



# POSTAL BOOK PACKAGE 2026

## MECHANICAL ENGINEERING

### ..... CONVENTIONAL Practice Sets

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#### HEAT TRANSFER

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# Introduction and Basic Concepts

## Practice Questions : Level-I

- Q.1** The ratio of radius of the earth's orbit to that of sun is 216 : 1. The solar insolation on the earth is  $1.4 \text{ kW/m}^2$ .

Find the surface temperature of the sun if it assumed to be an ideal radiator (black body).

**Solution:**

**Given data:**  $\frac{R}{r} = 216$ ; where  $r$  is radius of the sun and  $T$  is the surface temperature of the sun. Therefore,

Total radiation from the sun,  $Q_r = 1.4 \times 4\pi R^2$ ; where  $R$  is the radius of the earth's orbit.

Total radiation emitted by the sun,  $Q_r = \sigma 4\pi r^2 T^4$

Therefore,  $\sigma 4\pi r^2 T^4 = 1.4 \times 4\pi R^2$

$$\therefore T^4 = \frac{1.4 \times 10^3}{5.67 \times 10^{-8}} \times (216)^2 = 0.1152 \times 10^{16} \text{ K}^4$$

$$T = 5826 \text{ K}$$

- Q.2** A pipe 2 cm in diameter at  $40^\circ\text{C}$  is placed in (i) an air flow at  $50^\circ\text{C}$ , with  $h = 20 \text{ W/m}^2\text{K}$  and in (ii) water at  $30^\circ\text{C}$  with  $h = 70 \text{ W/m}^2\text{K}$ . Find the heat transfer rate per unit length of the pipe.

**Solution:**

**Given data:**  $D = 2 \text{ cm}$ ,  $T_w = 40^\circ\text{C}$

The definition of the mean heat transfer coefficient gives

$$Q = hA(T_w - T_\infty)$$

Here,  $T_w = 40^\circ\text{C}$ , and since 1 m length of pipe is being considered

$$A = \pi DL = \pi \times 0.02 \text{ m}^2$$

$$\therefore Q = h\pi \times 0.02 \times (40 - T_\infty)$$

For case (i),

$$h = 20 \text{ W/m}^2\text{K}, T_\infty = 50^\circ\text{C}$$

$$Q = 20 \times \pi \times 0.02 \times (40 - 50) = -12.57 \text{ W}$$

The negative sign indicates that the heat transfer is from the air to the cylinder.

For case (ii),

$$h = 70 \text{ W/m}^2\text{K}, T_\infty = 30^\circ\text{C}$$

$$Q = 70 \times \pi \times 0.02 \times (40 - 30) = 43.98 \text{ W}$$

This result is positive which indicates the heat transfer to be occurring from the cylinder to the water.

**Q3** The outer surface temperature of a refrigerator is  $16^{\circ}\text{C}$  where  $h = 10 \text{ W/m}^2\text{K}$  and the room temperature is  $20^{\circ}\text{C}$ . The sides are 3 cm thick and  $k = 0.1 \text{ W/mK}$ . Find the net heat flow and inside temperature of the refrigerator.

**Solution:**

**Given data:**  $T_{s,0} = 16^{\circ}\text{C}$ ;  $T_{\infty} = 20^{\circ}\text{C}$ ,  $L = 0.03 \text{ cm}$ ,  $h = 10 \text{ W/m}^2\text{K}$ ,  $k = 0.1 \text{ W/mK}$

Convective heat flux to the surface

$$q = \frac{Q}{A} = h(T_{s,0} - T_{\infty}) = 10(16 - 20) = -40 \text{ W/m}^2$$

Since this must be equal to the heat conducted through the sides,

$$q = -k \frac{dT}{dx} = -k \frac{T_{s,0} - T_{s,i}}{L}$$

$$\therefore T_{s,i} = -\frac{qL}{k} + T_{s,0} = -\frac{40 \times 0.03}{0.1} + 16 = 4^{\circ}\text{C}$$

**Q4** A steam pipe (O.D. = 10 cm,  $T_s = 500 \text{ K}$ ,  $\epsilon = 0.8$ ) passing through a large room at  $300 \text{ K}$ . The pipe loss heat by natural convection ( $h = 15 \text{ W/m}^2\text{K}$ ) and radiation.

