Engineering Thermodynamics
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Week-09
Lecture-41
Gas Power Cycle

Welcome to lecture 3 of Gas Power Cycle. In the previous lecture, we discussed the gasoline type engine which is based on Spark Ignition. We discussed how to approximate the ideal cycle of the motorcycle in which there are four processes. In this lecture we will discuss Diesel Cycle and some examples to understand how to solve it. So first let's talk about Diesel Cycle. What was the difference between it and Gasoline Cycle which we called otto Cycle? What was the basic difference? The fuel composition of both the air is different. The petrol in gasoline will have less molecular weight and the diesel will have higher molecular weight. Another property of this is the compression that we do in the process of the otto cycle, that’s why it is used as a spark to burn it. And the same thing, in the diesel cycle, the compression we will make, the temperature will be more than the auto ignition temperature. This means that it will be auto ignited, it will start burning automatically. So, this is the difference between the two. And that's why its cycle is also a little different. The combustion process in the diesel cycle, in which the fuel is burning, is slow. It takes time. And that's why in this and in the other case, which we are in spark condition, one is that the molecular weight is less, so it burns very fast. So, there is a difference between the two. And because of this, it is fast, we say that the combustion is at constant volume. And here, since it is for a longer duration, we approximate this process at constant pressure. There is a difference between the number of cycles and the number of processes in each cycle. The four processes in a cycle remain the same. But the only change is in the combustion process. In the auto cycle, it is at constant volume and in the diesel cycle, it is at constant pressure. So, this was invented by Rudolph Diesel, you can assume that it was made on an ideal cycle. And the major difference is the constant pressure. So, the heat addition process will be on constant pressure in the diesel. So, we are calling this idle cycle again because it has an idealization. This will be the same as the diesel engine. The only difference is in the diesel and the auto engine. As I said, the gasoline engine has a spark plug. Because the compression of the spark is below the temperature of the otto engine. So, the spark is needed for compression. Whereas the diesel engine has more compression. Due to this, it rises from the auto ignition temperature and starts to burn. So, this is the difference between the two.

Now, if you understand this in this form, which we call the process diagram form, then in the diesel cycle, as I said, the number of processes will remain the same as in the otto cycle. But the only difference is the heat addition, where the combustion process is called. We will call it heat addition. As we said in the otto cycle. So that part will be under constant pressure. Remember that the auto cycle was such that your isentropic Compression is 1-2, constant volume is heat addition, 2-3, then you have isentropic expansion, then 3-4, then 4-1 is heat rejection, which means exhaust. So here you have compression process, here you have exhaust, which is called heat rejection. So, this was the otto cycle. Here you can see the difference between 2 and 3 is the compression process. Here we are talking about heat addition. This is called heat addition. See here, 2 to 3 is the constant pressure. This is the difference. Rest, 1 to 2 is compression. And 2 to 3 to 4 is expansion. And 4 to 1 is rejection. So, first we compressed it, then we brought it to auto-ignition temperature, there is a compression, we replaced it with constant pressure heat addition, this is the idealization. Then it came to state 3, from 3 to 4, the volume has expanded, that is the isentropic process, in which we are hitting the entropy constant, which means it is internally reversible and adiabatic. and then 4 to 1 is the heat rejection at constant volume. You can write this in TS form as well, as I did in Auto. The only difference is that 1 to 2 will remain constant in entropy, 2 to 3 will remain pressure is equal to constant, which is the heat addition term, 3 to 4 again in constant entropy, 4 to 1 at constant volume. Just remember this. In the case of otto, remember that V is constant here. This is also V constant. Remember that.

Now let's do the analysis of this diagram. Note that the heat addition is between 2 to 3 and the heat reduction is between 4 to 1. If I want to calculate the efficiency of eta, then the efficiency of diesel will be W net equal to Q in, which we can see as 1 minus Q out by Q in. So, according to this, you should be able to extract this Qo Qin in state property 4-1 and 2-3.

