Advanced Thermodynamics and Combustion

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Module - 01
Review of Basic Thermodynamics
Lecture - 02
Work and Heat Transfer - First Law of Thermodynamics

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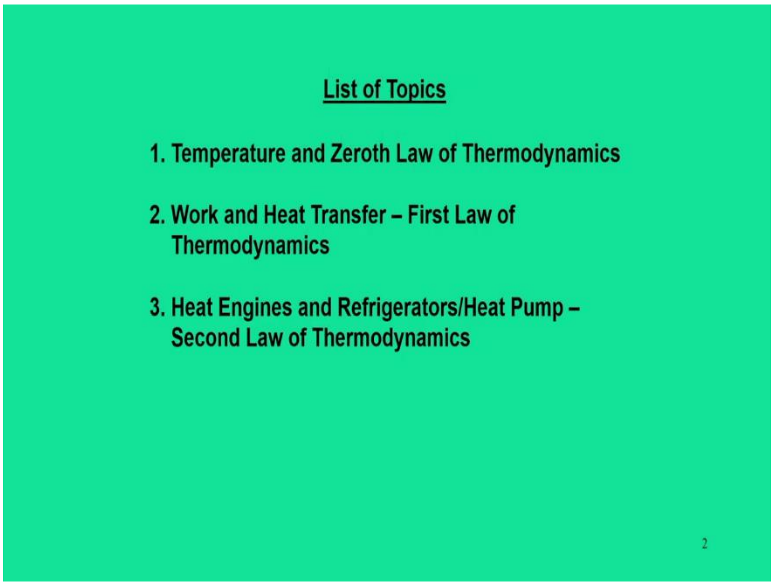

List of Topics

1. Temperature and Zeroth Law of Thermodynamics
2. Work and Heat Transfer – First Law of Thermodynamics
3. Heat Engines and Refrigerators/Heat Pump – Second Law of Thermodynamics

Dear learners greetings from IIT Guwahati, we are in this course Advanced Thermodynamics and Combustions and in the first module, that is Review of Basic Thermodynamics. We have three lectures, the first lecture we covered on temperature and zeroth law of thermodynamics; today we will be discussing on the first law of thermodynamics and which is mainly dealt with work and heat transfer.

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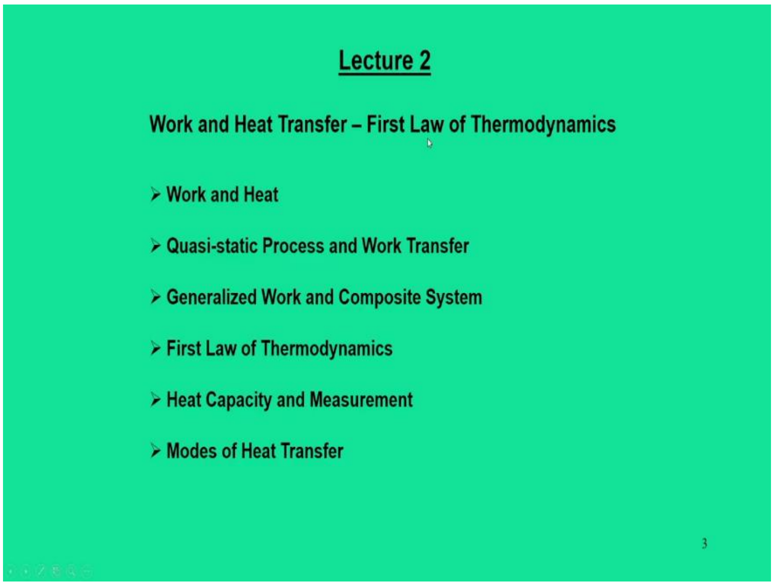

Lecture 2

Work and Heat Transfer – First Law of Thermodynamics

- Work and Heat
- Quasi-static Process and Work Transfer
- Generalized Work and Composite System
- First Law of Thermodynamics
- Heat Capacity and Measurement
- Modes of Heat Transfer

And in this lecture number 2, which is work and heat transfer that is first law of thermodynamics, we are going to discuss the following topics. The first one is the basic concepts of work and heat, then we will move to the thermodynamic definition of quasi static process and subsequent a work transfer, then we will move on to generalized equations for work system, and subsequently how that work equations can be applied for a composite systems involving multiple number of systems and processes which are non-thermodynamic in nature.

Then after discussing the concept of work and heat, will give the definition of the first law of thermodynamics and with this first law of thermodynamics, it gives another concept which is heat transfer or heat, and it is the another form of energy. Subsequently to discussion on the first law of thermodynamics, we will define some parameters and that which is heat capacity and its measurements and the last segment of this topic is the modes of heat transfers.

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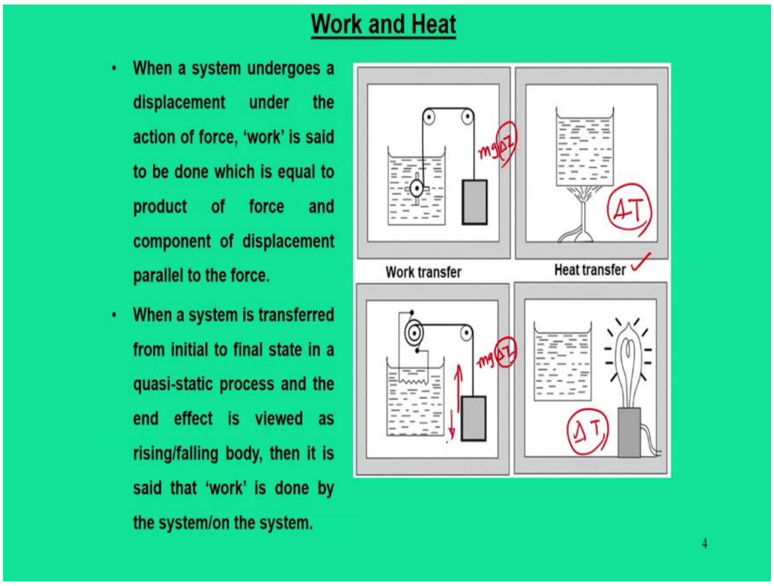

Work and Heat

- When a system undergoes a displacement under the action of force, 'work' is said to be done which is equal to product of force and component of displacement parallel to the force.
- When a system is transferred from initial to final state in a quasi-static process and the end effect is viewed as rising/falling body, then it is said that 'work' is done by the system/on the system.

Now, let us move on, first we will give the thermodynamic definition of work and heat. We all know that the energy interactions in a thermodynamic systems can occur in two modes, work and heat and there are some basic definitions which needs to be followed, if you want to this talk about work.

In mechanics principle, work is nothing but force times displacement and later on we convert the work to energy; subsequently it can be kinetic energy, potential energy. So, sticking to that definitions, the thermodynamic sense of defining the work refers to the fact that whenever we define this work and side by side we can visualize that systems either rising or falling a mass systems.

So, in the process of rise and fall of this certain mass, the potential energy of the system is changed and that gets transferred in the form of work. So, in this work transfer mode, in one sense we say there is a paddle wheel arrangements, which is used to change the thermodynamic state of the systems and in this case it may be a liquid inside a container and that thermodynamics state is going to change through this paddle wheel arrangement. And when you do some work on this paddle wheel and that is possible through rise and fall of this mass systems.

Now, similar work can also be introduced into the systems through an electric circuit, in which we can dump the same amount of work to an electrical systems; but still that energy can be used or view can be viewed as rise and fall of a mass systems. Now, in this process of the change of energy interactions, we really do not encounter the change in the temperature, substantial change in the temperature.

If this is not the case and whenever there is a energy interactions by virtue of temperatures, then that systems we refer as a heat transfer mode. So, in same systems we can say that in a close environment, a certain mass of liquid is getting heated by a burner; there is another viewpoint is that, we can have a electric systems in a enclosed container in which the water can be placed.

So, this particular sense there is no physical movement of mass systems; I mean these systems cannot be viewed as a rise and fall of mass systems, rather it can be viewed as rise in the temperatures. So, in this category we say there is a temperature change; ΔT is involved, so that is what they fall under the heat transfer, heat as the mode of energy interactions

But in this case, we have the work transfer can be viewed as $mg\Delta Z$, in this case also $mg\Delta Z$. So, delta Z is nothing, but the elevations, which can be quantified in the form of rise and fall of weight. So, this weight when it goes up, it does work on the systems; when it comes, that means work is done by the system.

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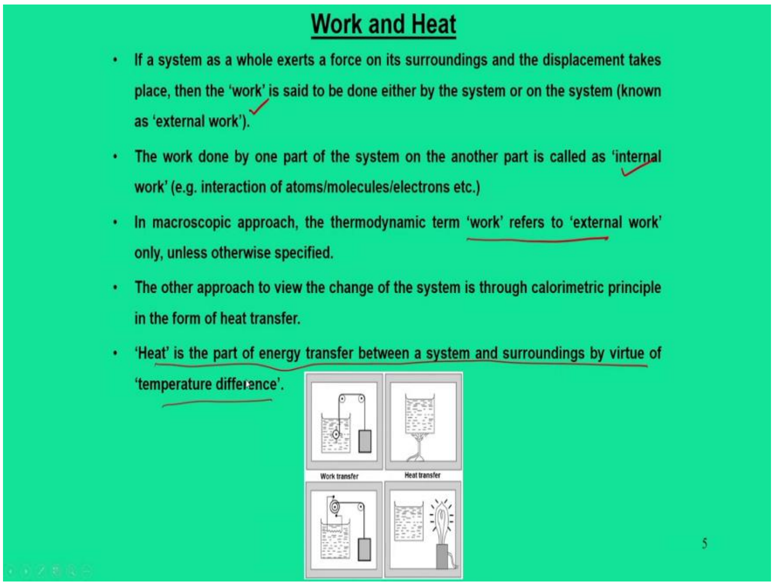

Work and Heat

- If a system as a whole exerts a force on its surroundings and the displacement takes place, then the 'work' is said to be done either by the system or on the system (known as 'external work').
- The work done by one part of the system on the another part is called as 'internal work' (e.g. interaction of atoms/molecules/electrons etc.)
- In macroscopic approach, the thermodynamic term 'work' refers to 'external work' only, unless otherwise specified.
- The other approach to view the change of the system is through calorimetric principle in the form of heat transfer.
- 'Heat' is the part of energy transfer between a system and surroundings by virtue of 'temperature difference'.

Having said this definition of work, then we are going to discussed about two form of this work; one is external work, other is internal work. So, in the internal work systems; that means this is mainly applicable for a microscopic system, where there is interaction of atoms, molecules, electrons and in that case if the analysis of work is done, so, that work is done by one part of the system to another part, then it is a internal work.

But if a system as a whole exerts a force on the surroundings and the displacement takes place, then the work is said to be done either by the system or on the systems and it is termed as external work. So, that means unless and otherwise specified, our viewpoint of work is always external work. And our viewpoint of heat is the part of energy transfer between the system and surroundings by virtue of temperature difference.

