Darshan Institute of Engineering & Technology-Rajkot

Department of Mechanical Engineering

B. E. - SEMESTER - 1 & 2

Elements of Mechanical Engineering (2110006)

Chapter-4 Properties of steam

Class Example

C1. Following data to be observed during test on throttling calorimeter.

Pressure in main before throttling = 13 bar

Pressure after throttling = 1 bar

Temperature of steam after throttling = 135°C

Specific heat of steam = 2.1 kJ/kg K

Determine dryness fraction for throttling

calorimeter.

ANSWER: X = 0.9818

$$P_1 = 13 \text{ bar at}$$

$$h_{f1} = 814.7 \frac{kJ}{kg}$$

$$h_{fg1} = 1910.1 \frac{kJ}{kg}$$

$$P_2 = 1 \text{ bar at}$$

$$h_g = 2675.4 \frac{kJ}{kg}$$

$$T_{sat} = 99.6$$
 °C

$$T_{\text{sup}} = 135 \, ^{\circ}\text{C}$$

$$C_{ps} = 2.1 \frac{kJ}{kg \cdot K}$$

$$x = h_{g2} + \frac{C_{ps}(T_{sup} - T_{sat})}{h_{fg1}} - h_{f1}$$

$$x = 2675.4 + \frac{2.1(408 - 372.6)}{1970.7} - 814.7$$

$$x = 0.9819$$

C2. Combined separating and throttling calorimeter is used to find out dryness fraction ofthe steam.

Following readings were taken,

Main Pressure = 12 bar abs.

Mass of water collected in separating calorimeter = 2 kg

Mass of steam condensed in throttling calorimeter = 20 kg

Temperature of steam after throttling = 110°C

Pressure after throttling = 1 bar abs. Assume C_p of steam = 2.1 kJ/kg K

Calculate dryness fraction of steam.

ANSWER: X = 0.8698

$$P_1 = 12$$
 bar at

$$h_{f1}=798.4\;\frac{kJ}{kg}$$

$$h_{fg}=1984.3\;\frac{kJ}{kg}$$

$$m_w = 2 \text{ Kg}$$

$$m_s = 20 \text{ Kg}$$

$$T_{\text{sup}} = 110 \, ^{\circ}\text{C}$$

$$P_2 = 1 \text{ bar at}$$

$$h_g = 2675.4 \; \frac{kJ}{kg}$$

$$T_{sat} = 99.6$$
 °C

$$C_{ps} = 2.1 \frac{kJ}{kg \cdot K}$$

For separating calorimeter

$$x_1 = \frac{m_s}{m_w + m_s} = \frac{20}{22} = 0.9090$$

For throttling calorimeter

$$x_{2} = h_{g2} + \frac{C_{ps}(T_{sup} - T_{sat})}{h_{fg1}} - h_{f1}$$

$$x_{2} = 2675.4 + \frac{2.1(383 - 372.6)}{1970.7} - 789.4$$

$$x_{2} = 0.9569$$

For the combined dryness fraction is

$$x = x_1 \cdot x_2 = 0.9090 \times 0.9569 = 0.8698$$

C3. Following data to be monitoring during test on combined separating throttling calorimeter.

Pressure in main before throttling = 8 bar Temperature of steam after throttling = 110°C

Barometer reading = 754 mm of Hg
Manometer reading = 81.5 mm of Hg

Mass of steam separated = 60 kgMass of moisture (water) separated = 1.5 kgSpecific heat of steam = 2.1 kJ/kg K

Determine dryness fraction for combined separating throttling calorimeter.

ANSWER: X = 0.9412

$$P_1 = 8 \text{ bar at}$$

$$h_{f1} = 720.9 \frac{\text{kJ}}{\text{kg}}$$

$$h_{fg1} = 2046.5 \frac{\text{kJ}}{\text{kg}}$$

$$m_w = 1.5 \text{ Kg}$$

$$m_s = 60 \text{ Kg}$$

$$T_{sup} = 110 \text{ °C}$$

Here barometer and manometer consider

$$\begin{array}{c} \textit{h} = \textit{barometer} \ + \text{manometer} \ = \ 754 + 81.5 = 835.5 \ \text{mm of Hg} \\ P_2 = \rho \times g \times h = 13.6 \times 1000 \times 9.81 \times 835.5 \times 10^{-3} = 1.11 \ \text{bar} \\ P_2 = 1.11 \ \text{bar} \ \text{at} \\ h_{g2} = 2675.4 \ \frac{kJ}{kg} \\ T_{sat} = 102.3 \ ^{\circ}\text{C} \\ C_{ps} = 2.1 \ \frac{kJ}{kg \cdot K} \end{array}$$

For separating calorimeter

$$x_1 = \frac{m_s}{m_w + m_s} = \frac{60}{61.5} = 0.9756$$

For throttling calorimeter

$$x_2 = h_{g2} + \frac{C_{ps}(T_{sup} - T_{sat})}{h_{fg1}} - h_{f1}$$

$$x_2 = 2679.8 + \frac{2.1(383 - 375.3)}{2046.5} - 720.9$$

$$x_2 = 0.9650$$

For the combined dryness fraction is

$$x = x_1 \cdot x_2 = 0.9756 \times 0.9650 = 0.9415$$

C₄. Determine dryness fraction of steam supplied to a separating throttling calorimeter.

