

Boiler Performance

Equation:

1 Heat used in producing steam (Q_s)

$$Q_s = m_s (h_2 - h_1) \text{ kJ/hr}$$

$h_1 \rightarrow$ depends on steam table

$$h_2 = h_f + x h_{fg}$$

$$= h_g + C_{ps} (T_{sup} - T_{sat})$$

2 Heat Supplied by Fuel (Q_f)

$$Q_f = m_f \times C_v \text{ kJ/kg}$$

3 Boiler thermal Efficiency (η_b)

$$\eta_b = \frac{Q_s}{Q_f} \times 100$$

4 Equivalent Evaporation

$$m_{SE} = \frac{m_a(h_2 - h_1)}{2257}$$

Brain Spot

1. A Boiler has equivalent evaporation of 5000 kg/hr at design conditions. The coal supplied to boiler at rate 500 kg/hr. the calorific value of coal is 31 MJ/kg. Calculate the thermal efficiency of the boiler.

$$m_{SE} = 5000 \text{ kg/hr}$$

$$m_f = 500 \text{ kg/hr}$$

$$C_v = 31 \text{ MJ/kg} = 31 \times 10^3 \text{ J/kg}$$

$$\eta_b = (?)$$

$$m_{SE} = \frac{m_a (h_2 - h_1)}{2257}$$

$$\therefore m_a (h_2 - h_1) = m_{SE} \times 2257$$

$$= 5000 \times 2257$$

$$= 11285000$$

$$\therefore \eta_b = \frac{Q_s}{Q_f} \times 100 = \frac{m_a (h_2 - h_1)}{m_f \times C_v} \times 100$$

$$= \frac{11285000}{500 \times 31 \times 10^3} \times 100$$

Thermal Efficiency of boiler $\eta_b = 72.8\%$.

- 2 A Boiler generates 4500 kg of wet steam per hour at pressure 1.3 MN/m². The dryness fraction of steam is 0.92 and the feed water temperature 35°C. Calorific value of fuel is 31000 kJ/kg and specific heat of water is 4.1 kJ/kgK. Calculate the amount of fuel is consumed per hour if efficiency of Boiler is 72%.

$$m = 4500 \text{ kg/hr}$$

$$P = 1.3 \text{ MN/m}^2 = 1.3 \times 10^6 \times 10^{-5} \text{ bar} \\ = 13 \text{ bar}$$

$$T = 35^\circ\text{C}$$

$$C_v = 31000 \text{ kJ/kg}, \quad X = 0.92$$

$$C_w = 4.1 \text{ kJ/kgK}$$

$$\eta_b = 0.72$$

$$m_f = (?)$$

35°C temperature at $h_f = 146.7 \text{ kJ/kg}$

13 bar temperature pressure $h_f = 814.9 \text{ kJ/kg}$

$h_{fg} = 1972.7 \text{ kJ/kg}$

$$h_2 = h_f + x h_{fg}$$

$$= 814.9 + 0.92(1972.7)$$

$$= 2629.7 \text{ kJ/kg}$$

$$m_f = \frac{m(h_2 - h_1)}{m_f \times C_v}$$

$$m_f = \frac{4500(2629.7 - 146.7)}{0.72 \times 31000}$$

$$m_f = 500.60 \text{ kg/hr}$$

- 3 A Boiler produces 5000 kg of steam per hour at 12 bar with dryness Fraction of 0.94, From feed water at 40°C The coal supplied to the boiler is 550 kg/hr. the calorific value of coal 32000 kJ/kg. calculate Equivalent evaporation in kg of steam / kg of coal burnt and Thermal Efficiency of boiler.

$$m = 5000 \text{ kg}$$

$$P = 12 \text{ bar}$$

$$x = 0.94$$

$$T = 40^\circ\text{C}$$

$$m_f = 550 \text{ kg/hr}$$

$$C_v = 32000 \text{ kJ/kg}$$

$$\frac{m_{SE}}{m} = C_1$$

~~m~~

$$\eta_b = C_2$$

at 40°C temperature $h_1 = 167.6 \text{ kJ/kg}$

at 12 bar pressure $h_f = 798.6 \text{ kJ/kg}$

$$h_{fg} = 1986.2 \text{ kJ/kg}$$

$$h_2 = h_f + x h_{fg}$$

$$= 798.6 + 0.94 (1986.2)$$

$$h_2 = 2665.6 \text{ kJ/kg}$$

$$\eta_b = \frac{Q_s}{Q_f} = \frac{m_a (h_2 - h_1) \times 100}{m_f \times C_v}$$

$$= \frac{5000 (2665.6 - 167.6) \times 100}{550 \times 32000}$$

$$550 \times 32000$$

સત્સંગથી જ પોતાનું દોષદર્શન શક્ય બને છે.

$$\eta_b = 70.96\%$$

$$m_{SE} = \frac{m \times (h_2 - h_1)}{m_f \times 2257}$$

$$= \frac{5000 \times 2498}{550 \times 2257}$$

$$= 10.06 \text{ kg of steam/kg of coal}$$

4 What is the amount of heat required to produce 10 kg of steam at 5 bar pressure and 250°C temperature from feed water at 35°C. Specific heat of water as 4.187 kJ/kg and specific heat of Superheated steam as 2.5 kJ/kgK.

