Thermal Engineering Basic and Applied
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Lecture - 57
Numerical Problems on Engine Performance

I welcome you all to the session of Thermal Engineering Basic and Applied and in today's class we shall solve two numerical problems on engine performance. In the last few classes we have discussed about the thermal performance of both Otto and diesel cycles as such through the discussion of this particular topic that is the thermal performance analysis. We could establish the mathematical form of thermal efficiency of both SI and CI engines.

So, now we shall solve two problems on engine performance and we will see that from the given data those are required to design several components of internal combustion engines, how can we estimate the efficiency and several other performance measuring parameters.

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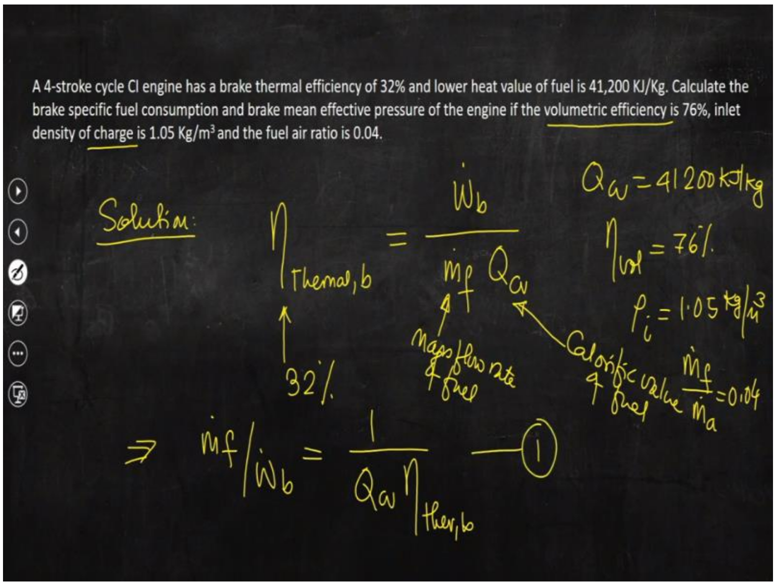

So, the first problem is given here, let me read out the statement of this problem. A 4 stroke cycle CI engine has a brake thermal efficiency of 32 percent. So, now though we are yet to discuss about several efficiencies of internal combustion engine, but we could discuss about brake thermal efficiency when we had discussed about several parameters like brake horsepower, indicated horsepower, brake power, indicated power etc.

So, in the last two, three classes we could establish the thermal efficiency of both Otto and diesel cycles. So, when it is brake thermal efficiency definitely it is the efficiency which is calculated based on the brake power. So, now if we write the mathematical form of this efficiency that is nothing but the ratio of break power that is the power available at the shaft to the amount of energy that is supplied to get this amount of power.

$$\eta_{th,b} = \frac{\dot{W}_b}{\dot{m}_f Q_{CV}}$$

So, this is mass flow rate of fuel and this is calorific value of fuel. So, now let me read out the rest of the statement of this problem and the lower heat value of the fuel is 41,200 kilojoule per kg, $Q_{CV} = 41200\,\frac{kJ}{kg}$.

So, what we need to calculate? We need to calculate the brake specific fuel consumption and brake mean effective pressure of the engine if the volumetric efficiency is 76 percent, inlet density of charge, ρ_i is 1.05 kg per meter cube and fuel air ratio, $\dot{m}_f/\dot{m}_a$ is 0.04. So, now it is though written charge but for the CI normally we need to supply air through the intake manifold into the engine cylinder.

