Basic Thermodynamics

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Lecture - 04

First Low-II

Good morning. Welcome to this session, last class we were discussing the first law of thermodynamics. We have started the first law of thermodynamics applied to a finite process and to a cyclic process, what was it that we recognized the algebraic sum of heat interactions between a system and the surrounding in a cyclic process becomes equal to the algebraic sum of the work interactions between a system and its surrounding in a cyclic process, which means that the cyclic integral of heat interactions minus the work interactions between the system and the surrounding is 0 and the immediate consequence of heat is that the difference between heat and work interaction executed by a system in a finite process becomes equal to the change in a property which we definite as internal energy of the system.

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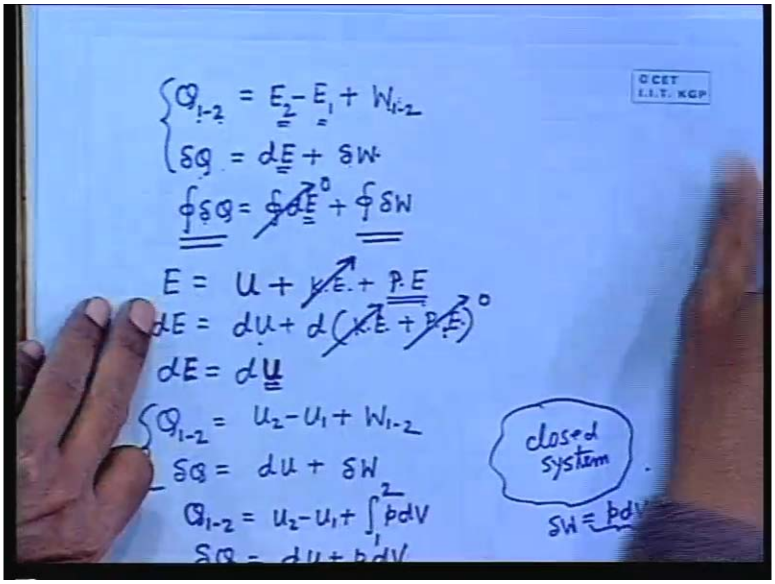

$$\begin{cases} Q_{1-2} = \underline{\underline{E_2}} - \underline{\underline{E_1}} + W_{1-2} \\ \delta Q = d\underline{\underline{E}} + \delta W \end{cases}$$

$$\underline{\underline{\oint \delta Q}} = \cancel{\oint d\underline{\underline{E}}}^{\,0} + \underline{\underline{\oint \delta W}}$$

$$E = U + \cancel{K.E.} + \underline{\underline{P.E}}$$

$$dE = dU + d(\cancel{K.E} + \cancel{P.E})^{0}$$

$$dE = d\underline{\underline{U}}$$

$$\begin{cases} Q_{1-2} = U_2 - U_1 + W_{1-2} \\ \delta Q = dU + \delta W \end{cases}$$

$$Q_{1-2} = U_2 - U_1 + \int_1^2 p\,dV$$

$$\delta Q = dU + p\,dV$$

closed system

$\delta W = pdV$

Now, let us write this, therefore if we just recognize which we discussed earlier that in a process connecting these two steps points 1-2 the heat added you want to is it’s change in internal energy E_2 minus E_1 plus the work coming out of this system during the process from state 1 to state 2 and our usual sign convention is the heat added to a system is positive while the work done by the system is positive.

If you write it for an infinite small process with differential amount of the quantity, that means, if deltaQ is the infinite small heat added for an infinite small process executed by a infinite small system, then this can be written in terms of this dE here, E is a point function it’s a change in internal energy which can be written in terms of its perfect differential that’s why I used d and delta W.

So, this is the first law that if we take the cyclic integral, then we get automatically cyclic integral of del Q is cyclic integral on both this sides dE plus this cyclic integral of delta W.

You know the E is a point function, so that cyclic integral is 0 the cyclic integral of delta Q, this is the first law. In fact we came this way that we first recognize this and then we define that this minus, this is a change in a property which is the internal energy E_2 minus E_1. So, this is the precise form of the first law. Now, if we write this in terms of per unit mass this will be internal energy per unit mass, but before that I should tell this way.

Now, you concentrate on these two equations, if a closed system now this first law first of all you must know this first law that heat added is change in internal energy plus work done is applied for both closed system and open system, but the version of this law in a open system is little different which I will tell afterwards.

So, when we deal basically with closed system, we write in this form that delta Q is equal to dE plus delta W. So henceforth, whatever we will be referring to a closed system. So, let us now think of a closed system, and then we can write this internal energy we have already recognized for a closed system is composed of intermolecular energy plus kinetic energy plus potential energy.

All types of energy stored within this system apart from the intermolecular energy which is because of the molecular kinetic and potential energy can be described in terms of microscopic potential energy.

For example the gravitational potential energy and kinetic energy because of the movement or motions of the particles of the system macroscopic particles of the system not the molecular motion, so therefore d of this comprises d of u plus d of this quantities kinetic energy plus potential energy.

Now, for a closed system, when it is at an equilibrium state it is at rest, there is no motion within in it and the properties are uniform throughout, so therefore the kinetic energy within the matter is 0.

So, therefore usually for a closed system at equilibrium state because we are interested between the equilibrium states from one equilibrium states, one to other equilibrium states, so at any equilibrium state these kinetic energy has to be 0, but potential energy may not be 0 because any system for example in the gravitational field of the earth it has some potential energy, but the change of potential energy in all practical cases are very negligible or very small compare to the change in its intermolecular energy.

So that we can neglect this change of potential energy, because of the fact there is no kinetic energy its change is also 0, so that finally for a closed system at equilibrium state we can write the change of its internal energy is the change of its intermolecular energy u only.

This is the usual sign convention, sign is used in nomenclature, u has the intermolecular energy and E has the internal energy. so therefore we will denote the internal energy for a closed system henceforth by the term u is actually the intermolecular energy.

so when we will refer the internal energy of a stationary closed system at equilibrium states we will refer to u only. so with this in mind, we can write then for a closed system $Q_{1\text{-}2}$ is equal to u_2 minus u_1 plus $W_{1\text{-}2}$ in differential form delta Q is du plus delta W. Now, we see that these are the first law when no restrictions about the system were given.

It is valid for a closed system, whatever maybe it’s internal energy, but when you write in this fashion we consider the internal energy is composed of only intermolecular energy, that means, closed system will be at rest there will be no kinetic energy and more over that changes in the potential energy during a process has to be a small as compare to the changes in its intermolecular energy so that we can write this form of the first law for a closed system.

Now, if we go little ahead now you see put little more constant now if we consider a closed system which perform only reversible displacement work which we discussed earlier, that may quasistatic displacement work which is nothing but pdv work we have recognize this earlier

So, any form of reversible or quasistatic displacement work that is the work interaction between the closed system and the surrounding because of the displacement of its system boundary that is the reversible or quasistatic displacement work is given by the expression pdv infinite small amount of work is given by pdv, that means delta W equals that's why this work will be refer henceforth as pdv work, so if we consider the closed system only performs this type of work that is pdv work, then we can write for that occasion Q_{1-2} is u_2 minus u_1 plus integration of pdv between the state 1-2 or deltaQ is equal to du plus pdv.

Now, we see that there are three different forms, now, this is valid there is no restriction input even the restriction of closed and open systems are not imposed here, this is the general statement of the first law usually we use this equation for closed system.

When the restriction of closed system at equilibrium state comes with the further assumption that change in potential energies are negligible compare to the change in intermolecular energy then this becomes these two, one is for a finite process another is for an infinite small process in differential form for closed system at stationary equilibrium states.

Then if we again further put another constant that closed system only interacts with the surrounding in the form of pdv work then the first law for a finite process becomes like that, now if we write this expression, sometimes it is written for a closed system conventionally per unit mass.

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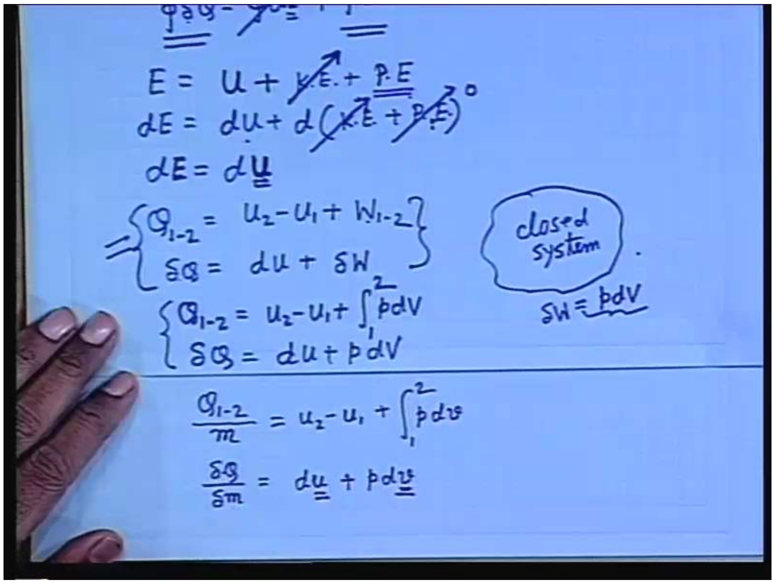

$$E = U + \cancel{K.E.} + \underline{\underline{P.E}}$$

$$dE = dU + d(\cancel{K.E} + \cancel{P.E})^{\to 0}$$

$$dE = d\underline{\underline{U}}$$

$$\left\{\begin{array}{l} Q_{1-2} = U_2 - U_1 + W_{1-2} \\ \delta Q = dU + \delta W \end{array}\right\}$$

closed system

$$\delta W = \underset{\sim}{\underline{pdV}}$$

$$\left\{\begin{array}{l} Q_{1-2} = U_2 - U_1 + \int_1^2 pdV \\ \delta Q = dU + pdV \end{array}\right.$$

$$\frac{Q_{1-2}}{m} = u_2 - u_1 + \int_1^2 pdv$$

$$\frac{\delta Q}{\delta m} = d\underline{\underline{u}} + pd\underline{\underline{v}}$$

That means if you write for a finite process let m is the mass of the closed system which remains fixed per unit mass then this becomes the change in the specific internal energy and this is expressed as small u script is same but the size is small u and this will be definitely p specific volume this is denoted by small v.

So, therefore here also del Q by del m, if del m is the mass of an infinite small system which receives infinite small amount of heat del Q here also it is the differential of small u that means small u refers to specific internal energy per unit mass plus p into dv specific volume, that means this is a point function in terms of specific values; these becomes an intensive property, this is also specific internal energy and this is the heat addition per unit mass after this I will go to the definition of a new property enthalpy.

