Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 14
First Law of Thermodynamics for Non-cyclic Process 1

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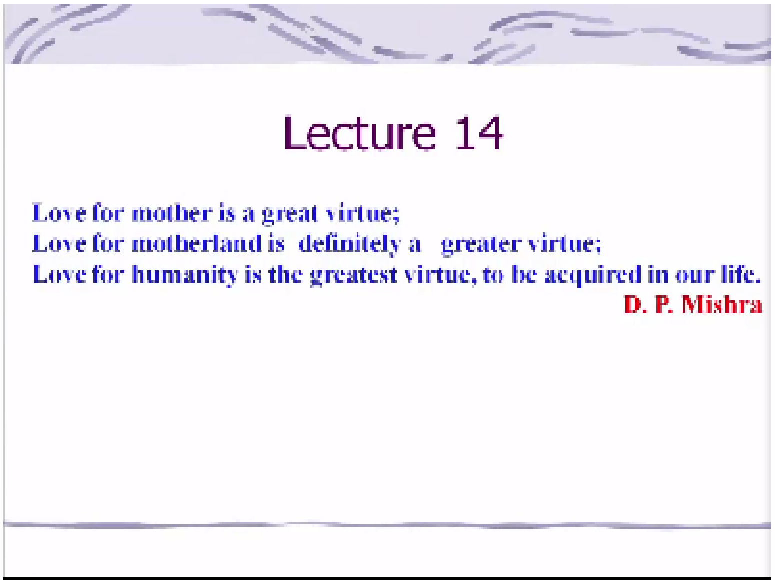

Lecture 14

Love for mother is a great virtue;
Love for motherland is definitely a greater virtue;
Love for humanity is the greatest virtue, to be acquired in our life.
D. P. Mishra

So let us start this lecture with a thought process what is very much inherited in our scriptures that is love for mother is great virtue, love for motherland is definitely a greater virtue, love for humanity is the greatest virtue, to be acquired you know in our life. So that we can have a very good, you know success in our life. So as usual let us recall what we learnt in the last lecture. So if you recapitulate that we discuss how the JP joule could you know manage to find out the first law of thermodynamics which states that whenever a system undergoes a cyclic process.

However the complex cycle may be the cycle integral of the work is proportional to cycle integral of the heat right. And that law was originally, you know put forward it for the cyclic process and of course it was based on series of experiments, later on it was you know derived for the non cyclic process, because you know the cyclic process consists of several non cyclic process and in a engineering application there will be several non cyclic process we need to analyze. Therefore we also derive a relationship between the work and the heat right and also rather among the work, heat and energy and that we say that dQ – dW = dE, if you look at that is the first law of thermodynamics.

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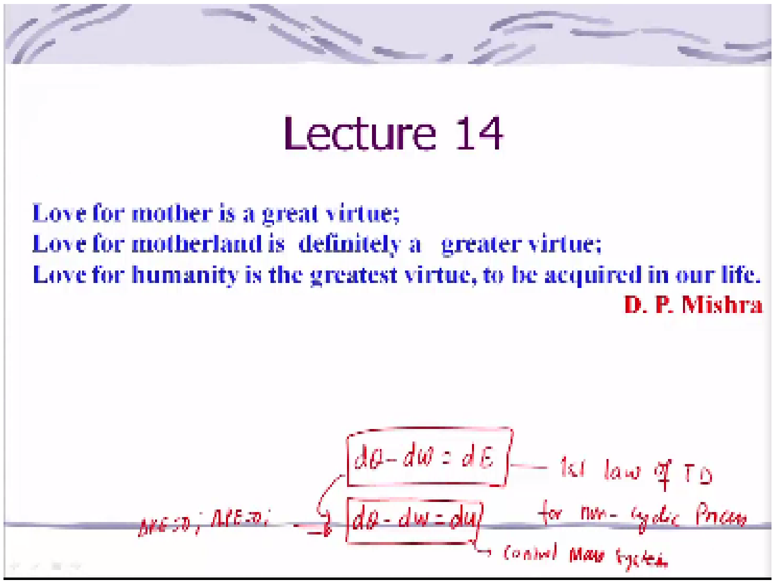

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$\Delta KE = 0$; $\Delta PE = 0$;

$\boxed{dQ - dW = dE}$ — 1st law of TD

$\boxed{dQ - dW = dU}$ for non-cyclic Process

Control Mass system

What we have derived is dQ - dW = dE and this law is valid basically for non cyclic process, if you look at what we are dealing now basically is a control mass system right in the control mass system except few exceptional cases most of the times will be the change in kinetic energy and change in potential energy will be what will be negligibly small or zero right. Therefore we can say that when change in kinetic energy is zero and change in potential energy is zero, so therefore this equation we can write down as dQ - dW = dU right only this is valid.

And is there, and that is for mean for control you know mass system control mass system, but is there any control mass system where you cannot really, you know change or you cannot take this assumption that change in kinetic energy and potential energy, is there any example coming to your mind yes or no right. Let me give example one of them, suppose somebody has slapped you okay, so I want to analyze particularly if you are you know color is I mean good in the sense good in the sense color is yellow or the white, you know then if the slap is intensity is high what will happen that you know your skin color becomes reddish right okay yes or no on the slap on your cheek or something like that.

So I want to analyze that what happens to you know changes if you look at what happens to the changes is it work being done, or is it being generated there or not whether I can apply you know whether I can manage to assume the change in kinetic energy will be zero, potential energy of course I can but change in kinetic energy you cannot you know say it to be 0 right yes or no right. So think about how to analyze that and there might be several other occasion where control mass system you know in case of control mass system you need to consider the change in kinetic energy, change in potential energy as well.

But most of the cases it is not right, so let us now take off some very basic processes like what we have seen earlier like control volume processes what we call isochoric.

