



ACE
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ESE – 2019 MAINS OFFLINE TEST SERIES



MECHANICAL ENGINEERING

TEST – 3 SOLUTIONS

All Queries related to **ESE – 2019 MAINS Test Series** Solutions are to be sent to the following email address
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01(a).

Sol:

Advantages of Tidal Power Generation:

- Large area of land is not required.
- Power generation from the tides is free from pollution as it does not use any fuel.
- Peak power demand can be effectively met when a tidal power plant works in combination with hydroelectric or thermal systems.
- It is completely independent of rain.
- It is inexhaustible source of energy.
- Maintenance cost of tidal plant is less.
- Prediction of tides is easy.
- It is a reliable source of energy.
- The dependency on nonrenewable sources such as coal, gas, oil, etc, can be reduced.
- It does not liberate green house gases.

Limitations of Tidal Power Generation

- Tidal energy can only be harnessed in places where significant change in water level is always available.
- If, at all, 100% tidal energy is converted to potential energy, then only 80% of it can be utilized and the remaining 20% of the energy will be lost.
- The tidal energy can be utilized for only 10 hours a day.
- The main drawback of tidal energy is that the output varies with the variation in the tidal range (R).
- Tidal energy can be utilized at only natural sites.
- When compared with other sources of energy, the power plants build for tidal energy have very high capital cost.

- As the sites employing tidal power are located away from the load centres, the cost of power transmissions is more.
- The machinery may get corroded because of the corrosiveness of the sea water.
- The efficiency of tidal energy generating plant is affected due to variation in the tide range.
- Sedimentation and liberates of tidal basins is a common problem.

01(b).

Sol: Total intensity of radiation (i) - The total intensity of radiation emitted by a surface in a given direction is equal to the radiant flux passing in the specified direction per unit solid angle.

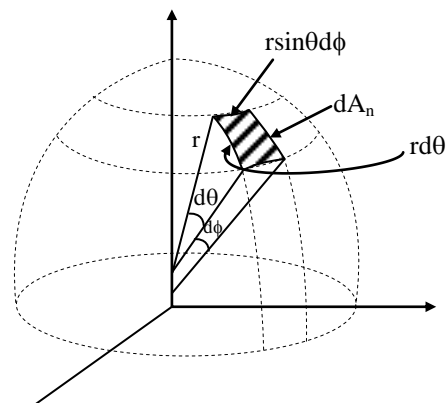
It will be denoted by the symbol (i) and its unit is W/m²-sr

$$i = \frac{de}{d\omega}$$

where $d\omega$ = solid angle.

Solid angle – Region subtended by an element of area on the surface of sphere with respect to the centre of the sphere is known as solid angle.

Mathematically, $\omega = \frac{A_n}{r^2}$





$$dA_n = r \sin \omega d\phi r d\theta = r^2 \sin \theta d\theta d\phi$$

$$\text{So, } d\omega = \frac{dA_n}{r^2} = \frac{r^2 \sin \theta d\theta d\phi}{r^2}$$

$$d\omega = \sin \theta d\theta d\phi$$

$$\therefore i = \frac{de}{d\omega}$$

$$\Rightarrow de = i d\omega$$

$$\therefore e = \int i d\omega = \int i \sin \theta \ell d\theta d\phi$$

Lambert's cosine rule,

$$i = i_n \cos \theta$$

where i_n = normal intensity of radiation

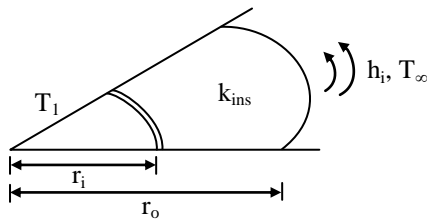
$$\Rightarrow e = \int_{\theta=0}^{\pi/2} \int_{\phi=0}^{2\pi} i_n \cos \theta \sin \theta d\theta d\phi$$

$$\Rightarrow e = \pi i_n$$

So, the total emissive power of a diffuse surface is equal to π times of its normal intensity of radiation.

01(c).

Sol:



$$h_o = 8.722 \text{ W/m}^2\text{K}$$

Without insulation:

$$Q = \frac{T_1 - T_\infty}{\frac{1}{h_o 2\pi r_i L}} = \frac{60 - 20}{\frac{1}{8.722 \times 2\pi \times 3.25 \times 10^{-3} \times 1}} = 7.124 \text{ W}$$

With insulation:

$$r_c = \frac{k_{ins}}{h_o}$$

$$= \frac{0.174}{8.722} = 0.0199 \text{ m}$$

$$= 19.94 \text{ mm (maximum heat loss)}$$

Insulation thickness

$$= r_c - r_i = 19.94 - 3.25 = 16.69 \text{ mm}$$

Heat loss (maximum) with insulation

$$Q_2 = \frac{T_1 - T_\infty}{\frac{\ln\left(\frac{r_c}{r_i}\right)}{2\pi k_{ins} L} + \frac{1}{h_o 2\pi r_c L}}$$

$$= \frac{60 - 20}{\frac{\ln\left(\frac{19.94}{3.25}\right)}{2\pi \times 0.174 \times 1} + \frac{1}{8.722 \times 2\pi \times 0.0199 \times 1}}$$

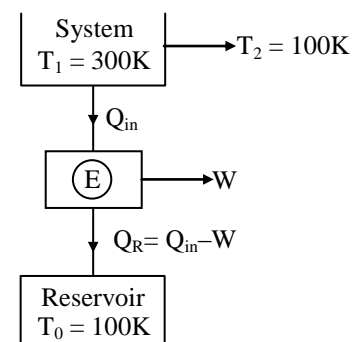
$$Q_2 = 15.53 \text{ W}$$

$$\% \text{ increase heat loss} = \frac{Q_2 - Q_1}{Q_1}$$

$$= \frac{15.53 - 7.124}{7.124} = 1.179 \approx 118\%$$

01(d).

Sol:



Heat removed from the system

$$= \int_{T_1}^{T_2} c_v dT$$

$$= \int_{300}^{100} 0.02 T^2 dT$$

$$= 0.02 \left[\frac{T^3}{3} \right]_{300}^{100}$$



$$= 0.02 \left[\frac{100^3 - 300^3}{3} \right] = -173.33 \times 10^3 \text{ J}$$

$$Q_{in} = 173.33 \times 10^3 \text{ J}$$

Now entropy of system is given as

$$(ds)_{system} = \frac{dQ}{T} = \frac{c_v dT}{T}$$

$$(ds)_{system} = \int_{300 \text{ K}}^{100 \text{ K}} \frac{0.02 T^2}{T} dT$$

$$= \frac{0.02}{2} [100^2 - 300^2]$$

Entropy of reservoir = - 800 J/K

$$(ds)_{reservoir} = \frac{Q_R}{T_O}$$

$$= \frac{Q_{in} - W}{100} = \frac{173.33 \times 10^3 - W}{100}$$

For maximum workout put the system must be reversible

For reversible system

$$(ds)_{uni} = 0$$

$$(ds)_{system} + (ds)_{res} = 0$$

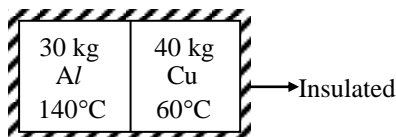
$$-800 + \frac{173.33 \times 10^3 - W}{100} - 0$$

$$W = 93333 \text{ J}$$

$$W = 93.33 \text{ kJ}$$

01(e).

Sol:



Energy balance :

Heat lost by hot Al block = heat gain by cold Cu block

$$30 \times 0.949 (140 - T_f) = 40 \times 0.45 (T_f - 60)$$

$$T_f = 109^\circ \text{C or } 382 \text{ K}$$

Total entropy change for this process can be determined as below:

$$ds_{cu} = m_{cu} c_{cu} \ln \frac{T_f}{T_{icu}} = 40 \times 0.45 \ln \left[\frac{382}{333} \right]$$

$$= 2.472 \text{ kJ/K}$$

$$dS_{Al} = m_{Al} C_{Al} \ln \frac{T_f}{T_{iAl}} = 30 \times 0.949 \ln \left[\frac{382}{413} \right]$$

$$= -2.221 \text{ kJ/k}$$

$$ds_{total} = ds_{cu} + ds_{Al}$$

$$= 2.472 - 2.221 = 0.251 \text{ kJ / K}$$

02(a).