Water separated in separating calorimeter = 0.45 kg
Steam discharged from throttling calorimeter = 7 kg
Steam pressure in a main pipe = 1.2 MPa

Barometer reading = 760 mm of Hg

Manometer reading = 180 mm of Hg

Temperature of steam after throttling = 140° C Take C_{ps} of steam = 2.1 kJ/kg K

ANSWER: X = 0.9270

$$P_{1} = 12 \text{ bar at}$$

$$h_{f1} = 798.4 \frac{\text{kJ}}{\text{kg}}$$

$$h_{fg1} = 1984.3 \frac{\text{kJ}}{\text{kg}}$$

$$m_{w} = 0.45 \text{ Kg}$$

$$m_{s} = 7 \text{ Kg}$$

$$T_{sup} = 140 \text{ °C}$$

Here barometer and manometer consider

$$\begin{array}{l} \textit{h} = \textit{barometer} \ + \, \text{manometer} \ = \ 760 + 180 = 940 \ \text{mm of Hg} \\ P_2 = \rho \times g \times h = 13.6 \times 1000 \times 9.81 \times 940 \times 10^{-3} = 1.25 \ \text{bar} \\ P_2 = 1.25 \ \text{bar} \ \text{at} \\ h_{g2} = 2683.4 \ \frac{kJ}{kg} \\ T_{sat} = 104.8 \ ^{\circ}\text{C} \\ C_{ps} = 2.1 \ \frac{kJ}{kg \cdot K} \end{array}$$

For separating calorimeter

$$x_1 = \frac{m_s}{m_w + m_s} = \frac{7}{7.45} = 0.9395$$

For throttling calorimeter

$$x_{2} = h_{g2} + \frac{C_{ps}(T_{sup} - T_{sat})}{h_{fg1}} - h_{f1}$$

$$x_{2} = 2683.4 + \frac{2.1(413 - 377.8)}{1984.3} - 798.4$$

$$x_{2} = 0.9872$$

For the combined dryness fraction is

$$x = x_1 \cdot x_2 = 0.9395 \times 0.9872 = 0.9274$$

C₅. Following data available for 5 kg of steam at different condition.

Determine 1. Enthalpy and internal energy when steam has dryness fraction 0.9 at 0.8 bar 2. Enthalpy and internal energy when steam is dry at 0.8 bar and 3. Enthalpy and internal energy when steam is superheated at 300°C at 20 bar.

ANSWERS: [1] H_{wet} = 12191.95 kJ, U_{wet} = 11440.63 kJ [2] H_{dry} = 13329 kJ, U_{dry} = 12494.24 kJ [3] H_{sup} = 14905.8 kJ, U_{sup} = 13730.6 kJ

Given data

1) Wet steam

$$P = 0.8$$
 bar at

$$h_f = 391.7 \frac{kJ}{kg}$$

$$h_{fg} = 2274.0 \ \frac{kJ}{kg}$$

$$v_g = 2.087 \ \frac{m^3}{kg}$$

$$h_{wet} = h_f + x h_{fg}$$

$$h_{\text{wet}} = 391.7 + (0.9 \times 2214.0) = 2438.3 \frac{\text{kJ}}{\text{kg}}$$

$$H_{wet} = h_{wet} \times m = 2438.3 \times 5 = 12191.5 \text{ kJ}$$

$$H = u + Pv$$

$$u = H - P(x \cdot v_g) = 12191.5 - 80(0.9 \times 2.087 \times 5) = 11440.18 \text{ kJ}$$

2) Dry steam

$$h_g = 2665.8 \frac{kJ}{kg}$$

$$H = u + Pv$$

$$u = m \big[H - P \big(v_g \big) \big] = 5 [2665.8 - 80(2.087)] = 2498.85 \times 5 = 12494.4 \ \mathrm{kJ}$$

3) Superheated steam

$$P = 20 \text{ bar at}$$

$$h_g = 2797.2 \frac{kJ}{kg}$$

$$T_{\rm sup} = 300$$
 °C

$$v_g = 0.0995 \; \frac{m^3}{kg}$$

$$T_{sat} = 212.4$$
 °C

$$h_{sup} = m[h_g + C_{ps}(T_{sup} - T_{sat})] = 5[2797.2 + 2.1(673 - 485.4)] = 15955.8 \text{ kJ}$$

