IC Engines and Gas Turbines

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Lecture – 09
Comparison between the cycles, Actual cycles and their analysis

So, we will continue our discussion on IC engine. Today, we will discuss about a comparison between the cycles that whatever I mean that we have discussed in my last lectures the Otto cycle and Diesel cycle and dual cycle. And, at last we will discuss about that when we talk about actual cycles I mean we have approximated different cycles like Otto cycle, Diesel cycle and dual cycle using air standard analysis rather we have invoked air standard analysis only to have a mathematical contribution of thermal efficiencies.

So, we will now to see that the process which is occurring in a real engine, real internal combustion engine maybe is not actually same what we have approximated in a air standard analysis while we are trying to obtain the mathematical expression of thermal efficiency.

Now, before we go to discuss about the difference between the approximations, I mean maybe we will discuss that the while we are approximating different cycles using an air standard you know cycle maybe Otto cycle, dual cycle and Diesel cycle. And we are approximating that ok, fine whatever processes are there in internal combustion engines are represented by you know isentropic compression, then constant volume heat addition, constant pressure heat addition, then isentropic compression and constant volume blow down. Those processes are not exactly same I mean what is there in a real internal combustion engine.

And, since these are approximations and sometimes this approximations leads to you know some error while we are calculating thermal efficiencies so, that means, while we are doing rather while we are calculating thermal efficiency of a cycle from a using an air standard analysis maybe we are under estimating the thermal efficiencies and that is what we discuss in detail today. So, before go to discuss about those aspects let us first discuss about our comparison of thermal efficiencies of different cycle of different cycles.

You know that we have discussed that Otto cycle, dual cycle and Diesel cycle for we have discussed that for a given compression ratio efficiency of the Otto cycle is higher than the Diesel cycle and also we have discussed that since the compression ignition engines I mean CI engines are normally operated at a higher compression ratio of course, compression ignition engine will have higher efficiency compared to the SI engines.

But, and that is why we have commented that the constant volume combustion is more efficient than the constant pressure combustion and for that in a dual cycle I we have seen that the entire combustion process is splitted into two different parts. First part that are, first part of the combustion is approximated by a constant volume heat addition, while the second part of the combustion is approximated by a constant pressure heat addition. And, we have calculated thermal efficiency through a rigorous mathematical analysis.

So, without going into, rather without going into the again mathematical analysis of a you know thermal efficiencies of different cycles only from of P-v and T-s diagram would like to have a qualitative comparisons of thermal efficiencies of different cycle.

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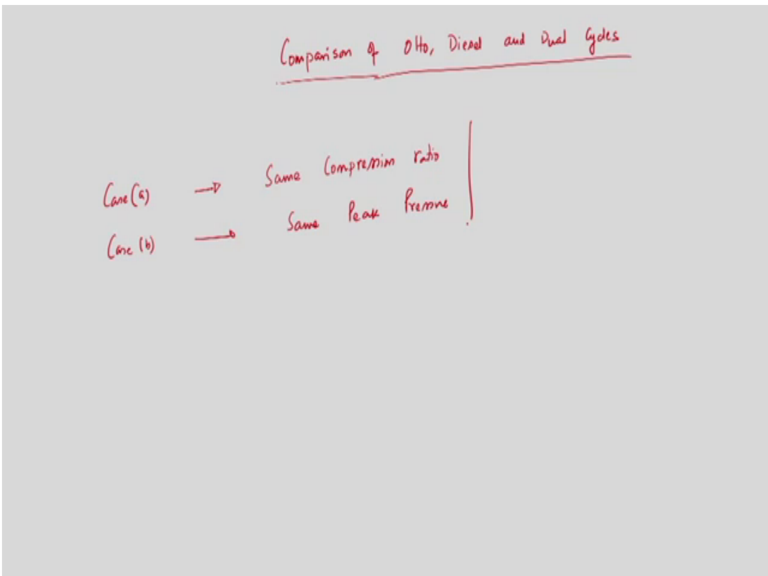

So, today we will discuss about comparison of Otto, Diesel and dual cycles . So, we will do this. So, now, again I am telling without looking into the mathematical expression of thermal efficiencies of Otto cycle, Diesel cycle dual cycle here we will try to quantify of course, qualitatively the order of efficiencies of different cycles only form a P-v and the corresponding T-s diagram.

So, while doing so we need to have, you know while we had trying to have a qualitative comparison between Otto, dual among Otto, dual and Diesel cycles we should have a common basis for the comparison; I mean we cannot have a comparison without having an common basis. So, that means, I would like to say that without looking at the mathematical expression of thermal efficiencies of different cycles just only having a look at P-v and corresponding T-s diagram we can quantify rather we can have a qualitative you know estimate of the thermal efficiencies of different cycles rather we can predict the order of you know efficiencies of order of thermal efficiencies.

And, to do that we should have a common basis for comparison. So, as a common basis for comparison we might have two different cases. As a first we have two different cases as a first case rather case a. So, while we are having comparison of Otto, dual and Diesel cycle to have a common basis for comparison as a first case we have same peak pressurise same peak pressure sorry same compression ratio for all three cycles I mean Otto, Diesel, Otto, Diesel and dual and for a second case; case b we have another common basis for comparison that is same peak pressure.

So, these two are the common basis. For the first case while we are trying to have a qualitative estimate of the order of efficiencies of three different cycles we will keep constant that I will keep the compression ratio is same for all three cases as a second case we will keep we will consider that the peak pressure is same for all three different cases. So, now we I like to discuss the first case that is when compression ratio is given in same for all three cases.

