Fundamentals of Aerospace Propulsion

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Lecture - 04

This is about lecture four and let us recall what we learnt in the lecture three and we basically discussed about the ram jet engine scam jet engine and also the combined cycle. Under that category I discuss about two cycles basically one is rocket based combined cycle and other is based on the turbo based combined cycle, but I did not discuss about cycle rather I talked about how we can combined two engine systems such that we can get lot of advantages over the each one of them. And later on we looked at the non-chemical rocket engines under that category we discuss about the nuclear rocket engines and solar rocket engines and also the electrical rocket engines.

Those are only being focus on the basic principles of rocket engines just to how a part side view of all the rocket propulsive systems and also the air breathing propulsive systems because it was just a introduction to the whole gamete of the propulsive devices. And today we will look at the what are the tools available for analysing these propulsive devices and I will try to cover rather review the thermodynamics principle which can be useful for analysing these propulsive devices. And let us start this lecture with a thought processes from your Ubbeelohde.

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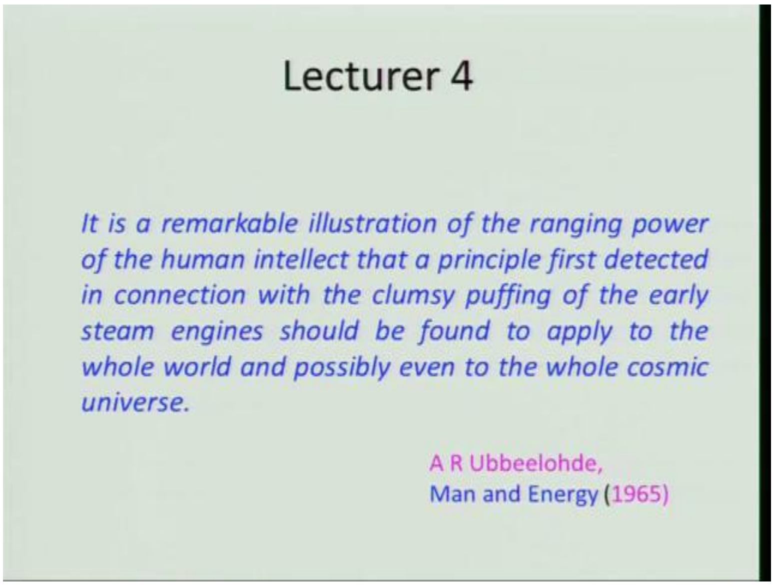

And who says that thermodynamic is a remarkable illustration of the ranging power of human intellect that a principle first detected in connection with clumsy puffing of a early steam engines and should be found to apply the whole world and possibly even to the whole cosmic universe. That means, if you look at thermodynamics is really very very important subject that encompasses to explain all the processes which will be occurring across the entire universe.

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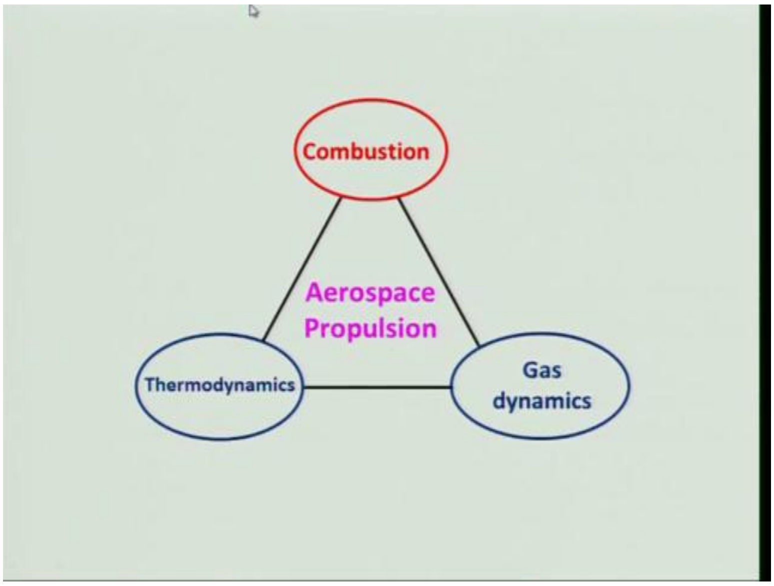

And before getting into the tenancy of the thermodynamics let us look at how these aerospace propulsion, you know can be applied or can be based on three subjects one is thermodynamics. Basically, the engineering thermodynamics what will be looking and it and other these gas dynamics keep in mind this gas dynamics is connected to the thermodynamics as well. And so also the combustion which is very important because we are interested to look at propulsive devices that will be using chemical energy. So therefore, we will be looking at all these fundamentals related to this three things first because if these tools will be important to analyse the propulsive devices.

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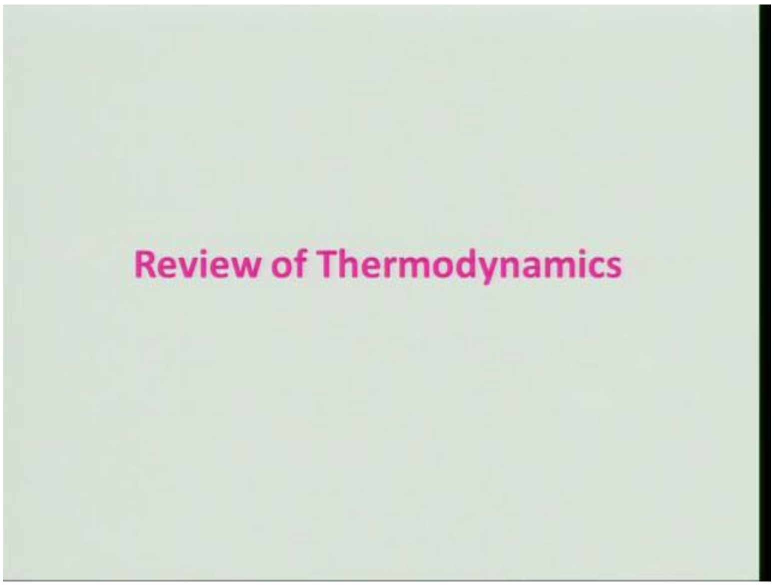

And now we will be reviewing the thermodynamics because you have already learned and several occasion about the basic principles of engineering thermodynamics, but however for completeness sake I will be starting from the very basic principles. We will ask a question what do you mean by thermodynamics if I ask this question you may be saying it is related to the heat engines or something like that. But if I look at a these terminology at the word thermodynamic it stems from two words one is therme and other is dynamics.

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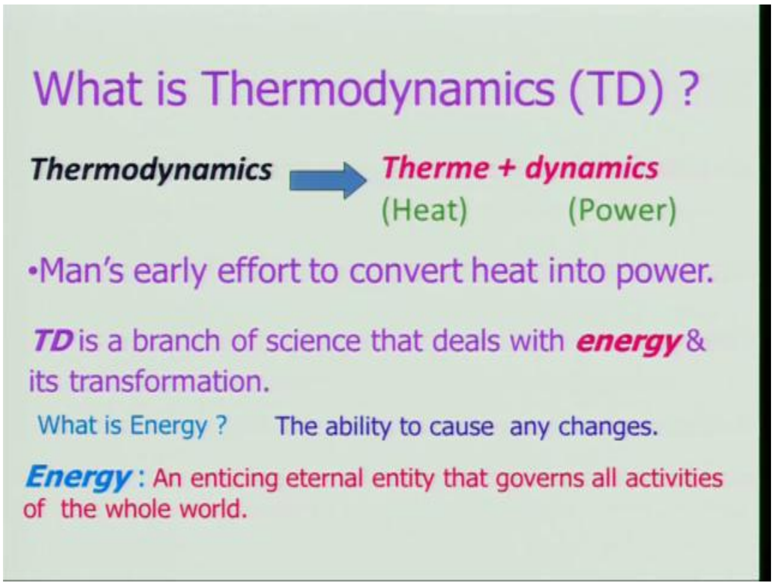

Therme means it is related to the heat and dynamics means it is related to you can consider it to be a power and if you look at what really means, the thermodynamics from the engineering sense is that converting heat into power. And that was the quest with each human being started to you know strive to convert heat into the power. As a result the steam engine came into existence by James Watt who was the pioneer in that, but keep one has to remember that we may know him, but the several people who have given their life's to convert this heat into power in the form of engine heat engine.

So, if you look at when you talk about this heat engines then question arises that thermodynamics can be considered as a branch of science that deals with energy and its transformation. And when I say this energy all of you might be feeling that I know it we need not to discuss because we already use it left and right in our day to day life isn't it, but however when you try to ask this question what is energy can anybody tell me what is energy.

Student: Capacity to do work.

Capacity to do work or it is it can cause a any change suppose I am trying to teach you and I am trying to give my intellectual energy so, that it can be change in your mind so any change which will be occurring is because of what because of energy. So, that means energy is everywhere if you start from even atom the molecules in the last lecture we discuss about nuclear energy in the nucleus itself that energy will be lying so everywhere energy is there. So, whatever you see any action any reaction any is anything whatever is occurring across the whole universe is nothing but manifestation of energy.

So, that is a very important therefore, I can define energy as an enticing internal entity that governs all the activities of the whole world, world means entire universe. If you look at the what you call stars planets galaxies and even including our day to day visiting so all will be the basically manifestation of energy. Whenever I want to convert the what you call I want to have a thrush power I need to use chemical energy and convert into the thrust power in aerospace propulsion off course you can use other forms energy.

As we have already discuss that is your nuclear energy solar energy and your what you call electrical energy you can, but basically what you are doing your trying to convert or utilize these energy in to thrust power. So, that is the basic idea of the propulsive you know propulsion.

