Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 15
First Law of Thermodynamics for Non-cyclic Process 2

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Let us start this lecture with a thought process from the Donald Haynie and who says that.

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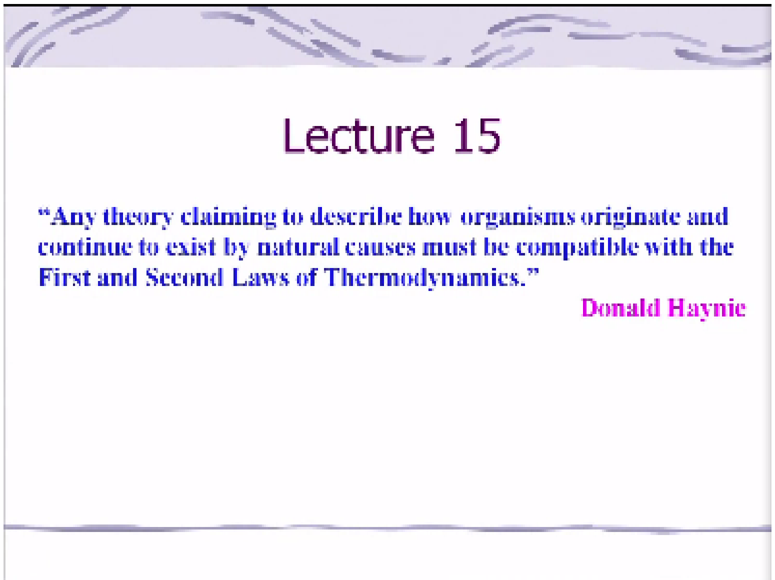

Lecture 15

"Any theory claiming to describe how organisms originate and continue to exist by natural causes must be compatible with the First and Second Laws of Thermodynamics."

Donald Haynie

Any theory claiming to describe how organisms originate and continue to exist by natural causes must be compatible with the first and second laws of thermodynamics. So if you look at it, it really has given a very great you know dimension of the first and second law of thermodynamics and which we are discussing particularly for control mass system. In the last lecture we have taken, you know isochoric process that is a constant volume process and isobaric process that is constant pressure process and seen that how you can apply the first law of thermodynamics for both reversible and irreversible processes.

And in last lecture also we defined two terms which is basically the specific heat at constant volume and specific heat at constant pressure and those are basically properties of the, you know substance and one can also look at although historically people have defined the specific volume at constant, specific heat at constant volume as the change in internal energy right for unit change in temperature and of course per unit mass of substance.

And similarly they have defined for the specific heat at constant pressure as the change in enthalpy per unit change in temperature per unit mass of substance. But if you look at it is basically instead of specific heat people could have, you know term it as a specific energy. And in the last lecture also we learnt how to evaluate the CP and CV values and we learnt also for ideal gas it is only the function of temperature.

And of course for real gases we did not look at, but it can be also function of pressure so it is quite complex to evaluate. And we will see also that one can take average values and then try to calculate particularly whenever you are doing the hand calculations. But today we will also little bit dwell upon how we can use, you know accurate values of the CPs and also compute, and do the, you know accurate calculations.

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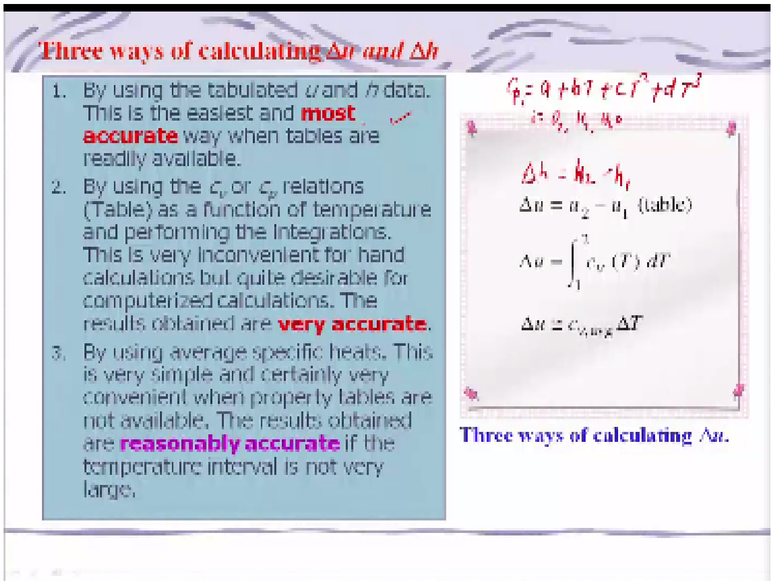

Three ways of calculating Δu and Δh

1. By using the tabulated *u* and *h* data. This is the easiest and **most accurate** way when tables are readily available.
2. By using the c_v or c_p relations (Table) as a function of temperature and performing the integrations. This is very inconvenient for hand calculations but quite desirable for computerized calculations. The results obtained are **very accurate**.
3. By using average specific heats. This is very simple and certainly very convenient when property tables are not available. The results obtained are **reasonably accurate** if the temperature interval is not very large.

