Applied Thermodynamics for Marine Systems

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Lecture - 1
Introduction & Some Definitions

Good afternoon everybody. Welcome to applied thermodynamics in marine systems. Today, we will have some introduction to this subject and some basic definitions which are needed for the study of thermodynamics. Now, the word thermodynamics is composed of two Greek words.

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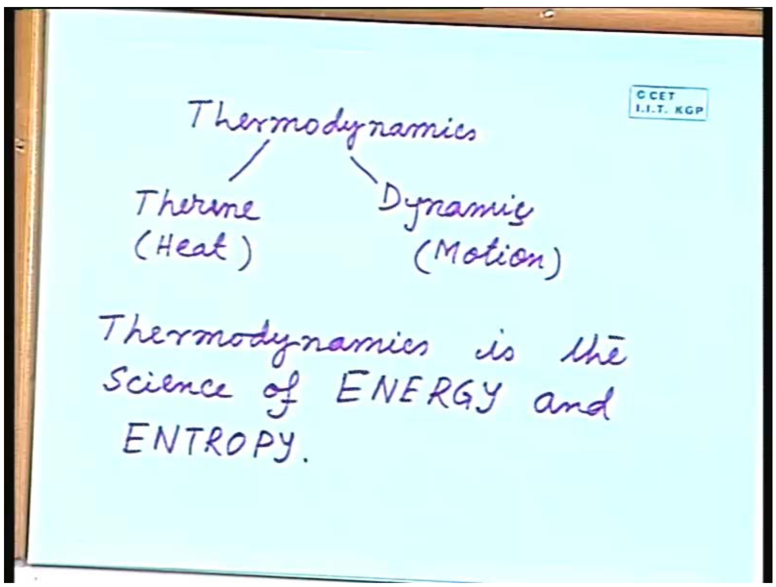

Thermodynamics is made of 'therme' and 'dynamics'. Therme means heat, while dynamics means motion. If we see the inception of thermodynamics, it was when people tried to study the motive power which one could get from different sources of thermal energy. So, that is how the subject evolved. But, after that, the scope of thermodynamics has been broadened enormously and today we have different definitions for thermodynamics.

A very elegant definition of thermodynamics could be like this: 'Thermodynamics is the science of energy and entropy'. This is a very elegant definition of thermodynamics, but probably not a very convenient definition for a beginner; because a beginner, who is studying thermodynamics for the first time may not have a good conception regarding energy and may be entropy is a very new word to him. So, let us try to have some other definition where we will use terms which are more familiar to us.

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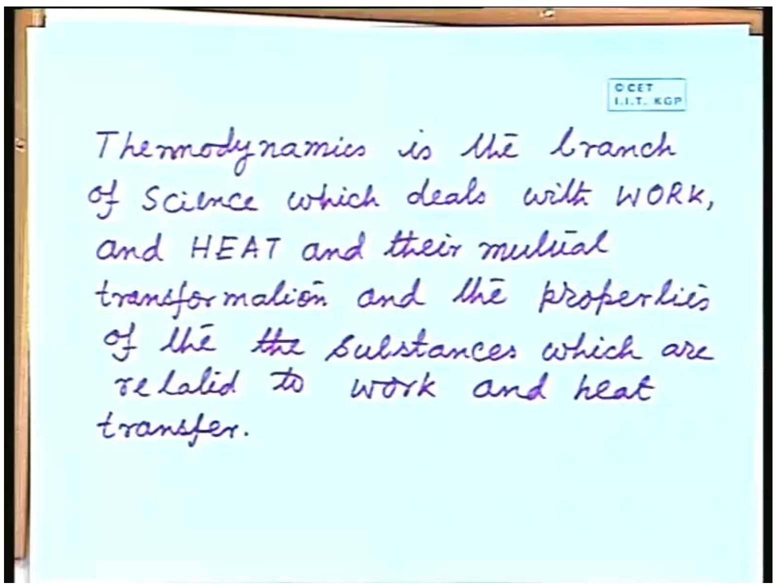

We can define thermodynamics like this: ‘Thermodynamics is the branch of science which deals with work and heat and their mutual transformation, and the properties of the substances which are related to work and heat transfer’. This is a more understandable definition particularly to a beginner. We are familiar with work and heat from our high school physics, from different branches of science. Thermodynamics basically deals or applied thermodynamics basically deals with the mutual transformation of work and heat, the effect produced by such transformation, and the properties which are relevant for this type of transformation.

Thermodynamics is studied by various disciplines. Physicists, chemists and engineers study thermodynamics. In various departments of engineering, thermodynamics is a very important subject, but the approach of studying thermodynamics is slightly different in science and engineering. That is why thermodynamics has a special branch called applied thermodynamics or engineering thermodynamics. In the present course, we are going to study engineering thermodynamics. Engineering thermodynamics is relevant for a number of important engineering systems and devices.

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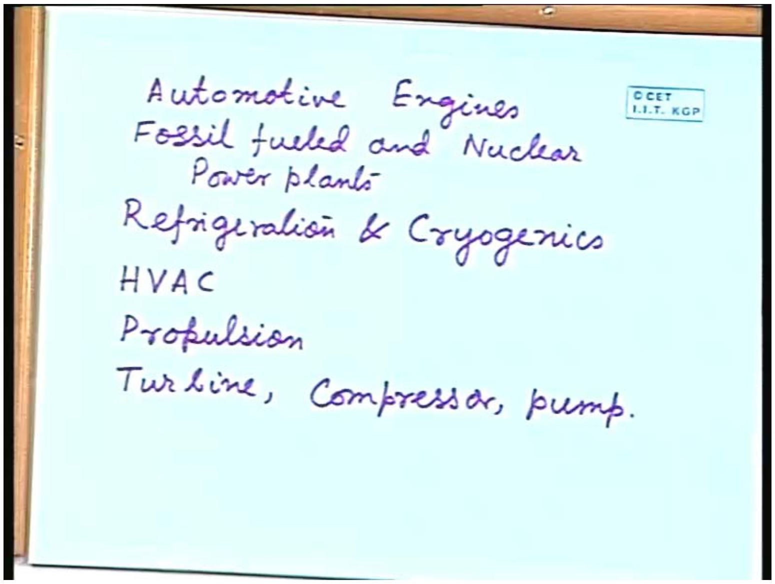