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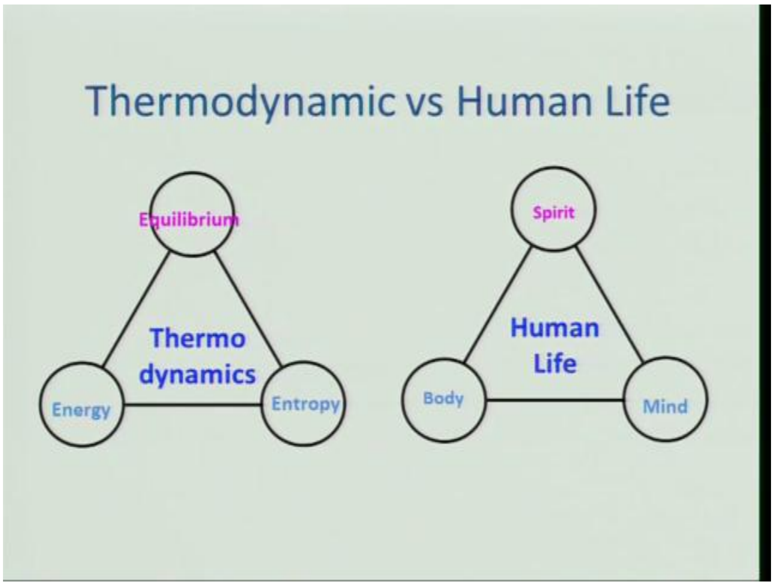

So, whenever you talk about this thermodynamics then whether can it be connected to the life and if you recall the thermodynamic is having three basic concepts or the principle on which it works. One is of course, the energy and which we have already discuss just now we discuss about energy and there is a another concept known as entropy which will be discussing little later on and whenever you talk about energy and entropy then we need to talk about the equilibrium. That means these 3 are connected to each other and when it is connected and also the govern the principles particularly the engineering thermodynamics or we call it as a classical thermodynamics.

And now if I compare this will with the life what are those things one is your body other is your mind and this is the spirit so which is very important for sustaining a balance human life. That means if you look at this 3 component must be balance and that is the basic objective of a education to have a balance life between the body, mind and spirit. When you look at your present or the modern education system it does not subscribed to do those things that means it is highlighting the basic principle of thermodynamics which is being governed. Which is governing all the activities of the world according to me it is not according to me, but the great scientist you know Albert Einstein feels that way.

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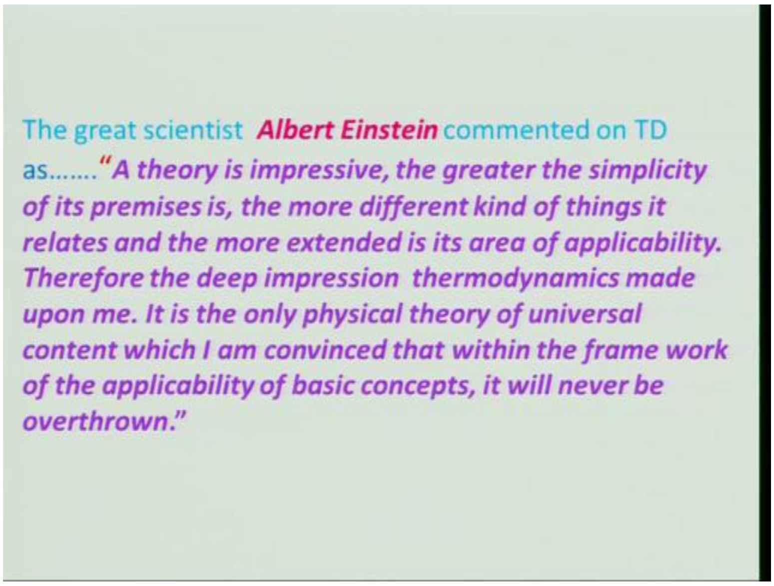

He comments that a theory is impressive the greater the simplicity of its premises is the more different kind of things it relates and the more extended is its area of applicability. Therefore, the deep impression the thermodynamics made upon me it is only the physical theory of universal content which I am convince that within the frame of work of the applicability of basic concepts, it will be never overthrown. That is the power of the thermodynamics, but let me make you to recall that it is the steam engine which brings our forth this subject as a magnanimous subject that in compares all the you know processes or all the activities of the entire universal. That means engineering leads to a science which is now very much extensive in nature.

We will now discussing about various concepts and terminologies involve in the engineering thermodynamics and most of you will be knowing about those concepts and terminologies. However, we will be reviewing it and re-look at it as it is quite important to recall and also the appreciate the points how it can be applied for propulsive devices. For example, like a propulsive devices we will be having several components if you consider a gas turbine engine there have been various components like air intake, compressor combustion chamber, turbine and nozzle.

If I take a simple in air intake then what I need to do if I want to understand what is happening during the flow for that I need to concentrate or focus my attention on the air intake component itself and see how it is interacting with the other components or its surrounding.

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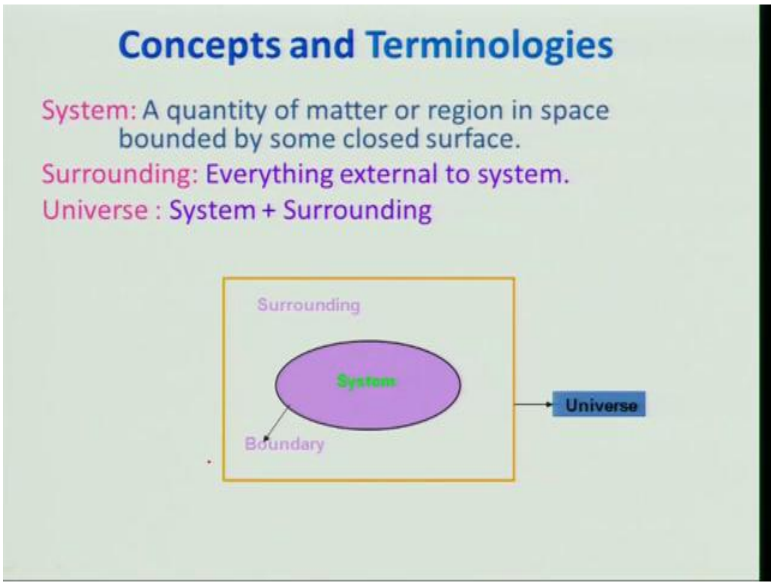

So therefore, whenever we are talking about a system and trying to carry out engineering thermodynamics analysis then naturally will have to consider a system which is nothing but a quantity of the matter or the region in the space bounded by certain close surface I took the example of the air intake. In that case the boundary of the air intake itself will be a close surface or a surface and which will be identifying the system so anything apart from the system we call it as a surrounding. For example, in this case this is the system and it is having boundary and anything outside of the system we call it as a surrounding and system and surrounding together we call it as a universe.

Let me take another example of a hot coffee cup right if I take a hot coffee cup then I will keep in a let us say on a table and I am interested to look at like how it is interacting with surrounding. What will be the surrounding because first I need to identify the system that means its boundary and when I identify a boundary I need to look at what I should consider as a boundary should I consider the hot coffee right. If it is full with the brim of the cup then as a boundary system boundary or I can consider as a full cup itself by the system boundary that depends upon your choice.

And what do you want, but what will be there in its surrounding how will I identify what is the surrounding. Suppose my cup of coffee here right and if you are sitting at faraway can I consider this as a surrounding for this system is it by definition it is, but I it cannot be how. Suppose I will measure the temperature here which is let says around 70 degree Celsius of the hot coffee and if I measure there it will be ambient temperature.

Even if I will allow this to transfer all the it becomes cools equilibrium with the surrounding then the temperature let say at around 5 meter, 6 meter or may be 5 feet kind of things only observe by the thermometer so naturally it cannot be surrounding. So, then how to go about it, it is very simple that you will have to consider wherever its effects will be. In the case of a hot coffee it will be within may be 1 centimetre there will be change in the temperature or the properties so with which the system is interacting therefore, we will call a system and surrounding.

So, it is very important to look at the what is system what is surrounding in the book what is given that anything external to the system will be surrounding is not possible you know. So therefore, it is important to understand this concept and the system and its surrounding is total is universe. For example, at this movement I am interacting with you if I consider myself as a system and interacting with surrounding right then it will be system and surrounding all of you people including surrounding will be consider as my universe system plus surrounding is a universe. Suppose, some of you are not listening will you be a part of surrounding certainly no you are dreaming or doing something else. So, you cannot be this interaction what we are trying to discuss the thermodynamics subject at this movement not possible. So therefore, one has to be worry about identifying a system and surrounding.

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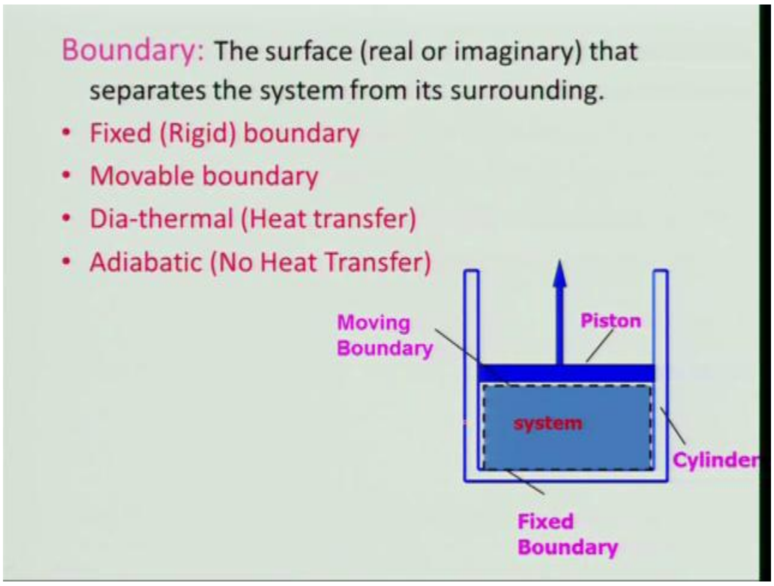

What we need to look at basically boundary, boundary can be a real or imaginary that separates system from its surrounding that we have already know, but how many ways we can divide this bound or we can classify the boundary. There can be a fixed or is it boundary there can be movable boundary there can be a dia-thermal where heat interaction will be taking place between system at surrounding and there is a another boundary where there would not be any heat interaction taking place we call it as a adiabatic boundary.

If I take a system as the gas in a piston cylinder what is being shown here you will find that whenever the system is interacting with the surrounding maybe we can heat it so that this the gas will be expanded and piston will move in this case the boundary is moving. So, we can call it as a moving boundary whereas, other places like on the other side it will be known as fixed boundary and if I will insulate it that means, I would allow any heat to be transfer around this system then it is basically an adiabatic boundary. Therefore, like we are aware that the several kinds of boundary, but in our case a propulsive devices can you use this and where will use and how will use is a matter of concern for which we will worried about.