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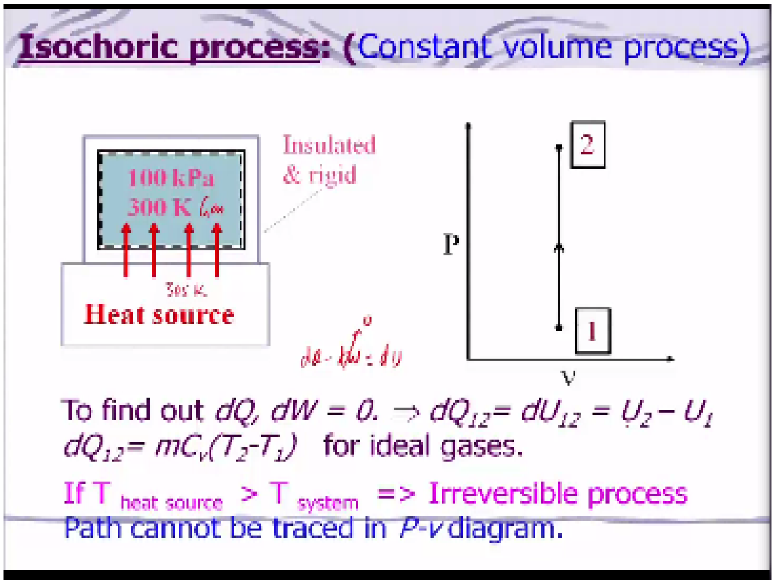

Isochoric process: (Constant volume process)

To find out dQ, $dW = 0. \rightarrow dQ_{12} = dU_{12} = U_2 - U_1$

$dQ_{12} = mC_v(T_2 - T_1)$ for ideal gases.

If $T_{\text{heat source}} > T_{\text{system}}$ => Irreversible process

Path cannot be traced in P-v diagram.

And we will be looking at also the constant pressure processes, isothermal processes and adiabatic processes and others right, we will see how we can apply this first law of thermodynamics. Let us consider a case a container which contains some kind of let us say gas at temperature 300 Kelvin and 100 kpa and it is a rigid, you know like no change in this change. So that if it is reason what is happening like there is no work done in PDV work basically.

And it is also insulated all the places here right however the other side one side of this chamber is in contact with a heat source whose temperature will be higher right. If I say this temperature heat source is 1000 Kelvin right what will happen the temperature gradient will be very high, then there will be change in the temperature of these gas if I say this is my gas right, there will be changes of temperature of the gas of the container right yes or no because heat being transferred is a no right.

If the temperature is changing then the process can I call it as a reversible process, because it would not be in equilibrium, because gradient is much more right, okay. So and also I cannot reverse the process back, but however if I consider the process let us say this temperature to start with here it is 300 Kelvin I will say this is something 305 Kelvin right. So the temperature gradient is very, very slow I mean very sorry not slow rather it is the temperature gradient is small right.

And then that will be taking place and then if you want you can you know reverse this process and, you know by changing the system that means you know you can take the heat out and then do that something. So therefore, if it is a slow process and it will be attaining a quasi equilibrium or why call quasi-static process right, then we can call it as a reversible process then the state from 1 to 2 can be described in this PV diagram of course as the heat being transferred there will be increase in the pressure also because this is a what we call constant volume, because volume is not changing.

So therefore, the pressure will go up and so also the temperature will go up and while the volume is remaining constant right. So then what we will do we need to find out what is happening here right, and kind of thing apply the first law of thermodynamics when we apply the first law of thermodynamics though if you look at that is the work done in this case the PDV work will be zero and we are not putting any staff to work, so therefore work done will be 0.

And if you look at this first law of thermodynamic what for a, what you call non cyclic process that is dQ - dW = dU and in this case the dW is zero, so therefore dQ between state 1 and 2 will be nothing but change in the internal energy between 1 to 2. As you giving heat therefore, you know in this case the internal energy at the state 2 that is U_2 will be greater than the U_1 okay. Now this heat, you know if I know these properties you know at let us say from a table and other things it will be easier to evaluate.

Let us say from the steam I instead of gas we are considering a steam. Now if it is steam it is an ideal condition then one can use you know dQ 1/2 mC_V (T_2-T_1) I will be knowing the temperature T2 and of course T1 is known and if I know the C_V specific you know what you call heat at constant volume then I can evaluate. Now what is that all those things we will see keep in mind that it is, you know very important to know this internal energy at both the state either one can use the what you call the tabular data or we can assume it ideal gas and then one can evaluate right.

So let us look at what you call you know some processes, irreversible processes and as I told in the very beginning that if the temperature of the heat source is very, very large as compared to the system temperature right then the temperature gradient will we are higher as a result the process will be reversible and this path cannot be trace in a PV diagram generally we use a dashed line to show the process irreversible processes in a process diagram like PV diagram is a process diagram.

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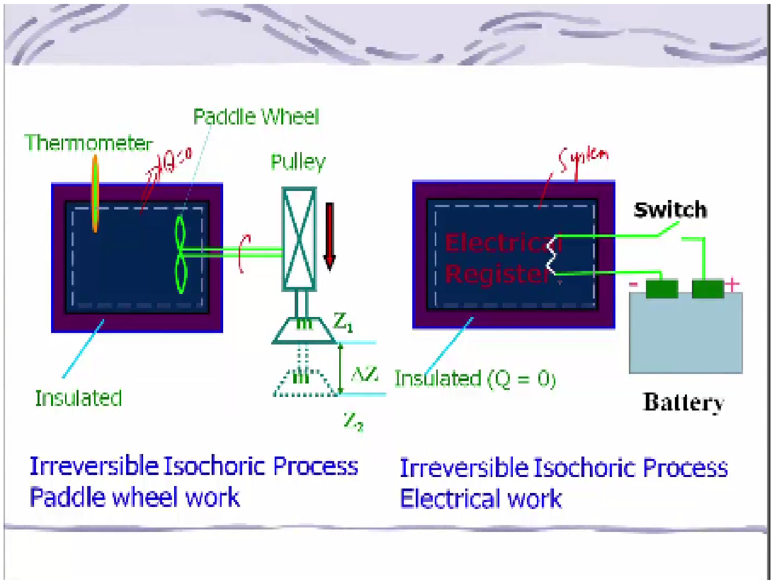

Irreversible Isochoric Process
Paddle wheel work

Irreversible Isochoric Process
Electrical work

So let us consider another what you call constant volume process in this case you know paddle wheel is there and then it is of course connected to use well we are just trying to look at the thermodynamic way of work and when it is rotated you know this kind of things through the mass is lowering down against the gravitational field, some work is being done, and as a result what will happen if it is the gas you know the temperature will be going up yes or no because some work being done here right.

And there will be this thing so and also it is insulated, no heat is passing through that this is if you look at bQ is 0 and this process is basically reversible or irreversible what is this process, this process cannot be reversible right, you can make the, this paddle wheel to rotate right externally that means work is done by the surrounding on the system but however you cannot do the other way around the you know like in this case if you are doing that the pressure will go up and then is it like this.

