III year ME 8693 - Heat & Mass Transfer Page 1

Unit - I Conduction (PART B & C)

1. Aluminium fins of rectangular profile are attached on a plane wall with 5 mm spacing. The fins have thickness t = 1 mm & length = 10 mm and the thermal conductivity K = 200 W/mK. The wall is maintained at a temperature of 200°C and the fins dissipate heat by convection in to the ambient air at 40°C with heat transfer co-eff h = 50 W/m²K. Determine the heat loss. - 2017 [A/M - 2018] - 2014

Given

fin

$t = y = 1\,mm = 0.001\,m$

$l = 10\,mm = 0.01\,m$

fin spacing $= 5\,mm$

$K = 200\,W/mK$

$T_b = 200°C$

$T_\infty = 40°C$

To find

Heat loss

Soln

Tip is insulated. This is short fin end insulated

Heat transfered HMT DB 50

$Q = (hPKA)^{0.5}(T_b - T_\infty)\tanh(mL)$

$= (50 \times 1 \times 2 \times 200 \times 1 \times 0.001)$

$(200-40)\tanh(m \times 0.001)$

$= 4.472 \times 160 \tanh(m \times 0.01)$

$m = \sqrt{\frac{hP}{KA}}$

P → 2 × length of plane wall

$= 2 \times 1\,m$

Area = length of wall × thickness

$= 1 \times 0.001\,m$

$m = \sqrt{\frac{50 \times 2}{200 \times 0.001}}$

$\boxed{m = 22.36\,m^{-1}}$

$Q = 4.472 \times 160 \tanh(22.36 \times 0.01)$

$\boxed{Q = 157.38\,W/m}$

Q) Calculate the critical radius of insulation for asbestos ($K = 0.172$ W/mK) surrounding a pipe and exposed to room air at 300K with $h = 2.8$ W/m²K. Calculate the heat loss from a 475 K, 60 mm diameter pipe when covered with the critical radius of insulation & without insulation. [A/M - 2018, N/D - 2016, 2014]

Given:

$K = 0.172$ W/mK

Room $T_2 = 300K$

$h = 2.8$ W/m²K

$d = 60mm = 0.06m$

Pipe $T_1 = 475K$

To find

1. Critical radius of insulation of asbestos
2. Heat loss from the pipe

Soln

1. Critical radius $r_c = \frac{K}{h_o}$

$$r_c = \frac{0.172}{2.8}$$

$$r_c = 0.06142\, m$$

2. Q with Insulation

$$= \frac{(T_1 - T_2)}{\frac{1}{2\pi L}\left(\frac{\ln\left(\frac{r_c}{r_1}\right)}{K} + \frac{1}{h r_c}\right)}$$

$$= \frac{2\pi(475-300)}{\frac{\ln\left(\frac{0.06142}{0.03}\right)}{0.172} + \frac{1}{2.8 \times 0.06142}}$$

$$Q_{with\ Insulation} = \boxed{110.16\ W/m}$$

3. Q without Insulation

$$= \frac{hA(T_1 - T_2)}{\frac{1}{1/ha}} = \frac{2\pi L(T_1 - T_2)}{1/h a r_1}$$

$\therefore L = 1m$

$$= 2\pi r_1 h_a (T_1 - T_2)$$

$$Q_{without\ Insulation} = \boxed{92.31\ W/m}$$

3. The rate of heat generation in a slab of thickness 160 mm with thermal conductivity of 180 w/m°C is 1.2x106 W/m3. If the temperature of each of the surface of solid is 120°C. Determine i) the temp. at the mid & quarter planes ii) The heat flow rate & temperature gradient at the mid-plane.

Given data:

Thick of slab = 160 mm
= 0.16m

$q_g = 1.2\times10^6$ W/m3

$K = 180$ w/m°C

Temp of each surface

$t_1 = t_2 = t_w = 120°C$

To find

i) The temp of at the mid plane & quarter plane

ii) Heat flow rate

iii) Temperature gradient at mid plane & quarter plane

Soln

i) The temperature of at the mid plane & quarter plane

$$T_0 = T_w + \frac{q}{2K} L^2$$

at mid plane

$\therefore L = L/2$

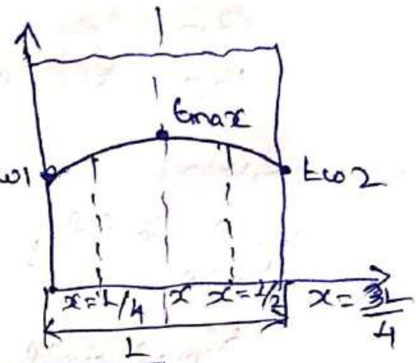
$$T_0 = 120 + \frac{1.2\times10^6}{2\times180}\left(\frac{0.16}{2}\right)^2$$

$\boxed{T_0 = 141.33°C}$

at quarter plane $L = L/4$

$$T_0 = T_w + \frac{q}{2K} L^2$$

$$= 120 + \frac{1.2\times10^6}{2\times180}\left(\frac{0.160}{4}\right)^2$$



$\boxed{T_0 = 125.33°C}$

Heat flow rate (Q): $\therefore A = 1m^2$

$q^\circ = \frac{Q}{V}$ $V = A\times L$

$Q_{L/2} = 1.2\times10^6 \times 1 \times \frac{0.16}{2}$

$= 96000$ W/m2

$Q_{L/4} = q \times V$

$= 1.2\times10^6 \times \frac{0.16}{4} \times 1$

$= 48000$ W/m2

Temperature gradient (ΔT)

$$Q = -KA\frac{(\Delta T)}{\Delta x}$$

at mid plane $L = L/2$

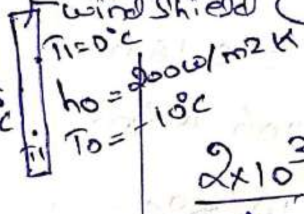
$$\left(\frac{\Delta T}{\Delta x}\right) = -\frac{Q_{L/2}}{KA} = -\frac{96000}{180\times1}$$

$= -533°C/m$

at quarter plane $L = L/4$

$$\frac{(\Delta T)}{\Delta x} = -\frac{Q_{L/4}}{KA} = \frac{48000}{180\times1} = -266.67°C/m$$

4. To defrost ice accumulated on the outer surface of a car windshield, warm air is blown over the inner surface of the wind shield. Consider windshield thickness is 5 mm and its thermal conductivity is 1.4 W/mK. The outside ambient temperature is -10°c and the convection heat transfer co-efficient is 200 W/m²K while the ambient temp. inside the car is 25°c. Determine the value of the convection heat transfer co.eff. for the warm air blowing over the inner surface of the windshield necessary to cause the accumulated ice to being melting. [A/M-19]



Given

wind Shield thick $= L = 5mm = 0.005m$

$K_{windshield} = 1.4\ W/mK$

outside air $T_o = -10°C$

Inside air $T_i = 25°c$

$h_o = 200\ W/m^2K$

Let the temperature of the wind shield at the outer surface be 0°c (or) 273 K, as the defrost ice starts melting.

