CBCS SCHEME

USN 1 C R 1 4 M E 0 6 2 15ME63

Sixth Semester B.E. Degree Examination, June/July 2018
Heat Transfer

Time: 3 hrs. Max. Marks: 80

Note: 1. Answer any FIVE full questions, choosing one full question from each module.
2. Use of Heat transfer data hand book, steam table are permitted.

Module-1

1 a. What do you mean by boundary condition of 1st, 2nd and 3rd kind? **(06 Marks)**

b. Explain briefly the mechanism of conduction, convection and radiation of heat transfer. **(06 Marks)**

c. A mild steel tank of wall thickness 20 mm is used to store water at 95°C. Thermal conductivity of mild steel is 45 W/m °C, and the heat transfer coefficient inside and outside the tank are 2850 W/m^2 °C and 10 W/m^2 °C respectively. If surrounding air temperature 20°C, calculate Rate of heat transfer per unit area of the tank. **(04 Marks)**

OR

2 a. Derive the general three dimensional heat conduction equation in Cartesian coordinate and state the assumption made. **(08 Marks)**

b. The wall of a house in cold region consists of three layers, an outer brick work 15 cm thick, the inner wooden panel 1.2 cm thick, the intermediate layer is insulator of 7 cm thick. The 'k' for brick and wood are 0.7 and 0.18 W/mK. The inside and outside temperature of wall are 21 and – 15°C. If insulation layer offer twice the thermal resistance of the brick wall, calculate (i) heat loss per unit area (ii) 'k' of insulator. **(08 Marks)**

Module-2

3 a. Derive the expression for critical thickness of insulation for cylinder. **(06 Marks)**

b. Differentiate between effectiveness and efficiency of fins. **(04 Marks)**

c. A rod [k = 200 W/mK] 5 mm in diameter and 5 cm long has its one end maintained at 100°C. The surface of the rod is exposed to ambient air at 25°C with convection heat transfer coefficient of 100 W/m^{2}K. Assuming other end is insulated. Determine (i) the temperature of rod at 20 mm distance from the end at 100°C (ii) Heat dissipation rate from the surface of rod (iii) Effectiveness. **(06 Marks)**

OR

4 a. Derive the expression for temperature variation and heat flow using Lumped Parameter Analysis. **(06 Marks)**

b. Explain significance of Biot and Fourier number. **(04 Marks)**

c. The average heat transfer coefficient for flow of 100°C air over a flat plate is measured by observing the temperature time history of a 3 cm thick copper slab exposed to 100°C air, in one test run, the initial temperature of slab was 210°C and in 5 min the temperature is decreased by 40°C. Calculate the heat coefficient for this case. Assume ρ = 9000 kg/m^3 ; C = 0.38 kJ/kgK , K = 370 W/mK. **(06 Marks)**

Module-3

5 a. Explain formulation of differential equation 1-D steady heat conduction. (06 Marks)
b. Explain different solution method used in numerical analysis of heat conduction. (06 Marks)
c. Explain applications and computation error of numerical analysis heat conduction. (04 Marks)

OR

6 a. Define (i) Blackbody (ii) Planks law (iii) Wein displacement law (iv) Lamberts law. (06 Marks)
b. Prove that emissive power of the black body in hemispherical enclosures in π terms of intensity of radiation. (06 Marks)
c. The temperature of black surface of 0.2 m^2 area is 540°C. calculate (i) the total rate of energy emission (ii) the intensity of normal radiation (iii) the wavelength of maximum monochromatic emission power. (04 Marks)

Module-4

7 a. Explain with neat sketches (i) Velocity Boundary layer (ii) Thermal boundary layer. (08 Marks)
b. Air flows over a flat plate at 30°C, 0.4m wide and 0.75m long with a velocity of 20m/s. Determine the heat transfer from the surface of plate assuming plate is maintained at 90°C.
Use $N_{UL} = 0.664\, R_e^{0.5}\, Pr^{0.33}$ for laminar
$N_{UL} = \left[0.036\, R_e^{0.8} - 0.836\right] Pr^{0.333}$ for turbulent. (08 Marks)

OR

8 a. *Explain the physical significance of the following dimensionless number:*
(i) Reynold's number (ii) Prandtl number (iii) Nusselt number
(iv) Stantor number. (06 Marks)
b. A stream pipe 5 cm in diameter is lagged with insulating material of 2.5 cm thick. The surface temperature is 80°C and emissivity of the insulating material surface is 0.93. Find the total heat loss by natural convection and radiation. The temperature of the air surrounding the pipe is 20°C. Also find the overall heat transfer coefficient. (10 Marks)

Module-5

9 a. Derive expression for LMTD for parallel flow heat exchanger and state the assumption made. (08 Marks)
b. Water enters a counter flow heat exchanger at 15°C flowing at a rate of 1300 kg/h. It is heated by oil [c_p = 2000 J/kgK] flowing at the rate of 550 kg/h with an inlet temperature of 94°C for an area 1 m^2 and overall heat transfer coefficient of 1075 W/m^2K. Determine the total heat transfer and outlet temperature of water and oil. (08 Marks)

OR

10 a. Explain different regimes of pool boiling with neat sketches. (08 Marks)
b. Draw saturated stream at a pressure of 2.0 bar condenses on the surface of vertical tube of height 1 m. The tube surface is kept at 117°C. Estimate the thickness of the condensate film and heat transfer coefficient at a distance of 0.2 m from the upper end of the tube. Assume the condensate film to be laminar. Also calculate the average heat transfer coefficient over the entire length of the tube. (08 Marks)

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Question Paper Solution

Subject: Heat Transfer

Sub Code: 15ME63 — SHASHANK DUBEY

Module - 1

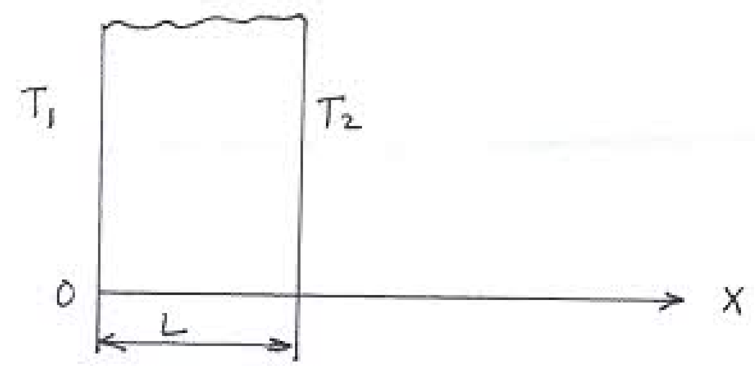
1

(a) **Boundary Conditions of first Kind:**

Here, the temperature is specified at the surface of the system. for one dimensional heat transfer through a plane wall, this would appear in the form:

at $x=0$, $T(0,t) = T_1$

at $x=L$, $T(L,t) = T_2$



The specified temperature can be constant (steady state heat conduction) or may vary with time.

It is used when temp. of exposed surface can be measured directly or easiely.