Sol: Given that,

Constants, $a = 0.31$, $b = 0.43$

$$\text{Ratio, } \frac{\bar{n}}{N} = 0.58$$

Monthly average radiation,

$$H_{avg} = H_o \left(a + b \left(\frac{\bar{n}}{N} \right) \right)$$

and,

$$H_o = \frac{24}{\pi} \left(1 + 0.033 \cos \left(\frac{360 n}{365} \right) \right)$$

$$\times \left(\cos \phi \cos \delta \sin \omega_s + \frac{2\pi}{360} \omega_s \sin \phi \sin \delta \right)$$

From data, $\phi = 18^\circ 29' = 18.48^\circ$

For August 15,

$$\Rightarrow \text{Jan} + \text{Feb} + \text{Mar} + \text{Apr} + \text{May} + \text{June} \\ + \text{July} + \text{Aug 15}$$

$$\Rightarrow 31 + 28 + 31 + 30 + 31 + 30 + 31 + 15$$

$$\therefore n = 227$$

$$\text{Declination, } \delta = 23.45 \sin \left(\frac{360}{365} (284 + n) \right)$$

$$\delta = 23.45 \sin \left(\frac{360}{365} (284 + 227) \right)$$

$$\delta = 13.783^\circ$$



Sunrise hour angle,

$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta)$$

$$= \cos^{-1}(-\tan(18.48^\circ) \times \tan 13.783^\circ)$$

$$\therefore \omega_s = 94.7$$

Average isolation at top of atmosphere,

$$H_o = \frac{24}{\pi} \times I_{sc} \left(1 + 0.033 \cos\left(\frac{360n}{365}\right) \right)$$

$$\times \left(\cos\phi \cos\delta \sin\omega_s + \frac{2\pi}{360} \omega_s \sin\phi \sin\delta \right)$$

$$\text{And, } I_{SC} = 1353 \text{ W/m}^2$$

$$H_o = \frac{24}{\pi} \times 1353 \times \left(1 + 0.033 \cos\left(\frac{360 \times 227}{365}\right) \right)$$

$$\times \left(\cos(18.48^\circ) \cos(13.783^\circ) \sin(94.7) + \frac{2\pi}{360} \times 94.7 \times \sin(18.48^\circ) \sin(13.783^\circ) \right)$$

$$H_o = \frac{24}{\pi} \times 1353 (0.976 \times (0.918 + 0.1248))$$

$$= \frac{24}{\pi} \times 1353 \times 1.018$$

$$H_o = 10522.2 \text{ W/m}^2 \text{ day}$$

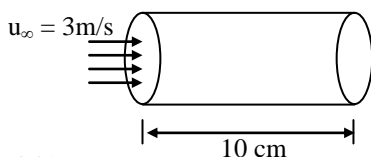
$$H_{avg} = H_o \left(a + b \left(\frac{\bar{n}}{N} \right) \right)$$

$$H_{avg} = 10522.2 (0.31 + 0.43 \times 0.58)$$

$$H_{avg} = 5886.12 \text{ W/m}^2 \text{ day}$$

02(b).

Sol.



Given:

$d = 5 \text{ mm}$	$L = 10 \text{ cm} = 0.1 \text{ m}$
$(T_b)_{inlet} = 27^\circ \text{C}$	$(T_b)_{exit} = 77^\circ \text{C}$
$Pr = 0.703$	$K_{air} = 0.028 \text{ W/m-K}$
$\nu = 18.22 \times 10^{-6} \text{ m}^2/\text{s}$	$\rho = 1.1774 \text{ kg/m}^3$
$c_p = 1006 \text{ J/kg-K}$	

$$Re = \frac{u_\infty \cdot d}{\nu} = \frac{3 \times 0.005}{18.22 \times 10^{-6}}$$

$$Re_d = 823.27$$

For developing flow:

$$\frac{Re_d}{\left(\frac{z}{d}\right)} > 10$$

$$\frac{823.27 \times 0.703}{10} > \frac{z}{d}$$

$$\frac{z}{d} < \frac{823.27 \times 0.703}{10}$$

$$z < 0.2893 \text{ m}$$

$$z < 28.93 \text{ cm}$$

upto 28.93 cm, the flow is developing flow, then the new $z = 10 \text{ cm} = \text{length of pipe}$.

$$Nu_z = 1.3 \left[\frac{Re_d \cdot Pr}{\left(\frac{z}{d}\right)} \right]^{1/3}$$

$$= 1.3 \left[\frac{823.27 \times 0.703}{\left(\frac{100}{5}\right)} \right]^{1/3}$$

$$Nu_z = 3.991$$

$$\frac{h \cdot d}{k} = 3.991$$

$$h = \frac{3.991 \times 0.028}{0.005}$$

$$h = 22.35 \text{ W/m}^2 \text{K}$$

(i) **Total rate of heat removed**

$$= \dot{m} \cdot C_p (T_{b_{exit}} - T_{b_{inlet}})$$

$$= 20 \times \frac{\pi}{4} \times d^2 \times \rho \times u_\infty \times C_p \cdot (77 - 27)$$

$$= 20 \times \frac{\pi}{4} \times 0.005^2 \times 1.1774 \times 3 \times 1006 (50)$$

$$= 69.77 \text{ W}$$



(ii) Heat removed by single conduit

$$= \frac{69.77}{20} = 3.4885 \text{ W}$$

$$3.4885 = hA\Delta T$$

$$3.4885 = 22.35 \times \pi \times 0.005 \times 0.1 \times \Delta T$$

$$\Delta T = 99.366^\circ\text{C}$$

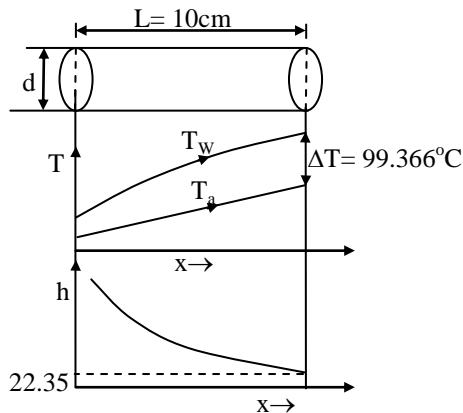
The exit conduit wall temperature

$$= 77 + 99.366$$

$$= 176.367^\circ\text{C}$$

(iii) Local heat transfer coefficient at the exit of each conduit

$$h = 22.35 \text{ W/m}^2\text{-K}$$



02(c).

Sol: The gas constants of N_2 , O_2 and CO_2 are

$$R_{\text{N}_2} = \frac{\bar{R}}{M_{\text{N}_2}} = \frac{8.314}{28} = 0.2969 \text{ kJ/kg.K}$$

$$R_{\text{O}_2} = \frac{\bar{R}}{M_{\text{N}_2}} = \frac{8.314}{28} = 0.2969 \text{ kJ/kg.K}$$

$$R_{\text{O}_2} = \frac{8.314}{32} = 0.2598 \text{ kJ/kg.K}$$

$$R_{\text{CO}_2} = \frac{8.314}{44} = 0.189 \text{ kJ/kg.K}$$

The gas constant of mixture

$$R_{\text{mix}} = \frac{m_1 R_1 + m_2 R_2 + m_3 R_3}{m_1 + m_2 + m_3}$$

$$= \frac{0.75 \times 0.2969 + 0.22 \times 0.2598 + 0.03 \times 0.189}{0.75 + 0.22 + 0.03}$$

$$= 0.285 \text{ kJ/kg.K}$$

Specific heat at constant pressure for the constituents :

$$(c_p)_{\text{N}_2} = \frac{\gamma \bar{R}}{M(\gamma - 1)}$$

$$= \frac{1.4 \times 8.314}{28(1.4 - 1)} = 1.039 \text{ kJ/kg.K}$$

$$(c_p)_{\text{O}_2} = \frac{1.4 \times 8.314}{32(1.4 - 1)} = 0.909 \text{ kJ/kg.K}$$

$$(c_p)_{\text{O}_2} = \frac{1.3 \times 8.314}{44(1.3 - 1)} = 0.819 \text{ kJ/kg.K}$$

Specific heat at constant pressure for mixture

$$(C_p)_{\text{mix}} = \frac{m_1 c_{p1} + m_2 c_{p2} + m_3 c_{p3}}{m_1 + m_2 + m_3}$$

$$= \frac{0.75 \times 1.039 + 0.22 \times 0.909 + 0.03 \times 0.819}{0.75 + 0.22 + 0.03}$$

$$= 1.0038 \text{ kJ/kg.K}$$

We know, $C_p - C_v = R$

$$C_v = 1.0038 - 0.2857 = 0.718 \text{ kJ/kg.K}$$

The process is polytropic with polytropic index 1.3

The final temperature of the mixture is

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} = 310 \left(\frac{500}{101} \right)^{\frac{1.3-1}{1.3}} = 448.4 \text{ K}$$

The workdone becomes

$$\begin{aligned} W &= \frac{P_1 V_1 - P_2 V_2}{n - 1} \\ &= \frac{m_{\text{mix}} R_{\text{mix}} (T_1 - T_2)}{n - 1} \\ &= \frac{2.2 \times 0.2857 (310 - 448.4)}{1.3 - 1} \end{aligned}$$

$$= -290 \text{ kJ}$$

$W = 290 \text{ kJ}$ (compression work on the gas)

The heat transfer, $dQ = dU + dW$

$$Q = m_{\text{mix}} C_{v \text{ mix}} (T_2 - T_1) \\ = 2.2 \times 0.718 (448.4 - 310) - 290$$

$$Q = -71.4 \text{ kJ}$$

(71.4 kJ heat is rejected from the system)

The change in entropy is given as :

$$S_2 - S_1 = m_{\text{mix}} \left(C_{p \text{ mix}} \ln \left(\frac{T_2}{T_1} \right) - R_{\text{mix}} \ln \left(\frac{P_2}{P_1} \right) \right) \\ = 2.2 \left(1.0038 \ln \left(\frac{448.4}{310} \right) - 0.2857 \ln \left(\frac{500}{101} \right) \right)$$

$$\Rightarrow S_2 - S_1 = -0.19 \text{ kJ/K}$$

03(a).

Sol: Once fuel cells of reasonably low cost and long life become available, they will be preferred in a large number of applications. Some of their potential applications are listed below:

- Fuel cells can be effectively used for load leveling. When the generation exceeds the demand, excess generated energy can be converted and stored as hydrogen by electrolysis of water. During peak load time, when the demand exceeds the generation, the stored hydrogen would be used in fuel cells to meet additional demand.
- A central station power plant using fuel cell is also possible using gasified coal as fuel. The efficiency of such a plant would be higher due to direct energy conversion as compared to conventional thermal plants. Thus coal will be used more efficiently with reduced emissions.
- Fuel cells are also suited for dispersed generation. By locating the fuel cells near

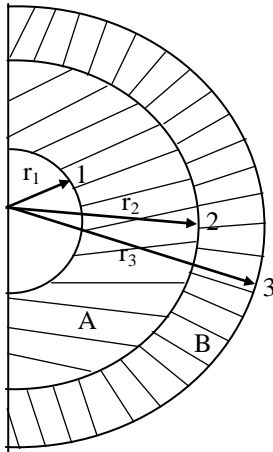
the load centre, transmission and distribution cost would be avoided / reduced, although there would be some cost for transporting the hydrogen.