$T_1 = 0°c = 273K$

To find :

$h_i = ?$

Soln:

$$Q = \frac{\Delta T}{R}$$

$$Q = \frac{T_i - T_o}{\frac{1}{A}\left[\frac{1}{h_i} + \frac{L_1}{K_1} + \frac{1}{h_o}\right]}$$

$$Q = h_o A (T_1 - T_o) = h_i A (T_i - T_1)$$

$$\frac{Q}{A} = 200 \times (0 + 10°c) \qquad \therefore A = 1m^2$$

$$\boxed{Q = 2 \times 10^3\ W/m^2}$$

$$\frac{2\times10^3}{A} = \frac{T_i - T_o}{\left[\frac{1}{h_i} + \frac{0.005}{1.4} + \frac{1}{200}\right]}$$

$$\frac{2\times10^3}{1} = \frac{(25+10)}{\left[\frac{1}{h_i} + \frac{0.005}{1.4} + \frac{1}{200}\right]}$$

$$h_i = 111.98\ W/m^2K$$

Result

$h_i = 111.98\ W/m^2K$

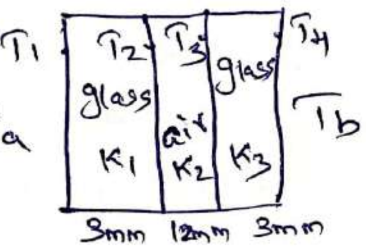
5. Consider a 1.2m high & 2m wide double Panel window Consisting of two 3mm thick layers of glass ($K=0.78$ W/mK) Seperated by a 12mm wide stagnant air space ($K=0.026$ W/mK). Determine the steady rate of heat transfered through this double - Panel window & the temperature of its inner surface when the room is maintained at 24°C while the the temp. of the outdoors is -5°C. Take the Convection heat transfer Co-eff. on the inner & outer surface of the window to be 10 W/m2K & 25 W/m2K respectively.

NOV/DEC-15
M/J = 17, 14

Given data:

$K_1 = K_3 = 0.78$ W/mK

$K_2 = 0.026$ W/mK



$h = 1.2m$

$W = 2m$

$A = 1.2 \times 2 \Rightarrow 2.4 m^2$

$T_a = 24°C \quad T_b = -5°C$

$L_1 = L_3 = 3mm = 0.003m$

$L_2 = 12mm = 0.012m$

$h_a = 10 \ W/m^2K$; $h_b = 25 \ W/m^2K$

To find

Q, T_1

Soln

$$Q = \frac{\Delta T}{R} \qquad \Delta T = T_a - T_b$$

$$R_{th} = \frac{1}{h_a A} + \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{1}{h_b A}$$

$$Q = \frac{24-(-5)}{\frac{1}{10 \times 2.4} + \frac{0.003}{0.78 \times 2.4} + \frac{0.012}{0.026 \times 2.4} + \frac{0.003}{0.78 \times 2.4} + \frac{1}{25 \times 2.4}}$$

$$\boxed{Q = 114.24 \ W}$$

To find 'T_1'

$$Q = \frac{T_a - T_1}{\frac{1}{h_a A}}$$

$$114.24 = \frac{24 - T_1}{\frac{1}{10 \times 2.4}}$$

$$\boxed{T_1 = 19.24°C}$$

Result:

$Q = 114.24 \ W$

$T_1 = 19.24°C$

60

ME 8693 - HEAT & MASS TRANSFER

III-year mech. (1)

UNIT-II - CONVECTION

[PART B & C]

1. Air at atmospheric pressure & 200°c flows over a plate with a velocity of 5 m/s. The plate is 15 mm wide & is maintained at temperature of 120°c. Calculate the thickness of hydrodynamic and thermal boundary layer & the local heat transfer coeff at a distance of 0.5m from the leading edge. Assume that flow is on one side of the plate. Take $\rho = 0.815\ kg/m^3$

$\mu = 24.5\times10^{-6}\ NS/m^2$, $Pr = 0.7$, $K = 0.0364\ W/mK$.

[N/D-18, 17]
N/D-19

Given data:

$T_w = 120°c$; $T_\alpha = 200°C$

$L = 0.5m$, $W = 15mm = 0.015M$

$U = 5\ m/s$; $K = 0.0364\ W/mK$

$\mu = 24.5\times10^{-6}\ NS/m^2$

$\rho = 0.815\ kg/m^3$; $Pr = 0.7$

$$\nu = \frac{\mu}{\rho} = \frac{24.5\times10^{-6}}{0.815} = 3\times10^{-5}\ m^2/s$$

To find

$\delta_{hx}, \delta_{Tx}, h_x, h$

Soln

$$Re_x = \frac{Ux}{\nu} \quad \boxed{x = L}$$

$$= \frac{5\times0.5}{3\times10^{-5}}$$

$$\boxed{Re_x = 83333.34}$$

$Re_x < 5\times10^5$ ∴ laminar flow

$$T_f = \frac{T_w + T_\alpha}{2}$$

$$= \frac{120+200}{2}$$

$$T_f = 160°C$$

1. Hydrodynamic boundary layer thickness

$$\delta_{hx} = 5\times x\times(Re)^{-0.5}$$

$$= 5\times0.5\times(83333.34)^{-0.5}$$

$$\boxed{\delta_{hx} = 8.66\times10^{-3}m}$$

2. Thermal boundary layer thickness

$$\delta_{th} = \delta_{hx}\,(Pr)^{-0.333}$$

$$= 8.66\times10^{-3}\times(0.7)^{-0.333}$$

$$\boxed{\delta_{th} = 9.75\times10^{-3}m}$$

3. Local heat transfer Co-eff.

$Nu_x = 0.332\ Re_x^{0.5}\times Pr^{0.333}$ for flat plate laminar flow

local Nusselt No.

$$Nu_x = 0.332\times(8.333\times10^4)^{0.5}\times(0.7)^{0.333}$$

$Nu_x = 85.1$ $\quad \boxed{\therefore Nu_x = \frac{h_x L}{K}}$

$$h_x = \frac{Nu_x K}{L}$$

$\boxed{h_x = 6.195\ W/m^2K}$ local 'h_x'

$h = 2\times h_x$ [laminar flow]

$\boxed{h = 12.39\ W/m^2K}$ Avg 'h'

2. Consider a hot automotive engine, which can be approximated as a 0.5 m high, 0.40 m-wide, and 0.8-m long rectangular block. The bottom surface of the block is at a temp of 100°c and has an emissivity of 0.92. The ambient air is at 20°c, the road surface is at 25°c. Det. the rate of heat transfer from the bottom surface of the engine block by convection & Radiation as the car travels at a velocity of 80 km/h. Assume the flow to be turbulent over the entire surface because of the constant agitation of engine block.

[A/M-18, 16]

Given:

Ht. of engine $h = 0.5m$

$w = 0.4m$

Length of rect. block $\boxed{L = 0.8m}$

Surface Temp $T_w = 100°C$

$T_\infty = 20°C$

Temp of road surface

$T_{SR} = 25°C$

$U = 80 km/h = \frac{80 \times 1000}{3600}$

$U = 22.22 \ m/sec$

To find

$h = ?$ $Q_{conv} = ?$

$Q_{Rad} = ?$ $Q = ?$

Soln

$T_f = \frac{T_w + T_\infty}{2}$

$= \frac{100 + 20}{2}$

$\boxed{T_f = 60°C}$

Properties @ 60°C

$\nu = 18.97 \times 10^{-6} m^2/s$

$K = 0.02896$

$Pr = 0.0696$

$Re = \frac{UL}{\nu} \Rightarrow \frac{22.22 \times 0.8}{18.97 \times 10^{-6}}$

$Re = 9.370 \times 10^5 > 5 \times 10^5$

∴ fully turbulant flow given in Problem

For Flat Plate

[Fully turbulent from leading edge]

Pg. No 114 HMT DB

$Nux = 0.0296 \ [9.3 \times 10^5]^{0.8} (0.696)^{0.33}$

$\boxed{Nux = \cancel{1645.4} \ 1573.51}$

$Nux = \frac{h_x L}{K} \Rightarrow \frac{h_x \times 0.8}{0.02896}$

$h_x = \frac{Nu K}{L} \Rightarrow \frac{1573.51 \times 0.0289}{0.8}$

$\boxed{h_x = 56.96 \ W/m^2 K}$

$h = 1.25 \ h_x$ [turbulent]