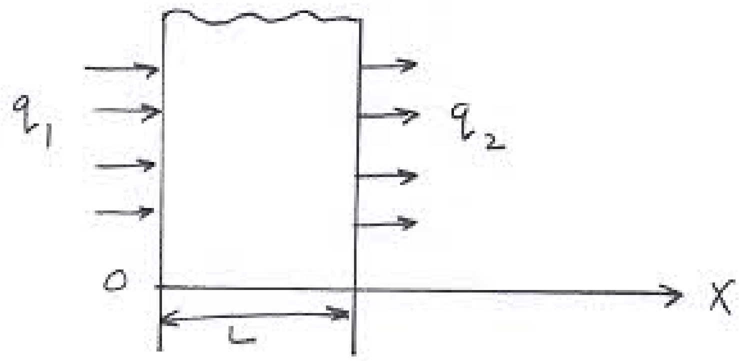
Boundary conditions of Second Kind:

When there is sufficient information about energy interactions at a surface, it may be possible to determine the rate of heat transfer & thus heat flux on the surface.

For one dimensional heat transfer through a plane wall, the specified heat flux boundary conditions are:

At $x = 0$, $-k\left(\frac{\partial T}{\partial x}\right)_{(0,t)} = q_1$

At $x = L$, $-k\left(\frac{\partial T}{\partial x}\right)_{(L,t)} = q_2$

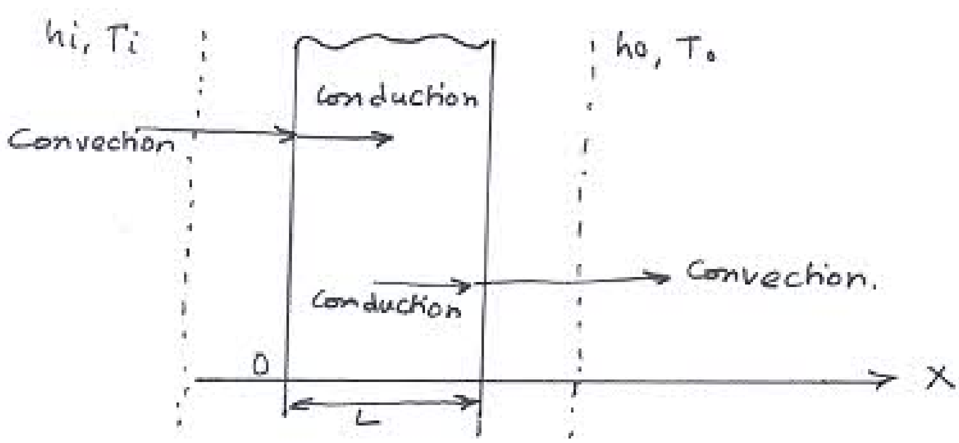


Boundary Condition of Third Kind:

It is commonly referred as convection boundary condition. It is based on energy balance on the surface.

It can be expressed as:

| Heat conduction at surface in a selected direction | = | Heat convection at the surface in the same direction |



At $x=0$, $h_i\left[T_i - T(0,t)\right] = -k\left(\frac{\partial T}{\partial x}\right)(0,t)$

At $x=L$, $h_o\left[T(L,t) - T_o\right] = -k\left(\frac{\partial T}{\partial x}\right)_{(L,t)}$

1 b

Conduction:

Conduction is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance.

In solids heat is conducted by two mechanisms:
i) By lattice vibration
ii) By transfer of free electrons (if present).

In case of gases, kinetic energy of molecules is a function of temp. When a molecule from high temp region collides with a molecule from low temp region, it loses energy by collisions.

In liquids, the mechanism of heat transfer is nearer to that of gases.

Convection:

Convection is the transfer of heat within a fluid by mixing of one portion of the fluid with another.

Convection is possible only in a fluid medium & is directly linked with transport of medium itself.

Forced Convection: Here energy is transferred as heat to a flowing fluid at any surface over which flow occurs. It is basically conduction in a very thin fluid layer & then mixing caused by flow.

Natural Convection: It occurs when fluid circulates by virtue of natural differences in densities of hot & cold fluids.

Radiation:

Radiation is the transfer of heat through space or matter by means other than conduction or convection.

Radiation heat is thought of as electromagnetic waves.

All bodies radiate heat, so a transfer of heat by radiation occurs because a hotter body receives less heat than it emits and a cold body emits less heat than it receives.

It requires no medium and can take place even in vaccum.

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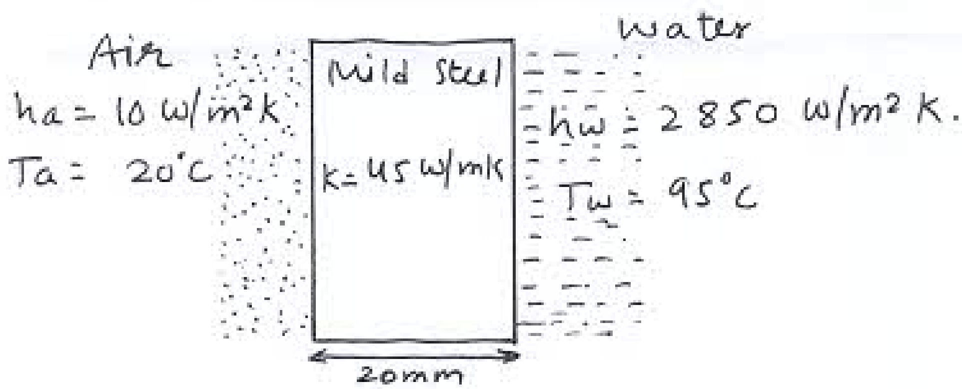
1 c



Given: $L = 20 \times 10^{-3}$ m

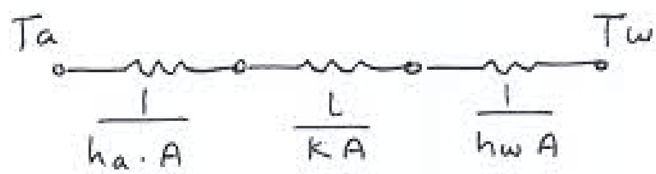
$k = 45$ W/mK

$h_a = 10$ W/m²K.

$h_w = 2850$ W/m²K

$T_a = 20°C$

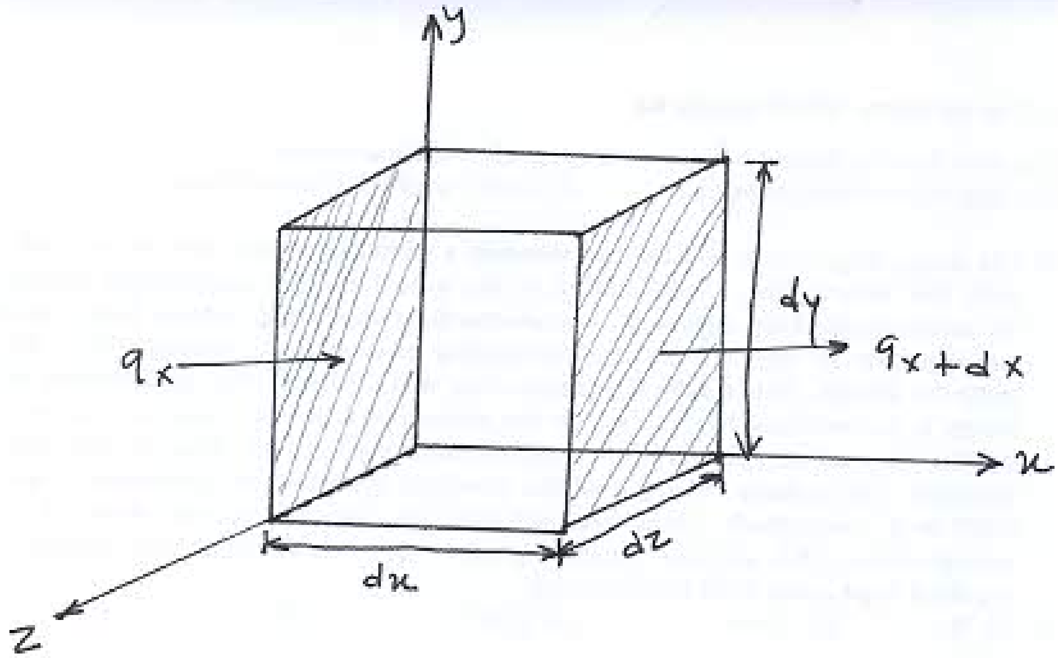
$T_w = 95°C$



Rate of Heat Transfer, $Q = \dfrac{T_w - T_a}{\dfrac{1}{h_w A} + \dfrac{L}{KA} + \dfrac{1}{h_a A}}$.