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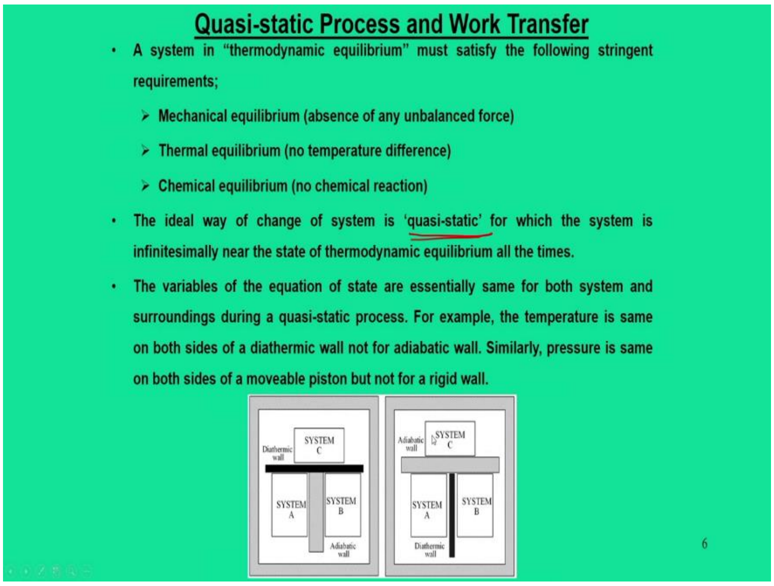

Quasi-static Process and Work Transfer

- A system in "thermodynamic equilibrium" must satisfy the following stringent requirements;
  - Mechanical equilibrium (absence of any unbalanced force)
  - Thermal equilibrium (no temperature difference)
  - Chemical equilibrium (no chemical reaction)
- The ideal way of change of system is 'quasi-static' for which the system is infinitesimally near the state of thermodynamic equilibrium all the times.
- The variables of the equation of state are essentially same for both system and surroundings during a quasi-static process. For example, the temperature is same on both sides of a diathermic wall not for adiabatic wall. Similarly, pressure is same on both sides of a moveable piston but not for a rigid wall.

Now, with this basic definition, we will now move to individual mode of analysis that is work transfer. The thermodynamic definition of work transfer always refers to the fact that when there is a change of state from one to other, then the process can be specified as a quasi static process. So, in a quasi static process what happens; that means change of state of the system happens without any disturbance to the surroundings.

So, to have such quasi static process possible, what we need to have requirement is thermodynamic equilibrium between the system and the surroundings. So, this is possible only when the system exists in mechanical equilibrium; that means there is no unbalanced force.

The system is in the thermal equilibrium with respect to surrounding, there is no transfer of energy by virtue of temperature difference and in fact there is also no chemical reactions. So, by virtue of it the system is in equilibrium chemically with respect to surroundings. If these three conditions are satisfied, and the change of state happens, then we say it is a quasi static process.

So, all the viewpoint of analysis of work transfer can be possible through quasi static process. Now, again for heat transfer situations, we can recall our previous analysis that transfer of heat is possible only when multiple system they are separated by diathermic wall.

So, diathermic wall means, the information of between the systems can be propagated through heat transfer; but if you put an adiabatic wall, there is no question of transfer of heat or energy in the form of heat. So, these are the viewpoints in which we are going to discuss the more details on the work transfers.

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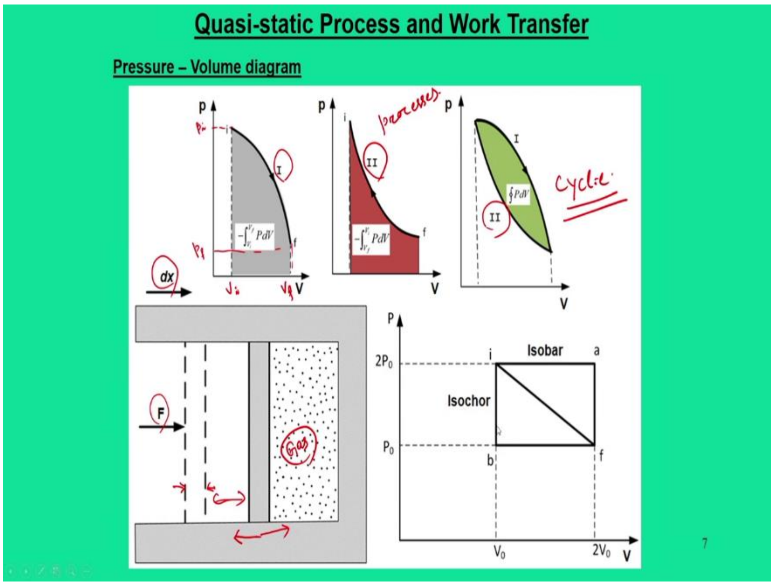

Quasi-static Process and Work Transfer

Pressure – Volume diagram

Now, when I say quasi static process; the first basic definition we say that, the work is nothing, but force times displacements. Now, here the force can be interpreted in the form of pressure, displacement can be interpreted in the form of volume; so that means there is a change in the volume and there is a change in the pressure.

So, we can define this in the coordinates of PV diagrams. So, that is what we say quasi static processes are often referred in the pressure volume diagrams. So, in a simple system like we have a piston cylinder device; and this piston is moving back and forth within the cylinders.

So, in the process of moving, we can view the systems that when the gas which is in inside this container or this inside the cylinder, it gets compressed when the piston moves in the forward directions and the gas expands when the piston moves in the backward directions.

And we say that if the process occurs in very slowly, so that the displacement can be represented in the form of dx small displacement for a given force F, then we can view this entire change in the pressure and volume of the gas in which we can write that gas which is at initial state i, its coordinates are specified as p_i and v_i. And this is at final volume is v_f and final pressure is p_f.

So, the work transfer in this process, we can see there is an increase in the volume. And you can say it is an expansion process and in another viewpoint is that, from the final system to initial system this process can also occur. So, these two I and II, they are referred to processes. Now, when I club them together; that means a gas goes from the initial state to final state in one path and you know again it returns to the initial state in another path.

So, if this happens, we say it is a cyclic process. And very specifically we can say that these processes can be defined in such a way that when the pressure remains constant, so it is a isobaric process; when volume remains constant, it is a isochoric process.

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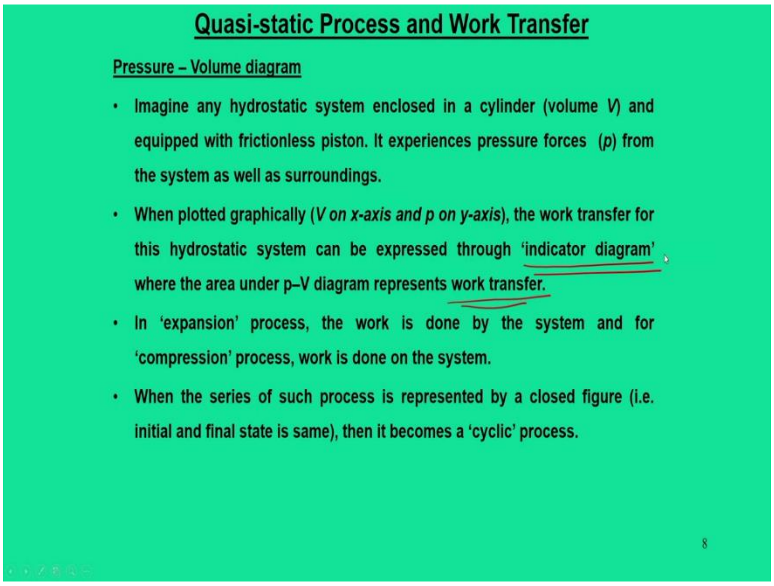

Quasi-static Process and Work Transfer

Pressure – Volume diagram

- Imagine any hydrostatic system enclosed in a cylinder (volume *V*) and equipped with frictionless piston. It experiences pressure forces (*p*) from the system as well as surroundings.
- When plotted graphically (*V on x-axis and p on y-axis*), the work transfer for this hydrostatic system can be expressed through 'indicator diagram' where the area under p–V diagram represents work transfer.
- In 'expansion' process, the work is done by the system and for 'compression' process, work is done on the system.
- When the series of such process is represented by a closed figure (i.e. initial and final state is same), then it becomes a 'cyclic' process.

Then we also know that what is an expansion process; that means in the expansion process, the work is generally done by the systems and in the compression process, the work is done on the systems.

Another point I would like to emphasize the fact that, the pressure volume diagrams which normally represents the work transfer is also called as an indicator diagram.

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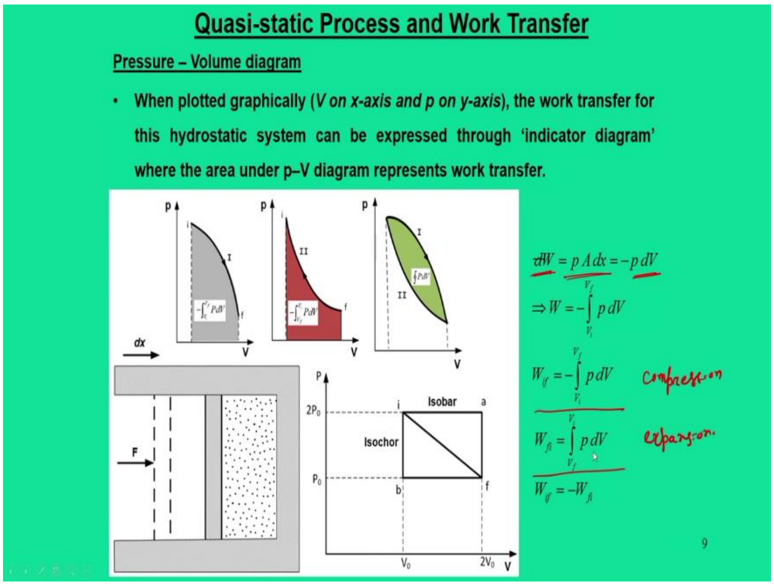

Quasi-static Process and Work Transfer

Pressure – Volume diagram

- When plotted graphically (*V on x-axis and p on y-axis*), the work transfer for this hydrostatic system can be expressed through 'indicator diagram' where the area under p–V diagram represents work transfer.

$$\text{đ}W = pA\,dx = -p\,dV$$

$$\Rightarrow W = -\int_{V_i}^{V_f} p\,dV$$

$$W_{if} = -\int_{V_i}^{V_f} p\,dV$$ compression

$$W_{fi} = \int_{V_f}^{V_i} p\,dV$$ expansion.

$$W_{if} = -W_{fi}$$

So, in the same philosophy, we can find out what is the work transfer that happens. So, starting from the first basic definition the when a force is exerted, displacement takes dx;

the work transfer since if you can see there is an inexact differential, because it depends on the path. So, $dW = pAdx$, Adx is nothing, but the volume change.

And they can be integrated once we know this relations between pressure and volume; so we can say work transfer $\int_{v_i}^{v_f} pdv$. And in one case the work transfer will be negative and in the other case positive; that means this is a situation for compression and this is the situation for expansion; in the process of work transfer, the volume increases.