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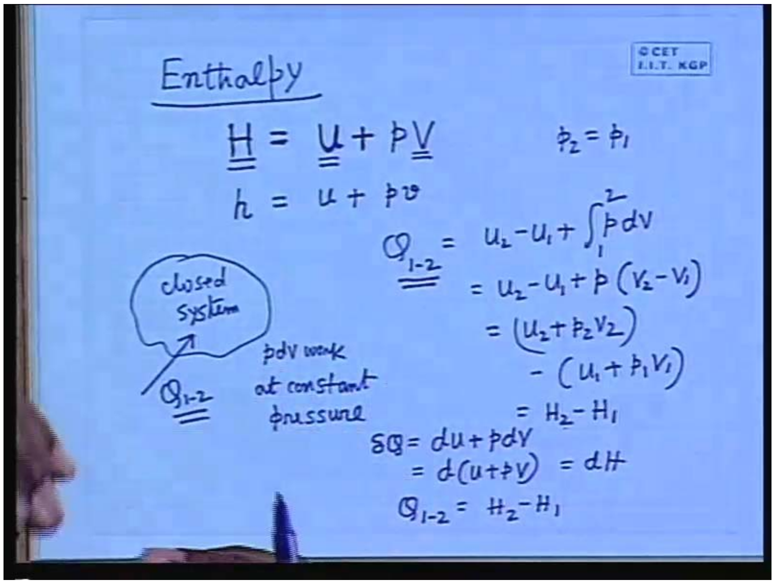

Enthalpy

$$\underline{\underline{H}} = \underline{\underline{U}} + p\underline{\underline{V}} \qquad p_2 = p_1$$

$$h = u + pv$$

$$\underline{\underline{Q_{1-2}}} = U_2 - U_1 + \int_1^2 p\,dV$$

$$= U_2 - U_1 + p(V_2 - V_1)$$

$$= (U_2 + p_2V_2) - (U_1 + p_1V_1)$$

$$= H_2 - H_1$$

$$\delta Q = dU + pdV$$

$$= d(U + pV) = dH$$

$$Q_{1-2} = H_2 - H_1$$

closed system

$\underline{\underline{Q_{1-2}}}$

pdV work at constant pressure

Now if you are asked at any time, what is the definition of enthalpy the very first line of this definition comes from the mathematical statement that enthalpy is a property which is defined as H is the denoted which is defined as summation of internal energy plus pressure and volume for this is the enthalpy, very first line of its definition there is no physical concept at the beginning.

Let us start with this definition that enthalpy is a property of a system with equals to u, the internal energy for a closed system, internal energy for a open system also it is the same internal energy u plus the product of p into v that is the definition of enthalpy.

So enthalpy is a property of a system it refers to both closed and open system in such a property which is defined by this. Now, the question comes that, if we define enthalpy why such a particular combinations of internal energy u pressure and volume has been defined as enthalpy, this will be made clear afterwards and which will give the physicals significance of enthalpy.

So, at the present moment first we start with this definition mathematically without understating much as if this particular combination is defined as a property which is known as enthalpy of a system which refers to both closed and open system, because it is the definition of a property which does not depend upon the type of the system or the type of the process executed by a system it is a property of the system.

So, it's very important sometimes it is asked that whether enthalpy is defined for a closed system or open system, for any system it's a property just like a internal energy pressure volume temperature like that enthalpy, now you see u is an extensive property v is an extensive property so, therefore H is a extensive property

so we can defined the intensive property corresponding intensive property that is enthalpy per unit mass which is specific enthalpy as specific internal energy plus pressure into specific volume, so this is the definition of specific enthalpy.

Now, with this definition of enthalpy, let us now find out one small thing or a small problem to solve one small problem that a closed system that a closed system receive some heat from outside and performing a process from state 1 to 2 and is doing pdv work at constant pressure understand

So, what is the amount of heat added? Now, let us find out these as a problem. Now, Q_{1-2} we can write as what is this u_2 minus u_1 plus integration of pdv. Now, earlier also we recognize that, integral cannot be found out or evaluated until and unless we know the process constant that what is the relationship between p in terms of v. Now, if we know that process constant is such that pressure is constant, then we can write this u_2 minus u_1 plus a constant pressure that is p times v_2 minus v_1. so you can write this we can use p_2 when you multiply with v_2 and or p_1 multiplied with v_1 since p_2 is equal to p_1 pressure remains constant that means that constant pressure the displacement is taking place.

That means, heat is added in such a way that whenever it is displaced it is at constant pressure then we get u_2 plus p_2 v_2 minus u_1 plus p_1 v_1 is equal to H_2 minus H_1. So, therefore we see the heat added is given by the difference is enthalpy at the two states enthalpy at state 2 minus enthalpy at states. This can be more easily found out from the differential form that delta Q is equal to those who are little smatter then du plus pdv then you can use it like this d of u plus pv why because p of dv is d of pv since p is constant it can go within this differential operator that means it is dH

So, from here one can conclude Q_{1-2} means if you integrate H_2 minus H_1, therefore we see that the heat interactions between a system closed system and the surrounding when closed system performs displacement that pdv work at constant pressure is giving by its the difference of enthalpy between the two states. That means, if it goes from state 1 to state 2, if the enthalpy at state 2 is more than the state 1 then heat is being added because Q is positive in that case if the enthalpy of state 2 is less than the enthalpy of state 1, the heat is being rejected by the system that is Q is negative.

That means the different between the enthalpy at the two states point gives the heat interactions between the system and the surrounding provided the system is a closed system and performs pdv work at constant pressure. How the pdv work at constant pressure is perform when the displacement work is being obtained, that means the system boundary expand the pressure will reduce, then heat is added in such a way that the pressure remains constant that means always expansion is taking place at constant pressure.

Similarly, you can conceive physically that is a compression type of thing, that means if the system boundary collapses then pressure should increase so that heat should be rejected in such a way that it counter balances that increase in pressure that means that compression takes places with constant. Next is we will define specific heats.

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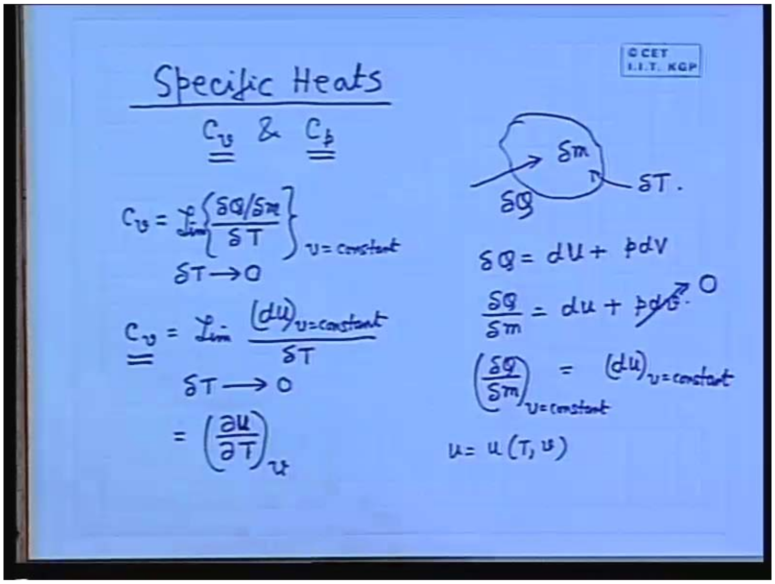

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Specific Heats

c_v & c_p

$$c_v = \lim_{\delta T \to 0} \left\{ \frac{\delta Q/\delta m}{\delta T} \right\}_{v = \text{constant}}$$

$$c_v = \lim_{\delta T \to 0} \frac{(du)_{v=\text{constant}}}{\delta T} = \left(\frac{\partial u}{\partial T}\right)_v$$

δQ, δm, δT.

$$\delta Q = dU + p\,dV$$

$$\frac{\delta Q}{\delta m} = du + \cancel{p\,dv}^{\,0}$$

$$\left(\frac{\delta Q}{\delta m}\right)_{v=\text{constant}} = (du)_{v=\text{constant}}$$

$$u = u(T, v)$$

Specific heats we have already we know there are two specific heats Specific heats at constant volume and specific heats at constant pressure which we have already read at school level specific heat at constant volume and specific heat at constant pressure. How do you define the specific heat? We define the specific heats in terms of the heat quantity but specific heat is a property of a system. Specific heat at constant volume or constant pressure, these are the process constant, we know the specific heat at constant volume is defined as the infinite small amount of heat added to a closed system at constant volume to raise its temperature by an infinite small amount delta T, then this ratio del Q by del t is the specific heat.

Now we will define these in terms of this system property rather than the path function and Q and W how do you do it? Let us start the definitions of specific heat, let us consider the similar way that a system of small mass delta m receives an infinite small amount of the delta Q for which there is a rise in a temperature delta T. Then, as you know that definition of specific heat is delta Q per unit mass, delta m divided by delta T, limit of this quantity as delta T approach a 0.

So, this is the basic definition of specific heat at constant volume provided, this is done at constant volume v is equal to constant that means heat has to be added at constant volume of the system. Now, if we look to the first law what is first law here, deltaQ is du plus pdv now in defining this specific heat one restriction is there you always forget that there should not be any other work transfer except the displacement work of the system.

So, we will not allow any other work transfer without the displacement work understand, so only displacement work that is pdv work will be allowed. If we write delta Q by delta m what is this is capital U I have just told this is small u that is means specific internal energy plus p into dv.

Now, when we make this at constant volume, that means heat added per unit mass at volume constant, then we can write is as du v is equal to constant, this is 0. So, therefore del Q by del m is du at constant volume.

So, if you substitute this, we get limit du at constant volume v is equal to constant divided by delta T as delta T tends to 0, which becomes is equal to del U del t at constant volume usually it is written like this in terms of the partial difference equation, U is function of two variables, in case of single phase single component system u may be expressed as a function of T and v small v small u.

So, therefore we can write partial differential, therefore you see that is specific heat at constant volume becomes equal to partial differential of specific internal energy with temperature at constant volume, it is clear cv is del U del t at constant volume.