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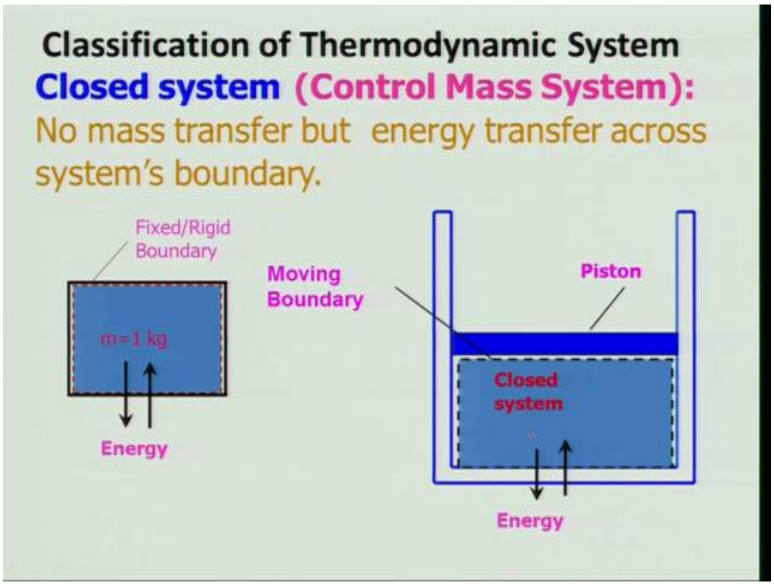

So, let us look at how many ways we can classify a thermodynamic system so can anybody tell me because all these thing, you know I just want to review it can anybody tell me how many ways we can classify the thermodynamic system what are those.

Student: Open system, close system and isolated system.

That means we can classify the thermodynamics system in to three categories open system, close system and isolated system. In case of a close system where the mass in the system will be remaining constant it would not be a what to call transferring across the boundary of the surface. However, it can allow the energy transfer to take place between the system and surrounding across its boundary and let us consider a simple a cylinder or a container which contain certain amount of gas of mass 1 kg. And whenever we are heating it what will happen it is having a fixed and rigid boundary it is not like a your balloon.

Whenever I push some air it will be inflated it is not flexible it is a rigid therefore, what will happen there will be change in the pressure because volume is remaining constant. So, and there will be interaction between system and surrounding because this dash line which I have shown is your system boundary and nearby is the is known as the surrounding. Now, this is known as a control mass system or a close system and if I take a piston cylinder example in this case the mass remaining constant it is not going out of the system boundary, but there is a heat interaction. Now, if you want to know how you can use this close system in case of a propulsive devices can you really use it or will just because of completeness sake we will be discussing.

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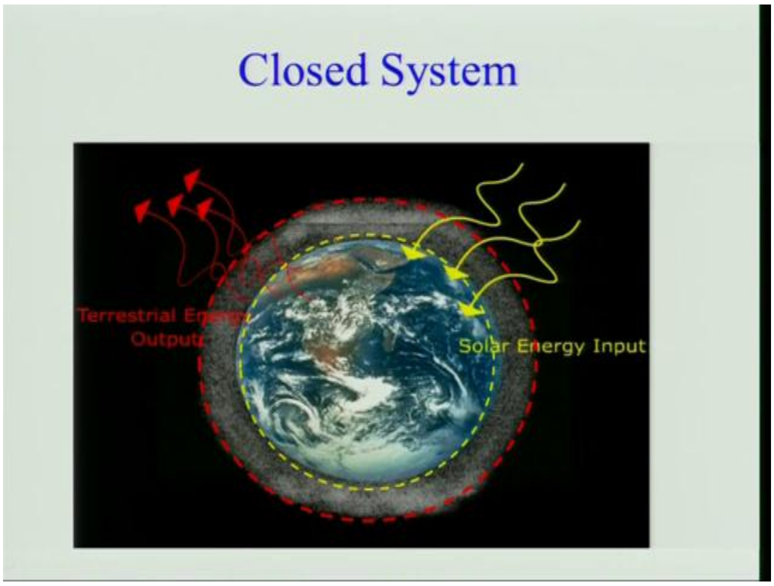

Let us look at a close system and how we can identify a boundary because unless we identify a boundary we cannot say that which is our system both system and surrounding without any boundary will be same. So, let us consider is our earth which I have shown here you can say this is the beautiful earth looks to be quite interesting. And this white colour things whatever I have shown is because of what it is because of precipitation and there will be lot of mass will be coming and evaporated and going and then re-circulated you know kind of things happening when your pollutions and other things.

Now, what is happening the heat is being coming from so sun as a solar energy input in to the surface and some of the heat will be going out as I have shown now I am interested to find out what will be the surface temperature and use as a closed system. So, how I will go about it for example, if I take these as my boundary that you mean the whole surface of the boundary can I call it as a close system I cannot because there will be evaporation you know the earth contain 70 percent of water.

Therefore, always evaporation will be taking place across the whole because we are interested to global temperature not as a local all right one temperature what is happening we are interested to find out. So, naturally there will be evaporation which will be going and the mass will be going out and there will be also be also concentration gradient. Therefore, movement will be there right there is a atmosphere which will be you know interaction will be taking place lot of fluid will be going up and down because of temperature because of concentration gradient because of your evaporations right so, mass will be going out can we use as a control mass system I cannot.

So therefore, I need to find out which is the right boundary for that I can consider this as the red one which I have shown here as a boundary for the close system. So therefore, it is very important to identify the proper boundary otherwise it is very difficult to carry out analysis by considering a close system or open system therefore, it is important to look at it to consider it.

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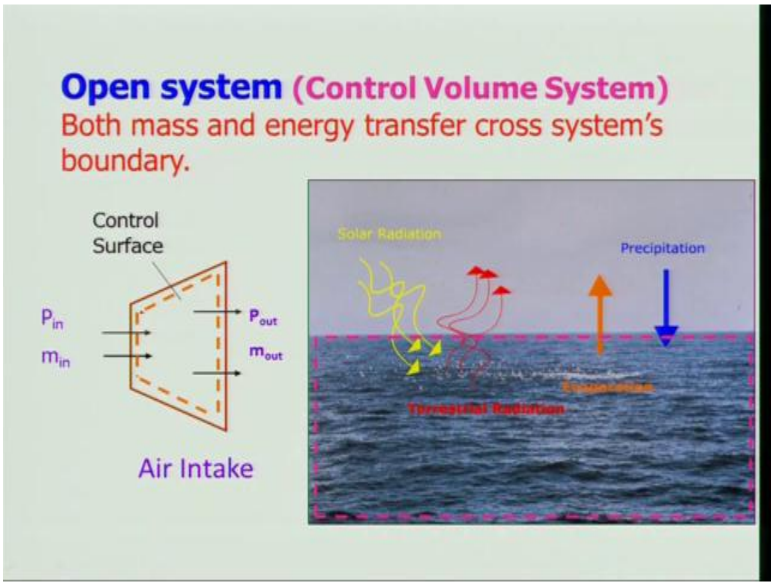

Let us look at an open system which we call it as also control volume system in this case both the mass and energy transfer will be taking place across the system boundary. That means the whenever system is interacting with the surrounding it will be having transfer of mass and so also the transfer of energy. For example, the same example I am taking it is from a surface of the sea and where there will be a solar radiation and also terrestrial radiation, evaporation and precipitation all those things will be taking place.

If I want to be boundary I can take this as my system boundary and look at an open system what is happening. And for example, we can take an air intake in case of a gas turbine engine and where, the fluid of the air will be getting into this diffuser of the air intake and going out there will be some interaction between system because this dash line I have taken as a system and rest of the things will be surrounding.

So, we need to identify a what to call a system now question arises whether will go for close system or whether will go for an open system where it will be convenient and how will choose it system boundary is a matter of concern and that depends on the individual and also the problem at hand. Now, most of the times in our propulsive devices you know we will be using the open system. However, whenever we are using the piston engine right then we need to consider the close system and some places we may consider.

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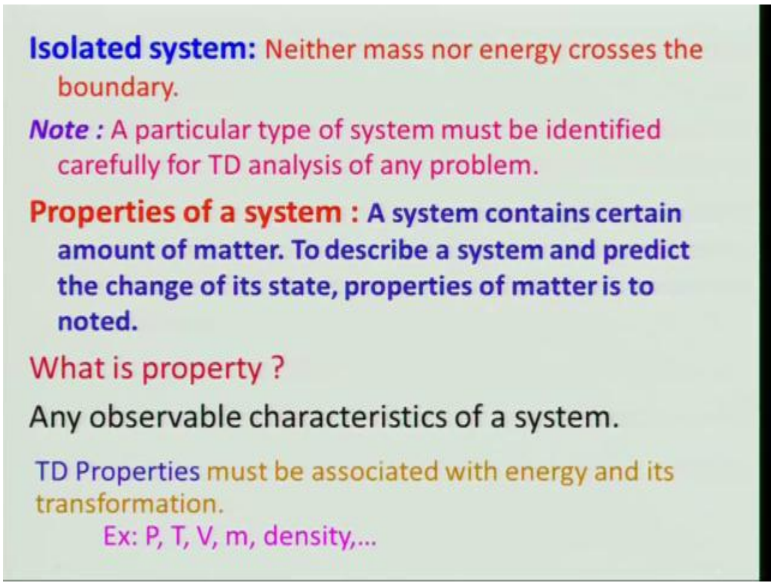

So but, in case of an isolated system neither the mass nor the energy crosses the boundary therefore, like there would not be any interaction then right then when will you use it, it is useless to have this kind of isolated system am I right then why it is there. Open system we may understand close system we may understand, but why an isolated system neither interaction of mass nor the interaction of energy so for thermodynamic system is concern you know energy interaction is essential, but all you of static I want to get the answer from you.

Let me just tell you briefly that this is being use very much whenever you talk about second law of thermodynamic therefore, it is very essential and important. So, I do not want to get in to that you please go back and look at you are thermodynamics book and how have handle while analysing the entropy in a system. So, what I would suggest here that a particular type of system must be identified carefully for thermodynamic analysis of any problem. Even in case of propulsive devices because otherwise everything will be wrong because unless your initial condition are the identification of boundary is not proper then your all other things will be fall apart so therefore, it is important.