$$m = 10 \text{ kg}$$

$$P = 5 \text{ bar}$$

$$t = 35^\circ\text{C}$$

$$C_w = 4.187 \text{ kJ/kg}$$

$$t_{sup} = 250^\circ\text{C}$$

$$C_{ps} = 2.5 \text{ kJ/kgK}$$

$$Q_s = C??$$

at 35°C temperature $h_1 = 146.7 \text{ kJ/kg}$

at 5 bar pressure $h_g = 2748.7 \text{ kJ/kg}$

$t_{\text{sat}} = 151.9$

$$h_2 = h_g + C_{ps} (t_{\text{sup}} - t_{\text{sat}})$$

$$= 2748.7 + 2.5 (250 - 151.9)$$

$$= 2748.7 + 245.25$$

$$= 2993.95 \text{ kJ/kg}$$

$$Q_s = m (h_2 - h_1)$$

$$= 10 (2993.95 - 146.7)$$

$$= 28472.5 \text{ kJ}$$

~~5/1/22~~

Properties of steam

Equation

1 Saturated liquid

$$\text{Enthalpy } h_f = C_{pw} (T_{\text{sat.}})$$

2 dry saturated steam

$$\text{Enthalpy } h_g = h_f + h_{fg}$$

$$\text{Dryness Fraction } x = \frac{m_s}{m_s + m_w}$$

3 Superheated steam

$$\text{Enthalpy } h_{\text{sup}} = h_g + C_{ps} (T_{\text{sup.}} - T_{\text{sat.}})$$

$$\text{Heat } Q = C_{ps} (T_{\text{sup}} - T_{\text{sat}})$$

specific volume $\frac{V_{sup.}}{T_{sup.}} = \frac{V_{sat}}{T_{sat}}$

4 Wet Steam

Enthalpy $h_w = h_f + x h_{fg}$

Specific volume $v = x v_g$

wetness Fraction $(1-x) = \frac{m_w}{m_s + m_w}$

1 Evaluate the condition of steam.

a Steam at 15 bar pressure and specific volume is $0.121 \text{ m}^3/\text{kg}$

$$P = 15 \text{ bar}$$

$$V = 0.121 \text{ m}^3/\text{kg}$$

From steam table $V_g = 0.132 \text{ m}^3/\text{kg}$

Here, $V < V_g$, therefore, steam is wet steam.

$$\therefore V = x V_g$$

$$\therefore x = \frac{0.121}{0.132} = 0.91$$

b Steam at 10 bar pressure and 200°C temperature.

$$P = 10 \text{ bar}$$

$$t = 200^\circ\text{C}$$

From steam table $t_{\text{sat}} = 179.7^\circ\text{C}$

Here, $t > t_{\text{sat}}$, therefore steam is Superheated.

સંપ અને શાંતિ માટે સહન કરવું ફરજિયાત છે.

c Steam at 20 bar and having specific enthalpy 2650 kJ/kg.

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

$$H = 2650 \text{ kJ/kg}$$

From steam table $h_f = 2908.8$

Here, $H < h_f \rightarrow$ wet steam

d Steam at temperature of 150°C and specific volume 0.3928 m³/kg.

$$T = 150^\circ\text{C}$$

$$V = 0.3928$$

From steam table $V_g = 0.3928$

Here, $V \leq V_g \rightarrow$ dry saturated steam

Fig

2 1.5 kg of steam at a pressure of 10 bar and temperature of 250°C is expanded until the pressure becomes 2.8 bar. The dryness fraction of steam is then 0.9. Calculate change in internal energy.

$$m = 1.5 \text{ kg}$$

$$P_1 = 10 \text{ bar}$$

$$T_1 = 250^\circ\text{C}$$

$$P_2 = 2.8 \text{ bar}$$

$$x = 0.9$$

$$U_2 - U_1 = (?)$$

U_1 = Internal Energy at 10 bar pressure and 250°C temperature.

U_2 = Internal Energy at 2.8 bar pressure

\Rightarrow For $U_1 \rightarrow h_1 - PV_1$

From steam table at 10 bar pressure
 $t_{\text{sat}} = 179.9^\circ\text{C}$

$t > t_{\text{sat}} \rightarrow$ Therefore steam is superheated

From steam table $h_g = 2778.1 \text{ kJ/kg}$
 $v_g = 0.194 \text{ m}^3/\text{kg}$

$$h_1 = h_g + C_{ps} (T_{sup} - T_{sat})$$

$$= 2778.1 + 2.1 (250 - 179.9)$$

$$h_1 = 2925.31 \text{ kJ/kg}$$

For Volume,

$$\frac{V_{sup}}{T_{sup}} = \frac{V_{sat}}{T_{sat}}$$

$$\therefore V_{sup} = 0.224 \text{ m}^3/\text{kg}$$

$$\therefore U_1 = h_1 - PV_1$$

$$= 2925.31 - 10 \times 100 \times (0.224)$$

$$= 2701.31 \text{ kJ/kg}$$

\Rightarrow For $U_2 \rightarrow h_2 - PV_2$

From steam table at 2.8 bar pressure

$$h_f = 551.4 \text{ kJ/kg}$$

$$h_{fg} = 2170.7 \text{ kJ/kg}$$

$$v_g = 0.646 \text{ m}^3/\text{kg}$$

$$h_2 = h_f + x h_{fg}$$

$$= 551.4 + 0.9(2170.7)$$

$$h_2 = 2505.03 \text{ kJ/kg}$$

For volume, $V = x v_g = 0.9 \times 0.646$

$$\therefore V = 0.581 \text{ m}^3/\text{kg}$$

$$\therefore U_2 = h_2 - P v_2$$

$$= 2505.03 - 2.8 \times 100 \times 0.581$$

$$= 2342.21 \text{ kJ/kg}$$

$$\Rightarrow \text{Change in internal Energy} = U_2 - U_1$$

Energy

$$= m_s (U_2 - U_1)$$

$$= 1.5 (2342.2 - 2701.3)$$

$$= -538.7 \text{ kJ}$$

6 Calculate the internal Energy per kg of superheated steam at 10 bar and temperature of 300°C . Find also change in internal Energy if this steam is expanded at 1.4 bar and dryness Fraction 0.8.

$$P_1 = 10 \text{ bar}$$

$$T_1 = 300^{\circ}\text{C}$$

$$P_2 = 1.4 \text{ bar}$$

$$X = 0.8$$

Change in internal Energy = (?)

