IC Engines and Gas Turbines

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Lecture – 8
Otto,Diesel and Dual cycles (Contd.)

So, we will continue our discussion on IC engine and today again, we will discuss about Diesel cycle, Otto cycle, Diesel dual. We have discussed about the Otto cycle. The ascended cycle which is you know used to approximate you know different processes in our for stroke cycle SI engine is the Otto cycle. Last class, we have discussed about the you known diesel cycle which is the extended cycle which is used to you know represent the represent different processes in a four stroke cycle diesel engine. And we have quantified the thermal efficiency for the diesel cycle and we also discussed that Otto cycle is known as constant volume cycle while combustion process is represented by constant volume process while diesel cycle is known as constant pressure cycle where the combustion process is represented by constant pressure process.

So, if we try to recall that we have seen that efficiency of the diesel cycle that are thermal, thermal efficiency of the diesel cycle can be written 1 minus that is ah, we did not do a few steps.

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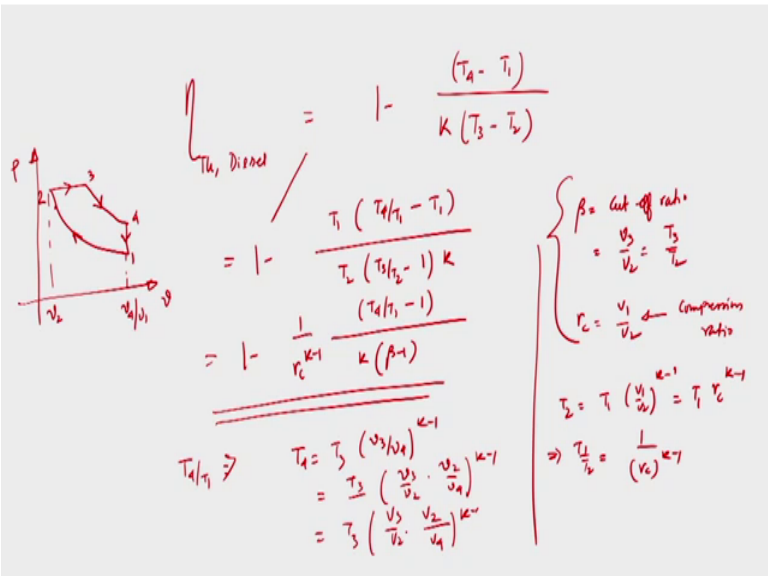

So, to arrive the final expression, rather I can write the you know final you know the expression of the you know efficiency of the thermal efficiency of the diesel cycle is 1 minus T 4 minus T 1 if I by T 3 minus T 2 into K, into K. So, I discuss that if you do more steps, a few more steps, then I will be able arrive at the final expression which is nothing but 1 minus 1. So, rather instead of you know writing the final expression of the diesel cycle, let us first let us try to you know do that steps, I mean so that we can arrive at the final expression.

So, you know that we have define a few terms that is you know beta is the cut off ratio which is known as cut off ratio that is the change in volume in the you know combustion process that is constant pressure heat addition process and that is very important that is known as v 3 by v 2. So, beta is equal to v 3 by v 2 is equal to T 3 by T 2. Similarly, compression ratio r c that is defined as the you know volume v dc or volume TDC that is v 1 by v 2.

So, that is what we have defined that is equal to T 1 ah, that will write in terms of you know I will ideal relationship say fine. So, can we write the efficiency thermal efficiency of diesel cycle in terms of this two parameter that is cut off ratio and the compression ratio. So, this is the compression ratio. If I try to recall that the PV diagram that T 4 would be equal to I mean so, I can do a few more steps, so that we can arrive at the final expression; 1 minus T 1 into T 4 by T 1. I can take T 1 outside and divide by again I can take T 2 outside, T 3 by T 2 minus 1 into K. So, you know T 1 by T 2 is so, T 2 if I use that process 1 to 2 was the isentropic compression process. So, T 2 is equal to T 1 into v 1 by v 2 to the power K minus 1 that is equal to T 1 into r c to the power K minus 1 that is what I have written.

