

BITS PILANI, DUBAI CAMPUS
FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: COMPREHENSIVE EXAM

Date: 4 June 2013

Duration: 3 hours

Maximum Marks: 40

Note: *Attempt ALL questions. Mention appropriate units in your answers.*

Without units, the answer will not be deemed as correct, even if the numerical value is correct. Assume missing data, if any, reasonably.

- 1(a) The insulation boards for air conditioning purposes are made of three layers, middle being of packed glass 10 cm thick and the sides are made of plywood each of 5 cm thickness ($k = 0.12 \text{ W/m.K}$). The outermost surface is at 45°C and the innermost surface is at 20°C . If the heat flow per unit area is 6 W/m^2 , what is the thermal conductivity of packed glass used? Also calculate the interface temperatures. [5]
- 1(b) A very long 3-mm diameter copper rod ($k = 305 \text{ W/mK}$) extends horizontally from a plane heated wall at 100°C . The temperature of the surrounding air is 28°C and convective heat transfer coefficient is $18 \text{ W/m}^2\text{K}$. Determine the heat loss. [4]
- 2(a) During a heat treatment process, spherical steel balls of 15 mm diameter are initially heated to 650°C in a furnace. Then they are cooled to 100°C by keeping them immersed in an oil bath at 35°C , with a convective heat transfer coefficient $70 \text{ W/m}^2\text{.}^\circ\text{C}$. [4]
- (i) Determine the time required for the cooling process.
- (ii) If it is desired to complete the cooling process in a period of 3 minutes, what will be the required value of convective heat transfer coefficient?
- Properties of steel balls: Density = 7750 kg/m^3 , specific heat = $520 \text{ J/kg.}^\circ\text{C}$, Thermal conductivity = $50 \text{ W/m.}^\circ\text{C}$
- 2(b) A very large slab of copper ($k = 310 \text{ W/m.K}$, thermal diffusivity = $2.4 \times 10^{-5} \text{ m}^2/\text{s}$) is initially at a temperature of 330°C . The surface temperature is suddenly lowered to 45°C . What is the temperature at a depth of 5 cm, 4 min after the surface temperature is changed? [3]
- 3 Air is flowing over a flat plate 10-m long and 2-m wide (maintained at 90°C) with a velocity of 9.5 m/s at 25°C . Given, density = 1.27 kg/m^3 , and kinematic viscosity = $1.45 \times 10^{-5} \text{ m}^2/\text{s}$, $k = 0.025 \text{ W/m.K}$, heat capacity = 990 J/kg.K .
- (i) Calculate the length of the plate over which the boundary layer is laminar,
- (ii) Calculate the laminar boundary layer thickness at the point of transition, using Blasius' exact solution,
- (iii) Calculate the thickness of the thermal boundary layer at this point, assuming that the plate is being heated over its entire length.

- 4(a) Consider two large parallel plates, one at 677°C with emissivity 0.8 and the other at 227°C having emissivity 0.6. A radiation shield is placed between them. The shield has emissivity 0.1 on the side facing hot plate and 0.3 on the side facing cold plate.

(i) Calculate the percent reduction in radiation heat transfer as a result of radiation shield.

(ii) Calculate the temperature of the shield.

(iii) Now, the shield is reversed, so that it has emissivity 0.1 on the side facing the cold plate. Will the temperature of the shield be affected? How? [6]

- 4(b) Consider a system of concentric spheres of radius r_1 and r_2 ($r_2 > r_1$). If $r_1 = 5$ cm, determine the radius r_2 if it is desired to have the value of shape factor F_{21} equal to 0.5. [2]

- 5 In a parallel flow heat exchanger, process fluid is cooled from a temperature of 103°C to 80°C with cooling water available at 27°C . The overall heat transfer coefficient is $450 \text{ W/m}^2\cdot^{\circ}\text{C}$. The flow rates are: process fluid = 28 kg/s , cooling water = 14 kg/s . Heat capacity of process fluid is $2090 \text{ J/kg}\cdot^{\circ}\text{C}$, and that of cooling water is $4180 \text{ J/kg}\cdot^{\circ}\text{C}$. Calculate: [5]

(a) The area of the exchanger,

(b) What will be the area if counter flow exchanger is used?

- 6(a) A vertical plate 0.7 m high and maintained at 33°C is exposed to saturated steam at atmospheric pressure. Calculate the rate of heat transfer, and the condensate rate per hour per meter of the plate width for film-wise condensation. [3]

The properties of water film at the mean temperature are:

Density = 985.0 kg/m^3 , thermal conductivity = $66.4 \times 10^{-2} \text{ W/m}\cdot\text{K}$,

Viscosity = $62 \times 10^{-5} \text{ kg/m}\cdot\text{s}$, $h_{fg} = 2260 \text{ kJ/kg}$.

Assume vapor density is small compared to that of the condensate.

- 6(b) In the tubes of a forced-convection reboiler, toluene is vaporized. Estimate the Lockhart-Martinelli parameter at a point where 40% of the liquid has been vaporized. The liquid velocity at the tube inlet is 2.5 m/s and the operating pressure is 0.5 bar . Given Physical property data: [2]

Liquid density = 910 kg/m^3

Liquid viscosity = 2.5 mNs/m^2

Vapor viscosity = 0.02 mNs/m^2

Vapor density = 2.9 kg/m^3 at NTP

Liquid thermal conductivity = $0.19 \text{ W/m}\cdot^{\circ}\text{C}$

Liquid heat capacity = $1.85 \text{ kJ/kg}\cdot^{\circ}\text{C}$

*** END OF PAPER ***

Note: Attempt ALL questions. Mention appropriate units in your answers.
Without units, the answer will not be deemed as correct, even if the numerical value is correct. Assume missing data, if any, reasonably.