$C_{p_i} = a + bT + cT^2 + dT^3$

$i = O_2, N_2, H_2O$

$\Delta h = h_2 - h_1$

$\Delta u = u_2 - u_1$ (table)

$\Delta u = \int_1^2 c_v(T)\, dT$

$\Delta u \cong c_{v,avg} \Delta T$

Three ways of calculating Δu.

So if you look at there are three ways of calculating the change in internal energy and enthalpy one is you can use a table or tabular data right, the data given in table like your steam table or the refrigeration table like you can find out U and H directly and then use it right, which will be give you the more accurate values right. So if you look at one can find out like particularly let us say internal energy I can find out internal energy from that table, steam table or internal energy from the, you know again steam table at a particular temperature or a pressure kind of thing.

Of course keep in mind that, you know in some book this internal energy for the steam and the refrigerant given, but in our book what we are following it is not given it is the enthalpy what is given. So for that one has to find out, you know enthalpy like, and then from using enthalpy data of course one can find out internal energy that one can do. There is another way of doing like, you know CV and CP either CV or CP can be related to a temperature right and then you can have a, you know polynomials as I told a third order polynomials.

For example if I say CP I can write down $a+bt+ct^2+bpq$ right. So if you look at if I get this coefficient and this can be, you know like coefficients A B C and D so these are coefficients or the constants right. And if I know these things I can evaluate integrate the equation very easily right and keep in mind this I have written I, this I can be for, you know like any other spaces like O2, it can be S2, it can be, you know S2O see for different you know spaces or different you know substance or gases it will be different this ABC and D will be different okay.

So I can have a table or I can feed this data and then integrate it and get a very accurate and particularly when you are using computer to compute your values right then one can manage, but hand calculation it is quite difficult you know will be time consuming. And there is another way which we will be doing right that is that you take some average values and keep in mind that the change is not much the temperature, you know its variation is not much and then you take average values and you calculate right.

And what we will be doing we will be most of the time we will be using this that is you use a steam table or a refrigeration table or any other, you know kind of things dateable and we will be using also, you know what you call average values kind of things this average values will be taking and using that will be using this and this most of the times of course this average values you will have to sacrifice their accuracy, but it will be good enough when you are you know doing some engineering calculation you need not worry too much about the accuracy and calculation of roughly doing.

And sometimes we may learn how to handle this using a polynomial feed kind of things you know people are having some experimental data's, people have generated and then they have used a polynomial fit or from the statistical you know like thermodynamics one can find out the properties. So as I told this is the, you know how we will be handling the gases right which are I am like properties for this gases.

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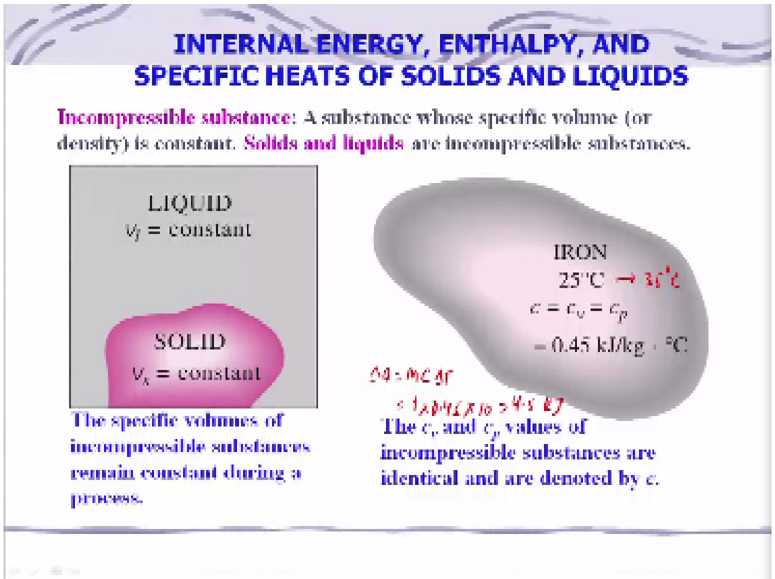

INTERNAL ENERGY, ENTHALPY, AND SPECIFIC HEATS OF SOLIDS AND LIQUIDS

Incompressible substance: A substance whose specific volume (or density) is constant. **Solids and liquids** are incompressible substances.

The specific volumes of incompressible substances remain constant during a process.

The c_v and c_p values of incompressible substances are identical and are denoted by c.

But let us look at now the internal energy and enthalpy and specificity of solid and liquids, because if you look at these solids and liquids are incompressible in nature and therefore you know like specific volume will be remaining constant in this case right, there would not be any change as such of the density kind of things I mean as compared to the gas the change is very, very, you know negligibly small we can assume it to be, you know to constant.

So as a result you know like the processes what you call the specific volume will be remaining constant kind of things. And therefore we can take the CP and CV as the same, you know there is no difference between CV value and CP values because there is no change in the specific volume and which is equal to the specific heat, and let us say for iron it you can say that is 0.45 kilo joule per kg degree C.

