Thermodynamics

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Lecture 01

Basic concepts and definitions – Part 1

Hello, and Welcome to this course on Thermodynamics. We are going to look at several aspects of thermodynamics over the next 12 weeks or so.

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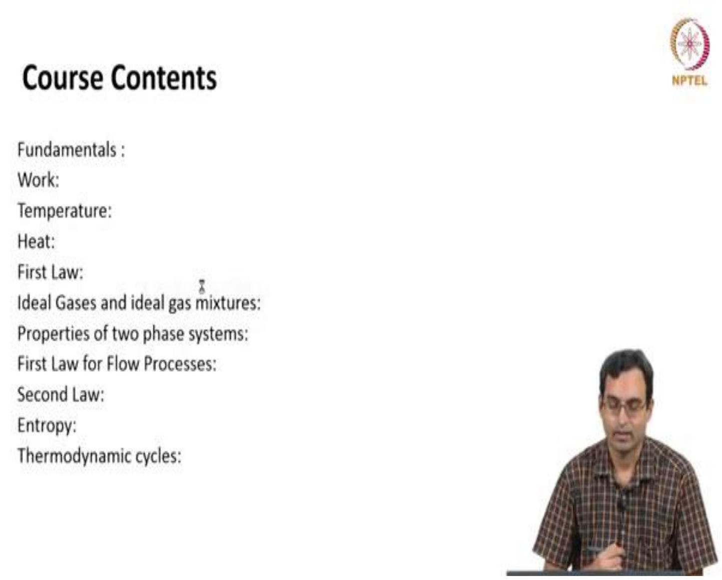

To look at the course contents, we also have about 11 or 12 topics listed here. So we will roughly do about one topic a week and that will get us through the course. For those of you who are watching this video online, what I would like to remind you is that you can always play this video slower or faster as you want it.

I have a cap to audience here and I am going to do it at some speed, but you may want to either slow it down or speed it up based on how it is convenient for you. One of the other things I would like to sort of remind you is that you can always pause the video. I would encourage you to pause and write down any equations, and I would also encourage you to pause and solve the tutorial problems yourself before looking at the solutions which we are going to do in this course.

This is especially important because thermodynamics is a subject where we would sort of look at the concepts but it is in theory. But it is much easier to find out our understanding of the concept by solving out problems where any, if you find any doubts or the finer points sort of get clarified. So, I sort of recommend that you pause in between, note down equations, solve tutorials with the problem statements given and then go ahead.

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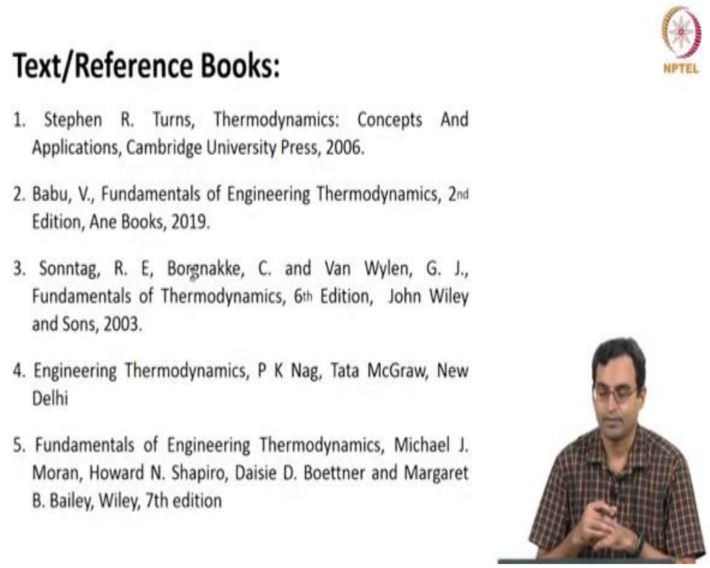

To look at the text books which are here, there are several text books which I have listed here. The book by Turns is quite nice. It has a lot of interesting pictures as well as data presented in an interesting way. I am also going to use a lot of figures from there in later parts of this course wherever it is not attributed, it is either made by us or from Turns.

