Thermal Engineering: Basic and Applied

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Lecture - 01

First Law of Thermodynamics for Control Mass and Control Volume Systems

I welcome you all to this session of thermal engineering. And in today's class, we shall discuss about the first law of thermodynamics applied to both control mass and control volume systems.

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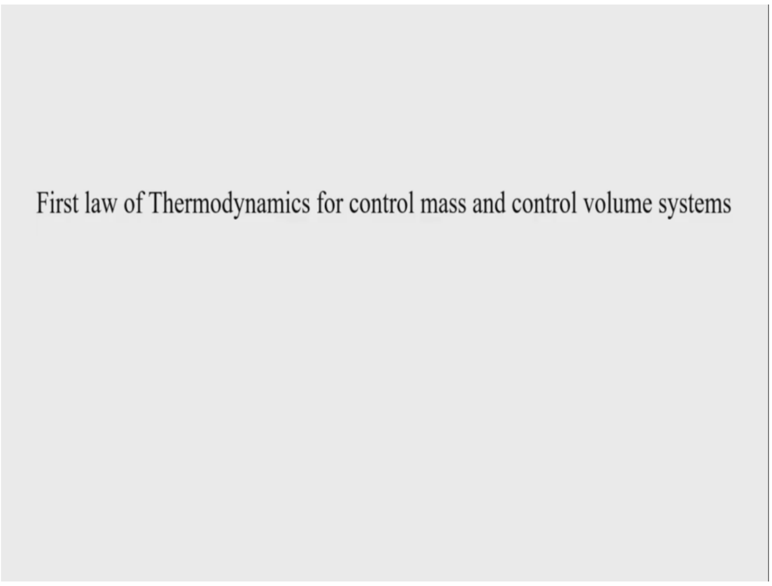

First law of Thermodynamics for control mass and control volume systems

You know that in this course, as the name suggest we shall be discussing about the thermal engineering systems essentially to learn the analysis & also the operational procedures of different thermal systems. So, question is why do need to learn all these aspects of thermal engineering systems? You know that for the human comfort along with considering different practical applications, be it power plant or any process industries, and as I was talking about human comfort, so, you know air conditioning as well as refrigeration system in all these systems, you know, whatever processes are there if we need to learn those processes we need to understand about the thermodynamics also the fluid mechanics. Now, learning the basic things which will be applied to understand the overall performance, overall analysis of the system is very important to the designer, at least to have the optimum design of the systems.

So, in this course, we will be discussing about different subsystems like power system, refrigeration system, along with a few mechanical systems in which we need to apply the basic concepts of thermodynamics that we have learned from our undergraduate course. But, since I will be focusing mostly on the applied part but to understand the procedure analysis of those applied system in a greater detail, I was thinking to discuss a little bit about the basic of thermodynamics like first law and second law. So, the combination of these 2 laws are important and if we need to map the processes in different thermodynamic planes, essentially to estimate the performance of these processes we must know the combination of first and second laws applied to different processes.

So to start with, today we shall discuss about the first law in fact, I am not going to discuss in detail about first law rather we shall try to recap whatever you have learned from our basic thermodynamics course.

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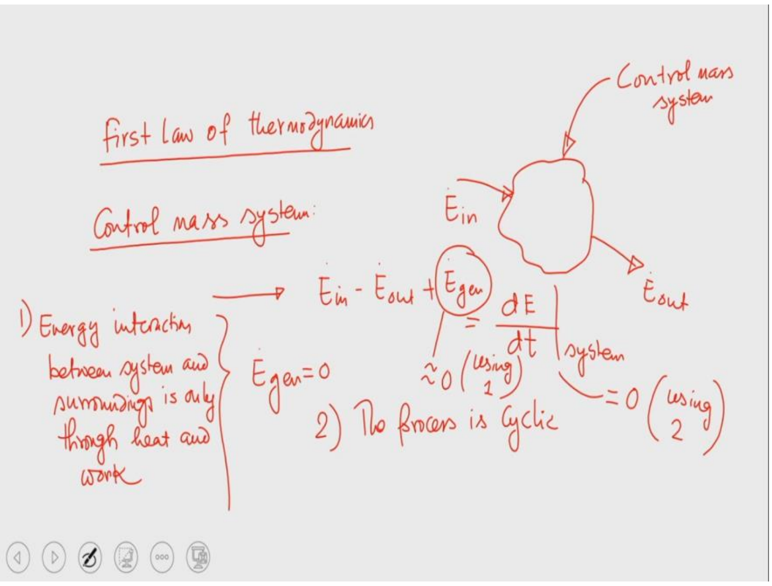

first law of thermodynamics

Control mass system:

1) Energy interaction between system and surroundings is only through heat and work

$$\dot{E}_{in} - \dot{E}_{out} + \boxed{\dot{E}_{gen}} = \frac{dE}{dt}\Big|_{system}$$

$\dot{E}_{gen} = 0$

≈ 0 (using 1)

2) The process is cyclic

$= 0$ (using 2)

So, you know that we have learned about first law of thermodynamics. So today, we shall see that if we try to apply this first law for the control mass as well as control volume system, what would be the form of the equation that we shall try to establish because these equations will be very much useful to understand the processes in different thermal systems.

So, let's try to apply first law for the control mass system initially. So, what is control mass system? We have seen that there is no introduction of mass with the surroundings. We have learned from thermodynamics course that even if we allow the mass in equal to mass out, so at any time we can see that the mass is remaining fixed.

But in that case identity will be changed, so, we cannot call it as a control mass system. So, control mass system means there is no mass interaction between system and the surroundings. So, now, if we try to apply the first law to the control mass system, we can consider any arbitrary control mass system or lump system. So this is a lump system and or lump body and this is a control mass system.

Now, we shall try to understand if we try to apply first law to the system, what would be the mathematical form of the equation. So, what we have learned from basic thermodynamics course is that first law is the statement of the conservation of energy to be precise. So, if we consider this is a control mass system, and energy input is $E_{in}$and from the system energy output is E_{out}, then from the conservation of energy we can write that

$$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} \ = \frac{dE}{dt}$$

So, for a system, the energy input or the rate of energy at which energy is entering into the system minus rate at which energy is leaving from the system is nothing but the change of energy within the system. And also we need to take into account one important term that is energy generation. There might be some ways by which energy may get generated within the system and that is why we have taken this particular term $\dot{E}_{gen}$.

Till now, we talked about the energy change. So, if we try to write this equation for a particular process, say we are trying to apply this equation for a process in which there is no energy generation, then the question is when we can consider that there is no energy generation. We are assuming that energy interaction with the system is only through heat and work. So, when the interaction of energy between system and surroundings is only due to the heat and work interaction, then this term can be 0. So, we are writing here that energy interaction between system and surroundings is only through heat and work that means $\dot{E}_{gen}$=0.

So, we have understood that energy interacting between system and surroundings in the form of heat and in the form of work, if these 2 forms are there, then there is no energy generation. So, this is the energy change within the system.

So, you can assume this assumption and you can also consider that the process is a cyclic process. So, the process is a cyclic process. So, I am not going to describe this because you have learned about different processes, reversible process, irreversible process, cyclic process etc. So, the process is cyclic that means, we can restore the system. I mean, if we try to give some energy input to the system, then after a certain time maybe after having interaction with the surroundings, system can be brought back to the initial state. So, this is a cyclic process. So, now, you know what I am telling you that if the process is cyclic, then the term $dE/_{dt}$ equal to 0.

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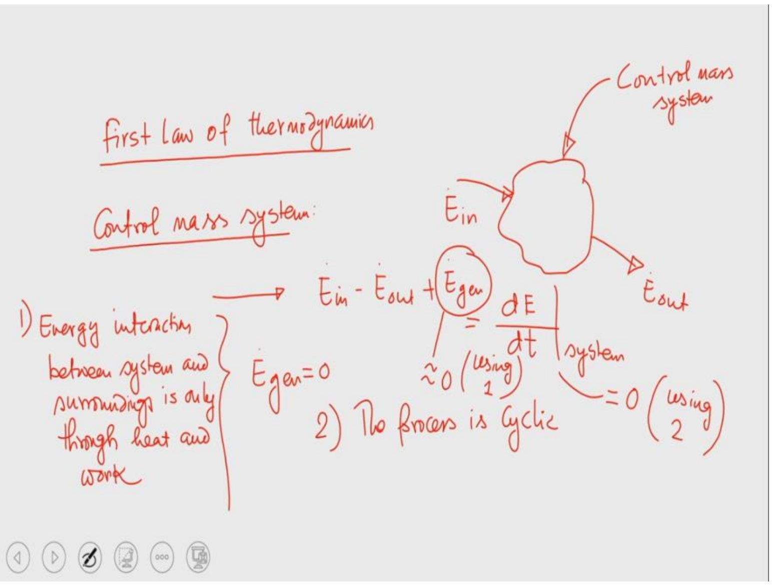

