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MECHANICAL ENGINEERING

CONVENTIONAL PRACTICE SETS VOLUME - I

CONTENTS

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THERMODYNAMICS

CONVENTIONAL PRACTICE SETS

Page No. 1 - 88

1 CHAPTER

Basic Concepts and Zeroth Law of Thermodynamics

Practice Questions : Level-I

Q.1 A new scale X of temperature divided in such a way that the freezing point of ice is 110°X and the boiling point is 450°X. At what temperature both the Celsius and new temperature scale reading would be same?

Solution:

	°C	°X
BP →	100°C	450°X
FP →	0°C	110°X

$$\frac{C-0}{100-0} = \frac{X-110}{450-110}$$

$\Rightarrow$ $34\,C = 10X - 1100$ (when X = C)

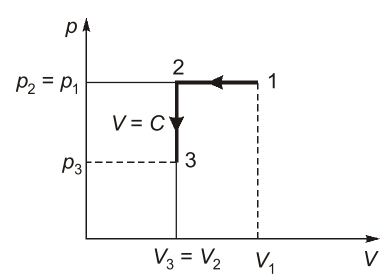
$\Rightarrow$ $24°C = -1100$

$\Rightarrow$ $C = -45.8°C$

Q.2 A certain amount of an ideal gas is initially at a pressure p_1 and temperature T_1. First, it undergoes a constant pressure process 1-2 such that $T_2 = 3T_1/4$. Then, it undergoes a constant volume process 2-3 such that $T_3 = T_1/2$. What is the ratio of the final volume to the initial volume of the ideal gas?

Solution:

Process 1 – 2: At $p = C$



$$T_2 = \frac{3T_1}{4} \quad \text{(given condition)}$$

or $$\frac{T_2}{T_1} = \frac{3}{4}$$

According to Charle's law

$$\frac{V_2}{V_1} = \frac{T_2}{T_1} = \frac{3}{4}$$

Process 2 – 3: At $V = C$

$$T_3 = \frac{T_1}{2} \text{ given condition}$$

$$\frac{\text{Final volume}}{\text{Initial volume}} = \frac{V_3}{V_1} = \frac{V_2}{V_1} = \frac{T_2}{T_1} \qquad (\because V_3 = V_2)$$

$$= \frac{3}{4} = 0.75$$

Q.3 The relationship of resistance R in ohm and temperature T in kelvin for a thermistor is given by: $R = R_0 e^{\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]}$ where R_0 is the resistance in ohms measured at temperature. T_0K and b is the material constant with units of K

For a particular case, $R_0 = 2.2\ \Omega$ at $T_0 = 310\,K$

And $R = 0.31\Omega$ at $T = 422\,K$

Determine the material constant β and hence find the resistance at 373 K and 273 K.

Solution:

The equation for the thermistor is given by

$$R = R_0 e^{\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]}$$

where, $R_0 = 2.2\ \Omega$ and $T_0 = 310\,K$

Since, $R = 0.21\ \Omega$ at $T = 422\,K$

$$0.31 = 2.2 e^{\left[\beta\left(\frac{1}{422} - \frac{1}{310}\right)\right]}$$

or $$0.31 = 2.2 e^{[-8.5613 \times 10^{-4}\beta]}$$

Therefore, $$\beta = \frac{\log e^{\left(\frac{0.31}{2.2}\right)}}{-8.5613 \times 0^{-4}} = \frac{-1.95964}{-8.5613 \times 10^{-4}} = 2288.95/K$$

Thus resistance at $T = 373\,K$

$$R_{373} = 2.2 e^{\left[2288.95\left(\frac{1}{373} - \frac{1}{310}\right)\right]} = 2.2\ e^{-1.247} = \mathbf{0.632\ \Omega}$$

and at $T = 273$ K $$R_{273} = 2.2 e^{\left[2288.95\left(\frac{1}{273} - \frac{1}{310}\right)\right]} = 2.2 e^{1.0007226} = \mathbf{5.9845\ \Omega}$$

Q.4 The gas in system received heat which causes expansion against at a constant pressure of 2 bar. An agitator in the system is driven by an electric motor. Using 100 W for 4 kJ of heat supplied the volume increase of the system in 30 sec is 0.06 m^3. Estimate net change in the energy of the system.

