Basic Thermodynamics

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Lecture - 24

Gas Power Cycle – I

Good morning. Last class we discussed about what is meant by gas power cycles and air standard cycles? And why it is necessary to study the air standard cycles? I just repeat a few words again and air standard cycle is a reversible cycle that all processes are reversible. Working fluid is air and where, heat is added from outside source is not like that, that it is generated internally though heat is not generated in fact this is a wrong word but the internal energy is generated inside which boost up the temperature of the working fluid.

The temperature of the working fluid increases because of a heat addition from the outside source why I am telling this because in much practical gas power plant the temperature is generated inside because of the generation of internal energy so the if working fluid gets heated. When you study an ideal cycles that is an air standard cycle we consider heat is coming from outside and heat is rejected also to the an outside sink source and sink concept and throughout the cycling processes air is the fluid which behaves as an ideal gas with constant specification.

Today we will first study about the Carnot cycle

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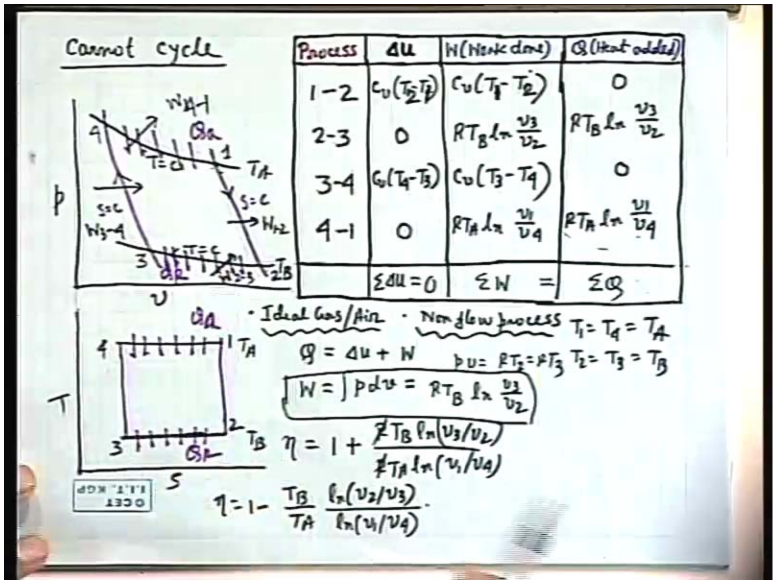

We have studied Carnot cycle in few last occasions, so we know what is a Carnot cycle. If you plot the PV diagram for Carnot cycles we will see the Carnot cycle consists of two isotherms and two isentropic so these are the two isentropic line air s is constant s is constant and this is e is T constant so this line is constant temperature line so these two lines is T is constant, T is constant so it consist of two isothermal and two isentropic.

We can start from any point as 1 it goes in this direction and isentropic expansion 2 where the specific volume is increased per unit mass I am drawing the cycle. This we have drawn earlier also in some other occasions then there is an isothermal compression that is 2 to 3 process then again 3 to 4 is an isentropic compression this is isentropic process and four to one is isothermal expansion. These three processes are there which constitute the Carnot cycles if we draw this diagram first and foremost task is to draw the diagram in PV and TS plane and we will have to develop this habit. Now 1 to 2, 2 to 3 we start with that 1, 2 is an isentropic process so an isentropic process obviously will be a line like this so this is 1, 2.

Similarly 2, 3 is isothermal process so this will be I am drawing by a black so this 2, 3. Again 3, 4 is an isentropic process, this is 3, 4 and 4, 1 is again the isothermal process. Let me stop drawing by different pen it will take unnecessary time therefore we see that

Before calculating the cycle efficiency net work output there are many things which may be up to calculate to calculated. Net work output, cycle efficiency what is the output? What is the power output in process 1, 2? What is the gross we added many things we can calculate.

Best process is to do it that you make a table like that process where you write the different process 1, 2 that means this process 2, 3 there are four process 3, 4 and you go on computing this delta u change in internal energy of that process work and heat quantity. One thing is very important in analyzing this type of air standard cycle two information are very important one information is the working fluid which is ideal gas which is ideal gas air? Air is the working fluid which behaviors as an ideal gas ideal gas is a broad thing air is the working fluid. Next important thing which is very much needed is this what type of process is performed by the gas? That means whether it is a Non flow process or flow process? The answer to this is non flow process that means process performed in a closed system this two are extremely important while evaluating the parameters like work done heat added all these things non flow process.

Though change in internal energy is not required it is a point function because it is difference of the property as you know for an ideal gas it is CV times delta T but for WNQ it is much important whether the process is a non flow or flow process. Accordingly things will change afterwards we will study another air standard cycles Brayton cycles where the processes are flow processed study flow process. It is extremely important to know what type of process? it is a non flow process being performed by the working fluid air during the cyclic operations. Non flow process means process executed by a closed system closed system process.

Now the process 1, 2 you start from process 1, 2 is an isentropic process so what happens reversible adiabatic process. First of all you see whether any of these three columns there is a special case or not so that I can put 0 or something like that so for this process is there any of these three columns would be 0? This one is 0 so better you do that first. What is the technique? this is the way if you do it will be very clear I am telling books may not tell that then what you do you write the first law of thermodynamics? Which is

Q which is valid for the closed system in this fashion del u plus W. Next is that first you search whether there is 0 for these two column next is the del u always shutting your eyes you can just write for any process without seeing any cycle that if process is 1, 2 then its change is internal energy is T_2-T_1 where it comes from the concept that ideal gas.