$= 1.25 \times 56.96$

$\boxed{h = 71.2 \ W/m^2 K}$

$Q_{conv} = h A (T_w - T_\infty)$ $L = 0.8$, $w = 0.4 m$

$= 71.2 \times (L \times w)(T_w - T_\infty)$

$= 71.2 \times (0.8 \times 0.4)(100 - 20)$

$\boxed{Q_{conv} = 1822.72 \ W}$

$Q_{rad} = \varepsilon A \sigma (T_w^4 - T_{SR}^4)$

∴ $\varepsilon = 1$ [road surface is black body]

$A = 0.8 \times 0.4$

$\sigma = 5.67 \times 10^{-8} \ W/m^2K^4$

$= 1 \times (0.8 \times 0.4) \times 5.67 \times 10^{-8} [100^4 - 25^4]$

$\boxed{Q_{rad} = 197.91 \ W}$

$Q_{tot} = Q_R + Q_{conv} \Rightarrow 2020.62 \ W$

3. A 6m long section of an 8cm diameter horizontal hot water pipe passes through a large room whose temperature is 20°C. If the outer surface temp. & emissivity of the pipe are 70°C & 0.8 respectively determine the rate of heat loss from the pipe by i) Natural Convection ii) Radiation. [N/D-2016, 2017]

Given data:

Cyl & Internal flow (horizontal hot water pipe)

$L_p = 6m$

$D_{HWP} = 8cm = 0.08m$

$\epsilon = 0.8$; $T_w = 70°C$; $T_\alpha = 20°C$

To find

Rate of heat loss from the pipe

i) Q_{conv}, ii) Q_{rad}

Soln:

$T_f = \frac{T_w + T_\alpha}{2} = 45°C$

Properties of air at 45°C

$\rho = 1.11\ kg/m^3$; $\nu = 1.744 \times 10^{-5} m^2/s$

$Pr = 0.6985$; $K = 0.02791\ W/mK$

$\beta = \frac{1}{T_f \text{ in } K} = \frac{1}{45+273} \Rightarrow \boxed{3.144 \times 10^{-3} K^{-1}}$

Grashof's No.

$$Gr_D = \frac{g \beta D^3 \Delta T}{\nu^2}$$

$$= \frac{9.81 \times (3.144 \times 10^{-3}) \times (0.08)^3 \times (70-20)}{(1.744 \times 10^{-5})^2}$$

$$\boxed{Gr_D = 0.258 \times 10^7}$$

$$\boxed{Gr_D \cdot Pr = 1.868 \times 10^6}$$

for horizontal cylinder (Internal flow) Free Convection

$$Nu_D = \left[0.60 + 0.387 \left[\frac{Gr_D \cdot Pr}{\left[1 + \left(\frac{0.559}{Pr}\right)^{0.5625}\right]^{0.296}}\right]^{0.167}\right]^2$$

$10^{-5} < Gr_D \cdot Pr < 10^{12}$

$$Nu_D = \left[0.60 + 0.387 \left[\frac{1.868 \times 10^6}{\left[1 + \left[\frac{0.559}{0.6985}\right]^{0.5625}\right]^{0.296}}\right]^{0.167}\right]^2$$

$$\boxed{Nu_D = 22.89}$$

we know

$Nu = \frac{hD}{K}$ $\quad h = \frac{K\, Nu_D}{D}$

$$\boxed{h = 7.985\ W/m^2K}$$

$$Q_{conv} = h A_s (T_s - T_\alpha)$$

$$= 7.985 \times \pi D L \times (70-20)$$

$$= 7.985 \times \pi \times 0.08 \times 6 \times (50)$$

$$\boxed{= 602.06\ W}$$

T_s & T_α Sub in K

$$Q_{rad} = \epsilon A_s \sigma (T_s^4 - T_\alpha^4)$$

$$= 0.8 \times 1.508 \times 5.67 \times 10^{-8} (343^4 - 293^4)$$

$$Q_{rad} = 442.65\ W$$

(4)

4) A thin 80cm long & 8cm wide horizontal Plate is maintained at a temp of 130°c in large tank full of water at 70°c. Estimate the rate of input in to the Plate necessary to maintain the Temperature of 130°c

Given:

$L = 80cm = 0.8m$

$w = 8cm = 0.08m$

$T_w = 130°C$

$T_\alpha = 70°C$

To find

$Q = ?$

Soln

$T_f = \frac{T_w + T_\alpha}{2}$

$= \frac{130+70}{2}$

$T_f = 100°c$

Properties of water @ 100°C from HMT DB

$\rho = 961 \ kg/m^3$

$\nu = 0.293 \times 10^{-6} m^2/s$

$P_r = 1.740$; $K = 0.6804$

$\beta_{water} = 0.76 \times 10^{-3} K^{-1}$

[from 38 HMT DB] get β_{water}

$G_r = \frac{g \cdot \beta L_c^3 \times \Delta T}{\nu^2}$

$L_c = \frac{W}{2} = \frac{0.08}{2} = 0.04m$

$= \frac{9.81 \times 0.76 \times 10^{-3} (0.04)^3 \times (130-70)}{(0.293 \times 10^{-6})^2}$

$\boxed{G_r = 0.333 \times 10^9}$

$\boxed{G_r P_r = 0.580 \times 10^9}$

Pg No. 144

for horizontal Plate, upper Surface heated

$8 \times 10^6 < G_r P_r < 10^{11}$

$Nu = 0.15 (G_r P_r)^{0.333}$

$= 0.15 (0.580 \times 10^9)^{0.333}$

$\boxed{Nu = 124.25}$

$Nu = \frac{h_u L_c}{K_c}$ $\boxed{h_u = 2113.49 \ W/m^2K}$

For horizontal Plate, lower Surface heated

Pg. No. 145

$Nu = 0.27 (G_r P_r)^{0.25}$

$10^5 < G_r P_r < 10^{11}$

$= 0.27 [0.580 \times 10^9]^{0.25}$

$\boxed{Nu = 42.06}$

$Nu = \frac{h_l L_c}{K}$

$42.06 = \frac{h_l \times 0.04}{0.6804}$

$\boxed{h_l = 715.44 \ W/m^2K}$

$Q = (h_u + h_l) A \Delta T$

$A = W \times L$

$\Delta T = T_w - T_\alpha$

$= (2113.49 + 715.44) \times (0.08 \times 0.8) \times (130-70)$

$\boxed{Q = 10.86 \times 10^3 W}$

5. Engine oil flows through a 50 mm diameter tube at an average temp. of 147°C. The flow velocity is 80 cm/s. Calculate the average heat transfer co-eff. if the tube wall is maintained at a temp. of 200°C & it is 2m long. [A/m-17]

Given

$D = 50mm = 0.05m$

$T_m = 147°C$

$u = 80cm/s = 0.8m/s$

$T_w = 200°C$; $L = 2m$

To find

$h = ?$

Soln

$T_m = \frac{T_{mi} + T_{mo}}{2} = 147°C$

Properties of Engine oil @ 147°C

$\rho = 810 \ kg/m^3$ $\quad \nu = 7\times10^{-6} m^2/s$

$Pr = 102$ $\quad K = 0.1323 \ W/mK$

$Re = \frac{uD}{\nu} = \frac{0.8\times0.05}{7\times10^{-6}}$

$Re = 5714.28$

$Re > 2300$ ∴ flow is turbulent

$L/D = 2/0.05 = 40$

Pg.No 134

$10 < L/D < 400$

$Nu = 0.036 \ Re_D^{0.8} Pr^{0.33} \times (D/L)^{0.055}$

$= 0.036 \times (5714.28)^{0.8} \times (102)^{0.33} \times \left(\frac{0.05}{2}\right)^{0.055}$

$\boxed{Nu = 136.96}$

$Nu = \frac{hD}{K}$

$h = \frac{Nu K}{D}$

$= \frac{136.96\times0.1323}{0.05}$

$\boxed{h = 362.4 \ W/m^2K}$

6. Air at 25°C flows over 1m×3m (3m long) horizontal Plate maintained at 200°C at 10m/s. Calculate the avg. heat transfer Co-eff. for both laminar & turbulent region Take Re (critical) = 3.5×10^5

Given

$T_\infty = 25°C$ $L = 3m$

$T_w = 200°C$ $U = 10m/s$

$Re_{critical} = 3.5 \times 10^5$

To find

$h_{laminar} = ?$

$h_{turbulent} = ?$

Soln

$T_f = \frac{T_w + T_\infty}{2} = 112.5°C$

Properties @ 112.5°C

$\rho = 0.092 \, kg/m^3$

$\nu = 24.29 \times 10^{-6}$ $Pr = 0.687$

$K = 0.03274 \, W/mK$

$$Re_L = \frac{UL}{\nu} = \boxed{1.23 \times 10^6}$$

$Re_{critical} = 3.5 \times 10^5$ ∴ flow is laminar up to $Re_{critical}$. after that is turbulant.