To name a few: automotives engines, fossil fueled and nuclear power plants, refrigeration and cryogenics, HVAC – heating, ventilation and air conditioning; then propulsion, devices like turbine, compressor, pump, etc. Topics like magneto hydrodynamics, environmental pollution issues, biomedical application, life support systems, artificial organs - in all these cases thermodynamics has a very important role to play. We will take one example which is of much of interest in marine science and we will see how thermodynamics plays a role in the design and operation of such a system.

Let us take the example of a steam-based power plant, where power is generated due to the combustion of fossil fuel. In such power plant, we will have four basic components.

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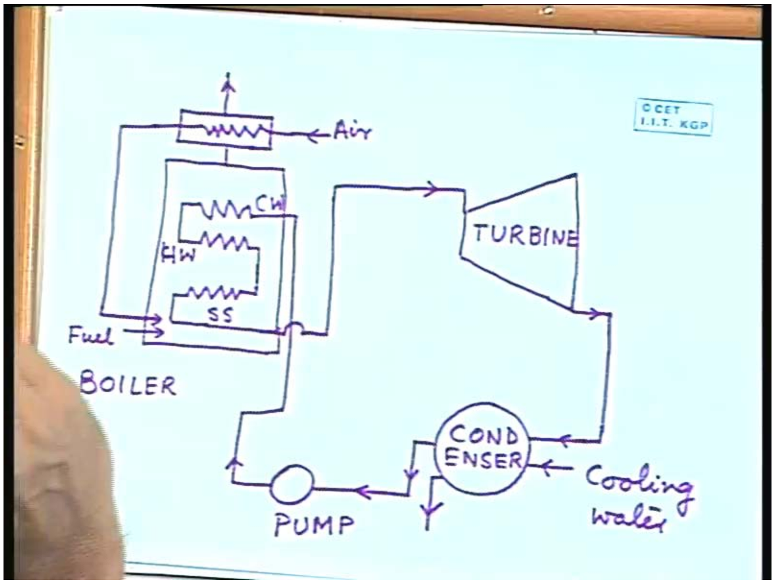

The first device where from the fossil fuels, we will derive the power that is known as boiler or steam generator. This is our boiler. Then, we will have a turbine where the motive power will be generated due to the expansion of steam through the blade passages of the turbine. Then, we will have a condenser, where the steam will be condensed back into water and lastly there will be a pump, which will pump back the condensed water into the boiler.

Now, let us see how these components are interconnected. The pump is pumping the low temperature water to the boiler. We will have water pumped from the low temperature. Low temperature water pumped from the pump goes to the boiler. In the boiler, initially the temperature of the water will rise. This is cold water. In one heat exchanger, we will have its temperature rise, we will get hot water and in this section here, evaporation will take place. After vapor is generated, in another section of the heat exchanger we will have super heating. At this point we will have super heated steam. The super heated steam will be sent back to the turbine. This is our turbine, as I have mentioned earlier. In the turbine, steam will expand through different blade passages and at the exit of the turbine, low pressure and low temperature steam will come out. Then, that goes to the condenser. It is condensed, this is our condenser. But the water is now at a low pressure, so it has to be pumped to high pressure so that it can go to the boiler or steam generator. In the condenser, the condensing will be done with the help of cooling water.

If we look into the boiler, in the boiler, fuel has to be supplied and for the combustion of fuel we need air. But, to increase the efficiency of the combustion what we do is, we heat the atmospheric air before it enters the boiler; for that, the flue gas of the boiler itself is used. So, air will go through the pre-heater and then it will enter the combustion chamber of the boiler. This is a schematic diagram of a steam power plant which is powered by fossil fuel.

Now, let us see how thermodynamics helps us to design, to analyze the operation of different components of this fossil-fueled power plant and operate it in an effective way. Firstly, the design of each and every component is guided by thermodynamics. If we want to size the boiler properly, if we want to know how many stages of turbine will be there, there thermodynamics is the guideline for us. Basic calculations have to be done by thermodynamics. Then, one can use specialized methods of analysis, where heat transfer and strength calculation etc., will come in.

Now, let us analyze the boiler. In the boiler, what are we doing? We are having combustion of fuel and air. Now, how much air has to be supplied? What will be the excess air, so that we can have the effective use of fuel? That is guided by thermodynamics. One can see that in the combustion we have the hot flue gas. The hot flue gas is doing different operations - it is heating cold water. We are having hot water almost at this saturation temperature. Then, from the hot water, we have steam or evaporation. From the steam, we are having super-heated steam which is to be supplied to the turbine. Where to place these three sections? Where to place the water heater? Where to place the evaporating section? Where to place the super heater? That will be guided by thermodynamics. Again, where to place the air pre-heater in the flue gas path? That is also guided by thermodynamics.

Then, if we go for a slightly detailed view of this steam power plant, we will see that there is reheating of steam, which means that after partial expansion in the turbine, steam is taken and again it is reheated in the boiler; then it goes for another stage of expansion. So, how to determine the point of preheating? That is also guided by thermodynamics. We can see that thermodynamics plays a very important role in power generation. Similarly, if we take another example from refrigeration, or let us say from air conditioning, we will see that thermodynamics plays a very important role. That is why it is one of the important subjects not only in mechanical engineering, it is also important in aeronautical or naval or some other departments of engineering where basic thermodynamics forms one of the basic courses or basic engineering courses. The rest of the course we will devote mainly on the study of thermodynamics.