In this column you can write without seeing even the shape of the cycle but from the particular process you can write here Q is 0 so when Q is 0 work done is minus delta e here I am writing only work done so plus minus sign will indicate whether work is done or work is being done on the process. W is minus delta u that means this will be simply Cv, T_1-T_2. Next comes to the process 2, 3 one thing is that in this process T_1 is equal to T_4 one has to write that T_1 is equal to T_4 let this is equal to T_A. T_1 is T_4 that means this T_A line isothermal similarly T_2 is equal to T_3 is equal T_B let this line is TB lines that means there are two isotherms TA and TB and two isentropic lines isentropes this is the Carnot cycle here also this is TA this is TB.

Next part is 2, 3 you tell me 2, 3 is there any column where I can write 0? Which column? Delta u the first column. You have studied thermodynamics well then if delta u is zero Q is equal to W if any of the two quantity is found that means we can write for both this how to find out? Which one is simple to find? How to find out Q?. T into delta h T in to delta h. Why T into delta? It is Q where from you get you have to find out from the basic why Q into delta it is T is a reversible process so what so what is the equation which gives you the heat transfer in this process 2, 3 is Q into delta h how do you know?

You have to find out W, W is what? this is a non flow process it is pdv if it is non flow process per unit mass that’s why small v it could not be pdv in that case work done is equal to something else we have to go for the study flow energy equations very careful at this stage do not do a blunder at this stage which you can calculate from equations. pdv is the work done reversible non flow process only work done is pdv there is no other work expect the displacement mode over. If you evaluate pdv you see that pv is equal to what RT_2 or RT_3 because this is same pv is equal RT_2 or RT_3 that means during this process temperature remains constant 2, 3 which is TB. I can write RTB T_2, T_3,TB RTB pv RTB by v that means this will be ln v_3 by v_2 so this the work done.

Therefore I write RTBln v_3 by v_2 since delta u is 0 from the first law Q is equal to W so Q is RTBln v_3 by v_2. Now 3, 4 one thing you see before that this is an isothermal process where volume is reduced that is a compression process this was explained physically earlier so in this process both work and heat transfer is there. If you consider this term work done v_3 is less than v_2 that means this is negative that means work is done on the fluid if you see this term RTBln v_3 by v_2 this is also negative the same term that means heat is being rejected by the fluid that means isothermal compression process. Where heat is being rejected by the fluid and fluid is being compressed.

What happens? Just you imagine in a piston cylinder arrangement this was explained earlier if there is an air if you want to compress the air at a constant temperature. What will happen you want to compress the air? That means you give the work so when the temperature is constant for the air the temperature has to be constant it behaves as an ideal gas and more over it is isothermal process that means if temperature is constant means the internal energy will ah remain constant that means you want to make an isothermal compression.

Isothermal means temperature remains same and temperature remain same means for an ideal gas internal energy remains same that means when you compress if the work of compression which is being added to the working fluid has to come out in the form of heat so that heat has to be rejected so that the temperature remain same. This is the way one can understand also one can understand without these heat and work that if I compressive it its temperature will increase to make the temperature constant I will have to take heat away so that it is cooled and temperature is maintained constant. Therefore this is a process where heat is being rejected and work is being done that means this is the process where heat rejection takes place. Let this is QR and work is being done on this process. Work done W I am just writing one W but in this process there is an work but there is no heat there is an work W_{12} this is W_{23} this QR is Q_{23} I am writing as QR because heat is rejected.

Heat transfer processes are only 1, 4, 4, 1and 2, 3 because these two processes are reversible adiabatic process there will be no heat transfer. Whenever you write these things in the table you complete one row different columns you fill then immediately physically understand that what the for example this process there is no heat transfer because it is reversible adiabatic is an isentropic process. There is a work done which is positive work is coming out and there is a change in internal energy. Now I come to the process three 4, 3 it is synonymous to 1, 2 in respect that this is 0. What is this Cv T_4 minus T_3? What is this Cv T_3 minus T_4 negative of this because Q0 W is minus delta u. You see there is T4 is more than T3 or T3 is more than T_4 here you cannot see it here T_4 is more than T_3. Therefore there is an increase in internal energy but there is a negative work that means work is being W_3, 4 given to the system there is no heat transfer.

4, 1 process again 4, 1 process which will be 0 it is the synonymous to the 2, 3 process so that means this is delta u 0. W is RTA in this case it will be RTAln final volume means v_1 divided by v_4 similar is the thing that for the work because delta u 0 RTAln v_1 minus v_4. If you recognize this you see there is no internal energy change just the reverse get an expansion so heat has to be added because it is expanded means its temperature is reduced so cost and temperature means it has to be added and if temperature remains constant internal energy remains constant that means the work which is being developed by the expansion has to be nullified by the amount of heat which has to be supplied so that summation of these two is 0 earlier expansion there is no change in internal energy.

Therefore v_1, v_4, v_1 is more than v_4 so therefore this is positive work is done so in this case work is done W_4, 1 and the heat quantity you see similar way v_1 is more than v_4 that means this is the quantity so that heat is being added to this system Q_a. Q_a is the heat added which is the isothermal heat addition 4 1 and Q_b is the heat rejected that means this is Q_a heat is added this was discuss earlier also in Rankine cycle the same cycles is Q_A and this is the heat rejections Q_R and OR quantities are involved in all the four processes.

In a closed system work quantity will become zero only if there is in process with constant volume dv is 0 isobaric process constant volume processes otherwise all processes work transfer is there. I think this is clear this table after you complete this table you check the first law thermodynamics for cyclic process. What is that sigma of delta u has to be 0 and it is 0 you see T_2 is T_3 and T_1 is T_4, T_2 is T_3 and T_1 is T_4 so they cancelled up it become 0. If you sum it up 0 because T_2 is T_3, T_1 is T_4, T_2 is T_3, T_1 is T_4.

Now delta W, if delta u is 0 this cyclic process delta W must have must be equal to delta Q delta W and delta Q are same. If you do that T_2 is T_3, T_1 is T_4 that means these two terms cancels out. Therefore this plus this is equal to this plus this so therefore the sum of this column is sum of this column. If one can do these things but he can calculate anything whatever is asked for but what is the most important thing that is asked for is thermal efficiency?