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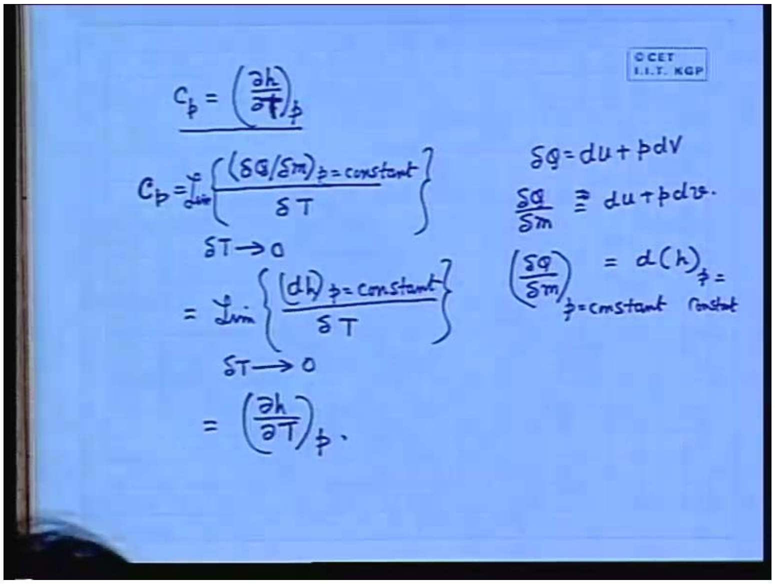

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

$$c_p = \lim_{\delta T \to 0} \left\{ \frac{(\delta Q/\delta m)_{p=\text{constant}}}{\delta T} \right\}$$

$$= \lim_{\delta T \to 0} \left\{ \frac{(dh)_{p=\text{constant}}}{\delta T} \right\}$$

$$= \left(\frac{\partial h}{\partial T}\right)_p .$$

$$\delta Q = du + pdV$$

$$\frac{\delta Q}{\delta m} = du + pdv.$$

$$\left(\frac{\delta Q}{\delta m}\right)_{p=\text{constant}} = d(h)_{p=\text{constant}}$$

Similar way we can prove that c_p is del h and del t at constant pressure. How? Let us define small cp is equal to, as we know the pressure constant has to be change only that means is the same thing at constant pressure that means with the same nomenclature delta Q by delta m delta Q is the small amount of heat added to a system of mass delta m, where p is equal to constant well divided by delta T and limit of this quantity as delta T tends to 0.

Now, we will have to look to the first law, delta Q is du, I have told only we will relax this work transfer no other work transfer only pdv work, if it has to be there at constant pressure what it will be delta Q, first of all per unit mass equal to small u, plus pdv, that means at constant pressure. Just now we have recognized this; so it is a repetition at p is equal to constant it is the change in enthalpy and it will be change in specific enthalpy because we are representing Q per unit mass.

We write it at pressure is equal to constant, that means p simply I am giving p is equal to or you can write p is equal to constant, that means here this things will be limit of change in specific enthalpy at constant p at constant p divided by deltaT and the limit when deltaT tends to 0, so this becomes delh delt, so it will be delh delt at constant pressure.

So, therefore specific heat at constant volume is the partial differential of specific internal energy with respect to temperature at constant volume. Similarly, the specific heat at constant pressure of a system is the partial differential of specific enthalpy with temperature at constant pressure.

So, this is now clear, with this I will close this lecture regarding first law applied to a closed system, now I will come to the first law to this section, first law applied to an open system or control volume.

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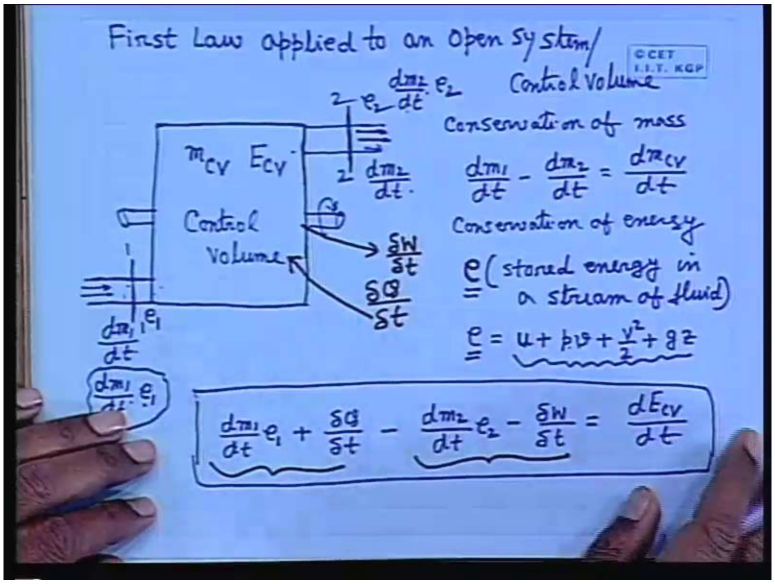

First Law applied to an Open system/ Control Volume

Conservation of mass

$$\frac{dm_1}{dt} - \frac{dm_2}{dt} = \frac{dm_{cv}}{dt}$$

Conservation of energy

$\underline{\underline{e}}$ (stored energy in a stream of fluid)

$$\underline{\underline{e}} = \underbrace{u + pv + \frac{V^2}{2} + gz}$$

$$\boxed{\underbrace{\frac{dm_1}{dt} e_1 + \frac{\delta Q}{\delta t}} - \underbrace{\frac{dm_2}{dt} e_2 - \frac{\delta W}{\delta t}} = \frac{dE_{cv}}{dt}}$$

Now, we may ask, first law, why it is not applicable? First law is the same, but how the different version when you use the control volume the version changes little bit, because of the fact that control volume and closed system that is open system and closed system, control volume system and control mass system.

Usually, when we tell system it means, I have told earlier that is the control mass system we usually do not use this word control mass system means control mass system on the other hand control volume means, control volume system or open system.

So, their basic definition, say the basic requirement of control volume system or control volume and open system and closed system are different, what is the control volume system. Let us recapitulate it is the fixed region in the space upon which the concentration is put and there is a continuous flow of matter into the control volume and continuous flow of matter coming out of the control volume and during this what happens the properties of the matter which comings in and going out coming in and going out changes and the control volume interacts with the surrounding in terms of work and heat.

For an example, we have appreciated a compressor is a control volume just an example where continuously air comes at certain properties and goes out at certain property. Whereas, the interactions with the surrounding in terms of taking work, work is being added to the compressor, so that a desired change in the properties of the air flow in through it is made.

Similarly the turbine continuously some gas or air is coming into heat and it is going out and this unit as a control volume delivers work to the surrounding, heat exchanger continuously a fluid is coming in and going out and heat is being added from the surrounding to this control volume.

So, these are the examples of control volume, let us discuss how the first law of thermodynamics, that is basically the conservation of energy principle is written for this type of control volume. Now, let us define a control volume like this, we are not much interested what happens exactly within that we are only recognizing these as well control volume.

Now, let us identify a section where the fluid or the material comes in switches is usually fluid it and the another sections where from the material which is usually fluid in practice goes out it is usually a fluid goes out there may be multiple such inflow streams. There will be multiple such outflow streams but it doesn’t matter much and the analysis will remain same, but for our simplicity we consider only one inflow stream and one outlet stream.

Let us define a section here just near to the control volume 1 1, let us define a section here ah just at the outlet of the control volume 2 2. Now, this is the control volume, this is the situation, now how do you make this analysis of the control volume and let us now consider as if the control volume is receiving some heat, always we make analysis with the positive quantity of the energy indirections, since control volume operates on the principle that always there is an continuous inflow and there is a continuous outflow, this is the definition of control volume.

We always prescribe the energy interaction quantities with respect to time on the time basis, because it is a continuous flow process, understand the continuous flow comes in and flows go out that is the control volume concept, it may be steady, may be unsteady but it is the continuous flow process. So, therefore because of this continuous process with time things are expressed in terms of time rate, so delQ delt let us consider the rate at which heat is added to the control volume. At the same time, we consider as if the control volume is delivering work to the surrounding by this amount delta which may be coming in terms of shaft work usually a control volume compressor turbine which I discussed there is a shaft mounted on it rotates against a resisting torque gives the work done but we are not much interested that mechanism by which work is transferred in thermodynamic. Let us consider some work is continuously being transferred to the surrounding at the rate of del w delt while the control volume receives heat by the amount delQ delt.

Now, first write the conservation of mass for the control volume which is very simple we have done it fluid mechanics class, let us denote the mass flow rate because it is rate is very important d m_1 and d t at the inlet and let us write d m_2 and dt is the rate of mass out and at any instant let us define m_{cv} is the mass of the control volume.

So, conservation of mass is very simple from commonsense, that is the mass rate flow coming in inflow rate of mass minus mass flow rate reflects dm to dt, that means rate of change of mass that means mass flow rate that is the mass flow rate mass flow rate coming into the control volume minus the mass flow rate going out of the control volume is equal to dm, that is the rate of change of mass within the control, this simple conservation of mass which was exploited in fluid mechanics to derive the equation in terms of the velocity components which we are not doing here that is known as popular continuity equation.

So, basically conservation of mass tells like that the rate of mass inflow minus rate of mass outflow is the rate of increase of control volume mass m_{cv} dt, now what about energy, that is the first law conservation of energy also will come from the same commonsense that if we denote Ecv as the internal energy of the control volume at any instant, the rate of change of this internal energy within the control volume will be the difference between the rate at which energy comes into the control volume minus the rate at which energy goes out of the control volume, but here we will have to recognize one thing as unlike the closed system, that in closed system energy comes in and goes out only in the form of the work and heat, because no matter no material no mass of the system goes out or comes in, but here since the masses are coming in and going out so the energy quantities associated with this mass also comes within the control volume and going out of the control volume.

So, we will have to recognize these two forms of energy which are coming into the control volume. For example here along with this mass the energy is coming into the control volume apart from that heat coming into the control volume. Similarly work is going out of the control volume energy same time the energy associated with this stream of mass going out of the control volume causes an energy going out of the control volume, so to recognize that one has to know what is the energy?

So, now to know what is the energy coming into the control volume associated with this stream of mass or what is the energy going out of the control volume associated with the stream of mass, one has to no first what are the different forms of energy which are being associated with a stream of mass as a stored energy within that stream.

If we defined e then we have to know, that means what is the stored energy in a stream of fluid or mass in a stream of fluid, so therefore we have to know this thing if we know that then we can find out what is the energy that is s coming into the control volume per unit time, so either to know then what is the different form of stored or what is the total stored energy in a stream of fluid.

Now, with the stream of fluid, what are the forms of energy that it can have stored in as an internal energy of the stream of fluid if we tell that internal energy of a stream of fluid. The Kinetic energy, potential energy, intermolecular energy because of its temperature, kinetic energy because of the velocity potential energy because of its position in a conservative force field intermolecular energy because of its temperature absolute above absolute 0 always as an internal energy intermolecular energy, then another one is pressure energy that is the pressure energy of flow work which we discussed in detail at the beginning of this class that pressure energy pv or the flow work.

So, a stream of fluid can be designated by all these sorts of energy at any section, that means when a fluid flows in a stream a section of this fluid possess all this energy if you describe in per unit of mass. So, therefore denoting that stored energy per unit mass as e we can write e therefore becomes equal to in general u first I write u that is per unit mass that is specific internal energy plus the flow you should write after work, that is the pressure energy p by rho in fluid mechanics we deal it at p by rho plus the kinetic energy as you told v square by 2 plus potential energy.

Here, we consider only the earth gravitational fields as the body force field there is no extra body force field imposed on the fluid, so that we tell d dash gz that means this total sum of these four quantities represents the energy stored per unit mass in a stream of fluid and designate it as e.

Now, if we designate the d here as e_1 and designate these as section e_2 then we can write the energy coming in with this stream is d m_1 dt into e_1, similarly energy going out with this stream is dm_2 dt e_2..

