IC Engines and Gas Turbines
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Lecture – 06
Otto, Diesel and Dual Cycles (Contd.)

So, we continue our discussion on IC Engine, today in fact we will continue our discussion on Otto cycle. So, today we will try to discuss about the thermodynamic analysis of Otto cycle. So, before I go to discuss about the, you know thermodynamic analysis of Otto cycle, would like to recapitulate whatever you have discussed in my last lecture. So, if it is Otto cycle I mean we have seen that, we have discussed that IC engine first took a IC engine I mean whatever you know processes are there.

I mean it if you would like to map the thermodynamic states at the end of each and every stroke in our thermodynamic plane, we need to consider air standard cycle. And, the air standard cycle with which you know compares the first different processes of the 4 stroke IC engine of the Otto cycle and we have discussed about the you know processes different processes that is you know what are different stroke in tech compression you know power and exhaust in both the P v and T s plane. So, again today we will recapitulate whatever we have discussed in the last lecture.

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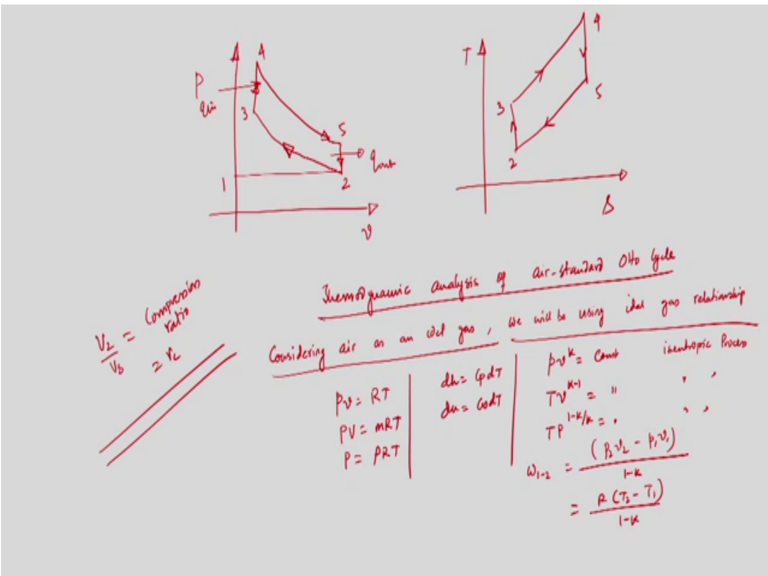

So, I am not going to discuss in details about those. So, this is P v diagram and if you can recall that. So, constant pressure air intake then these are isentropic compression, then a combustion process which is you know what is there in our IC engine that is we need to have spark plug and at the end of the compression we need to switch on the spark plug and combustion in the initiated.

Now, we are considering whether we are mimicking the constant combustion process by constant pressure heat addition process. So, this is constant pressure heat addition process, then again we will have a isentropic expansion that is so this is combustion process isentropic expansion and then constant pressure heat rejection, so this is the process.

So suppose this is process 1 2 then 3 4 5. So, this is heat rejection q out and this is q in which mimics the combustion process. Similarly if we draw a T s diagram then what do you obtain that you know for 2 to 3 isentropic process, then we are having 3 to 4 constant pressure heat addition so temperature will increase.

Then again it is you know isentropic process isentropic expansions and then we will have constant pressure heat reduction so temperature will drop, so this is the process. So, this is 2 3 4 5 so this is the process to 2 to 3 2 3 4 5 I mean in T s plane and this is a P v plane.

So, if you would like to go for thermodynamic analysis. So, today we will discuss about thermodynamic analysis, thermodynamic analysis of air standard cycle rather I can write of air standard Otto cycle is very important thermodynamic analysis of air standard cycle. So, before I go to discuss about the analysis I mean different processes and what the (Refer Time: 04:22) would like to discuss about that we are assuming although it is not a period there will be a air plus fuel mixture, but we are assuming this is an air standard cycle.

So, we will be using ideal gas relationship you know that is very important. So, we will be using while you are going to analyze rather while you are going for thermodynamic analysis of air standard Otto cycle, considering air as an ideal gas will be using although the Otto substance is not pure air, but still make air plus fuel mixture but the fraction of fuel is very less.