Before studying thermodynamics, we need to know a few definitions which we will be using very frequently during our study. Some of these definitions I would like to introduce today. For the study of thermodynamics, we need to apply the laws of thermodynamics on thermodynamic systems. So, first we should have a clear idea of the thermodynamic system.

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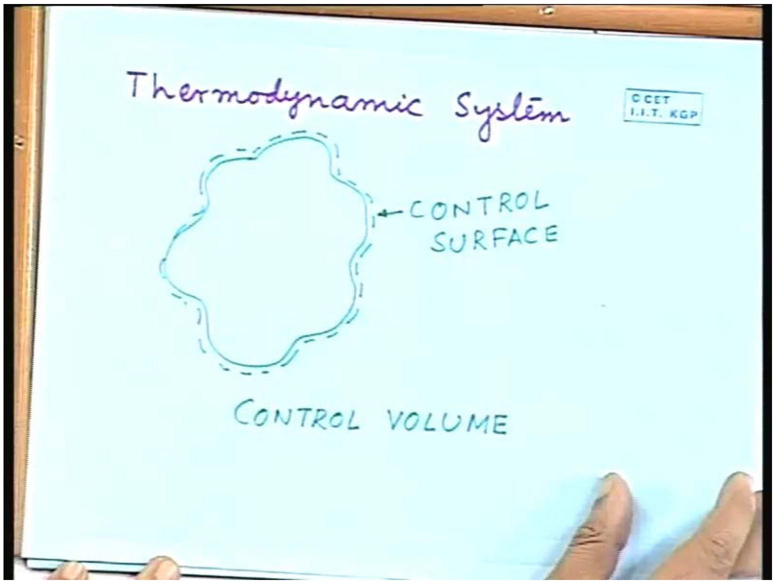

As in the study of mechanics, one should have a clear idea regarding the free volume. Here also in the study of thermodynamics we should have some clear idea of thermodynamic system.

What is a thermodynamic system? A thermodynamic system is a fixed quantity of matter or some space on which we focus our attention for the study of thermodynamics or for the application of the laws of thermodynamics. Now, the definition of thermodynamic system is a bit arbitrary. How we define the system for the analysis that depends on the person who is doing the analysis or who is doing the design. In general, it contains certain matter. It may contain one equipment, a device, or a number of devices.

Let us say this is some arbitrary thermodynamic system. We should have some boundary of this thermodynamic system. This boundary may be a fixed boundary or it may be a moving boundary. This boundary is known as the control surface and in general, this thermodynamic system is also termed as control volume.

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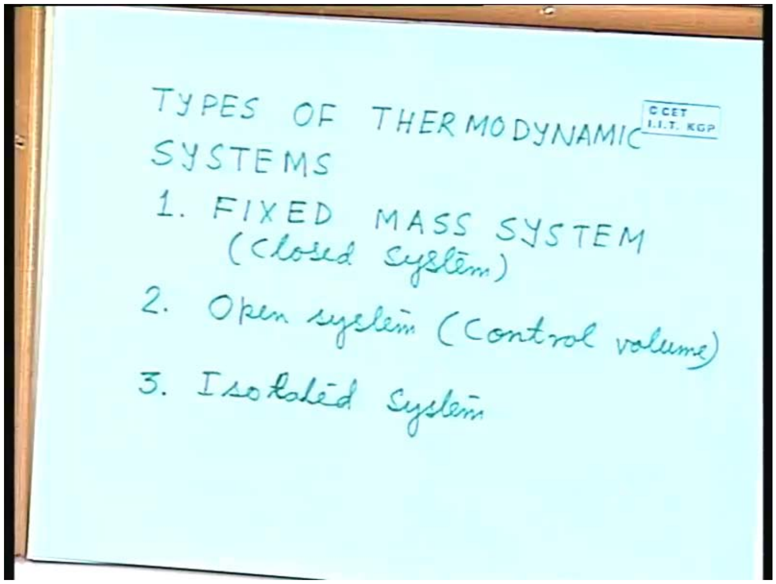

There are different types of thermodynamic systems. The first one is a fixed mass system. As the name suggests, in this system the mass remains fixed.

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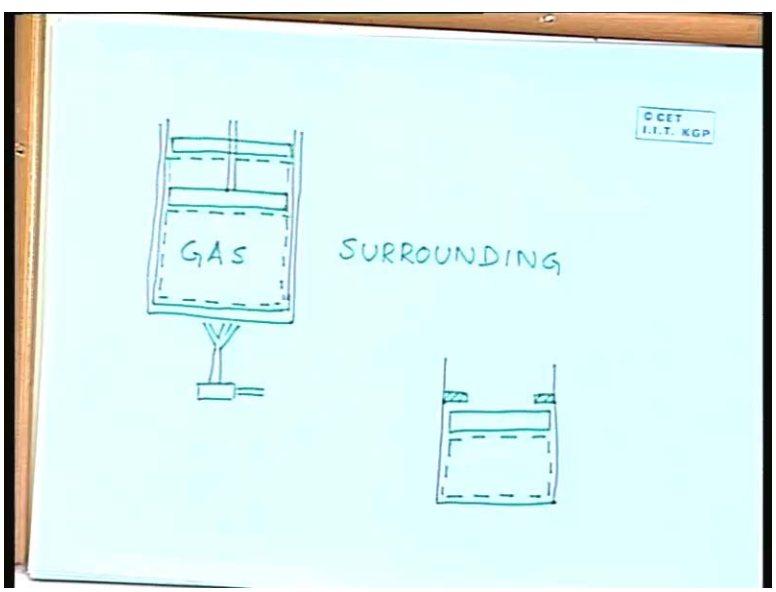

Let us take an example. I have taken a compressible fluid or a gas within a piston cylinder arrangement. Let us identify the control surface. This is the control surface. Here we have some gas. For the configuration which I have drawn, the mass of the system or mass of the control volume remains fixed. This is a fixed mass system. In some of the books of thermodynamics, it is referred to only as system or a control mass system or a fixed mass system. There are different names, but all of them refer to the same system where the mass is fixed. Through this control surface, only energy can transfer. No mass can cross the control surface, only energy can cross the control surface. When we define system, there are certain things which are external to the system. Everything which is external to the system is known as surroundings. This is our surrounding and system plus surrounding, if we combine these two, they constitute the universe.