SOLUTION

- 1 (a) The insulation boards for air conditioning purposes are made of three layers, middle being of packed glass 10 cm thick and the sides are made of plywood each of 5 cm thickness ($k = 0.12 \text{ W/m.K}$). The outermost surface is at 45°C and the innermost surface is at 20°C . If the heat flow per unit area is 6 W/m^2 , what is the thermal conductivity of packed glass used? Also calculate the interface temperatures. [5]

Solution:

$$q = \frac{T_1 - T_4}{\frac{\Delta x_A}{k_A A} + \frac{\Delta x_B}{k_B A} + \frac{\Delta x_C}{k_C A}}$$

Heat loss per unit area,

$$\frac{q}{A} = 6 = \frac{45 - 20}{\frac{0.05}{0.12} + \frac{0.1}{k} + \frac{0.05}{0.12}} = \frac{25}{0.4167 + \frac{0.1}{k} + 0.4167} = \frac{25}{0.8334 + \frac{0.1}{k}}$$

$$\text{Or } \frac{25}{6} = 4.1667 = 0.8334 + \frac{0.1}{k} \quad \text{or } k = 0.030$$

$$\text{Interface temperatures: } q = -k_A A \frac{(T_2 - T_1)}{\Delta x_A} = -k_B A \frac{(T_3 - T_2)}{\Delta x_B} = -k_C A \frac{(T_4 - T_3)}{\Delta x_C}$$

$$\frac{q}{A} = -k_A \frac{(T_2 - T_1)}{\Delta x_A} = -0.12 \frac{T_2 - 20}{0.05} = 6.0 \quad \text{Or } T_2 = 20 + 2.5 = 22.5^\circ\text{C}$$

$$\text{Similarly, } \frac{q}{A} = -k_C \frac{(T_4 - T_3)}{\Delta x_C} = -0.12 \frac{45 - T_3}{0.05} = 6.0 \quad \text{Or } T_3 = 45 - 2.5 = 42.5^\circ\text{C}$$

- 1(b) A very long 3-mm diameter copper rod ($k = 305 \text{ W/mK}$) extends horizontally from a plane heated wall at 100°C . The temperature of the surrounding air is 28°C and convective heat transfer coefficient is $18 \text{ W/m}^2\text{K}$. Determine the heat loss. [4]

Solution:

$$d = 3 \text{ mm}, k = 305 \text{ W/m.K}, T_o = 100^\circ\text{C}, T_a = 28^\circ\text{C}, h = 18.0 \text{ W/m}^2\text{K}$$

a) Heat loss from an infinitely long fin is given by,

$$q = k.A.m.(T_o - T_a) = (hPkA)^{0.5} \cdot \theta_o \quad \text{where } P = \pi.d = \pi \times 0.003 = 9.425 \times 10^{-3}$$

$$\text{and } A = \pi.d^2/4 = 7.0686 \times 10^{-6}$$

$$m = \sqrt{\frac{hP}{kA_c}} = \left[\frac{18 \times 9.425 \times 10^{-3}}{305 \times 7.0686 \times 10^{-6}} \right]^{0.5} = \sqrt{78.69} = 8.871$$

$$q = 305 \times 7.0686 \times 10^{-6} \times 8.871 (100 - 28) = \mathbf{1.377 \text{ W}}$$

- 2 (a) During a heat treatment process, spherical steel balls of 15 mm diameter are initially heated to 650°C in a furnace. Then they are cooled to 100°C by keeping them immersed in an oil bath at 35°C , with a convective heat transfer coefficient $70 \text{ W/m}^2\text{.}^\circ\text{C}$. [4]

- Determine the time required for the cooling process.
- If it is desired to complete the cooling process in a period of 3 minutes, what will be the required value of convective heat transfer coefficient?

Properties of steel balls: Density = 7750 kg/m^3 , specific heat = $520 \text{ J/kg.}^\circ\text{C}$,

Thermal conductivity = $50 \text{ W/m.}^\circ\text{C}$

Solution:

Characteristic dimension, $l = \text{volume} / \text{surface-area} = r/3 = 0.0025 \text{ m}$

$$Bi = h.l/k = 0.0035 < 0.1 \quad \text{so LSA is applicable.}$$

$$i. \quad b = h.A/\rho.C_p.V = 70/(7750 \times 520 \times 0.0025) = 0.00695$$

$$(T - T_a) / (T_i - T_a) = \exp[-b.t] = (100 - 35) / (650 - 35) = 65/615 = 0.1057$$

$$= [-0.00695 t] = -2.2472 \text{ or } t = \mathbf{323.34 \text{ s}}$$

- If cooling is required in 3 minutes,

$$(h.A/ \rho.C_p.V).t = h \times (3 \times 60)/ (7750 \times 520 \times 0.0025) = 0.01784 \text{ h} = 2.2472$$

$$\text{or } h = 125.96 \text{ W/m}^2.\text{ }^{\circ}\text{C}$$

- 2 (b) A very large slab of copper ($k = 310 \text{ W/m.K}$, thermal diffusivity $= 2.4 \times 10^{-5} \text{ m}^2/\text{s}$) is initially at a temperature of 330°C . The surface temperature is suddenly lowered to 45°C . What is the temperature at a depth of 5 cm, 4 min after the surface temperature is changed? [3]

Solution:

$$\frac{x}{2\sqrt{\alpha t}} = \frac{0.05}{2\sqrt{2.4 \times 10^{-5} \times 240}} = 0.329$$

$\text{Erf}(0.329) = 0.359245$ from Appendix-A

$$\text{From equation (4.8), } \frac{T - T_o}{T_i - T_o} = \text{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right) = \frac{T - 45}{330 - 45} = 0.359245 \quad \text{Or } T = 147.385$$

- 3 Air is flowing over a flat plate 10-m long and 2-m wide (maintained at 90°C) with a velocity of 9.5 m/s at 25°C . Given, density $= 1.27 \text{ kg/m}^3$, and kinematic viscosity $= 1.45 \times 10^{-5} \text{ m}^2/\text{s}$, $k = 0.025 \text{ W/m.K}$, heat capacity $= 990 \text{ J/kg.K}$.