Solution:

Given data: Pressure, $p = 2$ bar; Rating of motor = 100 W

Heat supplied, $Q = 4$ kJ; Duration of heat supply = 30 sec

Volume increase of the system, $\Delta V = 0.06$ m^3

Displacement work done of gas = $\int pdV = 2 \times 10^2 \times 0.06 = 12$ kJ (positive work)

Work done by motor = $100 \times 30 = 3$ kJ (negative work)

Net work done by the system upon the surroundings,

$$W = 12 - 3 = 9 \text{ kJ}$$

As per 1st law of thermodynamics:

$$Q_s = W + \Delta U$$

$$\Delta U = Q_s - W = 4 - 9 = -5 \text{ kJ}$$

The –ve sign indicates that energy of the system decreases

Practice Questions : Level-II

Q.5 The Van der Waals equation is given by $\left(p+\frac{a}{v}\right)(v-b) = RT$, where a and b are constant and other terms have usual meanings. Determine the work done in a reversible isothermal expansion.

Solution:

The Van der Waals equation is

$$\left(p+\frac{a}{v}\right)(v-b) = RT$$

It can be rearranged as $\quad p = \frac{RT}{v-b} - \frac{a}{v}$

The work done by the gas can be calculated as

$$w = \int_{v_1}^{v_2} p\,dv = RT\int_{v_1}^{v_2}\frac{1}{v-b}dv - \int_{v_1}^{v_2}\frac{a}{v}dv = RT\ln\left(\frac{v_2-b}{v_1-b}\right) + a\ln\left[\frac{v_2}{v_1}\right]$$

Q.6 The readings of two thermometers A and B agree at ice point and steam point as 0°C and 100°C. The two temperature readings are related by the following expression:

$$t_A = a + bt_B + ct_B^2$$

where a, b and c are constants. In a constant temperature bath, the temperature are shown as 51°C on thermometer A and 50°C on thermometer B. Determine the reading on thermometer B when the thermometer A reads 65°C. Can you comment which of the two thermometers is correct?

Solution:

Given: $t_A = a + bt_B + ct_B^2$

As the reading of two thermometers A and B agree at ice point (0°C) and steam point (100°C).

When $\quad t_A = 0°C$, t_B is also 0°C

$$= a + bt_B + ct_B^2$$

$$0 = a + b(0) + c(0)^2$$

$$a = 0$$

So, $\quad t_A = bt_B + ct_B^2$

when, $\quad t_A = 100°C$, t_B is also 100°C

$$100 = b(100) + c(100)^2$$

$$b + (100)c = 1 \qquad \text{... (i)}$$

when, $\quad t_B = 50°C$, $t_A = 51°C$

$$t_A = bt_B + ct_B^2$$

$$51 = (50)b + (50)^2c \qquad \text{... (ii)}$$

From equations (i) and (ii), we get $b = 1.04$

$$c = -4 \times 10^{-4}$$

$\therefore \quad t_A = 1.04\, t_B - 4 \times 10^{-4}\, t_B^2$

when, t_A reads 65°C $\quad 65 = 1.04t_B - 4 \times 10^{-4}\, t_B^2$

or $\quad t_B = 64.07°C$

None of the two thermometers are ideal. So we cannot comment on to which is more correct.

Q.7 A spherical balloon contains 5 kg of air at 200 kPa and 500 K. The balloon material is such that at the pressure inside is always proportional to the square of the diameter. Determine the work done when the volume of the balloon doubles as a result of heat transfer.

