Concepts of Thermodynamics
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Lecture – 60
Diesel Cycle

In the previous lecture, we discussed about Otto cycle and today, we will discuss about Diesel cycle. From the name itself, it is clear that this cycle, thermodynamic cycle is used to model the thermodynamic performance of diesel engines and that is why the name Diesel cycle.

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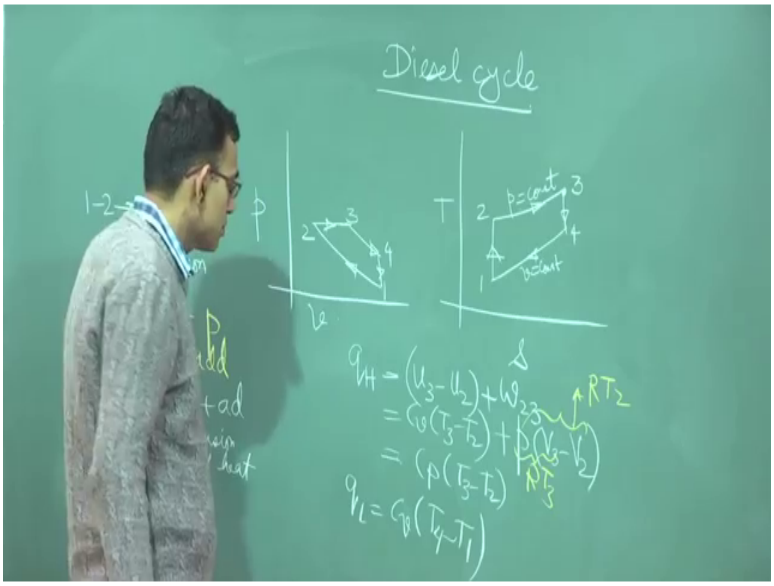

So, we will draw the p v and T s diagram and try to identify what is the difference between this cycle and the Otto cycle.

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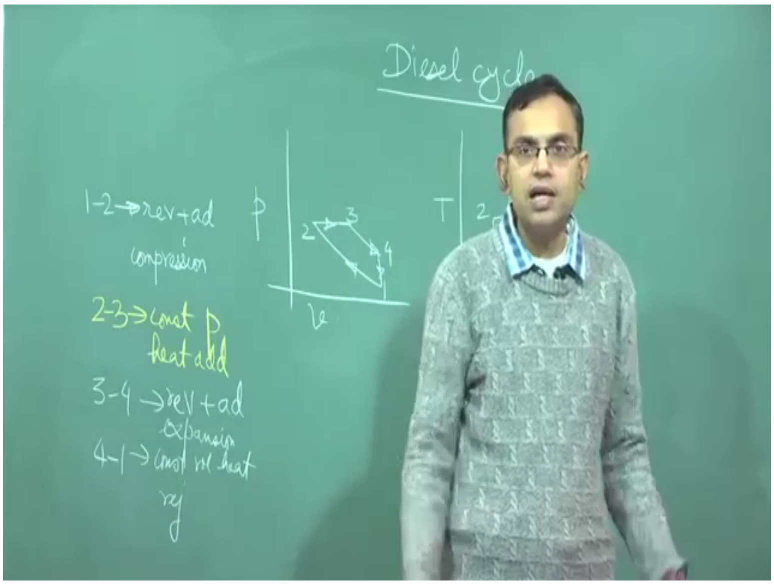

So, process 1 to 2, reversible adiabatic compression; this is same for both Otto cycle and Diesel cycle. The major difference between the Otto cycle and diesel cycle and perhaps the only difference is that the heat addition in diesel cycle is considered to take place at constant pressure, instead of constant volume.

So, 2 to 3, constant pressure heat addition. So, constant pressure heat addition means it will be a horizontal line here, so after the constant pressure heat addition. So, this is p equal to constant, there will be the expansion or the power stroke. So, 3 to 4 reversible plus adiabatic expansion and then, from 4 to 1, you have constant volume heat rejection. See the heat rejection is not done at constant pressure for the reason that it will increase the stroke volume to an extent that it will be a bulky cylinder for and too bulky for internal combustion engine purposes. So, all though the heat addition is constant pressure, but heat rejection for auto mobiles is traditionally constant volume.

Here, I have purposefully drawn these lines steeper than this because in a T s diagram the constant volume lines are steeper than constant pressure lines. Now, we are going to analyse the efficiency of this cycle and compare that with otto cycle that is one of the tasks that we will do. So, what is q H here? Without referring to you know individual systems for writing the first law of thermodynamics, we will simply now we will write that the heat addition is from 2 to 3.