This course I have been teaching earlier with several of my colleagues. Professor Sundarajan, Professor Raghwan, Professor Srinivasan, and Professor Babu who have, some of them have taught, and whom I have taught with. Professors Babu’s book on Fundamentals of Engineering Thermodynamics is quite interesting and I think it will sort of be in a similar fashion to which we go about in this lecture.

So, that may be a book which you may be interested in. As a student I used to follow a book by Van Wylen and others. It is I think gone into several editions now including I think 7th edition with Sonntag and Borgnakke and others, and there are also several other books. It does not matter which book you follow as long as you follow one consistently you should be quite alright in this course.

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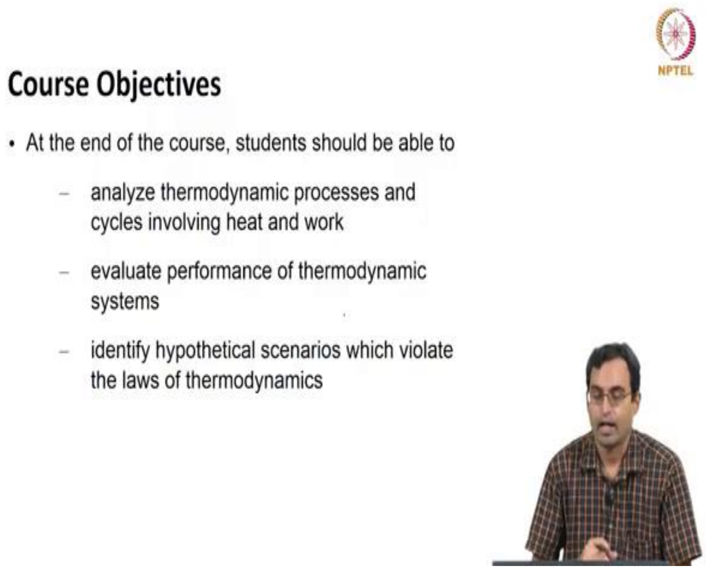

At the end of this course, what we expect is that if you go through all of the lectures and solve all of the tutorial problems, you should be able to analyze thermodynamics processes and cycles involving heat and work. We will see what heat and work are in a bit. We expect that you should be able to evaluate the performance of thermodynamic systems, and we also expect that you should be able to identify hypothetical situations which violate the laws of thermodynamics.

This I think is quite important because very often we see sort of newspaper articles and so on, which or for example we come across students projects, where students often think that for example you could run a generator which gives power to run a motor and then you use a motor to run a generator and do this in a cycle without any other input from anywhere else, and thermodynamics says that this is not something which you can do or there is often a conception that if you have, for example, an electric car and your batteries are running out of juice.

So, you can put like a turbine on the car and use wind power to charge the battery and then drive the car forward. If that is the only thing which you want to do, then thermodynamics says that it is not possible again. So, there are several scenarios like this which we come to think of has really interesting things but then we look at in detail we often see that they are not possible because thermodynamics says it cannot be true and if it says so it must be true. So, that is something.

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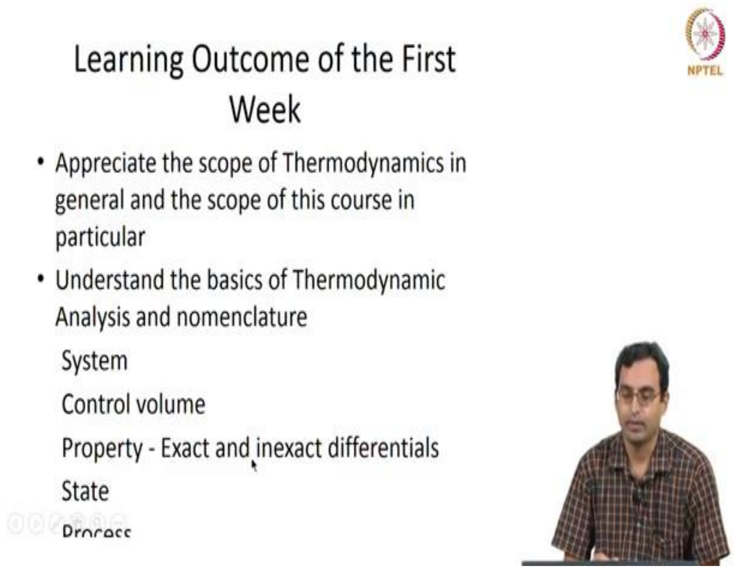