First law of thermodynamics

Control mass system:

1) Energy interaction between system and surroundings is only through heat and work

$\dot{E}_{gen} = 0$

$$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} = \frac{dE}{dt}\Big|_{system}$$

$\dot{E}_{gen} \approx 0$ (using 1)

$\frac{dE}{dt}\Big|_{system} = 0$ (using 2)

2) The Process is Cyclic

So, now, if we try to write this generic form, we will be getting

$$\dot{E}_{in} - \dot{E}_{out} = 0$$

We have discussed that the interaction between system and surroundings is only through heat and work. There is no other forms of energy which is either entering into the system or transferred from the system. So, except heat and work, there is no any other forms of energy which is either entering to the system or leaving from the system.

So, if that is the case, we have learned from thermodynamics which is mostly followed that the energy transfer by heat (Q) to the system is taken positive. So, when there is heat transfer to the system that is positive that is the keyword and now, if the energy is transferred from the system, then following this notation it should be negative.

In a similar way we can write energy transfer by work (W) from the system is taken positive. So, that means, if some amount of work is added to the system it should be negative. So, these 2 notations are largely followed. You can also consider reverse but accordingly you have to consider for the rest of the analysis. So, we can write that

$$\dot{Q} - \dot{W} = 0$$

Because energy interaction between system and surroundings is only through heat and work. This is in the form of rate equation so, what would be total? So, if we integrate it over cycle over time then we will be getting the total. So, if we try to write it then

$$\int \delta Q - \int \delta W = 0$$

So, if we integrate it over cycle over time, then we will be getting total.

$$\oint \delta Q - \oint \delta W = 0$$

$$\Rightarrow \oint \delta Q = \oint \delta W$$

So, if we try to integrate it over cycle over time, we will be getting this equation and this equation is very famous perhaps you have studied this & you can easily identify it. So, this is first law of thermodynamics for the control mass system undergoing a cyclic process. So, starting from the generic form of the energy balance equation we have established that the first law for a system undergoing through a cyclic process can be written in this form.

Now, what we can tell from this equation? Perhaps you have derived this expression in thermodynamics course. So, basically this equation indicates that, if we supply certain amount of heat to the system, I mean energy but in the form of heat, the system has capability to do some work. So, that is the message you can take from this expression. So, this is the first law of thermodynamics for the control mass system undergoing through a cyclic process. I am underlining these 2 words that is cyclic process. If the process is not cyclic, then what will be the form of the first law even if we apply for the control mass system?

So, this is very important, we can write the first law for the control mass system, even if the process is not the cyclic process. It is quite obvious that all processes will not be the cyclic process. So, if you need to write the expression or similar such expression for the general processes, what would be the form.

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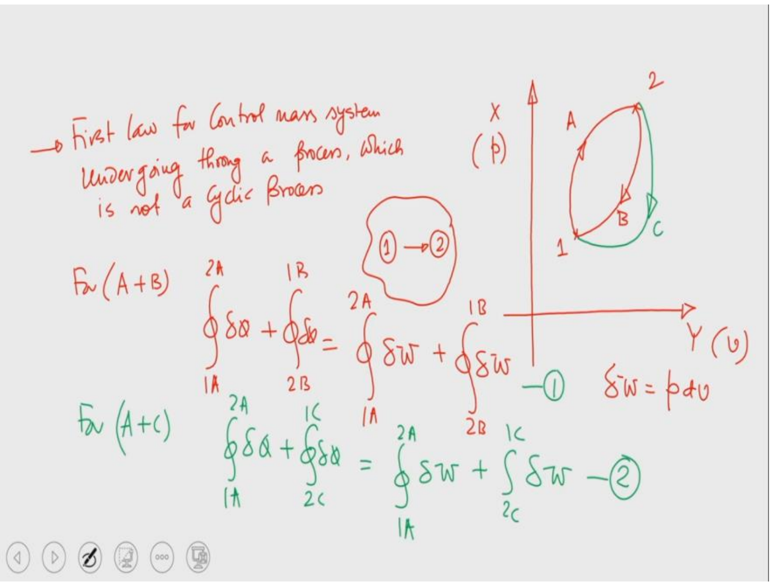