Find: (i) the surface emissive power of the pipe, (ii) the total radiation falling upon the pipe, and (iii) the total rate of heat loss from the pipe.

**Solution:**

**Given data:**  $D_0 = 10 \text{ cm}$ ;  $T_s = 500 \text{ K}$ ,  $T_R = 300 \text{ K}$ ,  $\epsilon = 0.8$

(i) Surface emissive power of the pipe,

$$E = \epsilon \sigma T_s^4 = 0.8 \times 5.67 \times 10^{-8} \times (500)^4 = 2835 \text{ W/m}^2$$

(ii) Total radiation falling upon the pipe surface = Total radiation leaving the surface,

$$G = \sigma T_R^4 = 5.67 \times 10^{-8} \times (300)^4 = 459.27 \text{ W/m}^2$$

(iii) Heat loss from pipe by radiation,

$$Q_r = \epsilon A \sigma (T_s^4 - T_R^4) = 0.8 \times \pi \times 0.1 \times 5.67 \times 10^{-8} \times (500^4 - 300^4) = 775.21 \text{ W/m}^2$$

Heat loss by natural convection,

$$Q_c = h_c A (\Delta T) = 15 \times \pi \times 0.1 \times (500 - 300) = 942.5 \text{ W/m}$$

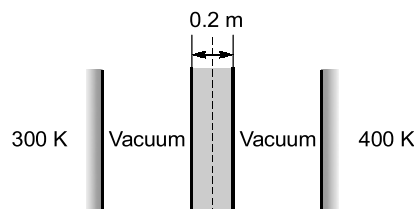
Thus, total rate of heat loss,

$$Q = Q_c + Q_r = 942.5 + 775.21 = 1717.71 \text{ W/m}$$

**Q5** A 0.2 m thick infinite black plate having a thermal conductivity of  $3.96 \text{ W/m-K}$  is exposed to two infinite black surfaces at  $300 \text{ K}$  and  $400 \text{ K}$  as shown in the figure. At steady state the surface temperature of the plate facing the cold side is  $350 \text{ K}$ . The value of Stefan-Boltzmann constant  $\sigma$  is

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

Assuming 1-D heat conduction, find the magnitude of heat flux through the plate (in  $\text{W/m}^2$ ).



**Solution:**

Given data:  $T_c = 300 \text{ K}$ ;  $T_h = 400 \text{ K}$ ;  $T_s = 350 \text{ K}$

Under steady state condition, all rate of heat transfer i.e. from surface at 400 K to black plate (via radiation), inside black plate (via conduction) and from black plate to surface at 300 K (via radiation) are equal.

So, heat flux through wall = Radiation flux from wall to surface at 300 K

$$\begin{aligned}
 &= \frac{\sigma(T_s^4 - T_c^4)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} \quad \therefore \epsilon_1 = \epsilon_2 = 1 \\
 &= \frac{5.67 \times 10^{-8} (350^4 - 300^4)}{\frac{1}{1} + \frac{1}{1} - 1} = 391.584 \text{ W/m}^2
 \end{aligned}$$

**Q6** A coolant fluid at 30°C flows over a heated flat plate maintained at a constant temperature of 100°C. The boundary layer temperature distribution at a given location on the plate may be approximated as  $T = 30 + 70 \exp(-y)$  where  $y$  (in m) is the distance normal to the plate and  $T$  is in °C. If thermal conductivity of the fluid is 1.0 W/mK, the local convective heat transfer coefficient (in W/m²K) at that location will be