- To meet the demand of isolated sites such as construction sites, military camps and small village communities or hamlets, fuel cells are more suited than diesel generator sets.
- For remote and inaccessible locations, fuel cell can be used unattended for a long period.
- Emergency/ auxiliary supply to critical loads such as hospitals, etc., can be better met using fuel cells as compared to diesel generator sets.
- Fuel cells can also be used as a mobile power source in vehicles, submarines and spacecrafts. A hydrogen-oxygen alkali fuel cell has been used successfully in USA to provide electric power in shuttle spacecrafts such as Apollo.
- Fuel cells are also proposed as a power source for propulsion of electric vehicles.
- Fuel cells can be used to power portable electronic devices (e.g., mobile phones and other low-power appliances, especially those used in military) as substitute for primary or rechargeable batteries. Instead of waiting for several hours for recharging, a small cartridge of methanol can be replaced in the same way as an ink cartridge in a computer printer.



03(b).

Sol:



$$r_1 = 0.6 \text{ m,}$$

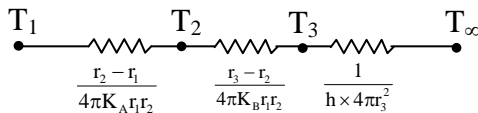
$$r_2 = r_1 + 0.125 = 0.6 + 0.125 = 0.725 \text{ m}$$

$$r_3 = r_2 + 0.04 = 0.725 + 0.04 = 0.765 \text{ m}$$

$$h_0 = 10 \text{ W/m}^2 \cdot \text{K}$$

$$K_A = 0.31 \text{ W/m} \cdot \text{K}$$

$$K_B = 0.05 \text{ W/m} \cdot \text{K}$$



$$\text{Heat loss through hemisphere} = \frac{1}{2} \times \frac{T_1 - T_\infty}{\sum R_{th}}$$

$$= \frac{1}{2} \times \frac{800 - 20}{\frac{0.725 - 0.6}{4\pi \times 0.31 \times 0.725 \times 0.6} + \frac{0.765 - 0.725}{4\pi \times 0.05 \times 0.765 \times 0.725} + \frac{1}{10 \times 4\pi \times (0.765)^2}}$$

$$= \frac{1}{2} \times \frac{780}{0.2021} = 1929.29 \text{ Watt}$$

Similarly:

$$\text{Total heat loss through sphere} = \frac{T_1 - T_2}{\frac{r_2 - r_1}{4\pi K_A r_2 r_1}}$$

$$3858.58 = \frac{800 - T_2}{\left(\frac{0.725 - 0.6}{4\pi \times 0.31 \times 0.725 \times 0.6} \right)}$$

$$3858.58 = \frac{800 - T_2}{4\pi \times 0.31 \times 0.725 \times 0.6}$$

$$\Rightarrow T_2 = 515.37^\circ\text{C}$$

$$\text{Heat loss} = \frac{T_3 - T_\infty}{\frac{1}{h_0 \times A_3}} = \frac{T_3 - 20}{\frac{1}{10 \times 4\pi \times 0.765^2}}$$

$$3858.58 = \frac{T_3 - 20}{\frac{1}{10 \times 4\pi \times 0.765^2}}$$

$$\Rightarrow T_3 = 72.46^\circ\text{C}$$

03(c).

Sol: Taking rod to be our system and applying first law of thermodynamics

$$Q - W = \Delta U$$

$$Q = 0 \quad (\because \text{Rod is insulated})$$

$$W = 0 \quad (\because \text{No work involved})$$

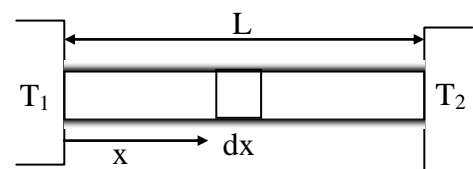
$$\Delta U = 0$$

$$U_{\text{initial}} = U_{\text{final}}$$

To, calculate U_{initial} let us take an small element of length 'dx' at a distance of 'x' from the wall which is at temperature T_1 .

Temperature of this element,

$$T_i = T_1 - \frac{T_1 - T_2}{L} \times x$$



$$\text{Mass of this element, } dm = \frac{M}{L} dx$$

where, M = Mass of total rod

Internal energy of this element

$$dU_i = \frac{M}{L} dx \times c \times \left[T_i - \frac{T_1 - T_2}{L} \times x \right]$$

$$U_{\text{initial}} = \int_0^L dU_i \quad \text{----- (1)}$$

$$U_{\text{final}} = M \times c \times T_f \quad \text{----- (2)}$$

Equating (1) and (2)

$$T_f = \frac{T_1 + T_2}{2}$$

Entropy change of this element

$$ds = dm \times c \times \ln \left[\frac{T_f}{T_1 - \left(\frac{T_1 - T_2}{L} \right) x} \right]$$

$$\text{Entropy change of this rod} = s = \int_0^L ds$$

$$= \frac{MC}{L} \int_0^L \left[\ln T_f - \ln \left\{ T_1 - \left(\frac{T_1 - T_2}{L} \right) x \right\} \right] dx$$

----- (A)

Now,

$$\int_0^L \ln T_f dx = L \ln T_f \text{----- (3)}$$

$$\int_0^L \ln \left\{ T_1 - \left(\frac{T_1 - T_2}{L} \right) x \right\} dx \text{----- (4)}$$

we know that,

$$\int \ln(a + bx) dx = \frac{1}{b} [(a + bx) \ln(a + bx) - (a + bx)]$$

⇒ (4) becomes

$$\frac{L}{T_2 - T_1} \left[\left(T_1 + \frac{T_2 - T_1}{L} x \right) \ln \left(T_1 + \frac{T_2 - T_1}{L} x \right) - \left(T_1 + \frac{T_2 - T_1}{L} x \right) \right]_0^L$$

$$= \frac{L}{T_2 - T_1} [(T_1 - T_2) + T_2 \ln T_2 - T_1 \ln T_1] \text{---- (5)}$$

using (3) and (5) in equation (A)

We get, Entropy change of this rod

$$S_{\text{rod}} = mc \left[1 + \ln T_f + \frac{T_2}{T_1 - T_2} \ln T_2 - \frac{T_1}{T_1 - T_2} \ln T_1 \right]$$

Entropy change of surrounding, $S_{\text{surr}} = 0$

$$S_{\text{gen}} = S_{\text{rod}} + S_{\text{surr}}$$

$$S_{\text{gen}} = mc \left[1 + \ln T_f + \frac{T_2}{T_1 - T_2} \ln T_2 - \frac{T_1}{T_1 - T_2} \ln T_1 \right]$$

04(a).

Sol: Given that,

Discharge of centrifugal pump,

$$Q = 40000 \text{ lit/day} = 40 \text{ m}^3/\text{day}$$

Q = discharge of water in (m^3/sec)

$$Q = \frac{40}{10 \times 3600} \text{ m}^3/\text{sec}$$

Total head of water, $H = 10 \text{ m}$,

Pump operation time/day, $t = 10 \text{ hrs}$

Wind speed, $V_w = 6 \text{ m/s}$

Power coefficient, $C_p = 0.3$

Density of air, $\rho_a = 1.2 \text{ kg/m}^3$

Transmission efficiency, $\eta_T = 95 \% = 0.95$

Pump efficiency, $\eta_p = 35 \% = 0.35$

Theoretical hydraulic power, $P_T = \rho_w g Q H$

where,

ρ_w = density of water = 1000 kg/m^3

g = acceleration due to gravity = 9.81 m/sec^2

H = head of water = 10 m

$$P_T = 1000 \times 9.81 \times \frac{40}{10 \times 3600} \times 10 = 109 \text{ W}$$

$$P_T = 0.109 \text{ W}$$

$$\text{Actual power, } P_a = \frac{\text{Theoretical power}}{\eta_T \times \eta_p}$$

$$= \frac{109}{0.95 \times 0.35}$$

$$\therefore P_a = 327.8195 \text{ W}$$

$$\text{But, } P_a = c_p \times \frac{1}{2} \times \rho_a A V_w^2$$

$$\text{or, } A = \frac{2 P_a}{c_p \times \rho_a \times V_w^2}$$

$$A = \frac{2 \times 327.8195}{0.3 \times 1.2 \times (6)^3} = 8.43 \text{ m}^2,$$

$$\therefore \pi R^2 = 8.43 \text{ m}$$

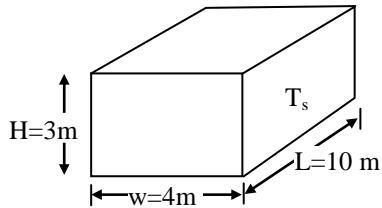
Rotor radius, $R = 1.638 \text{ m}$,

$$D = 3.276 \text{ m} \approx 3.28 \text{ m}$$



04(b).