- Calculate the length of the plate over which the boundary layer is laminar,
- Calculate the laminar boundary layer thickness at the point of transition, using Blasius' exact solution,
- Calculate the thickness of the thermal boundary layer at this point, assuming that the plate is being heated over its entire length.
- Average heat transfer coefficient. [6]

Solution:

$$(a) \text{ For laminar flow, } Re_x = 5 \times 10^5 \quad \text{So, } x = \frac{Re_x \nu}{u_{\infty}} = \frac{5 \times 10^5 \times 1.45 \times 10^{-5}}{9.5} = 0.763 \text{ m}$$

$$(b) \frac{\delta}{x} = \frac{5.0}{\sqrt{Re_x}} \quad \delta = 0.763 \times \frac{5.0}{\sqrt{5 \times 10^5}} = 5.395 \text{ mm}$$

$$(c) \frac{\delta_t}{\delta} = \frac{1}{1.026 \times (Pr)^{0.33}} \quad Pr = \frac{C_p \mu}{k} = \frac{\rho \nu C_p}{k} = \frac{990 \times 1.45 \times 10^{-5} \times 1.27}{0.025} = 0.729$$

$$\text{So, } \delta_t = \frac{5.395 \times 10^{-3}}{1.026 \times (0.729)^{0.333}} = 5.842 \text{ mm}$$

$$(d) \ Nu = \frac{x\bar{h}}{k} = 0.664(\text{Re}_x)^{0.5}(\text{Pr})^{0.333} = 0.664(5.0 \times 10^5)^{0.5}(0.729)^{0.333} = 422.61$$

$$\bar{h} = 422.61 \frac{0.025}{0.763} = 13.847 \text{ W/m}^2 \cdot ^\circ\text{C}$$

- 4 (a) Consider two large parallel plates, one at 677°C with emissivity 0.8 and the other at 227°C having emissivity 0.6. A radiation shield is placed between them. The shield has emissivity 0.1 on the side facing hot plate and 0.3 on the side facing cold plate. (i) Calculate the percent reduction in radiation heat transfer as a result of radiation shield. (ii) Calculate the temperature of the shield. (iii) Now, the shield is reversed, so that it has emissivity 0.1 on the side facing the cold plate. Will the temperature of the shield be affected? How? [6]

Solution:

$$\frac{(Q_{12})_{\text{no-shield}}}{A} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \frac{(5.67 \times 10^{-8})(950^4 - 500^4)}{\frac{1}{0.8} + \frac{1}{0.6} - 1} = \frac{42638.88}{1.9167} = 22.246 \text{ kW}$$

$$\frac{(Q_{12})_{\text{with-shield}}}{A} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} + \frac{1}{\varepsilon_{s1}} + \frac{1}{\varepsilon_{s2}} - 2} = \frac{(5.67 \times 10^{-8})(950^4 - 500^4)}{\frac{1}{0.8} + \frac{1}{0.6} + \frac{1}{0.1} + \frac{1}{0.3} - 2} = \frac{42638.88}{14.25} = 2.992 \text{ kW}$$

$$\% \text{ reduction} = 86.55\%$$

Original shield:

$$\frac{Q}{A} = \frac{\sigma(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_{s1}} - 1} = \frac{\sigma(950^4 - T_3^4)}{\frac{1}{0.8} + \frac{1}{0.1} - 1} = 2992 \quad \text{or } T = 723.83 \text{ K} = 450.83^\circ\text{C}$$

Reversed shield:

$$\frac{Q}{A} = \frac{\sigma(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_{s1}} - 1} = \frac{\sigma(950^4 - T_3^4)}{\frac{1}{0.8} + \frac{1}{0.3} - 1} = 2992 \quad \text{or } T = 889.32 \text{ K} = 616.32^\circ\text{C}$$

- 4 (b) Consider a system of concentric spheres of radius r_1 and r_2 ($r_2 > r_1$). If $r_1 = 5$ cm, determine the radius r_2 if it is desired to have the value of shape factor F_{21} equal to 0.5. [2]

Solution:

$$(a) \quad A_1 F_{12} = A_2 F_{21} \quad \text{but} \quad F_{12} = 1.0$$

$$\text{So } \frac{\pi}{4} (0.05)^2 \times 1.0 = \frac{\pi}{4} r^2 \times 0.5 \quad \text{or} \quad r_2 = \left[\frac{(0.05)^2}{0.5} \right]^{0.5} = 0.07071 \text{ m} = 7.071 \text{ cm}$$

- 5 In a parallel flow heat exchanger, process fluid is cooled from a temperature of 103 °C to 80 °C with cooling water available at 27 °C. The overall heat transfer coefficient is 450 W/m².°C. The flow rates are: process fluid = 28 kg/s, cooling water = 14 kg/s. Heat capacity of process fluid is 2090 J/kg.°C, and that of cooling water is 4180 J/kg.°C. Calculate: [5]

- (a) The area of the exchanger,
(b) What will be the area if counter flow exchanger is used?