What you call paddle will be start you know rotating if you would not give the external work it would not that means the war cannot be from the system will be done by the system right on its surrounding it is not possible in this case so therefore this process will be irreversible one and let us consider the another case which is you know control volume process and instead of paddle wheel we are putting a resistance and which is connected to a battery and if you look at this process because we have taken this as a system you know.

So is it a work interaction or heat interaction it will be basically the work interaction right because the electrical registers is already included in the system boundary so of course we are considering these are insulated so you know heat interaction will be from the system to surrounding will be 0 and this process is also you know is reversible isochoric process it is not possible to reverse the you know that means the system will be reverse back to its original state after the interactions right so let us now and this process.

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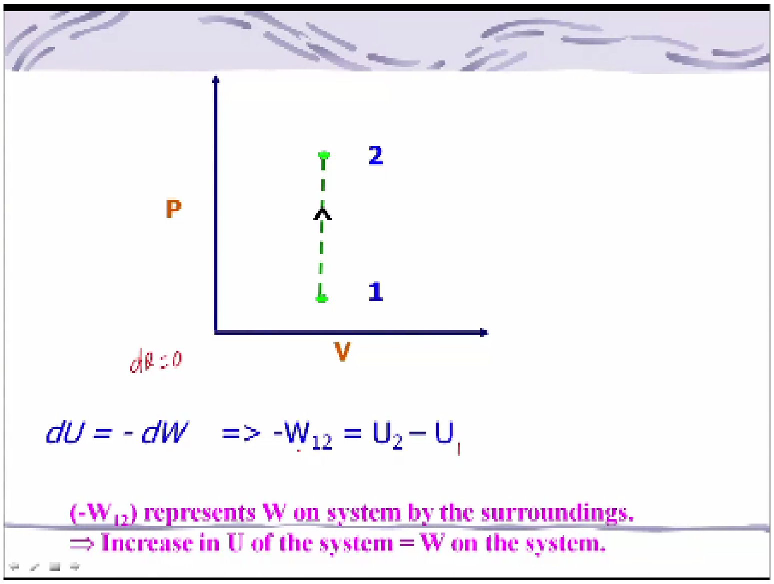

$dQ = 0$

$dU = -dW \quad => -W_{12} = U_2 - U_1$

(-W_{12}) represents W on system by the surroundings.

⇒ Increase in U of the system = W on the system.

Is basically can be described you know in a PV diagram generally people use a dashed line to show the process as I irreversible this is a convention you know like but in principle one cannot really describe the process irreversible process in a process diagram like PV here so if I apply the first law of thermodynamics then that will be du is equal to - dW because the dq is 0 right in this case so therefore the work done will be equal to change in the internal energy right change in either day u2 - u1keep in mind this work is negative.

What is the meaning that work is done by the surrounding on the system according to convention when work is done by the system and its surrounding it is positive when the work is done by the surrounding on the system it is negative so therefore it happens to be negative and so therefore there will be increase in the internal energy of the system right and we need to we have already introduced the concept of specific at eat a constant volume.

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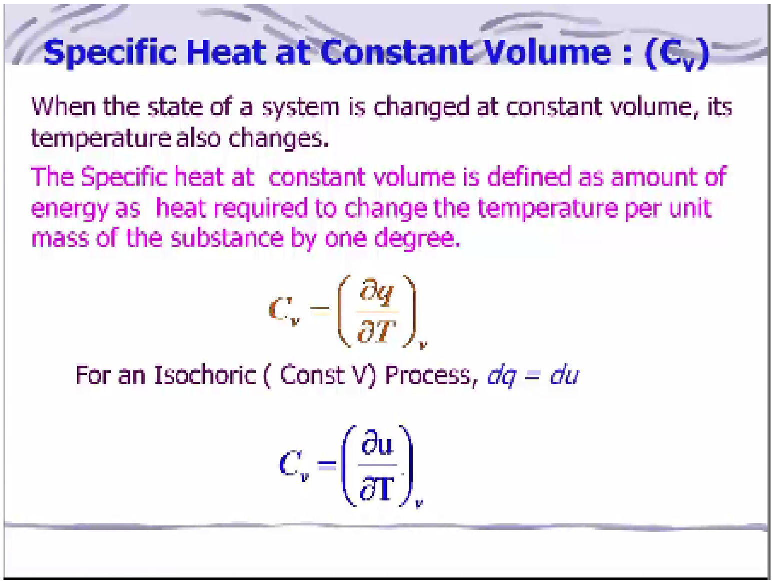

Specific Heat at Constant Volume : (C_v)

When the state of a system is changed at constant volume, its temperature also changes.

The Specific heat at constant volume is defined as amount of energy as heat required to change the temperature per unit mass of the substance by one degree.

$$C_v - \left(\frac{\partial q}{\partial T}\right)_v$$

For an Isochoric (Const V) Process, $dq = du$

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

But what do you mean by that let us take an example I am having 1 kg of water ok 1 kg of water is equal to 1 liter you know you can say 1liter of water is equal to 1 kg because and then I am going to heat it you know from let us say 25^0 Celsius to 35^0 Celsius so how much he heat I will have to give right or how much heat it will be containing you know they are the temperature has gone up that means you know so it will be if you look at it will be let us say you know certain amount of heat okay and suppose instead of one cage of water I will take you know 1 kg of water and rice okay.

So I will give certain amount of it and I will see that temperature is going from 25^0 to the what you call 35^0 Celsius what is the amount of heat I will allowed to give any idea is it higher or lower what I should give I mean I just say I mean whether it is a higher or lower or it will be same it can be same also right will it be same suppose I will take you know let us say 1 kg of iron I want to increase this temperature from again 25^0 Celsius to 35^0 Celsius 10^0 difference yeah so what will be amount of heat.

The amount of heat for heating you know iron ore, you know this thing will be basically say around 4.5 you know kilo joule whereas from the water you know it will be something around 41.8 kilos holes right okay let us say emulate the number may be very little bit suppose I will take another example like I will take 1 kg of air you know I want to heat it from again 25^0 Celsius to 35^0 what it will be and if instead of 25^0 Celsius right and 230^0 Celsius I will say I will heat it 25^0 Celsius to 250^0 Celsius.