If you look at like I have, you know ask this question when you increase this temperature of 1 kg of iron from 25°C to 35°C what will be the amount of heat you will have to give is basically 4.5kilo Joule right is not it, this is because the MCPDT like if you look at the amount of heat will be will be mCΔT because this iron. So this is 1x0.45 into the change in temperature is it is going from to 35°C right so it is tending cells so it is 4.5 kilo Joule.

But if I do this water 1kg of water and changing the temperature water, 1 kg of water from 25 to 35°C it will be around something 41.8 kilo Joule kind of thing is not it, because your CP value is 4.18 right, so it will be 41 it is something 9 times that of the iron that means the heat capacity of the water is higher right, than the iron.

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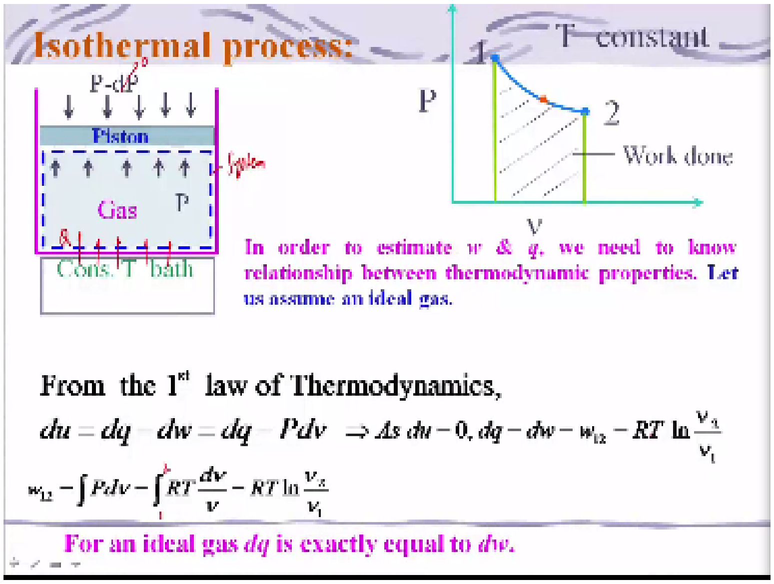

Isothermal process:

In order to estimate *w* & *q*, we need to know relationship between thermodynamic properties. Let us assume an ideal gas.

From the 1st law of Thermodynamics,

$$du = dq - dw = dq - Pdv \Rightarrow As\ du = 0,\ dq = dw = w_{12} = RT \ln \frac{v_2}{v_1}$$

$$w_{12} = \int Pdv = \int_1^2 RT \frac{dv}{v} = RT \ln \frac{v_2}{v_1}$$

For an ideal gas *dq* is exactly equal to *dw*.

So now let us look at another process is isothermal where the temperature will be remaining constant. So what we will do I mean like we will take again piston and cylinder arrangement containing gas will have a constant it what you call bath, and you keep in that this is having temperature here and then there will be some heat transfer will be taking place right this is the heat and what will happen if the temperature and we want to keep it temperature of this gas that is the system you know this is my system right constant.

So what else that means the piston will be moving and says that it will be remaining constant the temperature and we can assume this process to be isothermal provided the temperature gradient between the what you call constant bath and the gas is small and so also the change in pressure, you know this thing will be very, very small I mean it is pretending to a zero. It is like you can think of putting a sand grain and then removing one grain and keep the temperature constant of the system like you can assume that that way.

And then the process can be considered as a reversible process, because you can reverse the system you know after the change to the original one and you can describe the process from 1 to 2 and this process if you look at it is basically what happened it has been expanded right. So this is the work been done and applying the first law of thermodynamics we can say that you know du=dq-dw and this w is the PDV that is a change in the volume so therefore that is having. And in this case temperature is remaining constant.

Therefore what will happen internal energy, internal energy will be what will be 0 right, yes or no, because the change we have seen that. So keep in mind that we if you want to estimate this w what it will be and the Q kind of things then we need to know the properties and we can assume as the ideal gas we can also, you know then we will find out work done basically PDV which is nothing but RT/VD x DV and when you integrate this between state 1 to 2 I will get RTlnV_2/V_1 and we are assuming the process to be what we call isothermal.

So therefore I can do it very easily and as I told that du is 0 because isothermal process therefore dQ = dW and when you integrate this will be 1 work done between state 1 to 2 will be RT ln V_2/V_1. And for an ideal gas dQ exactly equal to the work done for an isothermal process and I mean like this is about the isothermal process when we considering the reversible right.