Sol:



$$u_{\infty} = \frac{90 \times 1000}{3600} = 25 \text{ m/s},$$

$$T_{\infty} = 50^{\circ}\text{C}$$

$$A = 2(3 \times 4) \times 10 = 140 \text{ m}^2$$

$$T_s = 10^{\circ}\text{C}$$

$$R_{eL} = \frac{u_{\infty} L}{\nu} = \frac{25 \times 10}{16 \times 10^{-6}} = 15.625 \times 10^6$$

Turbulent flow,

$$Nu = \frac{\bar{h} L}{k} = 0.036 R_{eL}^{0.8} Pr^{1/3}$$

$$\frac{\bar{h} \times 10}{0.02673} = 0.036 [15.625 \times 10^6]^{0.8} [0.701]^{1/3}$$

$$\bar{h} = 48.64 \frac{\text{W}}{\text{m}^2 \text{K}}$$

Heat loss from four surface, $Q = \bar{h} A \Delta T$

$$Q = \bar{h} P L \Delta T$$

$$Q = 48.64 \times 2(3 + 4) \times 10 \times 50 = 10$$

$$Q = 272.384 \text{ kW}$$

$$= 980582.4 \frac{\text{kJ}}{\text{hr}}$$

Average skin friction coefficient

$$c_f = \frac{0.072}{(R_{eL})^{1/5}} = 2.62 \times 10^{-3}$$

$$\text{Drag force } F_D = \frac{c_f}{2} \rho u_{\infty}^2 A$$

$$F_D = \frac{2.62 \times 10^{-3}}{2} \times 1.165 \times (25)^2 \times 140$$

$$F_D = 133.54 \text{ N}$$

Power required to drive the truck

$$P = F_D \times u_{\infty}$$

$$P = 133.54 \times 25$$

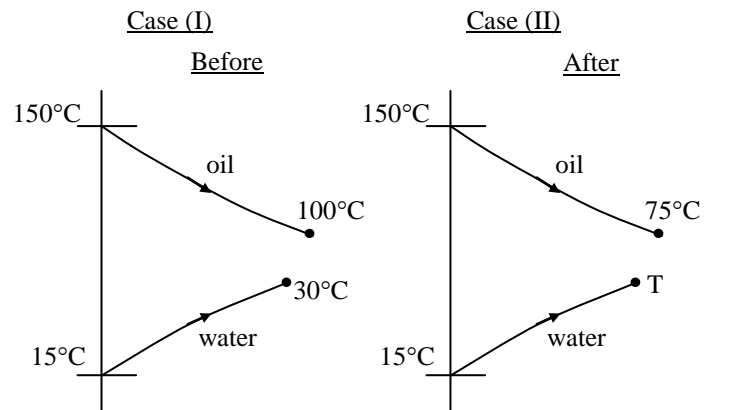
$$P = 3338.45 \text{ N}$$

Assuming 1 tonne of refrigeration is equal to the heat removal rate of 14000 kJ/h. Cooling capacity of the refrigeration plant is

$$= \frac{980582.4 \frac{\text{kJ}}{\text{hr}}}{14000 \frac{\text{kJ}}{\text{hr}}} = 70 \text{ TR}$$

04(c).

Sol:



Assumptions :

- Radiation effect is neglected
- No fouling

Given,

$$T_{hi} = 150^{\circ}\text{C},$$

$$T_{ci} = 15^{\circ}\text{C}$$

$$T_{he} = 100^{\circ}\text{C} \rightarrow \text{case (i)}$$

$$T_{ce} = 30^{\circ}\text{C}$$

Energy balance for case (i)

$$\dot{m}_w \cdot C_{pw} (30 - 15) = \dot{m}_o \cdot C_{po} (150 - 100)$$

$$15 \times (\dot{m}_w \cdot C_{pw}) = \dot{m}_o \cdot C_{po} (150 - 100)$$

$$\Rightarrow 15 \times (\dot{m}_w C_{pw}) = 50 \times \dot{m}_w C_{po} \text{ ---- (1)}$$



$$C_{\min} = \dot{m}_0 \cdot C_{p0}$$

$$C_{\max} = \dot{m}_w \cdot C_{pw}$$

For new case:

$$\dot{m}_w \cdot C_{pw} (T - 15) = \dot{m}_0 \cdot C_{p0} (150 - 75)$$

$$\dot{m}_w \cdot C_{pw} (T - 15) = \dot{m}_0 \cdot C_{p0} (75)$$

From equation (1)

$$\dot{m}_w C_{pw} = \frac{50}{15} \dot{m}_0 C_{p0}$$

$$\dot{m}_0 \cdot C_{p0} \times \frac{50}{15} (T - 15) = \dot{m}_0 C_{p0} (150 - 75)$$

$$T - 15 = 75 \times \frac{15}{50}$$

$$T = 37.5^\circ\text{C}$$

Exit temperature of water in new case is 37.5°C

LMTD for case (i):

$$\begin{aligned} \theta_{m1} &= \frac{(150 - 15) - (100 - 30)}{\ln\left(\frac{150 - 15}{100 - 30}\right)} \\ &= \frac{85 - 70}{\ln\left(\frac{85}{70}\right)} = 77.25^\circ\text{C} \end{aligned}$$

Energy balance

$$U \cdot A_I \cdot \theta_{m1} = \dot{m}_0 \cdot C_{p0} (150 - 100)$$

$$\begin{aligned} \theta_{m1} &= \frac{(150 - 15) - (75 - 37.5)}{\ln\left(\frac{150 - 15}{70 - 37.5}\right)} \\ &= \frac{85 - 37.5}{\ln\left(\frac{85}{37.5}\right)} = \frac{47.5}{0.2183} \end{aligned}$$

$$\theta_m = 58.46^\circ\text{C}.$$

Energy balance

$$U \cdot A_{II} \cdot \theta_{m1} = \dot{m}_0 \cdot C_{p0} \cdot (150 - 75) \text{ -----(2)}$$

Equation (1) \div (2)

$$\frac{U \cdot A_I \cdot \theta_{m1}}{U \cdot A_{II} \cdot \theta_{m1}} = \frac{\dot{m}_0 \cdot C_{p0} \times 50}{\dot{m}_0 C_{p0} \times 75}$$

$$\frac{\pi \times d \times 1 \times 77.25}{\pi \times d \times L \times 58.046} = \frac{50}{75}$$

$$L = 1.9962 \text{ m} \rightarrow \text{length of new cooler}$$

04(d).

Sol:

- (a) The energy that can be extracted from each block is given by

$$Q = m C_p \Delta T$$

Energy extracted from first block,

$$Q_1 = 1000 \times 0.5 \times (1200 - 300) = 450 \text{ MJ}$$

Entropy change of first block,

$$\begin{aligned} \Delta S_1 &= m C \ln \frac{T_0}{T_1} = 1000 \times 0.5 \ln \frac{300}{1200} \\ &= -693.15 \text{ kJ/K} \end{aligned}$$

Available energy of first block

$$\begin{aligned} &= Q_1 - T_0 |\Delta S_1| \\ &= 450000 - 300 \times 693.15 \\ &= 242.055 \text{ MJ} \end{aligned}$$

Energy extracted from second block,

$$\begin{aligned} Q_2 &= 1000 \times 0.5 \times (600 - 300) \\ &= 150 \text{ MJ} \end{aligned}$$

Entropy change of second block,

$$\Delta S_2 = 1000 \times 0.5 \ln \frac{300}{600} = -346.57 \text{ kJ/K}$$

Available energy of second block,

$$\begin{aligned} Q_2 - T_0 |\Delta S_2| &= 150000 - 300 \times 346.57 \\ &= 46.029 \text{ MJ} \end{aligned}$$

Total available energy of both the blocks,

$$= 242.055 + 46.029 = 288.084 \text{ MJ}$$

- (b) Let

T_f = equilibrium temperature of the blocks.

Energy balance gives

$$mC(T_f - 1200) + mC(T_f - 600) = 0$$

$$(\text{or}) \quad T_f = 900 \text{ K}$$



Energy change of blocks

$$= 2mC \ln \frac{T_0}{T_f} = 2 \times 1000 \times 0.5 \ln \frac{300}{900}$$

$$= -1098.61 \text{ kJ/K}$$

Available energy = $Q - T_0 |\Delta S|$

$$= 600000 - 300 \times 1098.61$$

$$= 270.417 \text{ MJ}$$

(c) Loss in available energy due to energy transfer between the blocks

$$= 288.084 - 270.417 = 17.667 \text{ MJ}$$

05(a).

Sol: "Fuel Cell" is an electrochemical device in which electrical energy is generated by chemical reaction. The basic difference between storage battery or primary cell and fuel cell is that the electrode and the electrolyte are invariant. When cell operates fuel is oxidized and chemical reaction provides the energy which can be converted into electricity. One of the major advantage of this type of fuel cell is it can be carried isothermally i.e, the Carnot limitation on efficiency is not applicable.

Grove demonstrated the first fuel cell in 1839 using Platinum electrodes.

The figure below shows a general simplified version of hydrogen or hydrocarbon fuel cell.

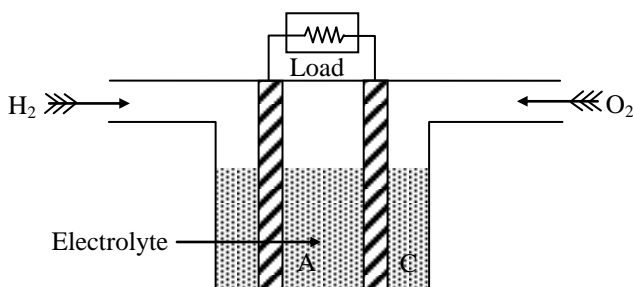
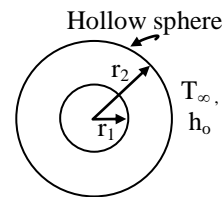


Figure: Hydrogen Fuel Cell

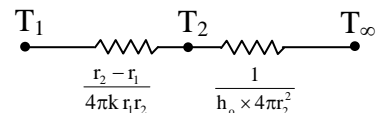
Working: Fuel is supplied to anode where it is oxidized thereby freeing electrons, which flow in the circuit, and the hydrogen ions which pass through the electrolyte to the cathode combine with oxygen and electrons to form water. Electrodes for this type of cell are usually porous impregnated with a catalyst. In liquid electrolyte, a delicate balance is achieved in which surface tension and density of the liquid must be considered.

