Chemical Principles II
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Module 05
Lecture 28
Gasoline Engine and Diesel Engine

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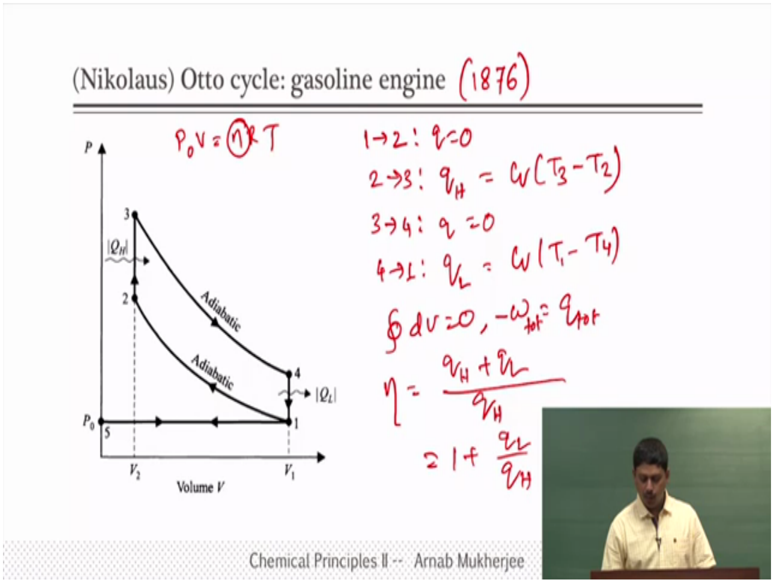

Now we are going to talk about two internal combustion engine, so one of that internal combustion engine is called gasoline engine which was proposed by Nikolaus OTTO around 1876 a long after of course Stirling engine. Internal combustion engine means wherever the heat is produced inside the engine, external combustion engine that combustion happens combustion happens to get the heat. So here we are not having any combustion but we are giving the heat from outside.

So if the engine is designed such a way that the heat is getting generated inside the engine then we call it that as internal combustion engine and gasoline engine is one of the internal combustion engine. So it has these typical four steps again, however there is a fifth step or the first step where the engine takes away the fuel gas combination, but fuel and gas it takes in the first step, initially there is nothing inside the engine so because of volume is 0 as you can see.

The first step is called intact step it goes to 1 meaning it takes away the gas inside the engine followed by an adiabatic compression. Now we know that in adiabatic compression what happens, the temperature increases. So in 1 to 2 the temperature you know suddenly increases from 1 to 2 and then this 2 to 3 is called a combustion step where the fuel that is there because of the high temperature the fuel gets burned, suddenly volume does not change but the burning of the fuel generates lot of heat.

And that heat will now help to move the piston in an adiabatic manner from 3 to 4 and that is called power stroke, this is what actually drives the piston and drives everything and then that followed by a cooling step from 4 to 1 where heat will go outside and then the fuel 1 to 5 the fuel will be ejected out of the or fuel gas combination ejected out is called exhaust this is the exhaust step.

In 1 step also the pressure in this 4 to 1 the pressure decreases where some of the gas is released unless until the pressure come to one atmospheric pressure, otherwise at 4 pressure is high than the atmospheric pressure, then at 1 it becomes atmospheric, so P 0 is the atmospheric pressure. Now in this particular step we are going to calculate again the efficiency of this particular engine.

So you can see that in 1 to 2 step it is an adiabatic compression process, okay. We can talk about 5 to 1 step which is nothing but if you talk about an ideal gas, so P V equal to nkT or nRT, so in that volume is 0, so at constant atmospheric pressure gas is just taken in, so n goes from 0 to some value that is it. Now main thing is I wanted to which is the compression process in which your q equal to 0, so no heat is ejected or taken in so therefore we do not have to worry about that.

In 2 to 3 you know that the q that is q in or you can say q H as it is given here is again C v T 3 minus T 2, 3 to 4 q equal to 0 again and 4 to 1 q L which is C v T 1 to T 4. Now you see I have not done the work done and all because we know that for any cyclic process U is going to be 0, if U is going to be 0 then we know that q equal to minus W. So total work done by the system is nothing but the negative of the heat or total work done by the system is just the heat.