$$\Rightarrow Q = \frac{95-20}{\frac{1}{A}\left[\frac{1}{2850} + \frac{20\times10^{-3}}{45} + \frac{1}{10}\right]} \Rightarrow \boxed{\frac{Q}{A} = 744.08 \ W/m^2}$$

(2) (a)



Consider a small rectangular element of dimensions dx, dy & dz in x, y & z directions respectively.

Assumptions:

- Material is homogeneous & isotropic.
- Density of material is constant & doesnot change with time.
- Specific heat of material remains constant.
- Temp. is a f^n of all three co-ordinates & time.

Applying Energy Balance at inlet & outlet of the element,

$$\left|\begin{array}{l}\text{Rate of heat conduction} \\ \text{into the element}\end{array}\right| - \left|\begin{array}{l}\text{Rate of heat conduction} \\ \text{out of the element}\end{array}\right|$$

$$+ \left|\begin{array}{l}\text{Rate of heat generated} \\ \text{in the element}\end{array}\right| = \left|\begin{array}{l}\text{Rate of change of} \\ \text{energy content of} \\ \text{the element}\end{array}\right|$$

$$\Rightarrow \boxed{E_{in} - E_{out} + E_{gen} = E_{st.}} \quad -(1)$$

Now,

$$(E_{in} - E_{out})_x = q_x - q_{x+dx}$$

$$= q_x - \left(q_x + \frac{\partial}{\partial x} q_x \, dx \right)$$

$$= -\frac{\partial}{\partial x} q_x \, dx$$

Using fouriers Eq^n, $q_x = -k\,(dy\,dz)\,\frac{\partial T}{\partial x}$

$$\therefore (E_{in} - E_{out})_x = -\frac{\partial}{\partial x}\left(-k\,(dy\,dz)\,\frac{\partial T}{\partial x} \right) dx$$

$$= k\,\frac{\partial^2 T}{\partial x^2}\, dx\,dy\,dz.$$

Similarly,

$$(E_{in} - E_{out})_y = k\,\frac{\partial^2 T}{\partial y^2}\, dx\,dy\,dz$$

& $$(E_{in} - E_{out})_z = k\,\frac{\partial^2 T}{\partial z^2}\, dx\,dy\,dz$$

$$\therefore (E_{in} - E_{out}) = (E_{in} - E_{out})_x + (E_{in} - E_{out})_y + (E_{in} - E_{out})_z$$

$$= k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right] dx\,dy\,dz. \quad -(2)$$

Let energy generated in the element per unit volume per unit time be q_g

$$\therefore E_{gen} = q_g \times dx\,dy\,dz. \quad -(3)$$

We know, $E_{st} = mC\,\frac{\partial T}{\partial t}$

$$= \rho\,(dx\,dy\,dz)\,C.\,\frac{\partial T}{\partial t} = \rho C\,\frac{\partial T}{\partial t}.\,dx\,dy\,dz$$

$-(4)$

From ①, ②, ③ & ④,

$$k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] dx\,dy\,dz + \dot{q}_g \cdot dx\,dy\,dz$$

$$= \rho c \frac{\partial T}{\partial t} dx\,dy\,dz$$

$$\Rightarrow \left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] + \frac{\dot{q}_g}{k} = \frac{\rho c}{k}\frac{\partial T}{\partial t}.$$

Now, $\frac{k}{\rho c} = \alpha$

$$\therefore \boxed{\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{\dot{q}_g}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}.}$$

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② b)

Given:

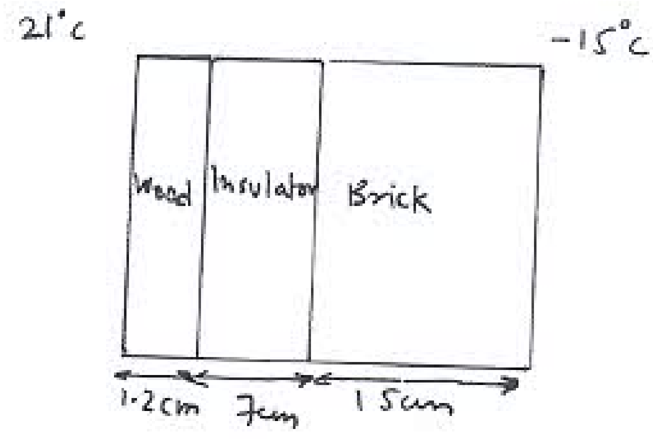
$L_b = 15 \times 10^{-2}\,m$

$L_w = 1.2 \times 10^{-2}\,m$

$L_i = 7 \times 10^{-2}\,m$

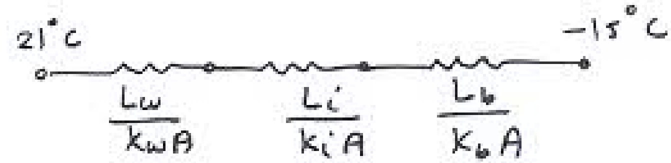
$k_w = 0.18\,W/mK$

$k_b = 0.7\,W/mK$



Now,

$(R_{th})_i = 2(R_{th})_b$



$$\Rightarrow \frac{L_i}{k_i A} = \frac{2L_b}{k_b A}$$

$$\Rightarrow \frac{7 \times 10^{-2}}{k_i} = \frac{2 \times 15 \times 10^{-2}}{0.7}$$

$$\Rightarrow \boxed{k_i = 0.163 \text{ W/mK}}$$

Now,

$$Q = \frac{\Delta T}{R_{net}}$$

$$\Rightarrow Q = \frac{21-(-15)}{\frac{1}{A}\left(\frac{1.2\times10^{-2}}{0.18} + \frac{7\times10^{-2}}{0.163} + \frac{15\times10^{-2}}{0.7}\right)}$$

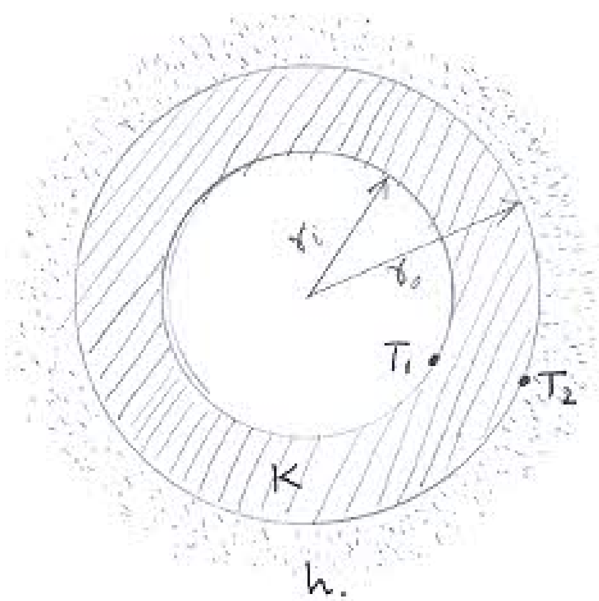
$$\Rightarrow \frac{Q}{A} = \frac{36}{0.7104}$$

$$\Rightarrow \boxed{\frac{Q}{A} = 50.67 \text{ W/m}^2}$$

Module-2.

