Fundamentals of Automatic Systems
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Module No # 03
Lecture No # 14
Engine Performance

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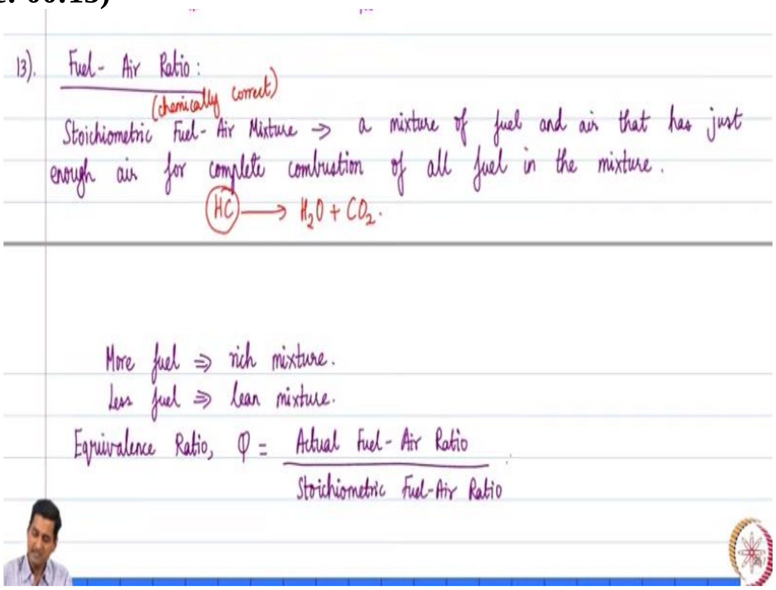

So another important parameter that is critical for internal combustion is the fuel air ratio the air fuel ratio. So as it indicates you know like you we have to essentially determine what is the ratio of fuel and air in a mixture of them right so that is what is specified by fuel to air ratio. And before we go into defining some parameters we are going to define what is called as a stoichiometry fuel air mixture I am sure we would have encountered this words sometime before right basic chemistry right.

So stoichiometry mixture is a chemically correct mixture in this case what is stoichiometry mixture? It is a mixture of fuel and air that has just enough air for complete combustion of all fuel in the mixture is what is called as a fuel air mixture okay. So what is mean by complete combustion? All the hydrocarbon should be completely oxidized to H2O and CO2 so that is a perfect fuel air mixture okay chemically correct fuel air mixture or what is called as a stoichiometric mixture okay.

So this is a chemically correct fuel air mixture now we can have more fuel in the mixture than the chemically correct mixture that implies what is called as a rich mixture. So a rich mixture is one which has more fuel in the fuel air mixture than the chemically correct mixture. So if you have less fuel we have what is called as a lean mixture okay so these are some terms and based on these we are going to define some parameters for the equivalence ratio Phi which is the actually fuel to air ratio to the stoichiometry fuel to air ratio okay so that is an definition of equivalence ratio.

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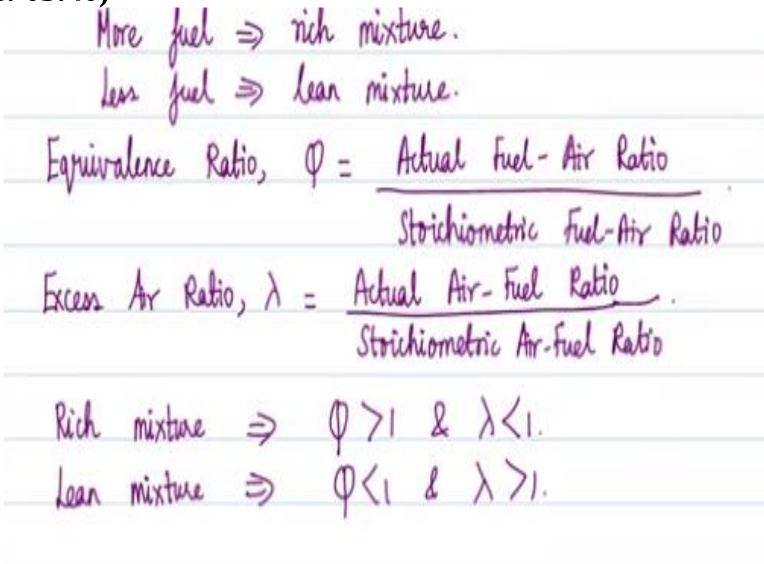

Some people use another parameter called excess air ratio it is just a inverse of this so it is the actual air fuel ratio divided by the stoichiometry air fuel ratio. Okay so that is another definition so you just swap the ratios okay first case it was fuel air now it is air to ratio. So why would some people prefer because typically you know like even if we consider a typical fuel where let us say the stoichiometric fuel to air mixture should contain one part of fuel and 15 parts of air.

