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 thermel Efficiency (η_b)

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

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4 Equivalent Evaporation

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

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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.

$m_{SE} = 5000\ kg/hr$
$m_f = 500\ kg/hr$
$C_v = 31\ MJ/kg = 31 \times 10^3\ J/kg$
$\eta_b = (?)$

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

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

$$= 5000 \times 2257$$

$$= 11285000$$

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

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

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

2 A Boiler generates 4500 kg of wet steam per hour at pressure $1.3\ MN/m^2$. The dryness fraction of steam is 0.92 and the feed water temperature 35°C. Calorific value of fuel is ~~0~~ 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%.

$m = 4500\ kg/hr$

$P = 1.3\ M\ N/m^2 = 1.3 \times 10^6 \times 10^{-5}\ bar$

$= 13\ bar$

$T = 35°C$

$C_v = 31000\ kJ/kg$, $X = 0.92$

$C_w = 4.1\ kJ/kg\,k$

$\eta_b = 0.72$

$m_f = (?)$

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

13 bar ~~tempera~~ pressure $h_f = 814.9\ kJ/kg$

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

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

$$= 814.9 + 0.92(1972.7)$$

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

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

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

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

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.

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$m = 5000$ kg
$P = 12$ bar
$x = 0.94$
$T = 40°C$
$m_f = 550$ kg/hr
$C_v = 32000$ kJ/kg

$\frac{m_{SE}}{m} = (?)$

$\eta_b = (?)$

at 40°C temperature $h_1 = 167.6$ kJ/kg

at 12 bar pressure $h_f = 798.6$ kJ/kg
$h_{fg} = 1986.2$ kJ/kg

$h_2 = h_f + x h_{fg}$

$= 798.6 + 0.94(1986.2)$

$h_2 = 2665.6$ kJ/kg

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

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

$\eta_b = 70.96\%$

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

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

$= 10.06$ 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.

$m = 10$ kg
$P = 5$ bar
$t = 35°C$
$C_w = 4.187$ KJ/kg
$t_{sup} = 250°C$ $\quad$ $C_{ps} = 2.5$ KJ/kgK
$Q_s = (?)$

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at 35°c temparature h_1 = 146.7 KJ/kg

at 5 bar pressure h_g = 2748.7 KJ/kg
t_{sat} = 151.9

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

$= 2748.7 + 2.5(250 - 151.9)$

$= 2748.7 + 245.25$

$= 2993.95$ KJ/kg

$Q_s = m(h_2 - h_1)$

$= 10(2993.95 - ~~151~~\ 146.7)$

$= 28472.5$ KJ

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Its nature and its own improvement is its duty. (Gujarati footer)

Properties of steam

Equation

1 Saturated liquid

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

2 dry saturated steam

Enthalpy $h_g = h_f + h_{fg}$

Dryness Fraction $X = \frac{m_s}{m_s + m_w}$

3 Superheated steam

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

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

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

4 Wet Steam

Enthalp $h_w = h_f + x\,h_{fg}$

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 m^3/kg

$P = 15$ bar
$V = 0.121\ m^3/kg$

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

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.

$P = 10$ bar
$t = 200°C$

From steam table $t_{sat} = 179.7°C$

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

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

$P = 20$ bar
$H = 2650$ 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 m^3/kg.

$T = 150°C$
$V = 0.3928$

From steam table $V_g = 0.3928$

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

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

$m = 1.5\ kg$ $P_1 = 10\ bar$
$T_1 = 250°C$ $P_2 = 2.8\ bar$
$x = 0.9$ $U_2 - U_1 = (?)$