3
(a)

Consider a cylinder with insulation as shown in fig.



r_i = Inside radius of insulation
r_o : outside radius of insulation
l = length of cylinder.

$$Q = \frac{T_1 - T_2}{\frac{\ln\frac{r_o}{r_i}}{2\pi k l} + \frac{1}{2\pi r l h}}$$

For, $Q : Q_{max}$,

$R_{th} = (R_{th})_{min}$

$$\Rightarrow \frac{dR_{th}}{dr_o} = 0$$

$$\Rightarrow \frac{d}{dr_0}\left(\frac{\ln\frac{r_0}{r_i}}{2\pi k l} + \frac{1}{2\pi r_0 l h}\right) = 0$$

$$\Rightarrow \frac{1}{2\pi k l}\left[\frac{1}{r_0/r_i} \times \frac{1}{r_i}\right] + \frac{1}{2\pi l h}\left(-\frac{1}{r_0^2}\right) = 0$$

$$\Rightarrow \quad \frac{1}{k} = \frac{1}{h r_0}$$

$$\Rightarrow \quad r_0 = \frac{k}{h} = r_c = \text{critical radius of insulation}$$

$\therefore$ Critical Thickness of insulation,

$$t_c = r_0 - r_i$$

$$\Rightarrow \boxed{t_c = \frac{k}{h} - r_i}$$

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3 b Efficiency of fin:

The efficiency of a fin is defined as the ratio of actual heat transfer from the fin to the heat that would be dissipated if whole surface of fin is maintained at base temperature (maximum heat).

It is denoted by η_{fin}

$$\boxed{\eta_{fin} = \frac{Q_{act}}{Q_{max}}}$$

It is always less than 1.

Effectiveness of fin:

It is defined as the ratio of actual heat transfer that takes place from the fin to the heat that would be dissipated from the same surface area without fin

It is denoted by ϵ.

$$\boxed{\epsilon_{fin} = \frac{Q_{fin}}{Q_{w/o\ fin}}}$$

Use of fins will be more effective with materials of large thermal conductivities.

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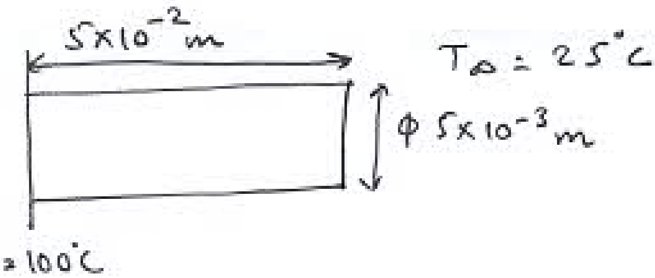
(3) (c)



Given: $k = 200\ w/mk$

$h = 100\ w/m^2k$

$l = 5\times10^{-2}\ m$

$d = 5\times10^{-3}\ m$

Now: $m = \sqrt{\frac{hp}{kA}} = \sqrt{\frac{100 \times \pi d \times 4}{200 \times \pi d^2}} = \sqrt{\frac{100\times 4}{200 \times 5\times10^{-3}}}$

$\Rightarrow \boxed{m = 20}$

Assuming insulated tip.

i)
$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{\cosh[m(l-x)]}{\cosh(ml)}$$

$x = 20 \times 10^{-3}\ m = 0.02$

$$\therefore \frac{T-25}{100-25} = \frac{\cosh[20(0.05-0.02)]}{\cosh(20 \times 0.05)}$$

$$\Rightarrow \frac{T-25}{75} = 0.768$$

$$\Rightarrow \boxed{T = 82.6^\circ C}$$

ii) $Q = (hpkA_c)^{1/2}\,\theta_0 \tanh(ml)$

$$\Rightarrow Q = \left(100 \times \pi \times 5\times10^{-3} \times 200 \times \pi \times \frac{(5\times10^{-3})^2}{4}\right)^{1/2} \times (100-25) \times \tanh(20 \times 0.05)$$

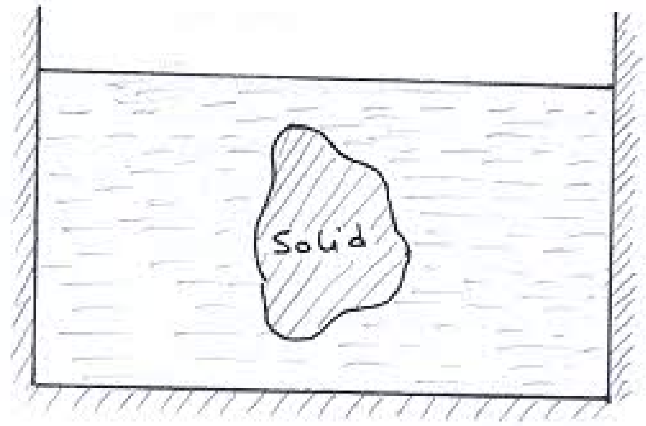
$$\Rightarrow \boxed{Q = 4.48\ W.}$$

iii)
$$\epsilon = \frac{Q_w}{Q_{w/o}} = \frac{4.48}{h \times \frac{\pi d^2}{4} \times \theta_0} = \frac{4.48 \times 4}{100 \times 3.14 \times (5\times10^{-3})^2 \times (100-25)}$$

$$\Rightarrow \boxed{\epsilon = 30.43}$$

4

a



Consider a solid suddenly immersed in a well stirred fluid maintained at a uniform temp T_∞.

Assuming temp is a f^n of time only,

Rate of heat flow into solid of volume V = Rate of increase in internal energy in solid of volume V.