What will be the heat I will have to give you know you assume that you know I am heating in a constant volume let us say right so what will be in this case this is another mu like this last two example I have given air and where the temperature is one order of my machine 1kis the 10^0 Celsius other case is the 100^0 you know difference to our 252 what I told now let us say 25 to35 other is let us say I can say you know like something do not you what we call 252 let us say 350^0 Celsius okay I think I change my this thing 250 to 350 100^0 Celsius that is 10^0 Celsius difference okay right

So what will happen should I give more amount of it or less amount of it actually if you look at if you increase temperature but in case of a you will have to give more amount of it okay I am just telling you just look at it the values. And then see that what it indicates this example from this one you can say that that means each substances one is water as it is iron and water is another water and raise you know like together and air so if you look at the each things are having different capacity of heat for the same change in temperature if you consider.

So basically that means we need to look at you know about a how much change in the temperature is taking place because per unit mass of the substance for degree Celsius or Kelvin right why we need to know because whenever a system is interacting with its surrounding there will be change in the temperature provided you know some heat interaction is taking place and if it happens to beat a constant volume you know then what will happen.

Then we need to define you know a specific heat at a constant volume as the amount of energy as a heat required to change the temperature per unit mass of substance by 1^0 it may be 1^0 Celsius or one Kelvin or 1^0 Fahrenheit or any other things okay so if you look at what we are discussing is basically a protocol can be a specific heat at constant volume can be expressed mathematically as CV is equal to ∂^3 by ∂T when volume is remaining constant right so if you look at in the constant volume right we have seen the change in energy is basically due to the change in heat right.

Kind of things and therefore we can write down for isochoric process dq is equal to t you so then CV is equal to basically ∂u by ∂T at constant volume right so this is a property means it does not depend on the path what it is taken right it is the properties of a substance right so let us look at it how we can utilize this property to evaluate you know what we call interaction between system and surrounding and in this example.

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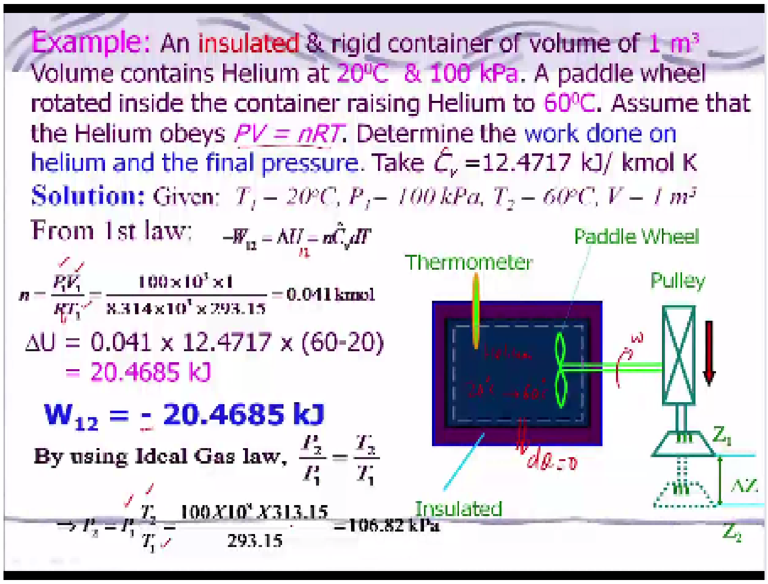

Example: An insulated & rigid container of volume of $1\ m^3$ Volume contains Helium at 20^0C & 100 kPa. A paddle wheel rotated inside the container raising Helium to 60^0C. Assume that the Helium obeys $PV = nRT$. Determine the work done on helium and the final pressure. Take $\hat{C}_v$ =12.4717 kJ/ kmol K

Solution: Given: $T_1 = 20^0C,\ P_1 = 100\ kPa,\ T_2 = 60^0C,\ V = 1\ m^3$

From 1st law: $-W_{12} = \Delta U_{12} = n\hat{C}_v dT$

$$n = \frac{P_1V_1}{RT_1} = \frac{100\times10^3\times1}{8.314\times10^3\times293.15} = 0.041\ \text{kmol}$$

ΔU = 0.041 x 12.4717 x (60-20)

= 20.4685 kJ

W_{12} = - 20.4685 kJ

By using Ideal Gas law, $\frac{P_2}{P_1} = \frac{T_2}{T_1}$

$$\Rightarrow P_2 = P_1\frac{T_2}{T_1} = \frac{100X10^3X313.15}{293.15} = 106.82\ \text{kPa}$$

We are considering insulated and rigid container of volume 1 meter cube which contains helium at 20^0 C and 100 kpa and a pedal will rotate it inside container raising helium gas temperature to 60^0 C and of course we can assume that helium gas obeys the ideal gas law that is PV is equal to NRT and we need to determine the work done on the helium and final pressure what it would be and you can take the CV as 12.4 7 17 kilo joule per kilo mole Kelvin you know like it can be in this case it is 4 kilo mole and one can also express.

This in terms of what you call in terms of kg also like kilo Joule kg and Kelvin in this case I am using this capacity a symbol to differentiate which one you are using so if you look at this is the diagram which contains the helium gas right and it was at 20^0 Celsius and it has gone to 60^0 Celsius at stage 2 so you need to basically find out and this is insulated so no heat being transferred here dq is equal to 0 and it is rigid so that there is no PDV war going on and only the shaft work going on because of rotation of this wheel and if we just apply the first law of thermodynamics you will get the change in the walk between state one and state 2 is nothing but change in the protocol internal energy is equal to nCV DT right and n is the number of moles and that you can get by using the ideal gas law.

Because we will be using this ideal gas law to protocol obtain this number of moles and keep it in a control mass system so number of moles remains same so we can obtain this number of moles at state 1 P1 is given right and V1 is also volume is given 1 meter cube and temperature is given right so you can find out very easily that and keep in mind that this is your universal gas constant right.

So the universal gas constant is here and temperature given you can find out very easily that is something 0.41 kilo mole and the change in the work done is basically nothing but your intend what you call number of moles into the CV and change in temperature 60˚-20˚ and that is 20.4685 kJ you just substitute values and the work done is equal to the change in the internal energy and which is having a negative sign here which indicates that work is done by the surrounding on the system right.

So therefore it is negative and by using because we know the what we call the temperature T2 and we know that temperature t1 right, and we can also find out the pressure P2 as we know the pressure P1 using the ideal gas law so you just substitute these values because all of this is known T2 T1 and then you just you know substitute these values and then you will get this 106.82 kilo Pascal's of course if you look at the pressure it change is very, very small that is something 6.82 kilo Pascal because the temperature change is not much due to the work done therefore the pressure change is very, very small in this example.