Solution:

$$q = 28 \times 2090 (103 - 80) = 14 \times 4180 (t_2 - 27) = 1345.96 \text{ kW} \quad \text{and } t_2 = 50 \text{ } ^\circ\text{C}$$

$$LMTD_p = \frac{76 - 30}{\ln \frac{76}{30}} = \frac{46}{0.9295} = 49.487$$

$$A_{parallel} = \frac{Q}{U \times LMTD} = \frac{1345960}{450 \times 49.487} = 60.44 \text{ m}^2 \quad LMTD_c = 53$$

$$A_{counter} = \frac{Q}{U \times LMTD} = \frac{1345960}{450 \times 53} = 56.43 \text{ m}^2$$

- 6 (a) A vertical plate 0.7 m high and maintained at 33 °C is exposed to saturated steam at atmospheric pressure. Calculate the rate of heat transfer, and the condensate rate per hour per meter of the plate width for film-wise condensation. [3]

The properties of water film at the mean temperature are:

Density = 985.0 kg/m³, thermal conductivity = 66.4 X 10⁻² W/m.K,

Viscosity = 62 X 10⁻⁵ kg/m.s, h_{fg} = 2260 kJ/kg.

Assume vapor density is small compared to that of the condensate.

Solution:

$$\text{Rate of heat transfer per unit width, } Q = \bar{h} A (T_{sat} - T_w)$$

$$\bar{h} = 0.943 \left[\frac{\rho_L (\rho_L - \rho_v) g h_{fg} k_f^3}{L \mu_f (T_{sat} - T_w)} \right]^{1/4} = 0.943 \left[\frac{\rho_L^2 g h_{fg} k_f^3}{L \mu_f (T_{sat} - T_w)} \right]^{1/4}$$

$$= 0.943 \left[\frac{(985)^2 (9.81) (66.4/100)^3 (2260 \times 1000)}{(0.7) (620 \times 10^{-6}) (100 - 33)} \right]^{1/4} = 3836.17 \text{ W/m}^2 \cdot \text{K} \quad [1]$$

$$Q = 3836.17 \times (0.7 \times 1.0) \times (100 - 33) = 179.92 \text{ kW} \quad [1]$$

Condensate rate,

$$\dot{m} = \frac{Q}{h_{fg}} = 179.92 / 2260 = 0.07961 \text{ kg/s} = 286.59 \text{ kg/h} \quad [1]$$

- 6 (b) In the tubes of a forced-convection reboiler, toluene is vaporized. Estimate the Lockhart-Martinelli parameter at a point where 40% of the liquid has been vaporized. The liquid velocity at the tube inlet is 2.5 m/s and the operating pressure is 0.5 bar. Given Physical property data:

Liquid density = 910 kg/m³

Liquid viscosity = 2.5 mNs/m²

Vapor viscosity = 0.02 mNs/m²

Vapor density = 2.9 kg/m³ at NTP

Liquid thermal conductivity = 0.19 W/m.°C

Liquid heat capacity = 1.85 kJ/kg.°C

Solution:

Lockhart-Martinelli parameter:

$$\frac{1}{X_{tt}} = \left[\frac{0.4}{1 - 0.4} \right]^{0.9} \left[\frac{910}{2.9} \right]^{0.5} \left[\frac{0.02}{2.5} \right]^{0.1}$$

$$= [0.6943] \times [17.7142] \times [0.6170]$$

$$= 7.5885$$

BITS PILANI, DUBAI CAMPUS

FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: TEST – 2 (Open Book)

Date: 28-4-2013

Duration: 50 Minutes

Maximum Marks: 20

Note: *Attempt ALL questions. Mention appropriate units in your answers. Without units, the answer will not be deemed as correct, even if the numerical value is correct. Assume missing data, if any, reasonably.*

Question 1: [6 Marks]

Air at atmospheric pressure and 22 °C flows over a flat plate with a velocity of 3.5 m/s. the plate is 30 cm wide heated uniformly throughout its entire length and maintained at a temperature of 78 °C. Calculate the following at 35 cm distance from the leading edge:

- (a) Thickness of hydrodynamic and thermal boundary layers, using exact solution,
- (b) Local and average heat transfer coefficients.

Properties of air: $\rho = 1.18 \text{ kg/m}^3$, $\nu = 17 \times 10^{-6} \text{ m}^2/\text{s}$, $C_p = 1007 \text{ J/kg}^\circ\text{C}$, $k = 0.0272 \text{ W/m}^\circ\text{C}$.

Question 2: [5 Marks]

Air at 1 atm and 90 °C is heated as it flows through a tube with 5.0 cm diameter at a velocity of 6 m/s. Calculate the heat transfer per unit length of tube if a constant-flux condition is maintained at the wall and the wall is 25 °C above the air temperature, all along the length of the tube. Use Sieder and Tate equation, neglect viscosity correction.

Given: Air properties at bulk temperature: Density = 1.42 kg/m^3 ,
kinematic viscosity = $1.95 \times 10^{-5} \text{ m}^2/\text{s}$, $k = 0.035 \text{ W/m.K}$, specific heat = 1.1 kJ/kg.K

Question 3: [5 Marks]

Air at 1 atm and 15 °C blows across a 20-cm diameter cylinder at a velocity of 19 m/s. The cylinder surface is maintained at 98 °C. Calculate the heat loss per unit length of the cylinder.

Given: Air properties at film temperature: Viscosity = $2.04 \times 10^{-5} \text{ kg/m.s}$,
Thermal conductivity = 0.031 W/m.K , Density = 1.3 kg/m^3 , $Pr = 0.695$

Question 4: [4 marks]

A horizontal tube of 2.5 cm diameter is exposed to steam at atmospheric pressure. The tube temperature is 98 °C. Calculate the heat transfer and mass of steam condensed per hour?