U_1 = Internal Energy at 10 bar and 300°C temperature

U_2 = Internal Energy at 1.4 bar pressure

\Rightarrow For U_1

From steam table at 10 bar pressure

$$t_{\text{sat}} = 179.9^{\circ}\text{C}$$

$t < t_{\text{sat}}$ $t > t_{\text{sat}}$ \rightarrow Therefore steam is Superheated

$$V_{\text{sat}} = 0.194 \text{ m}^3/\text{kg}$$

$$h_g = 2778.1 \text{ kJ/kg}$$

$$h_1 = h_g + c_{ps} (t_{\text{sup}} - t_{\text{sat}})$$

$$= 2778.1 + 2.1(300 - 179.9)$$

$$h_1 = 3030.31 \text{ kJ/kg}$$

For volume, $\frac{V_{\text{sup}}}{T_{\text{sup}}} = \frac{V_{\text{sat}}}{T_{\text{sat}}}$

$$\therefore V_{\text{sup}} = \frac{V_{\text{sat}} \times T_{\text{sup}}}{T_{\text{sat}}}$$

$$= 0.246 \text{ m}^3/\text{kg}$$

$$U_1 = h_1 - PV_1$$

$$= 2777$$

$$= 3030.3 - 10 \times 100 \times 0.246$$

$$U_1 = 2784.3 \text{ kJ/kg}$$

=> For U_2 ,

From steam table, $h_f = 458.4$

$$h_{fg} = 2232$$

સંપ અને શાંતિ માટે સહન કરવું ફરજિયાત છે.

=> For U_1 ,

$$h_1 = \frac{1}{2} R T_1 + \frac{5}{2} R T_1$$

$$= 458.4 + 0.8 \times 2232$$

$$= 2244 \text{ KJ/Kg}$$

For volume, $V = \gamma V_0$

$$= 0.8 \times 1.237$$

$$= 0.9896 \text{ m}^3/\text{kg}$$

$$U_2 = h_2 = P V_2$$

$$= 224.4 = 1.4 \times 10^5 \times 0.9896$$

$$= 2105.4 \text{ KJ/Kg}$$

=> Change in internal Energy,

$$\Delta U = U_2 - U_1 = 2105.4 - 2784.3$$

$$= -677.79 \text{ KJ/Kg}$$

3 A steam at 10 bar and dryness Fraction 0.98 receives 150 kJ/kg at the same pressure. What is the Final state of steam? Specific heat of superheated steam as 2.1 kJ/kgK

$$P = 10 \text{ bar}$$

$$x = 0.98$$

$$\text{Heat added} = 150 \text{ kJ/kg}$$

$$C_{ps} = 2.1 \text{ kJ/kgK}$$

at 10 bar pressure From steam

$$\text{table, } h_f = 762.8 \text{ kJ/kg}$$

$$h_{fg} = 2015.3 \text{ kJ/kg}$$

$$h_g = 2778.1 \text{ kJ/kg}$$

$$t_{\text{sat}} = 179.4^\circ\text{C}$$

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

$$= 762.8 + 0.98 \times 2015.3$$

$$h_w = 2737.39 \text{ kJ/kg}$$

$$h = h_w + \text{Heat added} = 2737.39 + 150$$

$$= 2887.79 \text{ kJ/kg}$$

$h_g < h \rightarrow$ therefore steam is Superheated

$$\therefore h = h_g + C_{ps}(t_{sup} - t_{sat})$$

$$\therefore 2887.79 = 2778.1 + 2.1(T_{sup} - 179.9)$$

$$\therefore T_{sup} = 232.47^\circ\text{C}$$

- 4 Determine Enthalpy and internal energy of 1 kg steam at pressure 12 bar when
- the dryness Fraction of steam is 0.8
 - the steam is dry saturated
 - the steam is superheated

a $P = 10 \text{ bar}$
 $x = 0.85$

Form Steam table at 10 bar pressure

$$h_f = 762.8 \text{ kJ/kg}$$

$$h_{fg} = 2015.3 \text{ kJ/kg}$$

$$h_g = 2778.1 \text{ kJ/kg}$$

$$v_g = 0.194 \text{ m}^3/\text{kg}$$

$$\rightarrow h = h_f + x h_{fg}$$

$$h = 762.8 + (0.85)(2015.3)$$

$$= 2475.81 \text{ kJ/kg}$$

$$\rightarrow U = h - Pv = h - p \times v_g$$

$$U = 2475.81 - 10(100)(0.85)(0.194)$$

$$U = 2310.91 \text{ kJ/kg}$$

B From steam table, $h_g = 2778.1 \text{ kJ/kg}$

$$\therefore U = h_g - Pv_g$$

$$= 2778.1 - 10(100)(0.194)$$

$$= 2584.1 \text{ kJ/kg}$$

C $P = 10 \text{ bar}$

$t = 300^\circ\text{C}$

at 10 bar pressure $t_{\text{sat}} = 179.9^\circ\text{C}$

$$h = h_g + C_{ps}(T_{\text{sup}} - T_{\text{sat}})$$

$$= 2778.1 + 2.1(300 - 179.9)$$

$$h = 3030.3 \text{ KJ/Kg}$$

For volume, $\frac{V_{\text{sup}}}{T_{\text{sup}}} = \frac{V_{\text{sat}}}{T_{\text{sat}}}$

$$\therefore V_{\text{sup}} = \frac{573 \times 0.194}{452.9}$$

$$= 0.246 \text{ m}^3/\text{Kg}$$

~~$$\therefore H = U h - V$$~~

$$\therefore U = h - pV$$

$$= 3030.3 - 10 \times 100 \times 0.246$$

$$= 2784.3 \text{ KJ/Kg}$$

5 Determine amount of heat is required to produce 7 kg of steam at pressure of 6 bar and temperature of 250°C from water at 35°C.

$$m = 7 \text{ kg}$$

$$T_{\text{sup}} = 250^\circ\text{C}$$

$$P = 6 \text{ bar}$$

From steam table $t_{\text{sat}} = 158.8^\circ\text{C}$

$$h_f = 670.4 \text{ kJ/kg}$$

$$h_{fg} = 2055 \text{ kJ/kg}$$

Enthalpy of steam,

$$h_{\text{sup}} = h_g + C_{ps}(T_{\text{sup}} - T_{\text{sat}})$$

$$= 670.4 + 2055 + 2.1(250 - 158.8)$$

$$= 2946.92$$

For 35°C temperature water $h_f = 146.56$

Net amount of heat = $h_{\text{sup}} - h_w$

$$= 2946.92 - 146.56$$

$$= 2800.36$$

Total amount of heat

$$H = m \times h_{net}$$

$$= 7 \times 2800.36$$

$$H = 19602.52 \text{ KJ}$$

5/11/22

Brain Spot

IC Engine

Equation:

Indicated Power (IP):

$$IP = \frac{P_m A L n}{60}$$

Here, P_m = main effective Pressure

A = Cross Section area of Piston

L = stroke length

n = number of working stroke

Brake Power (BP):

$$BP = \frac{2\pi NT}{60}$$

Here, N = speed of Engine

T = Resisting Torque

$$3 \text{ Friction Power (FP)} = IP - BP$$

4 Mechanical efficiency:

$$\eta_m = \frac{BP}{IP}$$

5 Indicated Thermal Efficiency:

$$\eta_{ith} = \frac{IP}{\text{Fuel Supplied}}$$

6 Brake Thermal Efficiency:

$$\eta_{bth} = \frac{BP}{\text{Fuel Supplied}}$$

1 A 6 cylinder 4 stroke IC engine is to produce 95 kW brake power at 800 rpm. The stroke to bore ratio is 1.25. Mean effective pressure is 7 bar. Determine the bore and stroke of the engine. Assume mechanical efficiency as 80%.

$$K = 6$$

$$BP = 95 \text{ kW}$$

$$N = 800 \text{ rpm}, \quad n = 400 \text{ rpm}$$

$$P_m = 7 \text{ bar} = 7 \times 10^5 \text{ Pa}$$

$$\frac{L}{d} = 1.25 \quad \rightarrow \quad L = 1.25d$$

$$\eta_{\text{mech}} = 80\%$$

$$\therefore \eta_{\text{mech}} = \frac{BP}{IP} \times 100$$

$$\therefore 80 = \frac{95}{IP} \times 100$$

$$\therefore IP = 118.75 \text{ kW}$$

$$\therefore IP = \frac{P_m L A n K}{60,000}$$

$$\therefore 118.75 = \frac{7 \times 10^5 \times 1.25d \times \pi \times d^2 \times 1400 \times 6}{60,000}$$

$$\therefore d^3 = 432.2 \times 10^{-5}$$

$$\therefore d = 0.163 \text{ m}$$

$$\therefore \frac{L}{d} = 1.25$$

$$\therefore L = 1.25 \times 0.163$$

$$\therefore L = 0.203 \text{ m}$$

2. A two stroke internal Combustion engine has stroke length of 140 mm and cylinder bore 90 mm. its mean effective pressure is 5.4 bar and speed of the engine is 1000 rpm. Determine brake power of engine. Assume mechanical efficiency as 85%.

given, $L = 140 \text{ mm} = 140 \times 10^{-3} \text{ m}$.

$$d = 90 \text{ mm} = 90 \times 10^{-3} \text{ m}$$

$$P_m = 5.4 \text{ bar} = 5.4 \times 10^5 \text{ Pa}$$

$$\eta_{\text{mech}} = 85\%$$

$$N = 1000 \text{ rpm}$$

$$\therefore IP = \frac{P_m L A N K}{60,000}$$

$$= \frac{5.4 \times 10^5 \times 140 \times 10^{-3} \times \pi \times (90 \times 10^{-3})^2}{60,000 \times 4}$$

$$\therefore IP = 8.11$$

$$\therefore IP = 8.0117 \text{ kW}$$

$$\therefore \eta_{\text{mech}} = \frac{BP}{IP} \times 100$$

$$\therefore BP = \frac{85 \times 8.0117}{100}$$

$$\therefore BP = 6.80 \text{ kW}$$

3. The following readings were taken during the test of single cylinder four stroke oil engine:

Cylinder diameter = 250 mm

Stroke length = 400 mm

Mean effective pressure = 6.5 bar

Engine speed = 250 rpm

Net load on the brake = 1080 N
 Effective diameter of the brake = 1.5 m
 Fuels used per hour = 10 kg
 Calorific value of fuel = 44300 kJ/kg

Calculate: TP, BP, η_{mech} , η_{th}

Given, $d = 250 \text{ mm} = 250 \times 10^{-3} \text{ m}$
 $r = 400 \text{ mm} = 400 \times 10^{-3} \text{ m}$
 $P_m = 6.5 \text{ bar} = 6.5 \times 10^5 \text{ Pa}$
 $N = 250 \text{ rpm} = 125 \text{ rpm}$
 $F = 1080 \text{ N}$
 $D = 1.5 \text{ m}$

$$T = F \times r = 1080 \times \frac{1.5}{2} = 810$$

$$BP = \frac{2\pi NT}{60000}$$

$$= \frac{2 \times \pi \times 250 \times 810}{60,000}$$

$$BP = 21.206 \text{ kW}$$

$$IP = \frac{P_m L A n k}{60,000}$$

$$IP = \frac{6.5 \times 10^5 \times 0.4 \times \pi \times (250 \times 10^{-3})^2 \times 125}{60,000 \times 4}$$

$$\therefore IP = 26.54 \text{ kW}$$

$$\eta_{\text{mech}} = \frac{BP}{IP} \times 100 \%$$

$$= \frac{21.2}{26.54} \times 100 \%$$

$$\therefore \eta_{\text{mech}} = 79.77 \%$$

$$\eta_{\text{ith}} = \frac{IP}{\text{mp} \cdot \text{CV}} \times 100$$

$$= \frac{26.54}{10/3600 \times 44300} \times 100$$

$$\eta_{\text{ith}} = 21.59 \%$$

4 A Four cylinder two stroke cycle petrol engine develops 30 kw at 2500 rpm. The indicated mean effective pressure of each is 800 kpa and mechanical efficiency is 80%. Calculate the diameter and stroke of each of the cylinder if $L/D = 1.5$. Also calculate the brake specific fuel engine if brake thermal efficiency is 28%. The calorific value of petrol is 44000 KJ/kg

$$K = 4$$

$$IP = 30 \text{ kw}$$

$$N = 2500 \text{ rpm}$$

$$\eta_{ith} = 28\%$$

$$C_v = 44000 \text{ KJ/kg}$$

$$P_m = 800 \text{ kpa} = 800 \times 10^3 \text{ Pa}$$

$$\eta_{mech} = 80\%$$

$$\frac{L}{D} = 1.5 \rightarrow L = 1.5D$$

~~$$m_p = (?)$$~~

$$IP = \frac{P_m L A N K}{60,000}$$

$$\therefore 30 = \frac{800 \times 10^3 \times 1.5D \times \pi D^2 \times 2500 \times L}{4}$$