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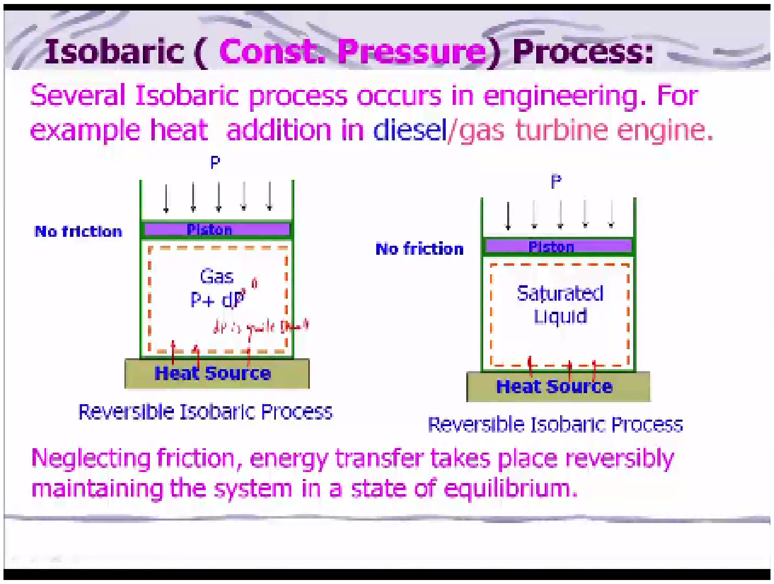

Isobaric (Const. Pressure) Process:

Several Isobaric process occurs in engineering. For example heat addition in diesel/gas turbine engine.

Reversible Isobaric Process

Reversible Isobaric Process

Neglecting friction, energy transfer takes place reversibly maintaining the system in a state of equilibrium.

So let us look at isobaric process which is a constant pressure process and if you look at whether it is an ideal or not but they know several processes in engineering can be considered as an isobaric for example like when you add heat in either in the diesel cycle or in a gas turbine engine or even in your burner you know like LPG burners you add heat you know like and that process also takes place at a constant pressure because the atmosphere is acting even though there is expansion but that expansion you know is not really what you call always with the with a constant pressure.

So that can be mimicked as a isobaric process right, and of course there might be you know kind of situation where it would not there might be some losses but what you can see atleast under ideal condition you can assume the heat addition in several you know kind of what you call engineering applications as a constant pressure even you will see in the steam power plant as when we will discuss about Rankine cycle see the brush processes in a boiler one can assume to be a constant occurring at constant pressure.

Because the vaporization will be taking place right, and so saturation pressure and temperature will be remaining constant you know. So now let us consider a again piston and cylinder arrangement in which the gas is there at pressure dP P+dP that means this pressure is little bit higher than the pressure acting by that must be on the piston and there is no friction in between and when you add a heat source so what will happen this pressure you know.

Let us say it is started with the same pressure that I am that much pressure is acting then because of heat transfer right from the heat source the change in the pressure will be very, very small as a result the piston is moving up and doing some work you know and as a result this is very, very small this deep is quite small you know sometimes you can say it is tending towards 0 kind of things you know that is not exactly 0 it is very, very small that means this dP is compared to the actual pressure is very small.

For example, if it is 100 kilo Pascal and if it is let us say change in pressure is one Pascal right, then we can call this system is in quasi equilibrium and if you remove that thing and then as the there is no friction between the piston and cylinder being assumed then we can call it as a basically a reversible isobaric process. Because it is all the time in the state of equilibrium and in real situation it need not because you cannot have a piston and cylinder where the friction want to be the friction will be there although we can minimize the resistances of the friction you know in actual system to reduce this work being lost due to the friction.

But however here we are considering there is no friction between the piston cylinder and it is the processes occurring very slowly in a quasi-static way so therefore we call it as a reversible process and there is another process we can say that saturated liquid and you know as you are giving the heat here right and the heat is you know slowly heating this then what will happen it will be vaporization will be taking place this is the what you call liquid and vapor.

And if you and some work is being done and if you remove this heat from here and then it will be condensed and come back so that you can call it as a reversible isobaric process as the system can move in a reverse way and reach its original state right, so therefore we call it as a reversible isobaric process.

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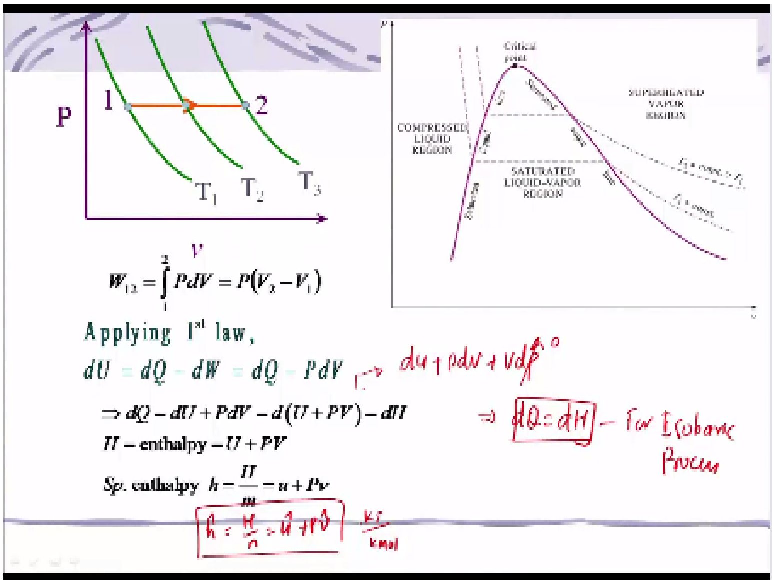

$$W_{12} = \int_1^2 PdV = P(V_2 - V_1)$$

Applying 1st law,

$dU = dQ - dW = dQ - PdV$ $\rightarrow$ $du + pdv + vd\cancel{p}^{0}$

$\Rightarrow dQ = dU + PdV = d(U + PV) = dH$ $\Rightarrow$ $\boxed{dQ = dH}$ – for Isobaric Process

H = enthalpy = $U + PV$

Sp. enthalpy $h = \frac{H}{m} = u + Pv$

$\boxed{\hat{h} = \frac{H}{n} = \hat{u} + P\hat{v}}$ $\frac{kJ}{kmol}$

And this passes you know can be easily described from the state 1 to 2 in a process diagram Pv of course in the process there will be change in what you call temperature and as I told that just to give you a idea that you know in this saturated liquid vapor V0 where the heat addition is occurring but temperature is remaining constant however the pressure also will be remaining constant and therefore that will be also known as the isobaric process.