So, therefore, T 1 by T 2 will be equal to 1 by r c to the power K minus 1. So, I can straight away write, 1 by T 1 by T 2 is equal to 1 by r c to the power K minus 1 into T 4 by T 1 minus 1 divide by K into T 3 by T 2 is equal to beta. So, this is beta minus 1. So, I have to write now T 4 by T 1 minus 1 in terms of cut off ratio and the compression ration. How can I write it and for that again, we need to do a few more steps. So, this is the expression but still it is it contains the temperature ratio T 4 by T 1. So, if I now T 4 by T 1, I can write T 4 by T 1 that is very important things because I have to write T 4 by T 1 in terms of beta and r c.

So, T 4 by T 3 is what because if I can recall that the if I try to recall the PV diagram over here, then process 1 to 2 was process 1 to 2 was like this, then 2 to 3 was combustion process that constant pressure process and this was 4. So, this is 1, this is 2, this is 3, this is 4. So, this v 2 is the v TDC and v this is V, this is P. So, this is v 2 and this is v 4 or v 1. So, this is v v dc. So, now, T 4 will be equal to that is isentropic expansion process 3 to 4 is isentropic expansion power stroke.

So, T 4 is equal to T 3 into v 3 by v 4 to the power K minus 1, that I can write right. So, now, I can rearrange this term T 3 is equal to v 3 by v 2 into v 2 by v 4 to the power K minus 1 or I can write T 3 into v 3 by v 2 into v 2 by v 4 to the power K minus 1.

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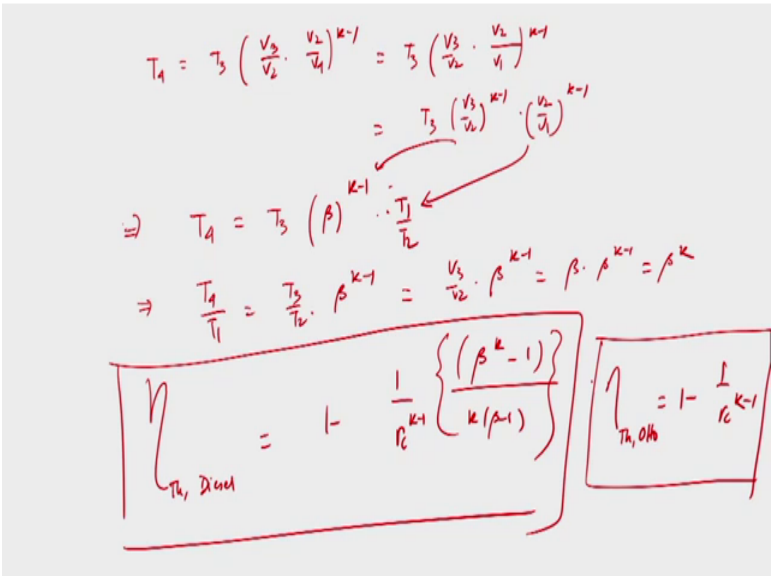

Now, question is, if I go to the next slides that is T 4 is equal to T 3 into v 4 by v 4 by sorry v 3 by v 2 into v 2 by v 4 ah, v 3 by v 2 into v 2 by v 4 to the power K minus 1. Now, question is what is v 4? So, if I look at the PV diagram v 4 is equal to v 1 that is v v dc.

So, I can write that T 3 into v 3 by v 2 into v 2 by v 1 to the power K minus 1. This is what is so, I can write it T 3 into v 3 by v 2 to the power K minus 1 into v 2 by v 1 to the power K minus 1. So, what is v 2 by v 1 to the power K minus 1, right? So, T 3 is equal to now therefore, I can write T 4 is equal to T 3 into v 3 by v 2 is equal to v 3 by v 2, T 3 into v 3 by v 2 is equal to beta. So, beta to the power K minus 1 into v 2 by v 1 is equal to what? v 2 by v 1 to the power K minus 1 is equal to is equal to T 1 by T 2, is equal to T 1 by T 2.

So, this is T 1 by T 2 and v 3 by v 2 is equal to beta to the power K minus 1. Therefore, I can write T 4 by T 1 is equal to T 3 by T 2 into beta to the power K minus 1. What is T 3 by T 2, it is if I go back to my previous slide T 3 by T 2. What is T 3 by T 2? T 3 by T 2 is equal to v 3 by v 2 into beta to the power K minus 1 that is beta into beta to the power K minus 1 that is beta to the power K. So, if I replace the value of T 4 by T 1 in the expression of thermal efficiency, so I can obtain the final expression eta thermal diesel equal to 1 minus 1 upon r c to the power K minus 1 into beta to the power K, beta to the power K minus 1 divide by K into beta minus 1. That is what we have we wrote last class, but without doing this intermediate steps. So, without doing this intermediate step straight away we have written the final step that the thermal efficiency of the diesel cycle can be written in terms of compression ratio and the cut off ratio.