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

U_2 = Internal Energy at 2.8 bar pressure

=) For $U_1 \rightarrow h_1 - PV_1$

Form steam table at 10 bar pressure
$t_{sat} = 179.9°C$

$t > t_{sat}$ → Therfore steam is superheated

From steam table $h_g = 2778.1\ KJ/kg$
$V_g = 0.194\ m^3/kg$

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

$= 2778.1 + 2.1(250 - 179.9)$

$h_1 = 2925.31$ KJ/kg

For Volume,

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

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

$\therefore U_1 = h_1 - PV_1$

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

$= 2701.31$ KJ/kg

$\Rightarrow$ For $U_2 \to h_2 - PV_2$

From steam table at 2.8 bar pressure

$h_f = 551.4$ KJ/kg

$h_{fg} = 2170.7$ KJ/kg

$v_g = 0.646\ m^3/kg$

$h_2 = h_f + x h_{fg}$

$= 551.4 + 0.9(2170.7)$

$h_2 = 2505.03$ KJ/Kg

For volume, $V = xV_g = 0.9 \times 0.646$

$\therefore V = 0.581\ m^3/Kg$

$\therefore U_2 = h_2 - PV_2$

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

$= 2342.21$ KJ/Kg

=) Change in internal Energy ~~Enrgy~~ $= U_2 - U_1$

$= m_s(U_2 - U_1)$

$= 1.5(2342.2 - 2701.3)$

$= -538.7$ 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.

$P_1 = 10$ bar $T_1 = 300°C$
$P_2 = 1.4$ 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

=) For U_1

From steam table at 10 bar pressure
$t_{sat} = 179.9°c$

$t < t > t_{sat}$ -) Therfor steam is Superheated

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

$h_g = 2778.1$ KJ/kg

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

$= 2778.1 + 2.1(300 - 179.9)$

$h_1 = 3030.31$ KJ/kg

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

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

$= 0.246$ m³/kg

$U_1 = h_1 - PV_1$

~~= 277~~

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

$U_1 = 2784.3$ KJ/kg

=> For U_2,

From steam table, $h_f = 458.4$

$h_{fg} = 2232$

=> For U_2,

$h_2 = h_f + x h_{fg}$

$= 458.4 + 0.8 \times 2232$

$= 2244$ KJ/Kg

For volume, $V = x V_g$

$= 0.8 \times 1.237$

$= 0.9896\ m^3/Kg$

$U_2 = h_2 - PV_2$

$= 2244 - 1.4 \times 100 \times 0.9896$

$= 2105.4$ KJ/Kg

=> Change in internal Energy,

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

$= -677.79$ 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/Kg K

$P = 10$ bar

$x = 0.98$

Heat added $= 150$ KJ/kg

$C_{ps} = 2.1$ KJ/kg k

at 10 bar pressure From steam table, $h_f = 762.8$ KJ/kg

$h_{fg} = 2015.3$ KJ/kg

$h_g = 2778.1$ KJ/kg

$t_{sat} = 179.9°C$

$h_w = h_f + x h_{fg}$

$= 762.8 + 0.98 \times 2015.3$

$h_w = 2737.39$ KJ/kg

$h = h_w +$ Heat added $= 2737.39 + 150$

$= 2887.79$ KJ/kg

$h_g < h$ -> therfore steam is Superheated

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

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

$\therefore T_{sup} = 232.47°C$

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

a $P = 10$ bar
$x = 0.85$

Form steam table at 10 bar pressure

$h_f = 762.8$ KJ/kg
$h_{fg} = 2015.3$ KJ/kg
$h_g = 2778.1$ KJ/kg
$V_g = 0.194$ m^3/kg

-> $h = h_f + x h_{fg}$

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

$= 2475.81 \ KJ/kg$

-> $U = h - PV = h - p x V_g$

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

$U = 2310.91 \ KJ/kg$

B From steam table, $h_g = 2778.1 \ KJ/kg$

$\therefore U = h_g - PV_g$

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

$= 2584.1 \ KJ/kg$

C $P = 10$ bar
$t = 300°C$

at 10 bar pressure $t_{sat} = 179.9°C$

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

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$= 2778.1 + 2.1(300 - 179.9)$

$h = 3030.3$ KJ/Kg

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

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

$= 0.246$ m^3/Kg

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

$\therefore U = h - PV$

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

$= 2784.3$ KJ/Kg

5 Determine amount of heat is required to produce 7 kg of steam at pressue of 6 bar and temperature of 250°c From water at 35°c.