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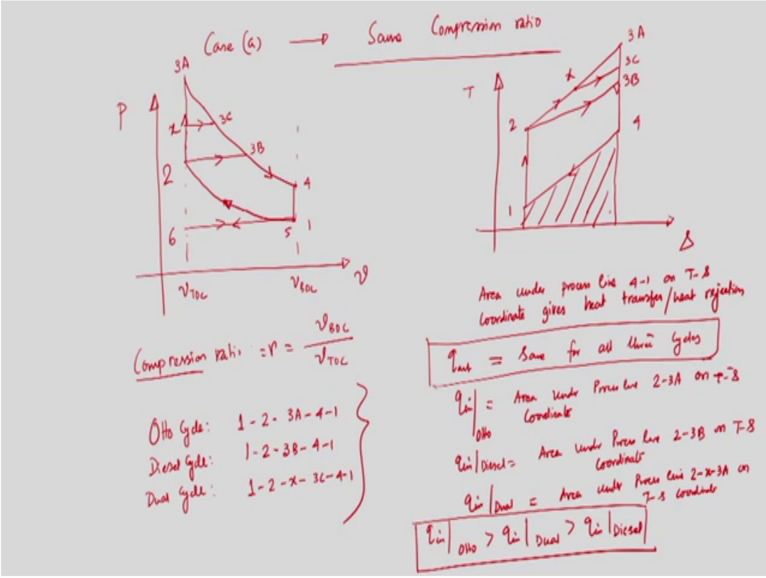

So, if we consider case 1; case a that is same compression ratio. So, for the same compression ration if you like to draw if you like to obtain the thermal efficiencies of Otto, dual and Diesel cycles we have to draw P-v and T-s corresponding T-s diagram, since we are not interest to look at their mathematical expression of thermal efficiencies. So, if I try to draw P-v and T-s diagram. So, this is the P and v diagram. So, compression ratio will remain same.

So, I mean what is compression ratio I will let me discuss again. Compression ratio we have discussed very beginning of this course that is compression ratio that is r equal to v BDC by v TDC. So, while you are trying to have a compression keeping compression ratio is same for all three different cases or three different cycles we need to ensure that the compression and expansion will take place between the same compression ratio that is v BDC and v TDC is fixed for all three cycles.

If that is the case let us first draw the so, this is v TDC and this is v BDC. So, this is the air intake process, let us say process I mean process is 6 to 1, that air intake process at constant pressure next process is you know isentropic compression. So, this is isentropic compression. So, maybe process 1 to 2 is isentropic compression. Then we have a Otto cycle that constant volume heat addition, combustion is represented by constant volume heat addition. So, maybe this is the peak pressure. Then we will have isentropic expansion, then we will have isentropic expansion and then this is constant volume blow down or rejection.

So, maybe this is 3A that is Otto cycle. So, if the compression ratio is remaining same for do Diesel cycle then maybe this is 3B that maybe this is 3B, this is the Diesel cycle and if it is a dual cycle then a part of the combustion is completed at constant volume process. So, maybe this point is x and this point is 3C and this is 4 this is 1. So, if I right over here that the Otto cycle Otto cycle that is 1 2 3A 4 1 and finally, 1 to 6 is the or 5 to 6 if it is 5 to 6 is the exhaust constant pressure exhaust. So, 1 2 3 41 they are Otto cycle.

Then if I try to plot Diesel cycle, what is Diesel cycle? 1 2 3B 4 1, this is a Diesel cycle and next is a dual cycle. Dual cycle is 1 2 x 3C 4 1. So, these three are different cycles that what you have plotted in a P-v diagram. If I would like to plot corresponding T-s diagram that is a very important diagram from there we should have, I mean you know qualitative estimate about the thermal efficiencies of three different cycle that is what we have plotted in P-v diagram. So, this is T-s diagram.

So, now, question is 1-2 is a isentropic compression that is therefore, for every cycles that is you know Otto, Diesel and dual whatever it is that that is there every cycles. So, process 1 to 2 is process 1 to 2 is isentropic compression. So, this is 1-2, this is isentropic compression then of course, 2 to 3A; 3A is a peak pressure of course, temperature will be higher. So, this is 3A. So, this is 3A and then we first draw the Otto cycle you know processes you know Otto cycle we have drawn in P-v diagram corresponding processes we will draw in the T s diagram. So, 1, so, this is 4, this is 3A. So, 1-2-3A-4 that is the Otto cycle that is what we have seen in P-v diagram. So, this is the corresponding T-s diagram.

Now, 2x; so, this is x, then 3C and then this is 3B. So, 3B-1-2-3B-4 because temperature at point 3B should be less than temperature point 3C this is the you know point from where you can draw the corresponding T-s diagram. So, we have drawn.

Now, question is we have seen rather we have discussed that the area under the process line in T-s diagram gives the heat transfer. So, similarly what we can see area under process line 4-1 gives the; process line 4-1 in on T-s coordinator T-s diagram on temperature entropy coordinate gives heat transfer error heat rejection from the system. So, what we can see that for all three different cycles we have plotted in P-v and T-s diagram process 4 to 1 is the exhaust or rather blow down constant volume blow down. So, if you try to draw the area under the process line 4-1 on T-s plane so, then this will give the heat rejected from the system.

So, what we can conclude from this diagram that the heat rejected from the system is remaining same for all three different cycles. Since process 4-1 is same for all three different cycles. So, maybe q out is same for all three cycles, but q in that is heat being added into the system that is different for three different cycle. From this T-s diagram we can see that q in is the area under process line 2 comma 3A on T-s coordinate, on T-s area under process line 2 to 3A on T-s coordinate, this gives the heat being added into the system for Otto cycle. So, this is for Otto, similarly q in for Diesel is equal to area under process line, 2 comma 3B on T-s coordinate and q in for dual is equal to area under process line 2 comma 2 stroke x stroke 3A, 2 dash x dash 3 a on T-s coordinate.