Solution:

Given data: $m = 5$ kg; $p_1 = 200$ kPa; $T_1 = 500$ K; $V_2 = 2V_1$

Consider D is the diameter of the balloon.

According to the given condition,

$$p \propto D^2$$

or $$p = KD^2$$

It is the equation of state with a constant of proportionality K.

Further, from the relation for a perfect gas, $p_1V_1 = mRT_1$

$$p_1v_1 = RT_1$$

$$v_1 = \frac{RT_1}{p_1} = \frac{0.287 \times 500}{200} = 0.7175 \text{ m}^3/\text{kg}$$

Thus, the volume of the balloon at initial state;

$$V_1 = mv_1 = 5 \times 0.7175 = 3.5875 \text{ m}^3$$

Thus, the diameter of the balloon can be calculated as

$$V_1 = \left(\frac{1}{6}\right) \times \pi \times D_1^3$$

or $$D_1^3 = 6.851$$

or $$D_1 = 1.899 \text{ m}$$

When the volume of the balloon doubles, the diameter of balloon or $D_2 = D_1 \times 2^{1/3}$

$$V_2 = \frac{\pi D_2^3}{6}$$

but $$V_2 = 2V_1 = 7.175$$

or $$D_2^3 = 13.703$$

or, $$D_2 = 2.393 \text{ m}$$

Now from the given relation at the state 1

$$p_1 = KD_1^2$$

or $$K = \frac{p_1}{D_1^2} = \frac{200}{(1.8993)^2} = 55.44$$

The work done by a system; $W = \int_1^2 pdV = \int_1^2 KD^2 dV = \int_1^2 D^2 d\left(\frac{\pi}{6}D^3\right) = \frac{K}{6}\pi \times \int_1^2 D^2 \times 3D^2 dD$

$$= \frac{1}{2}\pi \times 55.44 \int_1^2 D^4 dD = 87.08 \times \left[\frac{D_2^5}{5} - \frac{D_1^5}{5}\right]$$

$$= 87.08 \times \left[\frac{(2.393)^5}{5} - \frac{(1.8993)^5}{5}\right] = \mathbf{936.22 \text{ kJ}}$$

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REFRIGERATION AND AIR CONDITIONING

CONVENTIONAL PRACTICE SETS

Page No. 88 - 150

1 CHAPTER Introduction and Basic Concepts

Practice Questions : Level-I

Q.1 A reversed Carnot cycle refrigerator maintains a temperature of – 5°C. The ambient air temperature is 35°C. The heat gained by the refrigerator at a continuous rate is 2.5 kJ/s. What is the power required to run the heat pump?

Solution:

Given data: $T_2 = -5°C = (-5 + 273)\text{ K} = 268\text{ K}$; $T_1 = 35°C = (35 + 273)\text{ K} = 308\text{ K}$

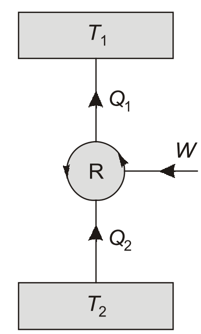
$Q_2 = 2.5\text{ kJ/s} = 2.5\text{ kW} = 2500\text{ W}$

$$(COP)_R = \frac{T_2}{T_1 - T_2} = \frac{268}{308 - 268} = 6.7$$

Also, $$(COP)_R = \frac{Q_2}{W}$$

∴ $$6.7 = \frac{2500}{W}$$

or $$W = \frac{2500}{6.7} = \mathbf{373.13\ W}$$



Refrigerator

Q.2 A refrigerator has working temperatures in the evaporator and condenser as –23°C and 37°C respectively. The environment temperature is 27°C. The required refrigeration temperature is –13°C. What is the maximum COP possible? If the actual COP of the refrigerator is 0.65 of the maximum, calculate the required power input for a refrigerating effect of 5 kW.