05(b).

Sol:



Thermal circuit :



$$Q = q_o 4\pi r_1^2 = \frac{T_1 - T_\infty}{\frac{1}{4\pi k} \left[\frac{1}{r_1} - \frac{1}{r_2} \right] + \frac{1}{h_o 4\pi r_2^2}}$$

$$T_1 - T_\infty = q_o 4\pi r_1^2 \left[\frac{1}{4\pi k} \left[\frac{1}{r_1} - \frac{1}{r_2} \right] + \frac{1}{h_o 4\pi r_2^2} \right]$$

$$T_1 - T_\infty = q_o r_1^2 \left[\frac{r_2 - r_1}{k r_1 r_2} + \frac{1}{h_o r_2^2} \right]$$

$$T_1 - T_\infty = q_o \left[\frac{r_1 (r_2 - r_1)}{k r_2} + \left(\frac{r_1}{r_2} \right)^2 \cdot \frac{1}{h_o} \right]$$

$$T_1 = T_\infty + q_o \left[\frac{r_1 (r_2 - r_1)}{k r_2} + \left(\frac{r_1}{r_2} \right)^2 \cdot \frac{1}{h_o} \right]$$



$$q_o 4\pi r_1^2 = \frac{T_2 - T_\infty}{\frac{1}{h_o 4\pi r_2^2}}$$

$$T_2 - T_\infty = q_o 4\pi r_1^2 \left[\frac{1}{4\pi r_2^2 h_o} \right]$$

$$T_2 = T_\infty + q_o \left(\frac{r_1}{r_2} \right)^2 \cdot \frac{1}{h_o}$$

$$T_1 = T_\infty + q_o \left[\frac{r_1(r_2 - r_1)}{kr_2} + \left(\frac{r_1}{r_2} \right)^2 \cdot \frac{1}{h_o} \right]$$

$$T_1 = 120 + 10^5 \left[\frac{0.04(0.06 - 0.04)}{16 \times 0.06} + \left(\frac{0.04}{0.06} \right)^2 \cdot \frac{1}{380} \right]$$

$$T_1 = 320.29^\circ\text{C}$$

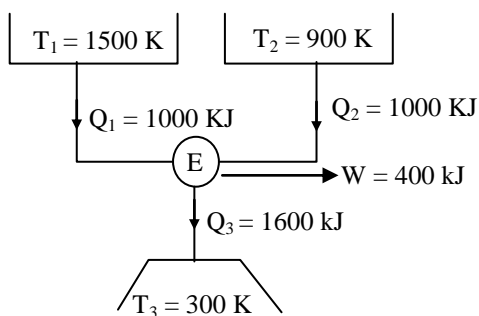
$$T_2 = T_\infty + q_o \left(\frac{r_1}{r_2} \right)^2 \cdot \frac{1}{h_o}$$

$$T_2 = 120 + 10^5 \left(\frac{0.04}{0.06} \right)^2 \times \frac{1}{380}$$

$$T_2 = 237^\circ\text{C}$$

05(c).

Sol:



(i) Applying first law

$$\Sigma Q = \Sigma W$$

$$Q_1 + Q_2 - Q_3 = W$$

$$1000 + 1000 - 1600 = 400 \text{ kJ} = W$$

$$\oint \frac{\delta Q}{T} \leq 0$$

$$\begin{aligned} \oint \frac{\delta Q}{T} &= \frac{Q_1}{T_1} + \frac{Q_2}{T_2} - \frac{Q_3}{T_3} \\ &= \frac{1000}{1500} + \frac{1000}{900} - \frac{1600}{300} \\ &= 0.67 + 1.11 - 5.33 \\ &= -3.55 \text{ kJ/K} \end{aligned}$$

$$\oint \frac{\delta Q}{T} < 0 \text{ Hence it is a irreversible cycle}$$

(ii) $dQ = du + dw \rightarrow$ First law

$$Tds = C_v dT + Pdv$$

$$V = C$$

$$\therefore dv = 0$$

$$Tds = c_v dT$$

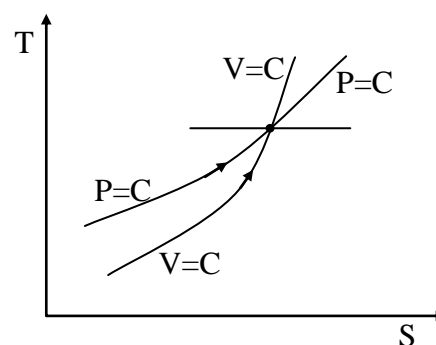
$$\left(\frac{dT}{ds} \right)_c = \frac{T}{c_v}$$

$$dQ = dh - vdp \rightarrow \text{Ist Law}$$

$$Tds = C_p dT - vdp$$

$$P = C$$

$$dP = 0$$



$$Tds = C_p dT$$

$$\left(\frac{dT}{ds} \right)_{p=c} = \frac{T}{c_p}$$

$$C_p > C_v$$

$$\therefore \left(\frac{dT}{ds} \right)_{v=c} > \left(\frac{dT}{ds} \right)_{p=c}$$



05(d).

Sol: Taking bottle boundary to be our control volume boundary

By mass conversation

$$\frac{dm_i}{dt} - \frac{dm_e}{dt} = \left(\frac{dm}{dt} \right)_{cv} \Rightarrow \frac{dm_i}{dt} = \left(\frac{dm}{dt} \right)_{cv} \dots (i)$$

where,

m_i = mass entering the control volume

m_e = mass leaving the control volume

By energy conservation

$$\frac{d}{dt} [m_i h_i + Q] = \left(\frac{dU}{dt} \right)_{cv}$$

$$h_i \frac{dm}{dt} + \frac{dQ}{dt} = \frac{dU}{dt}$$

$$h_i(m_2 - m_1) + Q = m_2 u_2 - m_1 u_1$$

[m_1 = initial mass c.v, m_2 = final mass in c.v]

$$m_2 h_i + \dot{Q} = m_2 u_2$$

$$\text{where, } m_2 = \frac{100 \times 0.02}{0.287 \times 300} = 0.023 \text{ kg}$$

$$0.023 \times 1.005 \times 300 + Q = 0.023 \times 0.717 \times 300$$

$$Q = -2 \text{ kJ}$$

05(e).

Sol: The main components of horizontal axis

Wind turbine are,

1. Turbine blades
2. Generators
3. Yaw system
4. Hub
5. Nacelle
6. Towers.

1. **Turbine Blades :** Epoxy composites and glass fibre are used in the manufacture of turbine blades. To reduce the air friction, the blades are slightly twisted from outer tip. Modern turbines have two or three blades having aerofoil type cross section.

2. **Generator :** The type of generators used are either constant speed or variable speed generators. Variable speed generators are expensive and inaccurate and are not used in common practice. There are different types of constant speed generators, among which synchronous induction and permanent magnet types are used.

3. **Yaw System :** Yaw system controls the position of the nacelle around the vertical axis. Hence, by using yaw system, the position of nacelle is adjusted such that it faces the wind. The yaw system is provided at the base of the nacelle.

4. **Hub :** The central part of a rotor, where all the blades are connected is called hub. The mechanism for pitch angle control is provided in the hub.

5. **Nacelle :** It houses the rotor brakes, gearbox, generator, electrical switch gear and control. The switch gear and control block enables to control the system, according to the requirement. It is placed on the top of a tower.

6. **Towers :** Four types of towers generally used are as follows,

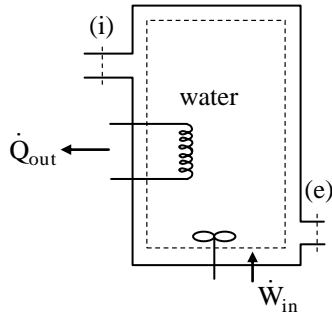
- (i) Truss tower
- (ii) Pole tower
- (iii) Reinforced concrete tower
- (iv) Built up shell-tube tower.

The most common and preferred tower is truss tower, because it is widely applicable. The parts of truss tower are stiff, inexpensive, readily available and can be transported easily. Truss tower is designed to withstand the wind load, even if they occur frequently over a short period.



06(a).

Sol:



Given:

Initial mass of water in tank, $m_i = 45 \text{ kg}$

Initial temperature, $T_i = 45^\circ \text{C}$

Inlet temperature, $T_i = 45^\circ \text{C}$

Mass flow rate, $\dot{m}_i = \dot{m}_e = 270 \text{ kg/hr}$

Energy removed, $\dot{Q}_{out} = 7.6 \text{ kW}$

Power input, $\dot{W}_{in} = 0.6 \text{ kW}$

Mass balance,

$$\frac{dm}{dt} = \dot{m}_i - \dot{m}_e = 0$$

Energy balance,

$$\frac{dU}{d\tau} = \dot{m}_i h_i + \dot{Q} - \dot{m}_e h_e - \dot{W}_{cv}$$

$$\frac{dU}{d\tau} = 270[h_i - h_e] + [-7.6 + 0.6] \times 3600$$

$$\frac{dU}{d\tau} = 270[(u_i + p_i v_i) - (u_e + p_e v_e)] - 7 \times 3600$$

$$p_i = p_e \text{ (given)}$$

$$v_i = v_e \text{ (incompressible)}$$

$$\frac{dU}{d\tau} = 270[(u_i - u_e)] - 7 \times 3600$$

$$\frac{dU}{d\tau} = 270 \times 4.2[318 - T] - 7 \times 3600 \quad (i)$$

We know, $U = mcT$

$$\frac{dU}{d\tau} = mc \frac{dT}{d\tau} = 45 \times 4.2 \frac{dT}{d\tau}$$

From equation (i)

$$45 \times 4.2 \frac{dT}{d\tau} = 270 \times 4.2(318 - T) - 7 \times 3600$$

$$\frac{dT}{d\tau} = 6(318 - T) - \frac{400}{3}$$

$$\int_{318}^T \frac{3}{5324 - 18T} dT = \int_0^\tau d\tau$$

$$\frac{-3}{18} \log_e \left[\frac{5324 - 18T}{-400} \right] = \tau$$

$$e^{-6\tau} = \frac{18T - 5324}{400}$$

$$T = \frac{400e^{-6\tau}}{18} + \frac{5324}{18}$$

$$T = 318 - 22(1 - e^{-6\tau})$$

06(b).