$$\therefore D^3 = 1.91 \times 10^{-4}$$

$$\therefore D = 0.057 \text{ m}$$

$$\therefore L = 1.5D = 1.5 \times 0.057 = 86.38 \text{ mm}$$

$$\eta_{\text{mech}} = \frac{BP}{IP} \times 100$$

$$\therefore BP = \frac{80 \times 30}{100} = 24 \text{ kW}$$

$$\eta_{\text{ith}} = \frac{BP}{m_p \times C_v} \times 100$$

$$28 = \frac{24}{\frac{m_p}{3600} \times 44000} \times 100$$

$$m_p = 7.0129$$

$$\text{Brake Specific Fuel Engine} = \frac{m_p}{BP}$$

$$\therefore \text{BSEC} = \frac{7.0129}{24}$$

$$\therefore \text{BSEC} = 0.2922 \text{ kg/kWhr}$$

5 A six cylinder 4 stroke IC engine is to develop 89.5 kw indicated power at 800 rpm. The stroke to bore ratio is 1.25:1. mechanical efficiency of 80% and brake mean effective pressure of 5 bar. Determine the diameter and stroke of the engine.

Given, $K = 6$

$$IP = 89.5 \text{ kw}$$

$$N = 800 \text{ rpm}$$

$$\eta_{\text{mech}} = 80\%$$

$$P_{\text{mb}} = 5 \text{ bar} = 5 \times 10^5 \text{ Pa}$$

$$\frac{L}{d} = 1.25$$

$$L = 1.25d$$

$$\therefore \eta_{\text{mech}} = \frac{BP}{IP} \times 100$$

$$\therefore BP = \frac{80 \times 89.5}{100}$$

$$\therefore BP = 71.6 \text{ kW}$$

$$\therefore BP = \frac{\rho P_{mb} L A N K}{60,000}$$

$$\therefore 71.6 = \frac{5 \times 10^5 \times 1.25d \times \pi \times d^2 \times 400 \times 6}{60,000 \times 4}$$

$$\therefore d^3 = 1405150$$

$$\therefore d = 0.1548 \text{ m}$$

$$\therefore \frac{l}{d} = 1.25$$

$$\therefore l = 0.1925 \text{ m}$$

~~$$\frac{h_0}{511122}$$~~

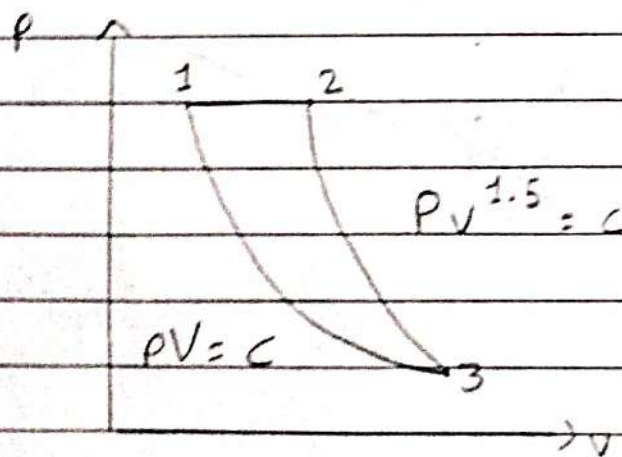
Properties Of Gases

1. 0.15 m^3 of air at a pressure of 900 kPa and 300°C is extended at constant pressure of 3 times its initial volume. It is expanded polytropically following the law $PV^{1.5} = c$ and finally compressed back to initial state isothermally.

Calculate (1) Heat Received (2) Heat Rejected (3) Efficiency of the cycle.

Given, $V_1 = 0.15 \text{ m}^3$, $V_2 = 3V_1$
 $P_1 = 900 \text{ kPa}$, $T_1 = 300^\circ\text{C} = 573 \text{ K}$

$Q_A = (?)$, $Q_R = (?)$, $\eta_{th} = (?)$



$$\rightarrow P_1 V_1 = m R T_1$$

$$\therefore m = \frac{P_1 V_1}{R T_1} = \frac{900 \times 0.15}{0.287 \times 573} = 0.821 \text{ kg}$$

\rightarrow For Process 1-2 (Constant Pressure)

$$\therefore \frac{V_1}{V_2} = \frac{T_1}{T_2}$$

$$\therefore T_2 = \frac{V_1}{3V_1} \times \frac{T_1}{1}$$

$$\therefore T_2 = 1719 \text{ K}$$

$$Q_{1-2} = m C_p (T_2 - T_1)$$

$$= 0.821 \times 1.005 (1719 - 573)$$

$$Q_{1-2} = 945.57 \text{ kJ}$$

\rightarrow For Process 3-1 (Isothermal) $\rightarrow T_1 = T_3$

$$W_{2-3} = \frac{P_2 V_2 - P_1 V_1}{n-1} = \frac{m R (T_2 - T_3)}{n-1}$$

$$\therefore W_{2-3} = \frac{0.821 \times 0.287 (1719 - 573)}{1.5 - 1}$$

$$\therefore W_{2-3} = 540 \text{ kJ}$$

$$Q_{2-3} = \frac{\gamma - n}{\gamma - 1} \times W_{2-3}$$

$$= \frac{1.4 - 1.5}{1.4 - 1} \times 540$$

$$= -135 \text{ kJ}$$

→ For Process 3-1 (Polytropically)

$$W_{3-1} = Q_{3-1} = mRT_1 \ln \frac{P_3}{P_1}$$

$$\rightarrow P_1 = P_2 = 900 \text{ kPa}$$

$$\therefore \frac{P_2}{P_3} = \left(\frac{T_2}{T_3} \right)^{\frac{\gamma}{\gamma - 1}}$$

$$\therefore P_3 = \frac{900}{3^{(1.4/0.4)}} = 19.25 \text{ kPa}$$

$$\therefore Q_{3-1} = 0.821 \times 0.287 \ln \frac{19.25}{900}$$

$$\therefore Q_{3-1} = -519.1 \text{ kJ}$$

$$\rightarrow \text{Heat Received } Q_{1-2} = 945.57 \text{ kJ}$$

$$\begin{aligned} \text{Heat Rejected } Q_{3-1} + Q_{2-3} &= -519.1 - 135 \\ &= -654.1 \text{ kJ} \end{aligned}$$

$$\rightarrow \text{Efficiency } \eta_{th} = \frac{1 - Q_R}{Q_A} \times 100$$

$$= \frac{1 - 654.1}{945.57} \times 100$$

$$= 30.82 \%$$

2 The gas constant for atmosphere air is $0.287 \text{ kJ/kg}\cdot\text{K}$ and its specific heat at constant volume is $0.7 \text{ kJ/kg}\cdot\text{K}$. Find the value of C_p and γ .