Fuel to air ratio will be 1 by 15 the air to fuel ratio will be 15 so some people find it convenient to say okay like 15 is to 1 or 14.2 is 1 right and so on right. Rather than saying 1 by 15 is to 1 right 1 by 15 goes into some decimal places and so on which is what to say which people and people find more convenient to state the air fuel ratio but both are the same so it is just a matter of convenience.

So the a rich mixture implies the equivalence ratio is greater than 1 and the excess air ratio is less than 1 right a lean mixture is 1 where the equivalence ratio is less than 1 and the excess air ratio is greater than 1 okay so that is the definitions of equivalence ratio and excess air ratio.

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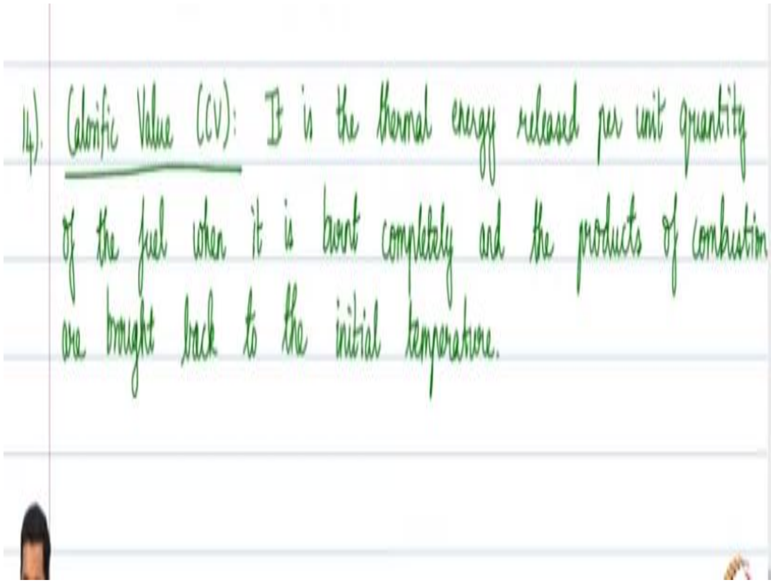

So one more parameter which we are going to encounter is the calorific value so we have already encountered calorific value when we defined the efficiency terms right so what is the calorific value. So the calorific value of a fuel is the thermal energy released per unit quantity of the fuel when it is burnt completely and the products of combustion are brought back to the initial temperature.

So that is what is the calorific value of the fuel so it is the indicative of how much what to say energy heat chemical energy right the heat energy that you can get by burning the fuel right combusting the fuel. So these are some parameters that are used for quantifying engine performance okay.

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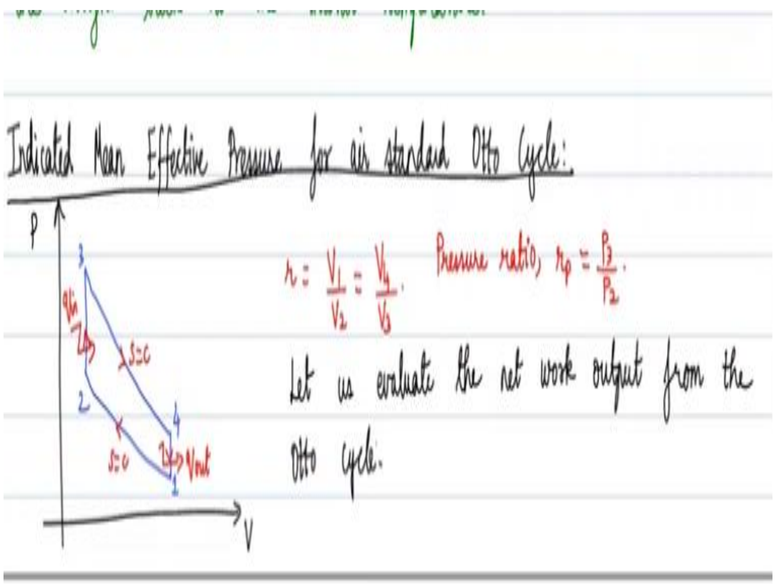

So the next thing I want to discuss in today's class is give a notion on the indicated mean effective pressure right. So let us derive an expression for the indicated mean effective pressure or IMEP for the air standard auto cycle. So that like that we understand what are the parameters that affect or influence this mean effective pressure. So just to quickly recap the air standard auto cycle the PV diagram looks something like this so this is state 1, 2, 3 and 4.