So we know for a cyclic process cyclic process your U equal to 0, so therefore total work done by the system is nothing but total heat. So now if I calculate the efficiency of the engine it will be total work done by the system which is q tot which is q H plus q L and the input heat is just q H so that is the efficiency of the engine, which again gives us q L by q H. Now this is always the case, every engine we see that it is 1 plus q L by q H except the way it is if it is done the way that in two steps you take in the heat and throw out the heat, but if you take the heat in multiple steps of course it will not be the case.

Now here there are two adiabatic steps so no heat is taken in and out, so it turns out that we can write that as 1 plus q L by q H.

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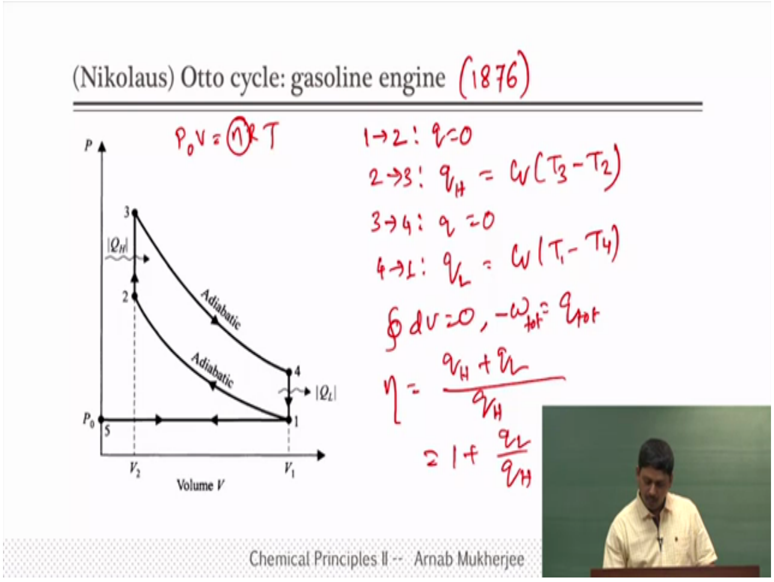

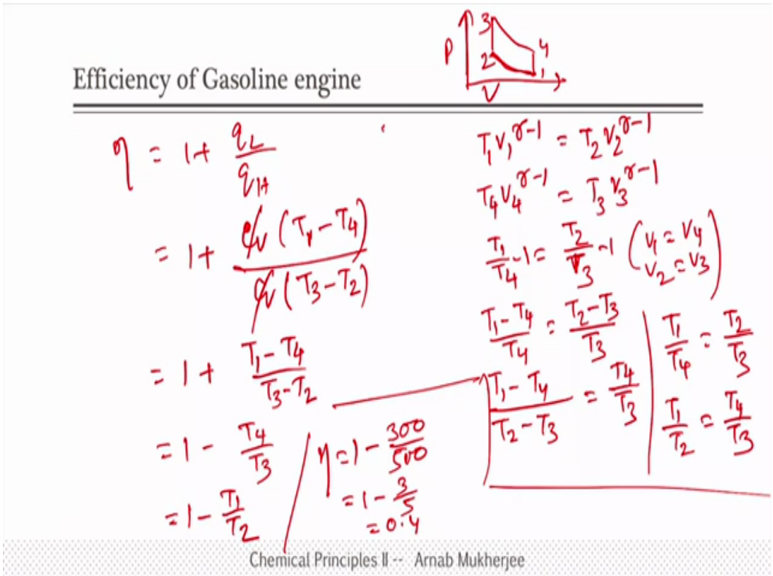

Now what will be the value of that? So Eta is 1 plus q L by q H and we know that q L is C v let us go back and see what is the q L, C v T 1 minus T 4 and q H is C v T 3 minus T 2. So 1 plus T 1 minus T 4 by T 3 minus T 2, now in order to simplify this process we have to get some relations from this. So let me draw it again just for remembering. Now you see that this 1 to 2 is an adiabatic process so we can use the formula for an adiabatic process which is T 1 V 1 to the power gamma minus 1 is T 2 V 2 to the power gamma minus 1.