So, what we can see from this that the heat rejected from all three different cycles is same, but the heat being you know included, rather heat being added into the system because of the combustion is different because area under the process lines are different in the T-s diagram. So, we can say that q in dual is less sorry q in Diesel or q in Otto is greater that q in dual greater than q in Diesel. So, this is the case. So, q in Otto greater than q in Diesel dual greater than q in Diesel but, q out is same for all three different cycles.

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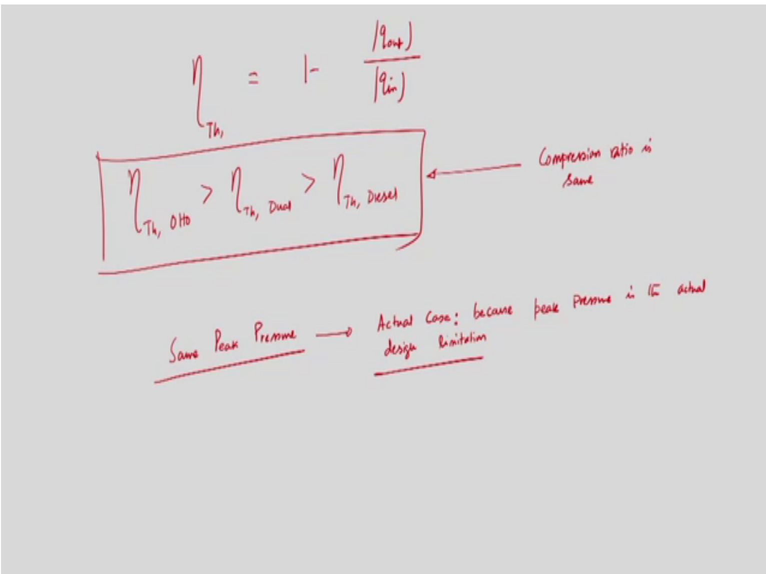

So, now, if we try to look at the thermal efficiencies, so, in general the thermal indicated thermal efficiencies irrespective of the cycle whether it is Diesel, dual or Otto is 1 minus q out divide by q in; q out is remaining same for all three different cycles while q in is changing. So, q in is higher for the Otto then dual, then diesel, then we can say the thermal efficiency of the Otto will be greater than thermal efficiency of dual greater than thermal efficiency of diesel. So, this order we are getting due to the change in heat being add in to the system which varies from Otto to dual to Diesel.

Now, this order we are getting essentially for a case when we are keeping compression ratio same for all three different cases. So, that is eta greater than eta or T Otto greater than eta T dual greater than eta thermal Diesel. So, this is the case for occurs when compression ratio is same. So, for a same compression ratio efficiency of the Otto cycle is greater than a efficiency of the dual cycle greater than efficiency of the Diesel cycle.

Of course, we have seen at least we did in discussed that whether efficiency of the Otto cycle will be higher then the dual or not, but we have discussed from the expression of you know mathematical expression of the thermal efficiency of Otto and Diesel that for a given compression ratio efficiency of the Otto cycle is higher than the Diesel cycle. So, that is what we have seen from another perspective that is from a from a look at the T-s diagram.

Next case before going to discuss about the next case that is while we are keeping the peak process same for all three different cases. See compression ratio same or keeping compression ratio same rather consideration of compression ratio as a common basis is not an ideal case, rather I mean this is very difficult to have a same compression ratio for all three different cycles. To be precise compression ratio of Diesel cycle is always higher than the dual and greater than the Otto because Diesel engines are always operated with a higher compression ratio.

So, while we are trying to find out the order of thermal efficiency of three different cycle considering compression ratio same it is not an actual case. So, it is always bettered to considered different other you know aspect to be the common basis for comparison and for that the peak pressure same is that is what we have discussed as the second case that is the most you realistic one. Because peak pressure same if we would need to fix it for all three different cases then it is very you know realistic rather it is very actual case because the peak pressure this is very important because it is a you know actual design limitation in all three engines in the real internal engine.

So, that is what I am telling that same peak pressure same peak pressure this is very important. The compression ratio same we have tried to estimate the order of thermal efficiency that is fine, but the compression ratio same is not the actual case because compression ratio will vary from one cycle to other, but if we try to keep peak pressure same for all three different cases that will be the actual case and it is more realistic because the you know peak pressure is the actual design limitation in most of the internal combustion engine.

So, this is the most actual case because you know this is very important because peak pressure is the actual design limitation, very important because as I said you that cylinder engine cylinder acts as a pressure vessel. So, whenever we are having higher pressure maybe at the end of the compression then we are having combustion. So, due to the combustion will have temperature since in case of a Otto cycle we are approximating constant volume process. So, pressure will high and also in case of a CI engine although we are having constant pressure, but still we trivially cannot ignored that the rise in temperature will leads to a you know rise in pressure as well.

So, the peak pressure that the engine cylinder needs to stand during the process of combustion is the actual limiting design limitation this is actual you know you know design criteria. So, and for that consideration of same peak pressure while considering the order of rather while considering the efficiencies of three different cycles would be the most realistic one and would be the most actual case. And, considering that next we will discuss that what will be the order of thermal efficiencies of three different cycle if we consider same peak pressure.