Sol: $k = k_o + \left[\frac{k_i - k_o}{T_i - T_o} \right] [T - T_o]$

$$k = k_o + c[T - T_o], c = \frac{k_i - k_o}{T_i - T_o}$$

$$Q = -kA \frac{dT}{dr}$$

$$Q = -k4\pi r^2 \frac{dT}{dr}$$

$$Q = -[k_o + c(T - T_o)]4\pi r^2 \frac{dT}{dr}$$

$$Q \frac{dr}{r^2} = -4\pi [k_o + c(T - T_o)] dT$$

$$Q \int_{r_i}^{r_o} \frac{dr}{r^2} = -4\pi \int_{T_i}^{T_o} [k_o + c(T - T_o)] dT$$

$$Q \left[-\frac{1}{r} \right]_{r_i}^{r_o} = -4\pi \left[k_o T + c \left(\frac{T^2}{2} - T_o(T) \right) \right]_{T_i}^{T_o}$$

$$Q \left[\frac{-1}{r_o} + \frac{1}{r_i} \right] = -4\pi \left[k_o (T_o - T_i) + c \left(\frac{T_o^2 - T_i^2}{2} - T_o(T_o - T_i) \right) \right]$$

$$Q \left[\frac{1}{r_i} - \frac{1}{r_o} \right] = -4\pi (T_o - T_i) \left[k_o + c \left(\frac{T_o + T_i}{2} - T_o \right) \right]$$



$$Q \left[\frac{r_o - r_i}{r_i r_o} \right] = -4\pi(T_o - T_i) \left[k_o + c \left(\frac{T_o + T_i - 2T_o}{2} \right) \right]$$

$$Q \left[\frac{r_o - r_i}{r_i r_o} \right] = -4\pi(T_o - T_i) \left[k_o + c \left(\frac{T_i - T_o}{2} \right) \right]$$

$$Q \left[\frac{r_o - r_i}{r_i r_o} \right] = -4\pi(T_o - T_i) \left[k_o + \left(\frac{k_i - k_o}{T_i - T_o} \right) \left(\frac{T_i - T_o}{2} \right) \right]$$

$$Q \left[\frac{r_o \cdot r_i}{r_o - r_i} \right] = -4\pi(T_o - T_i) \left[k_o + \frac{k_i - k_o}{2} \right]$$

$$Q = \frac{4\pi(T_i - T_o)r_i r_o}{r_o - r_i} \left[\frac{2k_o + k_i - k_o}{2} \right]$$

$$Q = \frac{4\pi(T_i - T_o)r_i r_o}{r_o - r_i} \left[\frac{k_i + k_o}{2} \right]$$

$$Q = 4\pi r_i r_o \left[\frac{k_i + k_o}{2} \right] \left[\frac{T_i - T_o}{r_o - r_i} \right]$$

$$Q = 4\pi r_i r_o \left[\frac{k_i + k_o}{2} \right] \left[\frac{T_i - T_o}{r_o - r_i} \right] = -\dot{m} h_{fg}$$

$$4\pi \times 0.9 \times 1.2 \left[\frac{0.125 + 0.157}{2} \right] \left[\frac{-183 - 0}{1.2 - 0.9} \right] = -\dot{m} \times 212.5 \times 10^3$$

$$\dot{m} = -5.5 \times 10^{-3} \text{ kg/sec}$$

06(c).

Sol: The different methods of obtaining energy from biomass are as follows:

1. Direct combustion
2. Thermo chemical conversion
3. Bio-chemical conversion

1. Direct Combustion

Combustion is a process of burning the biomass, to generate heat which is used for cooling, industries, generation of electricity and to obtain by-products. Combustion of products is related to all the fuels i.e, solids, liquids and gases. But, combustion of biomass is difficult compared to other fuels because of the moisture content present in it.

(i) **Incineration:** The method of burning completely to ashes is called incineration. This method is especially employed for burning municipal solid wastes, to reduce the volume of it and to generate steam and electricity.

(ii) **Pyrolysis :** In this process, the organic material is converted into solids, liquids and gases by heating it in the absence of oxygen at a temperature range of about 500°C–900°C. Material like vegetable wastes, wood, dung, etc, is dried and burnt to provide heat or to change them into gases having low calorific values by the action of rolysis.

2. Thermo chemical Conversion

It is a process in which biomass is decomposed a varying combinations of pressures and temperatures.

(i) **Gasification :** Gasification is achieved by heating biomass with a controllable amount of oxygen to produce low heating value gas or by reacting the biomass with steam and oxygen at high temperature and pressure to produce medium heating value gas. The resulting gas is called producer gas which is used in producing heat and steam and also used in generating electricity in I.C engines and gas turbines.

(ii) **Liquification:** Liquification is a process of pyrolytic heating of solid biomass in the absence of oxygen to produce a liquid oil. The producer gas and the pyrolytic oil can be used as fuels, as they are cheaper and more efficient than the solid biomass.

3. Bio-chemical conversion :

Bio-chemical process involves conversion of biomass to biomass to biofuels. It is a slow process as it is carried out at low temperatures. The two biochemical conversions are,

(i) **Anaerobic digestion:** It is the process in which the organic materials are broken down by microorganisms in the absence of oxygen. This process produces gas usually containing methane (CH_4) and carbon dioxide (CO_2) with minimum impurities. Anaerobic digestion is carried out at low temperature upto 65°C and requires a minimum of 80 % moisture content. The gas produced by this process can be burned directly and can also be converted to synthetic natural gas by removing carbon dioxide and impurities from it.

(ii) **Fermentation:** It is a process of decomposition of organic matter by microorganisms like bacteria, yeast, enzymes, etc., in the absence of oxygen. This process is widely used for the conversion of grain and sugar crops to form ethanol. The residue of the fermentation process is rich in protein and is also used as a cattle-feed supplement.

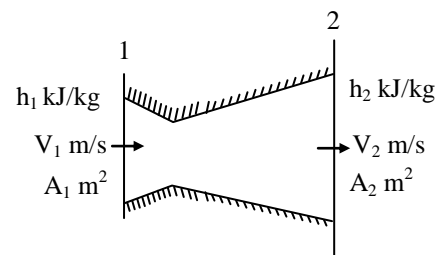
07(a)(i).

Sol: First law of thermodynamics for a Steady Flow Energy Equation on time basis :

$$\dot{Q} - \dot{W} = \sum_{\text{out}} \dot{m} \left(h_2 + \frac{V_2^2}{2} + gZ_2 \right) - \sum_{\text{in}} \dot{m} \left(h_1 + \frac{V_1^2}{2} + gZ_1 \right)$$

(i) Steam Nozzle:

- A schematic diagram of a nozzle is shown in fig. Since the primary purpose of a nozzle is to increase the flow velocity of the fluid the change in the kinetic energy cannot be ignored.



The flow conditions imply the following:

Steady state: $\dot{m}_1 = \dot{m}_2 = \dot{m}$

Horizontal: $Z_2 = Z_1$

Insulated: $\dot{Q} = 0$

No shaft work is involved: $\dot{W}_s = 0$

The control volume expression gives

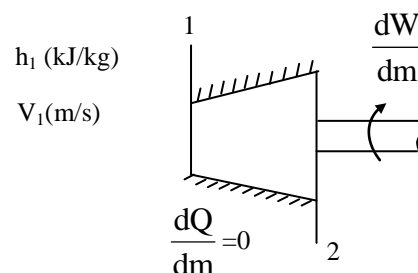
$$V_2 = \sqrt{V_1^2 + 2000(h_1 - h_2)} \quad (\because V_1 \ll V_2)$$

$$\Rightarrow V_2 = \sqrt{2000(h_1 - h_2)}$$

$$\therefore V_2 = 44.72\sqrt{\Delta h}$$

(ii) Gas Turbines

In turbines heat energy is converted into work energy



The flow conditions imply the following:

Steady state: $\dot{m}_1 = \dot{m}_2 = \dot{m}$



Horizontal : $Z_2 = Z_1$

Insulated: $\dot{Q} = 0$

$$h_1 + \frac{V_1^2}{2000} + \frac{dQ}{dm} = h_2 + \frac{V_2^2}{2000} + \frac{dW}{dm}$$

$$\frac{dW}{dm} = (h_1 - h_2) + \frac{(V_1^2 - V_2^2)}{2000} \quad \left(\because \frac{dW}{dm} = +ve \right)$$

\therefore Work is done by the system.

07(a)(ii).