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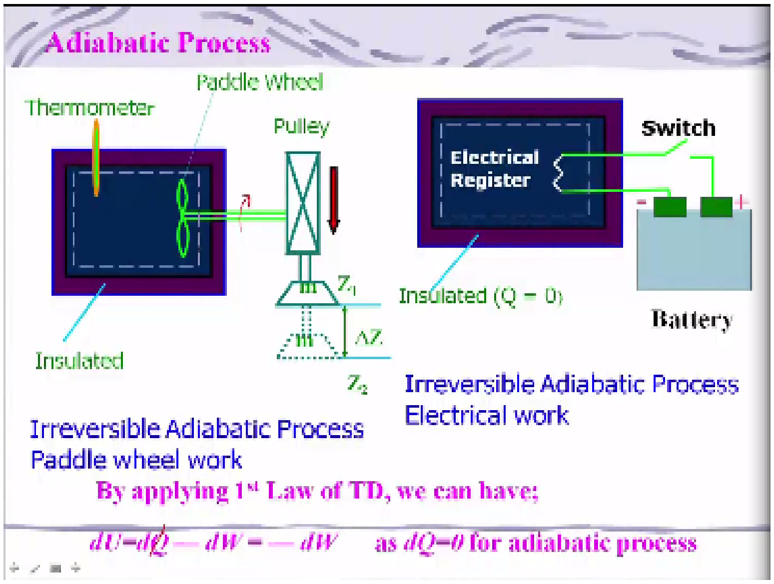

Adiabatic Process

Irreversible Adiabatic Process
Electrical work

Irreversible Adiabatic Process
Paddle wheel work

By applying 1st Law of TD, we can have;

$dU = dQ - dW = -dW$ as $dQ = 0$ for adiabatic process

And we will consider the adiabatic process where the heat interaction will be 0 like we can take the same our, what we call paddle wheel example which is being rotated in the this kind of a rigid vessel and then there will be because of this work done and then there will be change in the temperature and then kind of the gas if I consider is a gas. And but this process will be not reversible I have told earlier right, it will be an irreversible process let us consider the I am like electrical registers.

And this is work what you call some work is done by the system and surrounding whenever we put the switch on and it is insulated, so no heat is going out and this process is basically taking place adiabatically and it is an irreversible adiabatic process of course during which electrical work is being done. So we can apply the first law of thermodynamics that is dU dQ-dW and this dQ is basically the zero because the adiabatic process therefore the work done you know is equal to change in internal energy in this case the internal energy will be increasing of the system.

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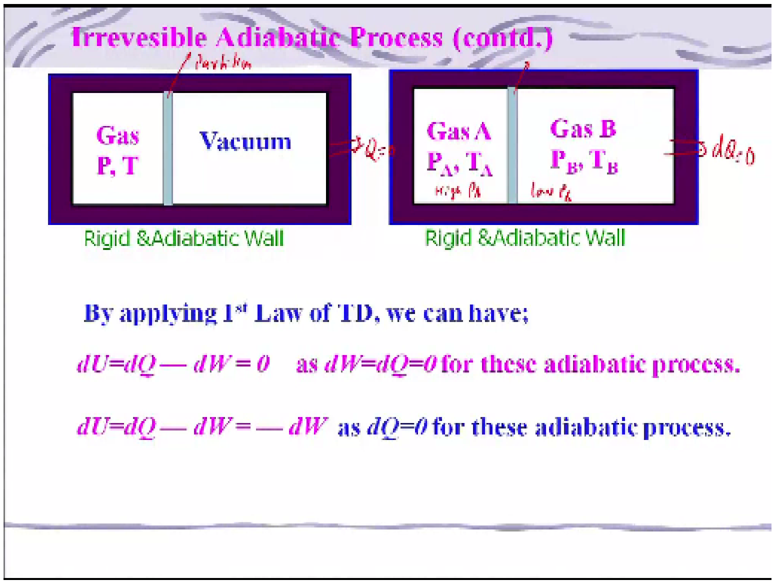

Irrevesible Adiabatic Process (contd.)

By applying 1st Law of TD, we can have;

$dU=dQ - dW = 0$ as $dW=dQ=0$ for these adiabatic process.

$dU=dQ - dW = - dW$ as $dQ=0$ for these adiabatic process.

So let us consider the another case that is you know rigid and adiabatic wall two chambers are there one is the gas chamber at a pressure P and temperature T and there is another chamber which is at vacuum. Now this is the partition and if this partition can be removed you know can be removed then, you know what will happen this gas will be expanded right and this is a insulated one that means no heat is going out right that is zero and it is rigid one.

And what will happen to the work done in this case what will happen to work done work done also will be zero because there is no PDV work and right. And however the pressure will be reduced right and we can apply the first law of thermodynamics in this case what you call the work done is zero and the heat, because adiabatic process that is also zero. So therefore there would not be any change in internal and internal energy will be remaining constant right.

Let us consider another case where the gas is at pressure P_V and temperature T_A and in another chamber like other chamber Gats B is at pressure P_B and T_B and keep in mind that let us assume that you know like P_V is greater than P_B okay or it can be other way around P_V v is greater than P_A but let us say that pressure P_A is greater than P_V and it is separated by a partition I can remove this partition right.