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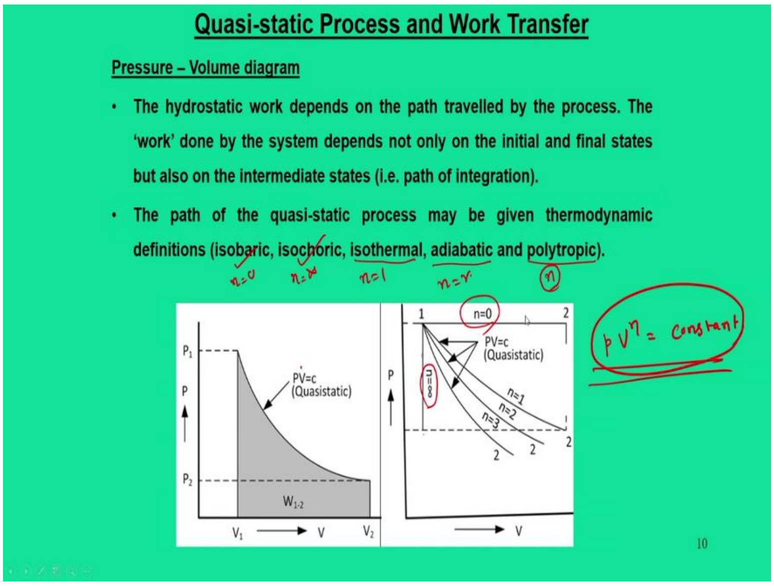

Quasi-static Process and Work Transfer

Pressure – Volume diagram

- The hydrostatic work depends on the path travelled by the process. The 'work' done by the system depends not only on the initial and final states but also on the intermediate states (i.e. path of integration).
- The path of the quasi-static process may be given thermodynamic definitions (isobaric, isochoric, isothermal, adiabatic and polytropic).

$n=0$ $n=\infty$ $n=1$ $n=\gamma$ n

$pv^n = \text{constant}$

Now, moving further, this is another angle of representing this pressure volume diagrams, where the standard way of representing this pressure volume relations as $pv^n = C$.

So, in the basic thermodynamics course, this is a very fundamental relation and for different values of n, we can say what are the nature of the processes. They can be isobaric, when you have say isobaric process; that means it is a constant pressure process. So, in this case n is equal to 0. So, here the pressure is constant. And when we say isochoric process, the volume remains constant; that means n is infinity.

And if you say isothermal process, $pv = C$; that is nothing, but $pv = RT$, so n is equal to 1. When we say adiabatic process, n becomes γ and when you have polytropic process, so typically there is a standard number we it is just a number that can be any value between 1 and γ. So, this is how we define this thermodynamic processes in our analysis.

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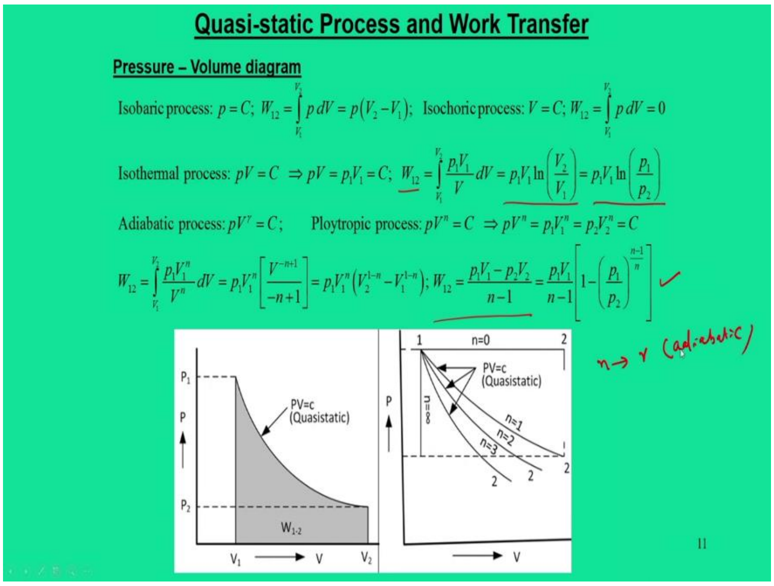

Quasi-static Process and Work Transfer

Pressure – Volume diagram

Isobaric process: $p = C;\ W_{12} = \int_{V_1}^{V_2} p\,dV = p(V_2 - V_1)$; Isochoric process: $V = C;\ W_{12} = \int_{V_1}^{V_1} p\,dV = 0$

Isothermal process: $pV = C \Rightarrow pV = p_1V_1 = C;\ \underline{W_{12}} = \int_{V_1}^{V_2} \frac{p_1V_1}{V} dV = \underline{p_1V_1 \ln\left(\frac{V_2}{V_1}\right)} = \underline{p_1V_1 \ln\left(\frac{p_1}{p_2}\right)}$

Adiabatic process: $pV^{\gamma} = C$; Ploytropic process: $pV^n = C \Rightarrow pV^n = p_1V_1^n = p_2V_2^n = C$

$$W_{12} = \int_{V_1}^{V_2} \frac{p_1V_1^n}{V^n} dV = p_1V_1^n\left[\frac{V^{-n+1}}{-n+1}\right] = p_1V_1^n\left(V_2^{1-n} - V_1^{1-n}\right);\ W_{12} = \underline{\frac{p_1V_1 - p_2V_2}{n-1}} = \frac{p_1V_1}{n-1}\left[1 - \left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}}\right] ✓$$

$n \to \gamma$ (adiabatic)

So, for each case, it is now possible to find out the work transfers. So, isobaric process, pressure is equal to constants. So, accordingly $W_{12} = \int_{V_1}^{V_2} pdV = p(V_2 - V_1)$. For an isochoric process, $W_{12} = \int_{V_1}^{V_2} pdV = 0$; for an isothermal process we say $pV = C \Rightarrow pV = p_1V_1 = C$. So, this particular equation can be integrated, so there are 2 forms. So, work transfer is equal to $p_1V_1 \ln\left(\frac{V_2}{V_1}\right) = p_1V_1 \ln\left(\frac{p_1}{p_2}\right)$.

Now, if it is an adiabatic process $pv^{\gamma} = C$; polytropic process, $pv^n = C$. So, indeed, the general definitions we can write as $W_{12} = \frac{p_1V_1 - p_2V_2}{n-1} = \frac{p_1V_1}{n-1}\left[1 - \left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}}\right]$. So, this is for polytropic process. Now, when n goes to γ, so this becomes adiabatic process. So, this is how you are going to calculate.

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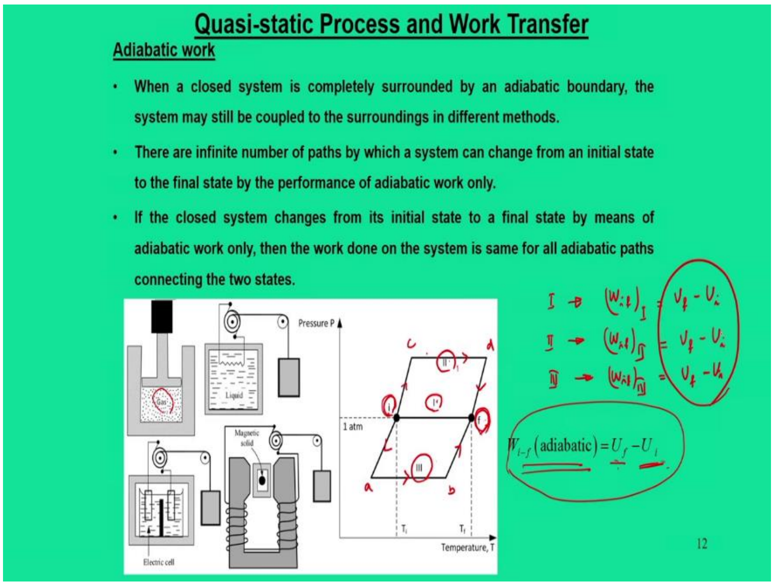

Quasi-static Process and Work Transfer

Adiabatic work

- When a closed system is completely surrounded by an adiabatic boundary, the system may still be coupled to the surroundings in different methods.
- There are infinite number of paths by which a system can change from an initial state to the final state by the performance of adiabatic work only.
- If the closed system changes from its initial state to a final state by means of adiabatic work only, then the work done on the system is same for all adiabatic paths connecting the two states.

$I \rightarrow (W_{i-f})_{I} = U_f - U_i$

$II \rightarrow (W_{i-f})_{II} = U_f - U_i$

$III \rightarrow (W_{i-f})_{III} = U_f - U_i$

$$W_{i-f}(\text{adiabatic}) = U_f - U_i$$

Then moving further, we are going to have another definition which is adiabatic work. The word adiabatic is normally used when there is no heat transfer; but when the system changes from state 1 to state 2, the work transfer is possible.

So, in a situation when there is no heat transfer, how adiabatic work can be calculated. So, these particular things we can say that if you recall our P V diagram; so a system goes from initial state i to final state f. So, a typical or maybe one of the best process is that is process I; through this process I, it can go from one state to other. And there are multiple ways that state point one that is initial state can reach to the final state by multiple ways.

So, I can go in one line, I can have a another method by involving process III. So, I can go from i to a, then a to b, then b to f or I can have another process i to c, then i to d then f. So, in this way we can say this different name of the processes we can have 1, 2, 3. So, there are three situations that I have mentioned here, in which the initial state can be changed to the final state.

Now, in this process of going from initial state to final state; what I am imposing a condition is that, we can view this as if there is a gas that changes its states when the piston moves within the cylinders. So, through this we can go from i to f; but there are some situations and in this process what I have mentioned is that this is a constant pressure process.

But there are some situations that without maintaining the constant pressures, I can choose this path and reach the final state. And while moving in this route, still I ensure there is no heat transfer. Now, while choosing another path II that is i, c, d and f; I also see that there is no heat transfer, that means entire route is completely enclosed by an adiabatic wall, for which there is no heat transfers.

But ultimately if we are able to see or do some experiments, in which we can find out the parameters and which is nothing but its internal energy. What it says is that this internal energy I am calculating at the initial states as well as the final state and what has been seen is that whatever path you choose; as long as that path is adiabatic, the internal energy change is equal to the adiabatic work.

So, means that if I go from 1 to f in the process I which is adiabatic, I calculate $U_i \; and \; U_f$. So, for the process I we can say, this $\left(W_{if}\right)_I = U_f - U_i$ and it is possible to also measure, this internal energy in process II, I also have same value $U_f - U_i$. And in the third process; if you have this work transfer by adiabatic process, it becomes $U_f - U_i$.

So, what it means is that, as long as the condition of adiabatic nature is ensured; this change in the internal energy is nothing but the adiabatic work done. So, this is the fundamental conclusion that we get out of this exercise.

