



POSTAL BOOK PACKAGE 2025

MECHANICAL ENGINEERING

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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 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°C is placed in (i) an air flow at 50°C , with $h = 20 \text{ W/m}^2\text{K}$ and in (ii) water at 30°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°C where $h = 10 \text{ W/m}^2\text{K}$ and the room temperature is 20°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: $T_{s,0} = 16^{\circ}$; $T_{\infty} = 20^{\circ}\text{C}$, $L = 0.03 \text{ cm}$, $h = 10 \text{ W/m}^2\text{K}$, $k = 0.1 \text{ W/mK}$
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 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,

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

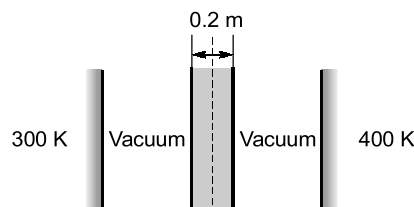
Thus, total rate of heat loss,

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

Q5 A 0.2 m thick infinite black plate having a thermal conductivity of 3.96 W/m-K is exposed to two infinite black surfaces at 300 K and 400 K as shown in the figure. At steady state the surface temperature of the plate facing the cold side is 350 K. The value of Stefan-Boltzmann constant σ 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 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 $y = 0$;

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

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

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

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

$$70 e^0 = h(70)$$

or

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

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

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

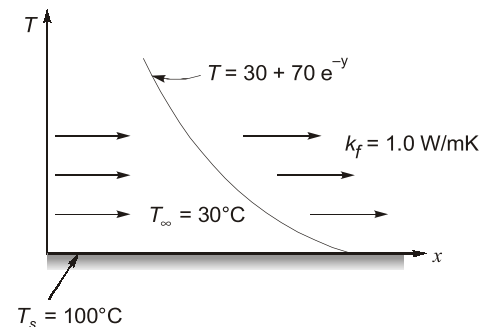
At

$$y = 0$$

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

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 15×10^{10} m from the earth. The diameter of the sun is 1.4×10^9 m and that of the earth is 12.8×10^6 m. Make calculations for

- (a) the total energy radiated by the sun,
- (b) the energy received per m^2 just outside the earth's atmosphere,
- (c) the total energy the earth would receive if no energy were blocked by the earth's atmosphere,
- (d) the energy received by a 1.25×1.25 m solar collector whose perpendicular is inclined at 35° 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 15×10^{10} 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.