# POSTAL Book Package 2023

## Mechanical Engineering

### Conventional Practice Sets

## Internal Combustion Engines

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MADE EASY Publications

# 1 CHAPTER Introduction and Basic Concepts

## Practice Questions : Level-I

**Q.1** An automobile engine operates at a fuel air ratio of 0.05, volumetric efficiency of 90% and indicated thermal efficiency of 30%. Given that the calorific value of the fuel is 45 MJ/kg and the density of air at intake is 1 kg/m$^3$, what will be the indicated mean effective pressure?

**Solution:**

$$\text{Volumetric efficiency} = \frac{\text{Actual volume}}{\text{Swept volume}} = \frac{V_a}{V_s} = 0.9$$

or $V_a = 0.9V_s$

Mass of air, $m_a = \rho_{air} V_a = 0.9V_s$ $(\rho_{air} = 1 \text{ kg/m}^3)$

$m_f = 0.05 \times 0.9V_s = 0.045V_s$

$$\eta_{thermal} = \frac{p_{mep} \times LA}{m_f \times C.V.}$$

$$0.3 = \frac{p_m \times V_s}{0.045\, V_s \times 45 \times 10^6}$$

or $p_m = 0.6075 \times 10^6$ Pa = **6.075 bar**

**Q.2** The brake thermal efficiency of a diesel engine is 30%. If air to fuel ratio by weight is 20 and calorific value of fuel is 41800 kJ/kg. Find brake mean effective pressure at STP (15°C and 760 mm Hg).

**Solution:**

$$\therefore \quad \text{Brake thermal efficiency} = \frac{B.P.}{\text{Thermal power}}$$

$$0.3 = \frac{B.P.}{m_f \times C.V.} = \frac{B.P.}{\frac{m_a}{20} \times 41800}$$

$$m_a = \frac{B.P. \times 20}{0.3 \times 41800} = \frac{B.P.}{627} \text{ kg/s} \quad \text{...(i)}$$

Assuming volumetric efficiency 100%

$\therefore$ $pV_S = m_a RT$

$$0.76 \times 13.6 \times 10^3 \times 9.81 \times V_S = \frac{B.P.}{627} \times 287 \times 288$$

$$\text{Brake mean effective pressure} = \frac{B.P.}{V_S}$$

$$= \frac{0.76 \times 13.6 \times 10^3 \times 9.81 \times 627}{287 \times 288} \text{ kPa} = 7.69 \text{ bar or } 5765.1 \text{ mm of Hg}$$

## Practice Questions : Level-II

**Q.7** A six cylinder 4-stroke diesel engine has a bore of 60 mm and a crank radius of 32 mm. The compression ratio is 9 : 1 and engine volumetric efficiency is 90%. Determine: (i) Stroke length, (ii) Mean volume per cylinder, (iii) Swept volume per cylinder, (iv) Clearance volume per cylinder, (v) Cubic capacity of the engine, (vi) Actual volume of air aspirated per stroke in each cylinder.

**Solution:**

Stroke length, $L = 2 \times \text{crank radius} = 2 \times 32 = 64 \text{ mm}$ **Ans.(i)**

$$\text{Mean piston speed, } \bar{V}_p = \frac{2LN}{60} = 2\times 64\times 10^{-3}\times\frac{1000}{60} = \frac{128}{60} = 2.13 \text{ m/s}$$ **Ans.(ii)**

$$\text{Swept volume per cylinder, } V_s = \frac{\pi}{4}D^2L = \frac{\pi}{4}\times 6^2\times 6.4 = 180.956\ (\text{cm})^3 \approx 181 \text{ cc}$$ **Ans.(iii)**

$$\text{Compression ratio, } r = \frac{V_s+V_c}{V_c} = \frac{V_s}{V_c}+1$$

$$\text{Clearance volume, } V_c = \frac{V_s}{r-1} = \frac{181}{9-1} = 22.625 \text{ cc}$$ **Ans.(iv)**

Cubic capacity of the engine = Number of cylinder × Swept volume

= 6 × 181 = 1086 cc **Ans.(v)**

$$\text{Volumetric efficiency} = \frac{\text{Actual volume flow rate of air}}{\text{Volume flow rate of air corresponding to displacement volume}}$$

$$\dot{V}_a = \eta_v\times\frac{\pi}{4}D^2L\times\frac{N}{2\times 60}$$

$$= 0.9\times\frac{\pi}{4}\times(0.06)^2\times 0.064\times\frac{1000}{2\times 60}$$

$$= 1.357\times 10^{-3} \text{ m}^3/\text{s} = 4.8858 \text{ m}^3/\text{hr}$$ **Ans.(vi)**