But we could define charge as the mixture of air and fuel. I mean charge means basically it is the air for the CI engine. Now one new term that we are getting today is the volumetric efficiency though I could not discuss about this particular efficiency, but for the timing to solve this problem I can tell you the mathematical expression of this efficiency and what this efficiency is all about.

$$\eta_{th,b} = \frac{\dot{W}_b}{\dot{m}_f Q_{CV}} \rightarrow \frac{\dot{m}_f}{\dot{W}_b} = \frac{1}{\eta_{th,b} Q_{CV}} \ldots \ldots (1)$$

So, you can see the first quantity that we need to calculate is the brake specific fuel consumption so that is bsfc. We have discussed about specific fuel consumption and we can also write the specific fuel consumption by adding prefix to it I or b if it is I then indicated specific fuel consumption. If it is b then it is brake specific fuel consumption.

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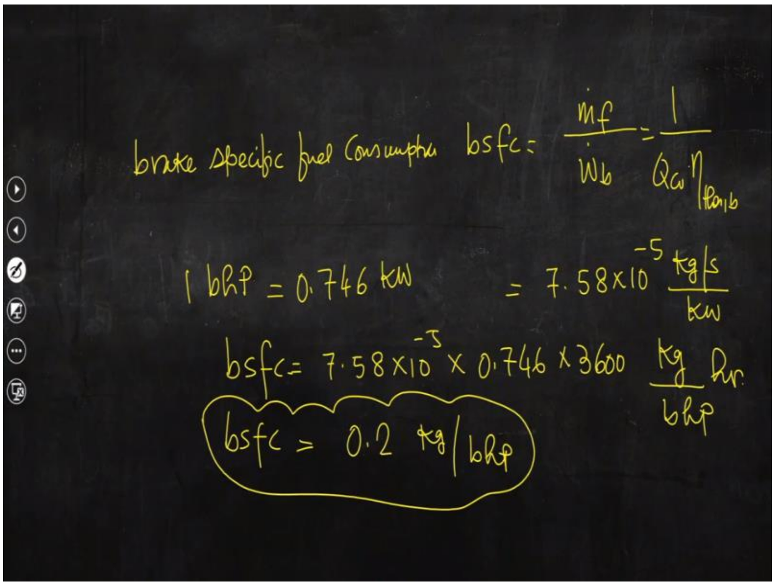

So, brake specific fuel consumption that is bsfc. So, this bsfc is nothing but mass flow rate of fuel that is the amount of fuel needed to be supplied to the engine to get the brake power. So, this is $\frac{\dot{m}_f}{\dot{W}_b}$. So, if you would like to get unit brake power the amount of mass flow we need to supply to the engine that is the brake specific fuel consumption bsfc.

$$bsfc = \frac{\dot{m}_f}{\dot{W}_b} = \frac{1}{\eta_{th,b} Q_{CV}} = (7.58 \times 10^{-5})(kg/s)/kW$$

Now it is quite convenient to write this unit like kg per BHP hour. So, basically that is the common unit of this quantity. So, we know that one brake horsepower equal to 0.74 6 kilowatt. If that is the case, so we can replace this kilowatt in terms of brake horsepower.

$$bsfc = 7.58 \times 10^{-5} \times 0.746 \times 3600 \frac{kg - hr}{bhp} = 0.2\ kg/bhp$$

So, the answer to the first part of this question is brake specific fuel consumption bsfc and that we have already calculated that is 0.2 kg per brake horsepower hour.

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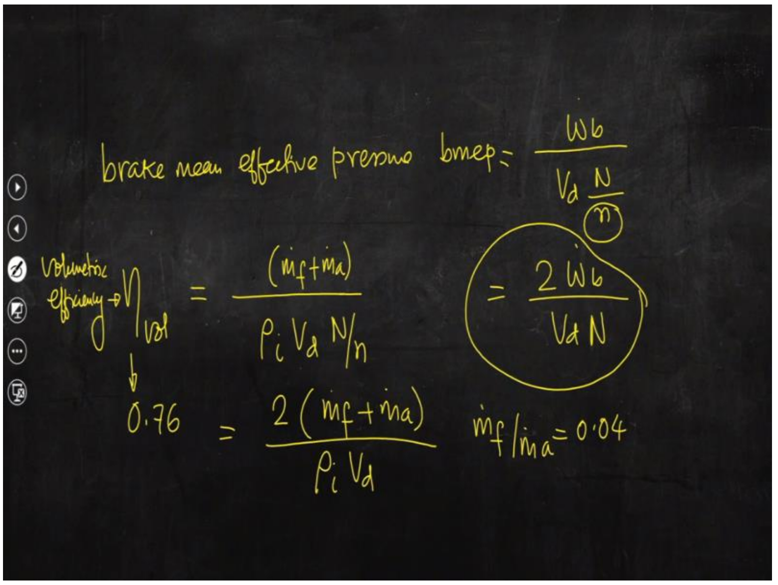