Here one assumption is made what is that the properties that means all these properties not only this properties all properties of stream inlet and outlet stream remains invariant with time they do not change time that means, the properties of the fluid stream entering into the control volume are going out of the control volume is invariant with time there is a change of this properties while flowing through the control volume, but at this section all the properties are invariant so that we can write the energy quantities entering into the control volume per unit rate is the mass flow rate into energy per unit mass flow rate into energy per unit mass.

now we can write the conservation of energy like this that the total energy coming into the control volume then what it will be it will be d m_1 dt into e_1 plus in the form of heat it is coming delQ by delt minus the energy going out with the flow of mass outlet stream into e_2 minus del W delt is equal to there is no other statement it has to be like that, means, energy quantity coming into the control volume minus energy quantity going out of the control volume is the rate of change of internal energy of the control volume. So, this is precisely the conservation of energy statement of the control volume.

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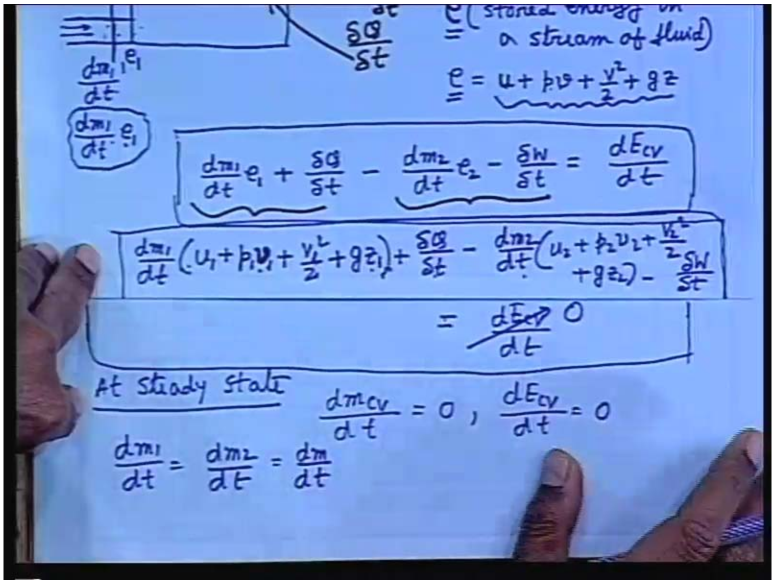

$\frac{dm_1}{dt} e_1$

$\frac{\delta Q}{\delta t}$

e (stored energy in a stream of fluid)

$e = \underbrace{u + pv + \frac{v^2}{2} + gz}$

$\frac{dm_1}{dt} e_1$

$$\boxed{\underbrace{\frac{dm_1}{dt} e_1 + \frac{\delta Q}{\delta t}} - \underbrace{\frac{dm_2}{dt} e_2 - \frac{\delta W}{\delta t}} = \frac{dE_{cv}}{dt}}$$

$$\boxed{\frac{dm_1}{dt}\left(u_1 + p_1 v_1 + \frac{v_1^2}{2} + g z_1\right) + \frac{\delta Q}{\delta t} - \frac{dm_2}{dt}\left(u_2 + p_2 v_2 + \frac{v_2^2}{2} + g z_2\right) - \frac{\delta W}{\delta t} = \frac{\cancel{dE_{cv}}}{dt} \rightarrow 0}$$

At steady state $\frac{dm_{cv}}{dt} = 0$, $\frac{dE_{cv}}{dt} = 0$

$\frac{dm_1}{dt} = \frac{dm_2}{dt} = \frac{dm}{dt}$

Now if we write this in terms of if we split this in terms of this then we get here itself we can write d m_1 dt you can see this one know u_1 plus p_1 v_1 plus v_1 square by 2 plus g z_1 plus delQ delt well minus d m_2 dt.

So we just splitting this u_1 u_2 terms u_2 plus p_2 v_2 it will be small v because it is per unit plus v_2 square by 2 plus g z_2 is equal to is equal to dEcv by dt so the energy coming in minus energy going out is the rate of change of energy within the control volume so this is the energy coming in with the inflow of the stream.

This is what specific internal energy internal energy per unit mass this is the flow work or pressure energy per unit must this is the specific volume this is the kinetic energy per unit volume this is a potential energy per unit this is total is this stored energy per unit mass with this flowing stream times the mass flow rate it is the energy flow rate or energy flow rate coming into the control volume plus the rate of heat coming into the control volume which we defined for the problem minus this is the similar way rate of energy coming out of the control volume minus.

Here minus the rate of work coming out of the control volume which we first defined for the problem must be equal to the rate of change of internal energy of the control volume and this is precisely the thermodynamic to a control volume, it is very important this is first law of thermodynamics to a control volume.

Here, what we have assume we have assume that the properties at the inlet stream and the outlet streams are invariant with time there may be multiple of inlets streams which will come here which will we go on adding all the energy quantities and there may be a multiple of outlet streams which will go on adding at the outlet stream

So only simplification is that in this analysis of thermodynamic that this is the invariant with time and this is uniform across a cross section obvious but here you always assume that all properties not only this velocity v specific value internal energy all this things are uniform across a cross section and invariant with time then it becomes as simple as this is only the accountability of energy for the control volume. Now at steady state, what is the definition of steady state?

When a control volume will be at steady state all its properties will remain invariant with time that means both the mass and the energy being two of its important properties will remain invariant with time which means at steady state a control volume is specified by this equation that the rate of change of mass dm_{cv} dt is 0 with time similarly rate of change of energy with time is 0 that means there will be in variant with time that means, the conservation of mass will tell that this will be 0 that means dm one dt is equal to d m 2 d t that means the mass inflow is equal to the mass outflow . Similarly, dEcbdt dEcv dt will be 0.

Now if we make this first condition then we get d m_1 dt is equal to dm 2 dt because the mass inflow is equal to mass outflow there are will be no mass change in the control volume let this becomes is equal to dm and dt and if we substitute this in this energy equation that means if we write d m_1 dt and dn 2 d t as dm dt.

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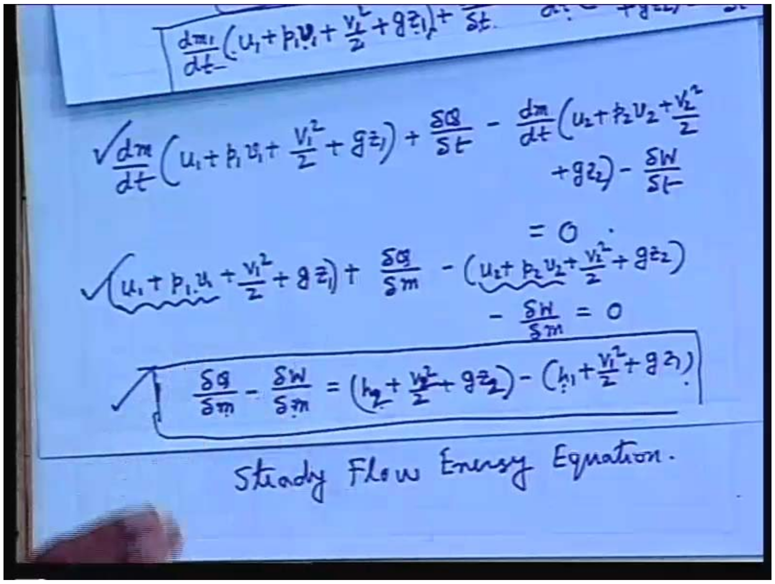

$$\frac{dm_1}{dt}\left(u_1+p_1v_1+\frac{V_1^2}{2}+gz_1\right)+\frac{\delta Q}{\delta t}$$

$$\checkmark\ \frac{dm}{dt}\left(u_1+p_1v_1+\frac{V_1^2}{2}+gz_1\right)+\frac{\delta Q}{\delta t}-\frac{dm}{dt}\left(u_2+p_2v_2+\frac{V_2^2}{2}+gz_2\right)-\frac{\delta W}{\delta t}=0$$

$$\checkmark\left(u_1+p_1v_1+\frac{V_1^2}{2}+gz_1\right)+\frac{\delta Q}{\delta m}-\left(u_2+p_2v_2+\frac{V_2^2}{2}+gz_2\right)-\frac{\delta W}{\delta m}=0$$

$$\checkmark\ \boxed{\frac{\delta Q}{\delta m}-\frac{\delta W}{\delta m}=\left(h_2+\frac{V_2^2}{2}+gz_2\right)-\left(h_1+\frac{V_1^2}{2}+gz_1\right)}$$

Steady Flow Energy Equation.

Then we can write, dm dt into this quantity u_1 plus p_1 v_1 plus v_1 square by 2 plus g z_1 just simply a repetition delQ by delt minus again dm dt into u_2 small u specific internal energy plus v_2 square by 2 plus g z_2 minus del W is equal to 0 because there is dcb is 0 d Ecv dt is 0.

Now this equation at steady state can be expressed in terms of the quantities per unit mass here all the quantities are energy per unit time but we will now express energy per unit mass to do that we will have to divide all the terms by dm dt.

So that we get u_1 plus p_1 v_1 plus v_1 square by 2 plus g z_1 then this quantity will appear as delQ del m whose meaning is that the heat transferred ah or heat added per unit mass heat added per unit mass u_2 plus p_2 v_2 plus v_2 square by 2 plus g z_2 minus del w del m is equal to 0.

That means, we transfer this equation from the time rate bases to mass rate bases that means this quantity contains internal energy per unit mass flow work per unit mass kinetic energy per unit mass potential energy per unit mass this is the stored energy per unit mass with the inflow stream, that means at the inlet section this is the heat added per unit mass.

Similarly, these are the stored energy at unit mass at the outlet sections of the fluid stream and this is the work done per unit mass. So, this can be written now in a fashion now by you want u_1 plus p_1v_1 by your definition h then I can write now little this way delQ del M minus del w del m is equal to h_1 plus v_1 square by 2 plus z g_1 minus h_2 minus h_1 plus v_1 square by 2 plus g z_1 this will be 2. This is known as steady flow energy equation any one of this either this or this or this is the time rate bases this is per unit mass bases and this is written in a different arrangement.

So, any one of this three are known a, steady flow energy equation, that means in steady flow energy equation we see that the heat added per unit mass minus the work done per unit mass is given by the difference of this stored energy per unit mass between the two system. Now you will find out the immense physical significant of the term enthalpy in almost all the practical appliances in engineering use the difference in kinetic energies and potential energies are negligible compare to the change in enthalpy.

We are interested in these two quantities as engineers so therefore we are interested in the changes not in the absolute value because engineer want what is the work what is the heating interactions and they are always described by the first law in terms of the changes of the properties, changes of enthalpy, changes of internal energy even changes of kinetic energy, changes of potential energy.

We are not bothered about the absolute potential energy if you want to know what is the work done in replacing a system from one point one to other point in a conservative force field you are not bothered about the absolute potential energy at a particular point where from it was taken and the particular point where it has been kept but you were only bothered about the change in the potential energy.