Here

$$v_{sup} = v_g \times \frac{T_{sup}}{T_{sat}} = 0.0995 \times \frac{673}{485.4} = 0.1379 \frac{m^3}{kg}$$

$$H = u + Pv$$

$$u = m \big[H - P \big(v_{sup} \big) \big] = 5 [3191.16 - 2000 (0.1379)] = 2915.25 \times 5 = 14576.2 \ kJ$$

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Elements of Mechanical Engineering (2110006)

Chapter-5 Heat Engine

Formula of Heat Engine :

- 1. Efficiencies:
 - For Carnot Cycle

$$\eta = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1}$$

• For Rankine Cycle

$$\eta_R = \frac{h_1 - h_2}{h_1 - h_4}$$

H = enthalpy of a water or gas in KJ

• For Otto Cycle (Petrol Cycle)

$$\eta = 1 - \frac{1}{\left(r\right)^{\gamma - 1}}$$

• For Diesel Cycle

$$\eta = 1 - \frac{1}{(r)^{\gamma - 1}} \left[\frac{\rho^{\gamma - 1}}{\gamma (\rho - 1)} \right]$$

2. Heat supplied

$$Q_{\rm s} = mC_{\rm v}\Delta T$$

3. Work done

$$W = P\Delta V$$

C1. An engine working on a Carnot cycle with working fluid as a gas has the maximum pressure and temperatures of the cycle as 30 bar and 550k respectively. The expansion and compression ratios for the isothermal and adiabatic processes are 4 and 6 respectively. The mass of gas in the system 1 is kg. Calculate the properties of gas at salient points, the work done during the cycle and thermal efficiency. Take γ =1.4 R=0.3 KJ/kgK.

Given data is,

$$P_1 = 30 bar, T_1 = 550 K, m = 1 kg$$

For isothermal process,
$$\frac{V_2}{V_1} = \frac{V_3}{V_4} = 4$$

For adiabatic process,
$$\frac{V_3}{V_2} = \frac{V_4}{V_1} = 6$$

We have,
$$p_1V_1 = mRT_1 \frac{30 \times 10^5 \times V_1 = 1 \times 0.3 \times 10^3 \times 550}{V_1 = 0.055m^3}$$

For adiabatic process(2-3)

$$p_2 V_2^{\gamma} = p_3 V_3^{\gamma}$$

$$\therefore p_3 = p_2 \left(\frac{V_2}{V_3}\right)^{\gamma} = 7.5 \times 10^5 \left(\frac{1}{6}\right)^{1.4} = 0.61 \times 10^5 \, N / m^2$$

$$V_3 = 6V_2 = 6 \times 0.22 = 1.32 \, m^3$$

$$\frac{T_3}{T_2} = \left(\frac{p_3}{p_2}\right)^{\frac{\gamma - 1}{\lambda}}$$

$$\therefore T_{2-3} = 550 \left(\frac{0.61}{7.5} \right)^{\frac{1.4-1}{1.4}}$$

$$T_{2-3} = 268.55 K = T_2$$

For isothermal process(3-4)

$$T_2 = T_{3-4} = 268.55 K$$

$$\therefore p_3 V_3 = p_4 V_4$$

$$p_4 = p_3 \left(\frac{V_3}{V_4}\right) = 0.61 \times 10^5 \times 4 = 2.44 \times 10^5 \ N / m^2$$

$$\frac{V_3}{V_4} = 4$$

$$\therefore V_4 = \frac{1.32}{4} = 0.33 \, m^3$$

Therefore properties at sailent points are

$$p_1 = 30 \, bar, V_1 = 0.055 \, m^3, T_{1-2} = 550 \, K$$

Heat supplied for isothermal process (1-2)

$$Q_1 = mRT_1 ln \left(\frac{V2}{V1} \right) = 1 \times 0.3 \times 550 ln(4)$$

$$Q_1 = 228.738 \text{ KJ}$$

Heat rejected for isothermal process (3-4)

$$Q_2 = mRT_2 ln \left(\frac{V3}{V4} \right) = 1 \times 0.3 \times 268.5 ln(4)$$

$$Q_2 = 111.69 \text{ KJ}$$

Work Done =
$$Q_1$$
 - Q_2 = 228.73 - 111.69 = 117.048 KJ

Thermal Efficiency =
$$\eta = \frac{W}{Q1} = \frac{117.048}{228.73} = 51.2 \%$$

C2: An engine is working on ideal Otto cycle. The temp of the beginning and the end of compression is 60°C and 450 °C. Determine the air standard efficiency and compression ratio.