So, brake mean effective pressure is bmep. So, this bmep is if we try to recall W dot b divided by this displacement volume into N divided by small n this is the expression.

$$bmep = \frac{\dot{W}_b}{\frac{V_d N}{n}} = \frac{2\dot{W}_b}{V_d N}$$

Now n is number of revolution per cycle. So, it is 4 stroke engine that means n equal to 2. Now we have no clue about the displacement volume from the data set given, but the numerical value of volumetric efficiency is given. Let me tell you once again we did not discuss about the mathematical expression and the definition of volumetric efficiency, but we need to use this particular term today.

$$\eta_{vol} = \frac{\dot{m}_f + \dot{m}_a}{\rho_i V_d N/n}$$

So, you can understand that we are supplying the amount of air during the intake stroke of course per cycle. So, there are two revolutions per cycle so definitely. So, per cycle we are supplying this is the amount of air that is drawn into the cylinder. So, we can get this Vd from this volumetric efficiency.

$$0.76 = \frac{2(1/0.04 + 1)\dot{m}_f}{1.05\, V_d N}$$

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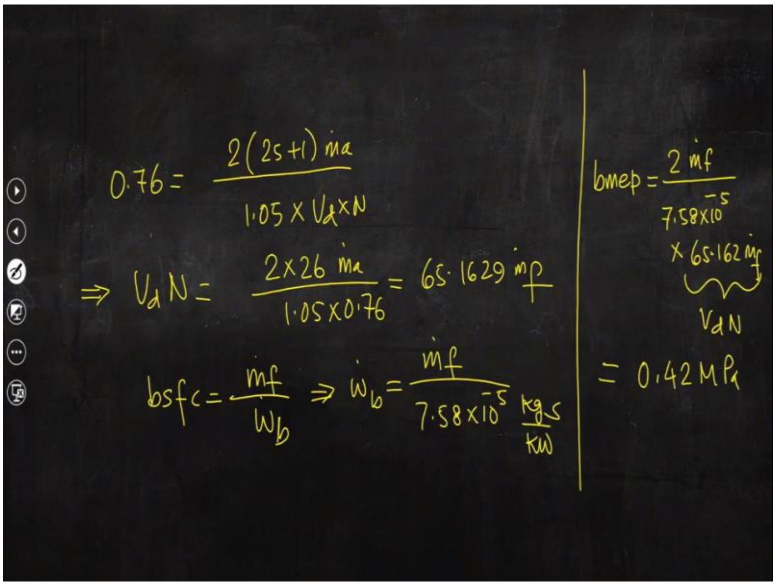

$$V_d N = 2 \times \frac{26\dot{m}_f}{1.05 \times 0.76} = 65.1629\dot{m}_f$$

Now, we need $V_d N$ to get brake mean effective pressure. So, we also can get Wb bsfc.

$$bsfc = \frac{\dot{m}_f}{\dot{W}_b} \rightarrow \dot{W}_b = \frac{\dot{m}_f}{(7.58 \times 10^{-5})(kg/s)/kW}$$

$$bmep = \frac{2\dot{W}_b}{V_d N} = \frac{2\dot{m}_f}{7.58 \times 10^{-5} \times 65.1629\dot{m}_f} = 0.42MPa$$

So, if we go back to the problem statement again. So, from the quantity is given we could calculate the brake specific fuel consumption as well as the brake mean effective pressure,.