Now, question is, if I compare and that is what I have discussed that if we compare this efficiency with the efficiency with the efficiency of Otto cycle where efficiency of the Otto cycle that are thermal efficiency of the Otto cycle, thermal efficiency of the Otto cycle is equal to 1 upon 1 upon r c to the power K right; that is 1 upon 1 upon 1 by r c to the power k. So, this is very important that thermal efficiency of the Otto cycle is basically 1 upon 1 1 by r c to the power K minus 1, K minus 1, not K. So, if I compare these two efficiencies I mean Otto cycle and diesel cycle that we have seen that the beta is always 1, K is always 1. So, you know the quantities in the bracket term is always greater than 1.

So, for a given compression ratio efficiency of the Otto cycle will be higher. Since, the compression ignition engines whether diesel engines are normally having higher compression ratio. So, the efficiency of the diesel cycle would be higher. Therefore, for a given compression ration since the quantities given in the bracket is always greater than 1. So, for a given compression ratio, efficiency of the Otto cycle will be always higher , but since the you know diesel engines are having you know by higher compression ratio. So, the efficiency of the diesel cycle will be you know will be higher than the Otto cycle and that is why, constant pressure combustion you know constant volume combustion , constant volume combustion is more efficient than the constant pressure combustion that is what we have written.

So, for the given compression ratio efficiency of the thermal efficiency of the Otto cycle will be higher than the diesel cycle. So, constant volume combustion is more efficient than the constant pressure combustion. That is what we have discussed in the last class. But since, diesel cycles are operated at a higher compression ratio. So, efficiency of the diesel cycle will be higher. Now, question is you know another important term is that if these two equations are compared, then you have seen that engine an ideal engine should be of compression ignition engine, but should operate with the Otto cycle. Why because , you know logical squared straight forward that since Otto cycle is very higher efficiency and compression ignition engines are normally have a higher compression ratio.

So, an ideal engine and engines should be operated ideally rather our engines should be ideal a compression ignition engine and should operate with Otto cycle. And that is why, you know that the you know is very important that the now recent ,you knowmodern diesel engines is very important that the modern high speed CI engines that diesel engines are you know accomplishes this by doing a little change in the you know little change in the operating system. How? So, that again I am repeating; since auto cycle efficiency will be higher than the diesel cycle while for a given compression ratio. On the other hand, since CI engines are having higher compression ratio, so efficiency of the diesel cycle will be higher.

So, an engine should be ideally a compression ignition engines and that would operate with the Otto cycle. So, that is why modern high speed CI engines are modified by changing their operating you know partly rather by simple by a part changing their simple operator that the operation principle; that means, high speed, modern high speed CI engines are you know operating with a little bit change in their operating system by how. You know that, we have seen that in a CI engine what is done that we have seen that you know, we are utilizing the high pressure and temperature there are condition of high pressure temperature of the compressed air, so that the whenever fuel will be injected and it combustion will start. And that is why, a combustion starts late at the compression stroke only to take into account the ignition delay. I mean it is not possible that the whenever piston will be reaching at the TDC and if the moment at whenever piston reaching the t dc, if you start injecting fuel combustion will be completed it would not be the case. Because there will be a some amount of ignition delay and although it is of the order of millisecond, but still it is a finite time required to have a final spray button of the fuel. It comprising the chemical delay as well as the physical delay.

So, to take that effect into account, what is done is that you know fuel is sprayed when piston is little bit away from the TDC and an combustion last even when piston is coming you know travelling from TDC towards BDC and that is why volume is remaining no longer constant rather we assuming the pressure is remaining constant. So, since volume is changing little bit so, pressure is remaining constant that is that was a good approximation. Now, question is instead of assuming that if we change a little bit change in the operating system; that means, instead of injecting fuel late at the compression stroke rather, if the fuel is injected late may be when a little bit away from the I mean tdc may be it around 20 degree below TDC.