In this week, we are going to look at the scope of thermodynamics in general and this course in particular, what we will also look at is the basics of thermodynamics, we will look at some nomenclature, definitions, we will look at things like what is called as a system, a control volume, we will look at properties and in that context we will look at exact and inexact differentials, we will define a state and a process and so on. So that is essentially what we going to do this week.

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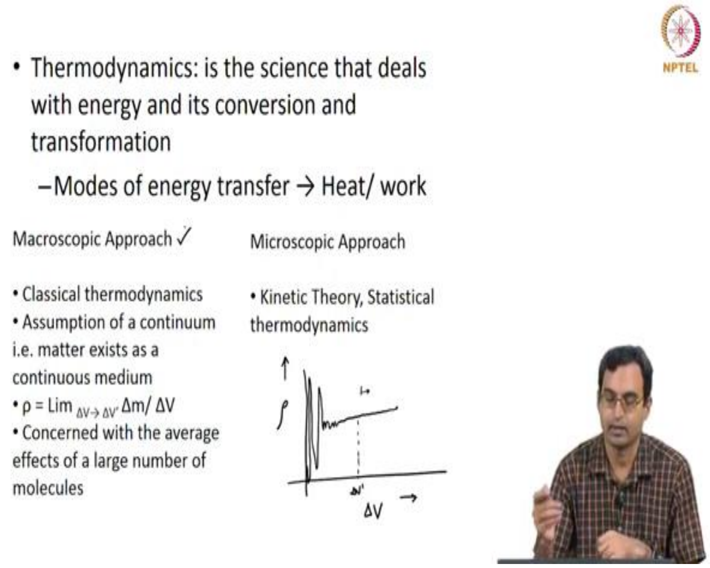

But before that let us define thermodynamics. Thermodynamics is defined variously in different text books and so on but as such it is a science which deals with energy and its conversion and transformation. So it deals with energy, it deals with the transformation of energy from one form to another, conversion to one form to another, and in the context of energy we have various ways in which you can transfer energy, and we roughly categorize them as heat or work.

We will look at the distinction between these in a bit of detail, we will look at each of these over at least a week for each of these so that we understand the distinction and when we later on go to the second law, we will see why we have this distinction. When you deal with thermodynamics, there are various approaches to deal with thermodynamics. So one of them which what is called as macroscopic approach, and another is what is called is microscopic approach. Macroscopic approach is also what is called as a classical thermodynamics approach and that is what we are going to follow in this course. Here we assume that matter exists in a continuum.

So, we will see what this means. So, what essentially this means is that if I have this marker for example, what we know is that this is composed of molecules and atoms and so on, but in continuum approach we do not care what is there inside it, what we will say is this is a solid and that is all we need to know about it. We can find out some properties of the solid but we will not worry about what it is composed of and the finite molecular details of this.

Similarly, if I want to look at for example a gas, the air inside this room, I will not worry about what it is composed of, I will say air is something which continuous and which is there in this room and I can study it. So, another way of looking at it is to look at the variation of say density with respect to the size of some box, the volume of some box. Let us say I have this a big box which is this entire room around me, it has air inside it. I can find out the density of air in this room, I have some value for it. I find out the mass of, total mass of air, and the total volume of this room divide the mass by the volume I get some density and that has some value.