So, we will be considering air as an ideal gas and then we will be using ideal gas relationship. So, we will be so considering air as an ideal gas right considering air in ideal gas, then we will be using ideal gas ideal gas relationship. So, considering air as an ideal gas we will be using ideal gas relationship very important. So, if we now what are the relationship that is very important, I am just recapitulating because that that is what you have learned in thermodynamics.

So, that is P v is equal to RT P capital V is equal to mRt P is equal to rho RT then dh is equal to CpdT dv is equal to CvdT then for where (Refer Time: 06:17) pv to the power k is equal to constant, this is for isentropic process. And, this will be equal to T v to the power k minus 1 is equal to constant again for isentropic process TP to the power 1 minus k by k is equal to constant for isentropic process. And, work done w 1 2 that will be p 2 v 2 minus p 1 v 1 divide by 1 minus k that is equal to R into T 2 minus T1 divided by 1 minus k.

So, these are the real sense if we will be using while, we are going to discuss about the thermodynamic analysis of a air standard Otto cycle whatever maybe Otto and diesel cycle.

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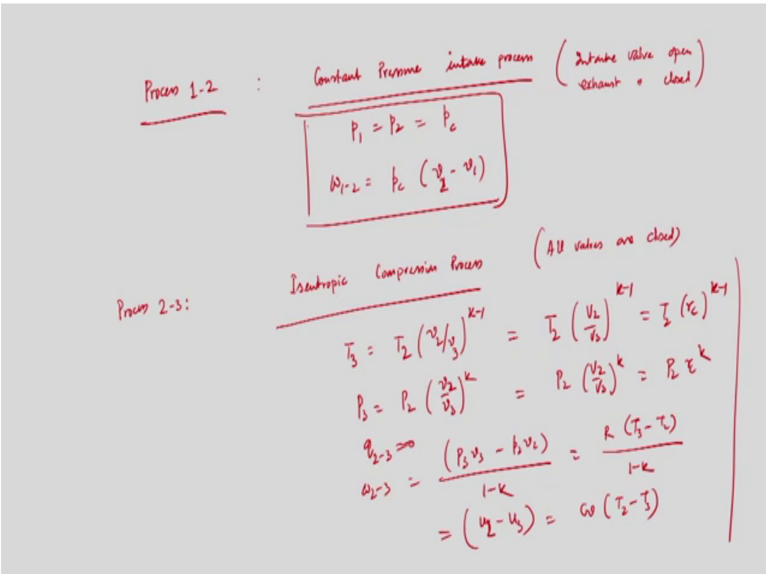

So, now we will discuss systematically, suppose if we discuss a process 1 to 2 process 1 to 2, why are doing because you need to know what is the efficiency. We are providing some energy in because where supplying fuel, so only to have only to have a mathematical expression for the mathematical expression for the thermodynamic efficiency of the cycle we need to do this analysis. So, process 1 to 2 if you can recall that is you know that constant pressure intake process. So, constant pressures so constant pressure constant pressure intake process right, so that is p 1 is equal to p 2 right.

So, whatever it is I mean constant pressure let us say this is p constant and w 1 to 2 that will be equal to p pc into v 1 minus v 2 or v 1 minus if we go back, so this is v 2 minus v 1 v 2 minus v 1. So, this is for process 1, similarly if we go back for if we go for process 2 to 3 what is the process 2 to 3 is isentropic compression. So, this is isentropic compression process this very important isentropic compression process that is what is on all valves are closed right. So, this process one to 2 intake valve open intake valve open exhaust close for process 2 to 3 all valves are closed. So, what I can write so T2 process T2, so T2 is equal to T3 very important v 1 by v 2 to the power k minus 1, whereas having AR has an ideal gas and we are using ideal gas relationship.

So, T2 is equal to T3 into v 2 v 1 as v to the power k minus1. So, that is equal to you know T1 sorry T2 equal to T1 sorry 2 3 I am writing 2 3. So, T3 will be equal to T2 into v 2 by that will be v 2 v 2 by v 3 to the power k minus one that is T2 into v 2 by v 3 to the power k minus 1 that is what is the 2 by v 3 if we back the previous slide v 2 by v 3 is the compression ratio. So, here V 2 by V3 is equal to compression ratio that is rc. So, this is very important this is compression ratio V 2 by V 3 is equal to r c is equal to compression ratio.