$$E_{in} - E_{out} = \Delta E$$

$$q_{in} - w_{b,out} = u_3 - u_2$$

$$q_{in} = (u_3 - u_2) + P_2(V_3 - V_2)$$

$$q_{in} = (h_3 - h_2) = c_p(T_3 - T_2)$$

So, let's see how to extract it. For diesel cycle, another important thing is that we call it closed system. It is idealization. As we have taken a closed system in the otto cycle. Now let's discuss the 2-3 process, how to get Q in and Q out from internal energy in process of 4-1 and 2-3. Let's talk about 2-3 first. If we balance the energy per unit mass, then Ein minus Eout is equal to change in delta U which is the system energy. So, Ein minus Eout is equal to delta U which is equal to U3 minus U2 per unit mass. But what will be the Qin and Qout? Ein, which you call, minus Eout is equal to delta E. E out will be in this, because this is a piston cylinder, so you have added heat to the Qin, but the volume is changing, so naturally because it is a piston cylinder, it will move the boundary at constant pressure, so your W will be out. We can simplify this. This is P2, which is at constant pressure 2. P2 V3 minus V2. This will be your total W, Vout. V3 minus Vout. This means that Q is in. U3 minus U2 plus P2 V3 minus V2. If I want this U3 plus P2 V3 P2 is constant so U3 plus P3 V3 minus U2 plus P2 is equal to P3. Normally, when there is a constant pressure process, we have discussed this Q earlier. You can call Q as change in enthalpy. I am proving it to you. This is your H3. This is your H2. This is your H3 minus H2. We have assumed this as the ideal gas. So, we can write S3 minus S2 as Cp T3 minus T2. So, this is your Qin. Similarly, we can write 1 as constant volume. If you have constant volume, then Wb out will be 0. If you balance energy on E in minus E out, what is E in E in minus E out? E in is nothing. So 0 minus e out is your Q out This will be your U1-U4 So your Q out is your U4 minus U1 This is your Cv T4 minus T1 You will write in the form of U commissar Cv T4 minus T1 Now if you want to remove eta And we are always assuming in this Basically, the assumption is that we will take a cold standard air assumption. Meaning, Cv and Cp will be considered constant, like at room temperature. Unless, otherwise, you are told that you have to take variable.

Meaning, variable occurs when you have to see the table in this case. You cannot apply this directly in this. You will see the table first and then you will take out U4 and U1. and in Qe in, H3 minus H2 will also be taken out of the table. H2 will be taken out of the table, H3 will be taken out of the uptable. It will work when you cannot take your constant Cp or Cv there. In that case, you will not take this cold standard assumption. It will be written in the question; it will be told. Otherwise, if you do not know, you can say that you are taking the cold air standard assumption. This means that you are directly considering that del U Your Cv T4 minus T1 is done and TA Cv is constant in this process which will be at room temperature Now let's take out the eta Eta is your Went , queuing, one minus queued out. Qin Now this is already given by me 1 minus Qout was your Cv T4 minus T1 And Qin was Cp T3 minus T2 This comes 1 minus Cp by Cv is your K and this is T4 minus T1 T3 minus T2 So this is your k And you can write this Or you can simplify it 1 minus the ratio of temperature. Normally, the ratio of temperature is between 1 and 2, 1 and 4 and 3 and 2. You can say this. Because your ratio will be valuable here. So, if you want, you can write it in the form of the ratio. in this way, you can take out T1. And this will be your T4 by T1 minus 1. You can write it like this. In other case, you can remove T2 from the bracket and write it like this. So, this is how it can be written.

$$\eta_{th,diesel} = \frac{w_{net}}{q_{in}}$$

$$\eta_{th,diesel} = 1 - \left(\frac{q_{out}}{q_{in}}\right) = 1 - \left(\frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)}\right)$$

$$= 1 - \left(\frac{(T_4 - T_1)}{\left(\frac{C_p}{C_v}\right)(T_3 - T_2)}\right)$$

$$\eta_{th,diesel} = 1 - \frac{T_1\left(\left(\frac{T_4}{T_1}\right) - 1\right)}{T_2\left(\left(\frac{T_3}{T_2}\right) - 1\right)})$$