$m = 7$ kg $T_{sup} = 250°C$
$P = 6$ bar

From steam table $t_{sat} = 158.8°c$
$h_f = 670.4$ KJ/kg
$h_{fg} = 2085.$ KJ/kg

Enthalpy of steam,

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

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

$= 2946.92$

For 35°C temperature water $h_f = 146.56$

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

$= 2946.9 - 146.56$

$= 2800.36$

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Total amount of heat

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

$$= 7 \times 2800.36$$

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

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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):

$$BP = \frac{2\pi N T}{60}$$

Here, N = speed of Engine
T = Resisting Torque

3 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%.

$K = 6$

$BP = 95$ kW

$N = 800$ rpm , $n = 400$ rpm

$P_m = 7$ bar $= 7 \times 10^5$ Pa

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

$\eta_{mech} = 80\%$

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

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

$\therefore IP = 118.75$ kW

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

$$\therefore 118.75 = \frac{7 \times 10^5 \times 1.25d \times \pi \times d^2 \times 400 \times 6}{60,000}$$

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

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

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

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

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

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

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

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

$\eta_{mech} = 85\%$

$N = 1000 \text{ rpm}$

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

$= \frac{5.4 \times 10^5 \times 140 \times 10^{-3} \times \frac{\pi}{4} \times (90 \times 10^{-3})^2}{60000 \times}$

$\therefore$ ~~IP = 8.71~~

$\therefore IP = 8.0117$ kw

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

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

$\therefore BP =$ ~~K~~ 6.80 kw

3 The following reading 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

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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 = 44,200 KJ/Kg

Calculate: IP, BP, η_{mech}, η_{ith}

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

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

$BP = \frac{2\pi N T}{60000}$

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

$BP = 21.206$ KW

.5 m

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

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

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

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

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

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

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

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

$\eta_{ith} = 21.59 \%$

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

$K = 4$

$IP = 30$ kw

$N = 2500$ rpm

$\eta_{ith} = 28\%$

$C_v = 44000$ KJ/kg

$P_m = 800$ kpa $= 800 \times 10^3$ Pa

$\eta_{mech} = 80\%$

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

~~$m_f = (?)$~~

$$IP = \frac{P_m LANK}{60{,}000}$$

$$\therefore 30 = \frac{500 \times 10^3 \times 1.5D \times \frac{\pi}{4} D^2 \times 2500 \times 4}{4}$$

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

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

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

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

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

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

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

$$m_p = 7.0129$$

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

$\therefore BSFC = \frac{7.0129}{24}$

$\therefore BSFC = 0.2922\ kg/kWhr$

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, $K = 6$

$IP = 89.5\ kw$

$N = 800\ rpm$

$\eta_{mech} = 80\%$

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

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

$l = 1.25d$

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

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

$\therefore BP = 71.6 \; kW$

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

$\therefore 71.6 = \frac{5 \times 10^5 \times 1.25 d \times \frac{\pi}{4} \times d^2 \times 400 \times 6}{60000 \times}$