So, whenever fuel is injected, the injected fuel first part of the injected fuel will be the you know combustion will be you know completed whenever piston is reaching the TDC; that means, if you start injecting the fuel in a CI engine, when piston is little bit away from TDC that is you know 20 degree below TDC. So, by that time when piston is reaching at TDC, that time the first injected fuel will start combustion rather combustion will be completed. So, as if whenever piston is reaching at the TDC that is volume is remaining constant, so, part of the combustion is completed at the constant volume process and the remaining part of the combustion will be completed when pistol is again traveling back from TDC towards BDC and pressure will remain constant. That is what we assume for a CI engine. So, our idea is that, since efficiency of the Otto cycle is always higher than the diesel cycle for a given compression ratio. On the other hand, CI engines are normally having higher compression ratio. So, an ideal engine should be a compression ignition engine and that would operate on a Otto cycle; that means, if we that is why modern high speed CI engines are you know operated with a little bit change in their operating system by how.

So, we are injecting fuel little bit away from TDC which is you know 20 degree higher from TDC. So, first part of the fuel whenever injected; that means, when by the time when piston will be reaching at TDC, the first part of the fuel being injected will complete the combustion rather the combustion is competed at constant volume. I mean whenever the pistol is reaching at TDC that they volume is remaining constant. So, the first part of the combustion is completed when piston is at TDC that a constant volume process while remaining part of the combustion will completed when again piston is coming back from TDC rather away from TDC and that time, we cannot say that the volume remain constant that or their pressure remains constant. So that means, if we assume that the part of the combustion or the first part of the combustion is completed at a constant volume process and the remaining part of the is completed at a constant pressure ah, at constant pressure in the cylinder; that means, we are breaking up the entire combustion part of the combustion is completed at constant volume and part of the combustion is completed at the constant pressure. So, we are utilizing the constant volume combustion and as I said you, that the constant volume combustion is more efficient than the constant pressure combustion. So, we may have higher efficiency that the diesel engine and we can have the total combustion.

Since, part of the combustion is completed at constant pressure and part of the combustion is completed at constant volume and this is known as dual cycle; that means, this is very important that what is dual cycle? So, analysis of you know this is very important that analysis of a CI engine which is done using an extended cycle where part of the combustion is completed constant volume and part of the combustion is constant is completed at constant pressure is known as dual cycle. So, dual cycle is an air standard cycle which you know represents the you know processes of a CI engine where entire combustion is completed into two parts; first part is at constant volume and second part is at constant pressure.

So, now we will need to do and we need to see what is a dual cycle and how we can quantify the thermal efficiency of a dual cycle. So, the concept of dual cycle is coming from the fact that the efficiency of Otto cycle is always higher than the you know CI engine a diesel cycle for a given compression ratio. On the other hand, since compression ratio CI engines are operated with a higher compression ratio, of course, a compression is efficiency of the diesel cycles should be higher. So, an ideal engine should be a CI engine which would operate on a Otto cycle. And for that, the concept of dual cycle coming where we are splitting the entire combustion process into two parts; first part is occurring at constant volume process while the remaining part is occurring at the constant pressure process.

So, now we would like to see what is the you know dual cycle.

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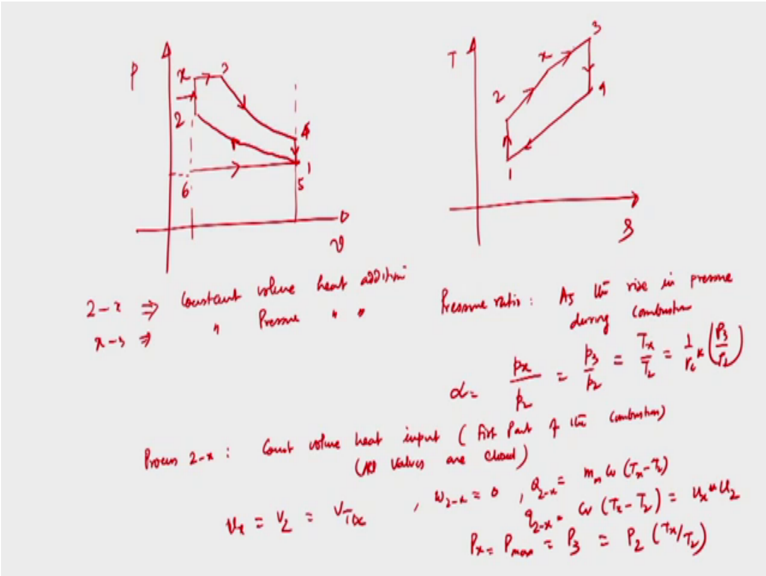