Now, whenever you are talk about this the interaction between system its surrounding naturally we need to look at how the properties of a system is changing and what do you mean properties right that we need to, but it is important why because a system contains matter certain amount of matter and it will be interacting with the system and it will be change its state during that. So therefore, we need to understand property so, if will ask a question what do you mean by property then what it would be each state of the system are attributes of the system or a characteristics of the system.

If I say what is the property of by human being can anybody tell me right we are all worried about property of a system property of a you know certain matter may be iron what is the properties what is aluminium what is this properties, but we should know what is the property of the human being. That is very essential then talking about a you know other material, but we never worry about it nor education give this an opportunity to think about it I would suggest say just you think about it. So, that means a property will be any observable characteristics of a system, characteristics means attributes of a system right which will be changing and which will be repeatedly you can change.

For example, if I say that water is a colourless, odourless liquid or may be tasteless liquid right is water is tasteless or taste full, tasteless that depends upon the salt content what it is having. So therefore, can we call it is this as the properties we can call it as a properties so for portability of the water is concern, but however when we are talking about thermodynamic we would not be really interested in those properties so this those will be not of much values so for thermo dynamical analysis concern systems.

So, hence when we will be talking about the properties which will be important for thermodynamics that we call it as a thermodynamic properties which must be associated with energy and its transformation because energy is you know is a basically, the thermodynamics can be consider as a science of energy and its interaction and its transformations. So therefore, the properties what will be there is pressure, temperature volume, mass, density any other things you know whatever related to energy and its interaction. So, when you talk about this properties we can classify it, how can you classify the properties in case of thermodynamic.

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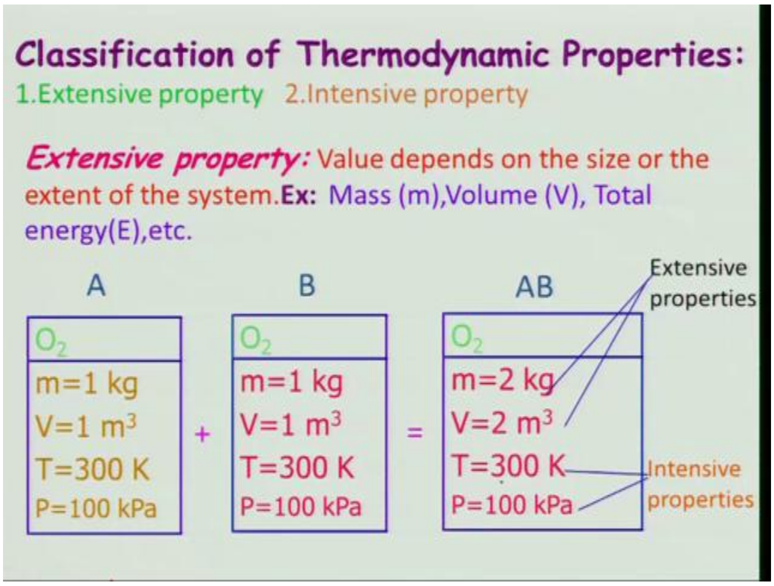

It can be classified into two categories one is extensive property other is an intensive properties what do you mean by extensive property it will be a property which will be dependent on the size or a extend of a system. For example, the mass, volume and total energy and others see always you know I find some of my students are get confuse extensive property, intensive property, but if will look at a milk man particularly in India what he will be doing he will be mixing may be 3 litres of milk 1 litre of water it becomes 4 litre of milk does you know that extensive property. He is experiencing he is using, but he does not know that you call it as a extensive property in thermodynamic sense.

So, let us take an example to appreciate this extensive property like we will consider the tank a contains oxygen, mass of 1 k g and volume of 1 meter cube and temperature 300 kelvin and pressure of 100 kP. And I will take another tank which is having same volume, same mass and same properties and will add together what we will get we will get a of course, a volume of 2 meter cube mass of 2 k g of oxygen and temperature is 300 kelvin and pressure is hundred kP kilo Pascal.

So, that means if you look at temperature and pressure is not changing whenever you are added or in some cases we will be subtracting that means it is does not depend on the extent of the system or the size of the system therefore, we call it as an intensive property. However we use also another property know as specific property for example, specific volume by definitions specific volume is volume divided by mass and if you look at volume is an extensive property mass is also an extensive property so the ratio of it is an intensive. So, we will be using that, but I would not be discussing now as you are all aware of it.

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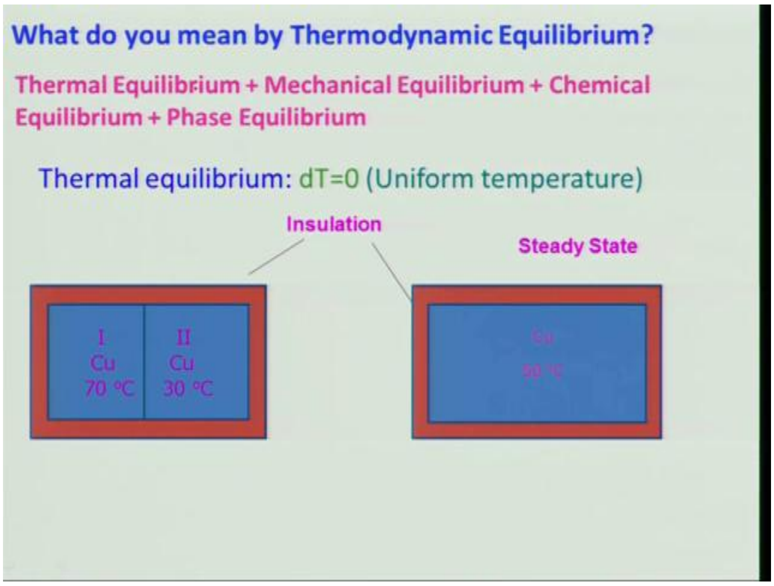

So, what do you mean by thermodynamic equilibrium you must be knowing like because engineering thermodynamic means always will be dealing with equilibrium systems so we must understand what do you mean by a system to be in thermodynamic equilibrium. So, let us consider a copper block at 70 degree Celsius and there is a another copper block at 30 degree Celsius which is having of course, a separator then we will remove this separators as that both the block will be coming in contact. And will allow enough time such that there will be heat transfer from the copper block one to the copper block two such that it will attempt a temperature of 50 degree Celsius.

That means it has reach a steady state and it has reach a equilibrium because all are insulated this block together is in equilibrium there no change in occurring between this two block. So, can we call it as a thermo system to be in thermodynamic equilibrium yes, but certainly no it is basically thermal equilibrium that means, uniform temperature occurring between the systems. Then something wrong then when we call it as a system to be in thermodynamic equilibrium when all this equilibrium like thermal equilibrium, mechanical equilibrium, chemical equilibrium and phase equilibrium are being satisfied are being maintained then only we call it as a basically thermodynamic equilibrium.

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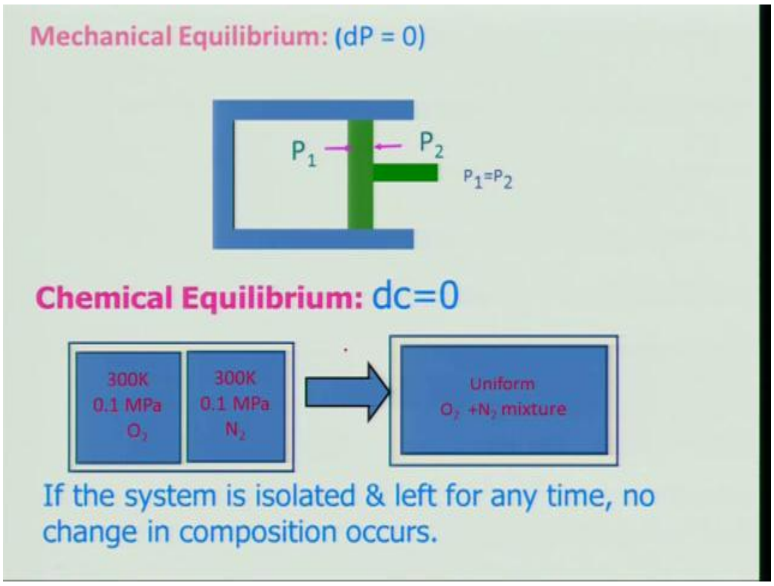

So, let us consider what do you mean by mechanical equilibrium where pressure across the system boundary will be 0. For example, if I take a piston cylinder arrangement and this white portion is will consider as our system and there is a pressure which is applying and there is a external pressure p 2 when p 1 is equal to p 2 we call it is in mechanical equilibrium. And similarly, when we consider there is a oxygen in the container left hand side container which is at 300 kelvin and 0.1 mega Pascal there is a another container adjacent to it that is having nitrogen, but at the same temperature and pressure.

If I remove this patrician and allow it to move slowly then what will happen the oxygen will be trying to move to the compartment one to the compartment two that means from the left hand side to the right hand side, nitrogen will be moving from right hand side to the lift hand side due to what due to concentration gradient. That means diffusion process, but if you allow a loss amount of time the process to take place then what will happen in the whole in a container it will be all remaining the same. So therefore, the concentration gradient will be 0 and we call it as a chemical equilibrium.