Sol: Analysis:

During cooling process of drinking water, entropy decrease of water takes place.

$$\Delta S_1 = mC_p \ln \left(\frac{T_H}{T_L} \right)$$

And heat removed from the water,

$$Q_L = mC_p (T_H - T_L)$$

Heat supplied to the atmosphere,

$$Q_H = W_{in} + Q_L$$

$$Q_H = W_{in} + mC_p (T_H - T_L)$$

The entropy increase of atmosphere

$$= \frac{W_{in} + mC_p (T_H - T_L)}{T_H}$$

$$S_{gen} = \Delta S_{system} + \Delta S_{Surrounding}$$

$$S_{gen} \geq 0$$

$$\therefore \frac{W_{in} + mC_p (T_H - T_L)}{T_H} - mC_p \ln \left(\frac{T_H}{T_L} \right) \geq 0 \quad \dots (1)$$

$$C_p = 4.187 \text{ kJ/kgK}, \quad m = 2 \text{ kg},$$

$$T_H = 298 \text{ K}, \quad T_L = 275 \text{ K}$$

Putting these values in eq (1), we get

$$W_{in} \geq 7.833 \text{ kJ}$$

$$\text{So, } W_{min} = 7.833 \text{ kJ}$$

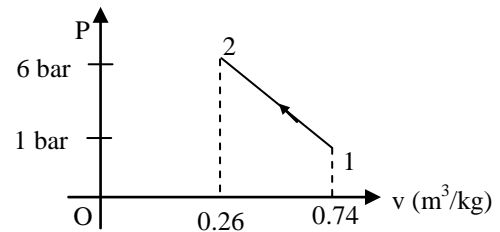
07(a)(iii).

Sol: By steady flow energy equation for unit mass

$$h_1 + \frac{V_1^2}{2} + Q = h_2 + \frac{V_2^2}{2} + W \quad \dots (i)$$

Q = heat transferred per unit mass.

W = work done per unit mass



$$Q = \int dQ = \int T ds$$

$$\int T ds = \int dh - \int v dp$$

$$Q = (h_2 - h_1) - \int v dp \quad \dots (ii)$$

From equation (i) & (ii)

$$W = - \int v dp - \frac{V_2^2 - V_1^2}{2}$$

Now $\int v dp$ = Area under P-v curve projected on P axis

$$= \frac{1}{2} [0.74 + 0.26] \times [6 - 1] \times 100$$

$$= 250 \text{ kJ/kg}$$

$$\frac{V_2^2 - V_1^2}{2} = \frac{100^2 - 0^2}{2} = 5000 \text{ J/kg} = 5 \text{ kJ/kg}$$

$$W = -250 - 5 = -255 \text{ kJ/kg}$$

$$W = 255 \text{ kJ/kg (by compressor)}$$

07(b).

Sol: Given:

$$d = 5 \text{ cm} = 0.05 \text{ m}$$

$$\dot{q} = 5 \times 10^7 \text{ W/m}^3$$

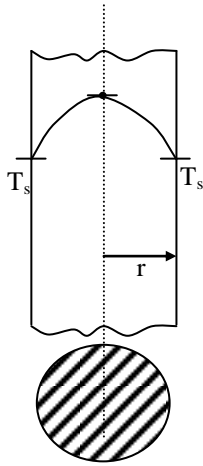
$$T = 800 - 4.167 \times 10^5 r^2$$

$$\rho = 1100 \text{ kg/m}^3, \quad c_p = 800 \text{ J/kg.K}$$

$$K = 30 \text{ W/m-K}$$



$$T = 800 - 4.167 \times 10^{-5} r^2$$



$$(i) \quad \frac{1}{r} \frac{\partial^2}{\partial r^2} \left(r \frac{\partial T}{\partial r} \right) = -\frac{\dot{q}}{K}$$

$$\frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) = -\frac{\dot{q}}{K} \cdot r$$

$$\frac{r \partial T}{\partial r} = -\frac{\dot{q}}{K} \frac{r^2}{2} + C_1$$

$$\frac{\partial T}{\partial r} = -\frac{\dot{q}}{K} \cdot \frac{r}{2} + \frac{C_1}{r}$$

$$= -\frac{\dot{q}}{K} \cdot \frac{r^2}{4} + C_1 \ln r + C_2$$

$$C_1 = 0$$

$$T = \frac{\dot{q}}{K} \frac{r^2}{4} + C_2$$

$$\text{at } r = 0, \quad T = 800 = T_{\max}$$

$$800 = C_2$$

$$T = -\frac{\dot{q}}{K} \cdot \frac{r^2}{4} + 800$$

$$\text{at } r = 0.025, \quad T = T_s$$

$$T_s = -\frac{5 \times 10^7}{30} \times \frac{0.025^2}{4} + 800 = 539.58^\circ\text{C}$$

Heat transfer rate at axis \rightarrow (at $r = 0$)

$$Q = -K.A \left(\frac{dT}{dr} \right)_{r=0}$$

$$Q = -30 \times (\pi \times d \times L) \times (0 - 4.167 \times 10^{-5} \times 2r)_{r=0}$$

$$Q = 0$$

Heat transfer rate at surface

$$(r = 0.025 \text{ m} = 25 \text{ mm})$$

$$Q = -K.A \left(\frac{dT}{dr} \right)_{r=0.025}$$

$$= -30 \times (\pi \times d \times L) \times (-4.167 \times 10^{-5} \times 2 \times 2.5 \times 10^{-2})$$

$$= -30 \times (\pi \times 0.05 \times 1) \times (-4.167 \times 10^{-5} \times 2 \times 0.025)$$

$$Q = 98.182 \text{ kW/m}$$

$$(ii) \quad \text{If } \dot{q} = 10^8 \text{ W/m}^3$$

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) + \frac{\dot{q}}{K} = \frac{1}{\alpha} \frac{\partial T}{\partial \tau}$$

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \times (-4.167 \times 10^5 \times 2r) \right) + \frac{\dot{q}}{K} = \frac{1}{\alpha} \frac{\partial T}{\partial \tau}$$

$$\frac{1}{r} \frac{\partial}{\partial r} (-4.167 \times 10^5 \times 2r^2) + \frac{\dot{q}}{K} = \frac{1}{\alpha} \frac{\partial T}{\partial \tau}$$

$$\frac{1}{r} (-4.167 \times 10^5 \times 4r) + \frac{\dot{q}}{K} = \frac{1}{\alpha} \frac{\partial T}{\partial \tau}$$

$$-4.167 \times 10^5 \times 4 + \frac{\dot{q}}{K} = \frac{1}{\alpha} \frac{\partial T}{\partial \tau}$$

$$-4.167 \times 10^5 \times 4 + \frac{10^8}{30} = \frac{1}{\left(\frac{30}{1100 \times 800} \right)} \cdot \frac{\partial T}{\partial \tau}$$

$$\frac{\partial T}{\partial \tau} = 56.81^\circ\text{C/S}$$

$$\frac{\partial T}{\partial \tau} \text{ is independent of radius that's why it is}$$

same for both axis and surface.

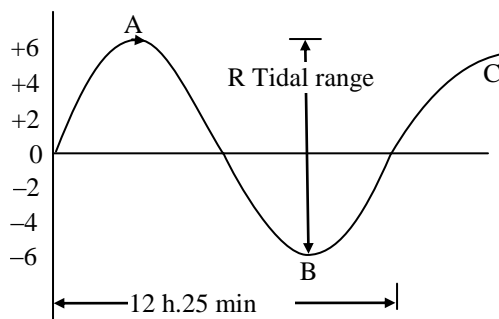
07(c).

Sol:

- The term tide refers to the rise and fall of sea level. Tides are produced by the gravitational attraction of several Celestian bodies on the water and is mainly considered due to the sun and moon. It is noted that, about 70 percent of the tide production force is due to moon and 30 percent is due to sun.



- The actual phenomenon for the formation of tide is that, water surface present on the side which is facing moon is pulled away from other end and at the same time the solid earth is pulled away from the water on opposite side. Therefore, high tides occur at these two areas and low tides occur in between them i.e., at intermediate points. When the earth rotates, the position of a given area relative to the moon changes, which in turn changes the tides. Therefore, a periodic succession of high and low tides are formed. The rise and fall of the water level follows a sinusoidal wave curve, as shown in figure.



- Two low tides and two high tides occur in one lunar day, which consists of 24 hours and 50 minutes. The effect of pull will be maximum when the earth, the moon and the sun are in one straight line. The time between high tides and low tides at any given location is approximately equal to 6 hours. The difference between consecutive high tide and low tide water level is called as the tidal range and this range varies continuously because of changing positions of the moon and sun relative to earth.

- When there is a new moon or full moon, the sun, moon and earth will be in a straight line as a result the sun and moon will enhance their gravitational pull, due to which the tidal range is exceptionally large i.e., the high tides are higher and the low tides are lower than the average. When the sun and moon are at right angles with respect to earth, then the tidal range will be exceptionally small. Therefore, the tidal range goes on varying and is never constant. But, the tides have a regular schedule which is termed as tide cycle.

Depending upon the cycles the tides are **classified** as :

1. Half Day Cycle

Half day cycle is also known as daily cycle. This cycle occurs due to the rotation of the earth within the gravitational field of the moon and repeat for every period of 12 hours 25 minutes. These tides rise and fall twice in every 24.83 hrs.

2. 14 Day cycle

The tide of this cycle occurs when each full moon and new moon day comes i.e., when the sun, moon and earth are in a straight line. Therefore, this cycle is repeated for every period of half of lunar cycle. In this cycle, the high tides occurring are higher than usual and low tides are lower than usual.

3. Half - year Cycle

This type of tides occurs due to the inclination of the moon's orbit to that of the earth and give rise to maxima in the spring tides in March and September.

- (i) **Lunar Tide:** This tide occurs due to the interaction of the moon and the



earth, due to which the oceans bulges towards the moon, whereas on the opposite side, the gravitational effect is partly shielded by the earth, resulting in a slightly smaller interaction on the oceans and that side bulges out away from the moon, due to centrifugal forces.