Let T_i be the initial temp. of solid & T be temp of solid at some time t.

$$\therefore \quad hA(T_\infty - T) = mC\frac{dT}{dt}$$

m → mass of solid.
C → specific heat of the solid.

$$\Rightarrow \quad hA(T_\infty - T) = \rho VC\frac{dT}{dt}$$

$$\Rightarrow \quad \frac{dT}{T_\infty - T} = \frac{hA}{\rho VC}\,dt$$

$$\Rightarrow \quad \frac{dT}{T - T_\infty} = -\frac{hA}{\rho VC}\,dt$$

Integrating the above expression, we get,

$$\ln(T - T_\infty) = \frac{-hA}{\rho VC}t + c \qquad -(1)$$

Applying Boundary Condition.

i.e. at $t=0$, $T=T_i$

$\therefore \ln(T_i - T_\infty) = C$

Substituting value of c in ①

$$\ln(T - T_\infty) = \frac{-hA}{\rho V C} t + \ln(T_i - T_\infty)$$

$$\Rightarrow \ln\left[\frac{T-T_\infty}{T_i - T_\infty}\right] = \frac{-hA}{\rho V C} t$$

$$\Rightarrow \boxed{\frac{T-T_\infty}{T_i - T_\infty} = e^{-\frac{hA}{\rho V C} t}} \quad — ②$$

$\frac{hAt}{\rho V C}$ can be rearranged as, $\frac{hL_c}{K} \times \frac{\alpha t}{L_c^2}$

$$\therefore \frac{hAt}{\rho V C} = Bi \times Fo$$

$$\therefore \boxed{\frac{T-T_\infty}{T_i - T_\infty} = e^{-Bi \cdot Fo}}$$

Instantaneous heat flow rate,

$$Q_i = mC\frac{dT}{dt} = \rho V C \frac{dT}{dt}.$$

From eqn ②, we get, $T = T_\infty + (T_i - T_\infty) e^{-\frac{hAt}{\rho V C}}$

$$\therefore \rho V C \frac{dT}{dt} = \rho V C \times \left(-\frac{hA}{\rho V C}\right)(T_i - T_\infty) e^{-\frac{hAt}{\rho V C}}$$

$$\Rightarrow \rho V C \frac{dT}{dt} = -hA(T_i - T_\infty) e^{-\frac{hAt}{\rho V C}}$$

$$\therefore \; Q_i = -hA(T_i - T_\infty)e^{-hAt/\rho v c}$$

or $$\boxed{Q_i = -hA(T_i - T_\infty)\, e^{-Bi \cdot Fo}}$$

Total heat flow,

$$Q_t = \int_0^t Q_i \, dt$$

$$Q_t = \int_0^t -hA(T_i - T_\infty) e^{-\frac{hAt}{\rho v c}} \, dt$$

$$Q_t = -hA(T_i - T_\infty)\left[-\frac{\rho V c}{hA} e^{-\frac{hAt}{\rho v c}}\right]_0^t$$

$$Q_t = \rho v c (T_i - T_\infty)\left(e^{-\frac{hAt}{\rho v c}} - 1\right)$$

$$\boxed{Q_t = \rho v c (T_i - T_\infty)\left(e^{-Bi \cdot Fo} - 1\right)}$$

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4 b

Biot Number: It is the ratio of internal resistance due to conduction to the surface resistance due to convection.

$$Bi = \frac{hL_c}{k} = \frac{\frac{L_c}{kA}}{\frac{1}{hA}}$$

$$\Rightarrow Bi = \frac{\text{Conduction Thermal resistance}}{\text{convection Thermal resistance}}$$

If $Bi < 0.1$, the lump gradient within the body can be neglected.

Fourier Number:

It is defined as the ratio of the rate of heat conduction to the thermal energy storage in the solid.

$$F_o = \frac{\alpha t}{L_c^2} = \frac{k}{\rho c} \times \frac{t}{L_c^2} = \frac{k A t}{\rho (A \times L_c) c L_c}$$

$$= \frac{k A \frac{dT}{L}}{\rho V c \frac{dT}{t}} = \frac{\text{heat conduction rate}}{\text{energy storage rate}}$$

It signifies the degree of penetration of heating or cooling effect through a solid.

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(4) (c) Given: $T_\infty = 100°C$, $L = 3cm = 0.03m$, $\rho = 9000 kg/m^3$,
$c = 0.38 \times 10^3 J/kgK$, $K = 370 W/mK$.

$T_i = 210°C$

$T = 210 - 40 = 170°C$.

$t = 5min = 300s$.

Now, $L_c = \frac{L}{2} = \frac{0.03}{2} = 0.015$

$$Bi = \frac{hL_c}{K} = \frac{h \times 0.015}{370} = 4.054 \times 10^{-5} \cdot h$$

$$F_o = \frac{\alpha t}{L_c^2} = \left(\frac{k}{\rho c}\right) \frac{t}{L_c^2} = \frac{370 \times 300}{9000 \times 0.38 \times 10^3 \times 0.015^2}$$

$$= 144.24$$

Assuming negligible temp. gradient,

By lumped parameter analysis,

$$\frac{T - T_\infty}{T_i - T_\infty} = e^{-Bi \cdot Fo}.$$

$$\Rightarrow -Bi \cdot Fo = \ln\left[\frac{T - T_\infty}{T_i - T_\infty}\right]$$

$$\Rightarrow -(4.054 \times 10^{-5} h) \times (144.24) = \ln\left[\frac{170-100}{210-100}\right]$$

$$\Rightarrow \boxed{h = 77.295 \ W/m^2K.}$$

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6 (a) (i) Black Body:

A body which absorbs all the radiations incident on it is called as a black body.

For a black body, $\alpha = 1, \rho = 0, \tau = 0$.

It neither reflects nor transmits any part of the incident radiation but absorbs all of it.

(ii) Planck's Law:

The energy emitted by a black surface varies in accordance with wavelength, temp & surface characteristics of the body. The amount of radiation is strongly influenced by wavelength even if temp of the body remains at constant fixed value.

The laws governing distribution of radiant energy over wavelength for a black body at a fixed temperature were formulated by Planck.

Planck suggested the following law for spectral distribution of emissive power.

$$(E_\lambda)_b = \frac{2\pi h C^2}{\lambda^5\left[e^{\frac{hc}{k_B \lambda T}} - 1\right]}$$

where, h = Planck's constant $= 6.6235 \times 10^{-34}$ Js

$c = 3 \times 10^8$ m/s.

k_B = Boltzman's constant $= 13.8 \times 10^{-23}$ JK.

or, $$\boxed{(E_\lambda)_B = \frac{C_1}{\lambda^5\left[e^{C_2/\lambda T} - 1\right]}}$$

$C_1 = 2\pi c^2 h = 0.3748 \times 10^{-15}$ Jm²/s.

$C_2 = 1.4388 \times 10^{-2}$ mK $= \frac{hc}{k_B}$.

(iii) Wein's Displacement Law:

It states that the product of absolute temp and the wavelength at which max. value of monochromatic emissive power occurs at that temp., is constant.

$$\lambda_{max} \cdot T = \text{Constant}.$$

$$\boxed{\lambda_{max} \cdot T = 2.9 \times 10^{-3}\ \text{mk}.}$$

(iv) Lambert's Law:

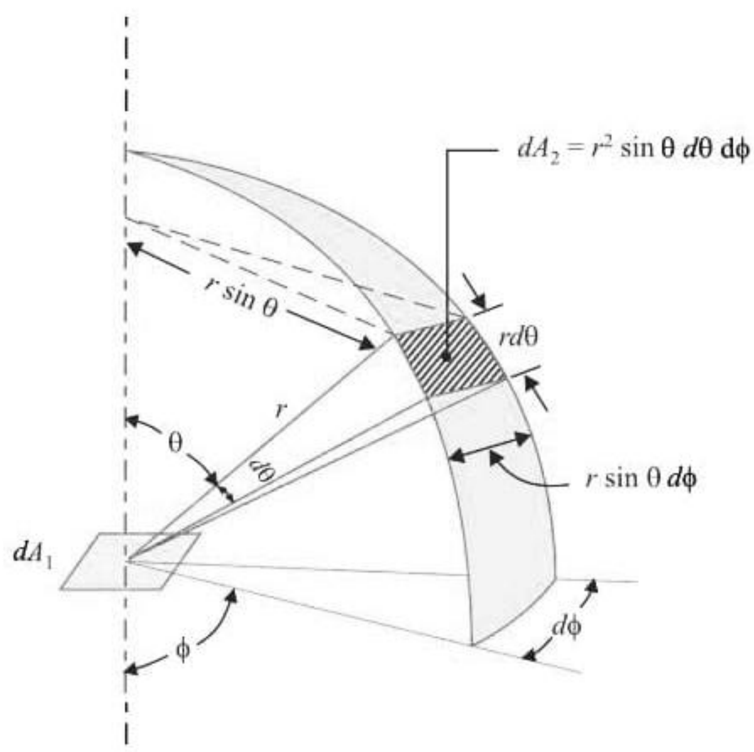
It states that the intensity of radiation in a direction θ from the normal to the surface of emitter is proportional to cosine of the angle θ.

$$I_\theta = I_n \cos\theta .$$

I_n = normal intensity

I_θ = intensity at an angle θ.

6 b



The fig shows a small black surface of area dA_1 emitting radiations in different directions. A black body radiation collector through which the radiation pass is located at an angular position characterised by zenith angle θ towards the surface normal & angle ϕ of a spherical co-ordinate system. The collector substends a solid angle $d\omega$ when veiwed from a point on the emitter.

Now, $dA_2 = dA_1 \cos\theta$

& solid angle subtended by $dA_2 = \frac{dA_2}{r^2}$

$\therefore$ Intensity of radiation = $I = \dfrac{dQ_{1-2}}{dA_1 \cos\theta \cdot \frac{dA_2}{r^2}}$

$$dA_2 = r\,d\theta\,(r\sin\theta\,d\phi)$$

$$\Rightarrow dA_2 = r^2 \sin\theta . d\theta \cdot d\phi$$

$$\therefore dQ_{1-2} = I\,dA_1 \sin\theta\cos\theta\, d\theta . d\phi$$

$$\Rightarrow Q = I\,dA_1 \int_{\theta=0}^{\theta=\pi/2} \int_{\phi=0}^{\phi=2\pi} \sin\theta \cdot \cos\theta \cdot d\theta \cdot d\phi$$

$$= 2\pi I\,dA_1 \int_{\theta=0}^{\theta=\pi/2} \sin\theta\cos\theta \cdot d\theta$$

$$= \pi I\,dA_1 \int_{\theta=0}^{\theta=\pi/2} \sin 2\theta . d\theta$$

$$= \pi I\,dA_1$$

$$\Rightarrow E_b\,dA_1 = \pi I\,dA_1$$

$$\Rightarrow \boxed{E_b = \pi I} \quad \text{or} \quad \boxed{I = \frac{E_b}{\pi}}$$

6
c

Given: $T = 540^\circ c$
$= 813 K.$
$A = 0.2 m^2.$

$\therefore E_b = \sigma T^4$
$= 5.67 \times 10^{-8} \times (813)^4$
$= 24,771.097 \; w/m^2$

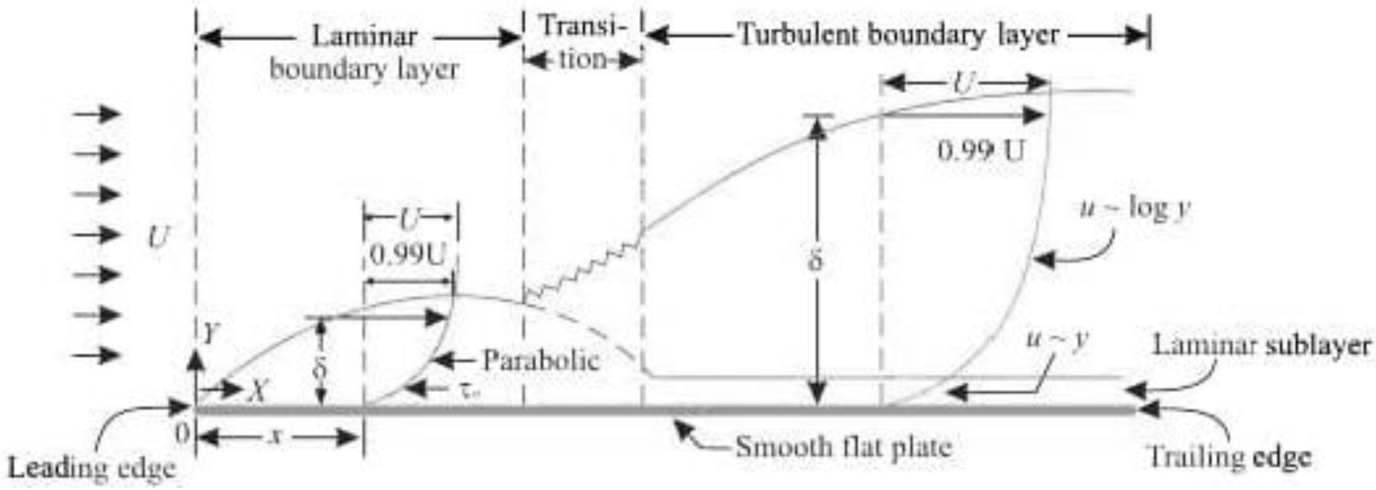
i) $Q = \sigma A T^4 = E_b \cdot A$
$Q = 24,771.097 \times 0.2$
$\boxed{Q = 4,954.2194 \; w}$

ii) $I = \dfrac{E_b}{\pi}$
$= \dfrac{24,771.097}{3.14}$
$= 7,888.88$

iii) By Wein's Law,
$\lambda_{max} \times T = 0.0029$
$\Rightarrow \lambda_{max} = \dfrac{0.0029}{813}$
$\Rightarrow \lambda_{max} = 3.56 \times 10^{-6} m$
$\Rightarrow \boxed{\lambda_{max} = 3.56 \mu m}$

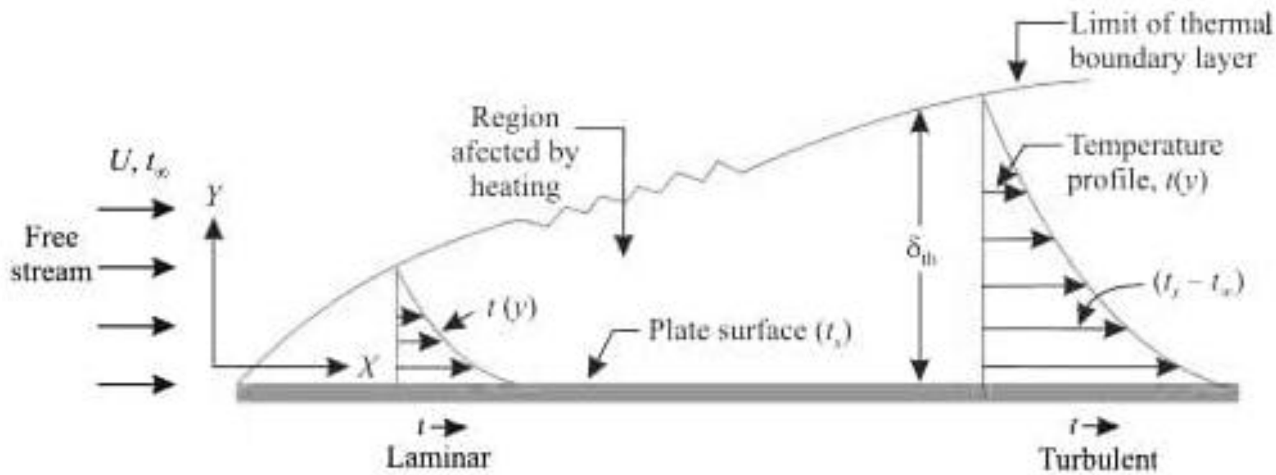
Module - 4

7 a) i) Velocity Boundary Layer:



When a real fluid flows past a stationary solid boundary, a layer of solid which comes in contact with the boundary surface adheres to it and condition of no-slip occurs. Thus the layer of fluid which cannot slip away from the boundary surfac undergoes retardation. This retarded layer further causes retardation for the adjacent layers of the fluid, thereby developing a small region in vicinty of the boundary surface in which the velocity of the flowing fluid increases rapidly from zero at the boundary & approaches velocity of the main stream. This layer adjacent to the boundary is known as velocity boundary layer.
It is a thin layer where viscous shear takes place.

ii) Thermal Boundary layer:



Whenever flow of fluid takes place past a heated or cold surface, a temprature field is set up in the vicinity of the surface. If the surface is hotter than the fluid, the temprature distribution will be shown as in the above fig. The zone or this layer wherein the temprature field exists is called as thermal boundary layer.

The temp. gradient occurs due to exchange of heat b/w plate and the fluid.

The thermal boundary layer concept is analogous to the velocity boundary layer.

7
6

Given: $T_0 = 90°C$

$T_\infty = 30°C$

$\therefore T_{mean} = \frac{90+30}{2} = 60°C$

Properties of air at 60°C are as follows-

$\rho = 1.06\ kg/m^3$

$\mu = 20.1 \times 10^{-6}\ Ns/m^2$

$Pr = 0.696$

$C_p = 1005\ J/kgK$

$K = 0.02896\ W/mK$

For flow over flat plate,

$Re_c = 5 \times 10^5.$

$\Rightarrow \frac{\rho V L_c}{\mu} = 5 \times 10^5$

$\Rightarrow \frac{1.06 \times 20 \times L_c}{20.1 \times 10^{-6}} = 5 \times 10^5$ $\qquad \because V = 20 m/s.$

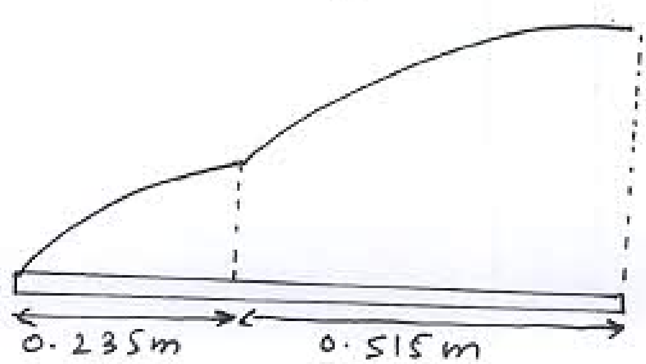
$\Rightarrow \boxed{L_c = 0.235 m}$

Total length of plate = 0.75 m

$\therefore$ Flow remains laminar for $L_1 = 0.235\ m$

& turbulent for $L_2 = 0.75 - 0.235$

$L_2 = 0.515 m.$



For Laminar,

$$Nu = 0.664\, Re^{1/2} . Pr^{1/3}$$

$$= 0.664\, (5\times10^5)^{1/2} (0.696)^{1/3}$$

$$= 416.09$$

$$\therefore h_{lam} = \frac{416.09 \times 0.02896}{0.235} \qquad \because Nu = \frac{hL}{K}$$

$$\boxed{h_{lam} = 50.639\ W/m^2K}$$

$$Q_{lam} = h_{lam} \times A\,(90-30)$$

$$Q_{lam} = 50.639 \times (0.4\times0.75)\,(60)$$

$$\boxed{Q_{lam} = 911.502\,W}$$

For Turbulent,

$$Re = \frac{\rho V L}{\mu} = \frac{1.06\times20\times0.75}{20.1\times10^{-6}} = 791044.77$$

$$Nu = [0.036\, Re^{0.8} - 0.836]\, Pr^{0.333}$$

$$\Rightarrow \frac{(h_{turb}).(0.515)}{0.02896} = [0.036\,(791044.77)^{0.8} - 0.836] \times 0.696^{0.333}$$

$$\Rightarrow \boxed{h_{turb} = 93.85\ W/m^2K}$$

$Q_{turb} = h_{turb} \cdot A(90-30)$

$Q_{turb} = 93.85 \times (0.4 \times 0.75)(60)$

$\Rightarrow \boxed{Q_{turb} = 1689.3 \text{ W}}$

$\therefore Q_{total} = Q_{lam} + Q_{turb}$

$\Rightarrow Q_{total} = 1689.3 + 911.502$

$\Rightarrow \boxed{Q_{total} = 2600.802 \text{ W}}$

8
(a)

i) Reynold's No: It is the ratio of inertia force to the viscous force

$$Re = \frac{F_i}{F_v} = \frac{\rho V L}{\mu} = \frac{VL}{\nu}$$

At low Re, the viscous effects dominate & the flow is laminar.
At high Re, the inertia effects lead to turbulent effects.

ii) Prandtl No: It is the ratio of kinematic viscosity (momentum diffusivity) to the thermal diffusivity.

$$Pr = \frac{\nu}{\alpha} = \frac{\mu C_p}{k}$$

It is an indicative of relative ability of fluid to diffuse momentum & internal energy by molecular mechanism.

iii) Nusselt No: It is the ratio of convection heat flux to conduction heat flux in the boundary layer.

Large value of Nu indicates large convection in the fluid.

$$Nu = \frac{h \Delta T}{K \frac{\Delta T}{L}} = \frac{hL}{K}.$$

iv) Stanton No: It is the ratio of heat transfer at the surface to that transported by fluid by its thermal capacity.

$$St = \frac{Nu}{Re \times Pr.}$$

It is the ratio of Nusselt no. to the product of Reynold's No & Prandtl no.