Now, in this case we can think of a situation; let us say we are putting some sort of thermal energy here. What will happen? The gas temperature will increase, the gas pressure will increase and at a certain instant of time, we will see that the piston has moved to this position. In this case, the control mass or the system has a flexible boundary; it is not a fixed boundary; whereas, if we have an arrangement like this, here also, certain gas is contained within the piston cylinder arrangement. This is also a closed system. Here, the system boundary is fixed; the control surface is fixed. So, we can have a closed system or a fixed mass system. Two types of fixed mass systems are possible. In one case, the system boundary is fixed; in another case system boundary can move. So, the fixed mass system or the closed system.

The second one is an open system. Again, some books refer to this as the control volume. But, in general, the control volume has a much broader connotation. It encompasses all types of systems, but in some books, it is used for a narrower meaning; it is used to mean only open system.

We can take another example. Let us say this is an air conditioning duct. Here inside the room there is some radiation source, so this is receiving certain amount of heat.

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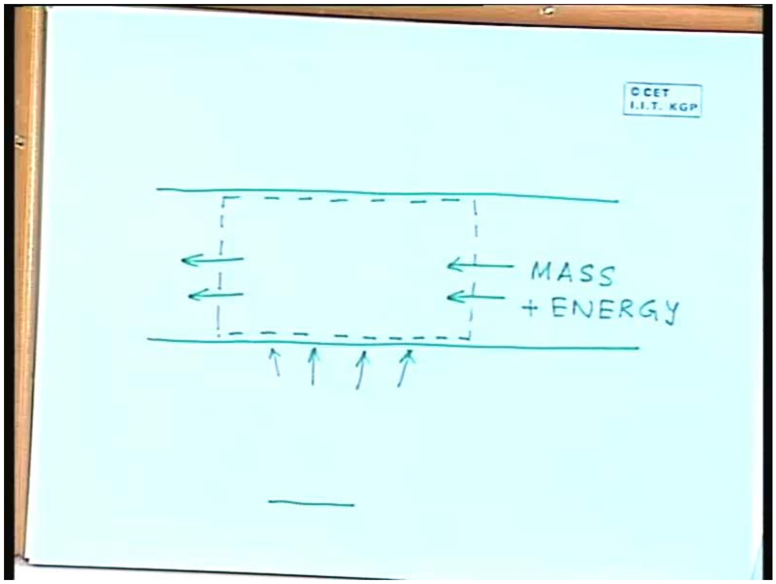

We are interested in the heated zone of the duct. What we can do is, we can imagine some sort of a control surface like this, and the fluid inside this control surface now becomes the system or the control volume of our interest. In this case, what we can see is that both mass and energy can cross the control surface. There lies the difference between an open system and a closed system. In case of closed system, only energy can cross the system boundary or the control surface. In case of open system, both mass and energy can cross the system boundary or the control surface.

The third type of system which one can think of is known as isolated system. In this case, neither mass nor energy can cross the system boundary. For example, one can take a heavily insulated tank, or let us say we are having some sort of a thermos flask which is very well designed.

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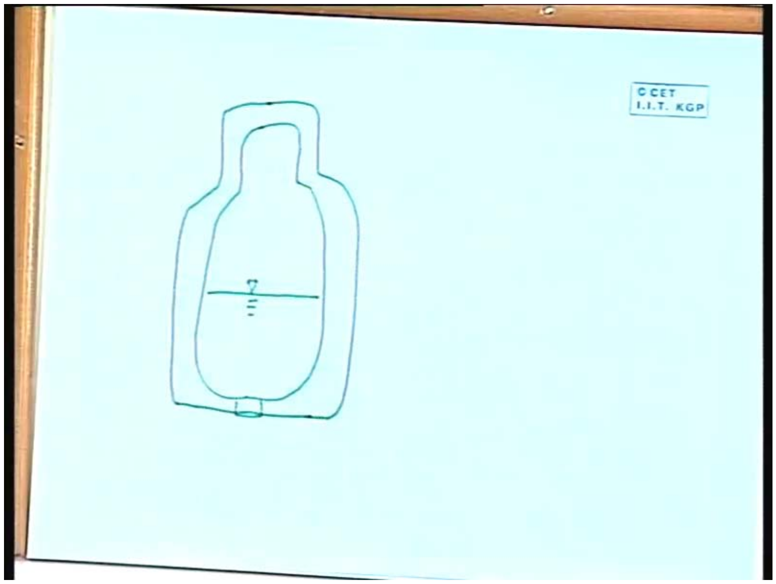

We do not have any sort of energy exchange between the fluid which is kept inside the flask and the surroundings. Then the fluid inside it or the inside of the thermos flask can be defined as an isolated system. Neither mass nor energy crosses the system boundary or the control surface.

So, what we have got is there are three types of thermodynamic systems. One is a closed system or fixed mass system, another is an open system or in some books, it is defined as a control volume, and third one is an isolated system where neither mass nor energy can cross the system boundary.

Now, as I have said in the definition of thermodynamics, we are also interested in studying the properties which are related to work and heat and their mutual interaction. These properties are known as thermodynamic properties. Let us have some idea regarding the thermodynamic properties.