Now, we can define one more thing in this. So, this is your eta. In this, you see that k is your ratio. Which is the ratio of your specific heat. Now, we can do one more thing. Another term used in the diesel cycle is cut-off radius. Cut-off radius is the ratio of the cylinder volume after and before the combustion process. In this case, if you see the RC, the combustion process ends at 3. So, this means that the V of the cylinder is This is V3, and this is V2. So, the ratio of V3 to V2 will be the cut-off ratio. So, you can either take the total volume or the specific volume or the mass. So, this is the same thing. If you use this ratio, so after this ratio, you can also see that because you can use your ideal gas relations which we have already used. We have used V3 by V2 related to the ratio of temperature. And what is used in that. So, the relations of the ideal gas are in such cases, which are isentropic cases. So, if we use isentropic relation of the ideal gas, then the efficiency of the thermal can be reduced in two forms. First, you can use compression ratio in this. which you know is a factor, that will normally be V1 by V2. And the second is that the Rcm that we have defined V3 by V2, so after that, the relation that comes out is this. You can also drive, but I am directly writing here. So, this is k. So, you can see the efficiency in this. This is completely different from auto. In this, the term is multiplied. In the case of otto, you saw that eta was 1 by r k-1 in the case of auto. So, this efficiency of eta is different. In fact, the term you are seeing is If you check it, it will always be greater than 1. This means that if this term is greater than 1, it means that if eta is actually seen, the efficiency of the diesel is higher. This is based on these expressions. Now if we pay attention to this, as you increase the cut-off radius, efficiency decreases. Or if you decrease the cut-off radius, the efficiency increases. So, this expression will come out. Like if you increase the cut-off radius, you can see that its efficiency has decreased. If you increase the cut-off radius of RC, you have increased it to 2, 3, 4. So, if R is fixed, then this condition is valid in fixed R. But suppose Rc is 1, then this expression is 1, so Rc is equal to 1. You can prove this. In such cases, if the RCA is 1, then the eta of the thermal auto and ETA of the thermal diesel are the same. So, then you get the question that why people say that diesel is more efficient, why diesel is sold. The practical reason for this is that the R ratio in diesel was here in the auto case. But in the case of diesel engines, it is usually higher. If the engine is higher, then naturally, look at your expression. If the compression ratio is high, then it will be higher. That is why in practical cases, the efficiency of the diesel engine is higher. The engine runs better because the compression ratio is higher.