So, q H is u 3 minus u 2 plus w 23 right, straight away this we are writing. So, one of the major assumptions in the air standard cycle which is their previous lecture I forgot to mention, but you also add it that you neglect changes in kinetic energy and potential energy of the working fluid. Because we are writing these expressions neglecting the changes in kinetic energy and potential energy although that is not what we explicitly tell always. For thermodynamic purposes, the thermal energy contribution is usually much more significant than the kinetic energy, potential energy contribution.

So, this will be C v into T 3 minus T 2 and what is w 23? So, this is the integral pdv from 2 to 3. So, p into V 3 minus V 2; pressure is constant ok. So, the fuel injection process which is typical to the diesel engines is such that during the fuel injection, so the differences in paradigm try to understand. In the previous cycle, we were trying to model the combustion in a already mixed air and premixed air and fuel in the Otto cycle. So, here we are considering that the air is highly compressed and the fuel is injected.

So, once you do that, the fuel injection process during which this chemical energy of the fuel is input to the highly compressed air, you will have roughly a constant pressure heat addition process. So, that is why this difference between the heat addition processes in Otto cycle and diesel cycle. So, now p V 3, this is as good as RT 3 and p V 2, this is as good as RT 2. So, you can write this as C v plus R into T 3 minus T 2. So, that is nothing but C p into T 3 minus T 2 ok. What is q L? q L is nothing but now it is a constant volume process so, C v into T 4 minus T 1.

Remember heat transfer sign, why is this is negative heat transfer, but when you are writing q L for the purpose of calculating efficiency, it is already the mod. It is already the magnitude. So, we have to write T 4 minus T 1 and not T 1 minus T 4. The efficiency we will calculate the efficiency in this side.

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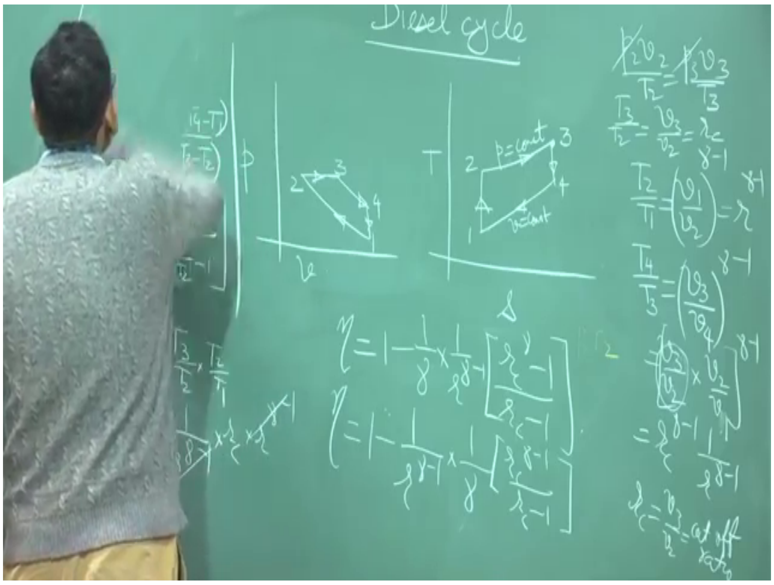

Is equal to 1 minus q L by q H. So, this is 1 minus C v into T 4 minus T 1 by C p into T 3 minus T 2. C v by C p is 1 by gamma; just like the previous example of water cycle, we will extract T 1 by T 2 here. We will write T 4 by T 1 minus 1 by T 3 by T 2 minus 1. Now, T 4 by T 1, we can write T 4 by T 3 into T 3 by T 2 into T 2 by T 1 right. Now, T 1 by T 2 or T 2 by T 1, but it is T 2 by T 1 v 1 by v 2 to the power gamma minus 1.

So, that is R to the power gamma minus 1 and what is T 3 by and what is T 4 by T 3? It is equal to v 3 by v 4 to the power gamma minus 1; v 3 by v 4 is v 3 by v 2 into v 2 by v 4. v 2 by v 4 is same as v 2 by v 1 right because v 4 is same as v 1. So, this is now before that what is v 3 by v 2? v 3 by v 2 we call as cut of ratio or r c. So, this is a new definition. So, r c to the power gamma into 1 by r to the power n minus 1; where, r c is v 3 by v 2 is equal to cut off ratio. Why this is called as cut off ratio? Because this is the volume ratio at which the heat addition is cut off otherwise you to have in definitely continued.