Now so isentropic compression process T 3 is equal to T 2 in to v 2 by v 3 to the power k minus 1 that is T 2 into r c k minus 1. So, that is T 2 into r c to the power k minus 1. So, this is the process T 3 isentropic compression process all the valves closed fine. Now question is in this process we need to do some work, so work done so I mean no heat interaction and P3 is equal to P2 into v 1by v 2 v 2 by v 3 to the power v 2 by v 2 the power k is equal to P2 into v 2 by v 3 to the power k that is P2 into r c 3 to the power k it is very important.

Isentropic process so q 2 to 3 is equal to 0 no heat interaction, but w 2 to 3 is there that that is what will w 2 to 3 that is p P 3 minus P 2 v 2 y it is very important that is you know P 3 v 3 minus P 2 v 2 divided by 1 minus k, that is equal to R T 3 minus T 2 divided by 1 minus k. So, this is as good as u 1 minus u 2 minus u 3 minus u 2 that is sorry that is u u 2 minus u 3. So, C v into T 2 minus T 3 so we are using all the ideal gas relationship while we are calculating the pressure temperature at the end of the compression stroke. So, at the end of the compression strokes we are calculating temperature pressure and work done because no heat interactions. So, P 2 3 is 0 and for that way utilizing the idea gas relationship.

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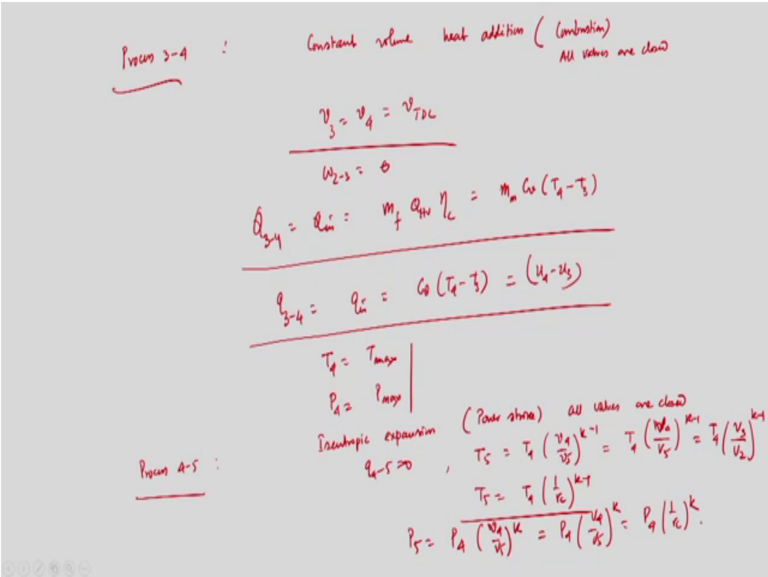

So, next is process next is process 3 to 4 and that process is you know that process is constant process heat addition that mimics the combustion process. So, constant pressure heat addition that is very important heat addition; so this process is constant pressure heat addition that is combustion right and again all valves are closed all valves are closed.

So, again you need to know the pressure constant pressure on change sorry this is constant volume I am writing constant volume sorry this is constant volume heat addition process this is constant volume not constant pressure constant volume heat addition process. In assigning combustion process is you know by a constant value heat addition process is not constant pressure, so volume will be same but we need to calculate pressure.

So, v 3 you know v that is v 3 is equal to v 4 is equal to v TDC is very important because, volume at dc work done w 2 3 constant volume set it will be 0. But we need to calculate heat addition, so Q 2 to 3 that is equal to Q in that is because of combustion process. So, that will be equal to m dot you know m dot f calorific Q H v heating value into eta c.

So, very important that the Q sorry Q 3 to 4, so this is Q 3 to 4 Q 3 to 4 is equal to Q in is equal to mass flow rate of well heating value into combustion efficiency that equal to m dot m mm into C v into T 4 T 4 minus T 3. So, this is the Q in but small q 3 three to 4 that equal to what that equal to q in that will be equal to C v into T 4 minus T 3.