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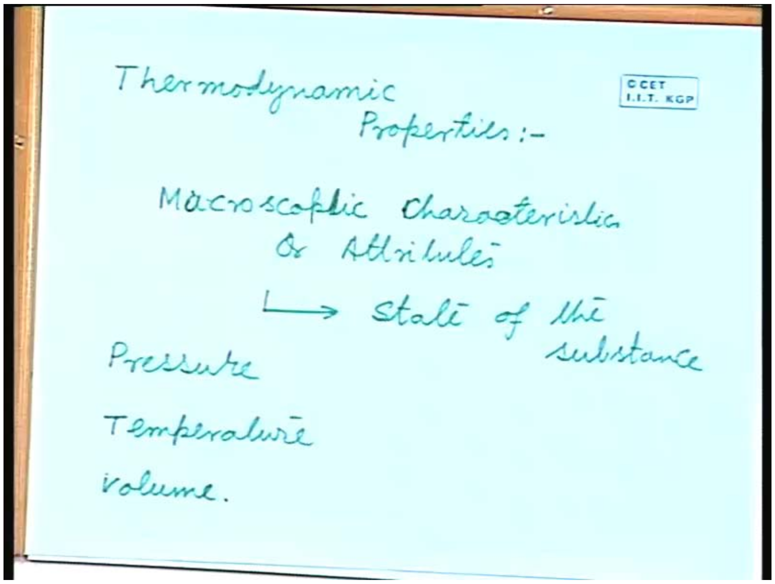

Thermodynamic properties are macroscopic characteristics or attributes. Let me write down the key words - macroscopic characteristics or attributes which defines the state of the substance. These are macroscopic characteristics or attributes and that means that these properties are observable and measurable quantities at the macroscopic level. Examples of these properties are pressure, temperature and volume. These are the thermodynamic properties. They are observable and measurable at macroscopic level.

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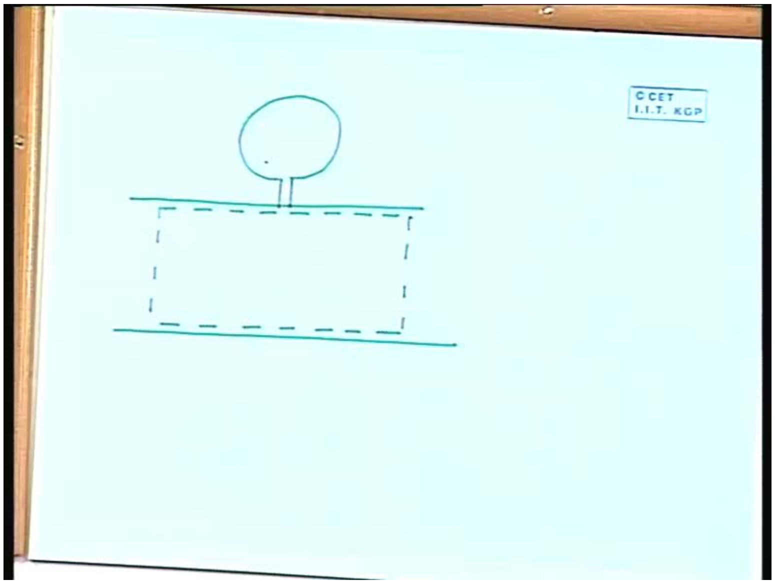

That means if we take the example of our duct which we have previously taken and this is our control volume, we are interested in the property of the fluid, which is there inside this control volume. We are interested in pressure, let us say. We can observe the effect of pressure at macroscopic level. We can measure it at the macroscopic level itself; we can put a pressure gauge and we can measure the pressure. One should realise that there is a microscopic attribute of the pressure. That means, how does the effect of pressure is felt at the wall. The fluid is composed of number of particles. These particles are at random motion; they are colliding with the wall and the effect of this collision is attributed in the form of pressure.

We are not interested in what is happening at the microscopic level; we are interested in the macroscopic result of that microscopic interaction and we will observe and measure only at the macroscopic level. The pressure here, we can measure with the help of a pressure gauge or any suitable device, or let us say we are interested in temperature. That also we can measure at the macroscopic level. These are the thermodynamic properties and they define the state of the substance.

Again, the thermodynamic property can be divided into two classes or groups.

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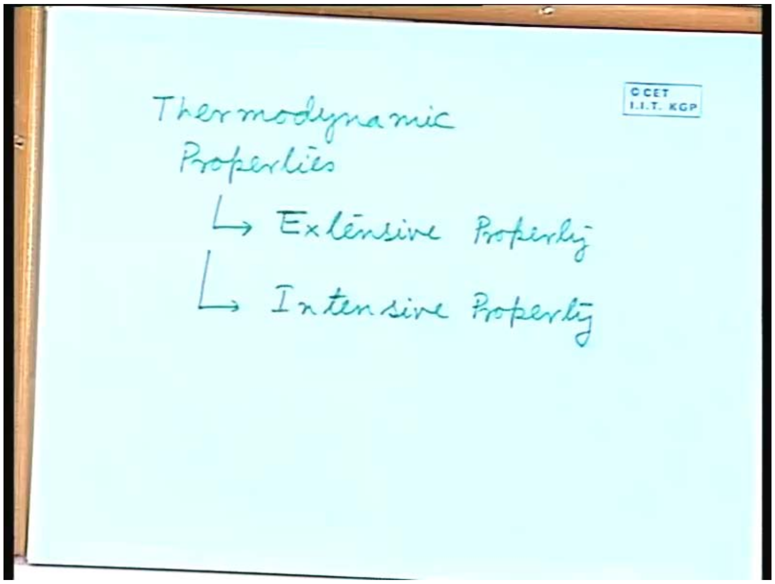

One is extensive property and another is intensive property. Extensive property depends on the mass, volume or extent of the system, like the total energy content, the total mass of the system; the mass of the system is also a property of the system. That is an extensive property. Total energy content of the system is an extensive property of the system. If in some case the area becomes a property, then, that is an extensive property because that depends on extent of the system.