Case (i) laminar flow

$$Nu_x = 0.332 (Re_{critical})^{0.5} (Pr)^{0.333}$$

$$Nu_x = 173.33$$

$$Nu_x = \frac{h_x L}{K}$$

$$h_x = 1.89 \, W/m^2K$$

$$h = 2 \times h_x \text{ (laminar)}$$

$$\boxed{h = 3.78 \, W/m^2K}$$

Case ii) turbulent

$$Nu_x = 0.0296 (Re_L)^{0.8} (Pr)^{0.33}$$

$$Re_L = 1.23 \times 10^6$$

$$\boxed{Nu_x = 1945}$$

$$Nu_x = \frac{h_x L}{K}$$

$$h_x = 21.22 \, W/m^2K$$

$$h = 1.25 \, h_x \text{ (turbulent)}$$

$$\boxed{h = 26.525 \, W/m^2K}$$

Result:

$h_{laminar} = 3.78 \, W/m^2K$

$h_{turbulent} = 26.525 \, W/m^2K$

Unit - 3

PHASE CHANGE HEAT TRANSFER & HEAT EXCHANGER

1. A Counter flow heat exchanger is to heat air entering at 400°C with a flow rate of 6kg/s by the exhaust gas entering at 800°C with a flow rate of 4kg/s. The overall heat transfer Coefficient is 100 W/m²K and the outlet temperature of air in 551.5°C. SP. heat of air CP for both air exhaust gas can be taken as 1100 J/kg K. Calculate i) Heat transfer area needed, ii) Number of transfer units (NOV-DEC-2018)

Given:-

Counter flow heat exchanger

$t_1 = 400°C \quad T_1 = 800°C$

$m_{as} = 6kg/s \quad m_{eg} = 4kg/s$

$t_2 = 551.5°C \quad C_{Pa} \& C_{Peg} = 1100 J/kgK$

To find

1) $A = ?$ 2) $NTU = ?$

Soln

Capacity of air $= m_c \times C_{pc} = 6 \times 1100 = 6600$

Capacity of Exhaust gas $= m_h \times C_{Ph} = 4400$

$C_{min} = C_h = 4400$

W.K.T

Heat transfered to Cold air = Heat transfered from hot gases

$m_c C_{Pc} (t_2 - t_1) = m_h C_{Ph} (T_1 - T_2)$

$6600 (551.5 - 400) = 4400 (800 - T_2)$

$$\boxed{T_2 = 572.75}$$

$Q = m_c \cdot C_{Pc} (t_2 - t_1)$

$Q = 999900 \text{ W}$

Heat transfer area needed

$Q = UA \, \Delta T_m$

ΔT_m for Counter flow $= \dfrac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left(\dfrac{T_1 - t_2}{T_2 - t_1}\right)}$

$= \dfrac{(800 - 551.5) - (572.74 - 400)}{\ln\left(\dfrac{800 - 551.5}{572.74 - 400}\right)}$

$$\boxed{(\Delta T)_m = 207.21°C}$$

$\therefore Q = UA (\Delta T)_m$

$A = \dfrac{Q}{U (\Delta T)_m}$

$= \dfrac{999900}{100 \times 207.21}$

$$\boxed{A = 48 m^2}$$

ii) NTU

$NTU = \dfrac{UA}{C_{min}} = \dfrac{100 \times 48}{4400}$

$$\boxed{NTU = 1.09}$$

RESULT:-

$A = 48 m^2$

$NTU = 1.09$

2. A Cross flow heat exchanger with both fluids unmixed is used to heat water flowing at a rate of 20 kg/s from 25°C to 75°C using gases available at 300°C to be cooled to 180°C. The overall heat-transfer Co-eff has a value of 95 (W/m2 K). Determine the area required. Assume for gas Cp = 1005 J/kg K. Also find the gas flow rate.

[A/M-2019. N/D-2017, 15]

Given:

Cold fluid-water	Hot fluid-gas
$\dot{m}_c = 20$ kg/s	$T_{h1} = 300°C$
$t_{c1} = 25°C$	$T_{h2} = 180°C$
$t_{c2} = 75°C$	$C_{P_h} = 1005$ J/kg K
$U = 95$ W/m2K	

To find:

i) $A = ?$ ii) $\dot{m}_h = ?$

Soln

for heat exchanger with fluids unmixed. water: $C_{PC} = 4180$ J/kg K

$$Q_c = m_c\, C_{PC}\,(t_{c2} - t_{c1})$$

$$= 20 \times 4180\,(75 - 25)$$

$$\boxed{Q_c = 418 \times 10^4 \text{ W}}$$

$$Q = U A (\Delta T)_m \times F$$

To find (ΔT)

Counter flow $(\Delta T)_m$ = Cross flow $(\Delta T)_m$ [Counter flow $(\Delta T)_m$ is used for cross flow]

$$(\Delta T)_m = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left[\frac{T_1 - t_2}{T_2 - t_1}\right]}$$

$$= \frac{(300-75) - (180-25)}{\ln\left[\frac{300-75}{180-25}\right]}$$

$$\boxed{(\Delta T)_m = 193.45}$$

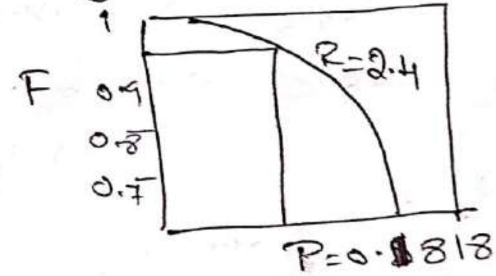
To find Correction Factor

∴ fluid unmixed heat exchanger

$$P = \frac{t_2 - t_1}{T_1 - t_1} \qquad R = \frac{T_1 - T_2}{t_2 - t_1}$$

$$P = 0.1818 \qquad R = 2.4$$

from graph



$$\boxed{F = 0.976}$$

$$Q = F U A (\Delta T)_m$$

$$A = \frac{Q}{F \times U \times (\Delta T)_m}$$

$$A = \frac{418 \times 10^4}{0.976 \times 95 \times (193.45)}$$

$$\boxed{A = 240.13 \text{ m}^2}$$

ii) Gas flow rate $(\dot{m}_h)$

$$Q_g = Q_c$$

$$m_h\, C_{Ph}\,(T_1 - T_2) = 418 \times 10^4$$

$$\dot{m}_h = \frac{418 \times 10^4}{1005 \times (300 - 180)}$$

$$\boxed{\dot{m}_h = 34.66 \text{ kg/s}}$$

3. The flow rate of hot & cold water streams running through a Parallel flow heat exchanger are 0.2 kg/s and 0.5 kg/s respectively. the inlet temp. on the hot and cold sides are 75°C & 20°C respectively, The exit temperature of hot water is 45°C. If the individual heat transfer coefficients on both the sides are 650 W/m²°C. Calculate the area of heat exchanger. [N/D-17, 16]