So, this is essentially u 4 minus u 3, so this is the heat addition in the combustion process and this T 4 is equal to T max that is that can be seen from Ts diagram and P you know 4 is equal to P max. So, this is this is process 3 to 4 that is constant value heat addition process fine. Then process 4 to 5 what is process 4 to 5 if we go back to my previous slide then it is see process 4 to 5 having isentropic expansion.

So, if it is isentropic expansion then of course we can write what again we need to calculate pressure and temperature T 3 is equal to T max P 4 is equal to P max that is what we obtain, then process 4 to 5 each you know isentropic power expansion strokes. So, this is isentropic expansions power stroke all valves are closed right and then q 4 5 is equal to 0, because isentropic process that is important T 5 is equal to T 4 into v 4 by v 5 to the power k.

So, k minus 1 so that is equal to T 4 into T 4 into v 4 v 4 by v 5 to the power k minus 1, so v 4 by v 5 if you go back to see v 4 is equal to what v 4 is equal to v 3 and v 5 v 5 is equal to v 2. So, I can write T 4 into v 4 is equal to v you know 3 by v 2 to the power k minus 1, so that T 5 equal to T 4 into one by r c to the power k minus 1 because v 2 by v 2 is equal to r c that is what you have written v 2 where v 2 is equal to rc.

So, now this is the temperature at the end of the expansion stroke power stroke. Now what is P 4 P 4 again P 4 is equal to sorry P 5 P 5 is equal to P 4 into v 4 by v 5 to the power k. So, that equal to P 4 into v 4 by v 5 to the power k, so v 4 by v 5 is equal to as I said 1 by rc, so v 4 by 1 by r c to the power k.

So, these are the pressure and temperature at the end of the expansion stroke that is the power stroke, no heat interaction isentropic process we are considering we are taking assumptions. But the pressure and temperature we are calculating using the ideal gas relationship. So, we have a different pressure and temperature at the end of the expansion stroke fine. Now, another process is constant volume heat rejection.

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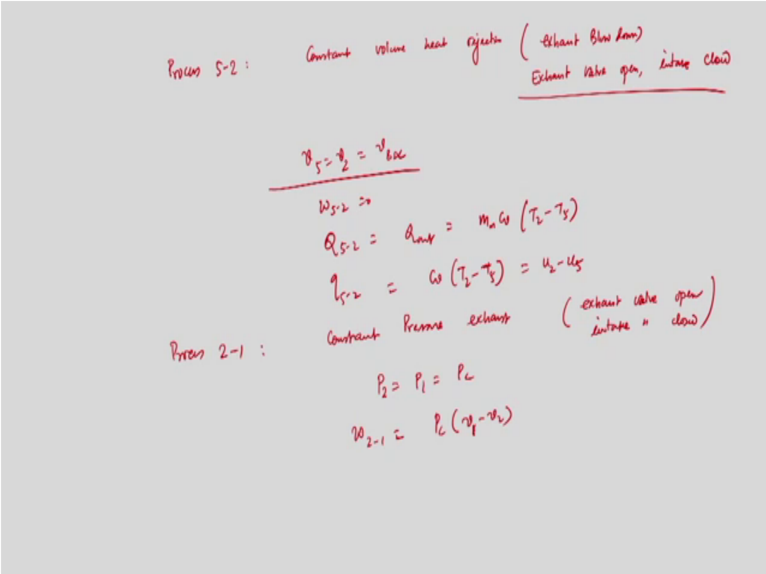

So, that is process 5 to 6 process 5 to 6, so if we go back to my previous slide process sorry process 5 to 2. So, process 5 to 2 is process 5 to 2 each constant volume heat rejection the constant value heat rejection. So, I mean again what you know that exhaust valve open integral close, so this is a this is exhaust basically exhaust blow down and exhaust valve open in tech close.

So, this is the process so now is constant volume process, so work done will be 0. So, v 5 is equal to v 2 is equal to v BDC this is there. Now w 5 to 2 equal to 0 w 5 to 2 will be equal to 0 and Q 5 to 2 that will be equal to Q out that will be equal to mm C v into T 5 minus T 2, because temperature of the 5 is higher than temperature of the 4 sorry T 2 minus T 5.