→ First law for Control mass system undergoing through a process, which is not a cyclic process

For (A+B) $$\oint_{1A}^{2A}\delta Q + \oint_{2B}^{1B}\delta Q = \oint_{1A}^{2A}\delta W + \oint_{2B}^{1B}\delta W \quad -①$$

$$\delta W = p\,dv$$

For (A+C) $$\oint_{1A}^{2A}\delta Q + \oint_{2C}^{1C}\delta Q = \oint_{1A}^{2A}\delta W + \int_{2C}^{1C}\delta W \quad -②$$

Now, we will be discussing the first law for control mass system under going through a process which is not a cyclic process. So, essentially our objective is to derive the equation when the process is not a cyclic process. In other words, we shall take an effort to establish the first law for the control mass system when the process is any general process. If this is the control mass system and the system is changing its state from state 1 to another state 2. So, this is the control mass system and the system is changing its state from state 1 to state 2, but not following a cyclic process, may be any other processes. So, if that is the case, we are trying to map that process in this thermodynamic plane, we really do not know what are the different properties X and Y it can be temperature- entropy or pressure-volume or enthalpy-entropy.

So, mostly in this course, we need to map different thermodynamic processes in different thermodynamic planes. Those planes can be pressure-volume, pressure-temperature, volume-temperature, temperature-entropy, enthalpy-entropy. I am not going to discuss in detail because you have learned from the basic thermodynamics course, but for the sake of completeness of the analysis, I am considering a plane that is X Y. So, these 2 properties again are generic, I really do not know.

Now, when the system is changing its state from 1 to 2 following this path A and coming back to the same state maybe following this path B. So, basically if we supply heat to the system, as I told you that it has capability to do some work, so, maybe again it is changing state from 1 to 2 and again it is coming back to original state. So, now, if we try to write this path process A + B

For (A + B)

$$\int_{1A}^{2A} \delta Q + \int_{2B}^{1B} \delta Q = \int_{1A}^{2A} \delta W + \int_{2B}^{1B} \delta W$$

We know again from thermodynamics that this heat and work are the path function. So, these 2 are not the property of the system rather these are the path function. Why so? Because, we have seen that for a control mass system even if the system is controlled volume system, but the process is quasi static we can write

$$\delta W = pdV$$

It is not necessary that the system has to be only control mass system, even if the system is controlled volume system but the processes is quasi static process then it can be written pdV, a simple compressible pure substance.

Now, this work done depends on pressure and volume. So, it does not depend on the state point 1 and 2 rather the path on which the pressure and volume changes. So, maybe the pressure changes with volume. So now, if X and Y correspond to pressure p and volume V respectively, so, you try to understand the change in volume and pressure following path A is not equal to following path B.

If that is the case definitely work done will be different. So, this is path function. So, the system is starting from point 1 is coming to state point 2 and it is again coming back to original state. But when it is coming to original state, it is coming through path B. So, if we just try to understand the area under the process line will give the work done pdV.

So, the change in pressure and volume for path A is not equal to path B and that is why these are path function. Though I mean the process is taking place between these 2 state points, but they are coming back following different paths. So, this is path function. Since these are path function, it is better to write the contour integral. So, we are writing like this.

$$\oint_{1A}^{2A} \delta Q + \oint_{2B}^{1B} \delta Q = \oint_{1A}^{2A} \delta W + \oint_{2B}^{1B} \delta W ----(1)$$

This is not a cyclic process, but since this is changing pressure, and heat and work are path function it is better to write in the form of contour integral. Since we are trying to establish the first law applied to the generic processes not for the cyclic processes, we are assuming now, after reaching at point 2 system is again coming back to point 1 following this path C.

So basically our objective is to write the first law for the generic process, so, it is now coming following path C, not path B then we can write

For process A + C

$$\oint_{1A}^{2A} \delta Q + \oint_{2C}^{1C} \delta Q = \oint_{1A}^{2A} \delta W + \oint_{2C}^{1C} \delta W ----(2)$$

So, this is the expression. So now we can subtract equation 1 from equation 2.