Now thermal efficiency it is always better without going for calculating this sigma W until and unless it is asked for what is the net power output of the cycle or work transfer for a particular process then you will cote this result. If only the thermal efficiency asked we should write from this what is thermal efficiency? Heat1 minus heat rejected by heat added that means heat added by heat rejected, heat divided by heat added. That means one minus heat rejected by heat added because here heat rejected term is already negative.

Which is the heat rejected term this one and what is the heat rejected term is this one which is already negative so that I can write 1 plus RTBln v_3 by v_2 divided RTAln v_1 by v_4. With a minus sign I can write eta is 1 minus R, R cancels T_B by T_A into ln v_2 by v_3 so that make it positive by ln v_1 by v_4. Immediately my commonsense dictates that since the efficiency of a Carnot cycle is 1 minus T_B by T_A so these two things automatically will cancel how can you cancel v_2 by v_3 as v_1 by v_4? You have to write now any manipulations you will have to do now with the process calculations. For this isentropic expansion process 1, 2 what can we write? We can write this if we before writing this I just tell you that these equations will be very important for isentropic process.

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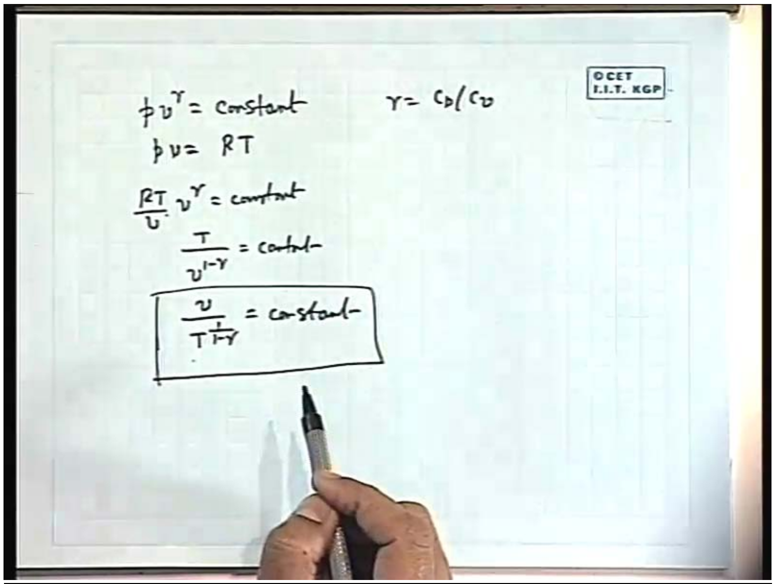

pv to the power gamma is equal to constant that we know for isentropic process performed by an ideal gas pv to the power gamma is constant where gamma is cp by cv it is the very important relation this will never be giving in examination. At the same time we know pv is equal RT, pv and TR related for an ideal gas like that at R is a constant characteristic gas constant this has been told so if you want to know pT and vT relationship we will have to substitute one either p or v which is not required from this equation.

If I want to know the vT relationship p is substituted that means RT by v into v to the power gamma is constant or i can write T by v to the power one minus gamma is constant or one can write v by T to the power 1 by 1 minus gamma is constant. We can write v by T to the power 1 by 1 minus gamma is constant. If I use this relation v by T to the power 1 by 1 minus gamma constant then it will be easier for me because here I want to relate this v.

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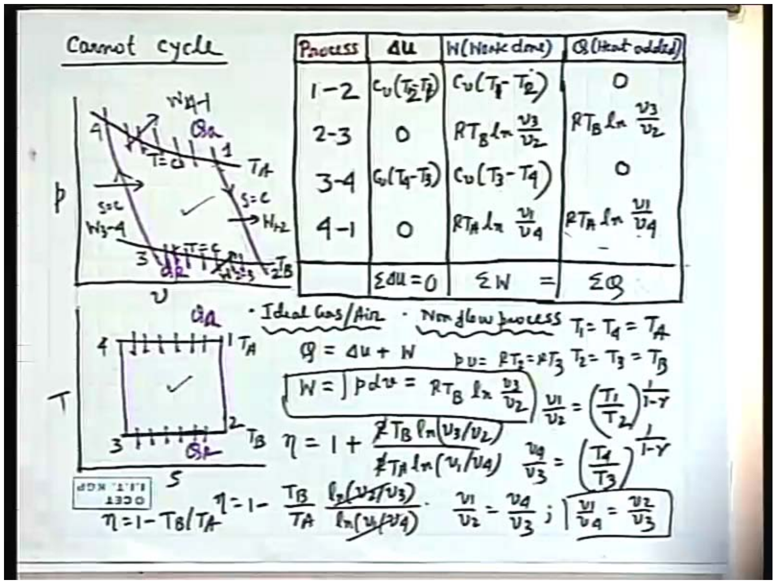

That means I can write v_1 by v_2 is T_1 by T_2 to the power one by one minus gamma. v is directly proportional to T to the power one by one minus gamma. You will have to work out this this you do not have to keep in memory. Similarly I can write for this process v_4 by v_3 is equal to T_4 by T_3 to the power 1 by 1 minus gamma. Now T_1 is equals to T_4 this is an isothermal process. Similarly T_2 equals to T_3 this is an isothermal process that means v_1 by v_{2o} is v_4 by v_3 that means v_1 by v_2, v_4 by v_3 which means that v_1 by v_4 is equal to v_2 by v_3 that means which I want to prove that this equals to this so these two cancels out and I get eta is 1 minus T_B by T_A which is the efficiency of a Carnot cycle that means 1 minus the temperature of heat rejection divided by the temperature of heat addition.