Given:

$T_{h1} = 75°C$ $t_{c1} = 20°C$

$T_{h2} = 45°C$ $m_c = 0.5\ kg/s$

$m_h = 0.2\ kg/s$ $h_i = h_o = 650\ W/m^2°C$

$C_{ph} = C_{pc} = 4180\ J/kgK$

To find:

$A = ?$

Soln:

$$m_h C_{ph}(T_{h1} - T_{h2}) = m_c C_{pc}(t_{c2} - t_{c1})$$

$$0.2 \times 4180\,(348 - 318) = 0.5 \times 4180\,(t_{c2} - 293)$$

$$\boxed{t_{c2} = 32°C}$$

Parallel flow LMTD

$$\Delta T_m = \frac{(T_{h1} - t_{c1}) - (T_{h2} - t_{c2})}{\ln\left[\frac{T_{h1} - t_{c1}}{T_{h2} - t_{c2}}\right]}$$

$$= \frac{(75 - 20) - (45 - 32)}{\ln\left[\frac{75 - 20}{45 - 32}\right]}$$

$$\boxed{(\Delta T)_m = 29.16\ °C}$$

overall heat transfer Co-eff

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

$$\boxed{U = 325\ W/m^2°C}$$

$$Q = m_h C_{ph}(T_{h1} - T_{h2})$$

$$= 0.2 \times 4180\,(75 - 45)$$

$$\boxed{Q = 25.08 \times 10^3\ W}$$

$$Q = UA(\Delta T)_m$$

$$A = \frac{Q}{U(\Delta T)_m}$$

$$A = \frac{25.08 \times 10^3}{325 \times 29.16}$$

$$\boxed{A = 2.64\ m^2}$$

4. A Counter flow double pipe heat exchanger is to heat water from 20°C to 80°C at a rate of 1.2 kg/s. The heating is to be accomplished by geothermal water available at 160°C at a mass flow rate of 2 kg/s. The inner tube is thin walled & has a dia. of 1.5 cm. The overall heat transfer coefficient of the heat exchanger is 640 W/m²K. Using the effectiveness-NTU method. Determine the length of the heat exchanger required to achieve the desired heating [N/D-16, M-J-2075]

Given data:

$t_{c1} = 20°C$ $T_{h1} = 160°C$

$t_{c2} = 80°C$ $m_h = 2\,kg/s$

$m_c = 1.2\,kg/s$ $D = 1.5\,cm$

$U = 640\,W/m^2K$

To find

$L = ?$ $C_{pc} = C_{ph} = 4180\,J/kgK$ (water)

Soln

$C_c = m_c \times C_{pc} \Rightarrow 1.2 \times 4180$

$C_c = 5016\ W/K$

$C_h = m_h \times C_{ph} \Rightarrow 2 \times 4180$

$= 8360\ W/K$

$C_{min} = C_c = 5016\ W/K$

$$C = \frac{5016}{8360} = \frac{C_{min}}{C_{max}}$$

$$\boxed{C = 0.6}$$

$Q_{max} = C_{min}(T_1 - t_1)$

$= 5016\,(160 - 20)$

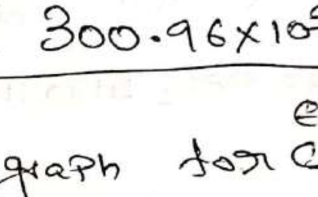
$$\boxed{Q_{max} = 702.8 \times 10^3\ W}$$

$Q_c = m_c\, C_{pc}\,(t_{c1} - t_{c2})$

$= 1.2 \times 4180\,(80 - 20)$

$$\boxed{Q_c = 300.96 \times 10^3\ W}$$

from graph for Counterflow effectiveness Pg.No 172 HMT DB



$\frac{C_{min}}{C_{max}} = 0.6$

$$\epsilon = \frac{Q}{Q_{max}} = \frac{300.96 \times 10^3}{702.8 \times 10^3}$$

$$\boxed{\epsilon = 0.428}$$

$\boxed{NTU = 0.65}$ From graph

$$NTU = \frac{UA}{C_{min}} \quad \therefore A = \frac{NTU \times C_{min}}{U}$$

$$\boxed{A = 0.005\ m^2}$$

$A = \pi D L$

$$L = \frac{A}{\pi D} = \frac{0.005}{\pi \times 0.015}$$

$$\boxed{L = 0.108\ M}$$

2. Saturated steam at 65°C condenses on horizontal cylinder of 0.2m dia at 55°C. Determine the value of convection Co-eff for i) single tube & ii) for a bank of tubes of 5 rows & 6 columns.
[A/M-18, M-J-15]

Given that:

$T_{sat} = 65°C$, $T_w = 55°C$ (or) $T_s = 55°C$

$D = 0.2m$

To find

i) $h = ?$ (single tube)

ii) $h = ?$ (Bank of tubes)

Soln

$$T_f = \frac{T_{sat} + T_w}{2}$$

$$= \frac{65+55}{2}$$

$$\boxed{T_f = 60°C}$$

The Properties of Condensate at Sat. Temp (65°C) (steam table)

$h_{fg} = 2341.63$ kJ/kg $\Rightarrow 2341.63 \times 10^3$ J/kg

$v_g = 6.22$ m3/kg

$$\rho_v = \frac{1}{v_g} = 0.1607 \text{ kg/m}^3$$

Properties of Condensate @ $T_f = 60°C$ are Pg.No 30 HMT DB

$\rho_l = 985$ kg/m3

$K = 0.6513$ W/mK

$\nu = 0.478 \times 10^{-6}$ m2/s

$\mu = \rho \times \nu = 4.7083 \times 10^{-4}$ kg/m-s

From HMT DB Pg. No 157

Horizontal tubes

Single tube $h = 0.728 \left[\dfrac{\rho_l^2 g h_{fg} K^3}{\mu D (T_{sat}-T_s)}\right]^{0.25}$

$$= 0.728 \left[\frac{(985)^2 \times 9.81 \times (2341.63 \times 10^3)(0.6513)^3}{(4.7083 \times 10^{-4})(65-55)}\right]^{0.25}$$

$$\boxed{h = 6546.49 \text{ W/m}^2\text{K}}$$

ii) for a bank of tubes of 5 Rows & 6 Columns

$N = 5$ (No. of horizontal rows)

$$h = 0.728 \left[\frac{\rho_l^2 g h_{fg} K^3}{\mu N D (T_{sat}-T_s)}\right]^{0.25}$$

$$\boxed{h = 4377.9 \text{ W/m}^2\text{K}}$$

Unit-4 - Radiation

1. Assuming the Sun to be black body emitting radiation at 6000 K at a mean distance of 12×10^{10} m from the earth. The diameter of the Sun is 1.5×10^{9} m and that of the Earth is 13.2×10^{6} m. Calculate the following
   i) Total energy emitted by the Sun, ii) The emission received per m^2 just outside the Earth's atmosphere.
   iii) The total energy received by the Earth if no radiation is blocked by the earth's atmosphere. [N/D 17, 19]

Given data:

$T = 6000 K$

Dist. b/w Earth & Sun $R = 12\times10^{10}$ m

Dia. of the Sun $D_1 = 1.5\times10^{9}$ m

Dia of the Earth $D_2 = 13.2\times10^{6}$ m

To find

i) $E_b = ?$

ii) Emission received per m^2 just outside the Earth's atm

iii) Energy received by the earth.

iv) Solar energy received by 2x2 m Solar Collector

Soln

1. Total Energy emitted:

$E_b = \sigma T^4$

$= 5.67\times10^{-8} \times (6000)^4$

$\boxed{E_b = 73.4\times10^{6}\ W/m^2}$

$A_1 = 4\pi R_1^2$

$= 4\pi\times\left(\frac{1.5\times10^{9}}{2}\right)^2$

$\boxed{A_1 = 7\times10^{18} m^2}$

$E_b = 73.4\times10^{6}\times(7\times10^{18})$

$\boxed{E_b = 5.14\times10^{26} W}$

2. Emission Received / m^2 Just outside the earth's atm.

$R = 12\times10^{10}$ m

$A_1 = 4\pi R^2$

$= 4\times\pi\times(12\times10^{10})^2$

$\boxed{A_1 = 1.80\times10^{23} m^2}$

Radiation received outside the earth atm / m^2.