For 3 to 4 also we can do the same thing T 4 V 4 to the power gamma minus 1 is T 3 V 3 to the power gamma minus 1. Now once we take the ratio of that we will get T 1 by T 4 is equal to T 2 by T 3 because V 1 equal to V 4 and V 2 equal to V 3, okay. So now once we get that we know that I can put minus 1 on both sides, we can get T 1 minus T 4 by T 4, T 2 minus T 3 by T 3, okay.

So now I can go (1 minus) T 1 minus T 4, I can take the numerator on this side to down T 2 minus T 3 is equal to T 4 minus T 3, but I have T 1 minus T 4 and T 3 minus T 2, so I need a minus sign so this one becomes 1 minus T 4 by T 3, also we know from this relation is that T 1 by T 4 is equal to T 2 by T 3 and if I rearrange that I will get T 1 by T 2 is equal to T 4 by T 3, you can also write as 1 minus T 1 by T 2.

So you see now the efficiency of this particular engine depends on the difference in temperature between 1 and 2 that is a difference of a compression, so during the compression how much difference of temperature you can make that will determine the efficiency of the engine. So typically at 1 it is at normal temperature 300 kelvin and in 2 by compression it goes approximately 500, so if you take that then you can calculate the efficiency to be 1 minus let us say 300 by 500, 1 minus 3 by 5d to 0.4, okay.

So basically depending on 500, 600 whatever so you get ideal efficiency as 0.4, 0.5, however the actual efficiency goes to 0.35 because of losses and many other things. So depending on how much you can compress that will give rise to the amount of temperature and that will give rise to efficiency, so that is the gasoline engine.

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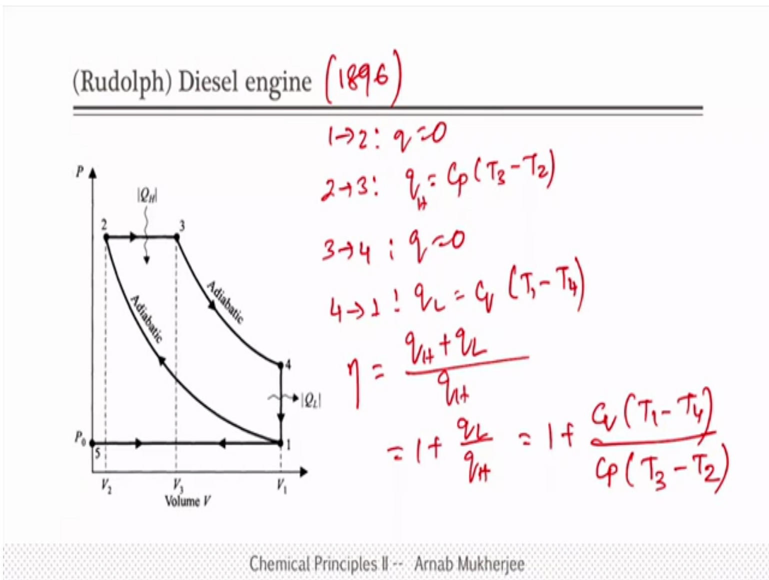

And little bit later like 20 years down the line around 1896 Rudolph Diesel proposed another type of engine called diesel engine and again we have the diesel cars also which works in that way. So the difference between gasoline engine and diesel engine is that, in diesel engine only air is taken in not the air fuel mixture. So again in the first step there is an intact step where the air is taken in and again it gets compressed to very large extent and during this compression process the air gets compressed so of course the temperature goes very very high and then in the 2nd to 3rd step the fuel gets injected.

And in that high temperature the fuel gets burned, you do not need any spark or anything to burn the fuel because the temperature is high enough at the stage 2 that the fuel gets burned and it is injected in such a way that the pressure remains constant between 2 to 3 and once that gets burned then the next step is the power stroke where it will push the piston and come from 3 to 4 and then the other two steps like 3 to 4 and 4 to 1 is same like a gasoline engine. So the only difference is that here it is like a air diesel engine where only the air is compressed, not the air fuel mixture that is the only difference.

Now here also you can calculate the efficiency, let us do that so again in the first step 1 to 2, it is an adiabatic step so q is 0 and 2nd to 3rd step is it is a constant pressure process so q is C P T 3 minus T 2 this is the q H actually and 3 to 4 step again q equal to 0 and 4 to 1 step where the q L is C v because it is a constant volume process T 1 minus T 4, you see here that I am not using any minus sign or anything because since I am going in a cyclic manner the signs will automatically come in.