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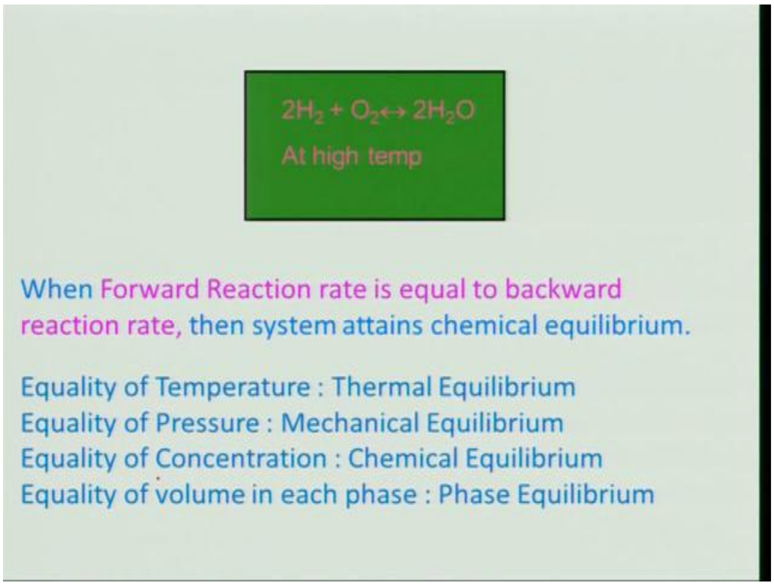

So, let us consider another one like hydrogen 2 mole of hydrogen reacting with 1 mole of oxygen going to the product of 2 mole of water and at a particular high temperature. That means some reaction is taking place otherwise water would not be form if it is a low temperature. And then if I allow this reaction to take place for quite some time then we will see that there no more reaction take it is not true what is happening that the forward reaction rate is equal to the backward reaction rate.

Then the system attains the chemically equilibrium that means and similarly, also phase equilibrium will be taking place during the phase transformation like example is the evaporation of water or solidifications and other things. That means we can call a system to be in thermo dynamic equilibrium only when equality of temperature exist equality of pressure that is mechanical equilibrium, equality of concentration that is chemical equilibrium and equality of volume in each phase that is phase equilibrium.

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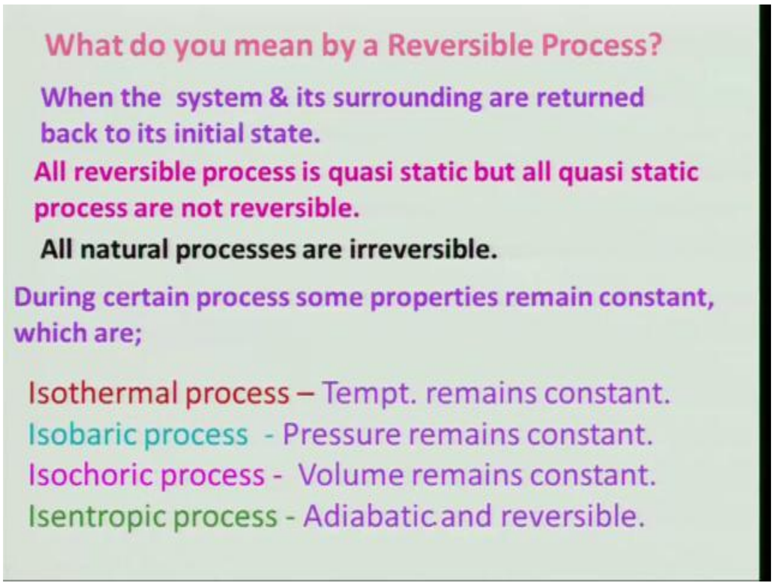

So, let us say just try to recall what do you mean by a reversible process that means whenever system and surrounding will be return back to its initial state then we call it as a reversible process. So, all reversible process is quasi static, but al quasi static process are not reversible so what do you mean by this quasi static can anybody tell me because this concept you will be knowing I am not discuss.

Student: ((Refer Time: 37:49))

That means the gradient which will be there is a very very slow a very small such that the changes would not be occurring or the change will be very very infinite decimal is small so there we call it as a quasi static process. For example, if I take a piston cylinder and I will put on the top of the piston some sand grain and then I will remove a small sand grain form it. And there will be change in the you know gas as a system pressure and the surrounding, but that change is very very small therefore, we call it as a quasi static change.

Now, in life what we need we need to have a quasi static process so that any changes occurring it would not affect your yourself or others dramatically or drastically however changes is innovative. So therefore, those are quasi static process you know which is essential, but all quasi static process need not to be reversible and keep in mind that all natural processes are irreversible in nature, but in thermo dynamic we will discussing more about irreversible process. So, during certain process some properties remains constant for example, if it is a temperature remaining constant we call it an isothermal process, if the pressure will remain constant we call it an isobaric process and the volume remains constant we call it as isochoric process. And if adiabatic that means no heat interaction between system surrounding take place and reversible that means what we call reversible also then we call it as an isentropic process. So, this processes which will be using particularly the isentropic process and isobaric process which will be using while analysing the propulsive devices.

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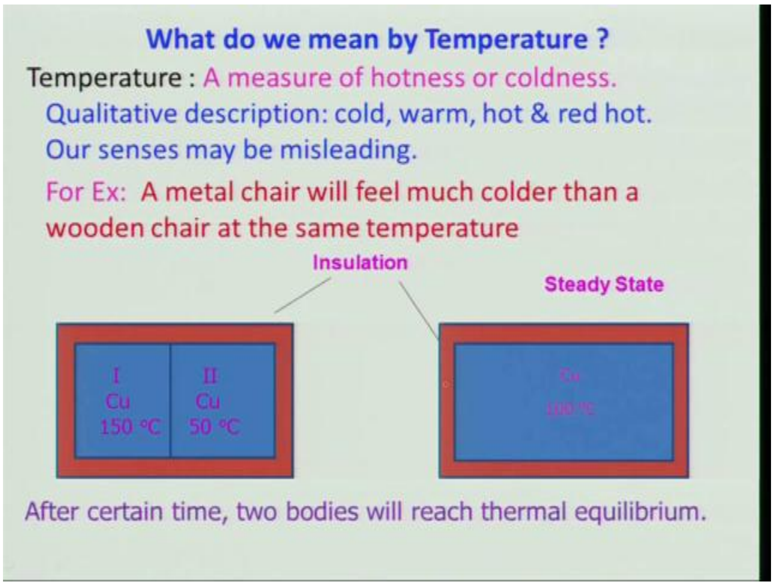

Now, question arise what do you mean by temperature because without temperature you cannot really think about any heat interactions what do you mean by that, means it is basically in layman term a measure of hotness or coldness right whether how good it is so far you know whether it is cold or hot. And it is basically qualitative description that means it will be cold or a warm or it may be hot it may be red hot, but is it really we can talk about it. Then it will be problem because our senses may be misleading that depends up on person to person and depends up on the mood of the person also right and it will be misleading.

Even if you take another example which is not having sense, but men can have a sense to observe for example, if I take 2 wooden chair sorry if I take 1 wooden chair and 1 metal chair right and will it be keep at the same room. Let us say in this AC room having the same temperature almost, but if you go and sit down you feel or you put your hand on it you will feel that one of them is colder which one will be colder, metal will be colder whereas, the wooden will be not that much as compared with the wood therefore, it will be misleading.

So, let us consider a example like copper block which is at 150 degree Celsius there is a second copper block at 50 degree Celsius and when this partition will be removed and they will come in contact and there will be heat transfer will be taking place and it will reach a state at steady state 100 degree Celsius.

That is the average temperature between these two what is the meaning, meaning is that two bodies has reached a thermal equilibrium and this concept is being used for measuring the temperature remember that. Whenever you will have fever we always use a thermometer. And then we will allow for some time to be in contact with the body right between contact between the body and the thermometer and then you will measure the temperature that we do routinely.

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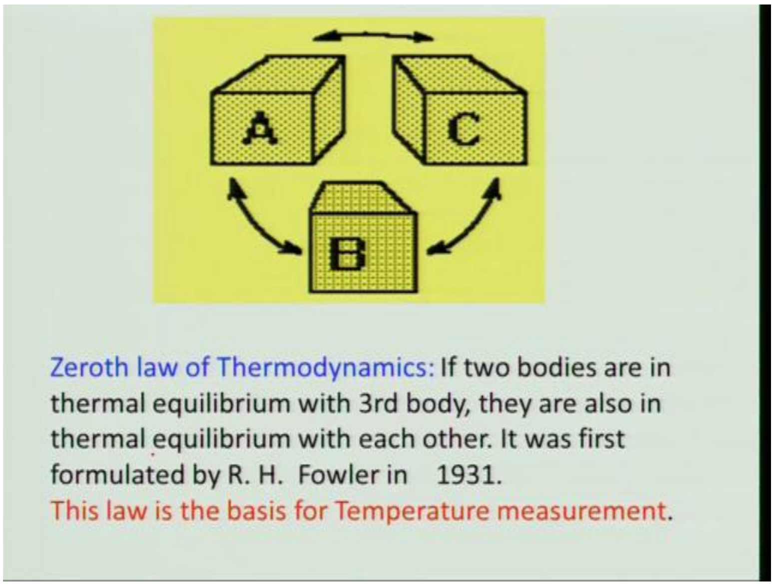

And this if we can and this is the basis of the thermal equilibrium is the basis of 0th law of thermodynamics let us consider there is a block A which is in equilibrium with the b and there is another block which is also in equilibrium with the C sorry the block C is in equilibrium with B. That means, which says that the block A is in equilibrium with the block C that is nothing but 0th law of thermodynamic if two bodies are in thermal equilibrium with the third body they are also in thermal equilibrium with each other.

And this is the very common things which is being formalized by the RH Fowler in 1931 after the first and second law being proposed. Therefore, it is known as 0th law and if you look at Galileo we are knowing and he have the device thermometer at that time. So, it is not everything, but he formalized this is the thing which he experienced, but we do not formalize into law and this law is the basis for the temperature measurement as I told just few minutes back.

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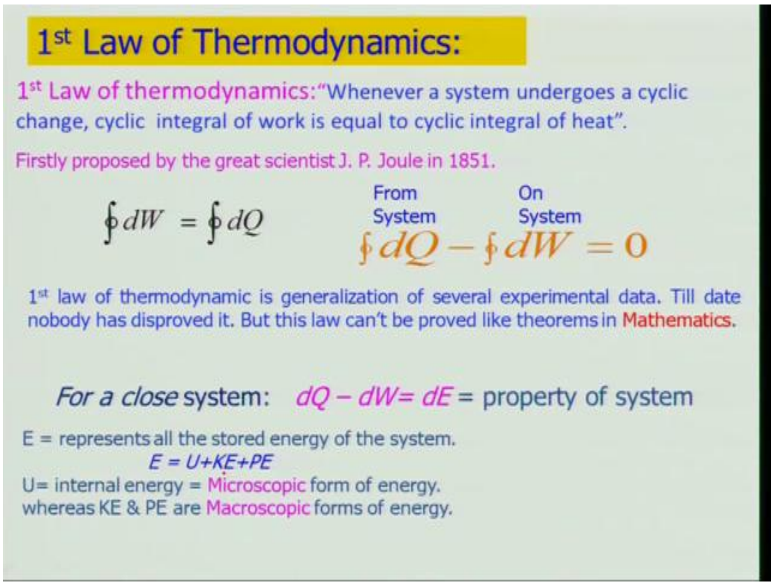

So, what we will now look at is the first law of thermodynamics and we state that whenever a system undergoes a cyclic change however the complex cycle may be the cyclic integral of work is equal to cyclic integral of heat. So, we say that the cyclic integral of work is proportional to the cycle integral of heat keep in mind that for SI unit this proportionality constant is equal to 1. Therefore, I have stated directly as that whenever a system undergoes a cyclic change cyclic integral of work is equal to cyclic change of heat.