If we go back to the so T 2 minus T 5 minus T 2, so that should be T 5 minus T 2 and Q 4 5 you know T 2 C5 m dot m C v into T 5 minus T 2. So, q 5 to 2 that will be equal to C v into T 5 minus T 2 T 5 minus T 2 that is equal to I mean this is exhaust valve exhaust go down. So, that is equal to that is equal to u 5 minus u 2 right.

Now last is you know Constant pressure exhaust, so that is constant pressure exhaust Constant pressure exhaust is 4 4 minus 5 that is T 5 minus T 4 T 5 minus T 4 that is T 1 minus T 4 that is T1 minus T 4 fine. So, that is this will be m dot C v into T 2 minus T 5 and this will be equal to T 2 minus T 5, so that will be equal to u 2 minus u 5 that will equal to u 2 minus u 5. So, that will be equal to u 2 minus u 5.

So, now process 2 to 1, that is non-constant pressure exhaust, constant pressure exhaust right. So, exhaust valve open intake valve close then P 2 is equal to P 1 is equal to Pc that is what we discussed and w p w P 2 to 1 2 to 1 w 2 to 1 that will be equal to pc into again v 1 minus v 2 v 1 minus v 2 this is work done. So, if we go back v 1 minus v 2 so this is the work done. Now we need to calculate the efficiency that is how would I make efficiency of the Otto cycle. So, thermal efficiency of the Otto cycle will calculate now, it is very important for that we are doing this analysis.

So, we have calculated pressure and temperature at the end of each and every strokes and for that we have used ideal gas relationship and using ideal gas relationship we have calculated pressure and temperature holding you know at the end of the, at the end of each and every stroke. Then we have we also have calculated work done or what is the heat input or what is the heat output from the during combustion and exhaust blow down process.

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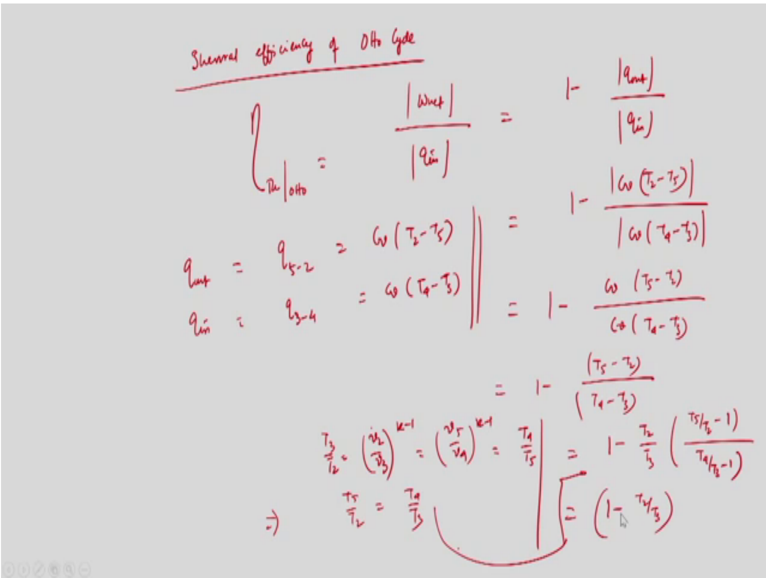

Now, based on this information we can calculate the thermal efficiency of the Otto cycle. So, thermal efficiency of Otto cycle the thermal efficiency of the Otto cycle eta thermal of Otto will be equal to w net by q in networker put by net input that is equal to 1 minus q out divided by q in this is important. So, what is q out from the side from that you know we have calculated q out is q 5 to 2 that is equal to C v in to T 2 minus T 5 C v into T 5 T 2 minus T 5 right. That is q 5 to 2 that equal to C v into T 2 minus T 5 and q in q in is equal to C v into T 4 minus T 3 equal to C v into T 4 minus T 3 so 3 to 4 q 3 to 4.