So that they should be defined from a conventional and same reference data. So, therefore it is the change, so these changes are small. In certain cases, the changes in kinetic energy in case of nozzles and diffusers, we come across afterwards, changes in kinetic energy may be appreciable compare to the change in enthalpies, but changing in potential energies are always negligible because change in potential energy means what? It is with respect to the gravitational force speed. So, we have to make a appliance very tall so that changes in potential energy becomes appreciable to that of its change in enthalpy it is not so.

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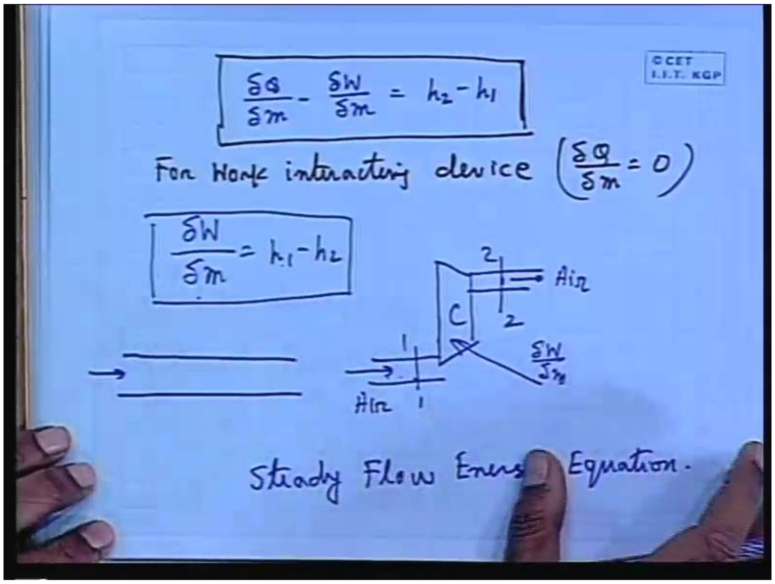

$$\boxed{\frac{\delta Q}{\delta m} - \frac{\delta W}{\delta m} = h_2 - h_1}$$

For Work interacting device $\left(\frac{\delta Q}{\delta m} = 0\right)$

$$\boxed{\frac{\delta W}{\delta m} = h_1 - h_2}$$

Steady Flow Ener Equation.

Therefore, if we consider those cases where changes in kinetic and potential energies are small with respect to change in enthalpy, then we can write this one that delQ by delm minus delW by delm is simply h_2 minus h_1. See the important implications that means, for a control volume the difference between the heat and work interaction comes out to be its changing enthalpy at the outlet and inlet stream of fluid, provided, its change of kinetic energy and change of potential energies are negligible to understand.

For a device which is only work interacting type for a work interacting device for which, delQ by delm is 0. I can write this equation as delW by delm is h_1 minus h_2 that mean, dealing with a compressor. I have a compressor. There is an inlet stream air 1 and there is an outlet stream air well 1 and 2; delW by delm is h_1 minus h_2 in this equation.

We see that in compressor that this h_2 is more than h_1; it comes at a lower pressure and temperature; it goes out with a higher pressure and temperature; h_2 is more than h_1 and this becomes negative which means the compressor takes the 1. Reverse is the case in turbine; turbine work is coming out, h_1 is more than h_2.

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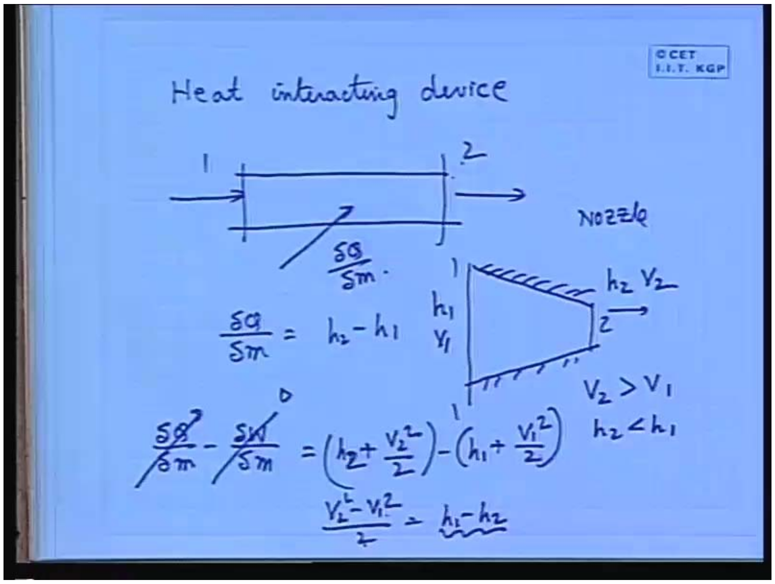

Heat interacting device

$$\frac{\delta Q}{\delta m} = h_2 - h_1$$

Nozzle

$$V_2 > V_1 \qquad h_2 < h_1$$

$$\cancel{\frac{\delta Q}{\delta m}}^{0} - \cancel{\frac{\delta W}{\delta m}} = \left(h_2 + \frac{V_2^2}{2}\right) - \left(h_1 + \frac{V_1^2}{2}\right)$$

$$\frac{V_2^2 - V_1^2}{2} = h_1 - h_2$$

Similarly, if we consider a pipe, just i am giving some example only heating interacting devices. You write this only for heat interacting device. If flow takes place like this and we give heat per unit mass, so if one wants to know what is the heat added, if i know the enthalpy at this two point i can write this steady flow energy equation making this term 0, that delQ by delm is simply… that means if heat is added h_2 will be more than h_1 or heat is rejected h_2 will be less than h_1. Sometimes in a control volume, there is no work in interaction; there is a conversion from one form to other form. For example, a nozzle, what you will do here in adiabatic nozzles? There is adiabatic surface insulated at stream 1 and stream 2. At stream 1, liquid or fluid comes with enthalpy h_1 and a velocity v_1 and here in fluid goes out enthalpy h_2 and velocity v_2 and what happens is that v_2 is greater than v_1, whereas, h_2 is less than h_1. At the expense of this enthalpy that means internal energy plus pressure energy, we create the kinetic energy. Then its kinetic energy is created out of the some of the internal energy and the pressure energy. In that case, we can write the energy equation not by neglecting this v_1 square by 2 terms that means we can neglect the change in the potential energy term.

In that case, we can write that delQ by delm minus delW by delm is equal to h_2 plus v_2 square by 2 minus... Since this is the adiabatic, no heat transfer is taking place, no work is performed by the nozzle with this surrounding and this term will be zero. We can write that v_2 square minus v_1 square by 2 is h_1 minus h_2. It is because of this enthalpy difference, the change in kinetic mass.

This way we can apply the steady flow energy equations in different control volume in practices.

[Conversation between professor and student.]

Try to understand volume is changed, pressure is changed everything is change but gross energy balance will be an increase in enthalpy because of the work done. Now, how we get it in increase in enthalpy within because increase in enthalpy knows enthalpy composed of two parts u plus pv. So whether there is a change in u or not i do not know so far that will come from the property relations if it is an air. So this is an ideal gas; internal energy is a function of temperature. Only if temperature increases, the internal energy will increase. So if there is an increase in internal energy we will find out there is an increase in temperature and there is an increase in internal energy. Similarly, there will be an increase in pressure energy also because of the product of p and v whether volume decrease and pressure increase, probably, their product is increased. We do not know these things, conclusively, that what will be there with this two counter acting effects. So specific volume is decrease at the same time pressure is increase, but the product will be increased. At the present moment we are not even going into that detail because we do not know how much pv is increased? How much u is increased so that there is a decrease in pv or increase in u? But we are not reading the air compressor. We are analyzing the thermodynamically that there is an increase in enthalpy.

We will find out whether this increases is because of increase in u or increase in pv or how much for u or how much for pv or a combination of increase decrease total increase that we are not going through at the present moment, that will be found out if we know the property relations and how do they change but only thing is that the enthalpy is increased. Think it from thermodynamic point of view, do not go into that detail, that will come afterwards, but in fact I tell you for your information, the pressure energy increased, because increase in pressure is much more than the decrease in the specific volume.

So, first law for a closed system and first law for an open system or a control volume that we have finished. Next class, what I will do, I will solve some problems in this class here, so you come prepared, you go through this lecture that first law and second low analysis to closed and open system, we will solve, some simple problems and some complicated problem also.

Thank you

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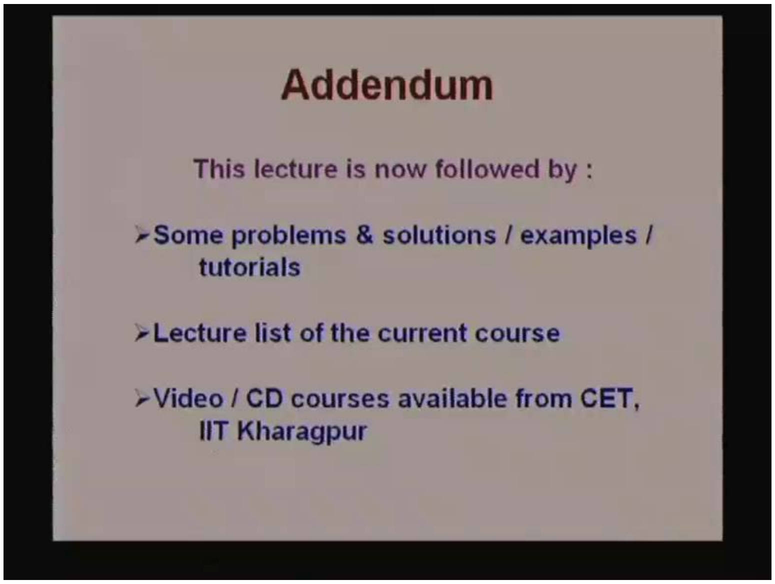

Addendum

This lecture is now followed by :

- Some problems & solutions / examples / tutorials
- Lecture list of the current course
- Video / CD courses available from CET, IIT Kharagpur

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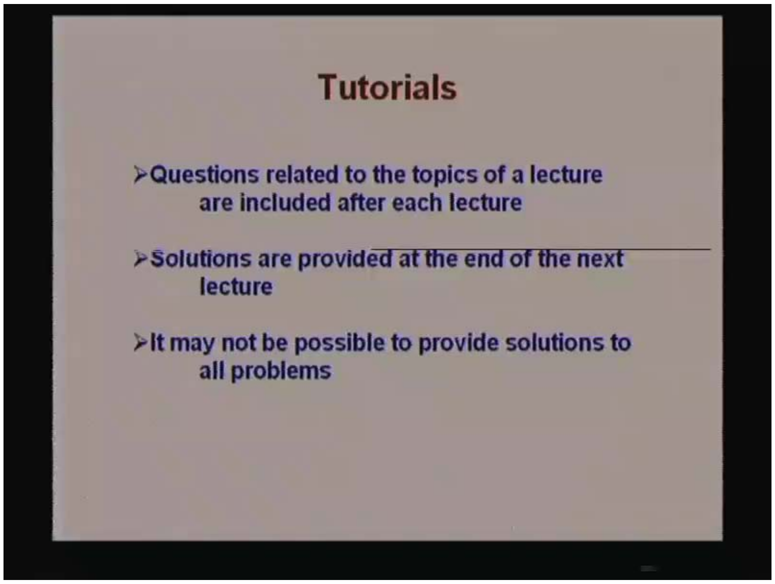