Another interesting feature that when you draw the pv diagram what does this area of the closed loop represent? This represents the work done. Total heat added net heat added net heat added so the area these two are they equal? yes sir yes this because delta u is 0 and the basic first law of thermodynamics is that algebraic sum of the work is equal to algebraic sum of the heat that is the conservation of energy because the system comes to the initial stage where that there is no change in the internal energy this is the Carnot cycle.

Now I will come to Otto cycle. What is an Otto cycle?

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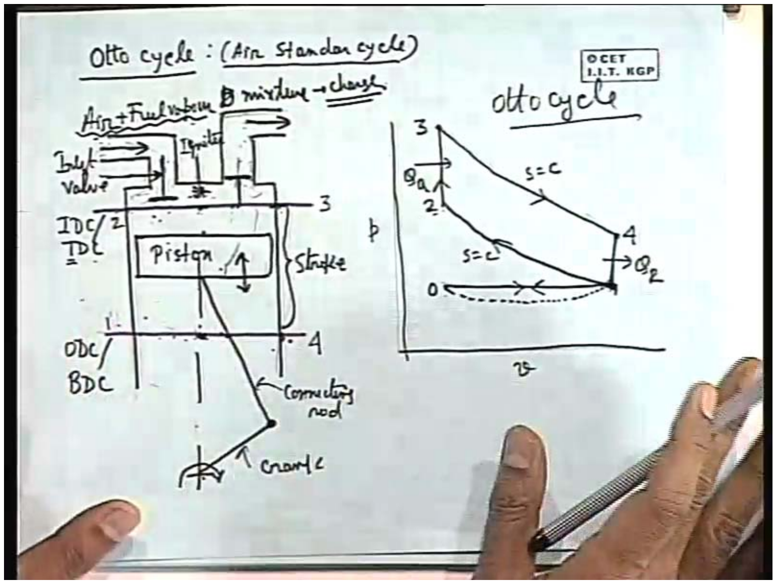

Next is an Otto cycle it is named by Carnot as we have as Sadi Carnot and French engineer Otto cycle is German Otto cycle. Otto cycle is another air standard cycle now I will explain afterwards why a Carnot cycle is not used for any gas power plant but air standard cycle Otto cycle is a theoretical cycle of gas power plant like the Rankin cycle was a theoretical cycle for a steam power plant. Similarly Otto cycle is followed for an automobile engineering automotive engines or automobile engines using petrol as the working fluid that is the petrol engine. You simply call that is a petrol engine and it is known as reciprocating IC engine.

Therefore without going in to any details of reciprocating IC engines reciprocating spark ignition IC engine this is a terminology. We like to know that what of the operations that a reciprocating IC engine performs spark ignition engine performs so that we can understand the cycle just like the way we appreciated the different components of a steam power plant and what are the operation?. For that reason only we just go probably you will know this thing from your popular knowledge that a reciprocating internal combustion engine which work on spark ignition process this is like this.

Let me draw this first the figure then I will explain this is a cylinder piston arrangement and a working fluid performance a non flow process. Let me explain this thing this performance a reciprocating motion this is the center line and this is a connecting rod and crank mechanism. Now there are two extreme positions between which it now thing is like this. This is a piston cylinder arrangement connected with two valves I will explain this afterwards. This is the piston which makes a reciprocating motion within this cylinder and this reciprocating motion is being generated by the use of a rotary motion through a crank and connecting rod mechanism. This is a connecting rod I am not writing everything this is the crank so I can write. This is the mechanical engineers will read connect this is one of the classical mechanism by which the rotary to reciprocating or a reciprocating rotary conversion may be made.

It reciprocates within the cylinder between two limits that means the inner most point and inner most plane to which it can go without heating the head of the cylinder is known as inner dead center position IDC or TDC top dead. So top dead center position the work top is justified when it is a vertical engine that mean it is the top one but IDC goes for both the case horizontal and vertical that means the inner dead center these two are known as dead center inner dead center or top dead center in case of a vertical configuration. Similarly this is ODC Outer Dead Center or Bottom Dead Center if it is a vertical engine so this is the bottom dead center that means between the inner most and the outer most that IDC and ODC the piston makes a reciprocating motion and this length is known as stroke not this length the volume actually this one movement from one dead center to another center is one stroke.

When the piston moves from one top IDC or Top Dead Center one dead center to other dead center either in this direction piston makes one stroke movement that is known as stroke. Now what happens I am telling that, if you start from this piston is at the piston is continuously moving like this in a continuous operation and we get the work done from here.

Now what happens I start from one particular position the piston is at the IDC or top TDC in that means what happens this valve is open this valve is made in such a way that this is opened in this direction. This valve is open and this valve is known inlet valve this is made to open by a mechanism known as cam which is attached to a shaft known as camshaft. Valve is made to open it take some time for a complete opening of the valve. So valve starts opening before the piston reaches the top dead center or inner dead center position that is true.

Before it reaches the inner dead center position valve starts opening but we consider as a when the piston has reached is undead center position valve is wide open. Then what happens when the piston moves down the gas or air. If you consider an air standard cycle it will be air but all usually it is a gas in practice expands which was almost at an atmospheric pressure. That will come back when you will complete the cycle. An atmospheric pressure gas expands because of the increase in volume due to the descending motion of the piston what happens the pressure inside when the piston descending and come here so this pressure inside will be less than the atmospheric pressure because some gases at atmospheric pressure is expanded so its volume is increased so pressure is decreased less than the atmosphere so there is a suction pressure inside the cylinder.

The fresh air from outside this is connected by a pipe line known as intake manifold this is intake manifold these are the usually terminologies so air comes through this intake manifold to this cylinder this is very simple. Most idealized case I am telling there are many things they are filter these that which will be reading in IC engine class so air comes in. When the piston descends down from the IDC due to the suction created within the cylinder the air comes in till the piston goes to the outer dead center position. Therefore this is the condition where you see the pressure goes below and again must comes so pressure is getting ah really equalized try to understand physically this is very important that when the piston goes down the suction is created immediately air comes piston goes down suction is created expansion and air comes.