So, if I plug in the value of q out and q in these expressions, so what you are getting 1 minus C v into T 2 minus T 5 and by C v into T 4 minus T 3. So, 1 minus C v will get cancelled out. So, C v into T 5 minus T 2 divided by C v in to T 4 minus T 3 just am writing the positive because T 5 had done T 2. So, I am writing this, now so it is 1 minus T 5 minus T 2 divided by T 4 minus T 3 this is this is what we are getting right T 5 minus T no that is we are getting.

Now T 2 by T 1 is equal to T 3 by T 4. So, you know T 2 by because T 2 by T one is equal to T 2 T 3 by T (Refer Time: 24:29) whether what is T 2 by T 1 T 2 by T one and T 3 T 4. So, if I go back to my previous slide where we can see the T 2 by T 3 and T 4 by T 5 that is the temperature we are getting and that is clearly seen from the Ts diagram. So, we are having T 5 T 2 and T 4 T 3. So, what we can write what we can write that you know T 2 by T 1 that is that is that is T 3 by T 2 that is T 3 by T 2 is equal to what is equal to v 3 by v 2 v 3 sorry v 1 by v 2 v 1 by v 2 to the power cup k minus 1.

So, what is v 1? v 1 is essentially not v 1 v 2 by v 3 sorry I am writing, so that is v 2 by v 3 to the power k minus 1 what is v 2 v 2 is from P v diagram v 2 is v 5 and v 3 is v 4. So, I can write that is v 5 by v 4 to the power k minus 1, so that is that is what that is equal to you know T 4 by T 5 T 4 by T 5.

So, if we rearrange so from P v diagram we can see that T 2 by T is equal to v 3 v 2 by v to the power k minus 1 v 2 equal to v 5 and v 3 is equal to v 4 that is clearly seen from the P v diagram. So now, if we rearrange what we can obtain that you know so if I again go one step further from the expression of eta thermal. So, one can we can write that you know what we can write that T 1 by T 2 is very important T 1 by T 2 that is you know T 2 by T 3.

So, 1minus T 2 by T 3 into T 5 by T 2 minus 1 divided by T 4 by T 3 minus 1. So now, from this expression I what we can right T 5 by T 2 will be equal to T 4 by T 3, so essentially these 2 expressions are equal. I mean if I plug in the if I plug in this value of expressions we get 1 minus T 2 by T 3.

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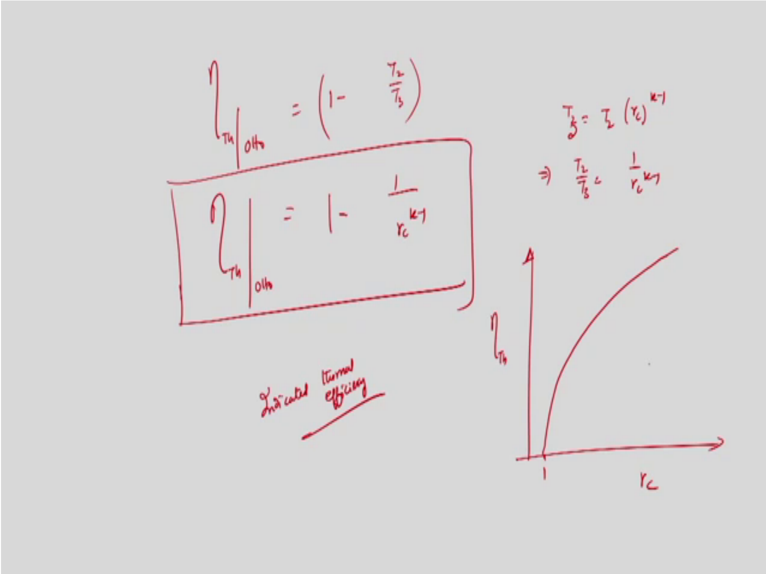

So, if I write that eta thermal Otto is equal to 1 minus T 2 by T 3 1 minus T 2 by T 3 very important 1 minus T 2 by T 3. So, what is 1 minus T 2 by T 3, so 1 minus T 2 T 2 by T 3 you know what is that. So now, T 2 by T T 2 you know if we go back to the process 2 to 3 process 2 to 3, then T 3 is equal to T 3 is equal to T 2 into r c to the power k minus 1.