Tutorials

- Questions related to the topics of a lecture are included after each lecture
- Solutions are provided at the end of the next lecture
- It may not be possible to provide solutions to all problems

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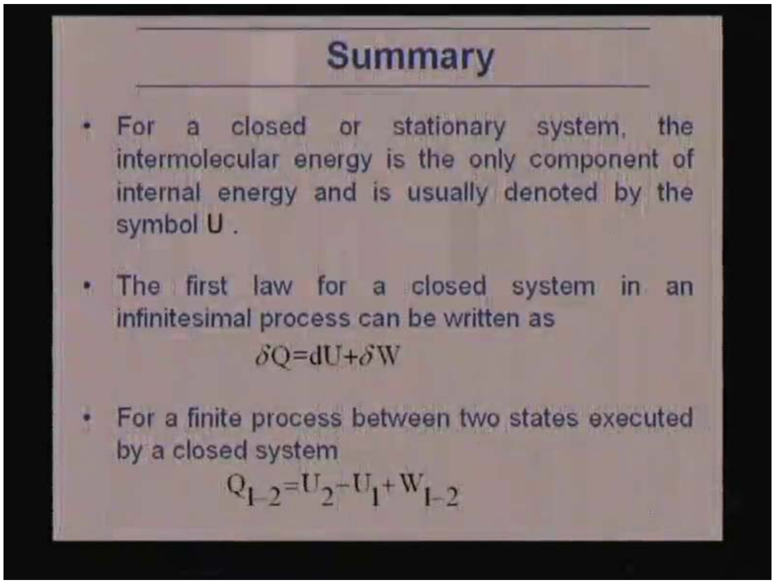

Summary

- For a closed or stationary system, the intermolecular energy is the only component of internal energy and is usually denoted by the symbol **U** .
- The first law for a closed system in an infinitesimal process can be written as

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

- For a finite process between two states executed by a closed system

$$Q_{1-2} = U_2 - U_1 + W_{1-2}$$

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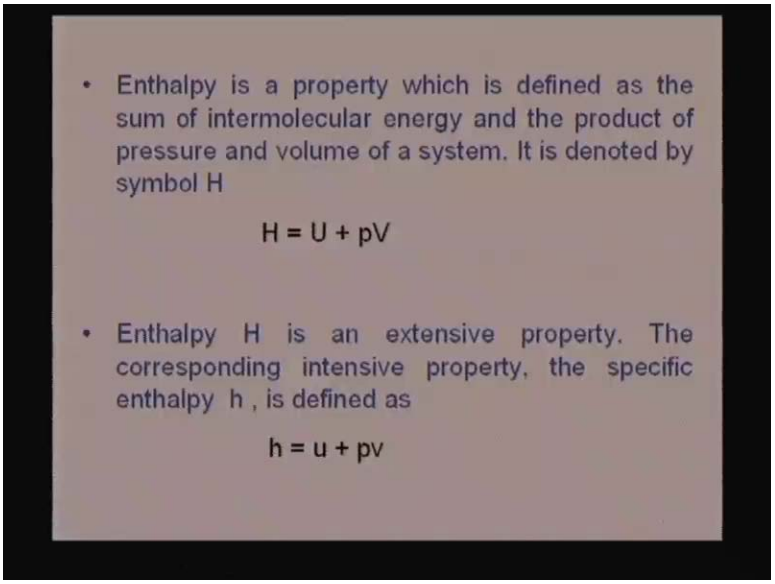

- Enthalpy is a property which is defined as the sum of intermolecular energy and the product of pressure and volume of a system. It is denoted by symbol H

$$H = U + pV$$

- Enthalpy H is an extensive property. The corresponding intensive property, the specific enthalpy h , is defined as

$$h = u + pv$$

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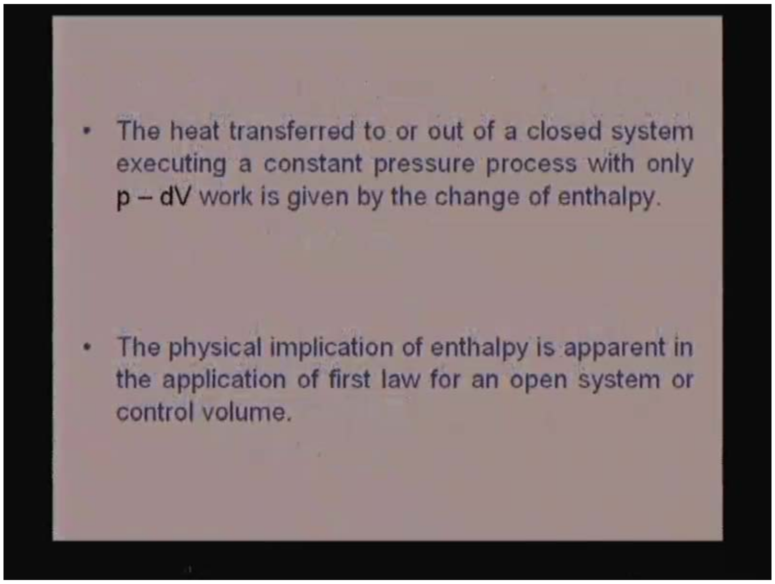

- The heat transferred to or out of a closed system executing a constant pressure process with only p – dV work is given by the change of enthalpy.
- The physical implication of enthalpy is apparent in the application of first law for an open system or control volume.

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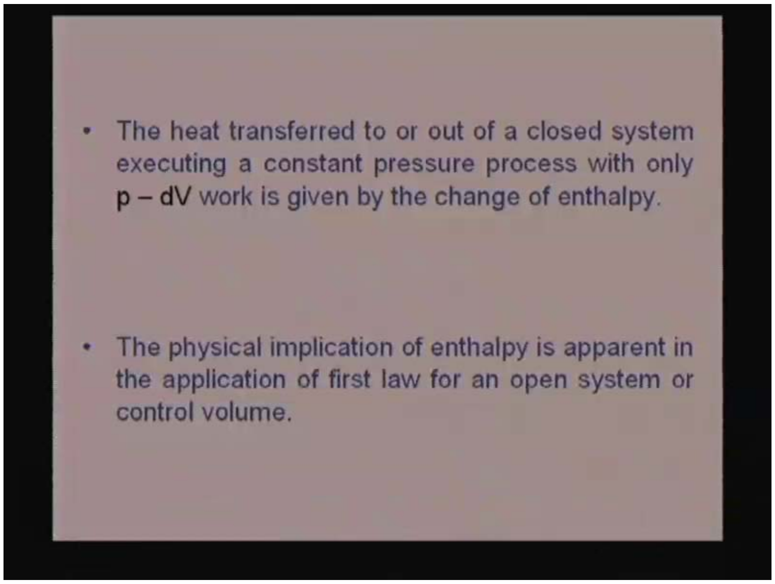

- The heat transferred to or out of a closed system executing a constant pressure process with only p – dV work is given by the change of enthalpy.
- The physical implication of enthalpy is apparent in the application of first law for an open system or control volume.

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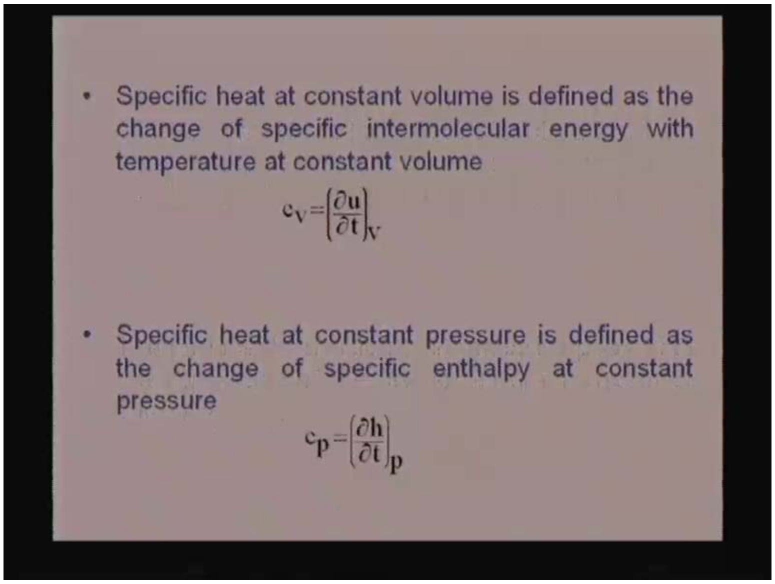

- Specific heat at constant volume is defined as the change of specific intermolecular energy with temperature at constant volume

$$c_V = \left(\frac{\partial u}{\partial t}\right)_V$$

- Specific heat at constant pressure is defined as the change of specific enthalpy at constant pressure

$$c_p = \left(\frac{\partial h}{\partial t}\right)_p$$

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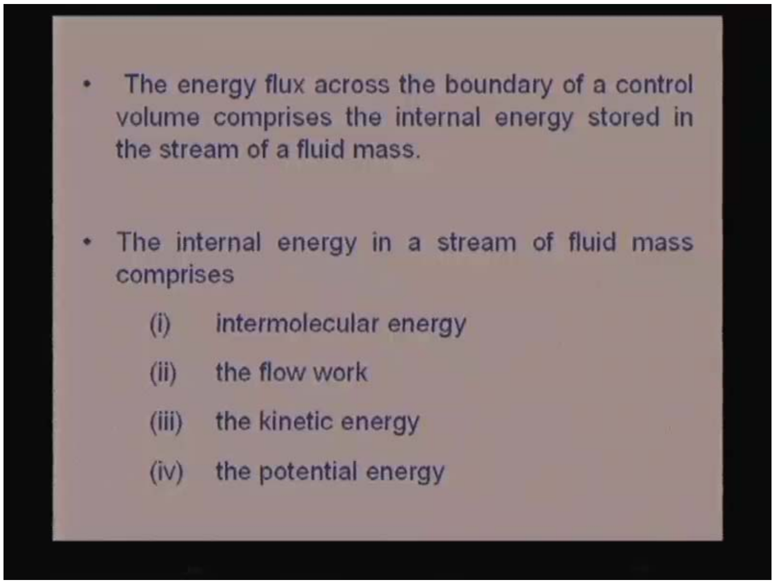

- The energy flux across the boundary of a control volume comprises the internal energy stored in the stream of a fluid mass.