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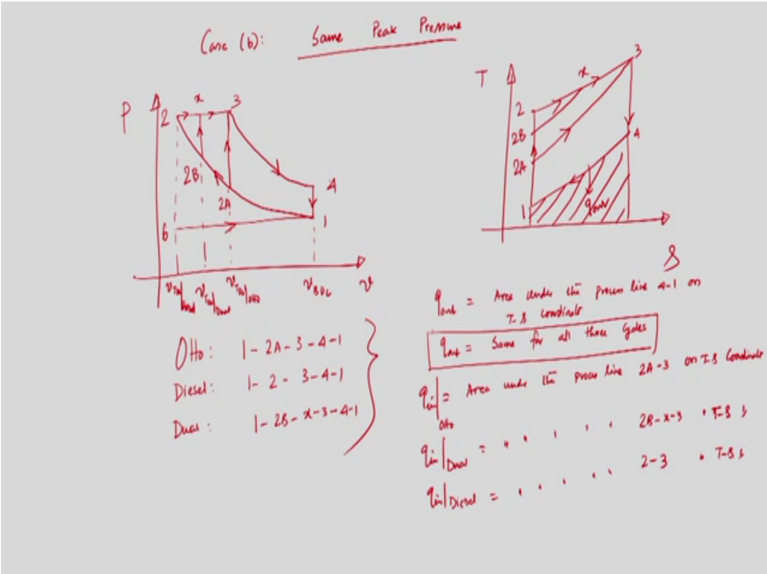

So, next case that the case b is the same peak pressure. So, this is the same peak pressure. So, this is the most actual case. So, if you would like to consider same peak pressure and what will be a P-v and then corresponding T-s diagram then you need to look into it and I would like to emphasize over here that while considering same peak pressure it is not mandatory that there we have to keep compression ratio same. Rather compression ratio will change and that is what is most important for all three different cycles because compression ratio is no longer even constant same for all three different cases.

So, if I try to draw P-v and T-s diagram. So, this is P-v and P-v diagram then we may have same peak pressure. So, maybe this is the case and this is same peak pressure. So, maybe this is v BDC. So, this is the process of maybe intake constant pressure intake, then we will have a, you know isentropic compression maybe this is 6, this is 1, this is 2; then we will have a blow down. So, maybe this is 4 and this is 3. So, 1-2-3-4 that is the Diesel cycle, that we can see from the P-v diagram.

Now, what will be the you know Otto cycle if you try to superimpose on that same P-v diagram. We have drawn the you know P-v diagram for the Diesel cycle, if you would like to superimpose the different processes in the on the same P-v diagram that is there in a Otto cycle then the cycle will be like this, maybe one this is 2A that is 1-2A-3-4-1 is a Otto cycle that you can see that the because combustion is again represented by constant volume heat addition.

Similarly, if you would like to you know represent dual cycle on the same P-v coordinate then probably this will be the case, maybe this is you know this is 2B and this is x. So, 1 comma 1-2A, 3, comma 4 is the Otto cycle 1, 2B-x-3-4 is the. So, if I write that Otto cycle 1 you know dash 2A dash 3 dash 4 dash 1. Diesel cycle that is what 1-2A-3-4-1 and dual cycle that is 1-2B-x-3-4-1. So, these three are that are different processes we have identified in the same P-v diagram.

And, we can see from the P-v diagram that v TDC for Otto. So, this is v TDC for dual and this is v TDC for Diesel. So, you can see from P-v diagram that the v BDC is remaining same for all three different cycles, but v TDC is changing. v TDC is less for Otto and then dual and then diesel. So, since v dt TDC is changing so, definitely the compression ratio will change and as I said you that the v BDC by v TDC is a compression ratio. So, v TDC is less definitely compression ratio for the CI engine would be higher and compression ratio for the SI engine will be less because v TDC is higher than the v TDC diesel, ok.

So, now, on when you took quantify or a we need to have a qualitative estimate about the thermal efficiency. So, if you draw the corresponding T-s diagram this is very important. So, this is T and this is entropy diagram. So, what will be the corresponding T-s diagram? See 1 comma 2, 1 to 2 this is the isentropic compression and this is 2 and then 2 comma 2 to 3, 2 to 3 is the constant pressure heat addition of course, this is combustion process temperature will rise and finally, you are having 3 to 4 is the you know this is 3 this is 4. So, 3 to 4 is a again isentropic expansion.

So, what about the Otto cycle? So, that is 1-2-3 1-2A-3 comma 1-2A-3 comma 4. So, maybe this will be twice A, this is 1, 1 comma 2A-3-4 the this is the you know because T 3 is the T max that is because of the combustion, but 2A you know you know temperature at point 2A should be temperature less than the temperature point 2 and finally, we will have off course temperature point 2A will be always higher then temperature at point 4 and finally, we should have 2B and 2B will be here. So, maybe this is point x, this is 2B. So, 1-2B-x-3-4-1 is the processes which is occurring in a dual cycle, fine.

So, from there again I would say that q out is the area under the process line 4-1 on T-s coordinate right and this is same and q out is same for all three cycles for all three cycles.

So, that means, if I try to drawn a area under the process line then q out is same for all three cycles to this is q out, but q in that is heat added into the system because of the combustion is different for three different cycle q in is area the q in Otto is area under the process line 2A dash 3 on T-s coordinate.

Similarly, q in dual is equal to area under the process line 2B comma x comma 3 on T-s coordinate and q in Diesel is equal to area under the process line 2 comma 3 on T-s coordinate. So, what we can conclude from this you know magnitude of magnitude of heat being added in to a system because of the combustion that we can conclude that q in Diesel is higher.