So, we have seen that T 3 is equal to T 2 into r c to the power k minus 1, therefore T 2 by T 3 is equal to 1 by r c to the power k minus 1. Therefore, expression is 1 minus 1 by r c to the power k minus 1. So, this is the thermal efficiency of the Otto cycle which essentially a function of compression ratio of the engine, so 1 minus r c in to the power k minus 1.

So, from these expression we can see that only the compression ratio needed to determine the recent Otto cycle, as the compression goes up thermal efficiency goes off this efficiency is not indicated thermal efficiency as heat transfer value is are not as the heat transfer values are those and those 2 and from the air within the combustion chamber. So, what we can see that if compression ratio is increased so if we plot now this into thermal efficiency.

So, if we plot that r c and if you plot the eta thermal, so from this expression it is clearly seen that if we increase compression ratio of the engine then efficiency of Otto cycle efficiency will increase. So, it will keep on increase may be from 1 it will be 1 and then it will keep on increase I mean with increasing the compression ratio. So, it will keep on increasing with the compression ratio.

So, this is the efficiency thermal efficiency of the Otto cycle, but this is known as Indicated thermal efficiency this is indicated thermal efficiency this is not break thermal efficiency. And, this is break thermal efficiency as the this efficiency is indicative thermal efficiency this is not break thermal efficiency, why because heat transfer values are those 2 and from the air with in the combustion chamber.

So, we have we did not consider heaters for loss, so I mean heat transfer of values are those as the heat transfer values are those to and from the combustion chamber from the air within the combustion chamber. Heat transfer values are from are those to and from the air within the combustion chamber. So, this is indicative thermal efficiency this is not the break thermal efficiency.

So, we have calculated so we did this analysis thermodynamic analysis only to have the mathematical expression for efficiency that the thermal efficiency of the Otto cycle, we have you know calculated the efficiency of the Otto cycle. And, we have seen that the efficiency of the Otto cycle or the thermal efficiency of the Otto cycle is a function of compression ratio.

So, if we keep on increasing compression ratio then efficiency will increase, but we cannot increase compression ratio to a certain limit that is that is we will discuss later because, if you would like to increase compression ratio then I would discuss that the engine cylinder has to be thicker so engine weight will be increased. So, our with increase in compression ratio although the efficiency of the Otto cycle will increase, but we cannot increase arbitrarily beyond a particular point and this efficiency is not the beak thermal efficiency this is not a indicated thermal efficiency.

Because, the heat transfer you know as a heat transfer values are those you know to and from the air within the combustion chamber so and see again I am telling this is we have while, we have when we are calculating this efficiency we have taken so many assumptions that the processes isentropic expansion isentropic compressions. But still you are having pulling out pulling out a pulling out a jacket around the periphery of the cylinder. So, we will always have heat transfer from the combustion chamber to the coolant or vice versa.

But always will have heat transfer from the initial into the coolant, but those who expect who did not consider as we are calculating efficiency and that is why it is indicated thermal efficiency not the break thermal efficiency. So, we have understood that it pushed IC engine I mean we are approximating engine is a you are approximating, this is I mean while we are calculating the work while you are interested to calculate efficiency rather than the thermodynamics state that each and every at the end of each and every strokes.

We need to consider I mean air standard cycle. So, we are calculating we are approximating the different processes using an air standard cycle and this is the absolute cycle which is known as Otto cycle which you know compares the different processes in the cycle I mean compress a different process in a 4 stroke IC engine. So, from that considering yes motorcycle we have calculated the pressure and temperature at the end of each and every stroke and for that we have considered you know different ideal gas different relationship following ideal gas relationship you know considering air as an ideal gas.

Because in reality walking substance is not a purely air, I mean there will be a mixtures although this assumption is not very bad assumptions because the faction of air will be very the faction of value very small. So, we can may we can consider air I mean as an ideal gas and following that air standard ideal gas relationship we have calculated temperature and pressure and using that we have calculated this efficiency. But, this is the air indicated thermal efficiency and we have seen that with increasing compression ratio efficiency will increase, but we cannot increase compression ratio we have a particular limit.

So, with this I stop my discursion today and we will continue our discussion on details right in the next class.

Thank you very much.