Given data,

 T_1 =60 °C , T_2 =45 °C η = ? , r = ?

$$r = \frac{v_1}{v_2}$$

$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\gamma - 1}$$

$$\therefore \frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma - 1}$$

$$\therefore \frac{723}{333} = r^{\gamma - 1}$$

$$\therefore r = (2.17)^{\frac{1}{\gamma - 1}}$$

$$r = 6.94$$

Now,

$$\eta = 1 - \frac{1}{r^{\gamma - 1}}$$

$$=1-\frac{1}{6.94^{0.4}}$$

$$= 53.92\%$$

C3. In an Otto cycle the compression ratio is 8. The temperatures at the beginning of compression and at the end of heat supply are 3 10 K and 1600 K respectively. Assume γ =1.4 and Cv = 0.717 kJ/Kg K. Find (i) Heat Supplied (ii) Efficiency of the cycle.

Given data is,

$$T1 = 310 K$$
, $T2 = 1600 K$

 $\gamma = 1.4$

$$Cv = 0.717 \, KJ/Kg.K$$

$$r = \frac{v_1}{v_2} = 8$$

Determine, Q=? $\eta=?$

Determine,

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma - 1} = r^{\gamma - 1}$$

$$Q = mC_{\nu}(T_3 - T_2)$$

= 1 × 0.717(1600 - 712.19)
= 636.55 KJ/Kg

$$\eta = 1 - \frac{1}{r^{\gamma - 1}} \\
= 1 - \frac{1}{8^{0.4}} \\
= 56.47$$

C4. An oil engine working on diesel cycle has cylinder bore of 190 mm and piston stroke of 230 mm. The clearance volume is 290 cm³; the fuel injection takes place at constant pressure for 6 % of the stroke. Determine the air standard efficiency. Also calculate the percentage of loss of efficiency if fuel cut off is delayed from 6 % to 11% of stroke with same compression ratio.

Given data,

$$d = 190 mm$$

 $l = 230 mm$
 $v_c = v_2 = 290 cm^3$

Determine,

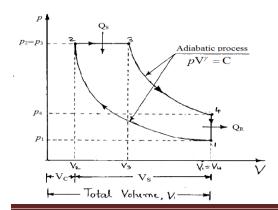
$$\eta_{air} = ?$$

$$v_s = \frac{\pi}{4}d^2l = \frac{\pi}{4}(19)^2(23) = 6521.16 \text{ cm}^3$$

$$v_1 = v_s + v_c = 6521.16 + 290 = 6811.16 \text{ cm}^3$$

Compression ratio =
$$r = \frac{v_1}{v_2} = \frac{6811.16}{290} = 23.49$$

Case-1)



Cut off = 6% of the stroke

$$\frac{v_3 - v_2}{v_1 - v_2} = 0.06$$

$$v_3 = 681.27 \ cm^3$$

$$\rho = \frac{v_3}{v_2} = \frac{681.21}{290} = 2.349$$

$$\begin{split} \eta &= 1 - \frac{1}{r^{\gamma - 1}} \bigg[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)} \bigg] \\ &= 1 - \frac{1}{(23.49)^{0.4}} \bigg[\frac{2.349^{1.4} - 1}{1.4(2.349 - 1)} \bigg] \end{split}$$

= 65.46 %

Case-2)

Cut off = 11 % of the stroke

$$\frac{v_3 - v_2}{v_1 - v_2} = 0.11$$

$$v_3 = 1007.33 \ cm^3$$

$$\rho = \frac{v_3}{v_2} = \frac{1007.33}{290} = 3.47$$

$$\eta = 1 - \frac{1}{r^{\gamma - 1}} \left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)} \right]$$
$$= 1 - \frac{1}{(23.49)^{0.4}} \left[\frac{3.47^{1.4} - 1}{1.4(3.47 - 1)} \right]$$

Due to cut off increase from 6 % to 11% there will be loss in efficiency from 65.46% to 61.48 %

% Loss in efficiency =
$$\frac{65.46 - 61.48}{65.46} \times 100$$

= 6.08 %

C5. An engine operating a diesel cycle has maximum pressure and temperature of 45 bars and 1500 °C. Pressure and temperature at the beginning of compression are 1 bar and 27 °C. Determine air standard efficiency of the cycle. Take γ =1.4

Given data, Determine, $p_3 = p_2 = 45 \text{ bar}$ $\eta = ?$

$$p_3 = p_2 = 45 \ bar$$

 $p_1 = 1 \ bar$
 $T_3 = 1500 \ ^{\circ}C$
 $T_1 = 27 \ ^{\circ}C$
 $\gamma = 1.4$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 300 \left(\frac{45}{1}\right)^{\frac{0.4}{1.4}} = 890.11 \text{ K}$$

$$\frac{v_1}{v_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}} = r = \left(\frac{45}{1}\right)^{\frac{1}{1.4}} = 15.165$$

$$\rho = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{1773}{890.11} = 1.992$$

$$\eta = 1 - \frac{1}{r^{\gamma - 1}} \bigg[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)} \bigg] = 1 - \frac{1}{(15.165)^{0.4}} \bigg[\frac{1.992^{1.4} - 1}{1.4(1.992 - 1)} \bigg] = 60.58 \,\%$$