If I remove this partition what will happen that gas will be expanded from high pressure this is let us say high pressure right high pressure right and this is low pressure P_B then what will happen some work is being done right because all the time this is giving a resistance so that work is being done and in this case as I mentioned already the adiabatic wall that means the heat transfer across the system boundary is 0 so therefore the if we apply the first law of thermodynamics this case the change in internal energy will be there which is nothing but work done kind of things because get the gas.

So this is also an easy base both the this example what we have considered is basically is reversible process right and you can apply the first law of thermodynamics and then can do that.

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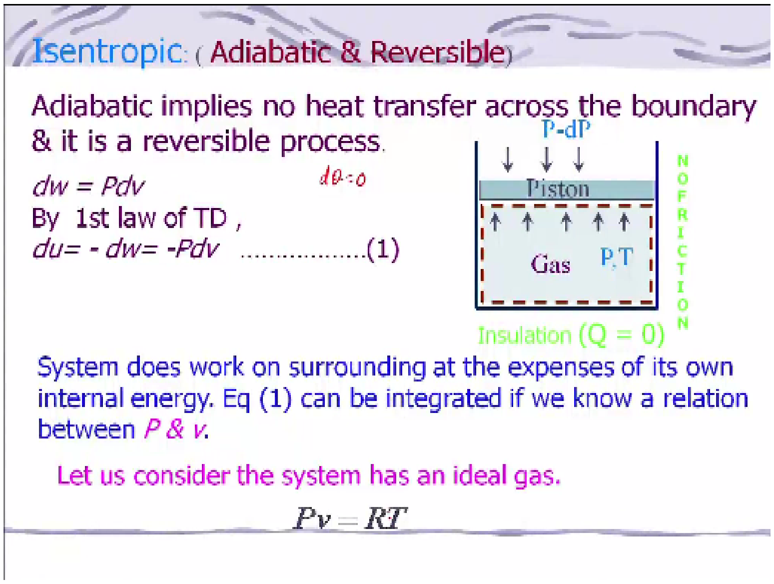

Isentropic: (Adiabatic & Reversible)

Adiabatic implies no heat transfer across the boundary & it is a reversible process.

$dw = Pdv$ $dQ=0$

By 1st law of TD ,

$du = - dw = -Pdv$ ....(1)

System does work on surrounding at the expenses of its own internal energy. Eq (1) can be integrated if we know a relation between P & v.

Let us consider the system has an ideal gas.

$$Pv = RT$$

So let us look at the not only the adiabatic process but also the reversible process what we call it as a isentropic and there would not be any heat transfer across the system boundary and it is reversible we will consider again our vertical piston cylinder assembly and then which containing gasps as better pressure P and T and it is insulated so therefore no heat bring transfer and this what you call if you the atmosphere pray or the pressure which is acting on the piston is reduced little bit I mean by the small amount then the piston will move upward and then there is no heat transfer.

So it will be expanded the gas is expanded because the pressure here the system is higher than the its surrounding and if we will apply the first law of thermodynamics that is du is equal to minus dw because if you look at DQ in this case is 0 right and the work done is nothing but your pdv so therefore du is equal to minus PDV and keep in mind that system does the work on its surrounding at the expense of its own internal energy right and equation 1 if I want to find out everyone integrate then you know I should know the relationship between P and V right but this is a generalize it can be applied for anything.

But if I consider the ideal gas you know it will be easy to relate this pressure and P and V by that PV is equal to RT and we can integrate this equation 1 so if I can do that this work done also.

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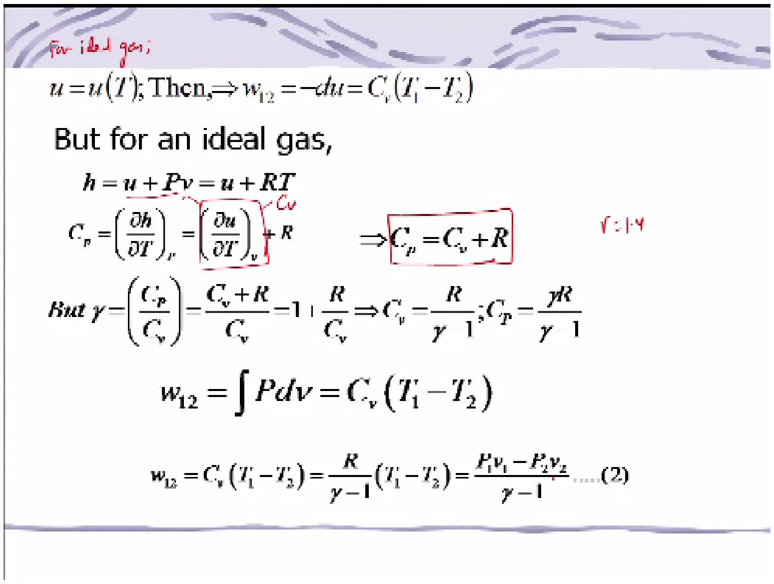

For ideal gas;