So we always need to mark the flow of the process is right and also some critical characteristics of each process okay. So we already know that the compression ratio r is going to be V1 / V2 and that is also going to be equal to V4 / V3 and pressure ratio which is given by rp is defined by P3/P2 okay so that is something which we these are parameters that we already are aware of. So now let us calculate or evaluate the net-work output from the auto cycle.

So let us do that exercise so why are we evaluating the net-work output because that is the definition of indicated mean effective pressure right is nothing but the net-work output per unit cycle divided by the displacement volume.

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$PV^{\gamma} = C \Rightarrow P = CV^{-\gamma}$, $\quad C = PV^{\gamma}$

$$3\rightarrow 4: \int_3^4 P\,dV = \int_3^4 C V^{-\gamma}\,dV = C\left.\frac{V^{-\gamma+1}}{-\gamma+1}\right|_3^4 = \left.\frac{PV}{-\gamma+1}\right|_3^4 = \frac{P_4V_4 - P_3V_3}{-\gamma+1} = \frac{P_3V_3 - P_4V_4}{(\gamma-1)}.$$

$$1\rightarrow 2: \int_1^2 P\,dV = \frac{P_1V_1 - P_2V_2}{(\gamma-1)}.$$

$$\Rightarrow W_{net} = \frac{P_3V_3 - P_4V_4}{(\gamma-1)} + \frac{P_1V_1 - P_2V_2}{(\gamma-1)}.$$

So we can immediately see that the net-work output as two component the first component is from during the expansion process so in the expansion process the work which is delivered is nothing but integral from going from 3 to 4 P times dV right so that is the work output correct. Now how do I simplify this I use a process relationship because we know PV power gamma equals constant right that is an isentropic process relationship.

So this implies that P is some CV power minus gamma right so I just substitute that here so if I substitute it here I am going to get this. So what will happen if I integrate I will get CV power minus gamma +1 divided minus gamma +1 going from 3 to 4 right. Before we evaluate here once again I can substitute C = PV power gamma right so what will I get? I will get PV divided by minus gamma +1 evaluated between 3 and 4 how did I get this?

Here I can substitute C equals PV power gamma right PV power gamma times V power minus gamma +1 will give you PV so that is what I did. So as a result we will get P4 V4 – P3V3 by gamma + 1 this I rewrite it as P3V3 – P4V4 by gamma -1 okay so that is what. So anyway this work is positive right so this is the positive quantity because it is work output term right during the expansion process and we can see that quantity is going to be positive.

So similarly if I consider the process from 1 to 2 and we evaluate this I would leave this as an exercise you will immediately see that if you follow a similar process we are going to get this expression okay. So that is the work interaction during the compression process obviously you see that this is going to have a negative sign because we are providing that is a sign convention it is used right work given to the system or work done on the system is negative so this is going to be negative.

So consequently the net-work output is going to be the sum of the 2 it is going to be P3V3- P4V4 divided gamma -1 + P1V1 – P2V2 by gamma -1 so this is the net-work output okay.

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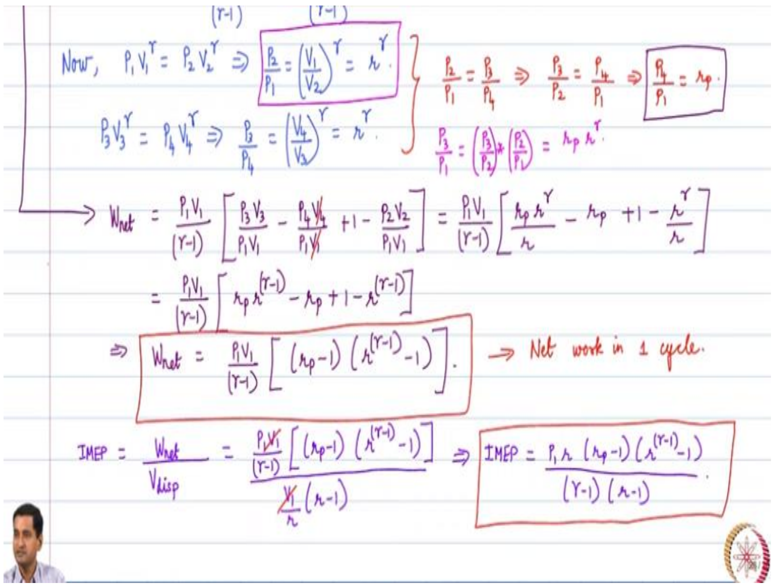