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Elements of Mechanical Engineering (2110006)

Chapter-7 Internal Combustion Engine

Formula of I.C Engine

1.
$$Pm = \frac{sa}{l} N/m^2$$

Let P_m = Actual mean effective pressure, N/m^2

I = Base width of the indicator diagram, cm

a = Area of the actual indicator diagram, cm²

s = Spring value of the spring used in the indicator, N/m²cm

2. Indicated power of an I.C Engine

$$I.P = \frac{P_m LANK}{60 \times 10^3 \times 2}$$
 for 4 – Stroke Engine

$$I.P = \frac{P_m LANK}{60 \times 10^3}$$
 for 2 – Stroke Engine

I.P = Indicated power, KW

 P_m = Mean effective pressure, N/m²

L = length of stroke, m

A = area of the cross section of cylinder, m²

N = RPM of engine crankshaft,

n = Numbers of power stroke per minute.

3. Brake power of an I.C Engine

$$B.P = \frac{2\pi NT}{60 \times 10^3} = \frac{P_{mb}LAN}{60 \times 10^3}$$
 , KW

P_{mb} = brake mean effective pressure

4. Braking Torque

$$T = WR$$
, or $T = (W - S)R_b$ Nm

W = Net load acting on the brake drum, N

T = Resistance torque, Nm

R = Radius of the brake drum, m

$$R_b = \frac{D+d}{2}$$

R_b = Radius of a brake

D = Brake drum diameter

d = Rope diameter

- 5. Efficiencies
 - a) Mechanical efficiency $\eta_{mech} = \frac{B.P}{IP}$
 - b) Thermal efficiency
 - Indicated thermal efficiency $\eta_{ith} = \frac{I.P}{m_f \times C.V}$ $m_f = mass of fuel supplied, kg/sec, C.V = calorific value of fuel, J/kg$
 - Brake thermal efficiency $\eta_{bth} = \frac{B.P}{m_f imes C.V}$ $\eta_{bth} = \eta_{mech} imes \eta_{it}$
 - Relative efficiency $\eta_{rel} = \frac{\eta_{ith}}{\eta_{air}}$
 - Air standard efficiency

For Petrol engine
$$\eta_{air} = 1 - \frac{1}{\left(r\right)^{\gamma-1}}$$

For Diesel engine
$$\eta_{air} = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{\rho^{\gamma-1}}{\gamma(\rho-1)} \right]$$

- Volumetric efficiency $\eta_{vol} = \frac{Actual\ vol\ of\ ch \arg e\ /\ air\ sucked\ at\ atm\ cond}{Swept\ vol}$
- 6. Specific fuel consumption

$$BSFC = \frac{m_f}{B.P}$$
 kg/kWh

7. Stroke volume (swept volume)

$$V_s = \frac{\pi}{4} d^2 l$$

L= Stroke length, d = Bore diameter

8. Compression ratio

$$r = \frac{Total\ cylinder\ vol}{Clearance\ vol}$$

$$V\ + V$$

$$r = \frac{V_c + V_s}{V_c}$$

 V_c = Clearance vol, Vs = Stroke vol

9. Piston Speed

$$V_p = \frac{2LN}{60} \text{ m/s}$$

Class Example

C1. Following readings taken during test on single cylinder four stroke Petrol engine,

Cylinder bore = 25cm

Stroke length = 400 mm

Mean effective pressure = 6.5 bar

Engine speed = 250 rpm

Net load on brake drum = 1080 N

Effective diameter of drum = 1.5 m

Fuel consumption = 10 kg/hr

Calorific value = 44300 kJ/kg

Clearance volume = 1.196 X 10⁻³m³

Determine 1.Indicated power 2.Brake power 3.Friction power 4.Mechanical efficiency 5.Indicated thermal efficiency 6.Brake thermal efficiency 7.Air standard efficiency 8.Relative efficiency 9.BSFC and 10. Brake mean effective pressure in bar. Take γ =1.4.