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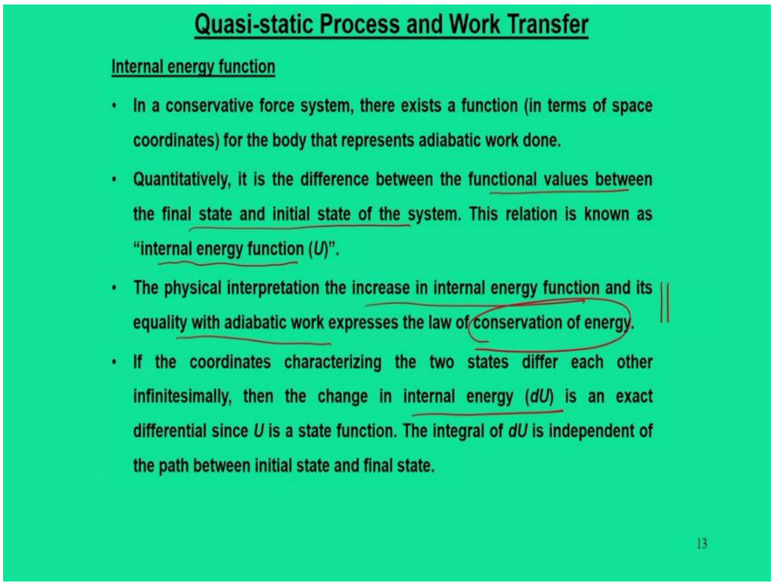

Quasi-static Process and Work Transfer

Internal energy function

- In a conservative force system, there exists a function (in terms of space coordinates) for the body that represents adiabatic work done.
- Quantitatively, it is the difference between the functional values between the final state and initial state of the system. This relation is known as "internal energy function (*U*)".
- The physical interpretation the increase in internal energy function and its equality with adiabatic work expresses the law of conservation of energy.
- If the coordinates characterizing the two states differ each other infinitesimally, then the change in internal energy (*dU*) is an exact differential since *U* is a state function. The integral of *dU* is independent of the path between initial state and final state.

Now, when I say internal energy, then you put another definitions what is this internal energy. So, quantitatively it is the difference between the functional values between the final state and initial state of the systems. So, the mathematical definition we can say, it is a functional values between the final and initial state of the systems. And because of this region; instead of giving a value, we call this as a internal energy function. Why we say function? I will come back to that point later.

But the physical interpretation tells is that, the increase in the internal energy function is equal to the adiabatic work and this is the basic definition for conservation of energy. In fact, when this conservation of energy in the beginning it was realized then it was started with a concept that finding adiabatic work and then equalizing it to internal energy function.

So, moving very specifically we can say that in the viewpoint of graphical representations, we say that the U the internal energy is a state functions; although we come to a different route, the work transfers in all the cases are equal, but when you try to equalize it with the energy transfer, this we say this internal energy dU it remains same for all the adiabatic path and then it is stated that internal energy is a state function.

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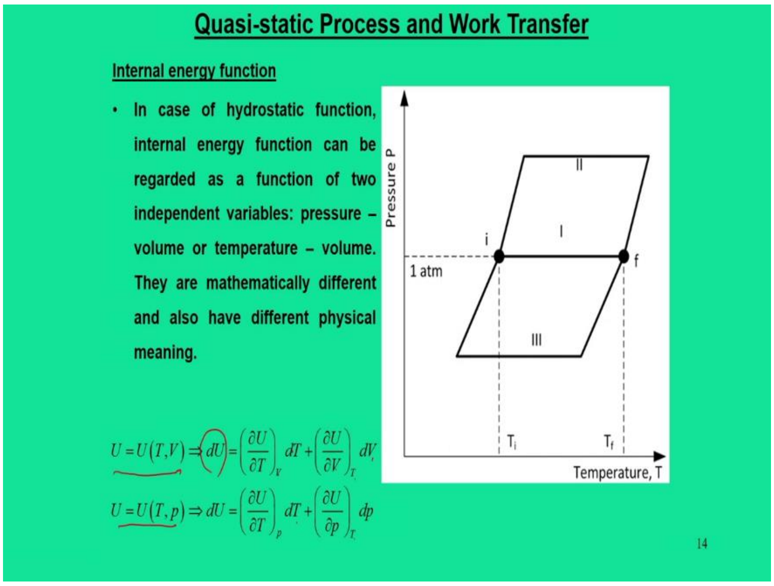

Quasi-static Process and Work Transfer

Internal energy function

- In case of hydrostatic function, internal energy function can be regarded as a function of two independent variables: pressure – volume or temperature – volume. They are mathematically different and also have different physical meaning.

$$U = U(T,V) \Rightarrow dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV$$

$$U = U(T,p) \Rightarrow dU = \left(\frac{\partial U}{\partial T}\right)_p dT + \left(\frac{\partial U}{\partial p}\right)_T dp$$

Here again like to emphasize why we say it is a function. Since internal energy is a thermodynamic variable, the ideal way of representing them is in two independent variables and these two independent variables could be either pressure, volume or temperature volume; because pressure volume they are internally related.

So, the ideal way of telling these that in the first expressions if you say, that U is a function of temperature and volume; then exact differential function $\boldsymbol{U} = U(T,V) \Rightarrow dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV$.

Now, if you say this internal energy function of temperature and pressure, then $U = U(T,p) \Rightarrow dU = \left(\frac{\partial U}{\partial T}\right)_p dT + \left(\frac{\partial U}{\partial p}\right)_T dp$. And because of this reason, we say that the internal energy has a functional relation.

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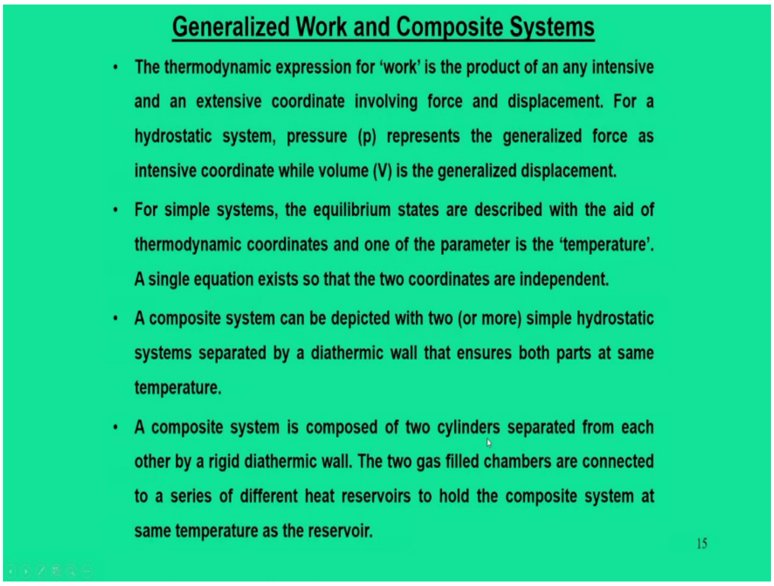

Generalized Work and Composite Systems

- The thermodynamic expression for 'work' is the product of an any intensive and an extensive coordinate involving force and displacement. For a hydrostatic system, pressure (p) represents the generalized force as intensive coordinate while volume (V) is the generalized displacement.
- For simple systems, the equilibrium states are described with the aid of thermodynamic coordinates and one of the parameter is the 'temperature'. A single equation exists so that the two coordinates are independent.
- A composite system can be depicted with two (or more) simple hydrostatic systems separated by a diathermic wall that ensures both parts at same temperature.
- A composite system is composed of two cylinders separated from each other by a rigid diathermic wall. The two gas filled chambers are connected to a series of different heat reservoirs to hold the composite system at same temperature as the reservoir.

Then moving further, we are now able to discuss about internal energy, we are now able to discuss about work and we have tried make a correlations and then we have a concept of generalized work.

So, the generalized work which is nothing but the thermodynamic definition of work and for an hydrostatic systems, the pressure and volume representation is the most ideal way and this pressure represents the generalized force in the intensive coordinates, where volume is the generalized displacement.

And the third parameter which is also important is nothing, but the another independent parameter that is temperatures. So, a single equation exists, so that two coordinates are independent. We also know that a composite systems can be depicted by two hydrostatics system separated by diathermic wall that, ensure both parts at same temperature; other way of looking at the system, this composite systems can be separated in a adiabatic one.

Through this diathermic wall there is a information of propagation of energy in the form of heat.

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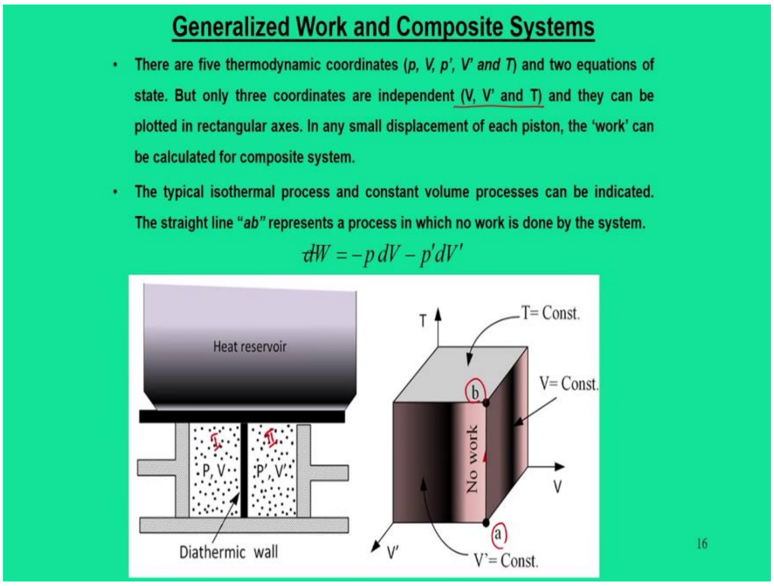

Generalized Work and Composite Systems

- There are five thermodynamic coordinates (*p, V, p', V' and T*) and two equations of state. But only three coordinates are independent (V, V' and T) and they can be plotted in rectangular axes. In any small displacement of each piston, the 'work' can be calculated for composite system.
- The typical isothermal process and constant volume processes can be indicated. The straight line "*ab*" represents a process in which no work is done by the system.

$$đW = -p\,dV - p'dV'$$

So, this particular things shows that we will now imagine a systems in which there are two gas system phase and these two gas systems are separated by a diathermic wall and with both sides there are pistons. The other part and on the top of this, we have a heat reservoir through which the information from this the part I that is gas in the system 1 and between the system 2 is possible through this heat mode.

That means if we can say it is this is a diathermic wall and this is an adiabatic wall; even though we put a heat reservoir, we cannot propagate the information between these two. And, if you do not imagine this to be an adiabatic wall, entire information can be rooted through this diathermic wall.

So, what through this process now? One says we can imagine that, as if we will put no restrictions on this top part, in which this heat reservoir is kept. So, only information that can be passed from system 1 to system 2 is through this diathermic wall. Initial conditions of this gas in the system 1 will be p, v and initial conditions of the system 2 will be p', v'.

So, now it is a composite systems, which involves the coordinates that is pressure, volume and temperatures. And since we say that there is no restrictions of adiabatic in nature, entire systems can be in the thermal equilibrium. So, when I say there is a thermal equilibrium; that means temperature is constant there.

So, there is a boundary, in which there is a constant temperatures. So, entire five coordinates; although we have a multiple composite systems involving their five coordinates; out of this, only three independent coordinates are possible that is $v, v' and\ T$, p, v are related, p', v' are related. So, out of them we are only choosing one and temperature is the another parameters.

Now, if these three things can be plotted in a independent coordinate systems that is $v, v' and\ T$. And what we can realize? We can imagine it is a cube involving these coordinates and for each plane, we can assign some the thermodynamic definitions.