So if it is I so very process then work done will be basically integral of PV TV and pressure is remaining constant so you can take it out and that will be equal to p into v2-v1. And we will do the apply the first law of thermodynamics which is equal to dU is equal to dQ-dW and there is no sapped work only the pd we work so therefore I can write down dQ-PdV so what I can do I can take this you know then we can write down dQ is equal d u plus PdV and keep in mind the pressure is remaining constant therefore I can write down you know differential of this dU+PdV.

Because you know like the if I expand this term what will happen this term if I expand this term this will be dU + PdV + VdP and dP is 0 so therefore you know this term is equal to that and if you look at by definition the enthalpy is U+PV so therefore the dQ is equal to the dH basically I can write down dQ is equal to dH in case of for isobaric process right, and this specific enthalpy also can be written as enthalpy per unit mass or it can be also known as enthalpy per unit mole right ĥ I can write down H/n is equal to Û+PV right this is per unit mole enthalpy per unit mole like kilo joule per you can say kilo mole unit.

So keep in mind that for a constant volume process what we have seen we have seen dQ is equal to dU in case of isobaric process or a constant pressure process we have seen dQ is equal to be a change in enthalpy right. So this is for the reversible process and we have seen that heat interaction is across the boundary is basically change in enthalpy.

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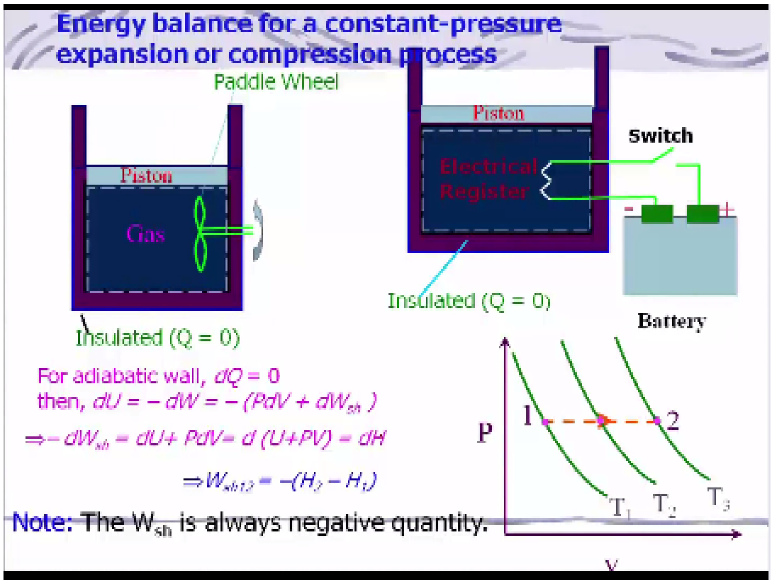

Energy balance for a constant-pressure expansion or compression process

For adiabatic wall, $dQ = 0$

then, $dU = -dW = -(PdV + dW_{sh})$

$$\Rightarrow -dW_{sh} = dU + PdV = d(U+PV) = dH$$

$$\Rightarrow W_{sh12} = -(H_2 - H_1)$$

Note: The W_{sh} is always negative quantity.

And let us look at energy balance for a constant pressure during expansion and compression processes right, because there we have looked at kind of heat interactions right and here we will look at work interaction where there is a shaft you know is being rotated the paddle wheel and this is the gas and it is basically insulated so what will happen there will be change in the what you call is temperature and other things right, and this process is basically irreversible process as I told that the work done on this paddle wheel cannot be reverse back that means system cannot really produce the work done by the rotation of the paddle wheel right.

Because in this case the work is done by the surrounding on the system like you will be having a motor or a pulley or something to rotate this 1 to 2 so that work can be transferred to the system. And we can also take another example which is you know electrical resistance and it will be connected to a battery and as usual this will be work will be done on this system and this is also insulated and this is a reversible process sorry, this is an irreversible process and for adiabatic wall dQ=0 we can you know the use the first law of thermodynamics therefore the internal energy is nothing but your -dW which is equal to PdV+d shaft kind of things.

So if you look at this case like then the shaft work will be Pd what you call dU+PdV because there will be piston will be moving and there will be some work and that is nothing but you what you call change in enthalpy right. And again the shaft work is negative and which indicates that what you call the work is done on the system and which is if you know as a result there will be change in enthalpy of the system. So the shaft worthy always a negative quantity in case of a constant pressure process.

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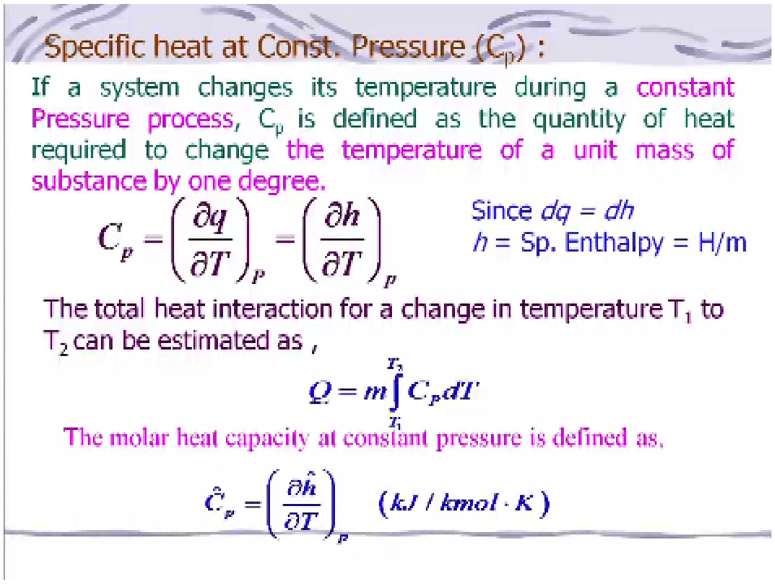

Specific heat at Const. Pressure (C_p) :

If a system changes its temperature during a constant Pressure process, C_p is defined as the quantity of heat required to change the temperature of a unit mass of substance by one degree.