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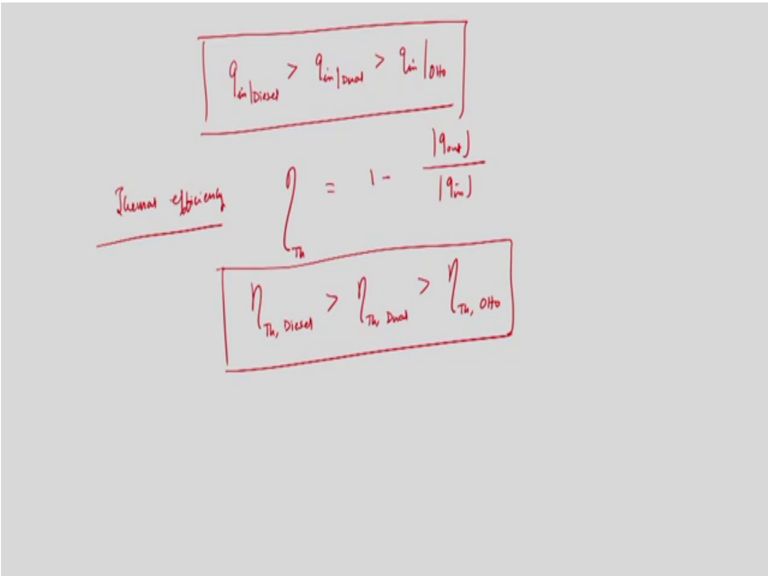

That is, from this T-s diagram we can say that q in Diesel is greater than q in dual greater than q in Otto. So, this is the order what we can see from the corresponding T-s diagram.

Now, thermal efficiency eta thermal is equal to 1 minus q out divided by q in; q out is remaining same for all three different cases q out is same for all three different cases while q in for the Diesel is higher than the dual than the Otto; that means, efficiency rather thermal efficiency of Diesel should be greater than thermal efficiency of dual greater than thermal efficiency of Otto. So, this will be the order of thermal efficiency for this three different cycles if we considered same peak pressure ratio.

That means, we have seen that while we are keeping compression ratio same that is for a given compression ratio efficiency of the Otto is higher than dual then Diesel, but what is the most actual case more realistic case rather more realistic basis for having a comparison is the same peak pressure because this is the actual design limitation in most of these internal combustion engines. There we can find that the deficiency of the Diesel cycle will be greater than the efficiency of the dual cycle and that will be greater than Otto cycle.

Not only that while you are considering the same peak pressure you know for three different cycles we have seen that the compression ratio is I mean, compression ratio for Otto is lesser than dual than Diesel and that is what is more you know you know much more actual it mimics the actual case I mean efficiency rather compression ratio of the Otto cycle is always higher than the compression ratio of the Diesel cycle.

So, from there so, we have seen that without going into the mathematical expression rather mathematical expression of the thermal efficiencies maybe for dual, Diesel and Otto we have at least qualitatively estimated what will be the order for two different cases, as a first case we have considered the compression ratio is same as for common basis and although it is not the actual you know basis because it is more ideal one because compression ratio will no longer remain same for all three different you know cycles.

So, you know this is not the way to compare. So, considering compression ratio same is not the best way to compare thermal efficiencies and there we have seen find that efficiency of the Otto is greater than dual and greater than Diesel that is what we have discussed may be in the last class that for a same compression is efficiency of the Otto is greater than efficiency of the Diesel. But, the most actual case is same peak pressure for there for that case we have seen that efficiency of the Diesel is greater than efficiency of the dual and which is greater than efficiency of the Otto.

So, with this we would like to conclude that the x compression of different engines essentially depends upon the heat being added in to the system and that essentially depend upon the combustion, fine.

Now, we would like to discuss that we have considered that you know we have used that you know we have approximated different air standard cycle. We have used air standard analysis rather you know thermodynamic thermal performance of different cycles different engines are approximated using an air standard analysis. And, while we are doing so we are assume air to an ideal gas and we have used ideal gas relationship.

Now, question is the actual processes there in an internal combustion engines you know is not in a true sense the thermodynamics cycle, rather I have discussed that we can call it a mechanical cycle. We will now discuss while we all call why we cannot call it a thermodynamic cycle rather we are calling it as a mechanical cycle. Because, you know that an ideal air standard cycle which occurs on a closed system and with constant composition I mean whatever will be the working substance undergoing the cycle that working substance the composition of working substance would not change.

So, and an ideal air standard cycle occurs on a closed system. If we try to recall that in a in an IC engine it is not your closed system because we are taking here and we are you know compelling out rather we are allowing combustion product to we compelled out from the system rather through the exhaust stroke. So, whatever combustion product is coming during exhaust strokes we are not you know using those combustion product into the cycle that is cycle is not path is not you know cyclic, that it is not a closed system.

And, and that is why and as I said you that a composition and we will discuss that the compositions rather the working substance will be changed. The composition of working substance will be changed you know after one cycle and that to in a real engine you know the whatever compositions we are having I mean whatever working substance having it is not following a closed loop rather it is open. So, that is why and air standard cycle I mean what happens in internal real internal combustion engine I mean actual internal combustion engine different processes, air standard if we try to use air standard analysis rather we have used air standard analysis to have a quantification of thermal efficiencies of Otto, dual and Diesel cycle that gives at best the approximation to actual condition it is not giving the you know actual conditions rather approximation should actual conditions.

That means, using an air standard analysis if you try we have quantified the thermal efficiencies of Otto, dual and diesel, but in reality the in reality the processes that is there in internal combustion engines those are not you know true sense a thermo dynamic cycle, while an air standard cycle and ideal air standard cycle occurs always in a closed system and without you know constant composition. The composition of the working substance would not change.

But, those are not true for the you know you know cycles that we have considered in a real internal combustion engine that is why you know if we try to you know mimic the actual processes in a internal combustion engine using an air standard analysis, I mean that at that will give a best approximation to the actual condition not the actual conditions.