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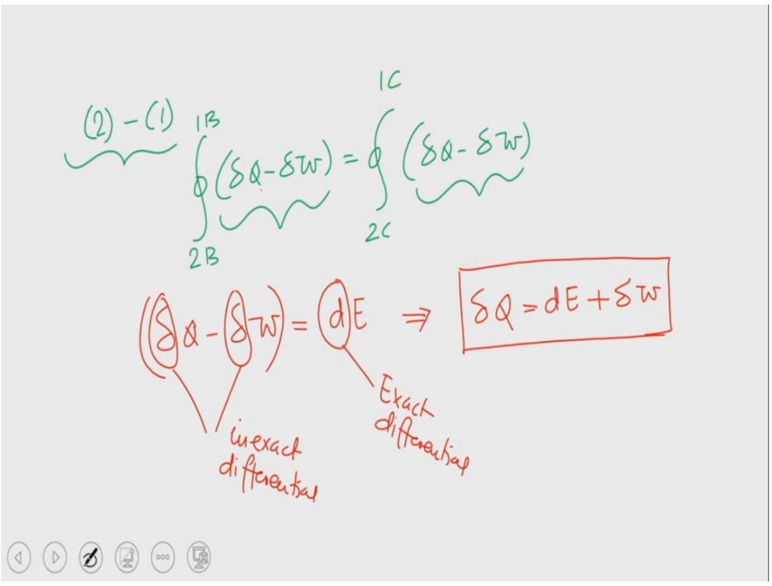

Subtracting equation 1 from equation 2

$$\oint_{2B}^{1B} (\delta Q - \delta W) = \oint_{2C}^{1C} (\delta Q - \delta W)$$

So, if we subtract equation 1 from equation 2, the interaction of heat and work following path A will get cancelled. Now what we can see from this expression though δQ and δW are path function individually, but the difference of these 2 quantities is same whether the path is B or C. So, the important conclusion from this exercise is that though δQ and δW are inexact differential because they are not the point function, they are not the property of the system. So, these 2 quantities depend on the path through which the process is taking place and the change in pressure and volume following that particular path. So, both these 2 quantities are path function individually, but difference of these 2 quantities does not depend on the path. Because you can understand δQ - δW following path B is equal to following path C. So, these quantities

δQ - δW is not the path function. Though δQ and δW are path function individually, the difference is not the path function that we can see from this expression. Now, this is the property of the system and we write it as δQ - $\delta W = dE$. If the difference between these 2 quantities is not the path function that means, it is a point function that is the property of the system and that is how we could write this in the differential form, I mean exact differential form to be precise.

Now, if we try to write 1 step further, we can write

$$\delta Q = dE + \delta W$$

So, perhaps you have studied this in your undergraduate course that is the first law of thermodynamics applied to the control mass system, when the system is performing a process, which need not be a cyclic process. So, this is first law of thermodynamics for the control mass system undergoing any generic or general process.

So, today before I complete this lecture, I would like to discuss a few important issues though those are not essential for this particular course, but at least I should discuss because, in the first of few lectures, I shall try to discuss about the basic or rather I shall try to recap the conceptual part of thermodynamics. Why I am discussing, because this will be very much is needed, when we will be discussing about different thermal systems essentially for the quantification of the performance.

So, you know that δQ and δW are the inexact differential, why? Because they are path function. While dE is exact differential. So, this is the property of the system. Nice thing to understand from here is that, though these 2 quantities are path function individually but they are difference is now the property of the system and that is why we could write it in the form of the exact differential.

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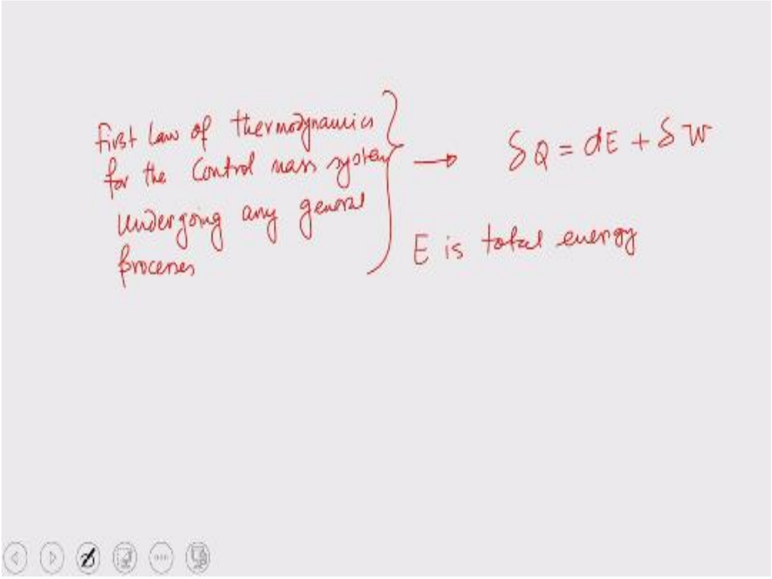

First law of thermodynamics for the Control mass system undergoing any general processes $\rightarrow$ $\delta Q = dE + \delta W$

E is total energy

So, next if we try to write that essentially, the first law of thermodynamics. I am writing first law of thermodynamics, at least for this lecture. From the next class onward I simply write first law second law like this so, essentially it refers to first law of thermodynamics.