Air continuously comes as the piston goes down this is approximated in theory to be a process of induction of air it is a process of induction of air at constant pressure that means it as expansion process from some volume which corresponds to the volume of this that is when the piston was IDC to a volume at constant pressure why at constant pressure? Practically it may not be at constant pressure there will be a change in pressure because whenever there is a suction air is coming that means fall in pressure is being utilized by the addition of the fresh mass that is why this is being concept as a be constant pressure expansion and in theory it is like this 0-1.

In practice it is not like that in practice the process is like this initially the pressure goes down initially the suction pressure fall in suction pressure is much more then the induction of the air is in such a way of the pressure is not being utilized and then slowly slowly when the air masses increase inside this the pressure takes up to the atmospheric pressure. It ends up to the atmospheric pressure but we we we approximate this in an ideal cycle or air standard cycle as if a constant pressure 0 one 0 is the starting point here that i will you will standard why I start with 0 not with one 0 one as the expansion process. v1 corresponds to the volume of the cylinder volume of the gas inside the cylinder when the piston is at the outer dead center position.

Now you consider a situation where the valve is closed it is not closing much before there but I am not going in to this practical things there are certain time for closing and opening the valves which are known as valve timing which is being done to get the maximum possible power needed that means heat the iron when it is what type of thing that means you have to open the valve. When valve opening is much more utilized you have to close the valve when the valve closing is much more utilized from view point of the operation of the IC engines that i am not going to describe.

In ideal case let us consider as a as soon as the piston reaches here instantaneously the valve is closed this valve is closed throughout so therefore now the two valves is closed these valves is closed throughout so far we have discussed these two valves are closed that means at this position piston has inducted somewhere that means the cylinder is full of air whose volume is v_{11}.

Now piston when ascends up what happens is air is getting compressed it is a spark ignition engine this is not air fuel vapor. This is not the air this was diesel engine air is being sucked. It sucks an air fuel mixture which is known as charge which mean that the mixture or air fuel vapor which is being inducted to the engine during this descending motion of the piston.

This is one stroke as I have told this trouble is known as suction stroke that before explaining this in this diagram pv diagram I first better explain the what happens actually in this engine when it reaches here after inducting this charge the mixture of air and fuel vapor. When it is full of air and fuel vapor this valve gets closed and this valve is also closed then what happen? Piston goes on ascending and what happen the fixed amount of mass which is the air and mixture of air and fuel vapor known as charge which is getting compressed. When the piston comes to this inner dead center position then some compressed air and fuel vapor mixture is there within this portion of the cylinder.

Whose pressure and temperature is high this is because the compression the piston is insulated during this but no heat is going out or is not allowed to go out so that the charge attains some high pressure and temperature because of the compression by the upward movement of the piston or inward movement of the depending upon the cylinder piston configuration. Then what happens at these pressure and temperature this charge mixture of air and fuel vapor cannot ignites spontaneously this stroke length and the design of the cylinder the cylinder it is designed in such a way that this compression cannot make the temperature as high as required for this spontaneous ignition or burning of fuel vapor with air. Even in the absence of any ignition ignite of source even in the absence of any initiation.

Therefore initiation is requiring by a igniter this is an igniter so which ignites the fuel vapor and air mixture for which the burning takes place. Now this burning is an is an exothermic reaction the fuel is actually an hydrocarbon compound which rapidly reacts with air which is a rapid exothermic reaction oxidation reaction because of which there is a huge pressure and temperature created within this discharge. This thing will be made very clear when I will take the reactive thermodynamics afterwards. This is an exothermic reaction though loosely many people tell that which generates heat or liberates heat that is the wrong terminology which I will make clear afterwards. So exothermic reaction does not mean that liberates heat because the question of heat does not come here.

This is the closed system which is insulated so that no question of heat is there because heat is then energy which is in transit because of a temperature different so therefore this is a exothermic reaction which makes the products of combustion to attain a very high temperature and pressure because of this burning that means the rapid exothermic oxidation reaction of fuel vapor and air.

Therefore a high pressure and temperature is created which gives a high thermal energy this is at form of internal energy form the energy conservation point of view this comes from the chemical energy of the fuel vapor all these things will be made clear in the subsequent chapter which I will describe in this chapter. That is the thermodynamics of reactive system so these high temperature and pressure of the gas pushes the piston downwards. Therefore the third stroke the second stroke is the compression stroke. Third stroke while the piston goes downward or goes outwards expanding this high temperature and pressure mass of the products of combustion products of combustion this the pushes the piston and the piston moves downward this is known as power stroke this stroke we get the power. When the piston comes at the bottom dead center position or outer dead center position then the temperature and pressure both of these charge which was here after burning is reduced pressure is reduced. The volume is increased and temperature is reduced because of the expansion and the work done.

What happens when it is at this position immediately this valve opens and we consider an instantaneous opening in the ideal cycle but it gradually opens it is starts opening even before the piston reaches this outer dead center position or top dead center position these details I am not teaching here. We consider theoretically or ideally as if the valve opens when the piston reaches this ODC that outer dead center or bottom dead center position then what happens some gases are expelled through this manifold or through this duct that means the exhaust duct which is known as exhaust manifold to atmosphere. Then what happen the piston again ascends upward during this upward movement of piston bodily pushes the remaining charge or relatively high temperature and pressure as compared to the atmospheric temperature and pressure through this port through this exhaust manifold to the air.

When piston goes to this portion the pressure air is almost atmospheric pressure there is an equalization of pressure. In fact when the valve is open immediately some charge is expelled and obviously the pressure equalization takes place and when the piston gradually moves up because of the mass going out what happens the pressure inhales the atmospheric pressure. We can consider this as an atmospheric constant pressure at atmospheric pressure discharge so therefore when the piston again comes to this a inner dead center position or top dead center position. It comes to its initial condition that means this volume which is full of charge that is burned products of combustion then again the piston moves downward to start the another cycle.