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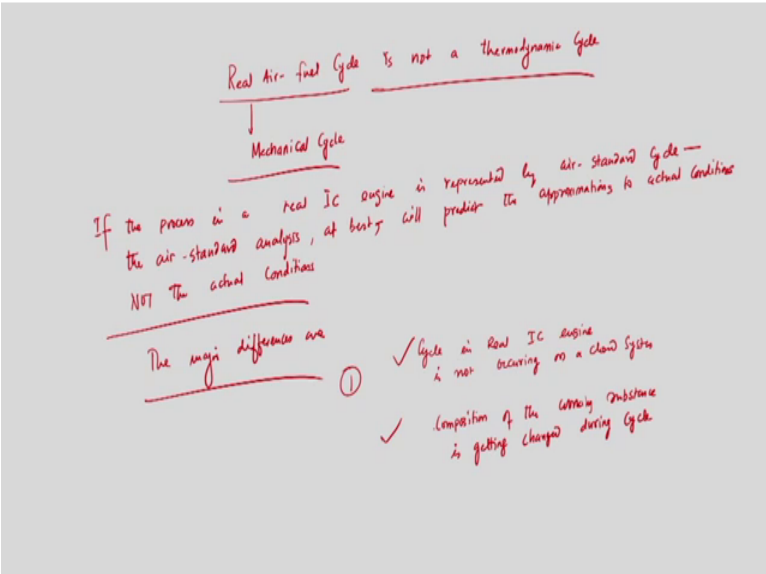

Now, what are the major difference; that means, you know real air fuel cycles. So, if you try to consider that real air fuel cycle is not a thermodynamic cycle. So, real air fuel cycle is not a thermodynamic cycle. So, what are the major differences? We have we have discussed that it is not a thermodynamic cycle rather we can call it that a mechanical cycle. It is not a thermodynamic cycle, but we call it mechanical cycle; that means, the processes; that means, the processes in a real IC engine in a processes in a real IC engine engines internal combustion engines.

So, if we try to represents the processes real IC and combustion engine is the processes in a real internal combustion engine is represented rather I can write if the processes in a real internal combustion engine is represented by air standard cycle, right, the analysis the air standard analysis at best will give at best will give only the other will predict at best will predict will predicts the approximations is approximations to actual condition.

So, if the processes in a real internal combustion engine is represented by air standard analysis the air standard analysis rather air standard cycle the air standard analysis at best we will predict we will predict the approximations to actual conditions not the actual conditions not the actual condition.

So, it the air standard analysis whatever you are doing only to have a quantification of thermal efficiencies that is what we have considered through different processes like isentropic compression, constant volume heat addition or constant pressure heat addition, then isentropic expansion constant volume blow down all these are not all these processes that what we have resumed using an air standard analysis those are not the same, those are not the correct processes rather those processes are not mimicking. Those processes are not mimicking the actual processes those are there in a real internal combustion engine.

But, still we are doing this analysis and that is why this air standard analyses we will give at best the approximation should actual condition not the actual conditions and we will now discuss the major differences are. So, why, what are the major differences? I mean it is not same; that means, the actual processes in a real internal combustion engines are not same what we have assumed while we are doing this air standard analysis. The major differences are we have to consider.

As a first case I can tell you I have discuss that the real air fuel cycle it is not a thermodynamic cycle we can call it a thermodynamic cycle if it you know if the processes occurring in a closed system with a constant composition. But, in real internal combustion engines it is not a closed system because you are taking air during intake stroke and at the exit you are getting combustion product. So, air we are getting in to face air if it is a CI engine or maybe certain amount of let us say very small fraction of fuel maybe 7 percent or 5 percent of fuel with air you know homogeneous mixture of air fuel during intake stroke for SI engine, but eventually you are getting combustion product at the exhaust and we had expelling it out in to the ambience. So, it is not a closed system.

Second thing: now, compositions. Composition is air at the intake while composition at the exit is defined you know in the combustion product they are might be carbon dioxide, carbon monoxide, nitrogen all those things. So, compositions is varying not only the inlet gas compositions is defying from the gas which at exit very often what do we do in case of a CI engine? Air is introduced at the during the intake stroke, but at the later the compression what do I what do we do we try to inject fuel through the fuel injected. That means, middle way through the cycle we are changing the compositions.

So, not only the composition is changing from inlet to outlet in SI engine composition is totally changing from inlet to outlet because at inlet is only a fuel mixture have the outlet is different combustion product. Not only that that is also true for the CI engine, but apart from that you know part way through the cycle what is happening in CI engine there we are injecting fuel at the later the compression and result of which the we are changing the composition at the middle of the cycle. So, this is a difference this is not this is not same.

Second thing you know during combustion although the mass is remaining constant, but the quality of the you know the molar quantity changes. So, although the mass is remaining same during the combustion, but the molar quantity changes and what we have discussed that the composition as well as the you know composition changes also the it is not a closed system. So, this is the one thing.

That is the processes in real IC engine rather cycle in real internal combustion engine is not occurring on a closed system. Number 2 – you know composition; during composition of the working substance is getting changed undergoing cycle during cycle. So, this is a one difference and as I said you that the all the mass is remaining same, but the molar quantity changes. Second thing as I said you, so, this is 1.