So, first law of thermodynamics for the control mass system undergoing any general processes

$$\delta Q = dE + \delta W$$

So, now, here E is the total energy again from this particular expression, I would like to tell you one important thing here. So, if you supply certain amount of heat to the system, system holds capacity to do some work, but try to understand if we now look at this particular expression, if we supply a certain amount of heat or a certain amount of energy by heat to the system, system has capacity or capability to do some work but all the heat which is being supplied to the system is not getting converted into the work, some part of that energy or heat remains stored within the system in the form of total energy.

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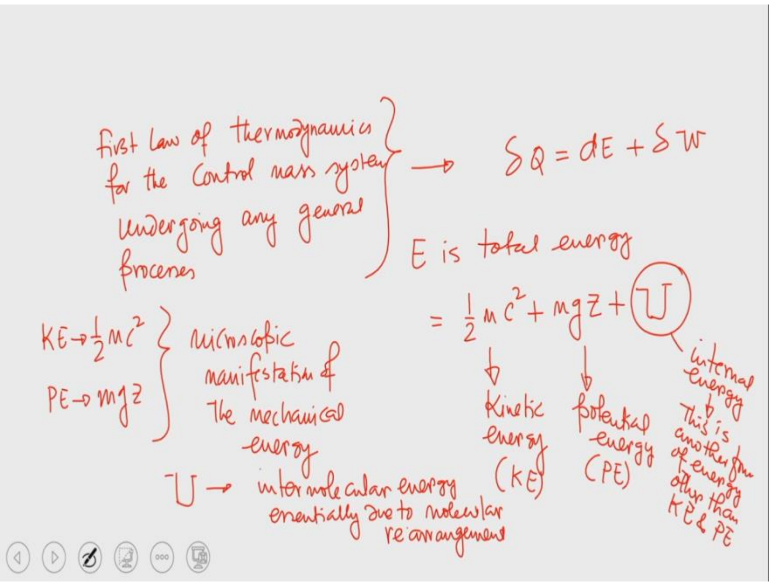

first law of thermodynamics for the Control mass system undergoing any general processes → $\delta Q = dE + \delta W$

E is total energy

$= \frac{1}{2}mc^2 + mgz + U$

↓ Kinetic energy (KE)

↓ Potential energy (PE)

internal energy ↓ This is another form of energy other than KE & PE

$KE \rightarrow \frac{1}{2}mc^2$, $PE \rightarrow mgz$ } microscopic manifestation of the mechanical energy

$U \rightarrow$ intermolecular energy essentially due to molecular rearrangement

So, *E* is the total energy and you know that it can be written in different parts.

$$\text{Total Energy}, E = \frac{1}{2}mc^2 + mgz + U$$

So, let me discuss briefly. So, you know it is not possible to have the equal conversion of energy from heat to the work, the remaining energy will be there within the system and that is nothing but the kinetic energy, potential energy & another form of energy other than these 2.

So, $\frac{1}{2}mc^2$ is the kinetic energy (KE), mgz is the potential energy (PE). Apart from these 2 different forms of energy, there is another form and that is known as internal energy (*U*). So, this is the form of energy other than the kinetic and potential energy. So, this is very important to understand.

So basically you know that kinetic energy and potential energy are the microscopic manifestation of the mechanical energy. So, basically $\frac{1}{2}mc^2$ and mgz that is kinetic energy and potential energy are the microscopic manifestation of the mechanical energy. Whereas, this internal energy is nothing but the intermolecular form of energy due to the molecule rearrangement. I will give you an example.

So, PE & KE are microscopic manifestation of the mechanical energy whereas, *U* is the intermolecular energy essentially due to the molecule rearrangement.