**Q.8** A three litre V 6 S.I. engine operates on a four stroke cycle at 3600 rpm. The compression ratio is 9.5, the length of the connecting rod is 16.6 cm and the engine is square (bore = stroke). At this speed, the combustion ends at 20° ATDC. Calculate:

(i) cylinder bore and stroke length (ii) average piston speed
(iii) clearance volume of one cylinder (iv) piston speed at the end of combustion
(v) distance the piston has travelled from TDC at the end of combustion.
(vi) volume in the combustion chamber at the end of combustion.

**Solution:**

Given data: Swept volume; $V_s = 3\times 10^{-3}$ m$^3$; Number of cylinders; $k = 6$,
$N = 3600$ rpm; Compression ratio, $r = 9.5$,

(i)
$$\text{Swept volume per cycle} = \frac{\text{Total swept volume}}{\text{Number of cylinders}} = \frac{V_s}{k}$$

$$V_{s,\text{per cyl}} = \frac{V_s}{6} = \frac{3\times 10^{-3}}{6}\text{m}^3 = \frac{\pi}{4}D^2\times L$$

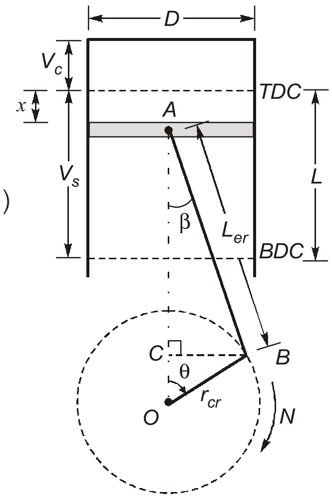
$$\frac{3\times 10^{-3}}{6} = \frac{\pi}{4}D^3 \qquad (\because D = L)$$

⇒ $D = L = 0.086 = 8.6$ cm; crank radius = $r_{cr}$

$$r_{cr} = \frac{L}{2} = 4.3 \text{ cm}$$

(ii) Average piston speed, $\overline{V_p} = \dfrac{2 \times L \times N}{60}$

$$= 2 \times 0.086 \times \frac{3600}{60} = 10.32 \text{ m/s}$$




(iii) $$r_c = 9.5 = \frac{V_s + V_c}{V_c}$$

$\Rightarrow$ $$V_{c,\text{ per cylinder}} = 59 \text{ cm}^3$$

$$V_{c,\text{ total}} = V_{c,\text{ per cylinder}} \times 6 = 354 \text{ cm}^3$$

(iv) $$x = (L_{cr} + r_{cr}) - [r_{cr}\cos\theta + L_{cr}\cos\beta] \quad ...(1)$$

$$n = \frac{L_{cr}}{r_{cr}} = 3.86$$

$$\omega = 2\pi\frac{N}{60} = 2\pi \times \frac{3600}{60} = 120\,\pi \text{ rad/s}$$

$$\sin\beta = \frac{\sin\theta}{n} = \frac{\sin\theta}{3.86}$$

At $\theta = 20°$, $\beta = 5.083°$

$$x = (L_{cr} + r_{cr}) - [r_{cr}\cos\theta + L_{cr}\cos\beta]$$

$$= (L_{cr} + r_{cr}) - \left[r_{cr}\cos\theta + L_{cr}\frac{\sqrt{n^2 - \sin^2\theta}}{n}\right]$$

$$= (L_{cr} + r_{cr}) - r_{cr}\left[\cos\theta + \sqrt{n^2 - \sin^2\theta}\right]$$

$$V_p = \frac{dx}{dt} = -r\left[-\sin\theta + \frac{1}{2\sqrt{n^2 - \sin^2\theta}}(-2\sin\theta\cos\theta)\right]\omega$$

$$= r_{cr}\left[\sin\theta + \frac{\sin\theta\cos\theta}{\sqrt{n^2 - \sin^2\theta}}\right] \quad ...(2)$$

At $\theta = 20°$ $\quad V_p = 6.89$ m/s

(v) Distance from TDC,

From equation (1), $\quad x = [16.6 + 4.3] - [4.3 \cos 20° + 16.6 \cos 5.083°] = 0.3246$ cm