For example in this particular plane, we will have volume constant; in this top part of the plane, we have temperature constant and in the third part, we have $v' = C$. And as you say there is no work across this boundary, so that boundary can be imagined as a typical isothermal process and constant volume process; that means when you say constant volume process, obviously there is no work the straight-line ab represents the process in which no work is done by the system

So, the ab system represents there is no work, because along this line volume remains constant. So, this is how we are going to realize a composite system analysis.

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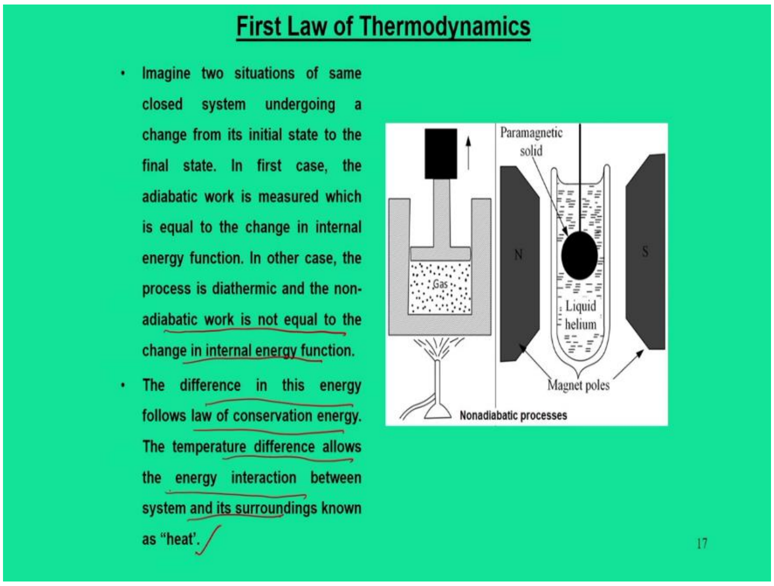

First Law of Thermodynamics

- Imagine two situations of same closed system undergoing a change from its initial state to the final state. In first case, the adiabatic work is measured which is equal to the change in internal energy function. In other case, the process is diathermic and the non-adiabatic work is not equal to the change in internal energy function.
- The difference in this energy follows law of conservation energy. The temperature difference allows the energy interaction between system and its surroundings known as "heat'.

Now, having said this composite systems, then again we will move back to the fact that we are looking at a situations when this work transfer is possible in a non adiabatic processes. So, non-adiabatic processes involves heat transfer; because that is another mode of energy interaction which is called as heat, so it is a non adiabatic process. One typical example can be given that, again we have same piston cylinder systems, where heat is added and we relax the conditions of adiabatic.

So, it is a non adiabatic process and if you try to quantify in this non adiabatic process; what is the change in the internal energy and what is the change in the work transfer. And in another situation in a magnetic field also when there is a strong magnetic field, which is experienced by a liquid helium gas; we may see that there will be change of temperatures of this liquid helium, some of the liquids may also evaporate.

So, in those situations where the adiabatic conditions cannot be ensured, then we say it is a non adiabatic systems. And if you want to try to quantify the work transfer and internal energy transfer; we see that this adiabatic work is not equal to the change in the internal energy functions.

So, this gives a definitions or concept which says that the difference in the energy follows the conservation of energy, which says that the temperature difference allows the energy interaction between the system and surroundings in the form of heat.

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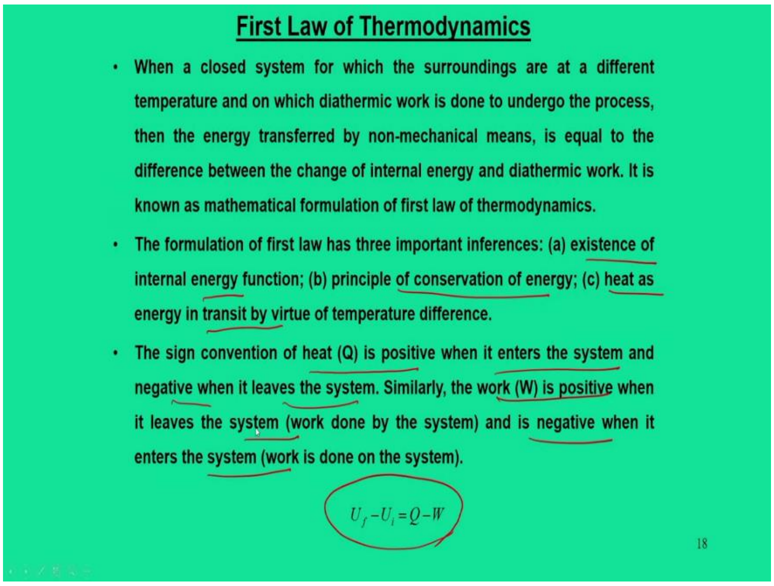

First Law of Thermodynamics

- When a closed system for which the surroundings are at a different temperature and on which diathermic work is done to undergo the process, then the energy transferred by non-mechanical means, is equal to the difference between the change of internal energy and diathermic work. It is known as mathematical formulation of first law of thermodynamics.
- The formulation of first law has three important inferences: (a) existence of internal energy function; (b) principle of conservation of energy; (c) heat as energy in transit by virtue of temperature difference.
- The sign convention of heat (Q) is positive when it enters the system and negative when it leaves the system. Similarly, the work (W) is positive when it leaves the system (work done by the system) and is negative when it enters the system (work is done on the system).

$$\boxed{U_f - U_i = Q - W}$$

Then with this, we will now move on to the definition of first law of thermodynamics. So, what it says is that for a closed systems for which the systems are at different temperature on which the diathermic work is done, then the energy transferred by the non mechanical means, is equal to the change in the internal energy and the diathermic work.

So, this gives the formulation of first law which signifies three aspects; first is existence of internal energy function, second one is conservation of energy, third one is heat as a energy in transit by virtue of temperature difference. So, based on that if we recall this our understanding, the change in the internal energy functions is quantified as the difference between heat and work transfer. $U_f - U_i = Q - W$

And here we must follow one particular sign convention which says that, heat is positive when it enters to the systems and it is negative when it is leaves the systems. Similarly, work is positive when it leaves the systems; in that sense we say it is a work done by the system and the work is negative when it enters the systems, in that sense we say work is done on the system.

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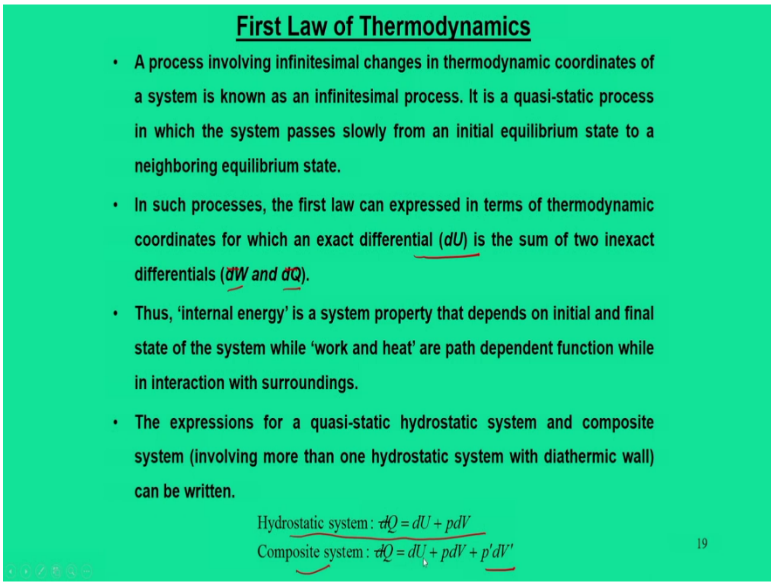

First Law of Thermodynamics

- A process involving infinitesimal changes in thermodynamic coordinates of a system is known as an infinitesimal process. It is a quasi-static process in which the system passes slowly from an initial equilibrium state to a neighboring equilibrium state.
- In such processes, the first law can expressed in terms of thermodynamic coordinates for which an exact differential (*dU*) is the sum of two inexact differentials (*đW and đQ*).
- Thus, 'internal energy' is a system property that depends on initial and final state of the system while 'work and heat' are path dependent function while in interaction with surroundings.
- The expressions for a quasi-static hydrostatic system and composite system (involving more than one hydrostatic system with diathermic wall) can be written.

Hydrostatic system : $đQ = dU + pdV$

Composite system : $đQ = dU + pdV + p'dV'$

Now, with this basic definitions, we are now going to talk about the definition of first law of thermodynamics for a very infinitesimally small processes; in which we can represent the internal energy function as an exact inter exact differential dU and the path functions are represented by dW and dQ, which are in exact in natures.

Now, if we want to equate them, we can say for an hydrostatic systems it is just a pressure volume system, we say $đQ = dU + pdV$. Now, if it is a composite systems, that means there are non pdV work; non pdV work involves work transfer by electrical circuit, work transfer through a magnetic field.

So, this is an equivalent amount of pdV work it is represented as $p'dV'$. So, when a composite systems involving multiple method of work transfer can be represented and for which the first law is written as $đQ = dU + pdV + p'dV'$.

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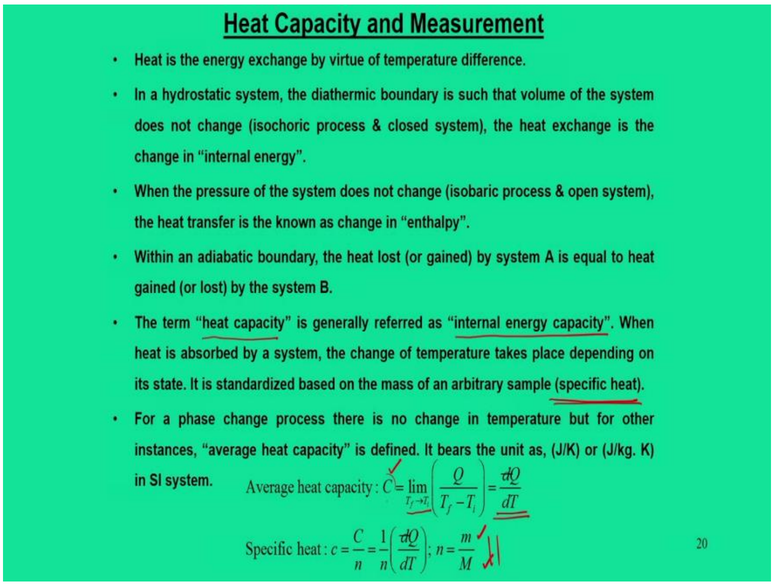

Heat Capacity and Measurement

- Heat is the energy exchange by virtue of temperature difference.
- In a hydrostatic system, the diathermic boundary is such that volume of the system does not change (isochoric process & closed system), the heat exchange is the change in "internal energy".
- When the pressure of the system does not change (isobaric process & open system), the heat transfer is the known as change in "enthalpy".
- Within an adiabatic boundary, the heat lost (or gained) by system A is equal to heat gained (or lost) by the system B.
- The term "heat capacity" is generally referred as "internal energy capacity". When heat is absorbed by a system, the change of temperature takes place depending on its state. It is standardized based on the mass of an arbitrary sample (specific heat).
- For a phase change process there is no change in temperature but for other instances, "average heat capacity" is defined. It bears the unit as, (J/K) or (J/kg. K) in SI system.

$$\text{Average heat capacity}: C = \lim_{T_f \to T_i}\left(\frac{Q}{T_f - T_i}\right) = \frac{\bar{d}Q}{dT}$$

$$\text{Specific heat}: c = \frac{C}{n} = \frac{1}{n}\left(\frac{\bar{d}Q}{dT}\right);\ n = \frac{m}{M}$$

Then the first law of thermodynamics gives best very basic definition of heat and we will now move try to quantify how we were going to evaluate this heat. So, for that we say, we define a term called as heat capacity and how we are going to measure it. So, heat is nothing, but a calorie.