This way the cycle of events repeat so therefore is see one cycle composites of four strokes that means four movements of the reciprocating motions of the piston from the IDC to ODC and then again the piston when starts descending downward what happens it inducts the fresh charge that is air mixture of air and fuel vapor along with that this charge products of combustion also is there which gets expanded and that causes some other problems which I will not describe here. Now this is the operation which takes place the primary operations which take place in an petrol engine in an internal combustion engine working with petrol this is known as the petrol engine or spark ignition engine. This is because the ignition is initiated by virtue of a spark here.

How do we simulate in ideal cycle?. Ideal cycle what we consider we do not consider air and fuel vapor mixture because when you consider air and fuel vapor mixture you see the first two strokes that is downward and upward stroke the system is the air and fuel vapor mixture but after burning the system constituents change from that of air and fuel vapor to the products of combustion so the system composition changes for the remaining two strokes that means the power stroke, downward stroke and the upward stroke or the inward stroke that is the exhaust stroke in during these strokes two strokes of the cycle the working fluid is the products of combustion.

Therefore this does not truly define a thermodynamic cycle so an ideal thermodynamic cycle define like this, as if air is being sucked by the piston and it is being sucked during the downward or outward stroke during which the pressure remains constant as I explain in the last the class this is because as it goes down the pressure inside falls below the atmospheric pressure. At the same time the air must comes in so these two things equalize the pressure to make it constant at atmospheric pressure and that is being represented by zero one line but in actually case the process is like this by dotted line. Where initially the pressure goes below the atmospheric pressure but the latter part the suction stroke the pressure increases to atmospheric pressure but is simulate this as a constant pressure induction of air.

When the air is pushed in the compression stroke from the outer dead to inner dead center position and when the piston is insulated the ideal process should be isentropic because when the piston is insulated no heat is allowed to flow out side because of the rise in temperature due to compression. This is adiabatic and moreover if you consider the process to be free from any or fluid friction less absence of viscous fluid friction or solid friction then we consider the process to be isentropic. Therefore this part of the curve represents the isentropic s is equal to constant so this is in pv diagram I am drawing the ideal cycle. This point2 represents the state when the piston reaches the top dead center position then when the burning takes place this is very important. When the igniter burns this mixture air and fuel vapor are so thoroughly mixed. Before it is being admitted to the chamber which is done in a device known as carburetor and the fuel which is used is petrol. It is so highly volatile that it is easily made vapor and can be thoroughly mixed with air.

The physical contact is very good and immediately after ignition it releases the heat which is very colloquial term. It makes the combustion complete and the pressure and temperature is instantaneously raised. This type of almost instantaneous combustion which takes place in a petrol engine which is known as a premixed combustion a fuel vapor and air is mixed before and thoroughly and immediately after ignition almost instantaneously the mixture burns. Sometimes colloquial heat is almost instantaneously heat is being generated but heat is not generated but it is immediately burned and raises the pressure and temperature so this process is so instantaneous.

We consider this as a constant volume process in ideal cycle as if with the limitations that during this process of completing the combustion and raising the temperature and pressure of the charge piston gets a little ah downward movement the time for which the downward moment of the piston is very little so that the process is almost complete within a constant volume and moreover we consider in ideal cycle where there is no fuel vapor mix there is air that means this particular burning almost instantaneous burning process is simulated as if piston is fixed at the out inner dead center position and air is heated some from outsource air is heated to raise that temperature at constant volume.

This is the reason for which this burning process in a petrol engine is simulated by an heating process of the air which is the cyclic fluid at a constant volume where heat is being added from outside QA this part is clear to everybody this is the most important part in this cycle. Obviously the power stroke which is the descending stroke or outward stroke from IDC or TDC to ODC or BDC which has to be also an isentropic process 3, 4 ideal case this should be an isentropic process but it is not the isentropic process. This is because the temperature is so high after the burning if you allow the piston to move downward temperature ah decreases relatively less during this descending motion so that the piston material the surface material cannot withstand that temperature.

Effective cooling arrangement is made by passing water through water jacket surrounding this cylinder tube surface from outside this is the actual case but when ideally we will consider this system should not reject any heat to the outside fluid so that we can get the maximum power. It is simulated by an ideal process at s is equal to an isentropic process then what happens again the important part is here that at when it reach is at 4 similar to this outer dead inner dead center position. When it reaches that ODC that means that straight port immediately the valve is open you consider that valve is opened instantaneously.

When instantaneously the valve is open we consider all the hot air which was there after the expansion is expelled through this so that this process is instantaneous and the piston almost remain at the outer dead center position. So this is replaced by the 4, 1 and then we consider as open this instantaneously some hot mass of air immediately is expelled to make this pressure same to the atmosphere pressure that means pressure equalization you make the valve open this pressure difference causes the air to flow so immediately the pressure equalization takes place the air here is at atmospheric pressure and then the piston moves upward to push the remaining part of the air going out of this exit manifold or outlet manifold. This thing happens similar way is simulate in the similar way of the suction stroke or the induction stroke that at constant atmospheric pressure why because when you push this there is a compression so pressure should rise but this an open system that means this is open system means this is going out so have you understand exactly this is an open system the mass is going out so that if we consider it as a close system we can consider it as a constant pressure exhaust that means constant pressure discharge of the air.

This is because the increase in pressure is being nullified by a this is by the exit or air flux or masses the way the decrease in pressure was nullified by the intake of mass so that the inlet admission of the air that is inlet stroke is taking place in this direction zero to one at atmospheric pressure. Similarly the exhaust of the air after the point1when the piston reaches the outer dead center position or bottom dead center position is also simulated by the process one zero they cancel each other. Ultimately we are remaining with 1, 2, 3, 4 process that remain that defines a cycle this is a constant volume I am not writing this is a pv diagram so you see here heat is rejected that means heated is added at constant volume heat is rejected.