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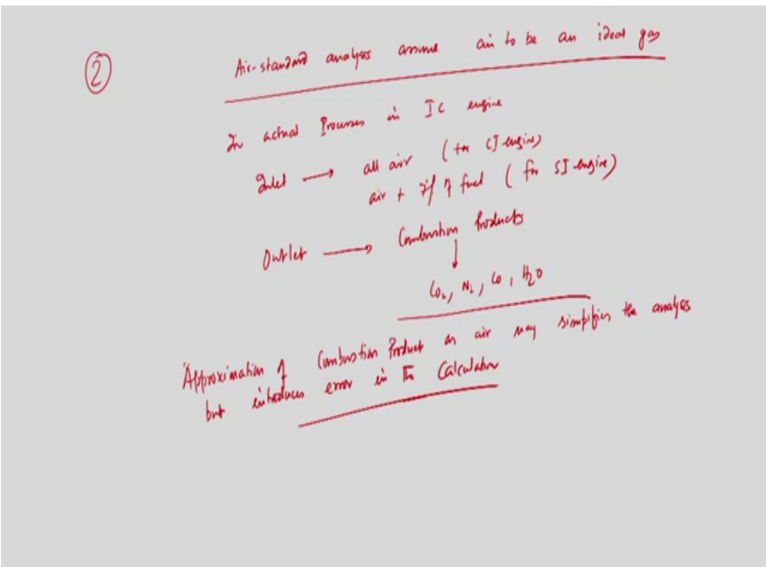

Number 2, is very important that while you are trying to mimic different processes in a internal combustion engine using an air standard cycle maybe will be we I have taken a few approximations and those approximations you know will eventually introduce error in the calculation that is what we have we will discuss. But, while we are taking rather while we are doing that analysis rather we are doing air standard analysis we are assuming that the you know entire analysis is based on the fact that air to be an ideal gas and we are using ideal gas relationship, right.

So, in real engine inlet flow by the air, but maybe up to 7 percent the air to be an ideal gas that is the best the important assumptions because all the equations we are using isentropic process that when we are calculating pressure and temperature at a at the end of the compression at the end of the expansions using ideal gas relationship.

So, at the inlet maybe all you know at the inlet particularly in case of a CI engine maybe all air the in a real engine inlet at the intake stroke or a inlet it will be all air for CI engine, but in case of a SI engine there is a little fraction of fuel that is 7 percent of fuel, but at the outlet we are getting a gaseous mixture, I mean we are getting combustion not the air at all. So, how can we assume that the combustion product, how can you treat that combustion product to be air while you are doing this and air standard analysis.

So, this is the second question. So, air standard analysis assume air to be an ideal gas. So, air standard analysis assume air to be an ideal gas and that is what you have seen because we have used ideal gas relationship to obtain the pressure and temperature at the end of compression and expansion stroke. But, if we now you know think about the processes in a real engine, at the inlet during the intake stroke maybe all air, I mean for CI engine maybe for SI engine little bit fraction of fuel is there, but in actual internal, in real processes in actual processes in IC engine inlet maybe all air for CI engine maybe air plus certain amount of let us say 7 percent of fuel for SI engine, 7 percent of fuel for SI engine, but outlet that is combustion product it is having CO 2, N 2, CO little bit H 2 O etcetera.

How can you assume the how can you treat the combustion product to be the air while you are doing the analysis. So, this is one of the major difference and for which we cannot say that the exhaust rather the combustion product during exhaust stroke will be there. So, this assumptions that this approximations are the exhaust product as air. So, this assumption rather approximation of combustion product as air this is very important simplifies the analysis.

So, we are approximating it that the combustion product to be air and that is why you have using isentropic expansion and from using ideal gas relationship we are calculating pressure and temperature at the end of the expansion, but this is an approximations. But, the approximation of the combustion product as a air maybe may simplifies the analysis simplifies the analysis, but introduces error in the calculation.

That means, into the calculation; that means, you know if we use that ideal gas relationship considering combustion product to be air while calculating pressure and temperature at the end of the expansion stroke maybe we will be doing some mistake and for their maybe we are under estimating the thermal efficiency of a internal combustion engine fine.

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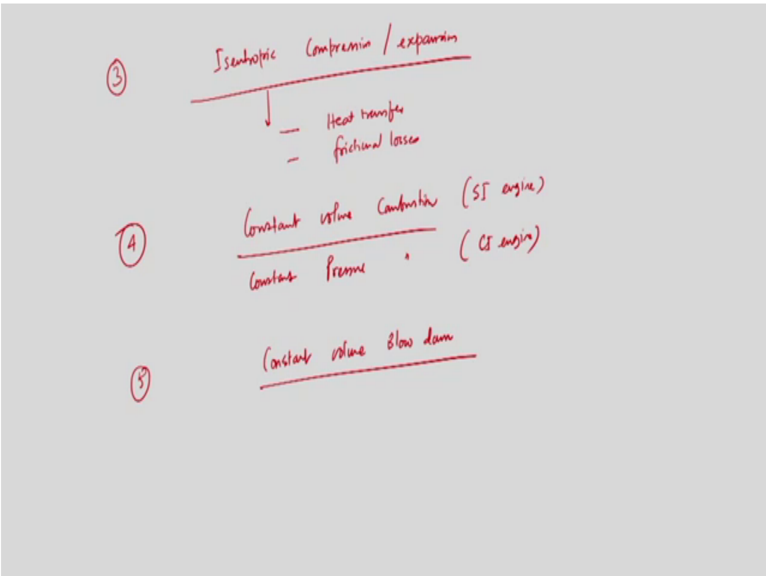

Number 3, is very important that isentropic compression and expansion. So, I assume that the process is isentropic expansion and isentropic compression and we are assuming there is no heat loss, so there is no heat transferred. But, in reality we have seen that engine cylinder should be surrounded by a cooling water jacket and it should have continuous supply of coolant only to set the engine out of excessive heating.

That means we should have continuous heat transfer from the cylinder if that is the case how can I assume that the expansion process or compression process to be an isentropic process? It is not possible because we are having heat transfer and also we are having frictional losses because whenever piston is moving inside the cylinder it is not possible to minimise, it is not possible to trivially ignore the frictional losses, but what we can do we can minimise, but we cannot make it 0.