$u = u(T)$; Then, $\Rightarrow w_{12} = -du = C_v(T_1 - T_2)$

But for an ideal gas,

$$h = u + Pv = u + RT$$

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p = \boxed{\left(\frac{\partial u}{\partial T}\right)_v}^{\,Cv} + R \qquad \Rightarrow \boxed{C_p = C_v + R} \qquad \gamma = 1.4$$

$$But\ \gamma = \left(\frac{C_p}{C_v}\right) = \frac{C_v + R}{C_v} = 1 + \frac{R}{C_v} \Rightarrow C_v = \frac{R}{\gamma - 1}; C_p = \frac{\gamma R}{\gamma - 1}$$

$$w_{12} = \int P dv = C_v(T_1 - T_2)$$

$$w_{12} = C_v(T_1 - T_2) = \frac{R}{\gamma - 1}(T_1 - T_2) = \frac{P_1 v_1 - P_2 v_2}{\gamma - 1} \ldots\ldots(2)$$

Will be basically what we have seen this work done is equal to change in internal energy right and that is C_V T_1 - T_2 we have already seen that in that and if I take the ideal gas you know where u is a function of for ideal gas you know u is a function of temperature only right therefore I have taken and for an ideal gas we know that h is equal to u + P_V and that is equal to u + u + RT and if I you know integrate this you know like from the definition of the CP values ∂S by ∂T by ∂T by P I can use this expression over here and then find out ∂u by ∂T at a constant volume plus equal to the RT.

I can you know this thing and this is basically nothing but you what you call C_V right so I can write down CV is equal to CB + R this will be using very often if I know the CV value for an ideal gas I can very easily calculate the CP and vice versa. So if you look at γ, γ is basically ratio of CP by CV and we already know that CP is equal to CB + R then I can find out basically is equal to 1 plus R by CV and then is nothing but CV is equal to R by R - 1 and once we know that from this definition I can find out CP is equal to γR divided by γ - 1 so if you look at if I know this γ and generally for the γ you know for air is 1.4 right.

And of course this γ will be different for different kind of constituents depending upon whether it is a monomolecular or add I molecular poly atomic sorry diatomic or mono atomic or polyatomic substance right so then what we will do we can integrate this we can evaluate this work done between station 12 to state 1 to 2 is as PDV and we can put this is which is equal to the CV T_1 - T_2 okay so if you look at this work done we can in place of CV can take that r by γ - 1 and if I look at this R T_1 is nothing but your P_1 V_1 from the ideal gas law and R T_2 is nothing but P_2 with V2 and therefore the work done will be is a for an isentropic process will be equal to P_1 V_1 - P2 V2 divided by γ – 1 and let us find out relationship for an isentropic process that is.

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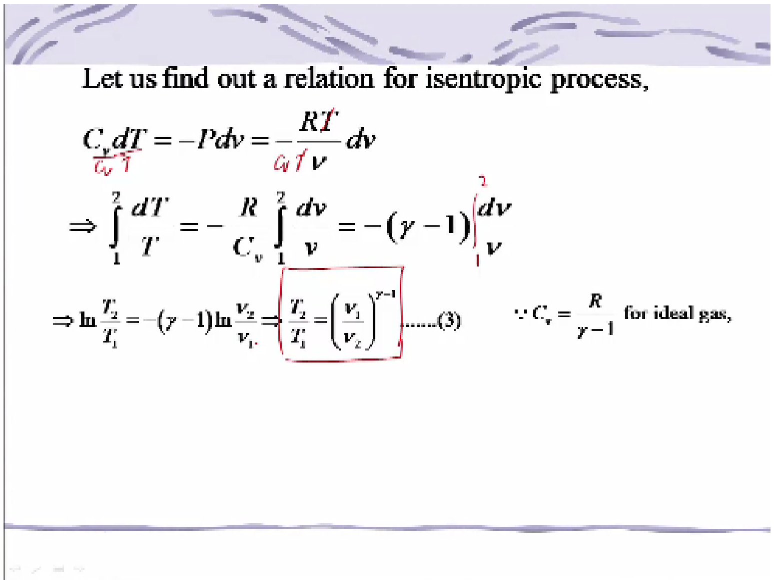

Let us find out a relation for isentropic process,

$$\underset{C_v\,T}{C_v dT} = -Pdv = -\frac{RT}{C_v T\, v} dv$$

$$\Rightarrow \int_1^2 \frac{dT}{T} = -\frac{R}{C_v}\int_1^2 \frac{dv}{v} = -(\gamma-1)\int_1^2 \frac{dv}{v}$$

$$\Rightarrow \ln\frac{T_2}{T_1} = -(\gamma-1)\ln\frac{V_2}{V_1} \Rightarrow \boxed{\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}} \text{.......(3)} \qquad \because C_v = \frac{R}{\gamma-1} \text{ for ideal gas,}$$

The CV DT is equal to - PDV is equal to from the ideal gas law you can find you know substitute this P with the RT by V into DV and so if you look at I can write and express this expression as dT by T I can take this t here or I can divide by this temperature here and also CV here and this side CV and T so this will cancel it out and then you will get our CV and then DV by D2 if you can integrate between state 1 to 2 and you will get that you know very easily and these are you know you can take it out is not changing with respect to volume.