Properties: $\rho_f = 960 \text{ kg/m}^3$, $\mu_f = 2.82 \times 10^{-4} \text{ kg/m.s}$, $k_f = 0.68 \text{ W/m}^\circ\text{C}$, $h_{fg} = 2255 \text{ kJ/kg}$.

*** END OF PAPER ***

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: TEST – 2 (Open Book)

Date: 28-4-2013

Duration: 50 Minutes

Maximum Marks: 20

SOLUTION**Question 1: [6 Marks]**

Air at atmospheric pressure and 22 °C flows over a flat plate with a velocity of 3.5 m/s. the plate is 30 cm wide heated uniformly throughout its entire length and maintained at a temperature of 78 °C. Calculate the following at 35 cm distance from the leading edge:

- Thickness of hydrodynamic and thermal boundary layers,
- Local and average heat transfer coefficients.

Properties of air: $\rho = 1.18 \text{ kg/m}^3$, $\nu = 17 \times 10^{-6} \text{ m}^2/\text{s}$, $C_p = 1007 \text{ J/kg}^\circ\text{C}$, $k = 0.0272 \text{ W/m}^\circ\text{C}$.

Solution:

$$Re_x = \frac{xu_\infty}{\nu} = \frac{0.35 \times 3.5}{17 \times 10^{-6}} = 7.2 \times 10^4 \quad \text{Since } Re_x < 5 \times 10^5 \quad \text{laminar flow} \quad [1]$$

$$(a) \frac{\delta}{x} = \frac{5.0}{\sqrt{Re_x}} \quad \delta = 0.35 \times \frac{5}{\sqrt{7.2 \times 10^4}} = 6.523 \text{ mm} \quad [1]$$

$$\frac{\delta_t}{\delta} = \frac{1}{1.026 \times (Pr)^{0.33}} \quad Pr = \frac{C_p \mu}{k} = \frac{\rho \nu C_p}{k} = \frac{1.18 \times 17 \times 10^{-6} \times 1007}{0.027} = 0.748 \quad [1]$$

$$\text{So, } \delta_t = \frac{6.523}{1.026 \times (0.748)^{0.33}} = 7.003 \text{ mm} \quad [1]$$

$$(b) Nu_x = \frac{xh_x}{k} = 0.332(Re_x)^{0.5}(Pr)^{0.33} = 0.332(7.2 \times 10^4)^{0.5}(0.748)^{0.33} = 80.875 \quad [1]$$

$$h_x = 80.875 \frac{0.027}{0.35} = 6.239 \text{ W/m}^2\text{.}^\circ\text{C} \quad [0.5]$$

$$\text{Average heat transfer coefficient, } \bar{h} = 2 \times h_x = 12.478 \text{ W/m}^2\text{.}^\circ\text{C} \quad [0.5]$$

Question 2: [5 Marks]

Air at 1 atm and 90 °C is heated as it flows thru' a tube with 5.0 cm diameter at a velocity of 6 m/s. Calculate the heat transfer per unit length of tube if a constant-flux condition is maintained at the wall and the wall is 25 °C above the air temperature, all along the length of the tube. Use Sieder and Tate equation, neglect viscosity correction.

Given: Air properties at bulk temperature: Density = 1.42 kg/m³,

Kinematic viscosity = 1.95 X 10⁻⁵ m²/s, k = 0.035 W/m.K, specific heat = 1.1 kJ/kg.K

Solution:

$$\text{Viscosity} = 1.95 \times 10^{-5} \times 1.42 = 2.769$$

$$\text{Calculate } Re_d = \frac{\rho u_m d}{\mu} = \frac{1.42 \times 6 \times 5 \times 10^{-2}}{2.759 \times 10^{-5}} = 15440 \quad [1]$$

So flow is turbulent. $Pr = 11 \times 2.759 \times 10^{-5} / 0.025 = 0.867 \quad [1]$

$$Nu = 0.027(15440)^{0.8} (0.867)^{0.333} = 0.027 \times 2243.5 \times 0.954 = 57.788 \quad [1]$$

$$\text{So, } h = 57.788 \times 0.035 / 0.05 = 40.45 \quad [1]$$

$$\begin{aligned} \text{Heat transfer per unit length, } q/L &= h \cdot \pi \cdot d (T_w - T_b) \\ &= 40.45 \times 3.14 \times 0.05 \times 25 = 158.77 \quad [1] \end{aligned}$$

Question 3: [5 Marks]

Air at 1 atm and 15 °C blows across a 20-cm diameter cylinder at a velocity of 19 m/s. The cylinder surface is maintained at 98 °C. Calculate the heat loss per unit length of the cylinder.

Given: Air properties at film temperature: Viscosity = 2.04×10^{-5} kg/m.s,
Thermal conductivity = 0.031 W/m.K, Density = 1.3 kg/m³, $Pr = 0.695$

Solution:

$$\text{Calculate Reynolds number, } Re_d = \frac{\rho u_\infty d}{\mu} = \frac{1.3 \times 19 \times 20 \times 10^{-2}}{2.04 \times 10^{-5}} = 242,156.86$$

From table 6.2, $C = 0.0266$, $n = 0.805$

From equation (6.17),

$$\frac{hd}{k} = 0.0266(242157)^{0.805} (0.695)^{0.333} = 0.0266(21587.29)(0.8859) = 508.7$$

$$\text{So, } h = 508.7 \times 0.031 / 0.2 = 78.8485$$

The heat transfer per unit length,

$$\frac{q}{L} = \pi h d (T_w - T_\infty) = 78.8485 \times \pi \times 0.2 \times 83 = 4111.98 \text{ W/m}$$

Question 4: [4 marks]

A horizontal tube of 2.5 cm diameter is exposed to steam at atmospheric pressure. The tube temperature is 98 °C. Calculate the heat transfer and mass of steam condensed per hour?