$$\text{Given } R = 0.287 \text{ kJ/kg}\cdot\text{K}$$

$$C_v = 0.7$$

$$\therefore \gamma = 1 + \frac{R}{C_v}$$

$$= 1 + \frac{0.287}{0.7}$$

$$\therefore \gamma = 1.41$$

$$\rightarrow \gamma = \frac{C_p}{C_v} \rightarrow C_p = \gamma \cdot C_v$$

$$= 0.7 \times 1.41$$

$$\therefore C_p = 0.987 \text{ kJ/kg}\cdot\text{K}$$

3 One kg of air at a pressure of 1 bar temperature of 300 K is compressed to a pressure of 10 bar isothermally and adiabatically. Calculate work done, heat transfer and change in internal energy in both the cases. Take $C_p = 1.005 \text{ kJ/kgK}$, $C_v = 0.718 \text{ kJ/kgK}$

Given, $m = 1 \text{ kg}$

$$P_1 = 1 \text{ bar}, \quad P_2 = 10 \text{ bar}$$

$$T_1 = 300 \text{ K}, \quad W = (?)$$

$$Q = (?)$$

$$\Delta U = (?)$$

$$\therefore R = C_p - C_v = 1.005 - 0.718 = 0.287 \text{ kJ/kgK}$$

$$\therefore \gamma = \frac{C_p}{C_v} = \frac{1.005}{0.718} = 1.4$$

→ 1) Isothermal Process

$$\text{For, } W = P_1 V_1 \log \left(\frac{P_1}{P_2} \right)$$

$$W = 1 \times 10^5$$

$$\text{For } V_1 \rightarrow P_1 V_1 = m R T_1$$

$$V_1 = \frac{1 \times 0.287 \times 10^3 \times 300}{1 \times 10^5}$$

$$V_1 = 0.861 \text{ m}^3$$

→ For $W = P_1 V_1 \log_e \left(\frac{P_1}{P_2} \right)$

$$= 1 \times 10^5 \times 0.861 \times \log \frac{1}{10}$$

$$W = -198.3 \text{ kJ}$$

→ In Isothermal Process,

Change In Internal Energy $\Delta U = 0$

→ $Q = W + \Delta U$

$$Q = -198.3 \text{ kJ}$$

→ 2) Adiabatic Process:

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\therefore V_2 = V_1 \left(\frac{P_1}{P_2} \right)^{1/\gamma}$$

$$\therefore V_2 = 0.861 \times \left(\frac{1}{10} \right)^{1/1.4}$$

$$\therefore V_2 = 0.166 \text{ m}^3$$

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma-1}$$

$$= 300 \left(\frac{0.861}{0.166} \right)^{1.4-1}$$

$$T_2 = 579.53 \text{ K}$$

$$\rightarrow \text{For } W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$= \frac{1 \times 10^5 (0.861) - 10 \times 10^5 (0.166)}{1.4 - 1 (1000)}$$

$$W = -199.75 \text{ KJ}$$

$$\rightarrow \text{Change in internal Energy } \Delta U = m C_v (T_2 - T_1)$$

$$\therefore \Delta U = 1 \times 0.718 (579.53 - 300)$$

$$\therefore \Delta U = 200.7 \text{ KJ}$$

સંપ ચાને શાંતિ માટે સહન કરવું ફરજિયાત છે.

→ In Adiabatic Process,

$$\text{heat transfer } Q = 0$$

4 An ideal gas is heated from 25°C to 145°C . The mass of gas is 2 kg . Determine,
 1) Specific heats 2) Change in Internal Energy 3) Change in Enthalpy.

Given, $T_1 = 25^\circ\text{C} = 298\text{ K}$

$$T_2 = 145^\circ\text{C} = 418\text{ K}$$

$$m = 2\text{ kg}$$

$$R = 267\text{ J/kg}\cdot\text{K}$$

$$\gamma = 1.4$$

$$C_p = (?) , \Delta U = (?)$$

$$C_v = (?) , \Delta H = (?)$$

$$\rightarrow C_v = \frac{R}{\gamma - 1} = \frac{267}{1.4 - 1} = 667.5\text{ J/kg}\cdot\text{K}$$

$$\rightarrow \gamma = \frac{C_p}{C_v} \rightarrow C_p = 1.4 \times 667.5$$

$$C_p = 934.5\text{ J/kg}\cdot\text{K}$$

$$\begin{aligned} \rightarrow \Delta U &= mC_V(T_2 - T_1) \\ &= 2 \times 667.5 (418 - 298) \end{aligned}$$

$$\Delta U = 160.2 \text{ kJ}$$

$$\begin{aligned} \rightarrow \Delta H &= mC_p(T_2 - T_1) \\ &= 2 \times 934.5 (418 - 298) \end{aligned}$$

$$\Delta H = 224.3 \text{ kJ}$$

5 Determine the work done in compressing one kg of air from a volume of 0.15 m^3 at a pressure of 1 bar to a value of 0.05 m^3 when the compression is Isothermal and Adiabatic, take $\gamma = 1.4$