Rather if a CI engine is operated on a dual cycle which is now you know most of the modern high speed engines a CI engines are you know operated on a dual cycle. So, if I draw the PV and PV diagram. So, this is PV diagram and we have to draw the corresponding T S diagram. So, this is T and this is S diagram. So, again I am saying that you know this is the process, may be constant pressure air intake. Then, what is done a very important that you know air is compressed may be this is process 6 to 1. So, this is process 6 to 1.

So, this is process 6 to 1, and then, so this is process 6 to 1. 1 to 2 is the isentropic compression, 2 to 3 is the first part of the combustion which is occurring at the constant volume; that means, in your CI engine fuel is injected when piston is little bit away from the TDC that is 20 degree below TDC. That means, by the time when piston is reaching the TDC, the first of the fuel being injected into this will complete their combustion that is at constant volume. Volume is remaining constant because piston has reached the TDC and the remaining part of the combustion is completed when piston is again traversing back from TDC that is constant pressure.

So, 2 to 3 is the constant volume combustion and 3 to 4 is the constant pressure combustion. This is very important and then again we are having isentropic expansion and then this is this is 3 to 4 and 4 to 5 , 5 to 1 is exhaust slow down right. So, sorry, so, this is let us say this is point x. I do not know this is point x and this is 0.3 and this is

0.4 , 3 to 4 is isentropic expansion and 4 to 1 is exhaust slow down and or I can say 4 to 5 and 5 to 6 is the exhaust stroke.

So, if I draw the corresponding TS diagram, process 1 to 2 is the isentropic process say entropy will remain constant, then process 2 to 3 2 to x is a constant volume heat addition process. So, temperature will go high, that I do not know. And again, x to 3 is again constant pressure heat addition. So, again temperature will go high, but you need to know the slope. So, this is 3, may be 3 and then 3 to 4 is again isentropic process and then you know 4 to 1 is the ah, 3 to 4 is isentropic process and you know 4 to 1 is exhaust slow down right 4 2 1, this is 4 2 1.

So, this is 1 to 2. So, this is the PV and TS diagram for a dual cycle. Why it is dual cycle because the combustion is completed, combustion is split into two parts; first part is 2 to x has constant volume heat addition. So, 2 to x is constant volume, heat addition; the combustion is represented by constant volume heat addition that is that represents dual cycle and that represents the Otto cycle while x to 3, constant pressure heat addition is constant pressure heat addition. Now, one ratio is defined here; pressure ratio.

So, just like a CI engine, you have defined cut off ratio change in volume, but here we are defined on pressure ratio. What is pressure ratio? Pressure ratio is defined the ratio of the as a rise in pressure during combustion. So, this is defined as the rise in pressure, rise in pressure during combustion, during combustion. So, what is this alpha? That is p x by p x or p 3 is the peak pressure. So, p x by p 2 that is the and that is equal to p 3 by p 2, that is equal to t x by T 2. So, I can write it in terms of compression ratio that is 1 upon r c to the power K minus sorry K into p 2 by p into p 3 by p 1, into p 3 by p 1. Because t x sorry that is alpha that is known as pressure ratio. So, now, we have to analyze thermodynamic analysis to have a quantification of the thermal efficiency.

So, as a rise in pressure during combustion is pressure ratio that is defined by alpha p s by p 2 that is equal to p 3 by p 2. So, p 3 by p 2 is equal to that is equal to what is you know p 3 is equal to p x is equal to T x by T 2. So, that is equal to 1 by r c into p 3 by p 1, if I do some I will get this expression if I do some you know some analyze I mean if you do a few more steps, fine. So, now, question is you know process 2 to x very important process process 2 to x is, what is process?

So, we have to analyze first process 2 to x 1 to 2 is very important process, but process x to 3 very you know straight forward. So, only thing we need to know that heat input and heat output. So, process 1 to 2 is very straight forward process I am not going to analyze. So, now, we will write process 2 to x. So, process 2 to x is a constant volume heat input, that is first part of the combustion. So, as I said you, this is constant volume heat input. First part of the combustion right, first part of the combustion.