So now we simplify so we know that P1V1 power gamma equals P2V2 power gamma right so that is from the process relationship. So we immediately can rewrite P2/P1 as V1/V2 is the power gamma and V1/V2 is the compression ratio so I get r power r. Similarly P3V3 power gamma is going to be equal to P4V4 power gamma so this will give me P3/P4 to be equal to V4/V3 power gamma and that is also equals to r/r power gamma correct.

So this essentially tells me P2/P1 is equal to P3/P4 why because both ratios are equal to r power gamma so obviously both ratios should be the same. So if I the change the order I will get P3/P2 to be equal to P4/P1 and what is P3/P2 equal to the pressure ratio rp. So you see that P4/P1 is also r subscript p right the pressure ratio okay. And another what to say equation which we are going to use here is a following if we take P3/P1 we are going to need all these pressure ratios shortly I can rewrite this P3/P2 times P2/P1 okay what is P3/P2 rp right.

What is P2/P1? r power gamma right so we are going to utilize all these equations okay so now what we are going to do is that following. We are going to simplify this expression so let us take the expression for W net let me take P1V1 / gamma -1 as common so what will I have? I will have P3V3 / P1V1 – P4V4 / P1V1 + 1 – P2V2 / P1V1 immediately we observe that V4 and V1 gets cancelled because they are the same right what is P3/P1 let us take the first term P3/P1 is going to be rp r power gamma we just deleted right.

We can also here correct that is rp r power gamma and what is V3 / V1 it is 1 / r V1 / V3 is r V3/V1 is going to be 1 / r so that is how the first expression will simplify P4 / P1 is rp we just got it here right P4 / P1 is rp right and going to substitute for that then I will have +1. What is P2 / P1 it is r power gamma we get it from here and what is V2 / V1 once again 1/r right it is a reciprocal of the compression ratio.

So what we have is that following we have P1V1 whole to the power gamma -1 times rp r power gamma -1 – rp +1 – r power gamma -1 okay so this is what we have. So this implies that the net-work output in one cycle is going to be equal to P1V1 to the power gamma -1 sorry divided by gamma – 1 multiplied by rp – 1 times r power gamma -1 -1 okay I can simplify that into product of these two factors right.

So this is the net-work in one cycle so what is IMEP? It is this network in one cycle divided by the displacement volume. So now going up what can I say about the displacement volume V displacement is going to be equal to V1- V2 I can rewrite this as V1 times 1 – V2 / V1 and what is V2 / V1 1 / r. So I can get V displacement as I can write V displacement as V1 / r times r – 1 right so very simple just using the definition of compression ratio to just rewrite the displacement volume in terms of V1 and obviously the reason will become very clear shortly right so that is fine displacement volume so let us come down.

So IMEP is going to be equal to the net work done in one cycle divided by displacement volume the net work done is this P1V1 power gamma – 1 multiplied by rp – 1 times r power gamma – 1 - 1 divided by the displacement volume that is going to be V1 divided by r times r – 1 right so we can immediately see that V1 and V1 cancel off. So this implies that the indicated mean effective pressure of the auto cycle becomes P1 times r because the r comes from the denominator times rp – 1 times r power gamma -1 -1 divided by gamma -1 times r -1.

So this is the expression for the IMEP for the auto cycle okay as an exercise I want you to do the same derivation that is fine an expression for IMEP for the air standard diesel cycle and the dual cycle. In terms of the initial pressure P1 and all other parameters are rp, rc as appropriate okay and gamma okay. So you can immediate see that the indicated mean effective pressure is dependent on P1 is the pressure at the start of the cycle right the initial state 1.

So going to back to our previous discussion we can immediate see that if I increase the value of P1 obviously the indicated mean effective pressure also would increase and the process of super charging would essentially increase the value of P1. So now one can easily observe the direct benefit of increase in the inlet pressure right and this process of super charging is something which we will discuss in the next class okay so I will stop here for this class and we will continue with super charging in the upcoming class fine thank you.