Now we have understood this, so let's clear our thoughts by questioning it. So, this question is on the ideal diesel cycle. And in this, the compression ratio is given 18, which means that R is given 18, which will be your V1 by V2. And the cut-off radius, which is given, RC is given, V3 by V2 is equal to 2. At the beginning of the compression process, the air conditioner is given as 100 kPa and 25 C and 19-17 cm3. Now we have to use the A equal to A standard. This means that we will take C, V and E constant at room temperature. We have to know the temperature and pressure of air after every process. network output and how much is the efficiency of the thermal and how much is the mean effective pressure. Let's understand it. First, you have to understand what the process diagram is. So, process diagram. So, this is 1, this is 2, this is 3, this is 4. This is your isentropic. This is the compression; this is the isentropic expansion. This is the heat in, Q in. And this is Q out. This is the pressure, and this is the volume. So, what are the assumptions given to us? First, assume that this is the cold standard. This means that we have to give constant specific heat. at room temperature. We will take it to room temperature. And we can take out its values from the table. So, its value will be like the Cp value will be 005 kJ per Kelvin. Cv will be 0.718 kJ per Kelvin. K is 1.4 This table is in A2A and you know gas in air value R is 287 kPa m cube per kg Kelvin So all these properties are derived from you Now what we have to do is We have to calculate the temperature and pressure of the end point. So, what we have been given is that initial conditions are given. At the beginning of compression process, state 1 is given. State 1 is given. V1 is given. V1 is given. P1 is given. 100 kPa T1 27 kPa 300 kPa Take care. Now we have received this information and also this information that V1 by V2 is 18 and V3 by V2 is 2 Let's start V1 is known here so V2 will be V1 by 18 which is 19.17 by 18 cm cube this is 106.5 cm cube After that comes V3, now you know V2, so what is V3? V3 will be taken out from here V3 will be 2 times V2 which will be 213 cube and V4 will be, V1 So you know the volume of all points Now we try to take out the temperature So, if we talk about process 1-2, then it has an isentropic process. In the isentropic process, you can write T2 by T1 as 1 by V2 k-1 because this is the constant of PV to the work k. You can get this relation from this. We got this in the ideal gas scale relations. So, from here you will get T2. which will be T1 times V1 by V2 V1 by V2 is nothing but 18 and K is 1.4 minus 1 T1 is 300 Kelvin so this is 953 Kelvin Okay. From here, we can also take out the pressure. Similarly, like we had the T1, T2 and T1 relations, P2 is also the relation of P2 by P1. This is the same as V1 by V2, but it has KL. Okay. So, from here, P2 will come out. P1 times 18, 1.4. Which comes out to be 572.20 kilopascal. So of course, P2 and P1 are out. Now you can do the rest of the things like this, but for the sake of completion, I will show you. So, you have removed 1 and 2, the pressure of 2 and 3 is the same. So P3 is removing the 3rd state, which is called state 3. So P3 is equal to P2. Since it is a constant pressure, we will simply take out the I.G. relation. So P3 V3 by T3 will be P2 V2 T2. And you have P2 and P3. So, you can cancel P3 and P2. So, your T3 will come out from here. T2 V3 by V2 V3 and V2 are ratio This is RC basically So this is T2 into RC So this is RC's 2 This is 953 So from here your T3 will be 1960 Kelvin So you know P2, P3 and T3 Now let's talk about state 4 For that we will do 3 to 4 which is an isentropic process. Expansion, now we will do the same thing that T4 by T3 will be V3 by V4 k-1 and similarly P4 by P3 will be V3 by V4 k. Now we can remove V3 by V4 easily. Why? You have already taken out V3 This relation So I already know all this information So we can take it out from here Which will actually come out the same The compression is from 2 to 1 So I have already taken it out from here I already know V3 And in this case i know V4 is your V1 Which is 106.5 cm3 No, no, this V1 is same so this value will come out 1917 cm3 So if you click here and enter this information then this value will come out T4 T3 213 by 1917 centimeter cube 791k T3 you have to plug in 1960 is the Kelvin so this is the answer 1791 Kelvin And similarly, the pressure will be released from here also. P4 is P3. V3 by V4. This is actually K, so it will be 1.4 minus 1. It will come here 1.4. So, this is 264 kPa. So, the process is the same. You just have to pay attention to this that what we are removing continuously, pay attention to it. Like this control, you have to highlight it well. Like you have to, because in many places you have to You can see that the temperature is being used. Note that you have to identify it clearly and highlight it so that you can use it well in future questions. So, this way you have got all the temperature and pressure. Now we have to get the network output and the thermal efficiency. So, let's go now. For the net output, you have to use eta, w net By Q in over. So, we can either remove it like this or I can remove it like this which we removed earlier. This relation, we can use this relation and this relation as well. It's the same thing. Since we have to remove the net work so it's easy for us to remove the Qw net first. Which is Q in minus Q out. So Q in is M dot S3 minus H2 which is constant pressure so this will be M Cp T3 minus T2 So from here this expression is out T3, T2, Cp, M will have to be taken out For M I will have to use Idle gas initial condition is given pressure state 1 is given pressure volume and the temperature is given, if we plug in the value of R then it will come out to be 0.00223 kg so this way you can get the Q in Q in comes out to be 21.136 kJ and Q out will come out to be Mu4-u1 which will come out to be McV Te4 minus Te1 If you plug in this Now it will be 0.786 kJ And in this way Wnet will come out 2136 0.786 So it is 1.35 kJ So it is 0.632 and 63.2% If you had plugged in, then your relation would have been the same because you would have to type RC to R18 that 1.4-1 here K-1 so this is the same so whether you do it like this or like that because the relation is the same, you can do it directly why you can do it? because you can easily calculate in one expression We can do this because we had put a cold air assumption in it. So, we can use this expression also. The expression should be similar. The expression of cold air which we had written as 1-1 by rk-1 and the other term which was there. Okay, so we can use this also directly. The third question was that we have to use mean effective pressure in this. Remember that Wnet, Vmax, Vmin, V1 minus V2, 746 kPa So this is the mean effective pressure 746 kPa I hope you understood the It was simpler, you didn't have to use a table. You directly used heat, specific heat, enthalpy relation and internal energy relation. And it was considered constant, Cp and Cv. So, it became easy for us, we didn't have to use a table. But the table is much easier. You will get it more quickly; you won't have to do calculations. You can directly take it out of the table, if there is data in the table and you don't have to do interpolation. So, I hope you understood this. In the next lecture, we will catch another cycle, which will be called Brayton cycle. See you in the next lecture.