ANSWERS: [1] I.P = 26.59kW [2] B.P = 21.206 kW [3] F.P = 5.384 kW [4] η_m =79.75 % [5] η_{ith} = 21.61% [6] η_{bth} = 17.23 % [7] η_{air} = 68.09 % [8] η_{rel} = 31.73 % [9] BSFC = 0.4583 kg/kW hr [10] P_{bm}= 2.59 bar

Solution. Given Data

$$d = 25 cm = 0.25m$$

$$l = 400 mm = 0.400m$$

$$P_m = 6.5 bar = 6.5 \times 10^5 \ N / m^2$$

$$N = 250 rpm$$

$$W = 1080 \ N$$

$$D_b = 1.5 m$$

$$m_f = 10 kg / hr = \frac{10}{3600} = 0.00277 kg / s$$

$$C.V = 443000 \ KJ / kg$$

$$C_v = 1.196 \times 10^{-3} \ m^3$$

$$\gamma = 1.4$$

$$k = 1$$

Determine 1) I.P , 2) B.P , 3) F.P , 4) $\eta_{\scriptscriptstyle m}$, 5) $\eta_{\scriptscriptstyle ith}$, 6) $\eta_{\scriptscriptstyle bth}$, 7) $\eta_{\scriptscriptstyle air}$, 8) $\eta_{\scriptscriptstyle rel}$, 9) BSFC ,

Here in data single cylinder 4 stroke engine is given

So, (i) Indicated Power

$$I.P = \frac{P_m LANK}{60 \times 10^3 \times 2} = \frac{6.5 \times 10^5 \times 0.400 \times \frac{\pi}{4} d^2 \times 250 \times 1}{60 \times 10^3 \times 2} = \frac{6.5 \times 10^5 \times 0.400 \times \frac{\pi}{4} \left(0.25\right)^2 \times 250 \times 1}{60 \times 10^3 \times 2}$$

$$I.P = 26.59 \ KW$$
... Ans (i)

(ii) Brake Power

$$B.P = \frac{2\pi NT}{60 \times 10^3}$$

$$T = W \times R_b = 1080 \times \left(\frac{1.5}{2}\right) = 810 \, Nm$$

$$B.P = \frac{2\pi \times 250 \times 810}{60 \times 10^3} = 21.206 \, KW$$
 ... Ans (ii)

(iii) Friction power

$$F.P = I.P - B.P = 26.59 - 21.206$$

 $F.P = 5.384 \, KW$ Ans (iii)

(iv) Mechanical efficiency

$$\eta_{mech} = \frac{B.P}{I.P} = \frac{21.206}{26.59} = 0.7975 = 79.75\%$$
 ...Ans (iv)

(v) Indicated thermal efficiency

$$\eta_{ith} = \frac{I.P}{m_f \times C.V} = \frac{26.59}{0.0027 \times 44300} = 0.2161 = 21.61\%$$
Ans (v)

(vi) Brake thermal efficiency

$$\eta_{bth} = \frac{B.P}{m_f \times C.V} = \frac{21.206}{0.00277 \times 44300} = 0.1728 = 17.28\%$$
Ans (vi)

(vii) Air standard efficiency

first we have to find out compression ratio r, for compression r we need Vc & Vs

$$V_s = \frac{\pi}{4} d^2 l = \frac{\pi}{4} (0.25)^2 \times 0.4 = 0.0196 \, m^3$$

$$r = \frac{Total\ cylinder\ vol}{Clearance\ vol}$$

$$r = \frac{V_c + V_s}{V_c}$$

$$r = \frac{0.001196 + 0.0196}{0.001196} = 17.38$$

$$\eta_{air} = 1 - \frac{1}{(r)^{\gamma - 1}} = 1 - \frac{1}{(17.38)^{1.4 - 1}} = 0.6809 = 68.09\%$$
 ...Ans(vii)

(viii) Relative efficiency

$$\eta_{rel} = \frac{\eta_{it}}{\eta_{circ}} = \frac{0.2161}{0.6809} = 0.3173 = 31.73\%$$
 ...Ans(viii)

(ix) Brake specific fuel consumption

$$BSFC = \frac{m_f}{B.P} = \frac{0.0027 \times 3600}{21.206} = 0.4583 \, Kg \, / \, Kwh$$
Ans(ix)

(x) Brake mean effective pressure

$$B.P = \frac{2\pi NT}{60 \times 10^3} = \frac{P_{mb}LAN}{60 \times 10^3} \Rightarrow P_{mb} = \frac{21.206 \times 60 \times 10^3}{0.4 \times \frac{\pi}{4} (0.25)^2 \times 250} = 2.59 \, bar \qquad \text{...Ans(x)}$$

C2. Following readings taken during test on single cylinder four stroke Petrol engine,

Stoke length = 40 cm

Cylinder bore = 25 cm

Mean effective pressure = 4 bar

Engine speed = 1400 rpm

Friction power = 10 kW

Fuel consumption = 20 litres/hr

Calorific value = 45000 kJ/kg

Specific gravity = 0.8

Determine: 1. indicated thermal efficiency 2.brake thermal efficiency.