In actually practice what happens when the piston descends at this position we keep a sink here where heat is being rejected and this air is coming to point. This thing that means the simulation is like that first of all it is air is being taken in and this is the process 1, 2 the air is taken in here. When we simulate the ideal cycle we just remove this air induction part and the discharge job air part because they two cancel each other so now you think in this way there is a cycle which starts like this there is some amount of air in a closed system it is a close system cycle. Which is first isentropically compressed then after isentropic compression to a volume two that means here I do this way 1, 2 to then at this point keeping the piston fixed at this point we bring a source and heat it to a temperature 3. Then from 3 we allow the piston to come down or come out so that an isentropic expansion is there when it come. This is 3, 2 to3 is the heating then when it comes to 4 then what we do we keep. Then we remove the insulation we keep a heat sink and make an instantaneous heat rejection process at constant volume or it may not be instantaneous it may be a heat rejection process which is made at constant volume because in reversible heat rejection or reversible heat addition will not be instantaneous it will take time but in actual case it is instantaneous so that we can simulate it at a constant volume but when we will explain it with respect to an ideal system with air as the working fluid. We will make that heat sink is there with which heat is being rejected making the volume constant so 4 to 1 so therefore 1, 2, 3, 4 is an ideal cycle.

If you have got any query you tell me and this cycle is known as Otto cycle so Otto cycle is this 1, 2, 3, 4 so I could have started like this there is another way of starting. Let us ah read the Otto cycle or analyze the Otto cycle which compresses of these four processes 1, 2 isentropic compressions in this direction 2, 3 a constant volume heat addition. Where the pressure and temperature is increased and 3, 4 is a isentropic is an isentropic expansion and 4, 1 is a constant volume heat rejection and the working fluid is air so this way I could have started the definition of Otto cycle but I tell you that that this Otto cycle is a theoretical representation or a theoretical cycle of an actual spark ignition or petrol engine. How do you conceive this Otto cycle from the actual operation of the spark ignition engine? Rest part is now a routine part.

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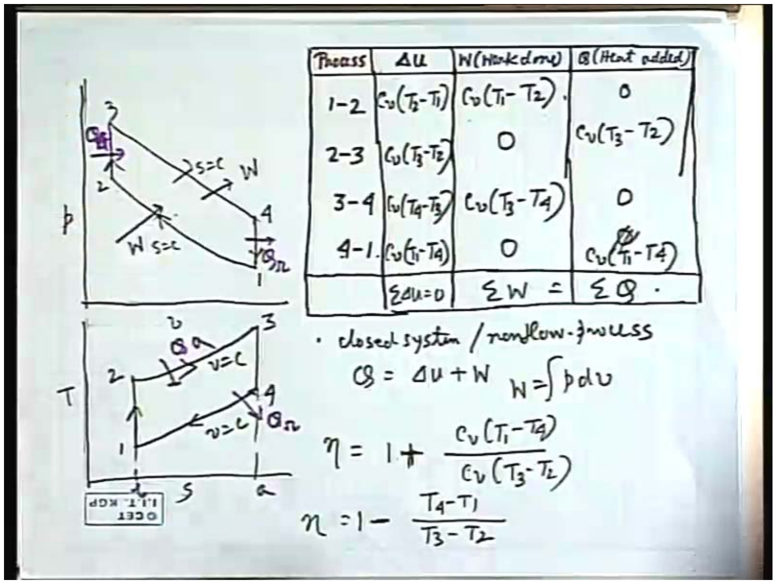

Now I again draw the pv diagram of the Otto cycle before do our routine job so this is like this so doing our routine job so this is 1- 2, 2 -3, 3- 4. This is s is equal to constant this is s is equal constant and we see that heat transfer takes place only in these two process that means in this process heat is added Qa small a also the give and this process Qr heat is rejected. Now we can draw the Ts diagram also because this practice we have developed in Ts diagram what you do 1-2 is the isentropic process which is like this 1, 2 then 2 to 3 is the constant volume process which looks like this in the Ts diagram then 3 to 4 is again an isentropic process and 4 to 1 is the constant volume process. Therefore this is constant volume, this is constant volume, these are isentropic process therefore heat addition is there only in two process this process heat added and this process heat rejected.

The area under 2, 3 this area 2, 3, a, b is the heat added and 1, 4, a, b is the heat reject these are all well known thing so that we can represent this cycle in pvts diagram here hs diagram is not necessary because the ideal gas air is an ideal gas as the working fluid. So enthalpy is nothing but cp in to t. Therefore Ts diagram is enough because there is no difference between enthalpy and temperature it is only a function of temperature like cp in to T directly proportional to T. Therefore enthalpy entropy diagram is not required. Now you go one by one 1, 2 this is s is equal to constant 1, 2 this is the diagram. Now you tell me one by one during 1, 2 process that means the isentropic compression is any one zero which column is zero? Third column then what is did now this is a closed system so again this thing is that closed system that is non flow process this is very important and air as the ideal gas non flow process then we have to write the corresponding first law of thermodynamics that Q is equal to delta u plus W.

Then delta u when Q is 0 W is minus delta u so you have the find out delta u delta uI have told always you write for any process 1, 2 it is cv T_2 minus T_1 there is no doubt so long it is an ideal gas the change in internal energy is cv T_2 minus T_1. Then what is work done so work done is minus delta u so work done is cv T_1 minus T_2 so T_1 is greater than T_2 so T_1 is less than T_2 so it is stated as T_1 is less than T_2 so work is done this negative work is done on this on this system. Then work constant volume process can you tell anything is 0 in this column W_0 so when W is 0 Q is delta u so delta u is same. What is delta u cv T_3 minus T_2 and T_3 minus T_2, T_3 is more than T_2 that means there is an increase in internal energy and since W is 0 Q is delta u. So Q is cv T_3 and that is positive that means heat is added during this process.