It is used for correlating forced convection data

8 b

$D_1 = 0.05m \Rightarrow r_1 = 0.025m$

$r_2 = 0.025 + 0.025 = 0.05m$

$T_w = 80^\circ C$, $T_\infty = 20^\circ C$

$\epsilon = 0.93$

$L = 10m$,

$Q = ?$

mean film temp. $T_f = \frac{80+20}{2} = 50^\circ C$

At $T_f = 50^\circ C$,

$\rho = 1.092 kg/m^3$, $C_p = 1.007 \times 10^3 J/kgK$, $\mu = 19.57 \times 10^{-6} Ns/m^2$

$K = 0.02781 W/mK$.

$$\beta = \frac{1}{T_f + 273} = \frac{1}{50+273} = 3.09 \times 10^{-3} /K$$

$$Gr = \frac{D_2^3 \rho^2 g \beta (T_w - T_\infty)}{\mu^2}$$

$$= \frac{0.1^3 \times 1.092^2 \times 9.81 \times 3.096 \times 10^{-3} \times 60}{(19.57 \times 10^{-6})^2}$$

$$= 5.67 \times 10^6$$

$Pr = \frac{\mu C_p}{K} = 0.708$. $\therefore Gr\,Pr = 4.017 \times 10^6$

for free convection, for $Gr\,Pr$ b/w 10^4 & 10^7

$$Nu = 0.48 (Gr Pr)^{0.25}$$

$$= 0.48 (4.017 \times 10^6)^{0.25}$$

$$= 21.489$$

$$Nu = \frac{hD_2}{k} = 21.489$$

$$\Rightarrow \frac{h \times 0.1}{0.02781} = 21.489$$

$$\Rightarrow h = 5.98 \ W/m^2K$$

$$\therefore Q_{conv} = hA_s(T_w - T_\infty) = 5.98 \times 3.14 \times 0.1 \times 10 (60)$$

$$= 1126.48 W.$$

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

$$= 5.67 \times 10^{-8} \times 0.93 \times 3.14 \times 0.1 \times 10 \times [(80+273)^4 - (20+273)^4]$$

$$= 1351.34 W$$

Total heat, $Q = 1126.4 + 1351.34$

$$\boxed{Q = 2477.74 W.}$$

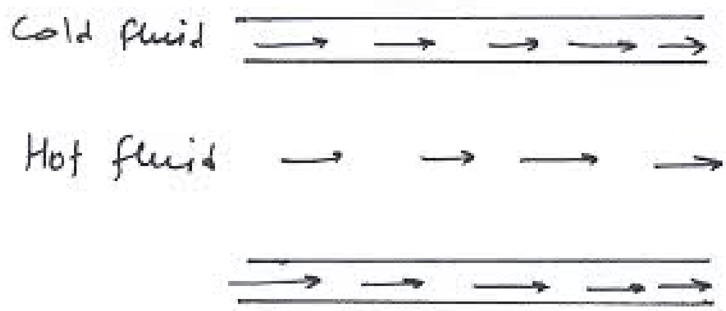
$$\Rightarrow UA_s(T_w - T_\infty) = 2477.74$$

$$\boxed{U = 13.14 \ W/m^2K}$$

$\Rightarrow$

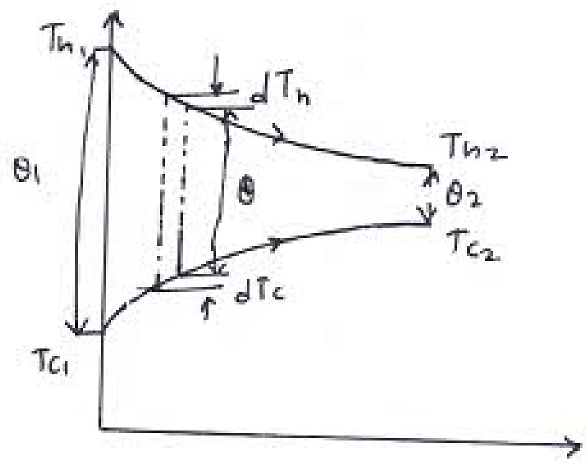
Module-5.

9 (a)



Let $\theta_1 = T_{h_1} - T_{c_1}$

$\theta_2 = T_{h_2} - T_{c_2}$



Consider a small element of thickness dx as shown in fig.

$$dQ = -m_h C_h dT_h = -C_h dT_h$$

$$\Rightarrow dT_h = -\frac{dQ}{C_h}$$

Also, $dQ = m_c c_c dT_c = C_c dT_c$

$$\Rightarrow dT_c = \frac{dQ}{C_c}$$

For element, $\theta = T_h - T_c$

$$d\theta = dT_h - dT_c.$$

$$\Rightarrow \quad d\theta = -dQ\left[\frac{1}{C_h} + \frac{1}{C_c}\right]$$

$$\Rightarrow d\theta = -U dA \theta \left[\frac{1}{C_c} + \frac{1}{C_h}\right]$$

$$\Rightarrow \frac{d\theta}{\theta} = -U dA\left[\frac{1}{C_h} + \frac{1}{C_c}\right]$$

Integrating both sides,

$$\int_{\theta_1}^{\theta_2} \frac{d\theta}{\theta_1} = -U\left[\frac{1}{C_h} + \frac{1}{C_c}\right]\int_0^A dA$$

$$\Rightarrow \ln\frac{\theta_2}{\theta_1} = -UA\left[\frac{1}{C_h} + \frac{1}{C_c}\right]$$

But $Q = C_h(T_{h_1} - T_{h_2}) \Rightarrow C_h = \dfrac{Q}{T_{h_1} - T_{h_2}}$

& $Q = C_c(T_{c_2} - T_{c_1}) \Rightarrow C_c = \dfrac{Q}{T_{c_2} - T_{c_1}}$

$$\therefore \ln\frac{\theta_2}{\theta_1} = -\frac{UA}{Q}\left[T_{h_1} - T_{h_2} + T_{c_2} - T_{c_1}\right]$$

$$\Rightarrow \ln\frac{\theta_2}{\theta_1} = \frac{-UA}{Q}\left[(T_{h_1} - T_{c_1}) - (T_{h_2} - T_{c_2})\right]$$

$$\Rightarrow \ln\frac{\theta_2}{\theta_1} = \frac{UA}{Q}(\theta_2 - \theta_1)$$

$$\Rightarrow \boxed{Q = UA\frac{(\theta_2 - \theta_1)}{\ln\frac{\theta_2}{\theta_1}}} = UA\theta_m$$

Where, $\boxed{\theta_m = \dfrac{\theta_2 - \theta_1}{\ln\frac{\theta_2}{\theta_1}}}$

9 $T_{c_1} = 15^\circ C$

b $m_c = 1300\ kg/hr$, $C_c = 4200\ J/kg K$

$C_h = 2000\ J/kg K$

$m_h = 550\ kg/h$

$T_{h_1} = 94^\circ C$

$A = 1 m^2$

$U = 1075\ W/m^2 K.$

Now, $C_c = m_c C_c = \frac{1300}{3600} \times 4200 = 1511.6\ W/K = C_{max}$

$C_h = m_h C_h = \frac{530}{3600} \times 2000 = 305.55\ W/K = C_{min}$

$C = \frac{C_{min}}{C_{max}} = \frac{305.55}{1511.6} = 0.202$

$NTU = \frac{UA}{C_{min}} = \frac{1075}{305.55} = 3.518.$

for counter flow,

$$\epsilon = \frac{1 - e^{-NTU(1-c)}}{1 - c e^{-NTU(1-c)}} = \frac{1 - e^{-3.578(1-0.202)}}{1 - 0.202 e^{-3.518(1-0.202)}}$$

$\Rightarrow$ $\boxed{\epsilon = 0.95}$

Also

Again, $\epsilon = \dfrac{C_c\,(T_{c_2} - T_{c_1})}{C_{min}\,(T_{h_1} - T_{c_1})} = \dfrac{1511.6}{305.55}\left(\dfrac{T_{c_2} - 15}{90 - 15}\right)$

$\Rightarrow \quad \boxed{T_{c_2} = 30.17^\circ C}$

$Q = m_c C_c\,(T_{c_2} - T_{c_1}) = 1511.6\,(30.17 - 15)$

$\Rightarrow \quad \boxed{Q = 22.93 \times 10^3\ W}$