If I now cut take only half of this room and find the density of one half of this room. It may or may not be equal to the density which I got when taking the entire room. The reason for that is that for example I have an air conditioner sitting here, which is putting out cold air, the cold air has a slightly higher density, then say the hot air next to the light because next to the light, the light bulb is heating the air around it. That air is slightly lighter there.

So, if I cut this room into half, the density will be slightly smaller. If I now cut this room into another small portion, the density will be slightly more different it may be slightly higher or smaller. So as I keep reducing the size of this box, finally I have some box which is this size, it has some density I take a smaller box which has smaller, different density, either smaller or larger and so on and so forth.

So this density may be varying and finally at some point I will come to a size of a box which is so small that it has only a few molecules in it, let us say it has 10 molecules in it. Now, if one molecule, these molecules in the air are all in motion, they are moving around, if one molecule comes in extra, if there is 11th molecule, then the density inside this box becomes very high, if like two molecules go out the density becomes very low and so on. And since molecules are coming in and going out density is beyond some point changing a lot.

And if I come to extremely small boxes, what I see is I may get to a size of a box, where there is either no molecule or there is a molecule and or if I go to even smaller box I may come to a size where there is nothing there or for example once in a while a nucleus of a molecule or an atom is inside it. And the density of a nucleus is extremely high, so I can consider it as very very high or close infinity for purpose when approximation or it is 0 because there is nothing there.

So, what we see is the density will vary like this at very small volumes as we go to reasonably large volumes where we have like say millions of molecules the density is fairly constant. So in our assumption of a continuum, what we want to do is, we want to look at volumes which are large enough that the density is not changing too much.

So we will not look at this region, we will only look at say somewhere over here, and we want a box which is big enough that is has so many molecules but you do not have to worry if there is one molecule more or some hundred molecules more or less. At the same time I do not want to have so large space that the properties, for example, density is changing within that space because I want to sort of define as an average density.

So what we mean by the continuum approach is that we are looking at somewhere here, where we can define a finite density for it. So mathematically we say that this ΔV the size of this goes to some, for example ΔV dash which is the smallest volume at which the density is not changing too much and I find out that mass by the volume, mass of that box by the volume of that box and that will be defined as a density.

So to put it more simply we are concerned with the average effect of a very large number of molecules, we are not going look at individual molecules. So, for example this marker again what I am concerned with is that it is there, I do not need to know how many molecules it is composed of. The net effect of all of these molecules is that it has some shape, I can press it, it does not deform very much, it has some temperature, it has some mass and it is sitting in some position and so on. That is what we are interested in.

In contrast to this, in many other courses, for example in courses on Statistical Thermodynamics or in courses in Chemical Engineering, or Chemistry or Physics and so on, we often use a microscopic approach, where we look at individual molecules. In one limit of it what we can think of is that if I knew where every single molecule is in this marker or in this room then I can predict what happens, I can predict what will be the temperature, what will be the pressure and so on.

But if I have every molecule I can solve equations for those molecules combine all with and find out any information I need. But the number of molecules is so high that that is indefinitely not a feasible approach. So, the next thing which could be to do is I could use a statistical approach, where I club the behavior of say a million molecules or a billion molecules and so on or much more that and say that in a statistical sense all of these molecules behave in such a fashion, and then use a kinetic theory and statistical thermodynamics to predict what happens.

That is also an approach which I could use. In this particular course, what we are going to do is we are going to confined ourselves with the microscopic approach but it is important that you know that this is not the only way in which we could approach thermodynamics there could be other ways to do this as well.