Intensive property is not dependent on mass or volume or extent of the system like pressure, temperature, etc. From some of the extensive property, we can derive intensive property or specific property like volume - that is an extensive property. But, if we take specific volume or volume per unit mass, then it becomes an intensive property. There are certain derived intensive properties.

Next, we go to the concept of equilibrium.

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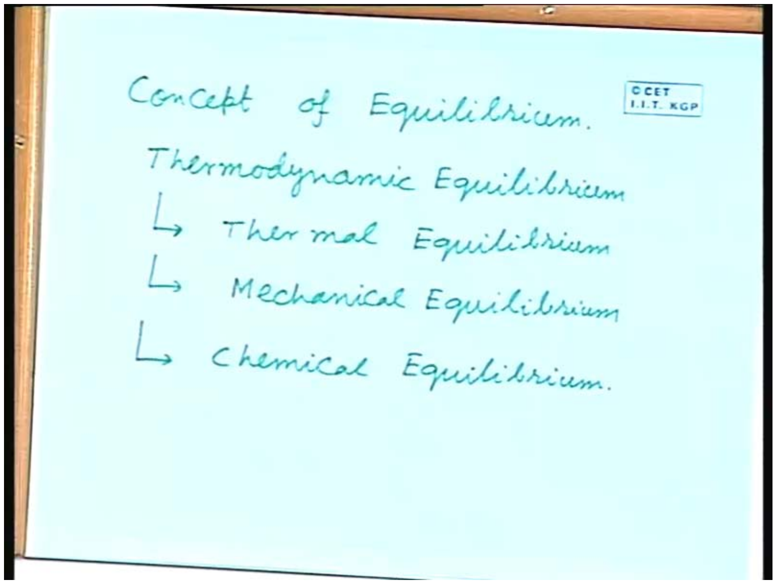

The study of thermodynamics, particularly, the way we want to learn it and we want to apply it for the analysis of different engineering systems and devices, is known as classical thermodynamics. Classical thermodynamics is based on the concept of equilibrium. We apply the laws of thermodynamics when there is thermodynamic equilibrium. So, we assume that the system is in thermodynamic equilibrium and then we apply the laws of thermodynamics.

Thermodynamic equilibrium has three components. The first is thermal equilibrium; the second is mechanical equilibrium and chemical equilibrium.

What is thermal equilibrium? Thermal equilibrium means that inside the system there will not be any temperature gradient.

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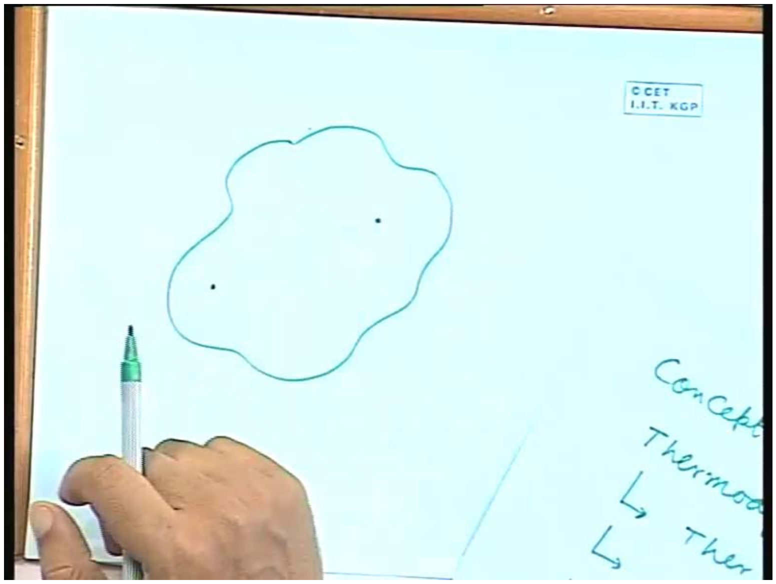

Let us say this is our system and we take any two points. Between these two points, there will not be any temperature gradient. If there is no temperature gradient between these two points, what does it mean? Between these two points, there will not be any heat transfer. That means, if we have defined this to be our system, then by defining one temperature we can have the property or the state of this system defined. By stating only one temperature, we can have the property of the system defined.

What is mechanical equilibrium? There will not be any resultant force, or there will not be any pressure gradient. If there is any pressure gradient inside the system, then we can call that the system is in mechanical equilibrium. Again, we can take these two points. If there is no resultant force, there will not be any motion also between these two points and we can say that the system is in mechanical equilibrium.

For chemical equilibrium, inside the system, there will not be any chemical reaction, and there will not be any transfer of mass from one point to another point.

If we have these three conditions satisfied, then the system is in thermodynamic equilibrium and we can easily apply the laws of thermodynamics for that system.

I will go to the definition of two very important quantities, that is, work and heat, because in our definition of thermodynamics we have introduced it like this: Thermodynamics is the branch of science which deals with the mutual transformation between work and heat. In the language of thermodynamics, or according to the concept of thermodynamics, we can divide all the energies in two forms - stored energy and energy in transit.