- The internal energy in a stream of fluid mass comprises
  - (i) intermolecular energy
  - (ii) the flow work
  - (iii) the kinetic energy
  - (iv) the potential energy

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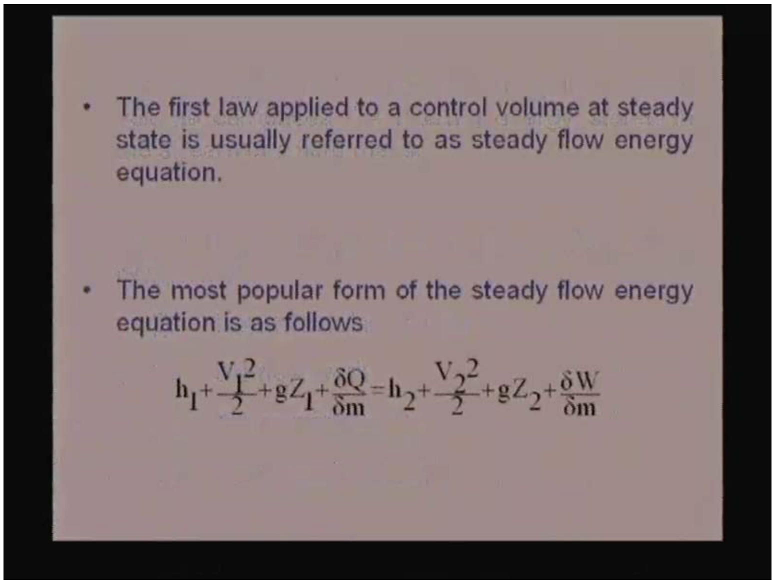

- The first law applied to a control volume at steady state is usually referred to as steady flow energy equation.
- The most popular form of the steady flow energy equation is as follows

$$h_1+\frac{V_1^2}{2}+gZ_1+\frac{\delta Q}{\delta m}=h_2+\frac{V_2^2}{2}+gZ_2+\frac{\delta W}{\delta m}$$

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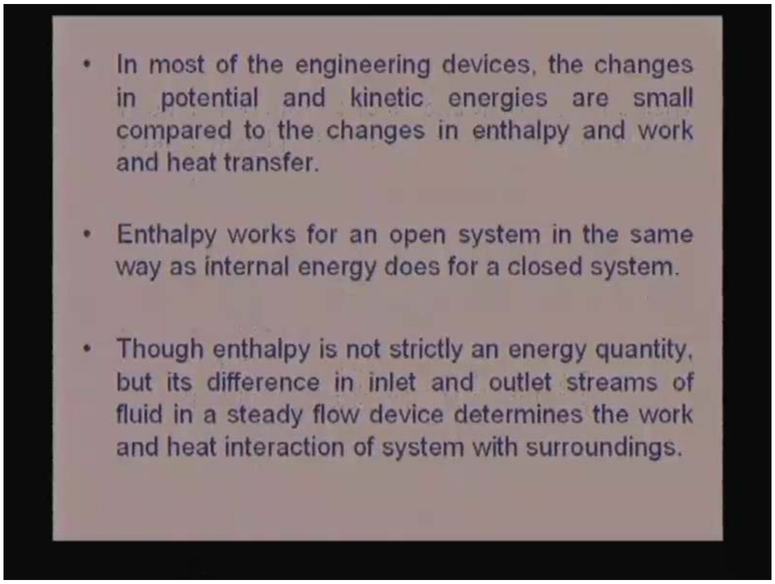

- In most of the engineering devices, the changes in potential and kinetic energies are small compared to the changes in enthalpy and work and heat transfer.
- Enthalpy works for an open system in the same way as internal energy does for a closed system.
- Though enthalpy is not strictly an energy quantity, but its difference in inlet and outlet streams of fluid in a steady flow device determines the work and heat interaction of system with surroundings.

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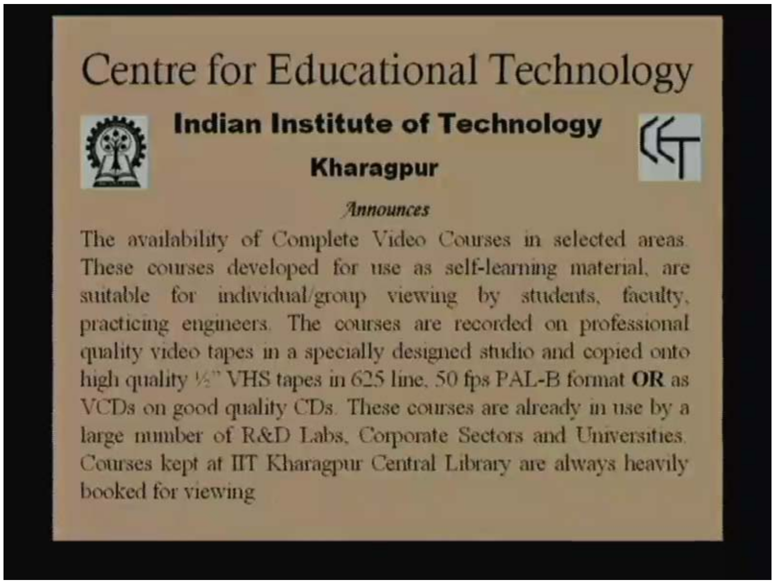

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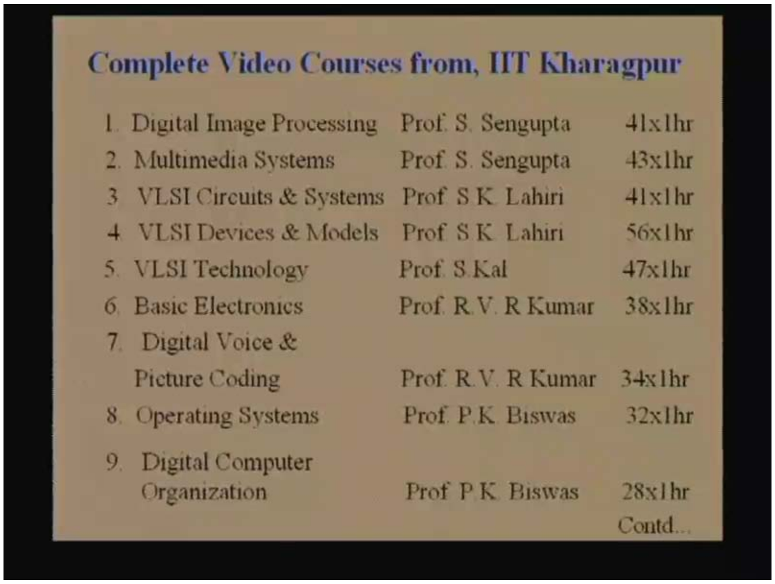

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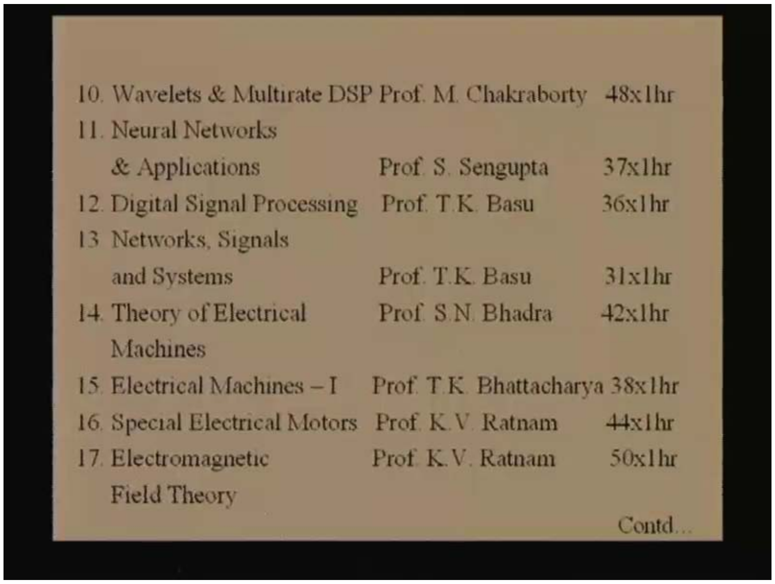

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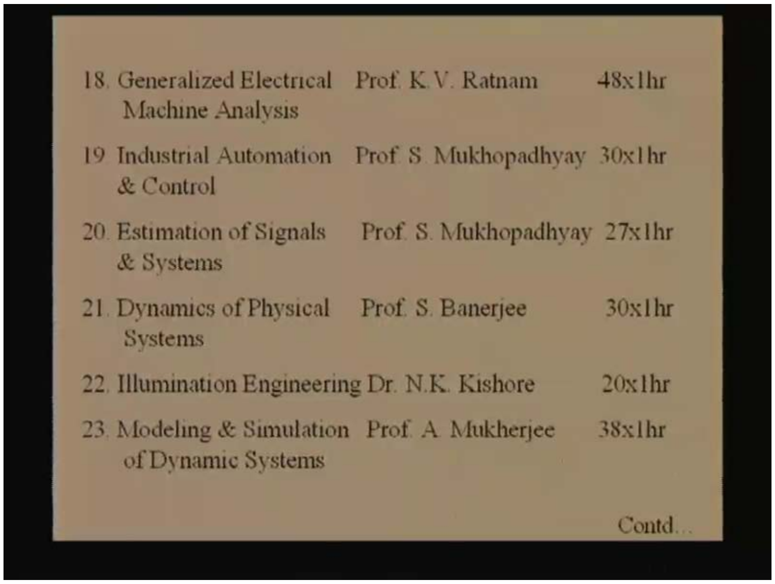

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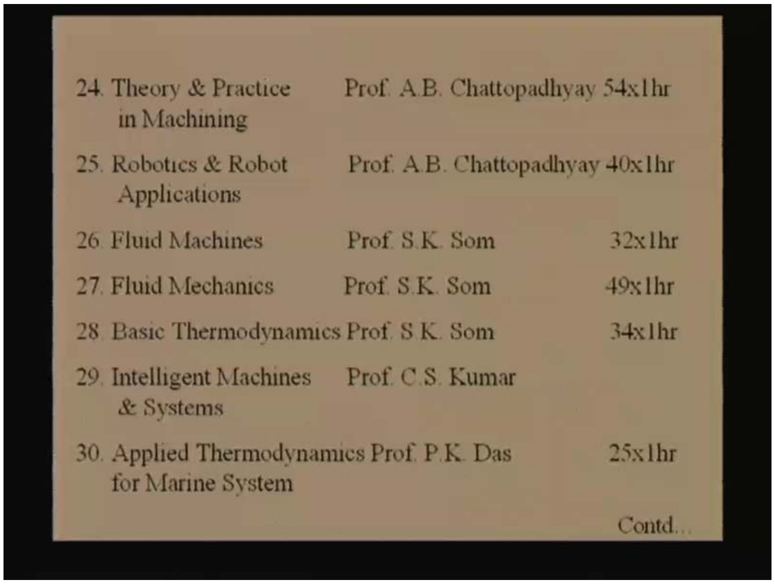