$\therefore d^3 = 1405150$

$\therefore \boxed{d = 0.1548 \; m}$

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

$\therefore \boxed{l = 0.1925 \; m}$

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Properties Of Gases

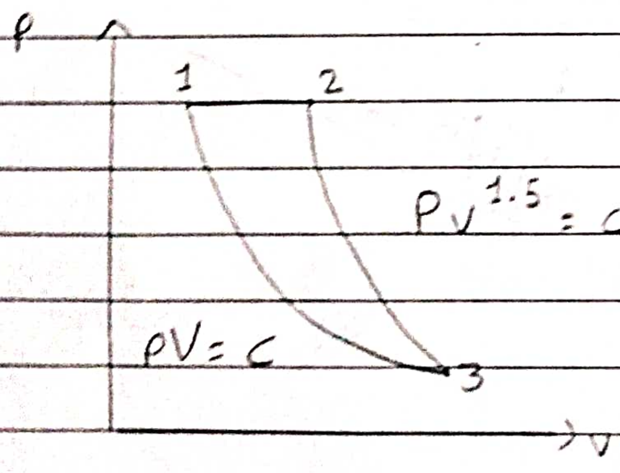
1 0.15 m^3 of air at a pressure of 900 kPa and 300°c is extended at constant pressure of 3 times its initial volume. It is expanded polytropically following the law $PV^{1.5} = c$ and finally compressed back to initial state isothermally.

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

Given, $V_1 = 0.15\ m^3$, $V_2 = 3V_1$

$P_1 = 900\ kPa$, $T_1 = 300°C = 573\ K$

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



→ $P_1 V_1 = mRT_1$

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

→ For Process 1-2 (Constant Pressure)

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

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

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

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

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

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

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

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

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

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

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

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

$= -135 \text{ kJ}$

→ For Process 3 - 1 (Polytropically)

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

→ $P_1 = P_2 = 900 \text{ kPa}$

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

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

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

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

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

Heat Rejected $Q_{3-1} + Q_{2-3} = -519.1 - 135$

$= -654.1 \text{ kJ}$

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

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

$= 30.82\%$

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

Given $R = 0.287$ kJ/kgK

$C_v = 0.7$

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

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

$$\therefore \gamma = 1.41$$

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

$$= 0.7 \times 1.41$$

$$\therefore C_p = 0.987 \text{ kJ/kgK}$$

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 $C_p = 1.005$ kJ/kgK, $C_v = 0.718$ kJ/kgK

Given, $m = 1$ kg

$P_1 = 1$ bar, $P_2 = 10$ bar

$T_1 = 300$ k, $W = (?)$

$Q = (?)$

$\Delta U = (?)$

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

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

→ 1) Isothermal Process

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

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

For V_1 → $P_1 V_1 = mRT_1$

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

$$V_1 = 0.861 \ m^3$$

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

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

$$W = -198.3 \ KJ$$

→ In Isothermal Process,

Chang In Internal Energy $\Delta U = 0$

→ $Q = W + \Delta U$

$$Q = -198.3 \ kJ$$

→ 2) Adiabatic Process:

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

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

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

$$\therefore V_2 = -0.166\ m^3$$

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

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

$$T_2 = 579.53\ K$$

-> For $W = \dfrac{P_1V_1 - P_2V_2}{\gamma - 1}$

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

$$W = -199.75\ KJ$$

-> Change in internal Energy $\Delta U = mC_v(T_2 - T_1)$

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

$$\therefore \Delta U = 200.7\ KJ$$

-> In Adiabatic Process,

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, $T_1 = 25°C = 298 K$
$T_2 = 145°C = 418 K$
$m = 2 kg$
$R = 267 J/kg \cdot K$
$\gamma = 1.4$
$C_p = (?)$, $\Delta U = (?)$
$C_v = (?)$, $\Delta H = (?)$

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

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

$C_p = 934.5 \ J/kg \cdot K$

-> $\Delta U = mC_v (T_2 - T_1)$

$= 2 \times 667.5 (418 - 298)$

$\Delta U = 160.2$ KJ

-> $\Delta H = mC_p (T_2 - T_1)$

$= 2 \times 934.5 (418 - 298)$

$\Delta H = 224.3$ 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, $m = 1$ kg
$V_1 = 0.15 \, m^3$, $V_2 = 0.05 \, m^3$
$P_1 = 1$ bar $= 1 \times 10^5$ Pa
$W = (?)$

-> 1) Isothermal

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

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

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

$= 1 \times 10^5 \times 0.15 \times \ln \frac{1}{3}$

$= -16.48 \text{ kJ}$

→ 2) Adiabatic

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

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

$= 4.66$

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

$W = -20.75 \text{ kJ}$

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, $r = 5$

$I.P = 20\ kw$

$m_f = 8\ L$

specific gravity $= 0.78$

$C.V = 44\ JM/Kg$

$\eta_{ith} = (?)$

$\eta_r = (?)$

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

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

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

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

$= 47.46\ \%$

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

$\eta_R = 65.24\ \%$

2 An oil engine working on diesel cycle has cylinder bore of 190 mm and piston stroke of 230 min. The clearance volume is 240 m^3. 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.