Solution:

Given data: $T_e = -23°C = 250\text{ K}$, $T_c = 37°C = 310\text{ K}$, $T_{surrounding} = 27°C = 300\text{ K}$

$$\text{Maximum COP} = \frac{T_e}{T_c - T_e} = \frac{250}{310 - 250}$$

$$(COP)_{max} = 4.166$$

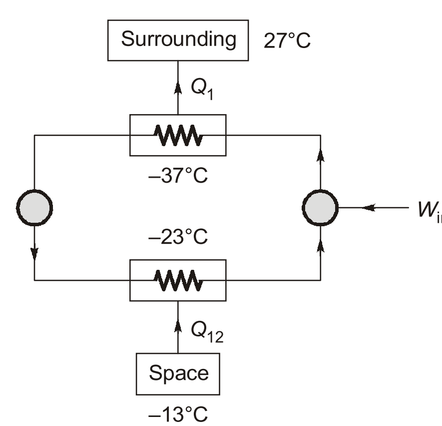
Now it is given that, $$(COP)_{actual} = 0.65(COP)_{max}$$

$$= 0.65 \times 4.166 = 2.708$$

⇒COP is defined as refrigerating effect/power

⇒ $$COP = \frac{5}{\text{Power}} = 2.708$$

⇒ $$\text{Power required} = \frac{5}{2.70} = 1.846\text{ kW}$$



Q.3 A thermoelectric refrigerator is powered by a car battery and has a COP of 0.1. The refrigerator cools a $0.35 \times 10^{-3}\text{ m}^3$ canned drink from 20°C to 4°C in 30 minutes. The properties of canned drink are same as that of water at room temperature, i.e., $\rho = 1000\text{ kg/m}^3$ and $c = 4.18\text{ kJ/kg K}$. Neglecting the heat transfer through the walls of the refrigerator, determine the average electric power consumed by the thermoelectric refrigerator.

Solution:

Given data: COP = 0.1; Volume = 0.35×10^{-3} m^3; $\Delta T = 20 - 4 = 16$°C;
t = 30 minutes; ρ = 1000 kg/m^3; c_p = 4.18 kJ/kg-K

$$\text{Refrigeration capacity} = \frac{mc_p\Delta T}{t} \qquad (m = \rho V)$$

$$= \frac{10^3 \times 0.35 \times 10^{-3} \times 4.18 \times 16}{30 \times 60} = 0.013 \text{ kW}$$

$$\text{COP} = \frac{\text{Refrigeration capacity}}{\text{Power input}}$$

$$\text{Power input} = \frac{0.013}{0.1} = 0.13 \text{ kW}$$

Q4 A cold storage plant is required to store 20 tonnes of fish. The fish is supplied at a temperature of 30°C. The specific heat of fish above freezing point is 2.93 kJ/kgK. The specific heat of fish below freezing point is 1.26 kJ/kgK. The fish is stored in cold storage which is maintained at –8°C. The freezing point of fish is –4°C. The latent heat of fish is 235 kJ/kg. If the plant requires 75 kW to drive it, find:

1. The capacity of the plant
2. Time taken to achieve cooling

Assume actual COP of the plant as 0.3 of the Carnot COP.

Solution:

(i)
$$\text{Carnot COP} = \frac{T_1}{T_2 - T_1} = \frac{265}{303 - 265} = 6.97$$

$\therefore$ Actual COP = $0.3 \times 6.97 = 2.091$

Heat removed by the plant = Actual COP × Work required

= $2.091 \times 75 = 156.8$ kW = 156.8×60 kJ/min = 9408 kJ/min

$$\therefore \text{Capacity of the plant} = \frac{9408}{210} = 44.8 \text{ TR}$$

(ii) Heat removed from the fish above freezing point

$$Q_1 = m \times c_{AF}(T_2 - T_3)$$
$$= 20 \times 1000 \times 2.93(303 - 269) = 1.992 \times 10^6 \text{ kJ}$$