So, all valves are closed, all valves are closed fine, valves are closed. So, how can I, so v x is equal to v 2 is equal to v TDC is fine. What is w 2 to x, constant volume is 0, but what is Q 2 to x? So, Q 2 to x equal to m m c v into T x minus T 2 that equal to or I can write small q 2 to x is equal to c v into t x minus T 2, t x minus T 2. So, that is u x minus u 2, that is u x minus u 2. And p x is a maximum pressure p x is equal to p max is equal to p 3 right is equal to p e is equal to p 2 into t x by T 2, that is what I have written p x by p 2 is equal to t x by T 2. So, p x is equal to p max is equal to p is equal to t x by T 2.

So, this is the process 2 to x, constant volume heat addition that is the first part of a combustion here pressure ratio is defined. As a rise in pressure during combustion that is p x by p 2 is equal to p 3 by p 2 is equal T x by T 2. If you do a few more step , it is highly possible to arrive at that expression that 1 by x into p 3 by p 1, fine. So, next process is, I did not do the analysis of process 1 to 2 process 1 2 is straight forward process 6 to 1 again straight forward I did this analysis for again for the you know Otto cycle and diesel cycle. Again we are assuming here to be an ideal gas and we are using the ideal gas relationship to obtain the pressure and temperature at each and every at the end of each and every stroke fine.

Now, process, very important process x to 3.

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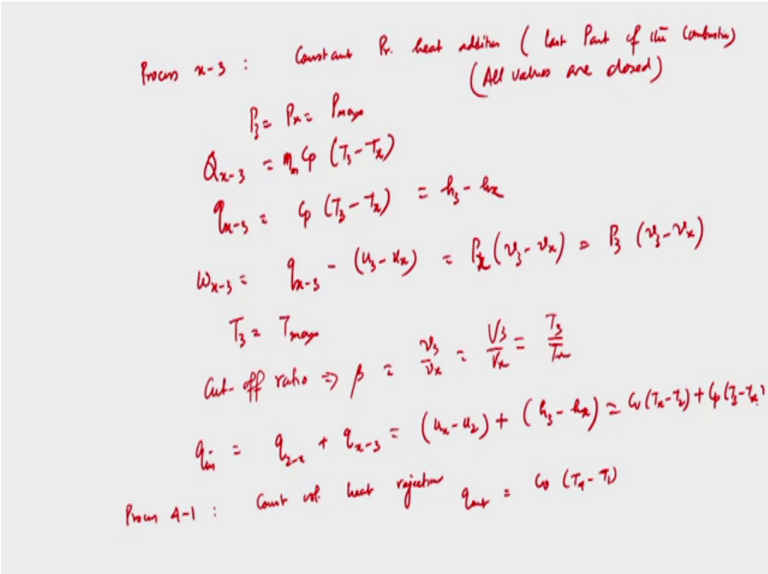

So, process, process x to 3 is constant pressure heat addition, constant pressure heat addition and it is second part of the combustion or last part of the combustion, last part of the combustion. So, what is I said you p 3 is equal to p x is equal to p max is maximum pressure. What is Q x 3 ? Q x 3 is equal to c p into m mass load of mixture into T 3 minus t x, right.

So, q x 3 small specific that is equal to c p into T 3 minus T x right that is equal to h 3 minus h x. What is work done? w x 3 this very important constant pressure process not constant volume process. So, that will be equal to q x 3 heat addition minus u 3 minus u x, minus u 3 minus u x is equal to what? So, q x is equal to work done plus u 3 minus u x that is equal to p 3 is equal to p max into v 3 minus v x, change in volume. So, that is you know that is equal to for p x into or equal to p 3 into v 3 minus v x because p x and p 3 are equal. So, this is v x. So, there is w x 3 and T 3 if you go back, this is T max.

If we go back to my previous slide it is written that T 3 is a maximum temperature in the cycle. So, fine we have obtained that 3 is equal to T max. So, constant pressure heat addition again, all valves are closed, all valves are closed. So, both the valves are remaining closed fine. Either define that cut off ratio. So, cut off ratio is again you have to define for this case. Cut off ratio there is change in volume beta is equal to what beta is equal to v 3 by v x is equal to capital V 3 by V x is equal to T 3 by T x , so T 3 by T x.