So, then let us write this T 4 by T 1 as T 4 by T 3 is r c to the power gamma minus 1 into 1 by r to the power gamma minus 1. What is T 3 by T 2? p two v 2 by T 2 is equal to p 3 v 3 by T 3 right and p 2 is same as p 3. So, T 3 by T 2 is equal to v 3 by v 2, which is again equal to r c. So, this becomes T 3 by T 2 is equal to r c and T 2 by T 1 is r to the power gamma minus 1.

So, T 4 by T 1 becomes r c to the power gamma therefore, the efficiency expression.

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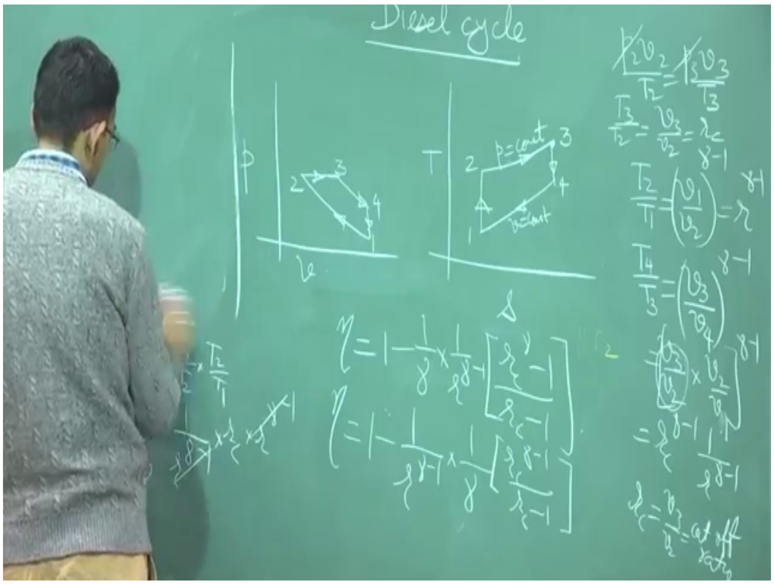

What is the efficiency expression? 1 minus 1 by gamma into T 1 by T 2 T 1 by T 2 is 1 by r to the power gamma minus 1 into T 4 by T 1 minus 1. So, r c to the power gamma minus 1 divided by T 3 by T 2 is r c right. So, essentially the efficiency expression is the Otto cycle efficiency expression multiplied by a correction factor right. With this basis now, let us compare the Otto cycle with this cycle. So, for the Otto cycle we have this term multiplied by. So, eta is equal to 1 by r to the power gamma minus 1. This multiplier is not there. So, let us see whether this multiplier is greater than 1 or less than 1 or what it is.

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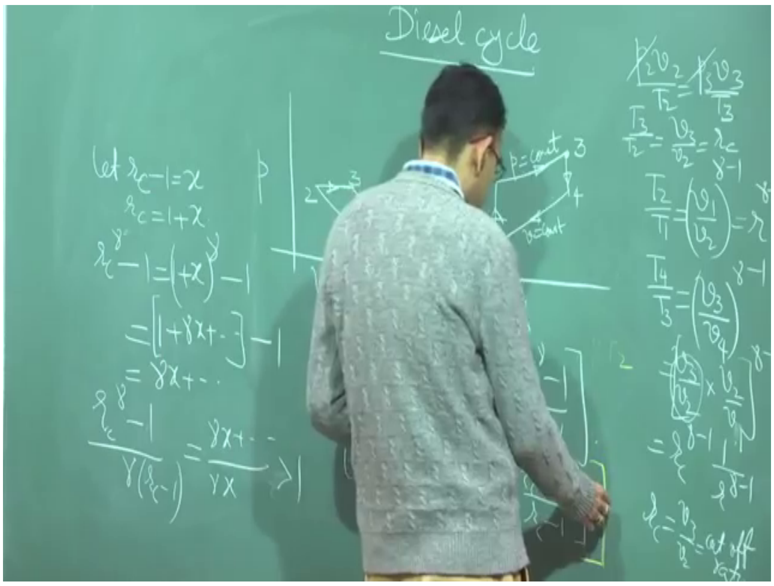

So, for that you just let r c minus 1 is equal to x just take it. So, r c is equal to 1 plus x. So, r c to the power gamma minus so not, so this minus 1 is full minus 1 not r c to the power gamma minus 1. So, r c to the power gamma minus 1 is equal to 1 plus x to the power gamma minus 1. 1 plus x to the power gamma is you can expand in the binomial series. So, 1 plus gamma x plus gamma into gamma minus 1 bi factorial 2 x square like that it goes on, minus 1.

So, this is gamma x plus higher order terms. So, r c to the power gamma minus 1 by gamma into r c minus 1 is equal to gamma x plus whatever by gamma x right. So, this is this plus whatever term which is greater than 0 right. So, this multiplier is a multiplier.