ANSWERS: [1] η_{ith} = 45.85% [2] η_{bth} =40.85%

Solution. Given data

$$l = 40 cm = 0.40 m$$

$$d = 25 cm = 0.25 m$$

$$P_m = 4 bar = 4 \times 10^5 \ N / m^2$$

$$N = 1400 rpm$$

$$F.P = 10 \ KW$$

$$m_f = 20 \ lit / hr = \frac{20 \times 10^{-3}}{3600} m^3 / sec$$

$$C.V = 45000 \ KJ / kg$$

$$S_f = 0.8$$

$$K = 1$$

$$m_f = Volume \ of \ fuel \ consumed \ in \ m^3 / sec \times S_f \times 1000$$

$$= \frac{20 \times 10^{-3}}{3600} \times 0.8 \times 1000 = 4.44 \times 10^{-3} \ kg / sec$$

(i) Indicated thermal efficiency

For Indicated power

Determine 1) η_{ith} , 2) η_{bth}

$$I.P = \frac{P_m LANK}{60 \times 10^3 \times 2} = \frac{4 \times 10^5 \times 0.40 \times \frac{\pi}{4} (0.25)^2 \times 1400 \times 1}{60 \times 10^3 \times 2} = 91.63 \, KW$$

Now,
$$\eta_{iih} = \frac{I.P}{m_f \times C.V} = \frac{91.63}{4.44 \times 10^{-3} \times 45000} = 0.4585 = 45.85\%$$
Ans(i)

(ii) Brake thermal efficiency

For Brake power

$$F.P = I.P - B.P \Rightarrow B.P = I.P - F.P = 91.63 - 10 = 81.63 \, KW$$
 Now, $\eta_{bth} = \frac{B.P}{m_{f} \times C.V} = \frac{81.63}{4.44 \times 10^{-3} \times 45000} = 0.4085 = 40.85\%$ Ans(ii)

C3. Following readings taken during test on single cylinder four stroke Diesel engine, Load on brake drum = 55 kg

Spring reading = 9 kg

Diameter of drum = 1.4 m

Diameter of rope = 0.8 m

Fuel consumption = 3.8 kg/hr

Calorific value = 42500 kJ/kg

Engine speed = 600 rpm

Mechanical efficiency = 83 %

Compression ratio = 7, Stroke to bore ratio = 1.25

Determine 1.Brake thermal efficiency 2.Indicated thermal efficiency

ANSWERS: [1]
$$\eta_{bth}$$
 = 70.90 %[2] η_{ith} = 85.42%

Solution. Given data

$$K = 1$$

 $W = 55 \ kg \Rightarrow W = mg = 55 \times 10 = 550 \ N$
 $S = 9 \ kg \Rightarrow W = mg = 9 \times 10 = 90 \ N$
 $D = 1.4 \ m$
 $d_r = 0.8 \ m$
 $m_f = 3.8 \ kg / hr = \frac{3.8}{3600} = 1.055 \times 10^{-3} \ kg / sec$
 $C.V = 42500 \ KJ / kg$
 $N = 600 \ rpm$
 $\eta_m = 83\%$
 $r = 7$
 $\frac{l}{d} = 1.25$

Determine 1) η_{bth} , 2) η_{ith}

(i) Brake thermal efficiency

For brake power

$$B.P = \frac{2\pi NT}{60 \times 10^3}$$

$$T = (W - S)R_b = (W - S)\left(\frac{D + d_r}{2}\right) = (550 - 90)\left(\frac{1.4 + 0.8}{2}\right) = 506 Nm$$

$$B.P = \frac{2\pi NT}{60 \times 10^3} = \frac{2\pi \times 600 \times 506}{60 \times 10^3} = 31.79 KW$$

$$Now, \eta_{bth} = \frac{B.P}{m_f \times C.V} = \frac{31.79}{1.055 \times 10^{-3} \times 42500} = 0.7090 = 70.90\%$$
 ...Ans(i)

(ii) Indicated thermal efficiency

For indicated power

$$\eta_m = \frac{B.P}{I.P} \Rightarrow I.P = \frac{31.79}{0.83} = 38.30 \text{ KW}$$

$$\eta_{ith} = \frac{I.P}{m_f \times C.V} = \frac{38.30}{1.055 \times 10^{-3} \times 42500} = 0.8542 = 85.42\%$$
Ans(ii)

C4. Following readings taken during test on two cylinder four stroke Petrol engine,

Swept volume = $1.3 \times 10^{-3} \text{ m}^3$

Brake power = 110 kW

Engine speed = 1000 rpm

Fuel consumption = 2.8 kg/hr

Mean effective pressure = 900 kN/m²

Calorific value = 42800 kJ/kg

Piston speed = 5 m/s

If clearance volume is 10 % of swept volume. Take γ = 1.4. Determine 1.Stoke length and diameter 3.Indicated thermal efficiency and 3.Relative efficiency.