Properties: $\rho_f = 960$ kg/m³, $\mu_f = 2.82 \times 10^{-4}$ kg/m.s, $k_f = 0.68$ W/m.°C, $h_{fg} = 2255$ kJ/kg.

Solution:

$$\bar{h} = 0.725 \left[\frac{\rho_f^2 g h_{fg} k_f^3}{d \mu_f (T_s - T_w)} \right]^{0.25} = 0.725 \left[\frac{(960)^2 (9.8) (2.255 \times 10^6) (0.68)^3}{(0.025) (2.82 \times 10^{-4}) (100 - 98)} \right]^{0.25}$$

$$= 18.821 \text{ kW/m}^2 \text{ } ^\circ\text{C}$$

$$\text{Checking } Re_f = \frac{4 h d (T_{sat} - T_w)}{h_{fg} \mu_f} = \frac{(4) (18821) (0.025) (100 - 98)}{(2.255 \times 10^6) (2.82 \times 10^{-4})} = 1.4998 \text{ laminar flow}$$

$$q = \bar{h} A (T_{sat} - T_w) = \bar{h} (2\pi L) (T_{sat} - T_w) = (18821) (\pi \times 0.025 \times L) (100 - 98) = 2956.4 L \text{ W}$$

$$\dot{m} = \frac{q}{h_{fg}} = \frac{2956.4}{(2.255 \times 10^6)} = 1.311 \times 10^{-3} \text{ kg/s/m} = 4.72 \text{ kg/h/m}$$

*** END OF PAPER ***

BITS PILANI, DUBAI CAMPUS

FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: TEST – 1 (Closed Book)

Date: 10-3-2013

Duration: 50 Minutes

Maximum Marks: 20

Note: *Attempt ALL questions. Mention appropriate units in your answers. Without units, the answer will not be deemed as correct, even if the numerical value is correct. Assume missing data, if any, reasonably.*

1. A thick-walled tube of stainless steel ($k = 19 \text{ W/m.K}$) with 3.2-cm inner diameter and 4-cm outer diameter is covered with a 3-cm layer of insulation ($k = 0.2 \text{ W/m.K}$). If the inside wall temperature of the pipe is maintained at 580°C , calculate the heat loss per meter of length. Also calculate the tube-insulation interface temperature. The temperature at the outer surface of insulation is 100°C . [6]

2. A longitudinal copper fin ($k = 280 \text{ W/m.K}$) 540-mm long and 4-mm diameter is exposed to air stream at 20°C , with $h = 12 \text{ W/m}^2\text{K}$. If the fin base temperature is 150°C , determine
 - (a) The heat transferred,
 - (b) The efficiency of the fin.Neglect the heat loss from the fin tip. [6]

3. A 5-kW resistance heater wire ($k = 12 \text{ W/m.K}$) has a diameter of 3 mm and a length of 0.8 m, and is used to boil water. If the outer surface temperature of the resistance wire is 104°C , determine the temperature at the center of the wire. [4]

4. A copper sphere having a diameter of 3 cm is initially at uniform temperature of 85°C . It is suddenly exposed to an air stream of 18°C with $h = 25 \text{ W/m}^2\text{K}$. How long does it take the sphere temperature to drop to 35°C ?
Given: properties of copper: $\rho = 8950 \text{ kg/m}^3$, $C_p = 383 \text{ J/kg.K}$, $k = 380 \text{ W/m.K}$ [4]

*** END OF PAPER ***

BITS PILANI, DUBAI CAMPUS

FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: TEST – 1 (Closed Book)

Date: 10-3-2013

Duration: 50 Minutes

Maximum Marks: 20

Note: Attempt ALL questions. Mention appropriate units in your answers.

Without units, the answer will not be deemed as correct, even if the numerical value is correct. Assume missing data, if any, reasonably.

Solution

1. A thick-walled tube of stainless steel ($k = 19 \text{ W/m.K}$) with 3.2-cm inner diameter and 4-cm outer diameter is covered with a 3-cm layer of insulation ($k = 0.2 \text{ W/m.K}$). If the inside wall temperature of the pipe is maintained at 580°C , calculate the heat loss per meter of length. Also calculate the tube-insulation interface temperature. [6]

$$r_1 = 1.6 \text{ cm} \quad r_2 = 2.0 \text{ cm} \quad r_3 = 2.0 + 3.0 = 5.0 \text{ cm}$$

$$T_1 = 580^\circ\text{C} \quad T_3 = 100^\circ\text{C}$$

$$k_s = 19 \text{ W/m.K} \quad k_i = 0.2 \text{ W/m.K}$$

$$\frac{q}{L} = \frac{2\pi(T_1 - T_2)}{\frac{\ln r_2/r_1}{k_s} + \frac{\ln r_3/r_2}{k_i}} = \frac{2\pi(580 - 100)}{\frac{\ln 2/1.6}{19} + \frac{\ln 5/2}{0.2}} = 656.61 \text{ W/m}$$

Interface temperature, $T_2 = 578.77^\circ\text{C}$

2. A longitudinal copper fin ($k = 280 \text{ W/m.K}$) 540-mm long and 4-mm diameter is exposed to air stream at 20°C , with $h = 12 \text{ W/m}^2\text{K}$. If the fin base temperature is 150°C , determine

(a) The heat transferred,

(b) The efficiency of the fin.