So, prior to this development of work, people you used to view as a heat, they call it as a calorie; they use the word calorie, how many calories of heat has been transferred, so in a sense that this calorie is also used as the unit of heat. But subsequently after the development of the first law, when it was realized heat and work they are nothing, but different names associated with energy, then the concept of heat definition got changed.

So, we say that both has same unit, but the way or viewpoint is different. Now, whenever there is a change in the temperature difference, the energy exchange will take place in the form of heat and in a hydrostatic systems, if the diathermic boundary such that; the volume of the system does not change, then heat exchange is the nothing, but the change of internal energy.

Now, in the process when the pressure of the system does not change, so in a case that either it is isobaric process or open systems, the heat transfer change or heat transfer is known as the change in the enthalpy; that means enthalpy and internal energy they are the very basic definition of the first law, which is applied for a closed systems and open systems.

We also found out that within an adiabatic boundary, the heat lost or gained by the system A is also equal to the heat gained or lost by the system B; if A and B are separated by a adiabatic boundary, which already we have proved. Then having said this then we define this heat capacity for a non adiabatic process, we can represent as a internal energy capacity.

So, heat capacity is generally referred as internal energy capacity. So, when heat is absorbed by the system, the change in the temperature takes place depending on the states and one way of quantifying them is representing this heat in the form of specific heat; that means change of heat per unit mass.

For a fluid systems, there is only one specific heat which is defined as a average specific heat C. And this average specific heat by definition we say that, when the systems goes from final state to initial state; we can say its average heat capacity $C = \lim_{T_f \to T_i} \left(\frac{Q}{T_f - T_i} \right) = \frac{đQ}{dT}$.

So, this is the definition of average heat capacity. Now, if this heat capacity can be represented in the specific forms, we say $c = \frac{C}{n}$, n stands for number of moles which is related to the mass of the systems and molecular weight of the gas. So, this particular definition also holds for gas part.

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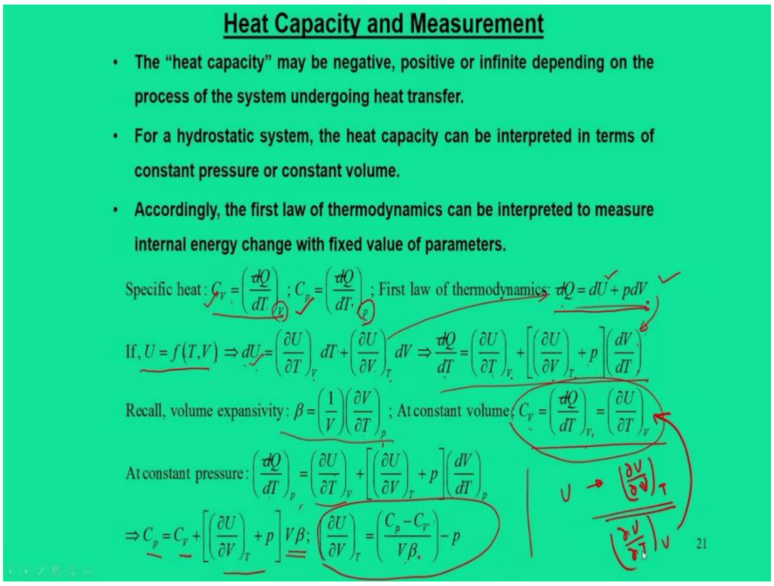

Heat Capacity and Measurement

- The "heat capacity" may be negative, positive or infinite depending on the process of the system undergoing heat transfer.
- For a hydrostatic system, the heat capacity can be interpreted in terms of constant pressure or constant volume.
- Accordingly, the first law of thermodynamics can be interpreted to measure internal energy change with fixed value of parameters.

Specific heat : $C_V = \left(\frac{đQ}{dT}\right)_V$; $C_p = \left(\frac{đQ}{dT}\right)_p$; First law of thermodynamics: $đQ = dU + pdV$

If, $U = f(T,V) \Rightarrow dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV \Rightarrow \frac{đQ}{dT} = \left(\frac{\partial U}{\partial T}\right)_V + \left[\left(\frac{\partial U}{\partial V}\right)_T + p\right]\left(\frac{dV}{dT}\right)$

Recall, volume expansivity : $\beta = \left(\frac{1}{V}\right)\left(\frac{\partial V}{\partial T}\right)_p$; At constant volume: $C_V = \left(\frac{đQ}{dT}\right)_V = \left(\frac{\partial U}{\partial T}\right)_V$

At constant pressure : $\left(\frac{đQ}{dT}\right)_p = \left(\frac{\partial U}{\partial T}\right)_V + \left[\left(\frac{\partial U}{\partial V}\right)_T + p\right]\left(\frac{dV}{dT}\right)_p$

$\Rightarrow C_p = C_V + \left[\left(\frac{\partial U}{\partial V}\right)_T + p\right] V\beta$; $\left(\frac{\partial U}{\partial V}\right)_T = \left(\frac{C_p - C_V}{V\beta}\right) - p$

$U \rightarrow \frac{\left(\frac{\partial V}{\partial V}\right)_T}{\left(\frac{\partial V}{\partial T}\right)_V}$

Then some other basic definition is that, the heat capacity can be negative, can be positive or infinite depending on the process that undergoes the heat transfer. Now, we are going to give some mathematical interpretation of this first law by including this heat transfer. So, we know what is the heat capacity now; we have the first law of thermodynamics, then let us correlate and we also know the mathematical relations when a thermodynamic parameter is specified as the function of any other two independent parameters.

So, with this three viewpoints, we have to now recall that how this internal energy functions can be found out from the first law. So, we recall our thought that we have a specific heat at constant volume; that means when there is a change of heat with respect to temperature, keeping volume is constant, we say specific heat at constant volume. When there is a change of heat with respect to temperature keeping pressure is constant, we say it is specific heat at constant pressures.

Now, with these two definitions and we now recall the first law of thermodynamics, which is $dQ = dU + pdV$ and it is a non adiabatic process. So, when we have said this, then we start our definition saying that let us see that what is this internal energy U; we can write them as a independent function of temperature and volume.

So, first we assume that U is a function of temperature and volume; then we can write $U = f(T, V) \Rightarrow dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV \Rightarrow \frac{\text{đ}Q}{dT} = \left(\frac{\partial U}{\partial T}\right)_V + \left[\left(\frac{\partial U}{\partial V}\right)_T + p\right]\left(\frac{dV}{dT}\right)$. Here from this equation we now recall the parameter what is called as volume expansivity $\beta = \left(\frac{1}{V}\right)\left(\frac{\partial V}{\partial T}\right)_p$.

Then we also have the $C_V = \left(\frac{\text{đ}Q}{dT}\right)_V = \left(\frac{\partial U}{\partial T}\right)_V$; when you impose this condition as constant volume, this parameter will go up. So, you this first law of expression becomes which is nothing but the specific heat at constant volume.

Then when we write this particular first law equation at constant pressure $\left(\frac{\text{đ}Q}{dT}\right)_p = \left(\frac{\partial U}{\partial T}\right)_V + \left[\left(\frac{\partial U}{\partial V}\right)_T + p\right]\left(\frac{dV}{dT}\right)_p$, then if you rewrite that equations, then we will find that this $C_p = C_V + \left[\left(\frac{\partial U}{\partial V}\right)_T + p\right] V\beta$.

So, finally, we have another expression $\left(\frac{\partial U}{\partial V}\right)_T = \left(\frac{C_p - C_V}{V\beta}\right) - p$. So, what I am trying to gain from this exercise that, we have this internal energy functions U and if you want to see this variation of U; means you want to measure $\left(\frac{\partial U}{\partial V}\right)_T$, it is possible that through the information of $Cp, Cv \ and \ \beta$ they are nothing, but the property, so through these things we are able to quantify this term.

Another one is $\left(\frac{\partial U}{\partial T}\right)_v$; this is nothing, but your Cv. So, what it says is that, the internal energy functions by definitions we can interpret it in the from the first law about the change of internal energy with respect to the independent property parameters and in this case, it is volume and temperatures.

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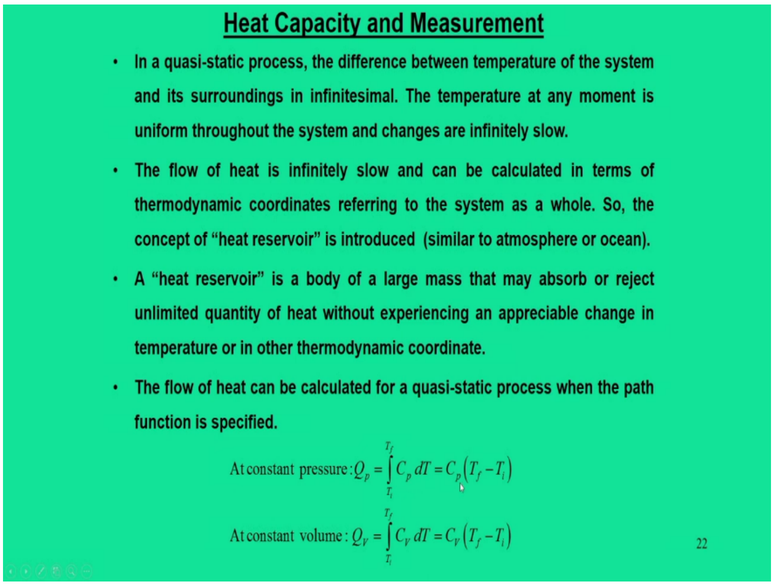

Heat Capacity and Measurement

- In a quasi-static process, the difference between temperature of the system and its surroundings in infinitesimal. The temperature at any moment is uniform throughout the system and changes are infinitely slow.
- The flow of heat is infinitely slow and can be calculated in terms of thermodynamic coordinates referring to the system as a whole. So, the concept of "heat reservoir" is introduced (similar to atmosphere or ocean).
- A "heat reservoir" is a body of a large mass that may absorb or reject unlimited quantity of heat without experiencing an appreciable change in temperature or in other thermodynamic coordinate.
- The flow of heat can be calculated for a quasi-static process when the path function is specified.

$$\text{At constant pressure}: Q_p = \int_{T_i}^{T_f} C_p \, dT = C_p\left(T_f - T_i\right)$$

$$\text{At constant volume}: Q_V = \int_{T_i}^{T_f} C_V \, dT = C_V\left(T_f - T_i\right)$$

22

Then moving further to the heat capacity and measurements, we have another concept in the basic thermodynamic courses we used to call as a heat reservoir. So, the word reservoir stands for the fact that whenever there is a change of temperatures; when you take out any heat from a reservoir, a heat reservoir is as if temperature do not change. This is something we can view you can if you want to take some bucket of water from a ocean or river, we do not view any change in the ocean systems as at the change of mass.