Given, $m = 1 \text{ kg}$

$$V_1 = 0.15 \text{ m}^3, \quad V_2 = 0.05 \text{ m}^3$$

$$P_1 = 1 \text{ bar} = 1 \times 10^5 \text{ Pa}$$

$$W = ?$$

\rightarrow 1) Isothermal

$$\therefore \frac{V_1}{V_2} = \frac{P_2}{P_1}$$

$$\therefore P_2 = \frac{0.15}{0.05} \times 1 = 3 \text{ bar}$$

$$\rightarrow \text{For } W = P_1 V_1 \ln \frac{P_1}{P_2}$$

$$= 1 \times 10^8 \times 0.15 \times \ln \frac{1}{3}$$

$$= -16.48 \text{ kJ}$$

\rightarrow 2) Adiabatic

$$\therefore \frac{P_2}{P_1} = \left(\frac{V_1}{V_2} \right)^\gamma$$

$$\therefore P_2 = 1 \left(\frac{0.15}{0.05} \right)^{1.4}$$

$$= 4.66$$

$$\rightarrow W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} = \frac{100 \times 0.15 - 466 \times 0.05}{1.4 - 1}$$

$$W = -20.75 \text{ kJ}$$

Heat Engine

1 A petrol engine with compression ratio of 5 develops 20 kW indicated power and consumes 8 liters of fuel per hour. The specific gravity of fuel is 0.78 and its calorific value is 44 MJ/kg. Calculate the indicated thermal efficiency and relative efficiency. Take $\gamma = 1.4$

Given data, $r = 5$

$$I.P = 20 \text{ kW}$$

$$m_f = 8 \text{ L}$$

$$\text{specific gravity} = 0.78$$

$$C.V = 44 \text{ MJ/kg}$$

$$\eta_{ith} = (?)$$

$$\eta_r = (?)$$

$$\rightarrow \eta_{ith} = \frac{I.P}{m_f \times C.V} = \frac{20 \times 1000 \times 60 \times 60}{8 \times 44000 \times 0.78 \times 1000}$$

$$\eta_{ith} = 26.22 \%$$

$$\rightarrow \eta_{\text{air}} = 1 - \frac{1}{r^{\gamma-1}}$$

$$= 1 - \frac{1}{5^{1.4-1}}$$

$$= 47.46\%$$

$$= 47.46\%$$

$$\rightarrow \eta_R = \frac{\eta_{\text{ith}}}{\eta_{\text{air}}} = \frac{26.22}{47.46}$$

$$\eta_R = 65.24\%$$

- 2 An oil engine working on diesel cycle has cylinder bore of 190 mm and piston stroke of 230 mm. The clearance volume is 240 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 the stroke with same compression ratio.

$$\Rightarrow \text{Given data, } d = 190 \text{ mm} = 190 \times 10^{-3} \text{ m}$$

$$L = 230 \text{ mm} = 230 \times 10^{-3} \text{ m}$$

$$V_c = 290 \text{ cm}^3$$

$$\rightarrow \text{Swept Volume } V_s = \frac{\pi d^2 L}{4}$$

$$= \frac{\pi \times (19)^2 \times (23)}{4}$$

$$V_s = 6521.16 \text{ cm}^3$$

$$\rightarrow V_1 = V_s + V_c = 6811.16 \text{ cm}^3$$

$$\rightarrow \text{Compression ratio } r = \frac{V_1}{V_2}$$

$$= \frac{6811.16}{290}$$

$$\therefore r = 23.49$$

\Rightarrow Case: 1: Cut off = 6%.

$$\therefore \frac{V_3 - V_2}{V_1 - V_2} = 0.06$$

$$\therefore V_3 = 0.06 (6811.16 - 290)$$

$$\therefore V_3 = 681.27 \text{ cm}^3$$

Cut off ratio,

$$s = \frac{V_3}{V_2} = \frac{681.27}{290} = 2.349$$

$$\rightarrow \eta = 1 - \frac{1}{\gamma^{\gamma-1}} \cdot \frac{1}{s} \left[\frac{s^{\gamma} - 1}{s - 1} \right]$$

$$= 0.6546$$

$$\eta = 65.46\%$$

\Rightarrow Case : 2 Cut-off = 11 %

$$\therefore \frac{V_3 - V_2}{V_1 - V_2} = 0.11$$

$$\therefore V_3 = 0.11 (6811.16 - 290)$$

$$\therefore V_3 = 1007.33 \text{ cm}^3$$

$$\rightarrow \beta = \frac{V_3}{V_2} = \frac{1007.33}{290} = 3.47$$

$$\rightarrow \eta = 1 - \frac{1}{r^{\gamma-1}} \cdot \frac{1}{\beta} \left[\frac{\beta^{\gamma}-1}{\beta-1} \right]$$

$$= 0.6148$$

$$\eta = 61.48\%$$

$$\rightarrow \therefore \text{loss in efficiency} = \frac{65.46 - 61.48}{65.46} \times 100$$

$$= 6.08\%$$

3 In an ideal diesel cycle, the temperatures at the beginning and at the end of compression are 57°C and 603°C respectively. The temperatures at beginning and end of expansion are 1950°C and 870°C respectively. Determine the ideal efficiency of the cycle. If the pressure at the beginning is 1 bar, calculate the maximum pressure in the cycle.

⇒ Given data

$$T_1 = 330 \text{ K}$$

$$T_2 = 876 \text{ K}$$

$$T_3 = 2223 \text{ K}$$

$$T_4 = 1143 \text{ K}$$

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

$$\Rightarrow \eta = 1 - \frac{1}{\gamma} \left| \frac{T_4 - T_1}{T_3 - T_2} \right|$$

$$= 1 - \frac{1}{1.4} \left| \frac{1143 - 330}{2223 - 876} \right|$$

$$= 0.5699$$

$$\eta = 56.99\%$$

→ For isentropic compression process,

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\therefore P_2 = P_1 r^\gamma$$

$$\therefore T_2 = T_1 \cdot r^{\gamma-1}$$

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

$$\therefore r = \left(\frac{876}{330} \right)^{2.5}$$

$$\therefore r = 11.48$$

$$\rightarrow P_2 = (1) \cdot (11.48)^{1.4}$$

$$\therefore P_2 = 30.473 \text{ bar}$$

4 A diesel engine has a compression ratio of 15 and heat addition at constant pressure takes place 6% of stroke. Find the air standard efficiency of the engine. Take $\gamma = 1.4$.

$$\Rightarrow \text{Given data, } r = \frac{V_1}{V_2} = 15$$

$$\therefore V_1 = r \cdot V_2 = 15$$

$$\therefore \frac{V_3 - V_2}{V_1 - V_2} = 0.06$$

$$\therefore (V_3 - 1) = 0.06(15 - 1)$$

$$\therefore V_3 = 1.84$$

$$\rightarrow \beta = \frac{V_3}{V_2} = 1.84$$

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

$$= 1 - \frac{1}{(15)^{1.4-1}} \times \frac{1}{1.4} \left[\frac{(1.84)^{1.4}-1}{1.84-1} \right] \times 100$$

$$\eta = 61.19\%$$

Compressor.