Student: Greater than 1.

Oh sorry! Greater than 1 not 0 ok; greater than 1 right so, 1 plus something not greater than 0; so, greater than 1; so, then these multiplier being greater than 1. So, what is the efficiency that we except? You are subtracting a number magnified by a factor greater than 1. So, this should be less as compared to what is there for the Otto cycle.

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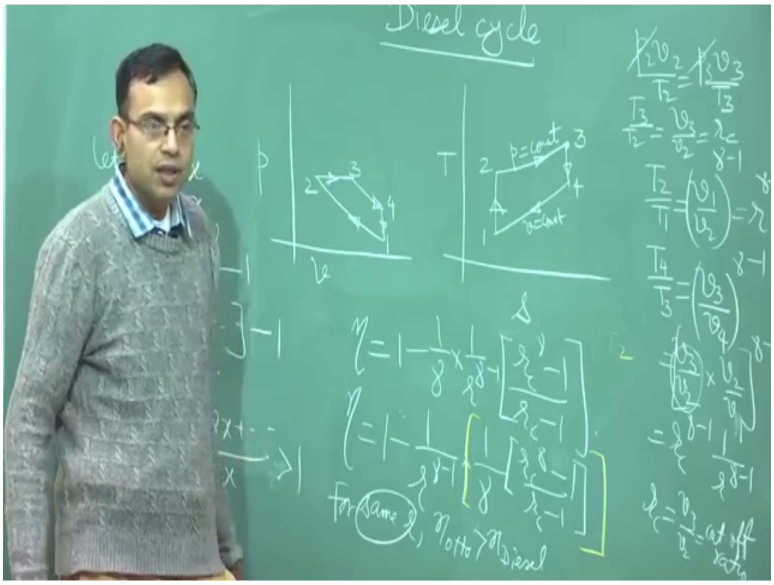

So, the conclusion is for the same r eta Otto should be greater than eta diesel, but this is very misleading you know. Why is this very misleading? This is misleading because same r is not a good basis for compression. Same compression ratio will not be the case for Otto cycle and diesel cycle. Because you are solely compressing air and not air fuel mixture in the diesel cycle, you can go up to very large compression ratio and at very low large compression ratios, the diesel cycle might have an efficiency which is quite large.

So, same r may not be the same basis for comparison, but hypothetically if you greater than same r, then Otto is greater than diesel. So, but this mathematical way of comparison can also be substituted by a more physical way of comparison. So, I will try to give you two examples of comparison of Otto cycle and diesel cycle before we call it a day today ok.

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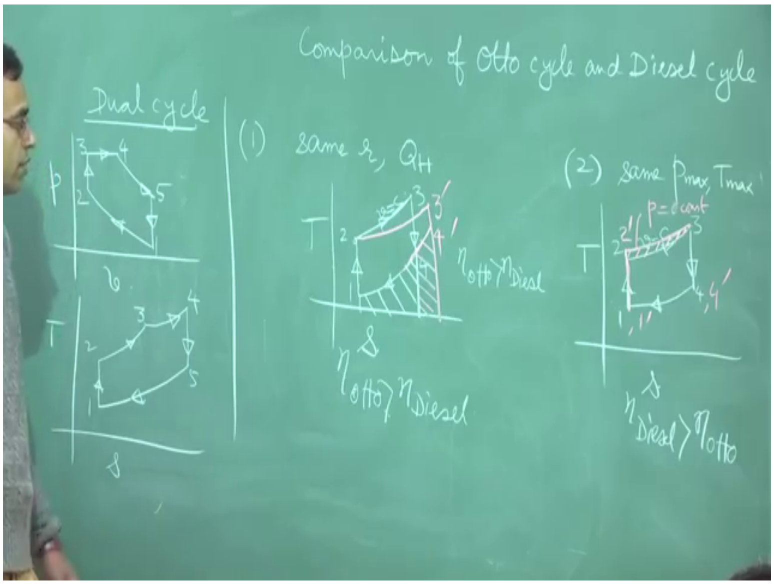

So, the first so for any comparison, there should be a basis for comparison. You should not compare apple with an orange. So, for common basis let us say for the same r and same Q H, when heat transfer is given as a basis, it is better to use the T s diagram because heat transfer information is directly available from T s diagram; work done information is directly available from the p v diagram. But interestingly, the area under the p v diagram is same as the area under the Ts diagram for a cycle. Because cyclic integral of heat equal to cyclic integral of work and area under the Ts diagram is cyclic integral of Tds which is cyclic integral of del q. So, area under the p v diagram is same as the area under the T s diagram is same as the net work and is same as the cyclic integral of heat; all this things are equal if it is an internally reversible cycle. Because if it is not an internally reversible cycle, you cannot write del q equal to Tds.