Similarly, heat removed from the fish below freezing point,

$$Q_2 = m \times c_{BF}(T_3 - T_1) = 20 \times 1000 \times 1.26 \times (269 - 265)$$
$$= 0.101 \times 10^6 \text{ kJ}$$

$$\text{Total latent heat of fish, } Q_3 = m \times (h_{fg})_{\text{fish}}$$
$$= 20 \times 1000 \times 235 = 4.7 \times 10^6 \text{ kJ}$$

$\therefore$ Total heat removed by the plant

$$= Q_1 + Q_2 + Q_3 = (1.992 + 0.101 + 4.7) \times 106 = 6.793 \times 10^6 \text{ kJ}$$

$$\therefore \text{Time taken to achieve cooling} = \frac{\text{Total heat removed by the plant}}{\text{Heat removed by the plant per min}}$$

$$= \frac{6.793 \times 10^6}{9408} = 722 \text{ min} = 12.03 \text{ hr}$$

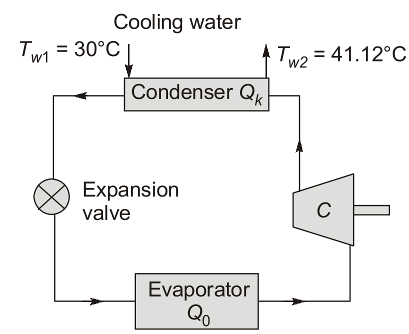
Practice Questions : Level-II

Q.5 A customer complained of poor cooling for an air-conditioning system of 100 TR capacity. The supplier carried out test on condenser which is water cooled and noted power input to the motor. The observations made are as under:

Cooling water flow rate	:	10 litre/s
Inlet water temperature	:	30°C
Outlet water temperature	:	41.12°C
Power input to motor	:	120 kW (94.92% efficiency)

Determine the actual refrigerating capacity and state whether the cooling capacity is lower, higher or as per specifications.

Solution:



Given data: Capacity = 100 TR; T_{w1} = 30°C, T_{w2} = 41.12°C

Water flow rate, $\dot{V}$ = 10 litre/s = 10×10^{-3} m^3/s,

Consider the refrigerating/AC system as shown

Heat rejection rate in condenser = rate of heat gain by water

$$\Rightarrow \quad Q_k = \dot{m}_w c_{p,w}(T_{w2} - T_{w1}) = \rho_w \dot{V} c_{p,w}(T_{w2} - T_{w1})$$

$$= 10^3 \times 10 \times 10^{-3} \times 4.18 \times (41.12 - 30)$$

$$= 464.81 \text{ kW}$$

Power input to motor = 120 kW

Actual power input to cycle = $120 \times 0.9492 = 113.904$ kW [As motor efficiency = 94.92%]

From 1st law of thermodynamics,

$$Q_k = Q_0 + W$$

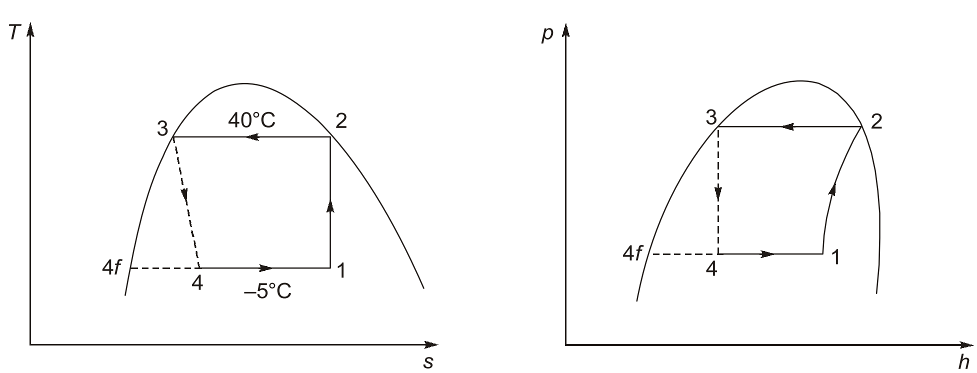
$$\Rightarrow \quad Q_0 = Q_k - W = 464.81 - 113.904 = 350.906 \text{ kW}$$

$$\therefore \quad \text{Refrigeration capacity, } Q_0 = \frac{350.906}{3.5167} = 99.78 \text{ TR}$$

This is slightly lower than ideal or specified cooling capacity.

