Lecture (4c)
Internal Combustion Engine

ENGINE PERFORMANCE

Performance Factors Of ICEs

The performance of an engine is evaluated on the basis of the following :

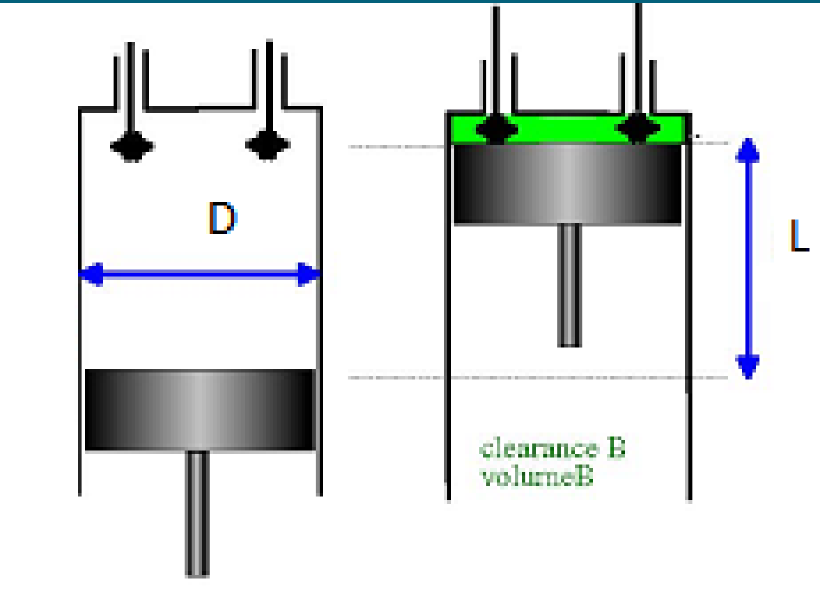
- **Specific Fuel Consumption.**
- **Brake Mean Effective Pressure.**
- **Specific Power Output.**
- **Specific Weight.**
- **Exhaust Smoke and Other Emissions.**

For an engine with:

Diameter (bore)	***D***	***m***
stroke length	**L**	**m**
an engine speed	***N***	***rpm***
No. of cylinder	***n***	

No. of revolution for one cycle ***x***

	x=2	***for 4-strok engine***
	x=1	***for 2-strok engine***



Air-Fuel Ratio:-

- For combustion to take place, the proper ratio of air and fuel must be present in the cylinder.

- The air-fuel ratio is defined as

$$AF = \frac{m_a}{m_f} = \frac{\dot{m}_a}{\dot{m}_f} \Rightarrow \frac{\mathrm{kg_a}}{\mathrm{kg_f}}$$

- For a SI engine the AF is in the range of 12 to 18 depending on the operating conditions.

- For a CI engine, where the mixture is highly non-homogeneous and the AF is in the range of 18 to 70.

- It is the ideal (Chemically Correct) A/F ratio that just burns all the fuel.

Natural gas: 17.2
Ethanol: 9
Diesel: 14.6

Gasoline: 14.7
Methanol: 6.4

Propane: 15.5
Hydrogen: 34

Equivalence Ratio:-

$$\phi = \frac{\left(F/A\right)_{actual}}{\left(F/A\right)_{chemically\ \text{correct}}}$$

$\phi = 1$ Chemically correct mixture

$\phi > 1$ Rich mixture

$\phi < 1$ Lean mixture

Calorific Value (CV):-

- The amount of heat liberated by the combustion of a unit weight (or if a gas, a unit volume) of fuel.

Fuel	CV	Units
Gasoline	48000	kJ/kg
Diesel	45000	kJ/kg
Natural gas	43000	kJ/m^3

Fuel Power:-

- Fuel power is the thermal power released by burning fuel inside the engine.

$$\dot{Q}_{Fuel} = \text{Mass burned of fuel per second} \times \text{Calorific value of fuel}$$

$$\dot{Q}_{Fuel} = \dot{m}_{Fuel} \times CV$$

$$\text{Units}: \frac{\text{kg}}{\text{s}} \times \frac{kJ}{kg} = \frac{kJ}{s} = kW$$

Power:-

The main purpose of running an engine is to obtain mechanical power.

- **Brake power (b.p.):**

  The power developed by an engine and measured at the output shaft.

$$B.P. = \omega \times T = \frac{2\Pi N}{60} \times T \Rightarrow \text{units}: \left(\frac{rad}{rev}\right)\left(\frac{rev}{s}\right)(J) = Watt$$

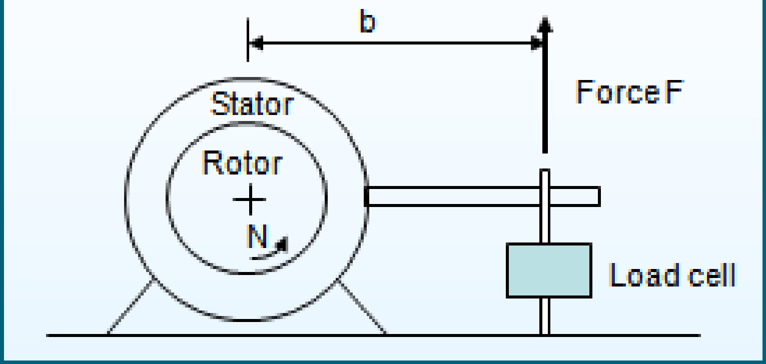
Where:

T	***is torque***	***N-m or J***
ω	***is the shaft angular velocity***	***rad/s***
N	***is the rotational speed***	***revolutions per minute.***

- **Torque is measured using a dynamometer.**

The **torque** exerted by the engine is *T*:

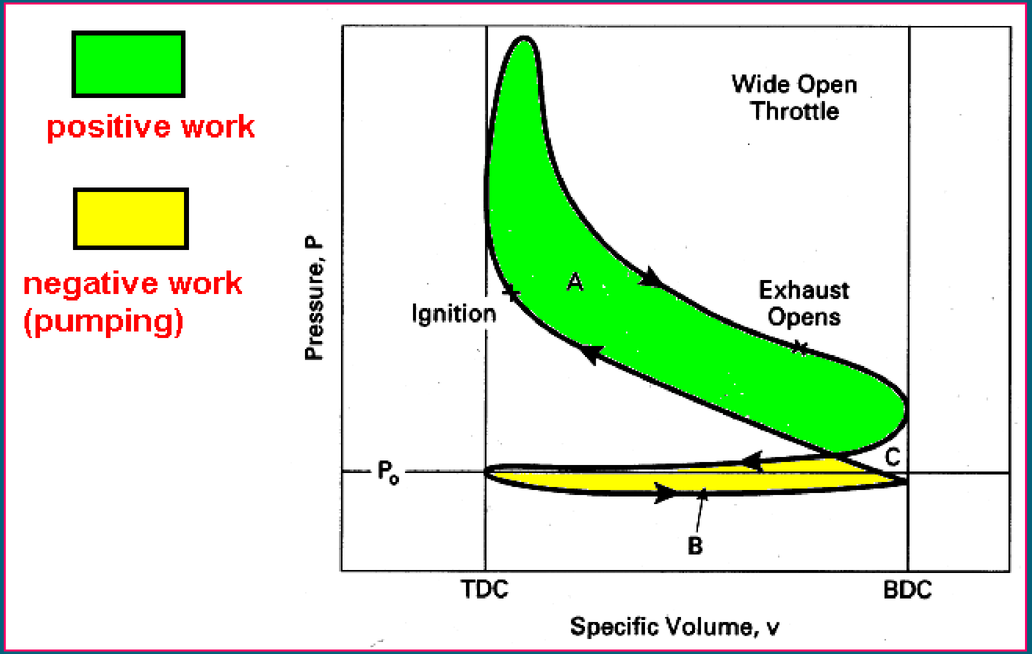
$$T = F \cdot b \qquad \text{units}: J$$



➢ Indicated power (i.p.):

It is the actual rate of work done by the working fluid on the piston.

$$I.P = \frac{W_i N}{60 \times x} \qquad \frac{(kJ/cycle)(rev/s)}{rev/cycle}$$



➢ Friction power (f.p.):

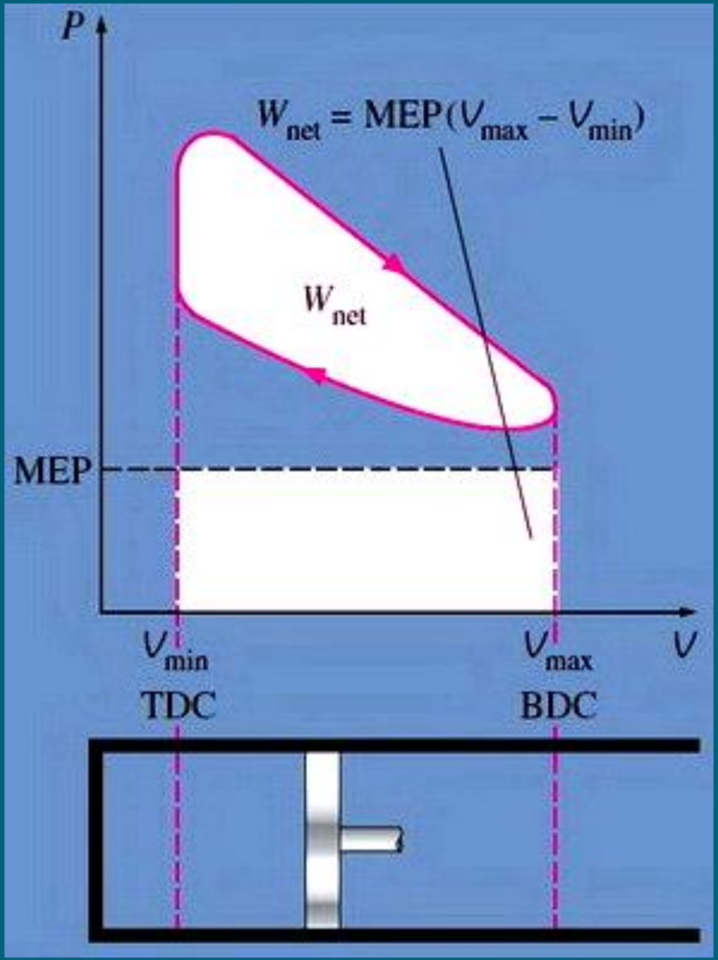
The difference between the i.p. and the b.p and it is the power required to overcome the frictional resistance of the engine parts.