3, 4 is synonymous to 1, 2 this is 0 and this will be cv T_4 minus T_3 final minus initial and therefore work done is cv T_3 minus T_4 and here you see T_3 is more than T_4. Therefore this is positive that means work is done on the system. The work is done by the system and there is a change in internal energy which is a decrease because T_4 is less than T_3 the internal energy is decreased. 4, 1 is synonymous to process 2, 3 constant volume why W is 0? pdv work done is 0. What is cv? This is always T_1 minus T_4 this is very simple a child can do that is the final minus initial so this is the process in this direction cvT_1 so heat added is equal to delta u that mean cv same thing T_1minus T_4.

T1 is less than T4 this is negative so heat is added to the system. If you can make this chart everything will be clear so you prove this delta u 0 and delta W is equal to delta Q. Then this part is clear next part we will find out the efficiency of this cycle. Efficiency of this cycle can be defined as 1 plus why I am writing plus because i am using this value so what is heat added? Heat is added during this and heat is rejected during this cv. So this is already negative cv T_1 minus T_4 divided by cv T_3 minus T_2 or I can write 1 minus T_4

minus T_1 divided by T_3 minus T_2. T4 minus T1 if I did do then this is a positive quantity and represents the heat rejection that is why I am writing with a minus sign now so 1 minus heat rejected by heat added so heat rejected is taken in its sign algebraic sign that is why I have written here plus or one can tell that cv T_4 minus T_1 is the heat reject to that is the amount of heat rejected.

We will have to derive this expression in terms of one important parameter which is known as the compression ratio I think time is up for today which I will do for the next class. From here I will derive this expression eta so we will have to make process calculation to express in terms of the compression ratio. I told you because this is an air standard cycle so here you consider air as an ideal gas, If we consider the air fuel mixture I cannot consider the air fuel mixture throughout the cycle so the constituents changes. It does not define the cycle definition. When you come back even if your pressure and temperature remains the same but if you start from this point you come back but the constituent elements that change so you have to do it only one single fluid and air standard cycle does that with a single fluid air as an ideal gas so that is the reason.

How it is model this is beyond the scope of this thermodynamics class. Modeling is not done in thermodynamics. We are studying the air standard cycles only how the air mixture is modeled? but how the air mixture is made in the carburetor? that is the different story. You have to understand that in petrol engine the air and fuel vapor are mixed before the engine and then it is being directed to the engine cellular so this is the practice but I am not going in to any detail of this modeling. We have simulating this cycle with an air standard cycle Otto cycle. Where air is the working fluid there is no air fuel vapor mixture nothing and air is being heated from outside the heat is being rejected with heat transfer to the outside that is the air standard cycle.

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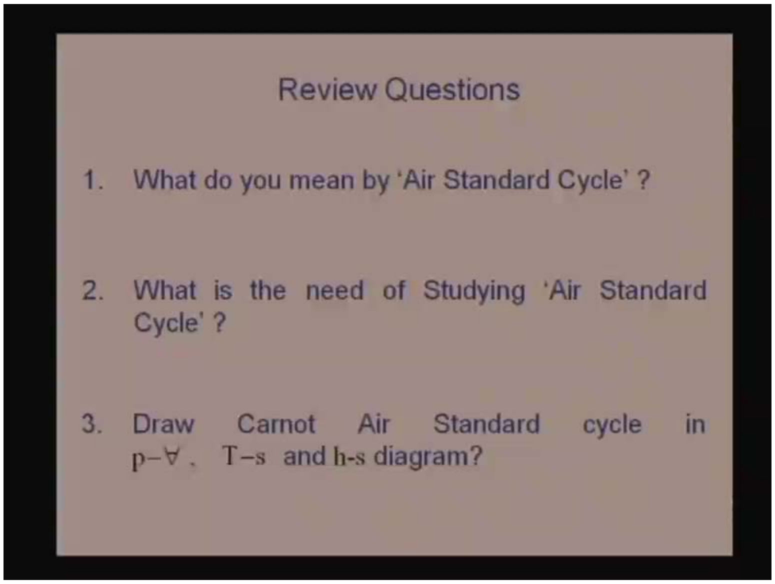

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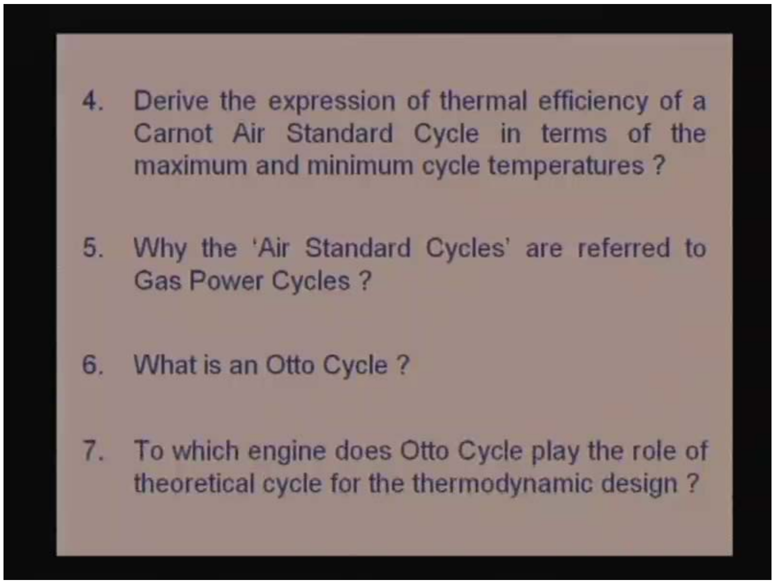

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