Q.6 A refrigerator machine uses R-12 as the working fluid. The temperature of R-12 in the evaporator coil is –5 °C, and the gas leaves the compressor as dry saturated at a temperature of 40 °C. The mean specific heat of liquid R-12 between the above temperatures is 0.963 kJ/kg K. The enthalpy of evaporation at 40 °C is 203.2 kJ/kg. Neglecting losses, find the COP.

Solution:



Given data: (h_{fg}) = 203.2 kJ/kg; $(c_p)_l$ = 0.963 kJ/kg

INTERNAL COMBUSTION ENGINES

CONVENTIONAL PRACTICE SETS

Page No. 151 - 199

1 CHAPTER Introduction and Basic Concepts

Practice Questions : Level-I

Q.1 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:

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

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

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

Assuming volumetric efficiency 100%

$$\therefore \quad pV_S = m_a RT$$

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

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

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

Q.2 A four cylinder 4-stroke diesel engine has a bore of 212 mm and stroke 292 mm. At full load at 720 rpm the Brake mean effective pressure is 5.93 bar and specific fuel consumption is 0.226 kg/kWH. The air fuel ratio as determined by exhaust gas analysis is 25 : 1. Calculate the brake thermal efficiency and volumetric efficiency of the engine. Atmospheric conditions are 1.01 bar and 15°C. The calorific value of fuel may be taken as 44200 kJ/kg.

Solution:

Given data: $n = 4$; $d = 212$ mm; $l = 292$ mm; $N = 720$ rpm; $p_{bm} = 5.93$ bar

SFC = 0.226 kg/kW hr.; $A/F = 12$, C.V = 44.2 MJ/kg; $P = 1.01$ bar, $T_1 = 288$ K

$$bp = \frac{p_{bm}LANK}{60000 \times 2} = \frac{5.93 \times 10^5 \times 0.292 \times \pi/4 \times 0.212^2 \times 4 \times \left(\frac{720}{2}\right)}{60000} = 146.69 \text{ kW}$$

$$\eta_{bth} = \frac{bp}{\dot{m}_f \times CV}$$

$$\dot{m}_f = 0.226 \times 146.69 = 33.15 \text{ kg/h}$$

$$\eta_{bth} = \frac{146.69 \times 3600}{33.15 \times 44200} = 0.36 = 36\%$$

$$\rho = \frac{p}{RT} = \frac{1.01 \times 10^5}{287 \times 288} = 1.2219\,\text{kg/m}^3$$

$$\frac{A}{F} = 25$$

$$\Rightarrow \quad \dot{m}_a = \dot{m}_f \times 25 = 828.75\ \text{kg/h}$$

Volume flow rate at intake condition:

$$\dot{V}_a = \frac{\dot{m}_a RT}{p} = \frac{828.75}{1.2219} \times \frac{1}{60} = 11.300\,\text{m}^3/\text{min}$$

$$\dot{V}_s = \frac{\pi}{4} D^2 \frac{LNK}{2} = \frac{\pi}{4} \times 0.212^2 \times 0.292 \times 360 \times 4 = 14.84\ \text{m}^3/\text{min}$$

$$\eta_v = \frac{\dot{V}_a}{\dot{V}_s} \times 100 = \frac{11.300}{14.84} \times 100 = 76.15\%$$

Q.3 The output of an engine is given as input to an agricultural pump set. The pump is used for lifting water from a depth of 30 m at the rate of 200 litres/minute. The transmission efficiency between the engine and the pump is 100% and the pump is considered to be 100% efficient. The brake thermal efficiency of the engine is 35%, the calorific value of the fuel is 43 MJ/kg, the cost of fuel is ₹ 53.00 per litre and the density of the fuel is 780 kg/m^3. Estimate the running cost of the fuel for 1000 m^3 of water lifted.