Similar way for heat concept of heat reservoir is utilized, where we can say that heat reservoir by definition is this infinite source of heat from which we can take out heat or we can add heat. This heat reservoir concept is very vital in understanding the subsequent law of thermodynamics that is second law of thermodynamics. Now, from the first law principle, we can find out what is the quantity of heat that gets transferred.

If by maintaining constant pressure, then we can write it as $Q_p = \int_{T_i}^{T_f} C_p dT = C_p(T_f - T_i)$, and at constant volume $Q_V = \int_{T_i}^{T_f} C_V dT = C_V(T_f - T_i)$. So, this is the quantification of heat in terms of temperature difference.

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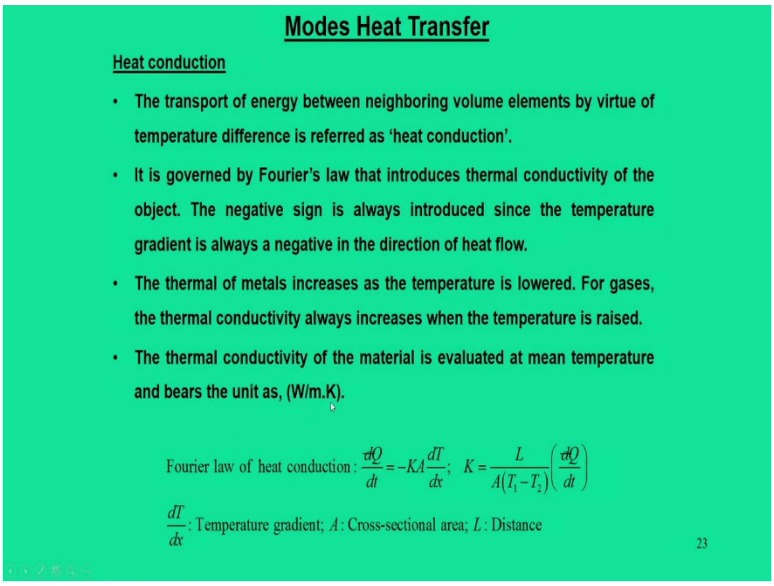

Modes Heat Transfer

Heat conduction

- The transport of energy between neighboring volume elements by virtue of temperature difference is referred as 'heat conduction'.
- It is governed by Fourier's law that introduces thermal conductivity of the object. The negative sign is always introduced since the temperature gradient is always a negative in the direction of heat flow.
- The thermal of metals increases as the temperature is lowered. For gases, the thermal conductivity always increases when the temperature is raised.
- The thermal conductivity of the material is evaluated at mean temperature and bears the unit as, (W/m.K).

Fourier law of heat conduction: $\frac{đQ}{dt} = -KA\frac{dT}{dx}$; $K = \frac{L}{A(T_1 - T_2)}\left(\frac{đQ}{dt}\right)$

$\frac{dT}{dx}$: Temperature gradient; A: Cross-sectional area; L: Distance

23

Now, after giving the very basic definition of work transfer, then we will see that what is the modes of heat transfers. So, we said that temperature difference is the essential requirement for transfer of energy in the form of heat; but we can say there are multiple phases of substance that occurs, heat can be transferred in a conductor or in a solid body, heat can also a transfer is possible in a liquid medium or in the gas medium. So, based on this medium, we define them in the form of heat transfer as its modes. So, the first mode is nothing, but the heat conductions.

So, it is referred as a conduction mode of heat transfer when the transport of energy is possible from one volume of element to a neighboring volume element through this temperature difference. So, it is a heat conduction, so volume is taken as one parameters. The Fourier's law of heat conductions is introduced that talks about this heat conduction mode.

So, it is represented by equations $\frac{đQ}{dt} = -KA\frac{dT}{dx}$, where it introduces a term which is called as thermal conductivity. And also the change of heat with rate of change of heat is proportional to the surface area and the temperature gradient.

So, there is a term which is negative sign in nature; because the $\frac{dT}{dx}$ is always a negative quantity, because it flows from higher temperature to lower temperature. Now, to make this entire quantity positive, so negative sign is introduced. Now, from these basic definitions, we can find out what is the thermal conductivity of a particular material and its SI unit is represented as W/m-K.

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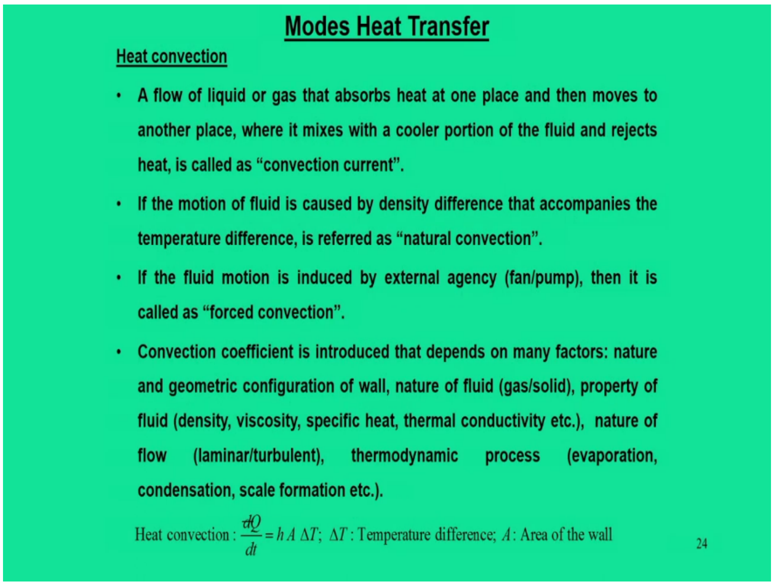

Modes Heat Transfer

Heat convection

- A flow of liquid or gas that absorbs heat at one place and then moves to another place, where it mixes with a cooler portion of the fluid and rejects heat, is called as "convection current".
- If the motion of fluid is caused by density difference that accompanies the temperature difference, is referred as "natural convection".
- If the fluid motion is induced by external agency (fan/pump), then it is called as "forced convection".
- Convection coefficient is introduced that depends on many factors: nature and geometric configuration of wall, nature of fluid (gas/solid), property of fluid (density, viscosity, specific heat, thermal conductivity etc.), nature of flow (laminar/turbulent), thermodynamic process (evaporation, condensation, scale formation etc.).

Heat convection : $\frac{đQ}{dt} = hA\,\Delta T$; ΔT : Temperature difference; A : Area of the wall

Now, moving further when the medium is liquid, we call this as a mode of heat transfer as convection or it can be also be a gaseous medium. So, the convection means that by virtue of temperature difference, a convection current is introduced; that means for example, when you boil water what happens, we are giving heat at the bottom surface of the container. So, temperature increases, but density drops.

So, by virtue of which the higher density mass will come down and the lower density mass will go up; through this process the communication of heat happens. And as long as you are supplying heat, this particular motion we call this as a convection current.

Now, if this convection current is possible naturally; that means without involving any external agency or it can only occur through this temperature difference, then it is a natural convection. So, if the convection current is produced by an external agency like running a fan or pump, then we call this as a forced convection.

So, in a heat convection there are two parts, natural convection and forced convections. And for all this case, the parameter which is of importance is the convection coefficient h. So, $\frac{dQ}{dt} = hA\Delta T$, where h is the convection heat transfer coefficient, A is the surface area and ΔT is the temperature difference.

So, the convection coefficient depends on many factors like nature and geometric configuration of the wall, nature of the fluid, property of the fluid, specific heat, nature of the flow whether it is laminar or turbulent, also the thermodynamic process evaporation or condensation or scale formation.

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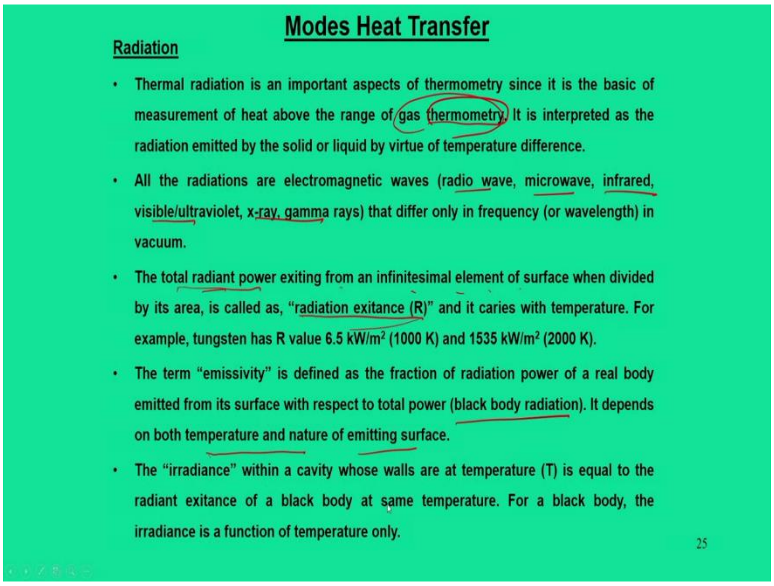

Modes Heat Transfer

Radiation

- Thermal radiation is an important aspects of thermometry since it is the basic of measurement of heat above the range of gas thermometry. It is interpreted as the radiation emitted by the solid or liquid by virtue of temperature difference.
- All the radiations are electromagnetic waves (radio wave, microwave, infrared, visible/ultraviolet, x-ray, gamma rays) that differ only in frequency (or wavelength) in vacuum.
- The total radiant power exiting from an infinitesimal element of surface when divided by its area, is called as, “radiation exitance (R)” and it caries with temperature. For example, tungsten has R value 6.5 kW/m^2 (1000 K) and 1535 kW/m^2 (2000 K).
- The term “emissivity” is defined as the fraction of radiation power of a real body emitted from its surface with respect to total power (black body radiation). It depends on both temperature and nature of emitting surface.
- The “irradiance” within a cavity whose walls are at temperature (T) is equal to the radiant exitance of a black body at same temperature. For a black body, the irradiance is a function of temperature only.

The last part of heat transfer study, we call this as a heat radiations; heat radiations also occurs for as a temperature difference, but there is no thermometry concept is introduced. So, it does not fall in the range of gas thermometry. So, in this case it is viewed by the radiation waves and typically we call them as a electromagnetic waves.

These electromagnetic waves falls as a radio waves, microwave, infrared, visible range or ultraviolet range, x ray and gamma ray and they differ in frequency and wavelength.

Then while talking about the radiation, we characterize that it this radiation as radiant power. So, this radiant power is termed with respect to radiation existence; which means that it is the radiation power that exists from an infinitesimally small surface, when it is divided by it is area is termed as radiation existence or simply R. And this value of R changes with temperature; for example, for a material like tungsten, the R value is 6.5 kW/m^2 when temperature is 1000 K.

But when the temperature increases, its value changes; temperature increases to 2000, this R value can be of $1535\ kW/m^2$. So, it means that radiation existence is a function of temperature and of course, with the material. Another important factor in the radiation is the emissivity and this emissivity term is defined as the fraction of radiant power for a real body which is emitted from the surface with respect to total power and it is referred as the black body radiations. And this black body radiations depends both temperature and the nature of emitting surface.