But most important part of this particular problem is we can see a new term that is volumetric efficiency. Though I have used the mathematical expression of this particular term, but we shall discuss about this particular efficiency again in one of the next classes. So, this is all about the first problem and finally we can solve another one problem. So, if we go to the next one.

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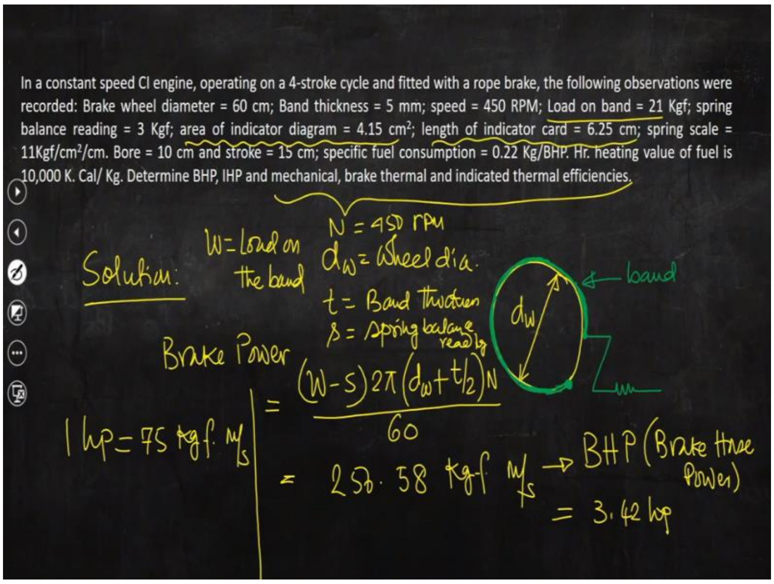

So, this is the second problem, in a constant speed CI engine operating on a 4 stroke cycle and fitted with a rope brake the following observations were recorded. Brake wheel diameter 60 centimeter, band thickness 5 millimeter, speed 450 RPM. Load on band is 21 Kgf, spring balance reading is 3 kg force, area of indicator diagram is 4. 15 centimeter square.

Length of the indicator card is 6. 25 centimeter, spring scale is 21 Kgf per centimeter square per centimeter, bore diameter is 10 centimeter, stroke is 50 centimeter, specific fuel consumption is given 0.22 kg per BHP hour. You can see that in the previous problem we could calculate the brake specific fuel consumption that was of course bsfc, but here it is given specific fuel consumption that is 0.22 kg per brake horsepower.

So, basically it is again bsfc per hour, heating value of the fuel is 10,000 kilo calorie per kg, determine brake power, indicated horsepower and mechanical brake thermal and indicated thermal efficiencies. So, though we are yet to discuss about several efficiencies you can understand from the problem we are going to solve today already we have discussed about volumetric efficiency.

In the previous class we have discussed about the mechanical efficiency and we are also going to see there are two other efficiencies like brake thermal and indicator thermal efficiencies. So, basically at the cost of the input energy you know brake work and indicated work these two works are not equal. So, if we consider the indicated work to calculate the efficiency then definitely it would be indicated thermal efficiency.

On the other hand if we consider the brake work that is the work available at the shaft and then it would be the brake thermal efficiency and as I said you that the work which is available at the shaft is not equal to the indicated power because there are several losses to overcome the friction between the mating components.

So that is why mechanical efficiency is coming into the picture. I am telling once again we shall be discussing about all these efficiencies in one of the next classes. So, we can solve this problem, that there is a test in thermal engineering lab and the test is done on internal combustion engine to calculate all these parameters and normally in lab scale what is done you know that this rope brake is used to provide load to the engine because if we do not provide load to the engine.

Because the load is given and load is measured. So, at the cost of that load what would be the several efficiencies that we can calculate. So, here it is rope brake, I am drawing one schematic. So, this is basically the break diameter. So, this is diameter of the wheel, d_W.