For example if you look at q H, since T 3 is higher than T 2, q H is the positive quantity. So a positive heat is as I told you in the first law of discussion time that a positive heat is heat that goes into the system because that is going to increase the internal energy of the system and negative heat automatically means that heat is going out of the system. Now you see that T 1 is less than T 4, so therefore q L by itself is a negative number which means the heat is going out of the system.

So now we have these 4 values, so when you calculate the efficiency Eta, this is again the same the total work done by the system is q H plus q L as I explained just now and the heat input is nothing but q H on the so it will be 1 plus q L by q H. Now let us calculate the you know we can write down one more step here 1 plus C V T 1 minus T 4 by C P T 3 minus T 2.

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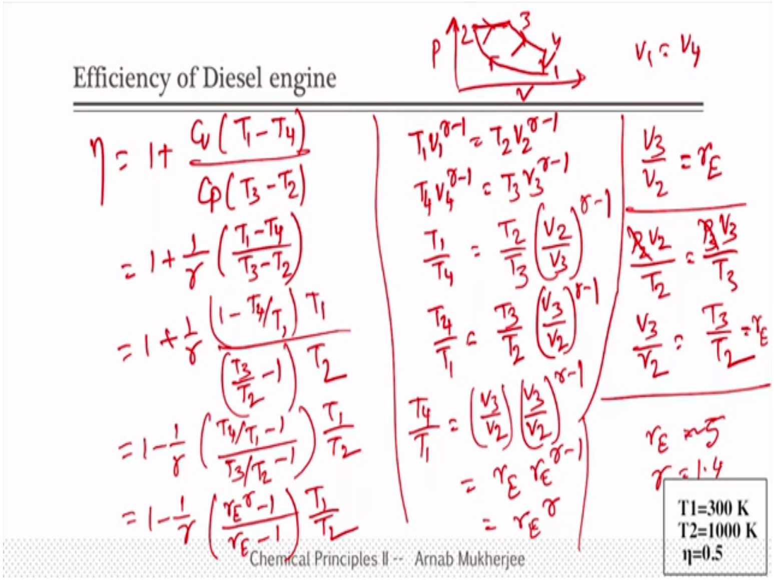

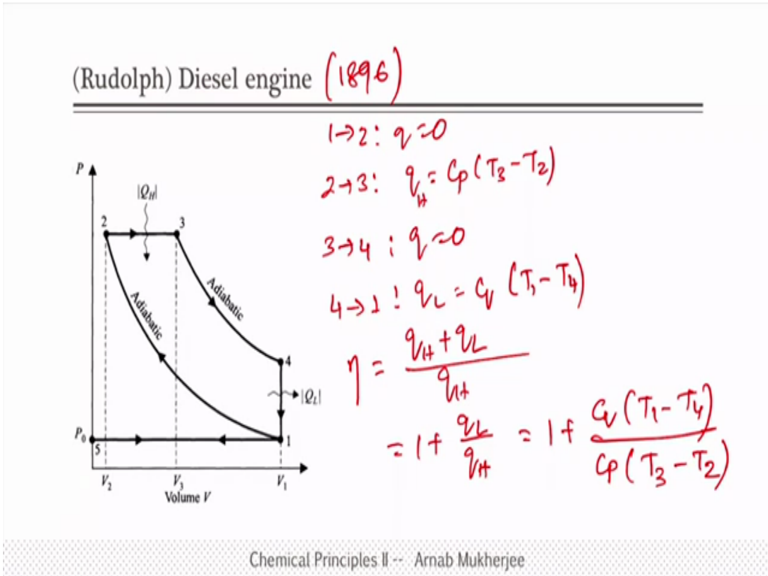

So efficiency Eta is 1 plus C V T 1 minus T 4 C P T 3 minus T 2. Now we know that C P by C V is gamma, so it is 1 by gamma T 1 minus T 4 and T 3 minus T 2. Now let us simplify this process and I am going to draw it here just for remembering this is a constant pressure process so 1, 2, 3 and 4 these are two adiabatic processes and this is a constant pressure process is constant volume process just to remember that this is a handy way to have that.