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

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

$V_c = 290\ cm^3$

→ Swept Volume $V_s = \frac{\pi}{4} d^2 \cdot L$

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

$V_s = 6521.16\ cm^3$

→ $V_1 = V_s + V_c = 6811.16\ cm^3$

→ Compression ratio $r = \frac{V_1}{V_2}$

$= \frac{6811.16}{290}$

$\therefore\ r = 23.49$

⇒ 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,

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

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

$= 0.6546$

$\eta = 65.46\%$

$\Rightarrow$ Case : 2 Cut-off = 11 %

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

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

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

→ $\rho = \frac{V_3}{V_2} = \frac{1007.33}{290} = 3.47$

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

$= 0.6148$

$\eta = 61.48\%$

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

$= 6.08\%$

3 In an idel 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 begnning is 1 bar, calculate the maximum pressure in the cycle.

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⇒ Given data.

$T_1 = 330K$
$T_2 = 876K$
$T_3 = 2223\ K$
$T_4 = 1143\ K$
$P_1 = 1\ bar$

⇒ $\eta = 1 - \frac{1}{\gamma}\left[\frac{T_4 - T_1}{T_3 - T_2}\right]$

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

$= 0.5689$

$\eta = 56.89\%$

→ For isentropic compression process,

$\therefore P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$

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

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

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

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

$$\therefore r = 11.48$$

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

$\therefore P_2 = 30.473$ 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 $\gamma = 1.4$.

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

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

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

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

$\therefore V_3 = 1.84$

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

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

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

$\eta = 61.19\%$

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 $PV^{1.2}$ = 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.

→ $V_1 = 2\ m^3/min$

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

$n = 1.2$

$B.P = 7.5\ kw$

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

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

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

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

$\therefore W = I.P = 6.152\ kW$

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

$\eta_m = 82.02\ \%$

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.

Given data, $d = 170\ mm = 0.17\ m$

$l = 260\ mm = 0.26\ m$

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

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

$N = 130\ rpm$

$n = 1.25$

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

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

Swept volume per second,

$\therefore V_1 = 5.90 \times 10^{-3} \times \frac{130}{60}$

$\therefore V_1 = 0.01278\ m^3/s$

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

$= 10^5 \times 0.01278 \times \frac{1.25}{0.25}\left[(9)^{0.2} - 1\right]$

$I.P. = 3.53\ kw$

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

$= 10^5 \times 0.01278 \times \log(9)$

$\therefore W = 2.808\ kw$

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

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

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

$\therefore P_1 = 1$ bar

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

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

$= \frac{1.3}{1.3-1} \times \frac{3}{60} \times 10^5 \left[(9)^{0.230} - 1 \right]$

$\therefore$ $W = 14.243$ kw

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

$N = 200$ 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 ratation of shaft is 190 m/min and 330 rpm respectively. Indicate power id 28 kw and Volumetric efficiency is 95%. Determine bore and stroke

-) Given data, $P_1 = 1 \times 10^5$ N/m^2

$P_2 = 15 \times 10^5$ N/m^2

$n = 1.3$

$V_p = 190$ m^3/min

$N = 330$ rpm

$IP = 28$ kw

$\eta_v = 0.95$

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

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

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

$\therefore V_1 - V_4 = 0.0135 \ m^3$

→ $\eta_V = \frac{V_1 - V_4}{V_s}$

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

→ $V_s = \frac{\pi}{4} D^2 l$

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

$\therefore D = 0.2507 \ m$