So, this is band. It has certain thickness and this band is fixed. What is done that when engine is rotating, now if we try to wrap one band over the periphery of this particular wheel and that is spring loaded you can see and if you try to just tight the band then perhaps the spring balance will give one reading. So, from there we can measure the load being applied by an external rope brake arrangement.

So, the load which is applied to the engine by this external arrangement, so from that particular load we can calculate several other performance measuring parameter. So, now question is first we can calculate brake power because this arrangement is to measure the brake power. So, what is the amount of work available at the shaft. So, as I said if you try to recall the schematic depiction engine is having reciprocating movement between two centers BDC and TDC.

Now the reciprocating motion is converted to the rotary one using the crank and connecting rod mechanism. So, the wheel is rotating and from there wheel is connected to a shaft. So, if we can measure the work or power available at the shaft by using this particular arrangement that would be the brake power.

$$BP = \frac{(W - s)2\pi\left(d_W + \frac{t}{2}\right)N}{60} = 256.58\, kgf - m/s$$

So, t is the band thickness, w is load on the band and s is the spring balance reading. So, this is the brake power and we can get it brake horsepower as $1hp = 75kgf - m/s$. So, $BHP = 3.42\, hp$. Now, area of the indicator diagram and length of the indicator card is given.

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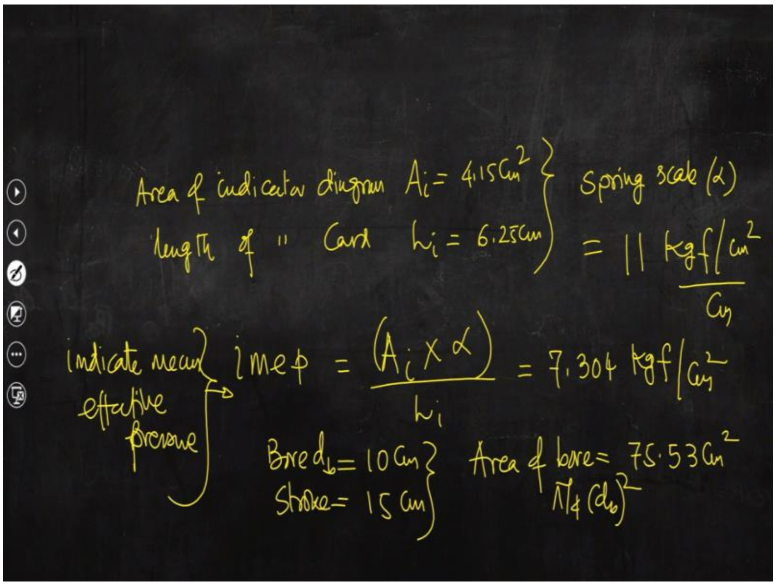

So, what is indicated mean effective power? I told you that the pressure inside the cylinder is continuously changing. But we could obtain the integral expression of that the work done, so this indicated mean effective pressure is this area of the indicator diagram into spring scale divided by L_i.

$$imep = A_i \times \frac{\alpha}{L_i} = 4.15 \times \frac{11}{6.25} = 7.304\, kgf/cm^2$$

Now, bore diameters is given 10 centimeter. So, area of the bore is $\frac{\pi}{4} d_b^2 = 75.53\ cm^2$. So, we know the stroke length then we can calculate the volume.