Now let us write the relation, so first relation that we write is between the adiabatic step, so T 1 V 1 to the power gamma minus 1 is T 2 V 2 to the power gamma minus 1. Similarly T 4 V 4 to the power gamma minus 1 is T 3 V 3 to the power gamma minus 1. Take the ratio T 1 by T 4 and we know that V 1 equal to V 4 because it is a constant process but however volume of 2 and 3 are not same. So here we are going to get T 2 by T 3 V 2 by V 3 to the power gamma minus 1, okay.

Now V 2 and V 3 so there is a volume change between 2 and 3, so V 3 by V 2 is typically called expansion ratio r E because here the expansion is happening and ratio between 1 and 2 is called compression ratio, these ratios are important in order for the efficiency that we can see you know in a moment. Now we have this relation, just we will invert it so T 4 by T 1 is T 3 by T 2 V 3 by V 2 to the power gamma minus 1.

Now what is the relation of T 3 and T 2 let us understand that for that we are going to use the relation between 2 and 3. Now since it is an ideal gas we can always write P 2 V 2 by T 2 is equal to P 3 V 3 by T 3 we can do that for any two points. Now you see that the pressure is same between P 2 and P 3 so cancels, so therefore V 3 by V 2 by expansion ratio is T 3 by T 2, okay.

So now we are going to get T 4 by T 1 as V 3 by V 2 into V 3 by V 2 to the power gamma minus 1, so since V 3 by V 2 is expansion ratio we are going to get r E r E to the power gamma minus 1, so therefore r E to the power gamma. So we got that and so now let us come back to this left hand side, so it is 1 plus 1 by gamma let us take a T 1 common so if I take T 1 common it will become 1 minus T 4 by T 1 and T 1 outside, let us take T 2 common so T 3 by T 2 minus 1 T 2.

Now we see that let us take a negative of these numerators so 1 minus 1 by gamma T 4 by T 1 minus 1 T 3 by T 2 minus 1 T 1 by T 2 now let us just put the values 1 minus 1 by gamma T 4 by T 1 is r E to the power gamma you can see here r E expansion ratio to the power gamma minus 1 and T 3 by T 2 is simply r E so r E minus 1 T 1 by T 2, so this is the you know efficiency of at diesel engine which of course depends on the expansion ratio as I said before and also on the gamma, so one can have a calculation typically expansion ratio as 5 r E you know typical values of thing will be 5 gamma typical value will be like say 1.4 and you are going to get an efficiency of around 0.5, ideal efficiency is also almost like 0.3, 0.4 similar to like gasoline engine although we know that a little bit more efficient than gasoline engine the diesel engine is right.

Okay, so one important thing to discuss here is that in both the gasoline engine and diesel engine there is this constant pressure process and constant volume process, in gasoline engine there are two constant volume processes and in diesel engine one constant pressure and constant volume processes.

Now in constant pressure or volume processes the temperature changes all the time and therefore in order to make a reversible engine we need to place this system in infinite number of heat reservoirs. Therefore one you know it is difficult to compare with a Carnot engine which says that it has to work Carnot engine works between a fixed two temperature reservoirs. In this case it is not possible to do so, although we are getting an efficiency which is (())(17:19) temperatures, but it cannot be directly compared with the Carnot engine which says that the efficiency is 1 minus T 1 by T 2 because in that case there is only two temperatures T 1 and T 2 but in case of diesel engine there is there are all temperatures are different 1, 2, 3 and 4 all are different and so it does not really work between only just two temperature reservoirs.

However, given that they are all reversible steps one can have an effective two temperature differences to represent the efficiency of this engine if possible, but it cannot be directly compared with that. We are going to show that all reversible engines have basically same efficiency, the point is that the diesel engines cannot have that you know reversibility because of this constant pressure and constant volume steps.

So now we are going to show later that Carnot engine has the highest efficiency for working within the two temperature reservoirs and so that means all reversible engines have highest efficiency than the irreversible engines and all reversible engines have the same efficiencies. So that is why I was telling that given that diesel engine and gasoline engine can be constructed in reversible manner its efficiency will be as good as the Carnot engine because all reversible engine will have to have the same efficiency, but practically it is not possible because a constant temperature difference process cannot be done in reversible.