So therefore we know that CVY CV is equal to R divided by γ - 1 so r by CB is nothing but γ - 1 and we can do that and we can what you call integrate this expression as 122 so then we will get ln T_2 by T_1 is nothing but equal to - γ - 1ln V_2 by V_1 and from that we can get this expression which is very commonly used T_2 by T_1 is equal to V_1 by V_2 γ - 1 keep in mind that this negative sign is you know being taken in so that it became V_1 by V_2 in place of V_2 by V1here.

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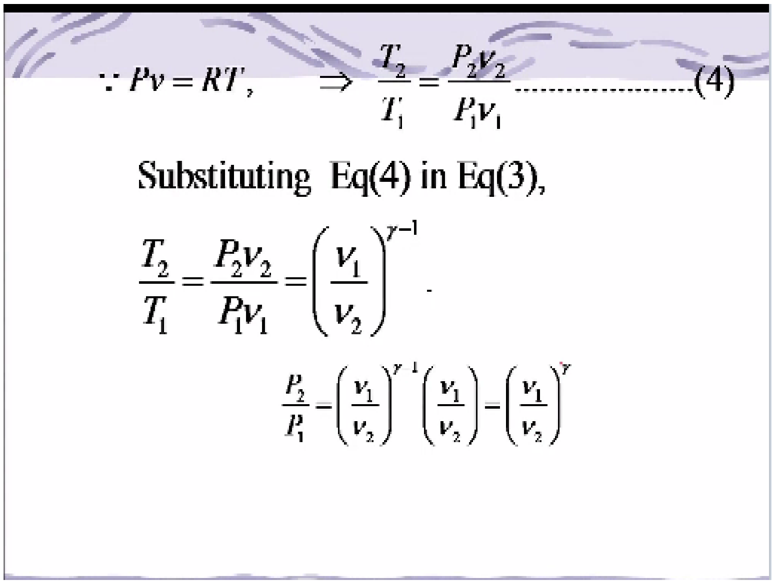

$$\because Pv = RT, \quad \Rightarrow \frac{T_2}{T_1} = \frac{P_2 v_2}{P_1 v_1} \text{....................}(4)$$

Substituting Eq(4) in Eq(3),

$$\frac{T_2}{T_1} = \frac{P_2 v_2}{P_1 v_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}\left(\frac{v_1}{v_2}\right) = \left(\frac{v_1}{v_2}\right)^{\gamma}$$

So now what we will do we have got a relationship for the isentropic relationship between the what we call temperature and specific volume now we will be finding out relationship between the pressure and specific volume for that we will consider the ideal gas law again PV is equal to RT and that Is equal to T_2 by T_1 is equal to P_2 V_2 divided by P_1 V_1 we can write down from that and if you substitute these values you know here like from this we know and then values between what you call P2 by this one and then because we have already derived that relationship right.

And we will say P2 by P1 in terms of that and you will get V_1 by V_2 γ - 1 and because if you look at I can find out this thing in the in terms of T2 by T1 I can put in terms of V V_2 by V_1 power to this γ - 1 so then we can evaluate is very easily that P_2 by P_1 is equal to V_1 by V_2 power to the γ - 1 into V_1 by V_2 and then that is nothing but your V1 divided by V to power to the γ and that is equal to the PV_2 γ is equal to P_1 V_1^{γ} is equal to P^{γ} constant so this if you look at this is the relationship what we keep in mind so that is easy and you can also find out other relationships between that.

So let us look at the polytrophic processes right and where it will be basically the various processes what we have seen like your isobaric process isochoric process isothermal process and what you call like a diabetic or isentropic process it can be together one can think of visualizing and this polytrophic process which you will learn later on is basically very important because you do not know really an actual system what will be happening if you could know that then you know one can use it so in practice there are several reversible processes in which heat trans.

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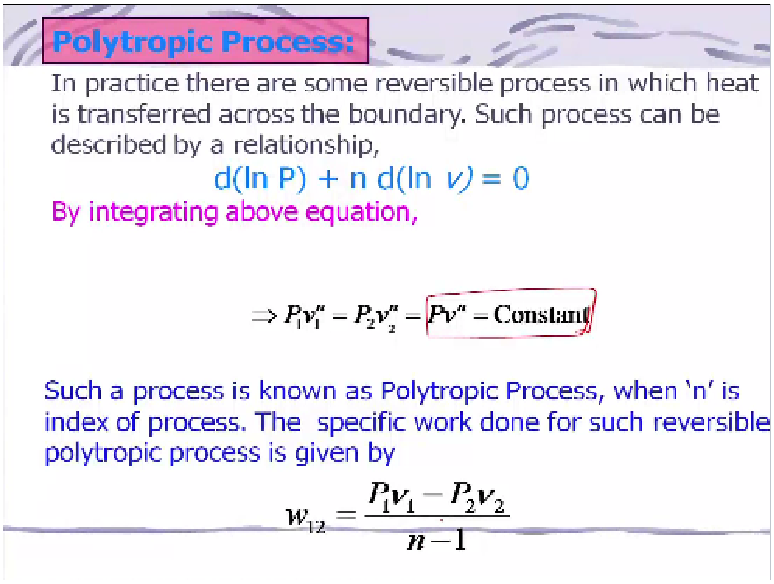