- (ii) **Solar Tide:** These tides occur due to the gravitational interaction of the sun which leads to the same effect of bulging towards and away from the sun on facing and opposing sides of the earth.
- (iii) **Spring Tide:** Spring tide is similar to that of a half year cycle tide.
- (iv) **Diurnal Tide:** It refers to the tide, in which one high and one low tide occurs on each lunar day.
- (v) **Neap Tide:** This tide occurs when the sun and moon are at right angle with respect to the earth. This tide has a minimum tidal range of its lunar cycle.

08(a).

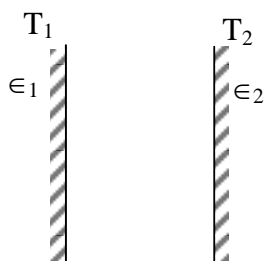
Sol: Given:

$$\begin{aligned} T_1 &= 1000\text{K}, & T_2 &= 750\text{K}, \\ \epsilon_1 &= 0.5, & \epsilon_2 &= 0.8 \\ \epsilon_{3,1} &= 0.12, & \epsilon_{3,2} &= 0.08 \end{aligned}$$

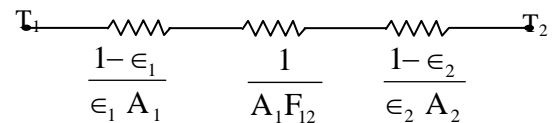
Case (i):

Heat transfer without radiation shield

$$F_{12} = 1, \quad F_{21} = 1, \quad A_1 = A_2 = A$$



Thermal circuit :

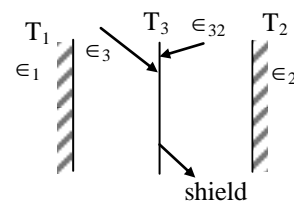


Net heat transfer :

$$\begin{aligned} Q &= \frac{\sigma(T_1^4 - T_2^4)}{\sum R_{th}} \\ &= \frac{5.67 \times 10^{-8} (1000^4 - 750^4)}{\frac{1-\epsilon_1}{\epsilon_1 A_1} + \frac{1}{A_1 F_{12}} + \frac{1-\epsilon_2}{\epsilon_2 A_2}} \\ &= \frac{5.67 \times 10^{-8} (1000^4 - 750^4)}{\frac{1}{\epsilon_1 A} - \frac{1}{A} + \frac{1}{A} + \frac{1}{\epsilon_2 A} - \frac{1}{A}} \\ &= \frac{5.67 \times 10^{-8} (1000^4 - 750^4)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} \\ &= \frac{5.67 \times 10^{-8} (1000^4 - 750^4) \times 1}{\frac{1}{0.5} + \frac{1}{0.8} - 1} \end{aligned}$$

$$Q = 17226.56 \text{ W/m}^2$$

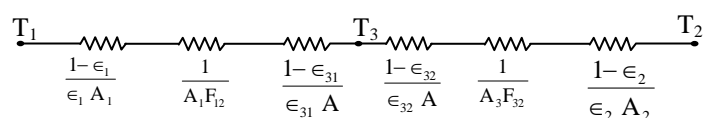
Heat transfer with radiation shield:



$$A_1 = A_2 = A_3 = A$$

$$F_{13} = 1, \quad F_{32} = 1$$

Thermal circuit:





$$\begin{aligned}\sum R_{th} &= \frac{1-\epsilon}{\epsilon_1 A} + \frac{1}{A} + \frac{1}{\epsilon_{31} A} - \frac{1}{A} + \frac{1}{\epsilon_{32} A} - \frac{1}{A} + \frac{1}{A} + \frac{1}{\epsilon_2 A} - \frac{1}{A} \\ &= \frac{1}{\epsilon_1 A} - \frac{1}{A} + \frac{1}{\epsilon_{31} A} + \frac{1}{\epsilon_{32} A} + \frac{1}{\epsilon_2 A} - \frac{1}{A}\end{aligned}$$

Net heat transfer

$$\begin{aligned}Q &= \frac{\sigma(T_1^4 - T_2^4)}{\sum R_{th}} \\ &= \frac{5.67 \times 10^{-8} (1000^4 - 750^4)}{\frac{1}{\epsilon_1 A} - \frac{1}{A} + \frac{1}{\epsilon_{31} A} + \frac{1}{\epsilon_{32} A} + \frac{1}{\epsilon_2 A} - \frac{1}{A}} \\ &= \frac{5.67 \times 10^{-8} (1000^4 - 750^4) \times A}{\frac{1}{0.5} - 2 + \frac{1}{0.12} + \frac{1}{0.08} + \frac{1}{0.8}} \\ &= 1755.16 \text{ W/m}^2\end{aligned}$$

08(b).

Sol: The performance of a flat plate collector is illustrated with the help of an energy balance, which represents the distribution of solar energy that is incident on the plate, into actual energy gain and incurred heat losses.

Under steady state,

Actual energy gain = Energy absorbed by plate – Heat losses to the surroundings.

- (i) The actual heat output of a flat – plate collector is,

$$Q = A [IF(\tau\alpha) - FU(T_i - T_\infty)] \text{ Watts}$$

Where,

A = Surface area of the collector in m²

I = Intensity of solar radiation in W/m²

F = Heat removal factor

τ = Transmissivity

α = Absorptivity of the plate

U = Overall heat transfer coefficient in W/m²°C

T_i = Fluid inlet temperature in °C

T_∞ = Ambient temperature in °C

- (ii) The efficiency of a flat plate collector is the ratio of actual heat gain and the energy incident on the plate. It is denoted by 'η'. The efficiency is given by

$$\eta_c = \frac{Q}{A.I} = \frac{FI(\tau\alpha) - FU(T_i - T_\infty)}{I}$$

$$\eta_c = F(\tau\alpha) - FU \left(\frac{T_i - T_\infty}{I} \right) \text{ -----(1)}$$

The above equation (1) shows that the curve plotted between efficiency and $\left(\frac{T_i - T_\infty}{I} \right)$,

will be a straight line.

- (iii) The effective optical efficiency is obtained by the following conditions:

$$\text{i.e.} \left(\frac{T_i - T_\infty}{I} \right) = 0 \text{ and } T_i = T_\infty$$

Substituting in the equation (1),

$$\eta_c = F(\tau\alpha) - FU(0)$$

∴ Effective optical efficiency,

$$\therefore \eta_c = F(\tau\alpha)$$

- (iv) Exit temperature of the fluid is given by,

$$T_o = T_i + \frac{Q}{\dot{m}C_p}$$

where,

\dot{m} – Mass flow rate of the fluid in kg / sec

C_p – Specific heat of fluid in J/kgK

- (v) Stagnant temperature is obtained, when there is no fluid flow in the collector and is given by,

$$T_s = T_\infty + \frac{IF(\tau\alpha)}{(FU)}$$



Thus, value of T_3 is directly proportional to I and $(\tau\alpha)$ and inversely proportional to (FU) .

08(c).

Sol: Initial volume, $V_1 = 2.25 \text{ m}^3$

Initial specific volume of the steam

$$= \frac{2.25}{3} = 0.75 \text{ m}^3/\text{kg}$$

At 1.4 bar = 140 kPa,

$$v_g = 1.24564 \text{ m}^3/\text{kg}$$

So, $v < v_g$.

\therefore The steam is initially wet and its dryness fraction is x_1

At 140 kPa, $v_f = ?$,

$$v_f = 1.045 \times 10^{-3} \text{ m}^3/\text{kg}$$

$$v = v_f + x (v_g - v_f)$$

$$0.75 = 1.045 \times 10^{-3} + x (1.24564 - 1.045 \times 10^{-3})$$

$$\Rightarrow x = 0.6017$$

$$h_1 = h_{f1} + x_1 h_{fg1}$$

At 140 kPa, $h_f = 458.022 \text{ kJ/kg}$,

$$h_{fg} = 2231.84 \text{ kJ/kg}$$

$$h_1 = h_{f1} + x_1 h_{fg1}$$

$$= 458.022 + 0.6017 \times 2231.84$$

$$= 1800.92 \text{ kJ/kg}$$

$$u_1 = h_1 - P_1 v_1 = 1800.92 - 140 \times 0.75$$

$$= 1695.92 \text{ kJ/kg}$$

Finally the steam is 400°C and volume

$$= 4.65 \text{ m}^3$$

$$\text{Specific volume} = \frac{4.65}{3} = 1.55 \text{ m}^3/\text{kg}$$

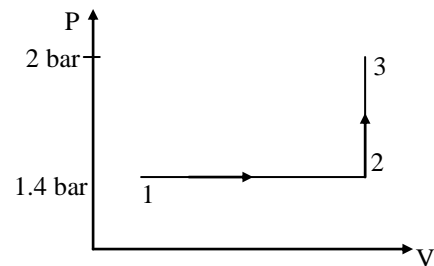
At 400°C , $v_g = 1.55 \text{ m}^3/\text{kg}$, the pressure of steam is 200 kPa

h_3 = specific enthalpy at 200 kPa & 400°C
temperature = 3277 kJ/kg

$$u_3 = h_3 - P_3 v_2 = 3277 - 200 \times 1.55$$

$$= 2967 \text{ kJ/kg}$$

The whole process can be shown on P-V diagram as shown below



$$W_{1-2} = 1.4 \times 100 \times (V_2 - V_1)$$

$$W_{1-2} = 1.4 \times (4.65 - 2.25) = 336 \text{ kJ}$$

$$W_{2-3} = 0$$

$$\Delta u (\text{for whole process i.e. } 1-3) = m(u_3 - u_1)$$

$$= 3 (2967 - 1695.92)$$

$$= 3813.24 \text{ kJ}$$

From 1st law of thermodynamics for process 1-3

$$Q - W = \Delta U$$

$$Q = W + \Delta U = 336 + 3813.24 = 4149.24 \text{ kJ}$$