And it was first proposed by the greater scientist JP Joule in 1851 conducting series of experiment he took some 4 years to conduct several experiment to make this statement in a very systematic manner. And if I write it down in this form that is cyclic integral of dQ minus cyclic integral dW is equal to 0 this work is basically on the system. And if it is on the system there will be always a negative sign you will be knowing the negative sign convention and from the system is basically is positive.

So, if the first law of thermodynamic is generalized of several experimental data generated by JP Joule and also he formulated as a first law of thermodynamics. And there is another person who was also working simultaneously or parallelly along with him, but he is not considered to the you know proposer of this j p first law of thermodynamic. Till that nobody has disproved it, but this law cannot be proved like theorem in mathematics may be you know that does not means that nobody will prove this to be wrong, may be some of you may try it out and then you know like we will have to see.

For a closed system this happens to be dQ minus dW is equal to dE and dE is basically what it is the total energy right which represent all the stored energy of the system. It can be have two term one is U which represent internal energy or the microscopic form of energy. And whereas, the kinetic and potential energy are microscopic form of energy and there are several other microscopic form of energy as well which are not listed here. And keep in mind that E is the energy is basically property of the system whether heat and work are the properties of the system or not is it so. Actually the heat and work are not the property of the system they are in energy in transit they are not energy in thermodynamic sense.

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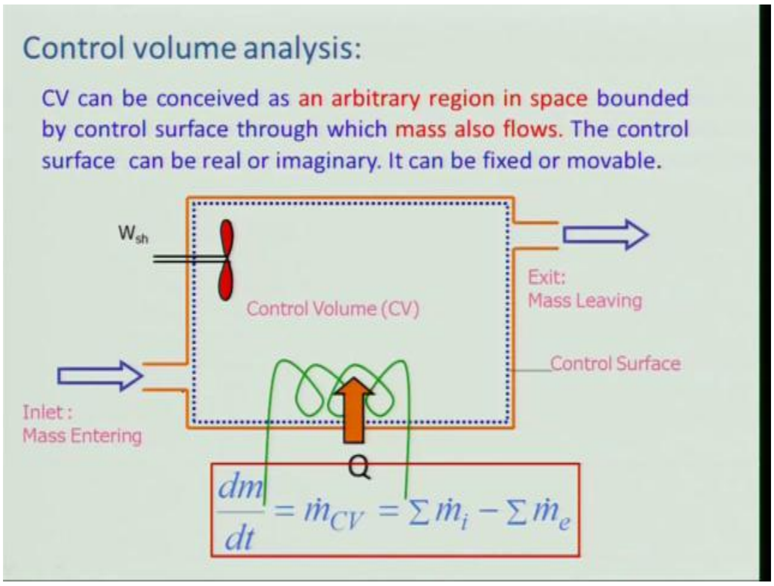

So, let us look at how we can really apply this first law of thermodynamics you know for an open system because we will be using for a propulsive devices analysis of propulsive devices. Therefore, we need to learn how we can use this equation or the closed system equations for an open system. So, we will little bit elaborate on this as we know that control volume can be conceived as an arbitrary region in space bounded by the control surface through which mass can also transfer or flows and the control surface can be real or it can be imaginary, it can be fixed or movable.

Let us consider a system which is containing a soft work which is having heat interaction and the what you call some flow is entering into the system some mass is leaving out of the system and I have taken this what you call dashed line as may system. If you look at this is basically imaginary boundary there is a flow there is no solid boundary, but it is you are imagining as if it is a boundary there. Now, how to what to call analyse this for this what we need to know we need to understand how much mass is entering how much mass is going out and how much mass is being accumulated in the control volume.

And that is is being expressed in mathematical term that is d m by d t is equal to m dot CV is equal to summation of m dot i minus summation of m dot e, keep in mind that this is a general equation, but however in this case there is a only one inlet one outlet therefore, it will be for this control volume it will be d m by d t is equal to m dot i minus m dot e. And this is a basically law of conservation of mass which is based on common sense it is like your money is flowing how much money you are getting how much it is you are using and how much being have you accumulated. So therefore, it is a very common sense you can apply and this is known as continuity equation also we will be using it where rough usely.

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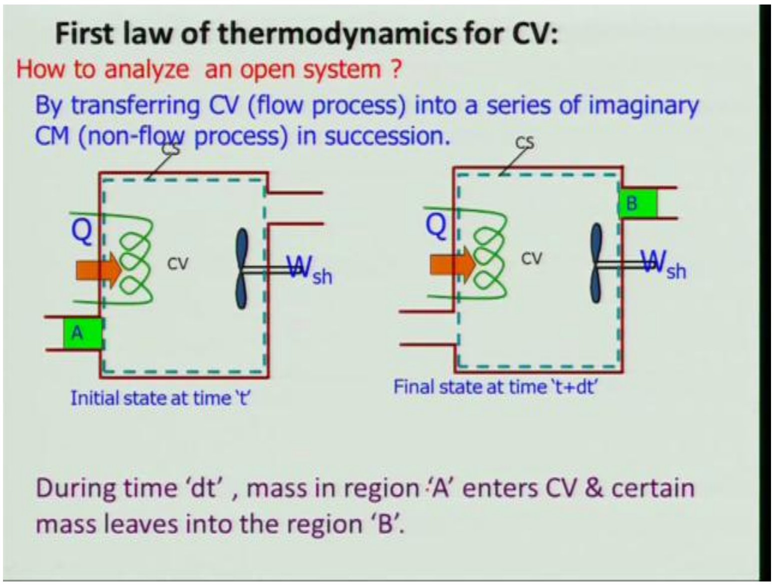

And let us look at how we can analyse an open system particularly applying the first law of thermodynamics so what we will do, we will consider the system as a you know transferring into series of imaginary non flow processes in succession. That means you might have taken some videos if you look at the flow the mass is coming in mass is going out. Now, if I take a video for certain time and convert into a snapshots then what will happen each format it will be different right.

So, what will say we will considered at the initial state this is a control mass that means the mass of this whatever there in these system boundary and plus the mass in the so in this green colour which is about to enter and at the mass at the time t plus d t and this d t is very, very small. That certain mass is about to leave the control volume and then this control volume plus this mass together will be considered as a flow system or a non-flow system. That means this itself is a non-flow system or a flow system and this is a also a flow system and two flow system in succession you can call it as an open system. Now during this time as I told you mass in region enters CV and certain mass leaves into the region b right during this process.

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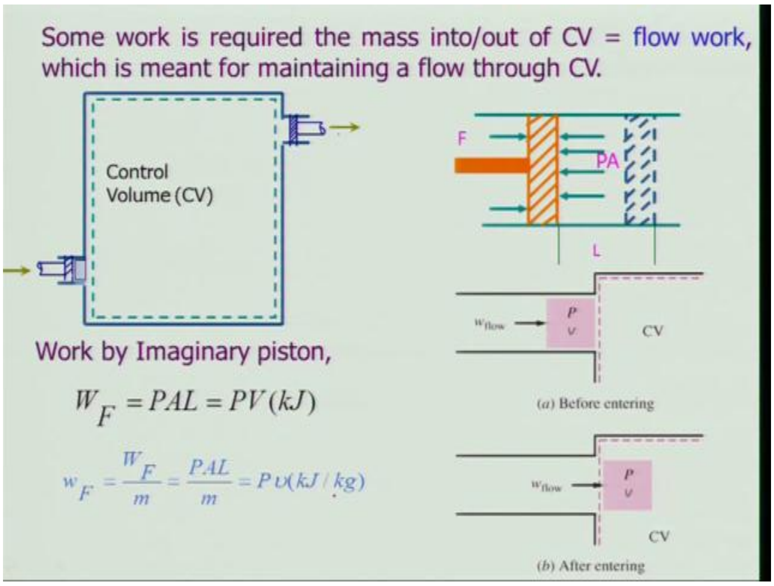

And some work is required to mass into and out of the CV and that we call it as a flow work which mean for maintaining the flow through the control volume because the flow will be coming in and going out. So, you can image as if there is a piston which is pushing the fluid like which I have shown here entering into the control volume similarly, a piston is moving out it is sucking the fluid from the out.

So, if you look at the flow work wise that means certain amount of you know pressure will be applied with certain amount of specify volume which will p into v will be work and that will be done it is before entering the thing and there will be flow which is after entering into the thing. It is just about to enter and this is already entered and if you look at it that means on this thing if I take a piston and then equilibrium condition that PA is nothing but your force being applied on this piston.

So therefore, the work done by this imaginary piston if you keep in mind this is we are just imagining actual piston not there it is the flow work right which is being pumped by the either compressor or a in a liquid it is a pump kind of thing. So, the work done will be PA that is the force into the displacement that will give me PV it is nothing but work done. So, specific work will be basically work done per unit mass that is P and specific volume it is kilo joule per kg.