So, once you have there is another term which is called as irradiance. Because when you view this radiation; we can say there is a small cavity which radiates. And let me switch up enough radiant power and radiation comes out of it and that term is called irradiance, when the radiant exitance of a black body occurs at the same temperature.

For example, there are two bodies; one is black body which has certain temperature T, we found its radiant power, there is an another body which is not a black body and if you want to calculate its radiant power at same temperatures, then that term we will call as irradiance.

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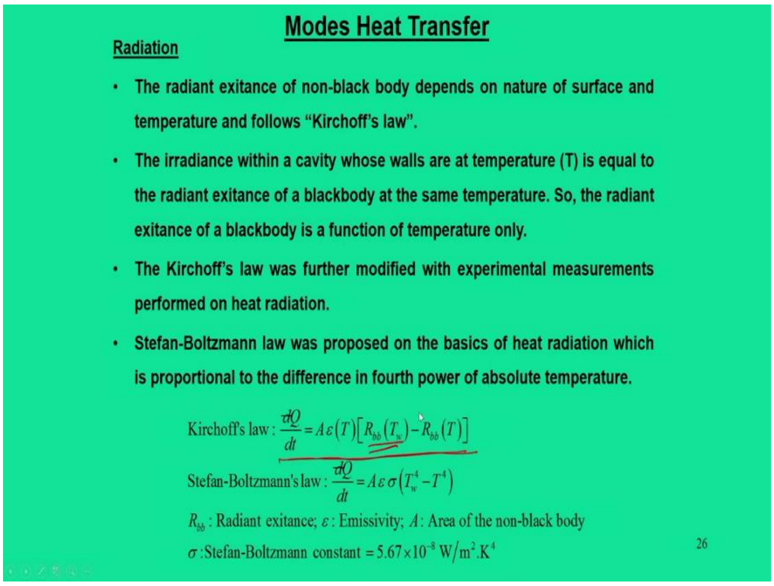

Modes Heat Transfer

Radiation

- The radiant exitance of non-black body depends on nature of surface and temperature and follows "Kirchoff's law".
- The irradiance within a cavity whose walls are at temperature (T) is equal to the radiant exitance of a blackbody at the same temperature. So, the radiant exitance of a blackbody is a function of temperature only.
- The Kirchoff's law was further modified with experimental measurements performed on heat radiation.
- Stefan-Boltzmann law was proposed on the basics of heat radiation which is proportional to the difference in fourth power of absolute temperature.

Kirchoff's law : $\frac{\text{đ}Q}{dt} = A\varepsilon(T)\left[\underline{R_{bb}(T_w)} - R_{bb}(T)\right]$

Stefan-Boltzmann's law : $\frac{\text{đ}Q}{dt} = A\varepsilon\sigma\left(T_w^4 - T^4\right)$

R_{bb} : Radiant exitance; ε : Emissivity; A : Area of the non-black body

σ :Stefan-Boltzmann constant $= 5.67\times10^{-8}$ W/m^2.K^4

To quantify this, the first concept that was introduced is Kirchhoff's law; which says that radiant power radiant mode of heat transfer $\frac{\text{đ}Q}{dt} = A\varepsilon(T)[R_{bb}(T_w) - R_{bb}(T)]$. So, this particular expressions was bit complicated and further it was simplified by using Stefan Boltzmann's law where this radiant power was quantified as proportional to the fourth power of the temperatures.

So, we can write rewrite this Kirchhoff's law as Stefan's Boltzmann's law and which is most widely used as of now which says that, $\frac{\text{đ}Q}{dt} = A\varepsilon\sigma(T_w^4 - T^4)$; where ε is emissivity, R is the radiant existence, A stands for the area of non black body. And here it is introduced a term which is called as Stefan's Boltzmann constant.

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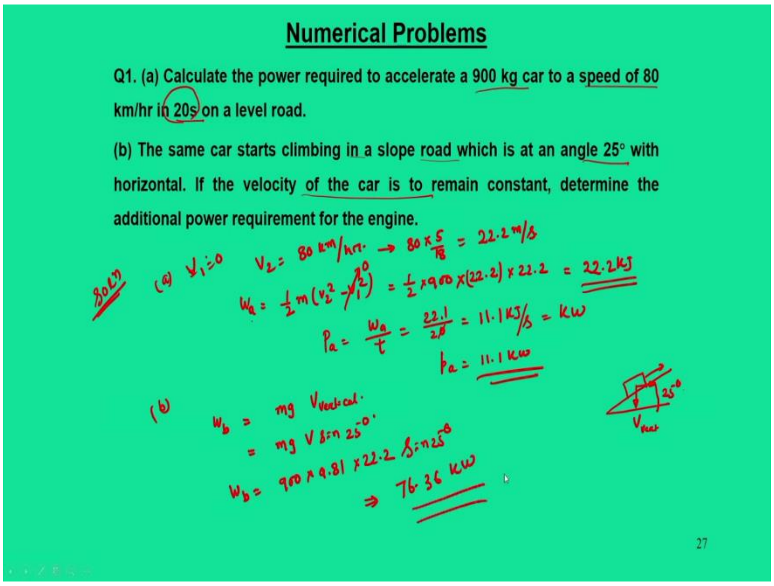

Numerical Problems

Q1. (a) Calculate the power required to accelerate a 900 kg car to a speed of 80 km/hr in 20s on a level road.

(b) The same car starts climbing in a slope road which is at an angle 25° with horizontal. If the velocity of the car is to remain constant, determine the additional power requirement for the engine.

Soln

(a) $V_1 = 0$ $\quad V_2 = 80\ km/hr \rightarrow 80 \times \frac{5}{18} = 22.2\ m/s$

$W_a = \frac{1}{2}m(V_2^2 - \cancel{V_1^2}) = \frac{1}{2} \times 900 \times (22.2) \times 22.2 = 22.2 kJ$

$P_a = \frac{W_a}{t} = \frac{22.1}{20} = 11.1 kJ/s = kW$

$P_a = 11.1 kW$

(b) $W_b = mg\ V_{vertical}$

$= mg\ V \sin 25°$

$W_b = 900 \times 9.81 \times 22.2 \sin 25°$

$\Rightarrow 76.36\ kW$

So, with this I have come to the end of this particular lecture, where we have introduced the important concept, work, heat, internal energy, and subsequently formulation of first law. So, the first law gives the indication of internal energy, enthalpy and the functional form of internal energy can be evaluated from the first law mathematically.

So, now, we will try to solve some very basic problems as far as the work transfer and heat transfer is concerned. So, the first problem concerns about a kind of a situations when there is a change in the velocity and the change in the velocity is associated with the change in the kinetic energy and how that kinetic energy can be related to work transfer thermodynamically.

So, the first problem says that, we have to calculate the power required to accelerate a 900 kg car to a speed of 80 km/hr in 20 seconds. So, initially we can imagine that the car is at rest. So, V_1 is equal to 0 and $V_2 = 80\frac{km}{hr} = 80 \times \frac{5}{18} = 22.2\ m/s$. And the rate of change of kinetic energy we say power $W_a = \frac{1}{2}m(V_2^2 - V_1^2) = \frac{1}{2} \times 900 \times 22.2^2 = 222\ kJ$.

So, this much power we have to use in 20 seconds. So, power requirement $P_a = \frac{W_a}{t} = \frac{222}{20} = 11.1\frac{kJ}{s} = 11.2kW$.

And in the second problem, the car is going to climb and this angle is taken as 25° . So, your movement is in this direction.

So, we can rewrite this equation that when the car is climbing in a slope road at an angle 25° with same condition as the question 1 and the velocity of the car is to remain constant; then we can put the power requirement as $W_b = mgV_{vertical} = mgVsin\,25° = 900 \times 9.81 \times 22.2\sin 25° = 76.36\ kW$

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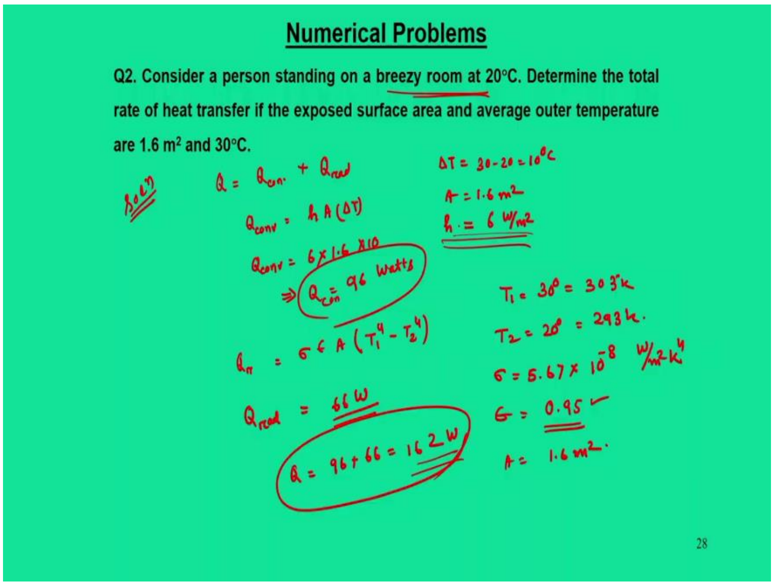

Numerical Problems

Q2. Consider a person standing on a breezy room at 20°C. Determine the total rate of heat transfer if the exposed surface area and average outer temperature are 1.6 m² and 30°C.

Sol^n

$Q = Q_{con.} + Q_{rad}$

$Q_{conv} = hA(\Delta T)$

$Q_{conv} = 6 \times 1.6 \times 10$

$\Rightarrow \boxed{Q_{con} = 96 \text{ watts}}$

$Q_{r} = \sigma \epsilon A(T_1^4 - T_2^4)$

$Q_{rad} = 66\,W$

$\boxed{Q = 96 + 66 = 162\,W}$

$\Delta T = 30 - 20 = 10^\circ C$

$A = 1.6\,m^2$

$h = 6\,W/m^2$

$T_1 = 30^\circ = 303\,K$

$T_2 = 20^\circ = 293\,K.$

$\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$

$\epsilon = 0.95$

$A = 1.6\,m^2.$

So, next problem is about the heat transfer. So, we are looking at a person who stands in a busy room; means it is a there is a bridge of wind and this wind room is maintained at $20°C$, we have to calculate the heat transfer if the exposed surface area and surface of the outer area temperature is $30°C$. Now, here the first thing that you need to understand is that what are the possible mode of heat transfer from the person.

So, the possible mode of heat transfer we can write $Q = Q_{conv} + Q_{rad}$; $Q_{conv} = hA\Delta T = 6 \times 1.6 \times (30 - 20) = 96\ watt,$ that is convection assuming $h = 6\ W/m^2$; other part of radiation you can quantify as $Q_{rad} = \sigma\epsilon A(T_1^4 - T_2^4) = 5.67 \times 10^{-8} \times 0.95 \times 1.6 \times (303^4 - 293^4) = 66\ watt$ assuming $\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$ and $\epsilon = 0.95$.

So, we can say that total heat is 96 + 66 = 162 watt. And of course, this number is very small, which we normally do not realize; but still the convection and radiation heat transfer at room temperature is possible. So, with this I conclude this presentation today.

Thank you for your attention.