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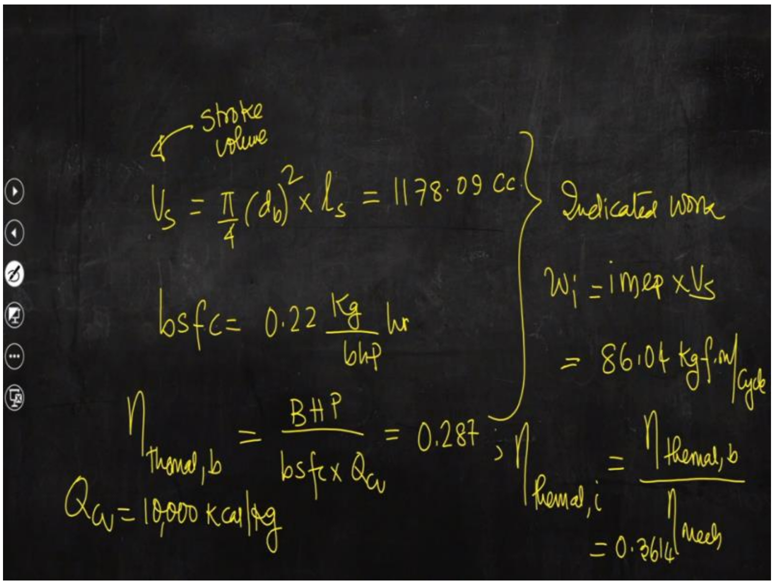

So, this is

$$V_s = \frac{\pi}{4} d_b^2 \times l_s = 1178.09\ cc$$

So, we can calculate indicated work that is

$$\dot{w}_i = imep \times V_s = 86.04\ kgf - m/cycle$$

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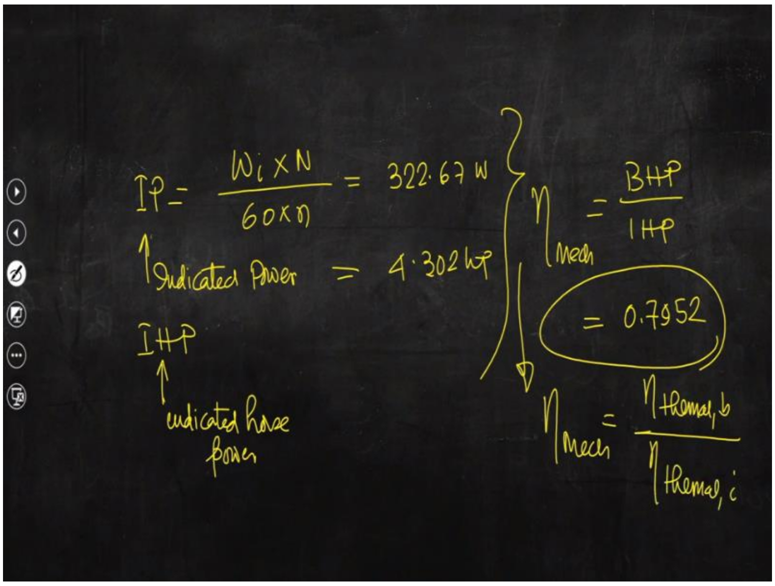

Then indicated power

$$IP = \dot{w}_i \times \frac{N}{60 \times n} = 322.67\ W; IHP = 4.302\ hp$$

So, definitely indicated horsepower is higher and the certain amount of indicated power will be used to overcome the frictional loss.

$$\eta_{mech} = \frac{BHP}{IHP} = 0.7952$$

So, we need to calculate brake thermal and indicated thermal efficiencies. So, already we have calculated brake specific fuel consumption.

$$\eta_{th,b} = \frac{BHP}{bsfc \times Q_{CV}} = 0.287$$

Now from mechanical efficiency we can write

$$\eta_{mech} = \frac{\eta_{th,b}}{\eta_{th,i}} \rightarrow \eta_{th,i} = 0.3614$$

And definitely you can understand that indicated thermal efficiency is higher than the brake thermal efficiency and that should be. So, we have calculated as per our expectation. So, basically what we have understood that the indicated power is higher than brake horse power naturally indicated efficiency will be higher than the brake thermal efficiency.

So, to summarize we have solved two problems on engine performance and we have seen that from the given set of data if we need to calculate several performance measuring indices then how can we calculate, we have solved considering two different problems. With this, I stop here today and we shall continue our discussion in the next class. Thank you.