Answer (1) I = 0.15 m (2) d = 0.105 m (3) η_{ith} = 58.58 % (4) η_{rel} = 94.98 %

Solution. Given data

$$K = 2$$

$$V_s = 1.3 \times 10^{-3} \, m^3$$

$$B.P = 110 \, KW$$

$$N = 1000 \, rpm$$

$$m_f = 2.8 \, kg \, / \, hr = \frac{2.8}{3600} = 0.777 \times 10^{-3} \, kg \, / \sec$$

$$P_m = 900 \, KN \, / \, m^2 = 9 \times 10^5 \, N \, / \, m^2$$

$$C.V = 42800 \, KJ \, / \, kg$$

$$V_p = 5 \, m \, / \, s$$

$$V_c = 0.10 \, V_s$$

Determine 1) I, 2) d, 3) $\eta_{\scriptscriptstyle ith}$, 4) $\eta_{\scriptscriptstyle rel}$

(i) For stroke length

$$V_p = \frac{2LN}{60} \Rightarrow L = \frac{5 \times 60}{2 \times 1000} = 0.15 m$$
 ...Ans(i)

(ii) For Bore diameter

$$V_s = \frac{\pi}{4} d^2 l \Rightarrow d^2 = \frac{1.3 \times 10^{-3} \times 4}{\pi \times 0.15} = 0.01103 \Rightarrow d = 0.105 m$$
 ...Ans(ii)

(iii) Indicated thermal efficiency

$$I.P = \frac{P_m LANK}{60 \times 10^3 \times 2} = \frac{9 \times 10^5 \times 0.15 \times \pi (0.105)^2 \times 1000 \times 2}{60 \times 10^3 \times 2 \times 4} = 19.48 \, KW$$

$$\eta_{iih} = \frac{I.P}{m_f \times C.V} = \frac{19.48}{0.777 \times 10^{-3} \times 42800} = 0.5858 = 58.58\%$$
 ...Ans(iii)

(iv) Relative efficiency

We have to find out first air standard efficiency, for that we have to find out

$$V_c = 0.10V_s = 0.10 \times 1.3 \times 10^{-3} = 1.3 \times 10^{-4} m^3$$

$$r = \frac{V_c + V_s}{V_c} = \frac{\left(1.3 \times 10^{-4}\right) + \left(1.3 \times 10^{-3}\right)}{1.3 \times 10^{-4}} = 11$$

$$Now, \eta_{air} = 1 - \frac{1}{\left(r\right)^{\gamma - 1}} = 1 - \frac{1}{\left(11\right)^{1.4 - 1}} = 0.6167 = 61.67\%$$

$$\eta_{rel} = \frac{\eta_{iih}}{\eta_{air}} = \frac{0.5858}{0.6167} = 0.9497 = 94.97\%$$
Ans(iv)

C5. Following readings taken during test on six cylinder four stroke Petrol engine,

Brake Power = 300 kW

Engine speed = 2500 rpm

Stroke to bore ratio = 1.25

Mean effective pressure = 0.9 MPa

Mechanical efficiency = 80 %

Indicated thermal efficiency = 30 %

Calorific value = 41900 kJ/kg

Determine stroke length, diameter and fuel consumption.

ANSWERS: [1] d = 0.150 m [2] l = 0.187 m [3] $m_f = 108 \text{ kg/hr}$

Solution. Given data

$$K = 6$$

 $B.P = 300 \, KW$
 $N = 2500 \, rpm$
 $l/d = 1.25$
 $P_m = 0.9 \, MPa = 9 \times 10^5 \, N / m^2$
 $\eta_m = 80\%$
 $\eta_{ith} = 30\%$
 $C.V = 41900 \, KJ / kg$

Determine. (1) d, (2) l, (3) m_f

(i) For Bore diameter

We have to find out I.P

$$\eta_{mech} = \frac{B.P}{I.P} \Longrightarrow I.P = \frac{300}{0.80} = 375 \text{ KW}$$

$$I.P = \frac{P_m LANK}{60 \times 10^3 \times 2} \Rightarrow 375 = \frac{9 \times 10^5 \times 1.25 d \times \pi d^2 \times 2500 \times 6}{60 \times 10^3 \times 2 \times 4} \Rightarrow d^3 = 0.00339 \Rightarrow d = 0.150 m$$

(ii) For stroke length

$$l = 1.25d = 1.25 \times 0.150 = 0.187 m$$

(iii) Mass of fuel consumption

$$\eta_{ith} = \frac{I.P}{m_f \times C.V} \Rightarrow m_f = \frac{375}{0.30 \times 41900} = 0.0298 \, kg \, / \sec = 0.0298 \times 3600 = 107.39 \, kg \, / \, hr$$
Ans(iii)

...Ans(ii)