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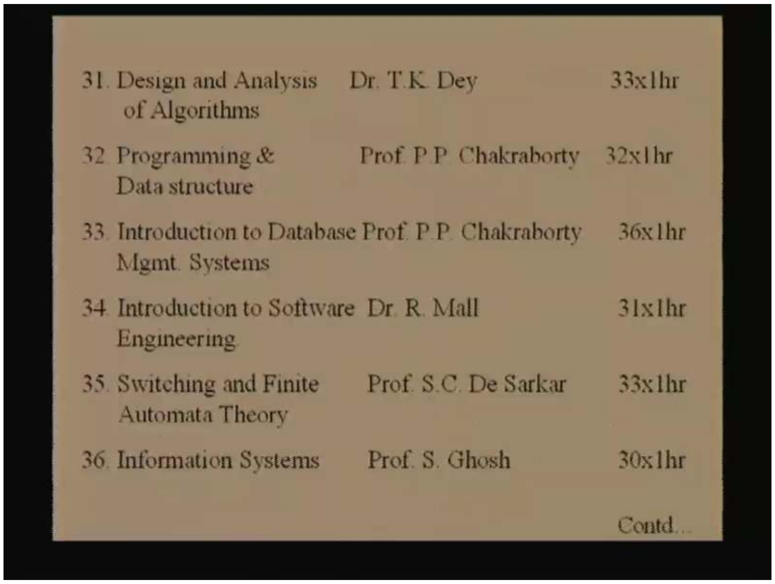

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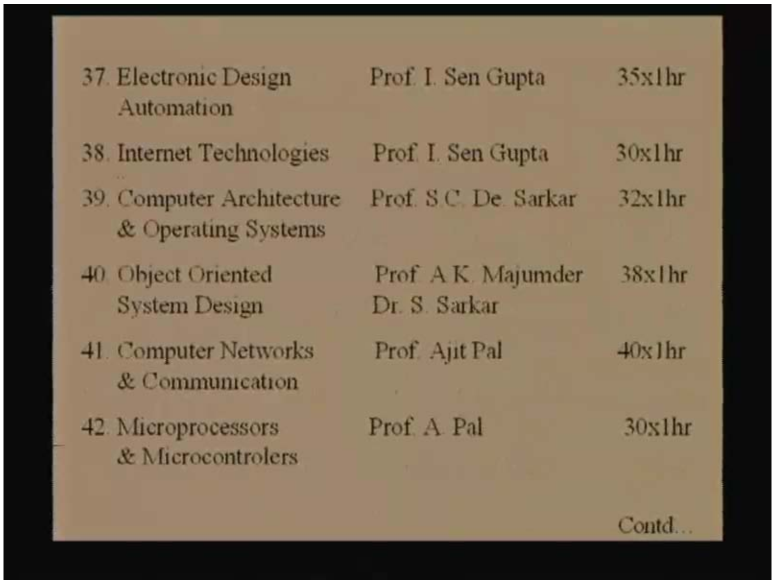

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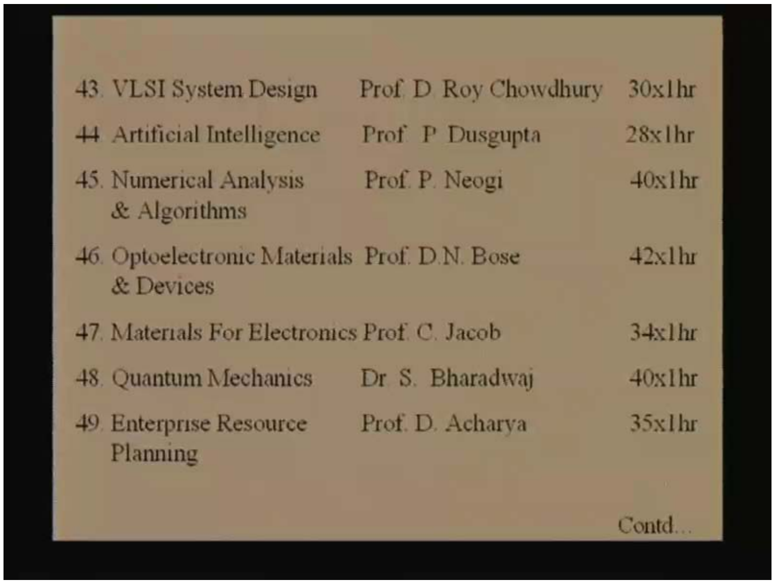

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46. Optoelectronic Materials & Devices	Prof. D.N. Bose	42x1hr
47. Materials For Electronics	Prof. C. Jacob	34x1hr
48. Quantum Mechanics	Dr. S. Bharadwaj	40x1hr
49. Enterprise Resource Planning	Prof. D. Acharya	35x1hr

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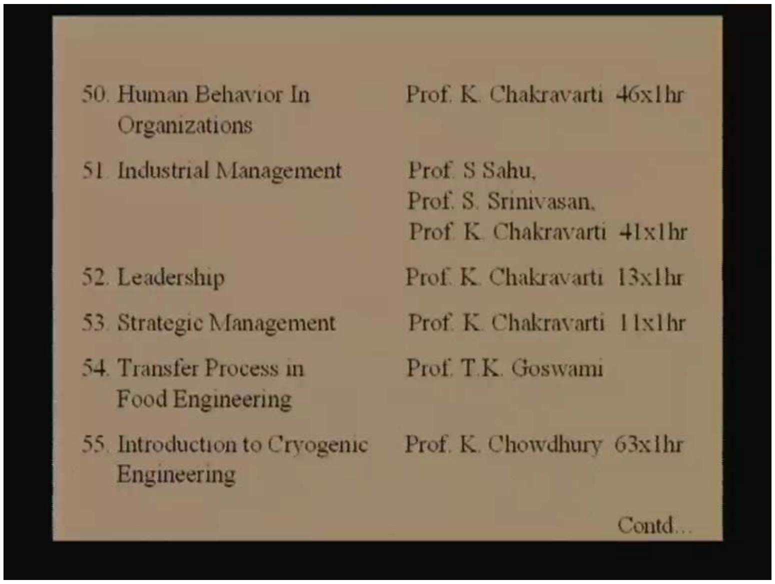

50. Human Behavior In Organizations	Prof. K. Chakravarti	46x1hr
51. Industrial Management	Prof. S Sahu, Prof. S. Srinivasan, Prof. K. Chakravarti	41x1hr
52. Leadership	Prof. K. Chakravarti	13x1hr
53. Strategic Management	Prof. K. Chakravarti	11x1hr
54. Transfer Process in Food Engineering	Prof. T.K. Goswami	
55. Introduction to Cryogenic Engineering	Prof. K. Chowdhury	63x1hr

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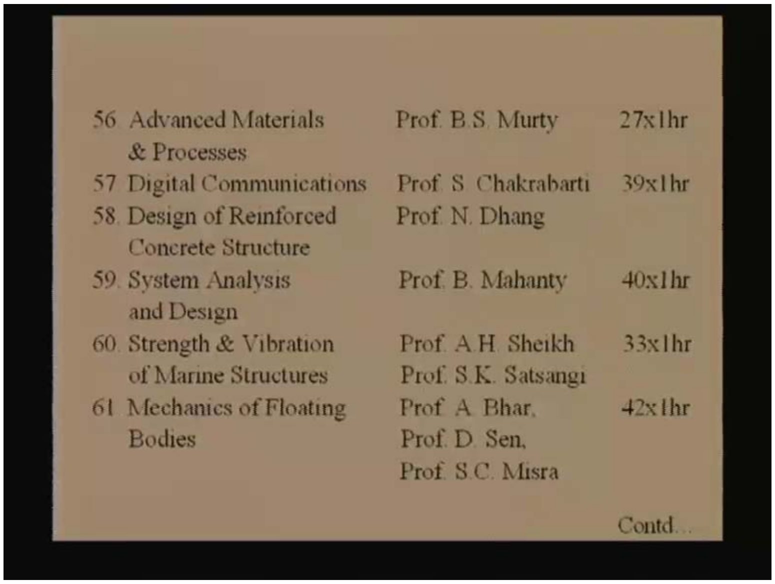

56. Advanced Materials & Processes	Prof. B.S. Murty	27x1hr
57. Digital Communications	Prof. S. Chakrabarti	39x1hr
58. Design of Reinforced Concrete Structure	Prof. N. Dhang	
59. System Analysis and Design	Prof. B. Mahanty	40x1hr
60. Strength & Vibration of Marine Structures	Prof. A.H. Sheikh Prof. S.K. Satsangi	33x1hr
61. Mechanics of Floating Bodies	Prof. A. Bhar, Prof. D. Sen, Prof. S.C. Misra	42x1hr

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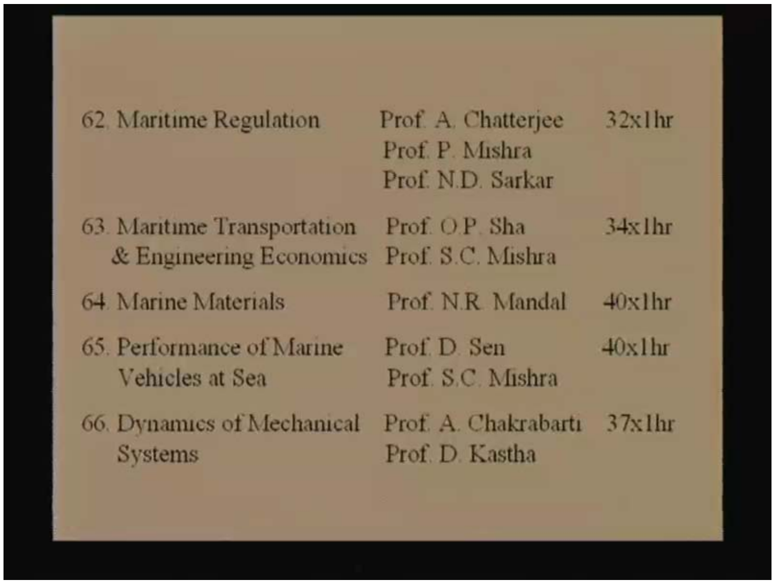

62. Maritime Regulation	Prof. A. Chatterjee Prof. P. Mishra Prof. N.D. Sarkar	32x1hr
63. Maritime Transportation & Engineering Economics	Prof. O.P. Sha Prof. S.C. Mishra	34x1hr
64. Marine Materials	Prof. N.R. Mandal	40x1hr
65. Performance of Marine Vehicles at Sea	Prof. D. Sen Prof. S.C. Mishra	40x1hr
66. Dynamics of Mechanical Systems	Prof. A. Chakrabarti Prof. D. Kastha	37x1hr