$= \frac{E_b}{A} \Rightarrow \frac{5.14\times10^{26}}{1.80\times10^{23}}$

$\boxed{= 2855.5\ W/m^2}$

3. Energy received by Earth

Earth Area $= \pi/4\ (D_2)^2$

$= \pi/4\ [13.2\times10^{6}]^2$

$\boxed{= 1.36\times10^{14} m^2}$

Energy received by the earth

$= 2855.5\times(1.36\times10^{14})$

$\boxed{= 3.88\times10^{17} W}$

4) The Energy received by a 2x2 m Solar Collector

Energy loss through the atm. is 50%. So energy reaching the earth

$= 100-50 \Rightarrow 50\% \Rightarrow 0.5$

Energy received by earth

$= 0.50\times2855.5$

$\boxed{\Rightarrow 1427.7\ W/m^2}$

Diffuse radiation is 20%.

$0.20\times1427.7 \Rightarrow \boxed{285.5\ W/m^2}$

Total Radiation reaching the Collection (2)

$\Rightarrow 1427.7 + 285.5 \Rightarrow \boxed{1713.2\ W/m^2}$ Plat Area $= A \times \cos\theta$

$= (2\times 2)\times \cos 45^\circ$

$\boxed{= 2.82\ m^2}$

Energy received by the Collector

$= 2.82 \times 1713.2$

$\boxed{= 4831.2\ W}$

---

(2) Calculate the net heat radiant exchange per m² area of two large parallel plates at temp of 427°C & 27°C respectively. $\varepsilon_{(\text{hot plate})} = 0.9$ & $\varepsilon_{(\text{cold plate})} = 0.6$, if a polished aluminium shield is placed between them, find the percentage of reduction in the heat transfer, $\varepsilon_{(\text{shield})} = 0.4$

[A/M - 2014, N/D-17]

Given:

$T_1 = 427^\circ C + 273 \Rightarrow 700K$; $\varepsilon_1 = 0.9$

$T_2 = 27^\circ C + 273 \Rightarrow 300K$; $\varepsilon_2 = 0.6$

$\varepsilon_3 = 0.4$

To find radiation shield

1) Net radiant heat exchange / m² area

2) % of reduction in the heat transfer

Soln

Case (i) Heat transfer without radiation Shield

$$Q_{12} = \bar{\varepsilon}\,\sigma A\left[T_1^4 - T_2^4\right]$$

$$\bar{\varepsilon} = \frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}$$

$$\bar{\varepsilon} = \frac{1}{\frac{1}{0.9}+\frac{1}{0.6}-1}$$

$$\boxed{\bar{\varepsilon} = 0.5625}$$

$$\frac{Q_{12}}{A} = 0.5625 \times (5.67\times10^{-8}) \times \left[700^4 - 300^4\right]$$

$$\boxed{\frac{Q_{12}}{A} = 7.39\times10^{3}\ W/m^2}$$

Case (ii) Heat transfer with radiation Shield.

$$Q_{13} = \bar{\varepsilon}\,\sigma A\left[T_1^4 - T_3^4\right]$$

$$\bar{\varepsilon} = \frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_3}-1}$$

Illy

$$Q_{32} = \frac{\sigma A\,(T_3^4 - T_2^4)}{\frac{1}{\varepsilon_3}+\frac{1}{\varepsilon_2}-1}$$

$$\frac{\sigma A\,(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_3}-1} = \frac{\sigma A\,(T_3^4 - T_2^4)}{\frac{1}{\varepsilon_3}+\frac{1}{\varepsilon_2}-1}$$

$$\frac{(T_1)^4 - T_3^4}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_3}-1} = \frac{T_3^4 - T_2^4}{\frac{1}{\varepsilon_3}+\frac{1}{\varepsilon_2}-1}$$

$$\frac{700^4 - T_3^4}{\frac{1}{0.9}+\frac{1}{0.4}-1} = \frac{T_3^4 - 300^4}{\frac{1}{0.4}+\frac{1}{0.6}-1}$$

$$\boxed{T_3 = 606.55\ K}$$

$$Q_{13} = \frac{\sigma A\,(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_3}-1}$$

$$\boxed{\frac{Q_{13}}{A} = 2.27\times10^{3}\ W/m^2}$$

% of reduction in heat loss due to radiation Shield $= \dfrac{Q_{\text{without Shield}} - Q_{\text{with Shield}}}{Q_{\text{without shield}}}$

$$= \frac{Q_{12} - Q_{13}}{Q_{12}}$$

$$= \frac{7.39\times10^3 - 2.27\times10^3}{7.39\times10^3}$$

$$\boxed{= 69.2\%}$$

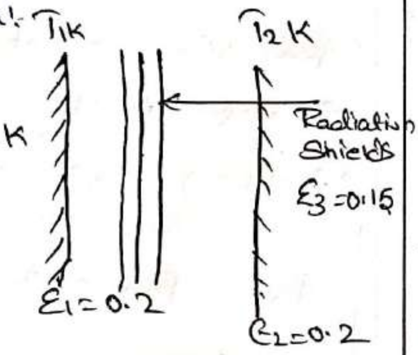
3) Two very Parallel Plates are maintained at uniform temp. of $T_1 = 1000\,K$ & $T_2 = 800\,K$ and have emissivities of $\varepsilon_1 = \varepsilon_2 = 0.2$ respectively. It is designed to reduce the net rate of radiation heat transfer b/w the two plates to one-fifth by placing thin aluminium sheets with an emissivity of 0.15 on both sides b/w the plates. Determine the number of sheets that need to be inserted [N/D-15, 17]

Given data:

$\varepsilon_1 = 0.2$; $\varepsilon_2 = 0.2$

$T_1 = 1000\,K$; $T_2 = 800\,K$

$\varepsilon_s = \varepsilon_3 = 0.15$



To find

No. of Shields Required

Soln

Heat transfer without shield i.e, $n = 0$

$$Q_{12\,(\text{no shield})} = \frac{A\,\sigma\,(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$= \frac{1 \times (5.67 \times 10^{-8})\,(1000^4 - 800^4)}{\frac{1}{0.2} + \frac{1}{0.2} - 1}$$

$$\boxed{Q_{12\,(\text{no shield})} = 3711.12\ W/m^2}$$

W.K.T

$$\tfrac{1}{5}\text{th of } Q_{12\,(\text{no shield})} = \tfrac{1}{5} \times 3711.12 \quad \boxed{= 742.2\ W/m^2}$$

Heat transfer with 'n' shield is given by

$$Q_{12\,(\text{no shield})} = \frac{A\,\sigma\,(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} + \left(\frac{2n}{\varepsilon_s}\right) - (n+1)}$$

$$742.4 = \frac{1 \times (5.67 \times 10^{-8}) \times (1000^4 - 800^4)}{\frac{1}{0.2} + \frac{1}{0.2} + \frac{2n}{0.15} - (n+1)}$$