So, this is a cut off ratio. So, what is the net heat input in the system? That is what you need to know because ultimately you have to calculate the thermodynamic efficiency. What is the heat input? What is the heat input in the system. So, total heat input q in that is constant volume process first constant pressure process. So, c v into, that is q 2 to x plus q you know x to 3 at constant first part of the combustion plus second part of the combustion. So, that is equal to u x minus u 2 plus h 3 minus h x , h 3 minus h x. So, here u x minus u 2 is the heat addition in the first part of the combustion where h 3 minus h x is the heat addition in the second part of the combustion that is q 2 to x q x 3 that is that is very straight forward fine.

So, how can I now calculate efficiency because heat output from a system is straight forward. What is the heat output from a system? Now, process 4 to 1 is the process 4 to 1 that is constant volume heat rejections, constant volume heat rejection that is what we have drive in the last class. So, what is it q out will be equal to c v into T 4 minus T 1, constant volume addition constant volume heat addition; so, c v into T 4 minus T 1.

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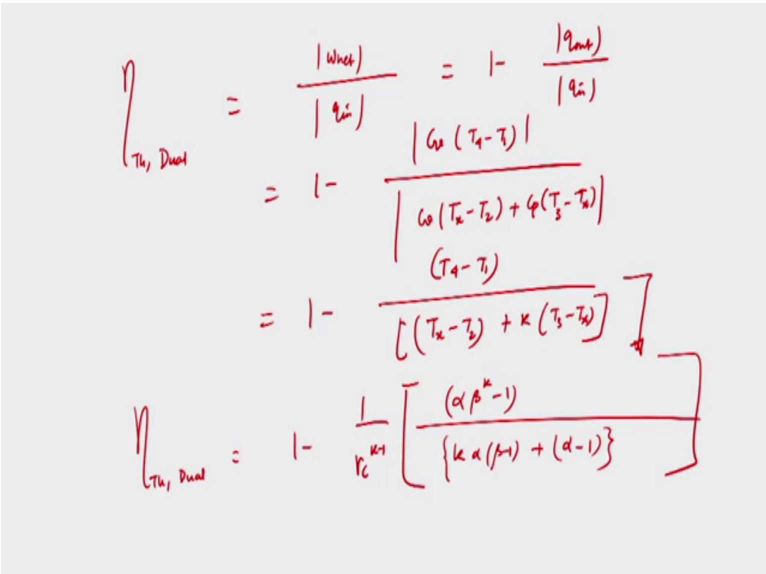

So, now, if I write the thermal efficiency of the system, so, what will be the thermal efficiency of the dual cycle? What is the thermal efficiency of the dual cycle; very important? So, what is, so, w net by q in, w net by q in that is the thermal efficiency of the diesel cycle a dual cycle sorry. So, that will be equal to nothing but 1 minus q out divide by q in.

So, what is q out? 1 minus c v into T 4 minus T 1, then divide by, what is q in is very important you have to write what is q in. So, what is if I go back to my previous slide, what is q in u x minus u 3 that is so that is what is c v into T x minus T 2. So, that is c v into T x minus T 2 plus c p into T 3 minus T x. So, if I write it that, c v into c v into is very important T x minus T 2 T x minus T 2 plus c p into c p into T 3 minus T x. So, this is the heat input to the system while heat out of the system is c v into T 4 minus T 1. So, if I do a few more steps; that means, I can write T 4 minus T 1, right T 4 minus T 1 divide by T x minus T 2 plus c p by cv is equal to K into T 3 minus T x.

So, this is the final expression K into, after a few re arrangements if you do a few more steps that is what I did the first half of my lecture for the diesel cycle that mean if you do a few more steps only to have some manipulation, only an in terms of some different temperatures, we can write the efficiency thermal efficiency of dual cycle in terms of cut off ratio and pressure ratio. However, the final expression for the thermal efficiency of the dual cycle can be given 1 minus 1 upon r c to the power K minus 1 into what is a first term is very important, alpha beta to the power K minus 1 divided by you know, K into alpha into beta minus 1 plus alpha minus 1. So, this is the thermal efficiency of the dual cycle.