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

Since $dq = dh$
h = Sp. Enthalpy = H/m

The total heat interaction for a change in temperature T_1 to T_2 can be estimated as ,

$$Q = m\int_{T_1}^{T_2} C_p dT$$

The molar heat capacity at constant pressure is defined as,

$$\hat{C}_p = \left(\frac{\partial \hat{h}}{\partial T}\right)_p \quad (kJ / kmol \cdot K)$$

So we can define the similar way what we have done for the constant volume that is specific it at a constant pressure. So that is defined as a quantity of heat required to change the temperature of a unit mass of substance by one degree, so the CP if you look at it is nothing but ∂q by ∂ t at constant pressure we have already seen that this DQ is equal to D H for a constant pressure process.

So therefore that is basically CP is equal to change in enthalpy per unit change at a constant pressure per unit mass also or it can be also or mold right the total interaction for a change in temperature went t1 to t2 can be estimated as q is equal to m CP DT and keep in mind that this CP you know like we need to know at what you call at a particular temperature and as I gave an example in the very beginning that it may be dependent on temperature also right.

So we will see as you go along the molar heat capacity at constant pressure is defined as basically CP cap as ∂ H by ∂ t FP and this unit is kilo Joule per kilo mole Kelvin and in this case for mass this will be kilo Joule per kg Kelvin right kind of things the unit is there. So if you now we need to look at how we can you know evaluate these properties and both the specific particle heat at constant pressure and constant volume these are property of the system right.

So this has to be we have to learn how to evaluate so that we can estimate you know the heat interaction or the work interaction whenever a system will be interacting with surrounding.

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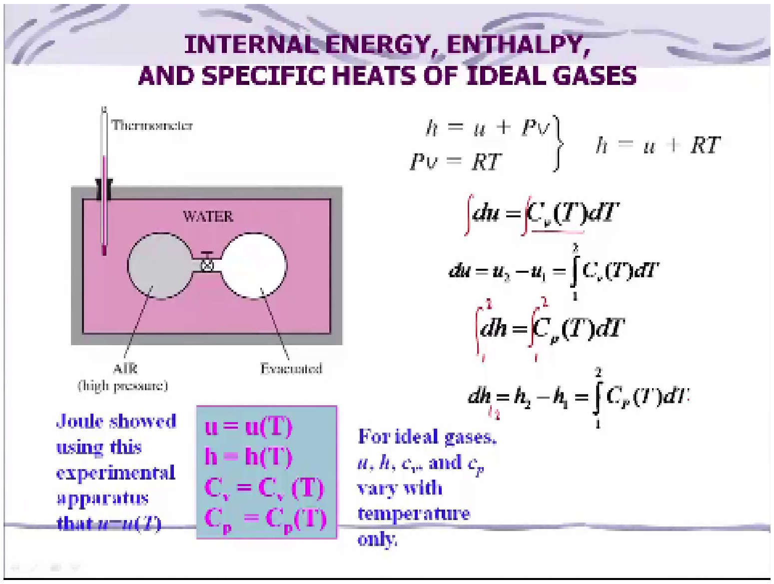

INTERNAL ENERGY, ENTHALPY, AND SPECIFIC HEATS OF IDEAL GASES

$$\left.\begin{aligned} h &= u + Pv \\ Pv &= RT \end{aligned}\right\} \quad h = u + RT$$

$$\int du = \int \underline{C_v(T)}dT$$

$$du = u_2 - u_1 = \int_1^2 C_v(T)dT$$

$$\int_1^2 dh = \int_1^2 C_p(T)dT$$

$$dh = h_2 - h_1 = \int_1^2 C_p(T)dT$$

Joule showed using this experimental apparatus that $u=u(T)$

$u = u(T)$
$h = h(T)$
$C_v = C_v(T)$
$C_p = C_p(T)$

For ideal gases, u, h, c_v, and c_p vary with temperature only.

So let us look at like internal energy and enthalpy and specificity of an ideal gases and we know that h is equal to u pv from the you know this thing and we have also know that this PV is equal to RT from ideal gas law, so then we can say that His nothing but u plus RT and let us you know look at a an experiment which was conducted by the jewels and he took somewhat we call two passes which is at a constant you know like air he has taken as a very high pressure here.

And it is and another chamber he has taken at evacuated or the vacuum kind of thing it is connected with the wall and he put into a water bath or this thing and measure its temperature and it open this voles you know what will happen the high-pressure gas will rush into the evacuated chamber and there will be change in pressure right and there will be also you know kind of effect and what will happen to this you know temperature of the bath what will happen because if you look at pressure is changing and so also.

You know what will happen to its temperature and he allowed this thing to have you know occur for a you know allow the this process you know anything is happening so that it can be register between this auto call process and this water what it is having so he observed that this there is no change in the temperature right and of course he has considered this air gaze at I the pressure says that it can be treated as an ideal gas right and therefore he you know concluded that there is no change in temperature.

Therefore internal energy you know is basically is a function of temperature only it is not a pressure because there is a change in pressure here right pressure becomes higher and it became a lower due to the expansion process but however there is no change in so therefore he says that internal energy is a function of temperature and that is valid only for an ideal gas law ideal gas but however if you conduct the same experiment at much higher pressure where you cannot treat the gas as an ideal then you can find that it is a function of you know not only the temperature but pressure and then one can say that the enthalpy is also a function of temperature and C_v C_p are also function of temperature for ideal gas right.

So that we will be considering so if you look at our CP and CV is changing you know with respect to temperature then we will have to learn how-to evaluate it because the change in internal energy will be basically CV DT and CV is a function of temperature this is a temperature it is a dependent on temperature and we if we integrate this thing equation you know I can get between the two system d u is equal beu2 minus u1 and CVT in DT unless I know this you know what you call how this specific heat is dependent on the temperature then only we can real indicate otherwise we cannot okay.

Or we can take an average temperature average specific heat value at a particular temperature then you can integrate otherwise difficult, so to do that and similarly we can also find out is equal to D H is equal to CP t dt and we can integrate this to get you know 12 2 onto to here and then we can evaluate their d h 1 to 2 is equal to S2 minus h 1 and 1 to 2 CP t dt. So these we need to see that how we can you know have these properties of the specific heat and specific heat at constant pressure and constant volume.