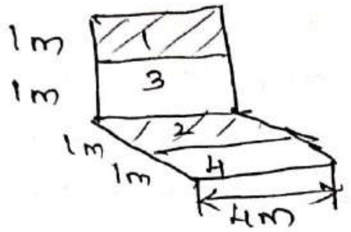
$$742.4\left[10 + \frac{2n}{0.15} - (n+1)\right] = 3.34 \times 10^4$$

$$n = \frac{4007.76}{1373.44}$$

$$\boxed{n = 2.91 \simeq 3}$$

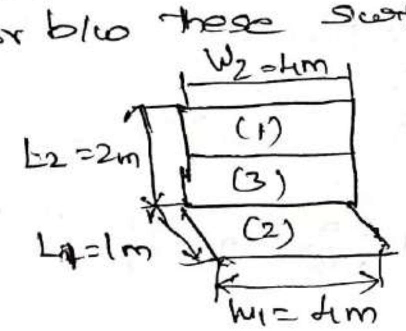
4. Determine the view factors between the rectangular surfaces shown in the fig [A/M-18, 16] N/D-17,

Given



(fig) 1

Considering the rectangular surfaces 1, 3, & 2. the shape (or) view factor b/w these surfaces is given as,



Length of surface (2) $L_1 = 1m$

Length of surface (1+3) $L_2 = 1+1 \Rightarrow 2m$

width of surface, $W_1 = W_2 = 4m$

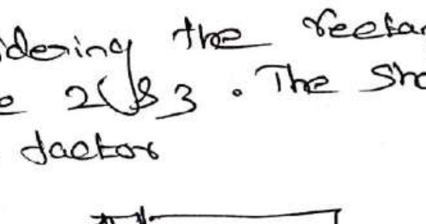
$$\frac{L_1}{W_1} = 0.25 \; ; \; \frac{L_2}{W_2} = 0.5$$

from Data book

The shape factor for corresponding value of $\frac{L_1}{W_1}$ & $\frac{L_2}{W_2}$ is taken as

$$F_{2 \to (1+3)} = 0.33422$$

Considering the rectangular surface 2 & 3. The shape (or) view factor



$L_1 = 1m$ $\quad \frac{L_1}{W_1} = 0.25$

$L_2 = 1m$ $\quad \frac{L_2}{W_2} = 0.25$

from data book

$$F_{23} = 0.26455$$

The view factor b/w two equal rectangular surfaces (1) & (2) as shown in fig. 1

$$F_{12} = F_{21} = F_{2(1+3)} - F_{23}$$

$$\boxed{F_{12} = 0.06967}$$

(5) the filament of a 75 W light bulb may be Considered a black body radiating in to a black enclosure at 70°C. The filament diameter is 0.10 m & length is 5cm. Considering the radiation, determine the filament temp. [N/D-18, M-J-16]

Given

Capacity of filament $Q = 75\ W$

Temp of black Enclosure $T_2 = 70°C = 343K$

dia $(d) = 0.1m$

$L = 0.05m$

To find

Heat exchange b/w two black enclosures

$$Q = \varepsilon A \sigma (T_1^4 - T_2^4) \qquad \varepsilon = 1 \text{ for black body}$$

$$75 = 5.67 \times 10^{-8} \times (1 \times \pi \times 0.1) \times 0.05 (T_1^4 - 343^4)$$

$$(T_1^4 - 343^4) = \frac{75}{5.67 \times 10^{-8} \times (\pi \times 0.1 \times 0.05)}$$

$$\boxed{T_1 = 2756°C}$$

Result

filament temp $= 2756°C$

Unit - 5 - MASS TRANSFER

1. Air at 20°C [$\rho = 1.205\ kg/m^3$; $\nu = 15.06 \times 10^{-6}\ m^2/s$; $D_{ab} = 4.166 \times 10^{-5}\ m^2/s$) flow over a tray [length = 320mm ; width = 420mm] full of water with a velocity of 2.8 m/s. the total Pressure of moving air is 1 atm and the Partial Pressure of water Present in the air is 0.0068 bar. if the temp. on the water surface is 15°C, Calculate the evaporation rate of water. [A/M-19] [M/J-17] [14]

Given data:

$T_a = 20°C$

$\rho = 1.205\ kg/m^3$; $\nu = 15.06 \times 10^{-6}\ m^2/s$

$D_{ab} = 4.166 \times 10^{-5}\ m^2/s$

Length of tray $(L) = 320mm = 0.32m$

width of tray $(\omega) = 420mm = 0.42m$

$U = 2.8\ m/s$

Total Pr. of moving air $(P_{atm}) = 1\ atm = 1.013\ bar$

Partial Pr. of water Pr. in the air $P_{w2} = 0.0068\ bar$

Surface temp. of water ~~at~~ $t_s = 15°C = 288K$

~~Sat. temp~~

The Partial Pressure of water at sat. temp 15°C is

$P_{w1} = 0.017\ bar$

To find:

$\dot{m}_w = ?$

Soln

$$S_c = \frac{\nu}{D_{ab}} = \frac{15.06 \times 10^{-6}}{4.166 \times 10^{-5}}$$

$$\boxed{S_c = 0.36149}$$

$$Re = \frac{UL}{\nu} = \frac{2.8 \times 0.32}{15.06 \times 10^{-6}}$$

$$Re = 5.9 \times 10^4 < 5 \times 10^5$$

for Flat Plate, laminar flow Pg. No 184

$$Sh = 0.664\ Re^{0.5}\ Sc^{0.333}$$

$$= 0.664 \times (59495.35)^{0.5} \times (0.36149)^{0.333}$$

$$\boxed{Sh = 115.37}$$

$$Sh = \frac{h_m L}{D_{ab}}$$

$$h_m = \frac{115.37 \times (4.166 \times 10^{-5})}{0.32}$$

$$\boxed{h_m = 0.0150\ m/s}$$

Amount of evaporation of water

$$\dot{m}_w = h_{mP} \times A \times (P_{w1} - P_{w2})$$

$$\therefore h_{mP} = \frac{h_m}{RT} = \frac{0.0150}{287 \times 288}$$

$$\dot{m}_w = \left[\frac{0.0150}{287 \times 288}\right] \times (0.32 \times 0.42) \times (0.017 - 0.0068)$$

$$\boxed{\dot{m}_w = 2.48 \times 10^{-5}\ kg/sec}$$

2. Hydrogen gas in maintained at 5 bar and 1 bar on opposite Sides of a Plastic membrane, which is 0.3 mm thick. the temperature is 25°c and the binary diffusion Co-efficient of hydrogen in the Plastic is $8.7 \times 10^{-8} m^2/s$ The Solubility of hydrogen in the membrane is 1.5×10^{-3} kg-mole/m^3 bar. what is the mass flux of hydrogen by diffusion through the membrane. [N/D-2018, 16]

Given:

Inside Pr. of H_2 = 5 bar

outside Pr of H_2 = 1 bar

Thick of Plane membrane = 0.3 mm = 0.3×10^{-3} m

$D_{ab} = 8.7 \times 10^{-8} m^2/s$

Solubility of $H_2 = 1.5 \times 10^{-3}$ kg-mole/m^3 bar

$T = 25°C$

To find:

Mass flux of H_2

Soln

Molar Concentration on inner side

C_{a1} = Solubility × Inner Pr

$= 1.5 \times 10^{-3} \times 5$

$= 7.5 \times 10^{-3}$ kg-mole/m^3

Molar Concentration on outer side

C_{a2} = Solubility × oute Pr.