Neglect the heat loss from the fin tip. [6]

$$L = 540 \text{ mm} = 0.54 \text{ m}, d = 4 \text{ mm} = 0.004 \text{ m}$$

$$T_0 = 150^\circ\text{C}, T_\infty = 20^\circ\text{C}, k = 280 \text{ W/m.K}, h = 12 \text{ W/m}^2\text{K}$$

$$\text{Heat transferred, } q = kA_m(T_0 - T_\infty) \tanh(mL)$$

$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{4h}{kd}} = \left(\frac{4 \times 12}{280 \times 0.004} \right)^{0.5} = 6.5465$$

$$q = 280 \times \left(\frac{\pi}{4} \times 0.004 \right)^2 \times 6.5465 \times (150 - 20) \tanh(6.5465 \times 0.54)$$

$$= 2.942 \text{ W}$$

$$\eta = \frac{\tanh(mL)}{mL} = \frac{\tanh(3.53511)}{3.53511} = 0.2824 = 28\%$$

3. A 5-kW resistance heater wire ($k = 12 \text{ W/m.K}$) has a diameter of 3 mm and a length of 0.8 m, and is used to boil water. If the outer surface temperature of the resistance wire is 104°C , determine the temperature at the center of the wire. [4]

$$k = 12 \text{ W/m.K}, d = 3 \text{ mm}, L = 0.8 \text{ m}, T_s = 104^\circ\text{C}, T_c = ?$$

$$\dot{q} = \frac{\dot{Q}_{GEN}}{\pi r_o^2 L} = \frac{5000}{\pi (0.0015)^2 (0.8)} = 0.884 \times 10^9 \text{ W/m}^3$$

$$T_c = T_s + \frac{\dot{q} R^2}{4k} = 104 + \frac{(0.884 \times 10^9)(0.0015)^2}{4 \times 12} = 104 + 41.45$$

$$= 145.45^\circ\text{C}$$

4. A copper sphere having a diameter of 3 cm is initially at uniform temperature of 85°C . It is suddenly exposed to an air stream of 18°C with $h = 25 \text{ W/m}^2\text{K}$. How long does it take the sphere temperature to drop to 35°C ? [4]

$$d = 0.03 \text{ m}, h = 25 \text{ W/m}^2\text{K}, T_i = 85^\circ\text{C}, T_\infty = 18^\circ\text{C}, T = 35^\circ\text{C}$$

$$\text{Copper: } \rho = 8950 \text{ kg/m}^3, C_p = 383 \text{ J/kg.K}, k = 380 \text{ W/m.K}$$

$$b = \frac{h}{\rho C_p} \frac{A}{V} = \frac{25}{8950 \times 383} \times \frac{3}{0.015} = 14.568 \times 10^{-4}$$

$$\frac{T - T_\infty}{(T_i - T_\infty)} = e^{-bt} \quad \frac{35 - 18}{85 - 18} = e^{-bt} = \frac{17}{67} = 0.2537$$

$$t = 940.27 \text{ s} \cong 15.67 \text{ min}$$

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 5 (Closed Book)

Date: 12-5-2013

Duration: 20 Minutes

Maximum Marks: 5

Note: Attempt all questions. This paper consists of 10 questions.

Name of the student: -----

I.D.: -----

1. The heat transfer rates in *dropwise/ filmwise* condensation are higher.
2. In condensation heat transfer, average heat transfer coefficient is given by:
 - a. $\bar{h} = \frac{4}{3} h_{x=L}$
 - b. $\bar{h} = \frac{3}{2} h_{x=L}$
 - c. $\bar{h} = \frac{1}{2} h_{x=L}$
 - d. $\bar{h} = 2 h_{x=L}$
3. Condensation Number Co , is defined as
 - a. $Co = \bar{h} \left[\frac{\mu^2}{\rho(\rho - \rho_v) k^3 g} \right]^{1/3}$
 - b. $Co = \left[\frac{\rho(\rho - \rho_v) k^3 g \sin \phi A / L}{\mu \dot{m}} \right]^{1/4}$
 - c. $Co = \left[\frac{\rho(\rho - \rho_v) k^3 g \sin \phi h_{fg}}{\mu L (T_g - T_w)} \right]^{1/4}$
 - d. $Co = \frac{\bar{h} A (T_{sat} - T_w)}{h_{fg}}$
4. The dimensionless number defined as the product of Grashof number and Prandtl number, $(Gr.Pr)$, is called
 - a. Peclet number
 - b. Stanton number
 - c. Rayleigh number
 - d. Schmidt number
5. Reynolds number for condensate film for condensation on a vertical tube is given as:
 - a) $Re_f = \frac{\bar{h} A (T_{sat} - T_w)}{4 h_{fg} P \mu_f}$
 - b) $Re_f = \frac{4 \bar{h} A (T_{sat} - T_w)}{h_{fg} P \mu_f}$
 - c) $Re_f = \frac{4 \bar{h} \mu_f A (T_{sat} - T_w)}{h_{fg} P}$
 - d) $Re_f = \frac{4 \bar{h} P (T_{sat} - T_w)}{h_{fg} A \mu_f}$

6. Nucleate boiling occurs at heat fluxes *lower/ higher* than the critical heat flux.
7. Which reboiler type has lowest heat transfer coefficient:
a) kettle-type b) Thermosyphon c) forced-circulation
8. Which reboiler type is most economical:
a) kettle-type b) thermosyphon c) forced-circulation
9. In forced-convective boiling, the effective heat transfer coefficient is taken as composed of:
a) Convective and nucleate boiling components,
b) Convective and film boiling components,
c) Nucleate and film boiling components,
d) Film boiling and natural convection components.
10. For handling viscous and heavily fouling process fluids, which reboilers are better suited?
a) kettle-type b) thermosyphon c) forced-circulation

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 5 (Closed Book)

Date: 12-5-2013

Duration: 20 Minutes

Maximum Marks: 5

Note: Attempt all questions. This paper consists of 10 questions.