(vi) Volume in the combustion chamber at the end of combustion

$$V = V_C + \frac{\pi}{4}D^2 x = 59 + \frac{\pi}{4}(8.6)^2 \times 0.3246 = 77.9 \text{ cm}^3$$

**Q.9** A six-cylinder, 4-stroke petrol engine has a swept volume of 3 litres with a compression ratio of 9.5. Brake output torque is 205 N-m at 3600 r.p.m. Air enters at 85 kN/m$^2$ and 60°C. The mechanical efficiency of the engine is 85% and air-fuel ratio is 15 : 1. The heating value of fuel is 44,000 kJ/kg and the combustion efficiency is 97%. Calculate:

(i) Rate of fuel flow
(ii) Brake thermal efficiency
(iii) Indicated thermal efficiency
(iv) Volumetric efficiency
(v) Brake specific fuel consumption

**Solution:**

Given data: No. of cylinders, $k = 6$; 4-stroke, petrol engine; Swept volume, $V_s = 3 \times 10^{-3}$ m$^3$;

Rate of volume swept, $\dot{V_s} = V_s \dfrac{N \times k}{2 \times 60} = 0.09$ m$^3$/s; Compression ratio, $r = 9.5$, Brake output torque, $T_b = 205$ N-m; Speed, $N = 3600$ rpm; Ambient pressure, $P_1 = 85$ kN/m$^2$

Ambient temperature, $T_1 = 60°C = 333$ K

Mechanical efficiency, $\eta_m = 85\%$

Air fuel ratio, AFR = 15 : 1

Calorific value of fuel, CV = 44,000 kJ/kg

Combustion efficiency, $\eta_{comb} = 97\% = 0.97$

Ideal gas equation, $p_1 v_1 = RT_1$

$$\Rightarrow \quad v_1 = \frac{RT_1}{p_1} = 1.124 \text{ m}^3/\text{kg}$$

$$v_2 = \frac{v_1}{r} = 0.1183 \text{ m}^3/\text{kg}$$

Swept volume/kg mass flow rate, $v_s = v_1 - v_2 = 1.006$ m$^3$/kg

For air flow, $$\dot{m}_a = \frac{\dot{V}_s}{v_s} = 0.089 \text{ kg/s} = 322.064 \text{ kg/hr}$$

**(i)** AFR = 15 : 1

$$\Rightarrow \quad \frac{\dot{m}_a}{\dot{m}_f} = 15 \Rightarrow \dot{m}_f = \frac{\dot{m}_a}{15} = 21.471 \text{ kg/hr}$$

**(ii)** Brake thermal efficiency,

$$\text{BP} = T_b \times \omega = T_b \times \frac{2\pi N}{60} = \frac{205 \times 2 \times \pi \times 3600}{60 \times 1000} = 77.283 \text{ kW}$$

$$\eta_{bth} = \frac{\text{BP}}{(\dot{m}_f \times \text{CV}) \times \eta_{comb}} = \frac{77.283}{(21.471/3600) \times 44000 \times 0.97} = 30.36\%$$

**(iii)** Indicated thermal efficiency, $\eta_{ith} = \dfrac{I.P.}{(\dot{m}_f \times CV) \times \eta_{comb}}$

$$\eta_{mech} = \frac{BP}{IP} \Rightarrow IP = \frac{BP}{\eta_{mech}} = 90.921 \text{ kW}$$

$$\therefore \quad \eta_{ith} = \frac{90.921}{(21.471/3600) \times 44000 \times 0.97} = 35.718\%$$

**(iv)** Volumetric efficiency, $\eta_{vol} = \dfrac{\dot{V}_a}{\dot{V}_s}$

where $$\dot{V}_a = \dot{m}_a \frac{RT_1}{p_1} = 0.103 \text{ m}^3/\text{s}$$

and $$\dot{V}_s = 0.09 \text{ m}^3/\text{s}$$

$$\Rightarrow \quad \eta_{vol} = \frac{0.103}{0.09} = 114.53\%$$

($\eta_{vol} > 100\%$ implies that it is a supercharged engine)

**(v)** Brake specific fuel consumption (bsfc)

$$= \frac{\dot{m}_f}{BP} = 0.278 \text{ kg/k Whr}$$