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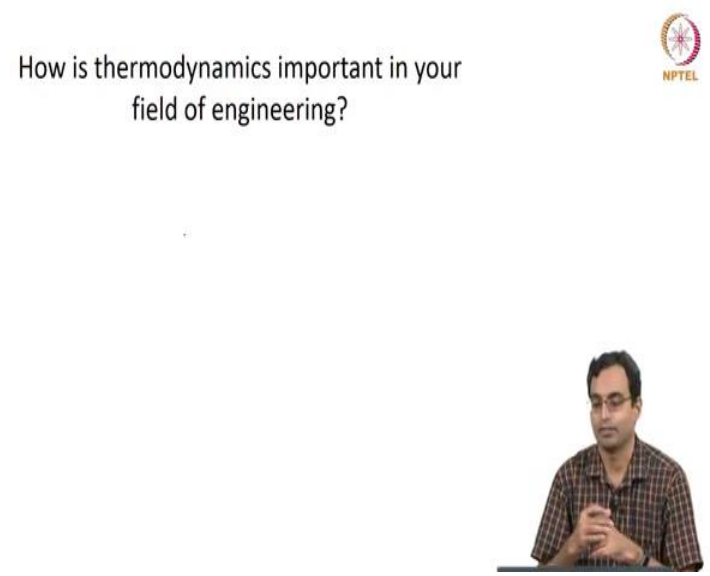

Before we go forward what I would also suggest is that you should sort of think about why this course or these concepts are important in your field of Engineering. I would encourage you to may be write some of these in the forum and share your thoughts with others who are taking this course.

I come from Mechanical Engineering background and anything which moves has usually some prime mover to it. We are usually interested in converting heat energy or chemical energy into work into something which is moving and thermodynamics plays a very important role in this.

There are other important aspects which may be useful to your field, for example, if you are designing a chip you may be worried about how much energy you can dissipate so that it does not burn out, if you are designing, say a bridge or a bunker something like that may be you are interested in how much energy of an impact it can take before it fails and so on. So there may be various aspects which maybe you may want to think about which sort of clarifies to you why it is important to learn about this.

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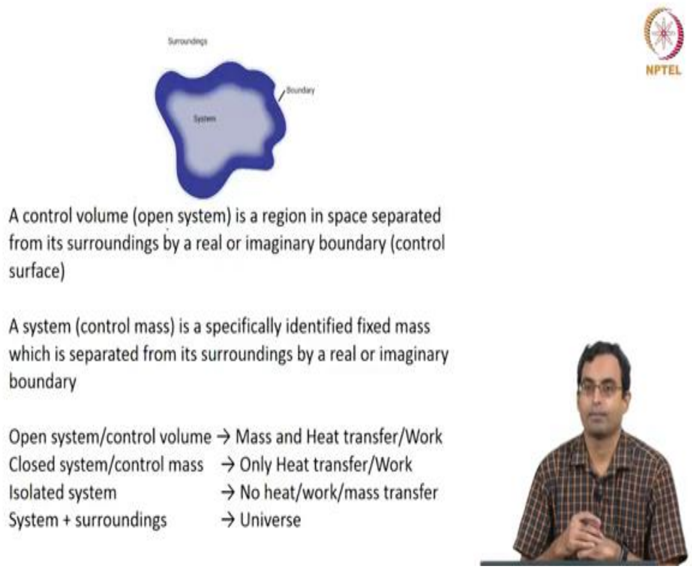

We will go on to some definitions. So first definition is what we have is what is called as a control volume, it is also often called as an open system. So we define it as a region in space, which is separated from its surroundings by either a real or an imaginary boundary and that boundary is called as control surface.

So here we have some arbitrarily shape region it has some boundary, which we call as a control surface, whatever is inside it is our control volume or open system, whatever is outside this boundary is what we call as a surroundings. So what we would typically do is take this region as something we are interested in. We have another definition of a system which is also often called a closed system or a control mass. This is specifically identified fixed mass which is separated from its surroundings by a real or imaginary boundary.

So what we see is in this case, we are talking of a fixed mass. In this case, we are talking of a region in space. So, in the case of a control volume the mass may not be fixed, it may be varying. In the case of a control mass or what we more commonly just call as a system, the mass is fixed. So that is the distinction between these two, here the mass can vary, here the mass is fixed. And both of these kind of systems either control volume or a control mass, both of them can have interactions in the form of energy transfers.