So, area under the T s diagram is equal to integral of del q, cyclic integral of del q that you can write only for an internally reversible cycle. Similarly, area under the p v diagram is same as the net work done for an internally or quasi equilibrium process or a collection quasi equilibrium processes. So, these things we must remember. So, same r and same QH; same r means if you start with the point 1, the state point 2 will be the same because T 2 by T 1 is governed by only R and gamma right. Then, so with white line, I will draw the let us say the Otto cycle. This is what? This is constant volume and with a red colour, I will draw the diesel cycle.

So, from 2, you will have a constant pressure line. So, if you have a constant pressure line, constant volume line is steeper than constant pressure line. So, constant pressure line from 2 will go like this and heat addition being the same the area under 2 to 3, represents the heat addition process in the T s diagram. So, from 2 to 3, whatever is the area under that that is the hat transfer, during heat addition for the Otto cycle.

For the diesel cycle because this line is going below to compensate for this loss of area, it should go further towards the right to make the area under 2 to 3 same as area under 2 to 3 prime. And then, so if you reject heat with constant volume, then it is a basic continuation of 1 to 4, diagram. Then you see for the same QH which is having more q L. For the Otto cycle, this is the q L and for the diesel cycle, you have this additional q L right.

So, for same Q H you have more q L for the diesel cycle; that means, its efficiency is less. So, the mathematical form that for same r the efficiency of Otto will be more than efficiency of diesel, we can just physically from the T s diagram. But this may not be a good basis for comparison as I have already mentioned that same r may not be very practical way to look into it.

So, let us say we give a constrain same p max and T max. If you have same p max T max; see p max and T max is occurring at straight point 3 right. So, if p max and T max is occurring at straight point 3 and if you specify these two states V max is also specified because p v equal to RT; that means, for same p max T max that is the combination of p max T max, you could in principle fix up the straight point 3 as unique straight point for both Otto cycle and diesel cycle.

So, let us; so, this is a Otto cycle with the white line, we have drawn it. So, with the same straight point 3, now so with the same straight point 3, the constant volume line is steeper than constant pressure line right. So, the constant pressure line will be less steep and it will go something like this. So, this is p equal to constant. It will go less steep than constant volume line and then, if you keep 4 and 4 prime and 1 and 1 prime same, the point 2 prime will be above the point 2 right. The point 2 prime will above the point 2 because of it being less steeper.

So, area the heat rejection being the same, heat addition is area under the T s diagram from 2 to 3 because 2 dash is above 2 you have an extra area representing extra heat addition for the diesel cycle. So, for same heat rejection, if you have more heat addition, you have more efficiency. So, this is a more logical way of comparing the two cycles and here you can see that you have eta diesel greater than eta Otto because the practical engine constants are most of the times dictated by what is the maximum pressure, it can withstand; what is the maximum temperature, it can withstand and so on and not intrinsically by the compression ratio.

So, if somebody ask you a question does Otto cycle have more efficiency than diesel cycle or does diesel cycle have more efficiency than Otto cycle. The first return question that you must ask what is the basis for comparison; what are the parameters that you are keeping fixed. So, depending on what you are keeping fixed, you will have different answers. Right in this case you have eta Otto greater than eta diesel, but in the case two you have eta diesel greater than eta Otto.

Now, finally, I will give you a small note, what does a real internal combustion cycle; internal combustion engine cycle look like. Is it Otto; is it diesel? In practice, the heat addition is neither a constant pressure heat addition nor a constant volume heat addition. So, it could be perceived as a combination of constant volume and constant pressure heat addition and there is a cycle that takes that into account. I will not get into the details of that cycle, but I will just draw the may be p v and T s of that cycle that is called as the dual cycle.

So, dual cycle is a combination of Otto cycle and diesel cycle in a sense that part of the heat is added at constant pressure and part of the heat is added at constant volume. So, if you draw the p v diagram. So, you have compression, then heat addition, partly constant volume and partly constant pressure, but heat rejection definitely at constant volume and the T s diagram. So, first constant volume curve which is steeper and then, less steep constant pressure curve, then reversible adiabatic expansion and then heat rejection ok.

So, to summarise we have discussed two important air standard cycles; one is the Otto cycle, another is the diesel cycle and we have compared their efficiencies. But air standard cycle is not just restricted to cycles for internal combustion engines. We could have other applications where air standard cycle can be applied. One such application is the gas turbine cycle for which we consider the Joule cycle or the Brayton cycle that we will study in the next lecture.

Thank you.