$= 1.5 \times 10^{-3} \times 1$

$C_{a2} = 1.5 \times 10^{-3}$ kg-mole/m^3

molar flux, $\frac{m_a}{A} = \frac{D_{ab}}{L}[C_{a1} - C_{a2}]$

$$\frac{m_a}{A} = \frac{8.7 \times 10^{-8}}{0.3 \times 10^{-3}}[7.5 \times 10^{-3} - 1.5 \times 10^{-3}]$$

$$\boxed{\frac{m_a}{A} = 17.4 \times 10^{-7} \text{ kg-mole}/m^2 s}$$

Mass flux = Molar flux × Molecular weight

$= 17.4 \times 10^{-7} \times (2)$

$$\boxed{\text{Mass flux} = 34.8 \times 10^{-7} \text{ kg}/m^2 s}$$

3. A vessel contains a binary mixture of O_2 and N_2 with partial pressures in the ratio 0.21 and 0.79 at 288K. The total pressure of the mixture is 1.1 bar. find, i) Molar concentrations, ii) Mass densities iii) Mass fractions & iv) Molar fractions of each species

[A/M-19] [N-D,-17]

Given that:

Temp. of Mixture $(T) = 288\,K$

Total Pr of the Mix $(P) = 1.1$ bar

Ratio of Partial Pr. of O_2 & N_2 in the mixture is

$$\frac{P_{O_2}}{P_{N_2}} = \frac{0.21}{0.79} = 0.26$$

Partial Pr. of O_2 $(P_{O_2}) = 0.21 \times$ Total Pr

$= 0.21 \times (1.1 \times 10^5)\ N/m^2$

Partial Pr. of N_2 $(P_{N_2}) = 0.79 \times$ Total Pr

$= 0.79 \times 1.1 \times 10^5\ N/m^2$

To find

1) C_{O_2}, C_{N_2} 2) ρ_{O_2}, ρ_{N_2}

3) $\dot{m}_{O_2}, \dot{m}_{N_2}$ 4) x_{O_2}, x_{N_2}

Soln

$\therefore G = 8314\ J/kg\,mole\text{-}K$

W.K.T

$$C_{O_2} = \frac{P_{O_2}}{GT} = \frac{0.21 \times 1.1 \times 10^5}{8314 \times 293}$$

$$\boxed{C_{O_2} = 9.48 \times 10^{-3}\ kg\text{-}mole/m^3}$$

$$C_{N_2} = \frac{P_{N_2}}{GT} = \frac{0.79 \times 1.1 \times 10^5}{8314 \times 293}$$

$$\boxed{C_{N_2} = 35.67 \times 10^{-3}\ kg\text{-}mole/m^3}$$

W.K.T

Molar Concentration $\therefore C = \frac{\rho}{M}$

$$\rho = C \times M \qquad \boxed{M_{O_2} = 32}$$

$$\rho_{O_2} = C_{O_2} \times M_{O_2} \Rightarrow 0.303\ kg/m^3$$

$$\rho_{N_2} = C_{N_2} \times M_{N_2} \Rightarrow 0.9987\ kg/m^3 \qquad \boxed{M_{N_2} = 28}$$

$$\rho = \rho_{O_2} + \rho_{N_2} \Rightarrow 1.302\ kg/m^3$$

Mass fractions

$$\dot{m}_{O_2} = \frac{\rho_{O_2}}{\rho} \Rightarrow \frac{0.303}{1.302} \Rightarrow 0.233$$

$$\dot{m}_{N_2} = \frac{\rho_{N_2}}{\rho} \Rightarrow \frac{0.9987}{1.302} \Rightarrow 0.767$$

W.K.T Total Concentration $C = C_{O_2} + C_{N_2}$

$$\boxed{C = 0.045}$$

Mole fraction

$$x_{O_2} = \frac{C_{O_2}}{C} = 0.210$$

$$x_{N_2} = \frac{C_{N_2}}{C} = 0.792$$

(4)

4. Two large tanks, maintained at the Same temp & Pressure are Connected by a Circular 0.15m dia duct, which is 3m in length. One tank Contains a uniform mixture of 60 mole % ammonia & 40 mole % air & the other tank Contains a uniform mixture of 20 mole % ammonia and 80 mole % air. The System is at 273K And $1.013 \times 10^5 N/m^2$. Det the rate of Ammonia transfer b/w the two Tanks Assuming a Steady State Mass Transfer. [M-J-17]

Given data:-

$d = 0.15\,m$

length $(x_2 - x_1) = 3m$

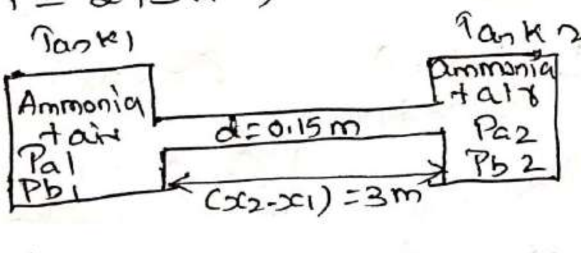
$P_{a1} = \frac{60}{100} = 0.6$ bar

$P_{b1} = \frac{40}{100} = 0.4$ bar

$P_{a2} = \frac{20}{100} = 0.2$ bar

$P_{b2} = \frac{80}{100} = 0.8$ bar

$T = 273K$; $P = 1.013 \times 10^5 N/m^2$



To find

Rate of ammonia transfer

Soln

$$\frac{m_a}{A} = \frac{D_{ab}}{G\,T}\left[\frac{P_{a1} - P_{a2}}{x_2 - x_1}\right]$$

$G - 8314$ J/Kg mole-K

$A = \pi/4\, d^2$

$A = 0.017 m^2$

Pg.No 181

$D_{ab} = 21.6 \times 10^{-6} m^2/s$ for ammonia with air

$$\frac{m_a}{0.017} = \frac{21.6 \times 10^{-6}}{8314 \times 273} \times \left[\frac{0.6 \times 10^5 - 0.2 \times 10^5}{3}\right]$$

$$\boxed{m_a = 2.15 \times 10^{-9}\ \frac{Kg.mole}{s}}$$

Mass Transfer rate of Ammonia = Molar Transfer rate × Molecular weight

$= 2.15 \times 10^{-9} \times 17.03$

$$\boxed{= 3.66 \times 10^{-8}\ Kg/s}$$

5. An open pan 20 cm in diameter and 8 cm deep contains water at 25 °C and is exposed to dry atmospheric air. If the rate of diffusion of water vapour is 8.54×10^{-4} kg/h, estimate the diffusion coefficient of water in air.

Given data:

$d = 0.2$ m

$(x_2 - x_1) = 0.08$ m

$T = 25°C + 273 = 298$ K

Diffusion rate (or)

Mass rate of water vapour $= 8.54 \times 10^{-4}$ kg/h

$= 2.37 \times 10^{-7}$ kg/s

To find

$D_{ab} = ?$

Soln

$$\frac{m_a}{A} = \frac{D_{ab}}{GT} \frac{P}{(x_2 - x_1)} \ln\left(\frac{P - P_{w2}}{P - P_{w1}}\right)$$

$A = \pi/4 (0.2)^2$ $\quad G = 8314$ J/kg-mole K

$\boxed{A = 0.0314 \, m^2}$

$P_{w1} \rightarrow$ Partial Pr @ the bottom of the test tube corresponding to Sat. temp 25 °C

[Steam table]

$\boxed{P_{w1} = 0.03166 \times 10^5 \, N/m^2}$

$\boxed{P_{w2} = 0}$ [at the top of the Pan ∴ air is dry and there is no water vapour, So, $P_{w2} = 0$]

$$2.37 \times 10^{-7} = \frac{D_{ab} \times 0.0314}{8314 \times 298} \times \frac{1.013 \times 10^5}{0.08} \times \ln\left[\frac{1.013 \times 10^5 - 0}{1.013 \times 10^5 - 0.03166 \times 10^5}\right] \times M_w$$

$\boxed{M_w = 18.016}$

$\boxed{D_{ab} = 2.58 \times 10^{-5} \, m^2/s}$