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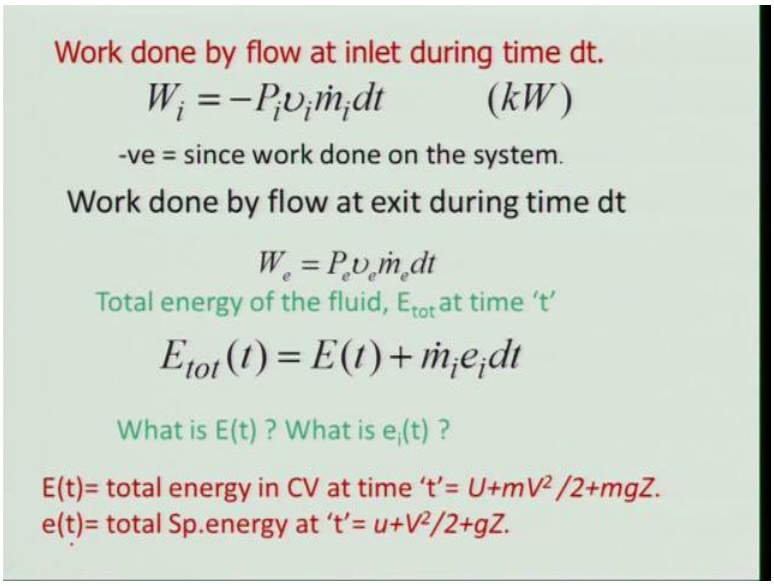

Work done by the flow at inlet during time what it will be Wi is equal to P i v i m dot i dt, which we have already seen and work done and keep in mind there is the negative signs, sign is being here because since is work done on the system and if you look at as per convention work done by the system will be the positive. So, work done by the flow at the exit during time dt will be W e P e v e m dot e dt, and total energy of the fluid E total at time t, will be then E total t is equal to E t and that means total energy the t n the energy due to the flow work that is m dot i e i d t.

And you keep in mind that what is this capital, capital is basically E t a total energy in the control volume at time t which consist of the internal energy kinetic energy and potential energy our case, but however there might be other forms of microscopic energy. And e t means total specific energy at time t that is u small u that is the specific internal energy and v square by 2 and g Z that is potential energy. So, if you look at what we will do we will be looking at this energy balance across this system during the time dt and trying to derive an expression for a control volume system so for the first law of thermodynamic is concerned.

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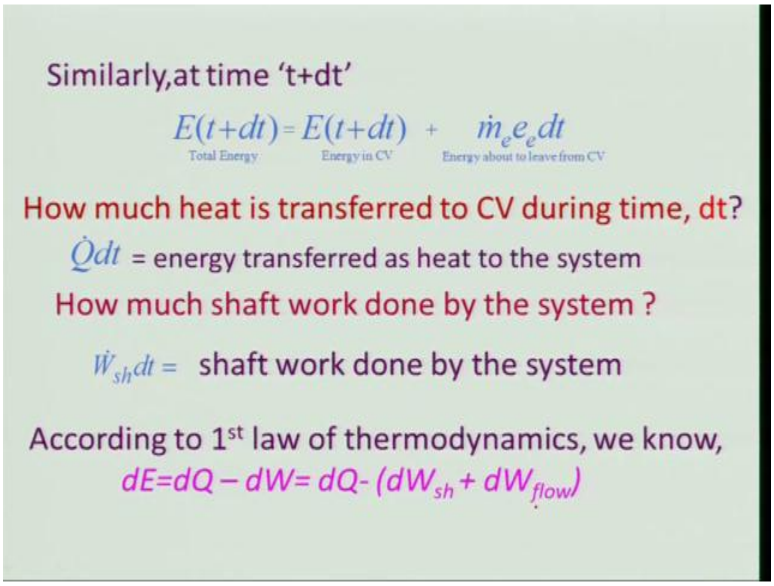

So similarly, at time t plus d t it will be E t plus d t the total energy is equal to the energy in the control volume plus the energy about to leave the control volume. So, how much heat is transferred to the CV during this time that will be the Q dot d t that means, the amount of heat per unit time into the d t that is the energy transferred as the heat to the system. Similarly, how much work you know to be done by the system here I am considering shaft work there might be other form of work as well right it can be electrical work it can be electromagnetic work or the things which we are not concerned.

So, the shaft work into rate into dt will give me the shaft work done by the system so what we will do we will now apply this thing to the you know all those terms in this first law of thermodynamic for a control mass system or a closed system. That is we know dE is equal to dQ minus dW keep in mind that dW is having two component, one is shaft work what will be our interest in purposive devices and there is a flow work. So, also we are interested in the flow work because ours is a open system most of the gas turbine and rocket engineering we will be considering as an open system.

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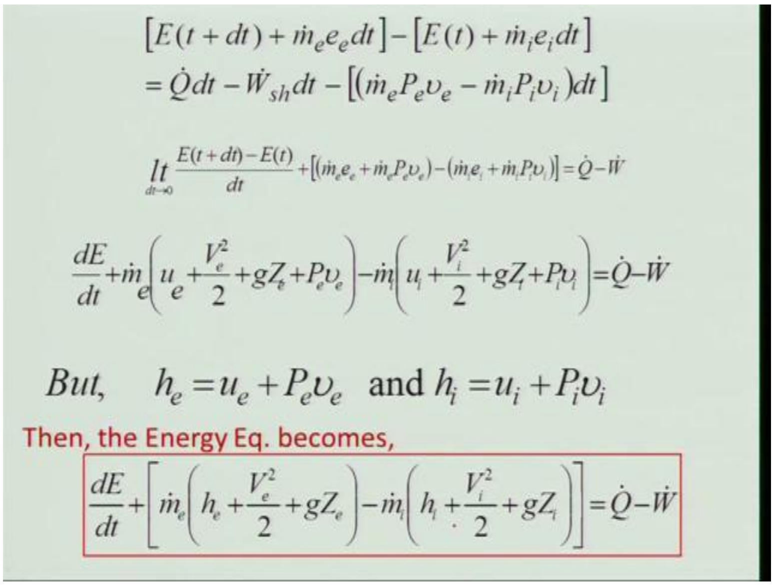

So, if I substitute all these values in that previous equation I will get this term at the you know total energy at the exit minus total energy at the inlet is equal to Q d t minus W dot shaft into d t this is the work done and this is the flow work which will be the flow work in the exit minus flow work in the inlet into d t. If I divide this equation by d t and when d t tending to us 0 what I will get, I will get E at time t plus d t minus E at time t divided by d t. And these are the terms which will be flow work and this is the energy m dot e and e e is the total energy which will be leaving and which will be entering into the control volume and this is your shaft work and this is the this is a shaft work and this is your heat interaction.

So, if I rewrite these equations I will get d E by d t plus you look at the how much energy is going out this is the mass flow rate of at the exit into the internal energy and this is your kinetic energy this is your potential energy and this is your flow work. And similarly, at the exit and this is the work heat interaction and the work interaction it can be shaft work it can be any other work. So, if you look at we know by definition it is h e is equal to u e plus P e v e by definition enthalpy total or the enthalpy is equal to internal energy into the flow work.

So, then total energy equation we can write down d E by d t into the m dot in the bracket h e plus V e square divided by 2 plus g Z e, that is the energy which is going outer from the exit of the control volume and this is the amount of energy entering into it and this is the heat interaction and the work interaction. This equation we will be using for our analysis of the propulsive devices so you should keep this in mind.

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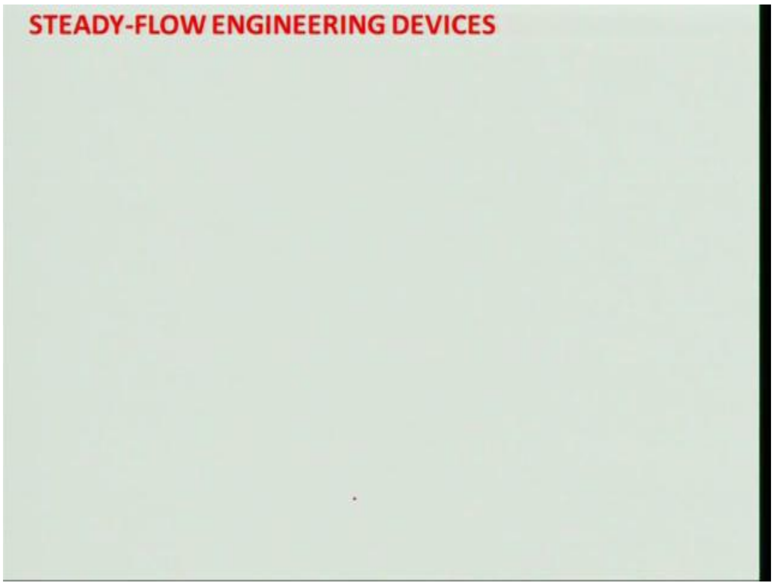

So, what we will do now we will be looking at some of the concept.

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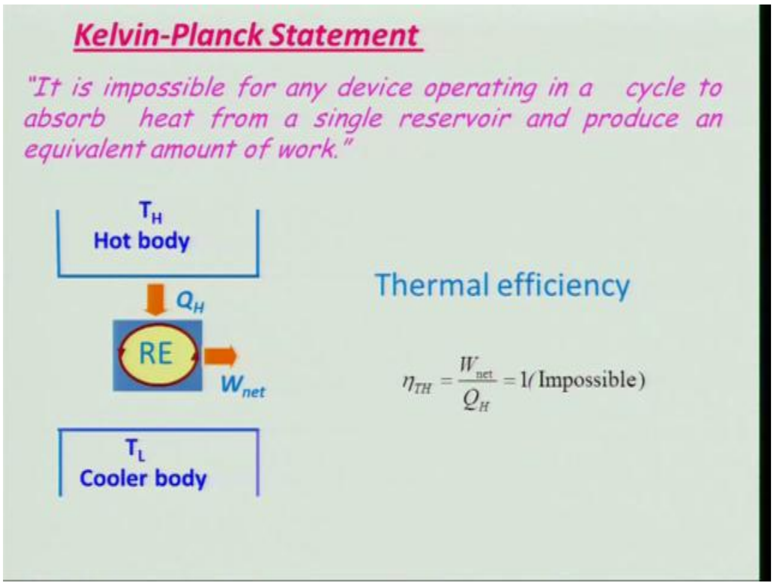

We have discuss about the first law of thermodynamics for both the control volume and control mass system now we will look at the second law of thermodynamics. Let us consider a reversible heating in which I have shown here and it is absorbing certain amount of heat that is TH from a thermal resolver at temperature TH it will be very interesting if it can convert all the heat into the work. Then what will be our thermal efficiency, thermal efficiency will be W net divided by Q h that means 100 percent efficiency actually it is impossible. And these observation was done by a scientist and who state that it is impossible for any device operating in a cycle to observe heat from a single reservoir and produce an equivalent amount of work.