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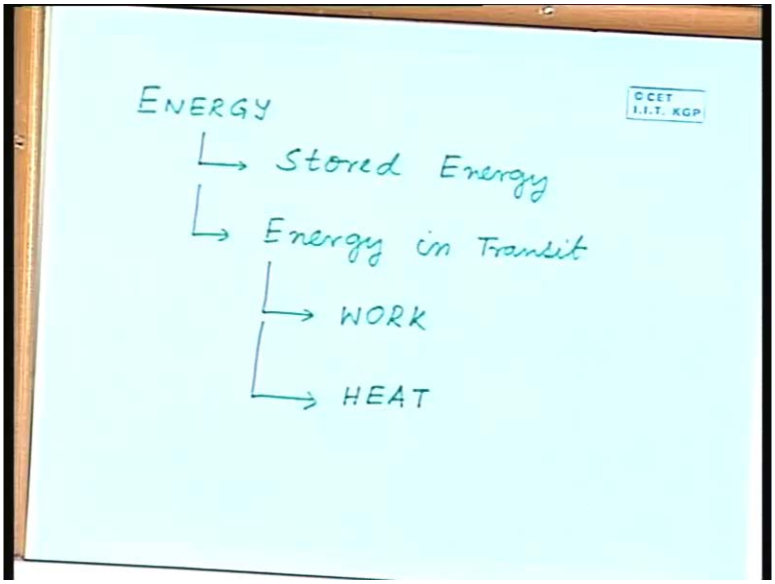

There are certain forms of energy which can remain stored inside the system, like potential energy, kinetic energy and internal energy. We will know more about internal energy later on. There are certain forms of energy which we can come across only when there is interaction between the system and the surrounding. If we think a little bit deeply, we will see that the energy in transit can have only two forms - one is work and another is heat.

Let us start with the definition of heat. The definition of heat is not much different from what we have learnt in our high school physics. In thermodynamics, heat is defined or heat energy is defined like this.

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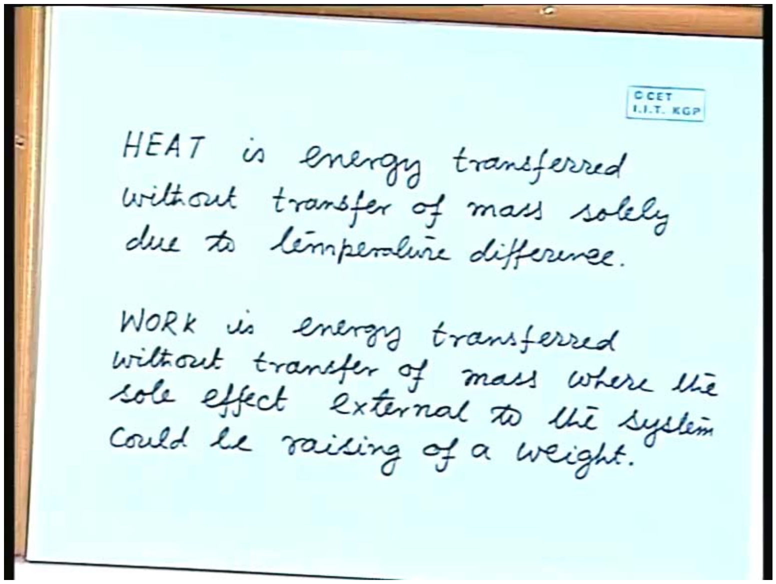

Heat is energy transferred without the transfer of mass solely due to temperature difference. If we see that there is any energy transfer due to the temperature difference between two bodies, between the system and surrounding, then we can be fully assured that this is nothing but heat energy.

Work is defined in a slightly different way. Work is energy transferred without the transfer of mass, where the sole effect external to the system could be raising of a weight. In physics, we have learned that if we apply a force and if there is displacement in the direction of force then we say that the force is doing some work. But, in thermodynamics, it is defined in a slightly different way, because here we want to broaden the concept of work. That is why we define it in a slightly different way. We define work is energy transferred without transfer of mass, where the sole effect external to the system could be the raising of a weight.

We will see in the case of work, how different types of energy transfer can be analyzed to be work transfer. Let us take one example where it is a bit confusing as to whether the energy transfer could be defined or could be taken as heat transfer or work transfer.

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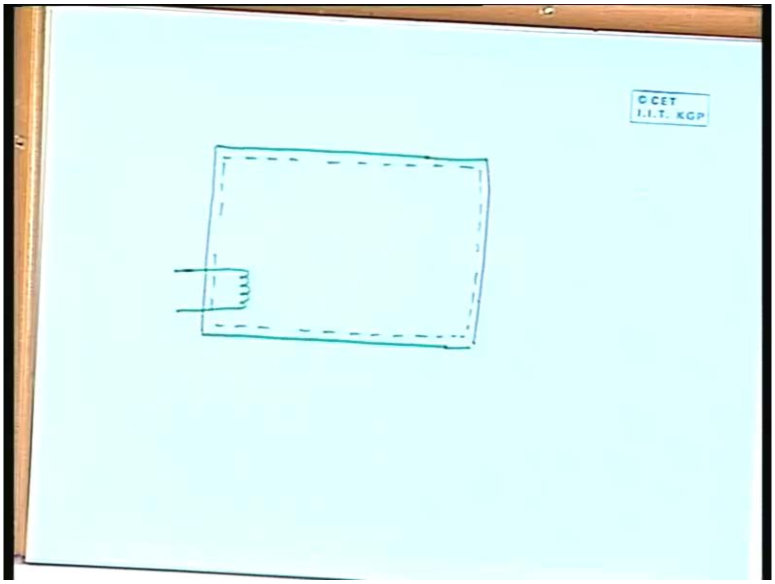

Let us say we have a room and the air inside the room is our control volume. This is the control surface and we have some electric heater which is heating the air inside. Obviously, we can see that there is some energy input. If we take the air to be our control volume, then to the control volume, there is some amount of energy which is being transferred from the surroundings. It is energy in transit because there is interaction between the system and the surrounding. But which form of energy is it? Is it work or is it heat? As the end effect of this energy transfer is heating, we are tempted to say that it is heat.