So the open system or control volume which is essentially this definition here can have mass transfer that is mass can come in and go out or and it can have heat transfer you can heat it or you can cool it. It can have work transfer you can do work on it or it can give out some work. Whereas a closed system or a control mass can have heat transfer and work but it cannot have mass transfer. So an example of a control volume would be for example, a water bottle, with the cap either open or closed, you can pour liquid into it or you can take liquid out of it.

So that is essentially mass transfer. You can heat it while putting it on a stove or may have an induction, immersion rod which you put into it, so that is heat transfer and you can compress the substance inside it or by pressurizing it or you can have some other kind of a fan which is sitting inside it and doing some work or something like that. So you can have mass and heat transfer or you can have work.

In the case of a control mass you have the mass which is fixed, so you cannot put in or take out mass but you can heat it, for example you have a pressure cooker with the weight ON, you can heat what is inside it if you had some kind of a fan inside it or something like that you can do work or if you have a heating coil you can do work, so that is what you see in these two cases. If you have a system, which is essentially a control mass, where there is no heat transfer, there is no work transfer and there is no mass transfer, then we call that as an isolated system.

So essentially something which is not interacting with the surroundings because there is no transfer of heat, work or mass, we call it an isolated system. And by our definition the system is what we are interested in, everything else outside the system is the surroundings. So, for example if I am interested in this class room where I am sitting my surroundings include the classrooms around here, my surroundings include the buildings, in the next compound, it includes rest of the city, rest of the country, the rest of the Milky Way and any other stars which are outside and so on. So by definition if I look at the system plus the surroundings that is the universe, it is whatever there is.

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So here I have an example of a control volume, this is this volume. In some books a control volume is defined as a rigid surface which does not change in volume but more generally a control volume can be any volume which is also deforming, we have ways of taking into account the deformation of the control volume but for a first-cut approximation we usually deal with rigid volumes as control volumes.

So, this is for example, a balloon the surface is the surface of the balloon. The volume is a volume inside the surface and in this case we are seeing a balloon where the neck has been released, the air inside is going out. So, there is transfer of mass as in the form of an air jet.

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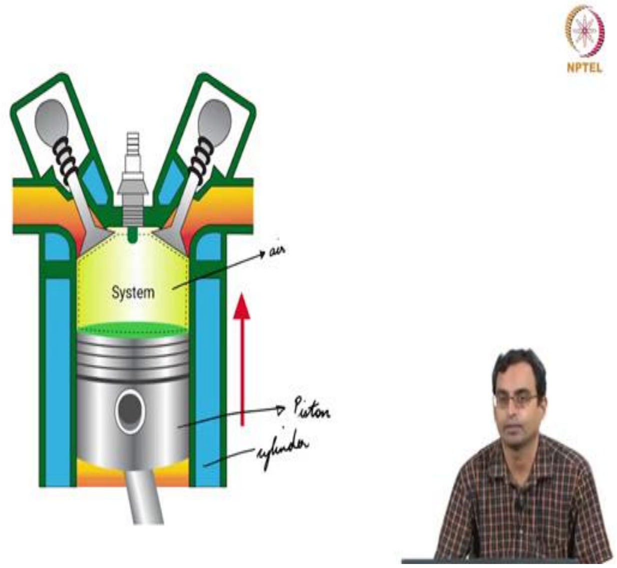

An example of a system or a control mass is shown over here. This is actually representative of an engine which is seen for example two wheelers, and four wheelers all our cars and trucks and so on. So this is what we call as a cylinder and this is what we would call as a piston, and we see that we have some amount of air trapped over here between in the cylinder and the piston which is essentially this is our system.

So, you have some air which is trapped here, which is our system, we can heat this air, we can cool it, we can push this piston up and in pushing that up we can make the volume of this air smaller or we can pull the piston down and make this volume larger but the mass of the air is fixed as long as the values are closed. So, we are interested in a fixed mass here which we can heat or cool.

So there is no exchange of mass but we can expand or compress the air and we can have it do work or exchange heat and so on. Of course, you can think of many other systems this is a system over here, fixed quantity of mass, I can lift it, I can lower it, I can heat it, I can cool it and so on. So practically anything you want can be a system or a control volume.