Polytropic Process:

In practice there are some reversible process in which heat is transferred across the boundary. Such process can be described by a relationship,

$$d(\ln P) + n\, d(\ln v) = 0$$

By integrating above equation,

$$\Rightarrow P_1 v_1^n = P_2 v_2^n = \boxed{Pv^n = \text{Constant}}$$

Such a process is known as Polytropic Process, when 'n' is index of process. The specific work done for such reversible polytropic process is given by

$$w_{12} = \frac{P_1 v_1 - P_2 v_2}{n-1}$$

Heat is transferred across the boundary right and sauce such process can be described by relation d (ln P+ nd ln v) kind of things and if we integrate this aerobic equation will get a relationship like basically P_V^n is equal to constant we can get that which is if you can say that P_1 V_1 is power to the n is equal to P_2 V_2 power to the n and n is the your coefficient like your specific ratio this is the polytrophic coefficient kind of thing n that indicates this n is basically the index of process like whether it is you know in can be you know various values.

And like that we will see like if it is n is equal to 0 so what will happen this process if n is equal to 0 this will be which process you can see if it is 0 V^0 what will happen this one anything power to the 0 what this basically isobaric process right so the specific work done for such reversible process can be given as in the similar way like what we have derived for a vertical isentropic process work done 12 is equal $P_1 V_1$ - $P_2 V_2$ divided by n - 1 in case of what you call the isentropic process like in place of n γ is being used that is all right so by applying the first law of thermodynamics to this process.

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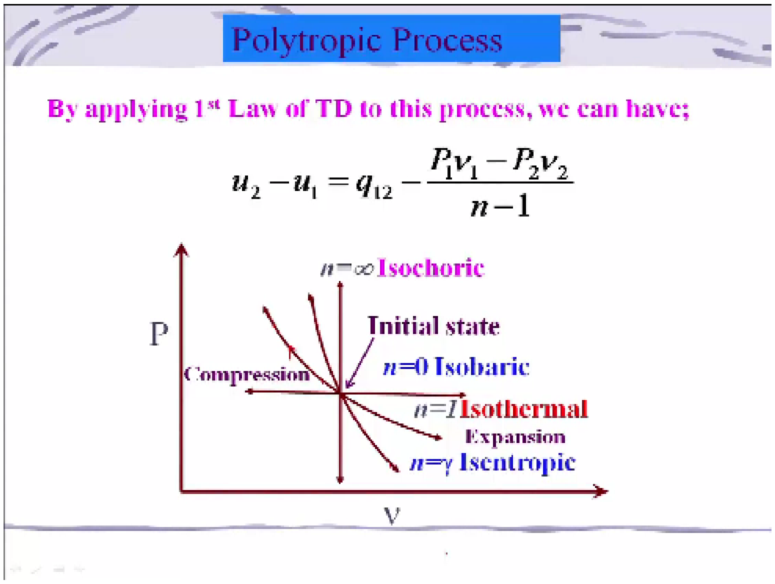

Polytropic Process

By applying 1st Law of TD to this process, we can have;

$$u_2 - u_1 = q_{12} - \frac{P_1 v_1 - P_2 v_2}{n-1}$$

We can have basically u_2 - u_1 is nothing but q1 2 - $P_1 V_1$ - $P_2 V_2$ divided by n - 1 so if you look at you can apply this process and then get this change in internal energy and the heat interaction and the work done and so if n is equal to 0 as I told that is basically the isobaric process and if n is equal to 1 right that is a isothermal process right and n is γ is nothing but your isentropic process keep in mind that in this passes right and in n is equal to infinity this is basically isochoric process right isochoric process and this portion.

If you look at it is basically expansion processes because the change in where the volume is increasing suppose you are at here and then you are moving towards that then this will be what you call expansion process and when you are in this quadrant is basically the compression process because the volume is basically what you call you can go from like a higher volume to the lower volume so if the process is this way therefore that process is compression process so you can have a process.

For example like you know isothermal expansion isentropic expansion kind of things and similarly you can have the isothermal to call compression and isentropic compression kind of processes so we have seen basically how you can apply the protocol control mass system how you can apply the first law of thermodynamic to the control mass system and we have taken the various processes like your constant pressure passes that is isobaric and constant temperature passes isothermal crosses isentropic process isochoric process and other things.

And we can apply and you can I mean very easily and what we will be doing in the next class will be now looking at how we can apply the first law of thermodynamics for control volume process where the you know the what you call mass will be coming in and going out and there will be this thing and so we look at in the next lecture thank you.

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