$$F.P. = I.P. - B.P.$$

mean effective pressure:-

Mean effective pressure is defined as a hypothetical/average pressure which is assumed to be acting on the piston throughout the power stroke.

$$mep = \frac{W_{net}}{V_d} = \frac{W_{net}}{V_{Total} - V_{Clearance}} \Rightarrow \text{Pa}$$



mep **is a better parameter than torque to compare engines for design and output because it is independent of engine speed, N, and engine size, V_d.**

➢ Indicated mean effective pressure (imep):

It is a hypothetical pressure which if acting on the engine piston during the working stroke would results in the indicated work of the engine.

$$\text{imep } (P_i) = \frac{\text{Net area of the indicator diagram}}{\text{Swept volume}} \times \text{Indicator scale}$$

or

$$imep = \frac{W_{indecated}}{\frac{\Pi}{4} D^2 L}$$

➢ Brake mean effective pressure (bmep):

It is the mean effective pressure acting on the pistons which would give the measured b.p.

$$bmep = \frac{W_{break}}{\frac{\Pi}{4} D^2 L}$$

➢ **Fraction mean effective pressure (fmep):**

$$fmep = imep - bmep$$

Note:-

- **The maximum bmep is obtained at WOT at a particular engine speed.**
- **Closing the throttle decreases the bmep.**
- **For a given displacement, a higher maximum bmep means more torque.**
- **For a given torque, a higher maximum bmep means smaller engine.**
- **Higher maximum bmep means higher stresses and temperatures in the engine hence shorter engine life, or bulkier engine.**
- **For the same bmep 2-strokes have almost twice the power of 4-stroke**

- **The power can also calculated by:-**

Indicated Power

$$I.P. = imep \times \frac{\Pi}{4} D^2 L \times \frac{N}{60} \times \frac{n}{x}$$

Break Power

$$B.P. = bmep \times \frac{\Pi}{4} D^2 L \times \frac{N}{60} \times \frac{n}{x}$$

- **The mean effective pressure can also calculated by:-**

Indicated mean effective pressure

$$imep = \frac{I.P.}{\frac{\Pi}{4} D^2 L \times \frac{N}{60} \times \frac{n}{x}}$$

Break mean effective pressure

$$bmep = \frac{B.P.}{\frac{\Pi}{4} D^2 L \times \frac{N}{60} \times \frac{n}{x}}$$

Specific fuel consumption (s.f.c.):

It is the mass of fuel consumed per unit power output per hour, and is a criterion of economic power production.

$$\text{sfc} = \frac{\dot{m}_f}{Power} \quad \text{kg/kW.hr}$$

Brake Specific fuel consumption

$$\text{bsfc} = \frac{\dot{m}_f}{B.P.}$$

Indicated Specific fuel consumption

$$\text{isfc} = \frac{\dot{m}_f}{I.P.}$$

Note:-

$$bsfc \cong 0.270 \ \text{(Kg/kW.h)} \quad \text{for SIE}$$

$$bsfc \cong 0.200 \ \text{(Kg/kW.h)} \quad \text{for CIE}$$

Specific Power Output:-

Specific power output of an engine is defined as the brake power (output) per unit of piston displacement.

$$\text{Specific Power Output} = \frac{B.P.}{V_d} = \frac{B.P.}{A_{piston} \times L_{strok}} = \frac{B.P.}{\frac{\pi}{4} D^2 L} \left[\frac{\text{kW}}{\text{m}^3}\right]$$

Volumetric efficiency (η_v):

the ratio of the volume if air induced, measured at the free air conditions, to the swept volume of the cylinder

$$\eta_v = \frac{\dot{m}_a)_{act}}{\dot{m}_a)_{the}} = \frac{\dot{m}_a)_{act}}{\rho_a \times \dot{V}_d} = \frac{\dot{m}_a)_{act}}{\frac{P_1}{R.T_1} \times \frac{\Pi}{4} D^2 L \times \frac{N}{60} \times \frac{n}{x}}$$

Thermal efficiency:-

$$\eta_{\text{th}} = \frac{Power}{m^{\cdot}_{f} \times CV.}$$

Brake Thermal efficiency

$$\eta_{b.\text{th}} = \frac{B.P}{m^{\cdot}_{f} \times CV.}$$

Indicated Thermal efficiency

$$\eta_{\text{i.th}} = \frac{I.P.}{m^{\cdot}_{f} \times CV.}$$

Mechanical efficiency (η_m):

$$\eta_m = \frac{B.P.}{I.P.} = \frac{bmep}{imep} = \frac{isfc}{bsfc} = \frac{\eta_{b.th}}{\eta_{i.th}}$$