Solution:

$$\text{Power required to lift the water} = \rho g Q H = \frac{1000 \times 9.81 \times 200 \times 10^{-3} \times 30}{1000 \times 60} = 0.981\ \text{kW}$$

$$\text{Brake work done} = \text{Power} \times \text{time} = \frac{(0.981) \times (1000) \times (60)}{200 \times 10^3} = 294.3\,\text{MJ}$$

$$\text{Brake thermal efficiency} = \frac{\text{Brake work done}}{\text{Calorific value} \times \text{Mass of fuel}}$$

$$\Rightarrow \quad 0.35 = \frac{294.3 \times 1}{43 \times \text{Mass of fuel}}$$

$$\Rightarrow \quad \text{Mass of fuel} = 19.55\ \text{kg}$$

$$\text{Volume of fuel} = \frac{\text{Mass of fuel}}{\text{Density of fuel}} = \frac{19.55}{780} = 25.0769\ \text{litre}$$

Running cost of engine = 25.07 × 53 = **₹ 1328.7 only**

Q.4 A single cylinder 4-stroke SI engine is producing 100 kW power at an overall efficiency of 20%. Engine uses fuel-air ratio of 0.07. Determine how many m^3/hr of air is used if air density is 1.2 kg/m^3. The fuel vapour density is 4 times that of air. How many m^3/hr of mixture is required? Calorific value of fuel is 42000 kJ/kg.

Solution:

$$\text{Overall efficiency, } \eta_o = \frac{BP}{\dot{m}_f \times CV}$$

$$\dot{m}_f = \frac{BP}{\eta_o \times CV} = \frac{100}{0.2 \times 42000} = 0.012\ \text{kg/s}$$

$$\text{Air density, } \rho_a = 1.2 \text{ kg/m}^3$$

$$\text{Fuel vapour density, } \rho_f = 4 \times 1.2 = 4.8 \text{ kg/m}^3$$

$$\text{Fuel mass flow rate, } \dot{m}_f = 0.012 \times 3600 = 43.2 \text{ kg/h}$$

$$\text{F/A ratio} = 0.07$$

$$\dot{m}_a \text{ (Air flow rate)} = \frac{\dot{m}_f}{0.07} = 617.143 \text{ kg/h}$$

$$\text{Volumetric flow rate of air} = \frac{\text{Mass flow rate}}{\text{Density}} = \frac{617.43}{1.2} = 514.525 \text{ m}^3/\text{hr}$$

$$\text{Volumetric flow rate of fuel} = \frac{\dot{m}_f}{\rho_f} = \frac{43.2}{4.8} = 9 \text{ m}^3/\text{hr}$$

$$\text{Volumetric flow of fuel mixture} = \dot{V}_a + \dot{V}_f = 514.525 + 9 = 523.525 \text{ m}^3/\text{hr}$$

Practice Questions : Level-II

Q.5 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:

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

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

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

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

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

$$\text{Cubic capacity of the engine} = \text{Number of cylinder} \times \text{Swept volume}$$

$$= 6 \times 181 = 1086 \text{ cc} \qquad \text{Ans.(v)}$$

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

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

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

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

Q.6 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, $\dot{V}_s = V_s \dfrac{N \times k}{2 \times 60} = 0.09 \text{ m}^3/\text{s}$; 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, $T_1 = 60°\text{C} = 333$ K

Mechanical efficiency, $\eta_m = 85\%$

Air fuel ratio, AFR = 15 : 1

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

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

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,

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

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

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

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

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

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

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

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

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

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

(v) Brake specific fuel consumption (bsfc)

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