So, frictional losses is there also we are having continuous heat transfer from engine cylinder to the coolant, then how can we assume that the processes are to be the isentropic process. So, this is an approximations. Not only that while we are doing this analysis, while we are considering the expansion process isentropic process or compression isentropic process mind it that because of this continuous heat and heat transfer may be the amount of heat being generated because of the combustion that will be reduced.

So, the heat being generated the temperature rise because of the combustion will be lesser in case of a real internal combustion engine because of the continual heat transferred, if temperature drops then pressure will drops as a result of which we will get lesser amount of work output during the expansion stroke that then that predicted by the air standard analysis. So, if we tried to; that means, we have use isentropic relationship rather isentropic expansion ideal gas relationship to have to calculate the pressure and temperature at the outlet of the at the end of the expansion stroke. But, this is not the case in reality.

And, you know quantification rather you know estimation of pressure and temperature at the end of the expansion process or at the beginning of the expansion process using air standard analysis will underestimate the actual pressure and temperature rather we will over estimate the sorry we will over estimate the pressure and temperature because temperature which is developed during combustion and because of that pressure that will reduce because of the continuous heat transfer as a result of which we will get lesser amount of workout to engine.

So, this is the case and although heat transfer is there because at the compression during compression stroke heat transfer is there that we cannot minimise, I mean you know, but deviation is less because expansion stroke the lower temperature at this time. So, during the compression stroke since temperature is not that much high at the beginning of the compression stroke takes temperature at even at the end of the compression stroke temperature is not that much high. So, we the deviation is very less, but at the beginning and also at the end of the expansion stroke I mean temperature is so high and because of the continual heat transfer temperature will reduce and it will try to reduce the pressure and we will get lesser amount heat work output. So, this is an approximation.

Last thing; so, their pointer this points are heat transfer and frictional losses. So, these two are there important point. Number 4, is we are assume constant volume combustion in case of SI engine and that is why what we did we are assume that whenever piston will be reaching at TDC volume will remaining same and entire combustion will be completed. This is not the case because of the chemical delay which depends upon the chemical composition of the fuel itself; the fuel itself require a finite time to complete the combustion.

Not only that, maybe while when you are switching when you are you know igniting this power player by switching it on then it records the finite time and for that way approximating that we should switching on the spark plug when piston is little bit away from TDC and by the time when piston reaches at TDC that time entire combustion will be complete this is again an approximations. It is not possible that the movement of the piston is very you know spontaneous, it is not possible that piston will be there for a while and the entire combustion will be completed and then piston will come back from TDC it is not the case.

So, the movement of the piston is spontaneous and we can you cannot you know ensure that the entire combustion will be completed when piston is reaching exactly a TDC, I mean volume will remain constant this is not the case. And, that is why what is done you know the spark plug switch is on when piston is little bit away from TDC and we need to give some certain amount of time only to take into account the chemical delay also the you know time required to switching it switch on the spark plug etcetera. This is all about the you know this is constant volume combustion.

This is constant volume combustion for SI engine and constant pressure combustion for CI engine. So, this is the case. Now, even for a CI engine we are approximate a constant pressure process and what we are doing that when piston is at the late of the compression stroke when piston is away from TDC, we try to ignite we try to spray fuel through fuel injector and we assume that by the time interval fuel will be you know accumulated over entire fuel spraying will be completed by that time piston will be reaching TDC and again travelling back from TDC and entire combustion will be completed.

So, how we can ensure that pressure will remain constant because maybe when we are spraying certain amount of fuel at the you know beginning rather at the when piston is little bit away from TDC, the first part or the first phase of the fuel being sprayed they might take part in the combustion and because of that combustion pressure will rise and the pressure might change inside the cylinder. So, the pressure will remain constant inside the cylinder it is again a approximations.

Since we require finite time for spraying the fuel so, the first part of the fuel being injected into the cylinder they will take part in the combustion and because of what we will have a high temperature and pressure. So, if the pressure changes how we can assume that the pressure will remain constant inside the cylinder to complete the entire combustion and this is again an approximation for the SI engine. Third thing is exhaust blow down. What we do you know fifth is constant volume blow down.

Constant volume blow down that is we have assume for all three different cycles diesel, dual and Otto. So, that assuming we are we are what do we do we try to open the exhaust valve when piston is little bit away from BDC during end of the expansion stroke and by opening exhaust valve we are trying to reduce the pressure inside the cylinder so that in the next stroke when piston is coming back from BDC to TDC during exhaust stroke it will experience it will encounter less resistance. And to do that we will try to remove certain amount of combustion product before piston reaching at BDC during at the end of the expansion stroke and we open the exhaust valve.

While we are doing so, then how can we assume the volume will remain constant? Because the open the movement when we open the exhaust valve certain amount of combustion product will go out from the extender and volume we will no longer remain constant. Not only that while we are doing so, then we are again try to under estimating the thermal efficiency because before piston reaching at BDC during end of the power stroke we are opening a exhaust valve and we are allowing certain amount of combustion product to go out. That means, we are not allowing that amount of combustion product to do work on the piston phase; that means, eventually we are sacrificing certain amount of work output from the system.

So, all these approximations are not you know truly sense occurring in a real engine and that is why although we are doing those approximations only to simplify your analysis. But, all those approximations introduce error in the analysis and as a result of which maybe the thermal efficiency what you are getting from different from Otto, dual and Diesel cycle from considering air standard analysis that will give us the indicated thermal efficiency. But, the efficiency in the real case will be somewhat different than what predicted by the air standard analysis.

So, with this I stop my discussion today and I will continue my discussion next class. Thank you very much.