1 A single stage air compressor draws 2 m^3 of air/min at 1 bar abs. and compresses it according to the law $PV^{1.2} = \text{constant}$ to the delivery pressure of 5 bar abs. The compressor is driven by an electric motor having a power of 7.5 kw. Calculate the indicated power and the mechanical efficiency assuming no clearance.

$$\rightarrow V_1 = 2 \text{ m}^3/\text{min}$$

$$P_1 = 1 \times 10^5 \text{ N/m}^2$$

$$n = 1.2$$

$$B.P = 7.5 \text{ kw}$$

$$P_2 = 2 \text{ bar} = 2 \times 10^5 \text{ N/m}^2$$

$$\rightarrow W = P_1 V_1 \cdot \frac{n}{n-1} \left[\left(\frac{P_2}{P_1} \right)^{n-1/n} \right]$$

$$= 10^5 \times 0.033 \times \frac{1.2}{1.2-1} \left[(5)^{0.166} - 1 \right]$$

$$W = 6.152 \times 10^3$$

$$\therefore W = I.P = 6.152 \text{ kW}$$

$$\rightarrow \eta_m = \frac{IP}{BP} = \frac{6.152}{7.5} \times 100$$

$$\eta_m = 82.02\%$$

2. A single stage, single acting compressor has a bore of 170 mm and stroke of 260 mm. It runs at 130 rpm. The suction pressure is 1 bar and delivery pressure is 9 bar. Find the Indicated power if compression follow the law $PV^{1.25} = c$ and isothermal efficiency. Assume there is no clearance volume.

$$\text{Given data, } d = 170 \text{ mm} = 0.17 \text{ m}$$

$$l = 260 \text{ mm} = 0.26 \text{ m}$$

$$P_1 = 1 \times 10^5 \text{ N/m}^2$$

$$P_2 = 9 \times 10^5 \text{ N/m}^2$$

$$N = 130 \text{ rpm}$$

$$n = 1.25$$

$$\rightarrow V_1 = \frac{\pi}{4} d^2 l = \frac{\pi}{4} \times (0.17)^2 \times 0.26$$

$$\therefore V_1 = 5.6 \times 10^{-3} \text{ m}^3$$

Swept volume per second,

$$\therefore V_1 = 5.6 \times 10^{-3} \times \frac{130}{60}$$

$$\therefore V_1 = 0.01278 \text{ m}^3/\text{s}$$

$$I.P. = W = P_1 V_1 \cdot n \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= 10^5 \times 0.01278 \times \frac{1.25}{0.25} \left[(4)^{0.2} - 1 \right]$$

$$I.P. = 3.53 \text{ kW}$$

$$W = P_1 V_1 \log \left(\frac{P_2}{P_1} \right)$$

$$= 10^5 \times 0.01278 \times \log(4)$$

$$\therefore W = 2.808 \text{ kW}$$

$$\rightarrow \eta_{iso} = \frac{2.808}{3.53} = 79.66\%$$

3 A single stage air compressor air through pressure ratio of 9 from a pressure of 1 bar. Free air delivery is $3 \text{ m}^3/\text{min}$. Swept volume and index of compression are 15 l and 1.3 respectively. Determine 1) Power required 2) Rotational speed of the compressor speed of the compressor in rpm. Neglect clearance.

Given data, $\frac{P_2}{P_1} = 9$

$$\therefore P_1 = 1 \text{ bar}$$

$$\rightarrow V_1 = \frac{3}{60} \text{ m}^3/\text{sec}$$

$$\rightarrow W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{1.3}{1.3-1} \times \frac{3}{60} \times 10^3 \left[(9)^{0.230} - 1 \right]$$

$$\therefore W = 14.243 \text{ kw}$$

$$\Rightarrow \text{rotational speed} = \frac{1000 \times 3}{15}$$

$$N = 200 \text{ rpm}$$

4 A single stage single acting compressor has intake pressure 1 bar and delivery pressure 15 bar. The compression and expansion follows the law $PV^{1.3} = C$. The piston speed and rotation of shaft is 190 m/min and 330 rpm respectively. Indicate power is 28 kw and volumetric efficiency is 95%. Determine bore and stroke

$$\begin{aligned} \rightarrow \text{Given data, } P_1 &= 1 \times 10^5 \text{ N/m}^2 \\ P_2 &= 15 \times 10^5 \text{ N/m}^2 \\ n &= 1.3 \\ V_p &= 190 \text{ m}^3/\text{min} \\ N &= 330 \text{ rpm} \\ IP &= 28 \text{ kw} \\ \eta_v &= 0.95 \end{aligned}$$

$$\rightarrow V_p = 2LN = \frac{190}{2 \times 330} = 0.2878 \text{ m} = L$$

$$\rightarrow I.P. = \frac{n}{n-1} P(V_1 - V_4) \left[\left(\frac{P_2}{P_1} \right)^{\frac{1.3-1}{1.3}} - 1 \right] \frac{330}{60}$$

$$\therefore 28 \times 10^3 = \frac{1.3}{1.3-1} \times 10^5 (V_1 - V_4) \left[(15)^{0.230} - 1 \right]$$

$$\therefore V_1 - V_4 = 0.0135 \text{ m}^3$$

$$\rightarrow \eta_v = \frac{V_1 - V_4}{V_s}$$

$$\therefore V_s = \frac{V_1 - V_4}{\eta_v} = \frac{0.0135}{0.95} = 0.0142 \text{ m}^3$$

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

$$\therefore D^2 = \frac{0.0142 \times 4}{3.14 \times 0.2878}$$

$$\therefore D = 0.2507 \text{ m}$$