But let us analyze. Is this energy transferred due to some temperature difference? That means, we are having the surrounding and the system; is this energy transfer due to the temperature difference between the system and the surrounding? The answer is no. This energy transfer is not due to the temperature difference. Could this arrangement be made slightly different so that the effect could be the raising of weight? Yes, because we can change the arrangement. We can transfer this electricity into a motor and by sending the same amount of current, we can raise a weight with the help of this energy transfer. Basically, this is work transfer and this is not heat transfer. Where is the heat transfer taking place? Or the end effect is heating, so where is the heat transfer taking place?

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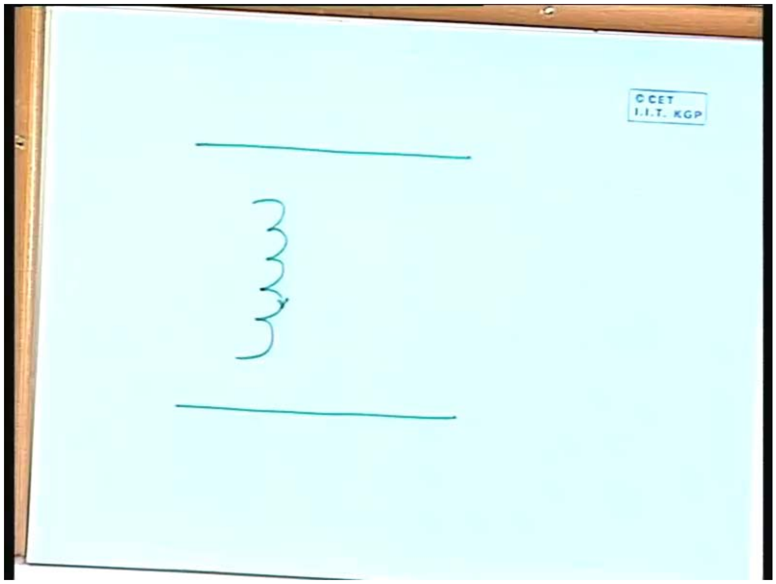

If we go to a slightly detailed view of it, we will see that due to the passage of current the surface of the heating element is getting heated up, whereas the surrounding air molecules are at a low temperature. So there is a temperature difference between the surface of the heating element and the air molecule. Due to the temperature difference, there is some energy transfer from the heating element to the air molecule. This energy transfer is heat transfer; whereas the supply of current between the surrounding or from outside the room to the room is not heat transfer; it is work transfer.

Why is this subtle difference important? This is important because we follow some sort of a sign convention. Again, the sign convention is optional. One can have his own sign convention and one could be consistent. If one is consistent with his sign convention and he follows that sign convention everywhere while he is applying the laws of thermodynamics, then, there is no chance of error. Now, what is the sign convention?

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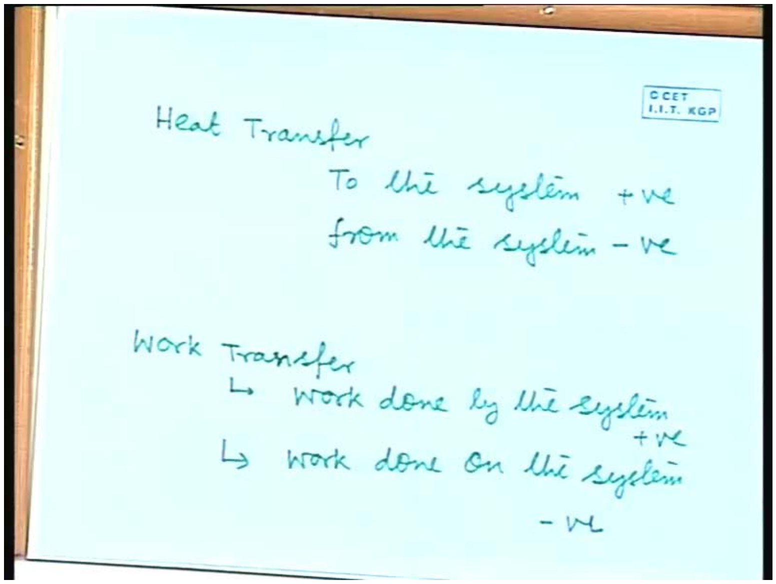

Heat transfer and work transfer. So, in case of work transfer, work is done by the system that is positive; work done on the system is negative. In case of heat transfer, heat transfer to the system is positive; heat transfer from the system is negative. This is the sign convention we are going to follow. If somebody has his own sign convention, he can follow that but he has to be consistent in following the sign convention.

Regarding the definition of work and heat, let me quickly recapitulate what we have done in today's lecture, and then, we will end this lecture. Initially, I started with the definition of thermodynamics, and the way I have defined it finally, it deals with work and heat, and their mutual transformation. Then we have seen different definitions. For the study of thermodynamics, the concept of thermodynamic systems is very important. We have seen that different types of systems are possible. Mainly there are closed systems and open systems, and there could be an isolated system which will not have any type of interaction with the surroundings.

Then we had thermodynamic properties. There could be intensive property and extensive properties. These are macroscopic characteristics or attributes of the system which gives the state of the system.

We have seen thermodynamic equilibrium. Three types of equilibriums are there, and are necessary for the thermodynamic equilibrium. One is thermal equilibrium, which is equilibrium of temperature or equality of temperature; then mechanical equilibrium which is equality of forces or pressure fit and then chemical equilibrium which is equilibrium of spaces - that means there will not be any mass transfer, there will not be any chemical reaction inside the system. Once these three equilibriums are there, we can apply thermodynamic laws.

We have seen the definition of work and heat. They are defined, particularly work is defined, in a slightly different way in thermodynamics. The definition is slightly different compared to the definition in physics. Depending on that definition, we should understand when there is any energy transfer between system and surrounding whether it is heat transfer or work transfer. Then it is important to follow some sign convention for work and heat and the sign convention which we are going to follow that also I have introduced.

I think that is all for today's lecture.

Thank you.