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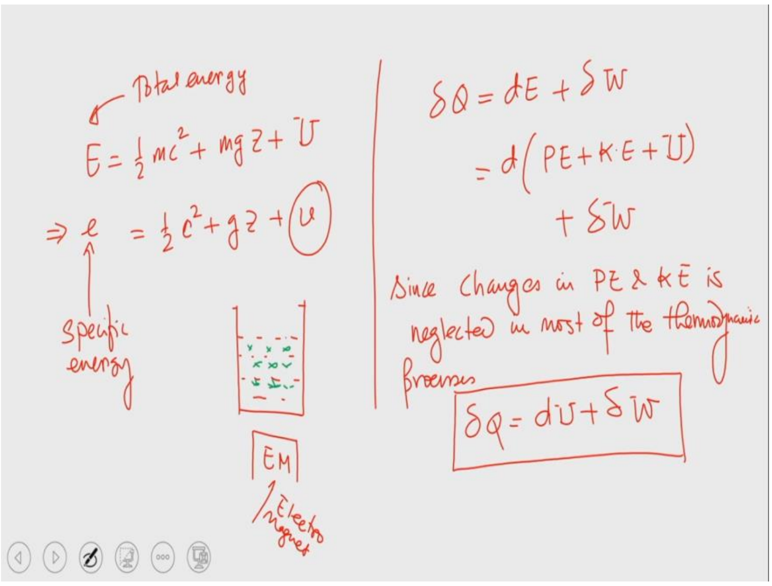

Total energy

$E = \frac{1}{2}mc^2 + mgz + U$

$\Rightarrow e = \frac{1}{2}c^2 + gz + \boxed{u}$

Specific energy

EM

Electro magnet

$\delta Q = dE + \delta W$

$= d(PE + K.E + U) + \delta W$

Since changes in PE & KE is neglected in most of the thermodynamic processes

$\boxed{\delta Q = dU + \delta W}$

So, basically you can write this total energy in terms of the specific energy.

$$\text{Total Energy}, E = \frac{1}{2}mc^2 + mgz + U$$

$$\Rightarrow \text{Specific Energy}, e = \frac{1}{2}c^2 + gz + u$$

Now, we have discussed already that potential energy and kinetic energy is the microscopic manifestation of the mechanical energy, whereas, this *U* that is the form of energy other than the potential and kinetic energy, is the intermolecular energy, which is essentially due to molecule rearrangement. So we have already derived that it first law of thermodynamics applied to the control mass system undergoing any general processes can be written in this form.

$$\delta Q = dE + \delta W = d(PE + KE + U) + \delta W$$

In most of the thermodynamic processes, the change in kinetic and potential energy is neglected. It is not because of the fact that it is ignored intentionally rather it is seen that in most of the thermodynamic processes, the changes in kinetic and potential energies negligibly small as compared to the part which is *U*. Since changes in PE and KE is neglected in most of the thermodynamic processes we can write

$$\delta Q = dU + \delta W$$

So, this is the final form of the first law of thermodynamics for the control mass system undergoing any general process. We could write this form taking this assumption that the change in potential and kinetic energy is negligible and what is true for most of the thermodynamic processes.

So, this is the first law of thermodynamics for the control mass system. Now, question is I told you 1 important thing that this U is essentially due to the molecule rearrangement. I can give you an example. If you take a certain amount of liquid in a container and container is as shown in slide and we are taking water with a few iron particles. So, this is the container which is containing DI water or any water and a few iron particles are injected in this liquid. If we have one magnet at the bottom, so, we have one electromagnet EM at the bottom. So, if we have the electromagnet and we energise this magnet by switching on the circuit, then all the particles will move towards the bottom of the container and they will remain stored in there. When they are even stored in there due to the molecule rearrangement of the total substance, which is there in the container, energy will be stored in there.

If we switch off the circuit or we deactivate this electromagnet, what will happen? Because of the stored energy, particles will try to discharge from the initial positions and they will again slowly come to the original configuration. So, this is the concept of the internal energy. So, basically other forms of the potential and kinetic energy, it is because of the molecular rearrangement, some energy stored within the system and that is known as the internal energy.

So to summarise today's lecture, you know we have discussed about first law of thermodynamics, we have started discussing first law for the control mass system. Then you have seen that if the system is control mass system and if the system is undergoing through a cyclic process then you could write the equation in the integral form. But since all the processes are not cyclic in reality, we also could establish the first law for the control mass system undergoing any general processes. So, with this I stop here today and we will continue our discussion on this particular topic in the next class. Thank you.