this is common sense ok.

So, the phase is quantified by certain properties, from common practice we know that we can specify the pressure of a phase, the temperature and the density. So, these are the common things we can use to quantify what that state is. So, liquid water in ambient pressure; so, it is ambient pressure it is at 20 degree Celsius, it has some density. This is how you would define and the important thing is the property of that phase; so, these two things are a different properties no problem. There are two different properties, there are at two different temperatures. For example, or two different pressures for example, but it does not matter how the point got to that political property.

So, it does not matter how it reached that state all that matters is that state. So, the state is independent of the path taken. It does not depend on how you reached to that state from some other state, the more important thing is you are in that state ok. So, it is independent of the path and by definition it is only dependent on the state. So, there can be two kinds of properties: one is known as intensive property and one is called as extensive property.

Intensive properties are properties which are independent of the mass. So for example, the pressure, the temperature, the specific volume will come to those definitions. All these are properties which are not really dependent on the mass, that is to say if I scale the mass the pressure can remain the same no problem. However, for an extensive property it is dependent on mass. So, the mass of the system for example, it is the most obvious extensive property.

The total volume of a system because, if the density remains fixed if I double amount of mass the total amount volume has to also increase correspondingly. Hence, total volume is also an extensive property. So, an extensive property can be converted to an intensive property by division of the mass. So for example, total volume divided by the mass of the system is called as the specific volume. So, any specific quantity refers to a quantity per unit mass. So, specific we will come across these things such as specific enthalpy which is the enthalpy per unit mass and so on ok.

So, essentially v is the symbol for specific volume in thermodynamics convention; that is equal to the total volume capital V by the mass. Essentially it is nothing, but 1 by the density ok, density is equal to mass upon volume.

So, with this we wrap up our first lecture in which we are covered just the preliminaries. And, later on we will look at what a process is, what a cycle is and then what the properties of a pure substance are. And, with this we will move on further our journey to understand the concepts of thermodynamics.

Thank you.