So, I can come from this step to this, I can come from this step to this steps and for that we have to do a few more steps, we have to do we have to do a few re arrangement and eventually we will arrive at the efficiency of the dual cycle will be 1 minus 1 upon r c to the power K minus 1 into alpha to the power beta, alpha beta to the power K minus 1 divide by this quantity. That means, we have established the efficiency of the dual cycle in terms of compression ratio, cut off ratio and the pressure ratio fine. So, now, question is; that means, we have seen. So, we have first we have discussed about Otto cycle where the combustion process is represented by a constant volume process.

Second, we have discussed about the diesel cycle where we have represented the combustion process by a constant pressure process, we have seen by comparing the efficiencies of Otto and diesel cycle we have seen that the efficiency of the dual cycle is always higher than the diesel cycle for a given compression ratio. But since the compression ratio compression is sorry a efficiency of the diesel is Otto cycle is already higher than the diesel for a given compression ratio, but for the diesel cycle that are for the compression since the compression ignition engines are having higher compression ratio as compared to that of the you know SI engines, then efficiency of the diesel cycle will be always higher. And keeping that in mind it is suggested that an engine ideally should be a CI engine because it is having higher compression ratio, it should get higher compression efficiency, but it would occur in the Otto cycle because Otto cycle is having higher efficiency than the diesel cycle for a given compression ratio.

So, whatever is the compression ratio, Otto cycle will always give the higher efficiency. That is why constant volume combustion is more efficient than the constant pressure combustion. Considering that aspect, modern days, modern high speed CI engines are operated using a little bit change in their you know operational precedure operating cycle by how , that is what I have discussed that what we what is done during the combustion process for a CI engine, fuel is injected when piston is late part of the compression strokes; that means, piston is very close to the TDC only to taking to account the ignition delay that is the physical delay chemical plus chemical delay. But instead of doing so, if we ignite fuel when piston is little bit away from TDC, that is 20 degree below TDC so that the first part of the fuel being injected or introduced into the cylinder will combustion of that first part of the fuel being introduced or injected in the cylinder will be completed whenever piston will be reaching at the TDC.

That is, as if the first part of the combustion is competed at the constant volume because piston is reaching at TDC while the second part of the last part of the combustion will be completed when piston is again travelling back from TDC towards BDC and by these, we can split the entire combustion into two parts; first part is the constant volume combustion and second part is the constant pressure combustion.

Since, we are having a constant volume combustion in this cycle and constant pressure combustion cycle we are calling it dual cycle that is we are having dual combustion and we are since, we are having constant volume combustion, so efficiency of the dual cycle should be higher because it as I said you the constant volume combustion is more efficient than constant pressure and we have seen how we can represent the you know pressure volume that you know change in pressure volume in the during the in a engine cylinder during different stroke you have PV diagram as well as the TS diagram and from, there we have tried to quantify the thermal efficiency of the dual cycle and for that we have tried to quantify we did not discuss about a few processes like process 6 to 1, process 1 to 2 because these are straight forward process. Similarly, process 3 to 4 because we have discussed this process in the context of I discussed in Otto cycle as well as a diesel cycle, but here two important process of process 2 to x that the first part of the combustion when volume remaining constant, while second part of the combustion is the you know x to 3 that is constant pressure combustion where pressure is remaining constant and we have included in both these processes, we are having heat input to the system.

So, we have quantified total heat input of system. On the other hand, process 4 to 1 is the heat rejection process exhaust slow down. So, we have quantified that what is the heat ejected from the system and doing this, we have quantified the thermal efficiency and we have derived the expression of thermal efficiency in terms of different temperature. But, if you do a few more steps, then we will be able to arrive at the final expression in terms of compression ratio, cut off ratio and pressure ratio. So, with this, I stop here today and we will discuss that the for a given compression ratio, if we could try to compare the efficiency of all these cycles, then we will be able to show that the efficiency of the Otto cycle is greater than the dual greater than diesel and if you consider that because compression so, while you are comparing considering the same compression ratio, then would be able to show that the efficiency of the dual diesel Otto cycle is greater than dual greater than a diesel. But, compression ratio is not same for all the cases. So, compression ratio will be changed. So, that is why you know considering same compression ratio is not a ideal case rather you can consider same peak pressure and for that we will be able to show that efficiency of the diesel cycle greater than dual greater than Otto. So, with this I stop here discussing today and I will continue our discussion in next class.

Thank you.