And this was being stated by a kelvin and also another scientist Planck therefore, we call it as a Kelvin-Planck statement and this is known as basically perpetual motion machine kind of things which will take all the heat and then convert into work it will be interesting if somebody can do that.

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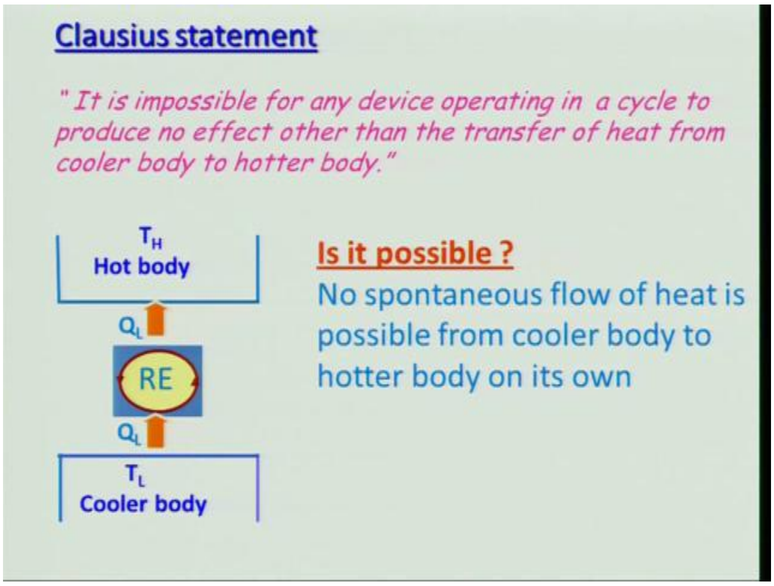

And let us look at other way around that is that reversibility engine which will be absorbing the heat Q L and it is from the lower temperature and transferring to the hot body which will be at a higher temperature. Question arises is it possible actually it is not possible that means no spontaneous flow of heat is possible from cooler body to the hotter body on its own. However, if it is other way around that means heat can flow very naturally from hot body to the cool body that we always observe like we have experienced so that is possible whereas, reverse is not possible.

And that is known as Clausius statements which states it is impossible for any device operating in a cycle to produce no effect other than the transfer of heat from a cooler body to the hotter body. These statements although it is a part of second law of thermodynamics will it help us to analyse certainly it cannot only it can give you qualitative way of you know interpreting the process whether it is a possible or not.

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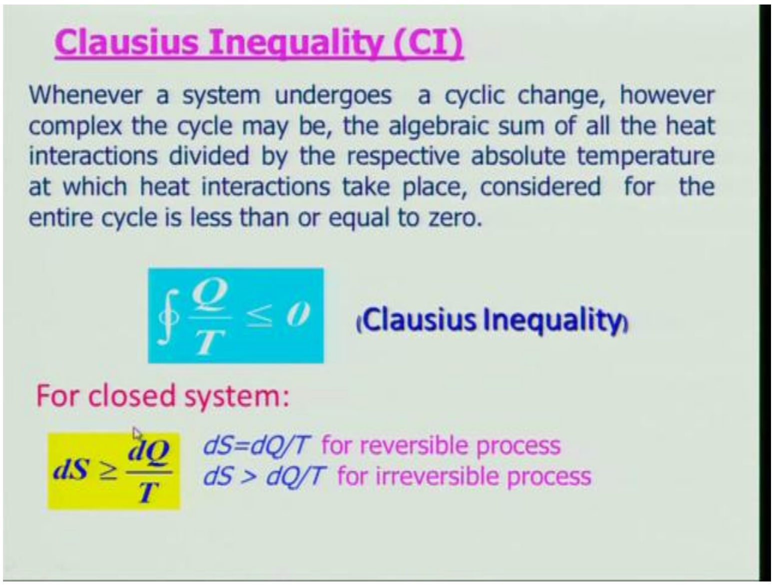

But there comes another you know state statement which is known as Clausius inequality which states that whenever a system undergoes a cyclic change, however complex the cycle may be algebraic sum of all the heat interaction divided by the respective absolute temperature at which heat interactions take place, consider for the entire cycle is less than equal to 0. And this statement is mathematically can be written as Q divided by temperature over the entire cycle is less than equal to 0 which is known as Clausius inequality.

And for a closed system and when you apply this kind of inequality Clausius inequality you can arrive at change in entropy is greater than equal to d Q by T and for reversible process this entropy is equal to change in entropy is equal to d Q by T. Whereas, for irreversible process the change in entropy is always greater than the d Q by T and this is you can apply generally for a closed system, but we will be more interested in an open system therefore, we need to derive expression for the open system.

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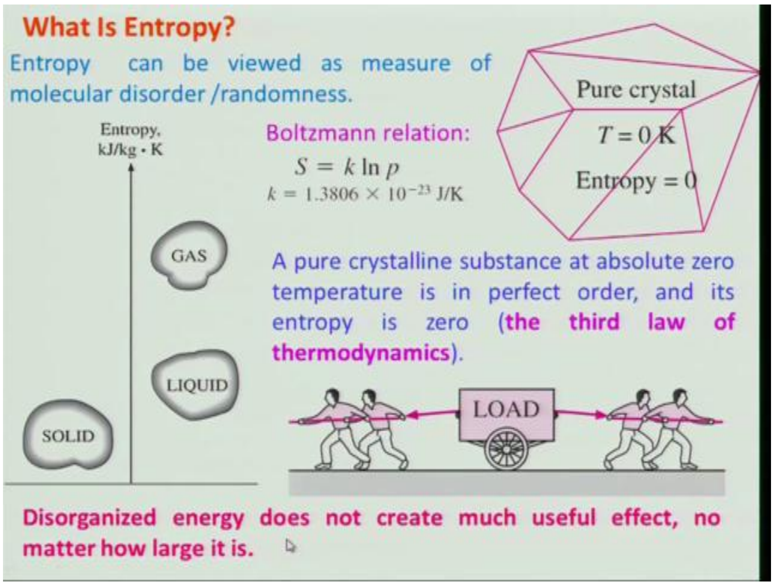

Which I would not be doing I will be only talk about little later on, but let us understand fast that what do you mean by entropy. Entropy can be viewed as a measure of molecular disorder and randomness I mean if you look at a solid which is having a very low entropy because it is randomness will be very very low why because the molecules will not be vibrate will be vibrating only it would not be just moving apart like a gas where it will be going wherever it will be you know around the space

Therefore, the liquid is having a low entropy and gas is having a higher entropy and a Boltzmann relation gives you a definition of the entropy which state that entropy is equal to k into l n p, where k is the Boltzmann constant the value is given here and p is the thermodynamic probability, but how you will define it because always whenever we are talking about it we always talk about change in entropy. We may know find out from the Clausius inequality change in entropy, but we need to know actual value for that we need to look at a pure crystal and for a pure crystal at temperature 0 kelvin entropy will be 0 and that is nothing but your third law of thermodynamic.

Which states that a pure crystalline substance at absolute 0 temperature is in perfect order and its entropy is 0 what is the meaning of it that means the molecules will be vibrating and at temperature 0 kelvin it will be not vibrating it will be remaining in the same place, but now how it is a solution or some other thing you can not apply this statement that means entropy cannot be 0 even if the temperature is at 0 kelvin. So, it is very important to what to call talk about this entropy it is very useful in our day to day life also as well because our objective in the life must be to reduce the entropy or minimize the entropy.

For example, if I take a load and some people are you know trying to pull in the one direction where as other people are pulling in the other direction can this the load are they will be moved certainly no. This is the similar thing what is happening in our country each individual is having their own way of looking at thing of selfish interest so that they are pulling apart each other not in a direct way. So therefore, entropy is a very important and it is important to you know look at it and handle it so disorganized energy does not create much useful effect, no matter how large it is and that is true for our ourself also.

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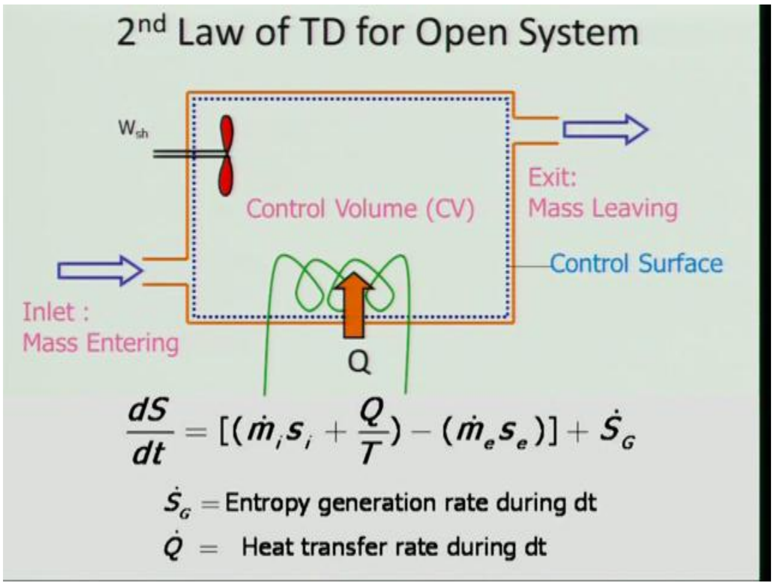

So, let us look at now the second law of thermodynamic for on open system I have already shown here this kind of you know system where shaft work and heat interaction taking place and there is the mass is entering mass is leaving and if you apply this you know Clausius inequality for the control mass. In the similar way, we have used for the first law of thermodynamic control volume we can arrive at this expression d S by d t is equal to mass of what we call mass flux at the inlet into entropy into Q by T minus the amount of entropy, total entropy.

That is mass exit and then entropy what you call at the exit going and this is known as the exit is the entropy generation rate during time d t and heat transfer rate during time d t. So, I mean this is the portion what we have covered now I will just summarize that what we have learned today we have learned about the about the various concepts and definitions of system and its surrounding. Then you move into 0th law of thermodynamics, first law of thermodynamics, and second law of thermodynamics for both control volume and control mass system with this we will stop over here.