**Solution:**

At  $y = 0$ ;

$$q_{\text{cond}} = q_{\text{conv}}$$

$$-k_f \left. \frac{\partial T}{\partial y} \right|_{y=0} = h \Delta T = h(T_s - T_\infty)$$

$$-(1) \left. \frac{\partial}{\partial y} [30 + 70 e^{-y}] \right|_{y=0} = h(100 - 30)$$

$$-[0 + 70(-1) e^{-y}]_{y=0} = h(70)$$

$$70 e^{-0} = h(70)$$

$$h = 1 \text{ W/m}^2\text{K}$$

or

**Alternative :**

Given data:

$$T_\infty = 30^\circ\text{C}, T_s = 100^\circ\text{C}, k_f = 1 \text{ W/mK},$$

$$T = 30 + 70 \exp(-y)$$

Differentiating w.r.t  $y$ , we get

$$\frac{dT}{dy} = -70 e^{-y}$$

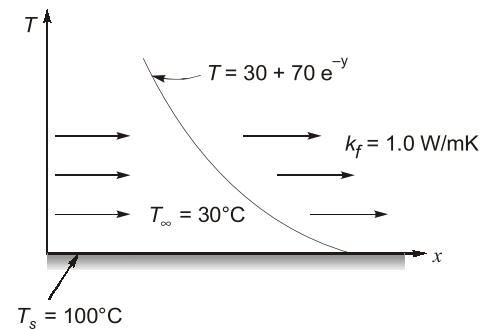
At

$$y = 0$$

$$\left( \frac{dT}{dy} \right)_{y=0} = -70$$

We know that local convective heat transfer coefficient:

$$h_x = \frac{-k_f \left( \frac{dT}{dy} \right)_{y=0}}{T_s - T_\infty} = \frac{-1 \times (-70)}{100 - 30} = 1 \text{ W/m}^2\text{K}$$



## Practice Questions : Level-II

**Q.7** The sun may be regarded as a black body with a surface temperature of 5600 K at a mean distance of  $15 \times 10^{10}$  m from the earth. The diameter of the sun is  $1.4 \times 10^9$  m and that of the earth is  $12.8 \times 10^6$  m. Make calculations for

- the total energy radiated by the sun,
- the energy received per  $\text{m}^2$  just outside the earth's atmosphere,
- the total energy the earth would receive if no energy were blocked by the earth's atmosphere,
- the energy received by a  $1.25 \times 1.25$  m solar collector whose perpendicular is inclined at  $35^\circ$  to the sun. The energy loss through the atmosphere is 35% and the diffuse radiation is 15% of direct radiation.

**Solution:**

Given data:  $T = 5600$  K

- (a) For the sun:  $\epsilon = 1$  (Black body) and Surface area  $= 4\pi r^2 = 4\pi(0.7 \times 10^9)^2$

$\therefore$  Energy radiated by the sun,

$$Q = \epsilon \sigma_b A T^4 = 1 \times (5.67 \times 10^{-8}) \times 4\pi (0.7 \times 10^9)^2 \times (5600)^4 = 3.43 \times 10^{26} \text{ W}$$

- (b) The sun may be regarded as a point source at a distance of  $15 \times 10^{10}$  m from the earth. The mean area over which the radiation is distributed becomes  $4\pi(15 \times 10^{10})^2$

$\therefore$  Radiation received at this distance

$$= \frac{3.43 \times 10^{26}}{4\pi(15 \times 10^{10})^2} = 1.213 \times 10^3 \text{ W/m}^2$$

- (c) The earth is nearly spherical and as such the energy received by it will be proportional to the perpendicular projected area, i.e., that of a circle.

$\therefore$  Energy received by the earth  $= 1.213 \times 10^3 \times \pi(6.4 \times 10^6)^2 = 1.56 \times 10^{17} \text{ W}$

- (d) Direct energy reaching the earth,

$$= \left(1 - \frac{35}{100}\right) \times 1.213 \times 10^3 = 788.45 \times 10^3 \text{ W/m}^2$$

$$\text{Diffused radiation, } = \frac{15}{100} \times 0.788 \times 10^3 = 118.2675 \text{ W/m}^2$$

Total radiation reaching the plate,

$$788.45 + 118.2675 = 906.7175$$

Since the plate surface is not oriented perpendicular to the incoming radiations, the relevant area is equivalent to the projected perpendicular surface area.

$$\text{Projected plate area} = A \cos \theta = 1.25 \times 1.25 \times \cos 35 = 1.28 \text{ m}^2$$

$\therefore$  Energy received by the plate  $= 906.7174 \times 1.28 = 1160.6 \text{ W}$

A reduction in energy received due to inclination explains the variation in solar intensity with season and much reduced solar intensity at the poles of earth.