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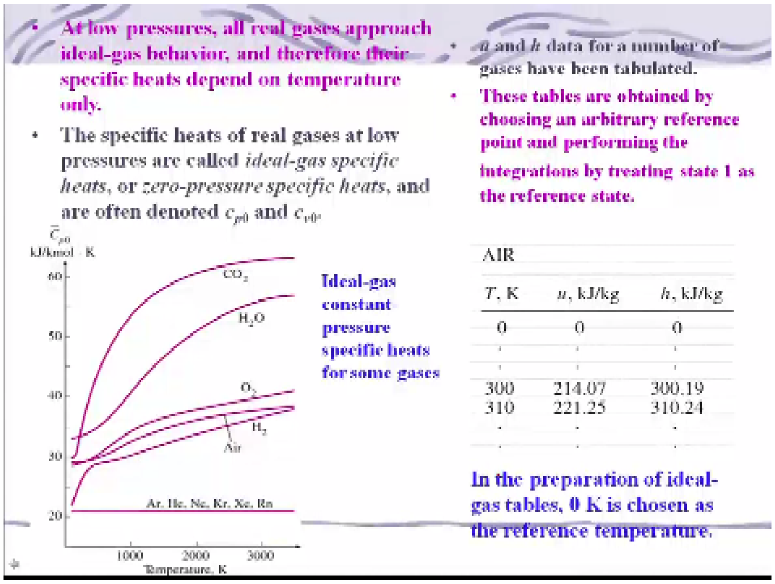

- At low pressures, all real gases approach ideal-gas behavior, and therefore their specific heats depend on temperature only.
- The specific heats of real gases at low pressures are called *ideal-gas specific heats*, or *zero-pressure specific heats*, and are often denoted c_{p0} and c_{v0}.

Ideal-gas constant pressure specific heats for some gases

- u and h data for a number of gases have been tabulated.
- These tables are obtained by choosing an arbitrary reference point and performing the integrations by treating state 1 as the reference state.

AIR

T, K	u, kJ/kg	h, kJ/kg
0	0	0
·	·	·
·	·	·
300	214.07	300.19
310	221.25	310.24
·	·	·
·	·	·

In the preparation of ideal-gas tables, 0 K is chosen as the reference temperature.

So if you look at low pressure all the real gases approach the ideal gas behavior and therefore their specific depends on the temperature only right as we as Jules have conducted experiment and found out and the specific heat for of the real gases at low pressure are called ideal gas specific heats or the zero pressure specific heats are often denoted by CP$_0$ and CV$_0$ if you look at how these properties are changing with respect to various you know what we call gases as shown here the CP versus the temperature if you look at mono atomic gases does not change.

And whereas the diatomic gases do change but not much as compared to try atomic gases are kind of things and question arranges if you are evaluated at different temperature you know particularly high temperature zone this curve is very steep so how you will evaluate it, so you need to relate this thing you know in terms of certain maybe third order or some polynomials and carpet you can do and then you can evaluate and UH data for a number of gases have been tabulated right you can use the tablet value.

And these tables are obtained by choosing arbitrary reference point and performing the integration by treating the state one as a reference state for example like generally if you look at the temperature zero Kelvin is taken as a reference here because all this you know a first temperature internal energy enthalpy is0 and at different temperature it will be different values you know like kind of things so it will be a function of template.

So if you can take a reference and then you know you can do it will be easier but however you should know how it is very right.

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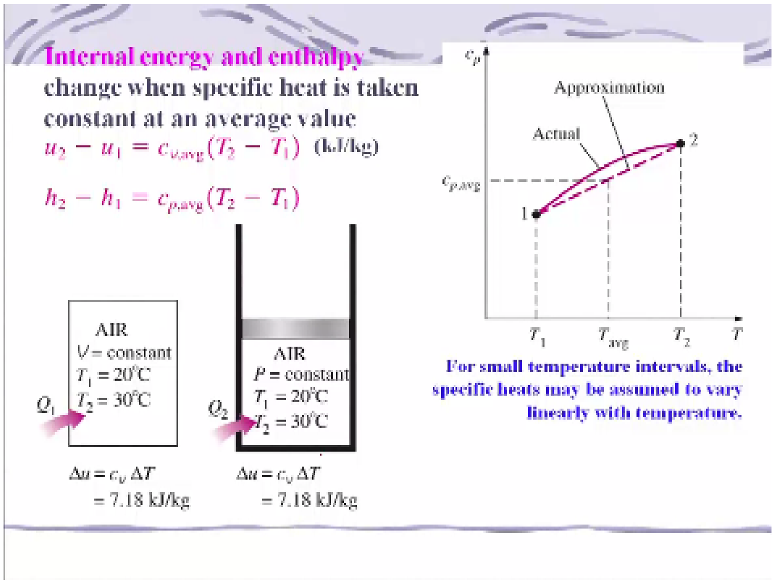

Internal energy and enthalpy change when specific heat is taken constant at an average value

$$u_2 - u_1 = c_{v,avg}(T_2 - T_1) \quad \text{(kJ/kg)}$$

$$h_2 - h_1 = c_{p,avg}(T_2 - T_1)$$

For small temperature intervals, the specific heats may be assumed to vary linearly with temperature.

So let us see that how we can do that and internal energy and enthalpy change and when specific it is taken as a constant at an average because we need to do a calculations, so therefore we can take an average values right because all the time whenever system is enduring surrounding there will be change in internal energy or change in enthalpy so therefore we need to evaluate and we can take that you know u 2 minus u 1 C average and t2 man and this you can do only when you know the changes is not much.

For example if you look at it state one here and state to it is actual process taking place here but if I take a approximation this is a vertical linear I am assuming but you are making some error between that then I can take average values here at T average C_p average then I can take it out and integrate very easily and then evaluate so this is true only for a small temperature intervals right otherwise it would not be.

And if you let me just give that always you may feel that you know whether a constant volume process is there right cv temperature change from 20^0 2 30^0 Celsius and there is a constant pressure process temperature also change in 20 to30 d Celsius if you look at change in internal energy is remaining same whether the process is constant volume or a isobaric process or constant friction so therefore we need not to get bogged down that you know whether the process is this thing the change in internal energy will be remained same.

Whether the process is constant pressure or constant volume so far the change in internal energy will be always related to the CV you know DT and the change in enthalpy will be related to the CP DT so it is does not really depend on the weather the process is constant volume or a constant pressure or any other passes okay, so that you should keep in mind you should not get bogged down by the definition of the CP and C okay, we will stop over here and in the next lecture we will see how to handle also for the you know solid because we have discussed the CP CP for the gases and we will handle also how to for the liquid and solid which are incompressible in nature thank you.

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