Name of the student: -----

I.D.: -----

SOLUTION

1. The heat transfer rates in *dropwise/ filmwise* condensation are higher.

2. In condensation heat transfer, average heat transfer coefficient is given by:

a. $\bar{h} = \frac{4}{3} h_{x=L}$ ✓

b. $\bar{h} = \frac{3}{2} h_{x=L}$

c. $\bar{h} = \frac{1}{2} h_{x=L}$

d. $\bar{h} = 2 h_{x=L}$

3. Condensation Number Co , is defined as

a. $Co = \bar{h} \left[\frac{\mu^2}{\rho(\rho - \rho_v) k^3 g} \right]^{1/3}$ ✓

b. $Co = \left[\frac{\rho(\rho - \rho_v) k^3 g \sin \phi A / L}{\mu \dot{m}} \right]^{1/4}$

c. $Co = \left[\frac{\rho(\rho - \rho_v) k^3 g \sin \phi h_{fg}}{\mu L (T_g - T_w)} \right]^{1/4}$

d. $Co = \frac{\bar{h} A (T_{sat} - T_w)}{h_{fg}}$

4. The dimensionless number defined as the product of Grashof number and Prandtl number, $(Gr.Pr)$, is called

a. Peclet number

b. Stanton number

c. Rayleigh number ✓

d. Schmidt number

5. Reynolds number for condensate film for condensation on a vertical tube is given as:

a) $Re_f = \frac{\bar{h} A (T_{sat} - T_w)}{4 h_{fg} P \mu_f}$

b) $Re_f = \frac{4 \bar{h} A (T_{sat} - T_w)}{h_{fg} P \mu_f}$

c) $Re_f = \frac{4 \bar{h} \mu_f A (T_{sat} - T_w)}{h_{fg} P}$

d) $Re_f = \frac{4 \bar{h} P (T_{sat} - T_w)}{h_{fg} A \mu_f}$ ✓

6. Nucleate boiling occurs at heat fluxes *lower/higher* than the critical heat flux.
7. Which reboiler type has lowest heat transfer coefficient:
a) kettle-type ✓ b) Thermosyphon c) forced-circulation
8. Which reboiler type is most economical:
a) kettle-type b) thermosyphon✓ c) forced-circulation
9. In forced-convective boiling, the effective heat transfer coefficient is taken as composed of:
a) Convective and nucleate boiling components, ✓
b) Convective and film boiling components,
c) Nucleate and film boiling components,
d) Film boiling and natural convection components.
10. For handling viscous and heavily fouling process fluids, which reboilers are better suited?
a) kettle-type b) thermosyphon c) forced-circulation✓

BITS PILANI, DUBAI CAMPUS
FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 6 (Closed Book)

Date: 19-5-2013

Duration: 20 Minutes

Maximum Marks: 5

NOTE: ATTEMPT ALL QUESTIONS. Do rough work on the back of this sheet.

Name of the student: -----

I.D.: -----

Question 1. Consider the following exchanger data: [2 + 1 = 3]

Flow arrangement	Fluid	Flow rate, kg/min	Heat capacity, J/kg.°C	Inlet temperature, °C	Outlet temperature, °C
Counter flow	Oil	125	2500	95	40
	Toluene	175	3150	25	?

Calculate:

Counterflow LMTD =

Heat load of the exchanger (in Watts) =

Question 2. Consider the following exchanger data: [2]

Flow arrangement	Fluid	Flow rate, kg/s	Heat capacity, J/kg.°C	Inlet temperature, °C	Outlet temperature, °C
Parallel flow	Methanol	3.5	2200	28	60
	Hot water	?	4200	95	65

Overall heat transfer coefficient, $U = 550 \text{ W/m}^2.\text{K}$

Calculate:

The heat transfer area of the exchanger =

BITS PILANI, DUBAI CAMPUS
FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 6 (Closed Book)

Date: 19-5-2013

Duration: 20 Minutes

Maximum Marks: 5

NOTE: ATTEMPT ALL QUESTIONS. Do rough work on the back of this sheet.

Name of the student: -----

I.D.: -----

SOLUTION

Question 1. Consider the following exchanger data: [2 + 1 = 3]

Flow arrangement	Fluid	Flow rate, kg/min	Heat capacity, J/kg.°C	Inlet temperature, °C	Outlet temperature, °C
Counter flow	Oil	125	2500	95	40
	Toluene	175	3150	25	?

Calculate:

Counterflow LMTD =

Heat load of the exchanger (in Watts) =

$$Q = (125/60) \times 2500 \times (95 - 40) = (175/60) \times 3150 \times (t_2 - 25) \\ = 17187.5/60 \text{ kW} = 286.458 \text{ kW}$$

Outlet temperature of toluene = 56.18 °C

$$(LMTD)_{cc} = \frac{38.82 - 15}{\ln \frac{38.82}{15}} = 23.82$$

Question 2. Consider the following exchanger data: [2]

Flow arrangement	Fluid	Flow rate, kg/s	Heat capacity, J/kg.°C	Inlet temperature, °C	Outlet temperature, °C
Parallel flow	Methanol	3.5	2200	28	60
	Hot water	?	4200	95	65

Overall heat transfer coefficient, $U = 550 \text{ W/m}^2.\text{K}$

Calculate:

The heat transfer area of the exchanger =

$$Q = 3.5 \times 2200 \times (60 - 28) = m_h \times 4200 \times (95 - 65)$$

$$Q = 246400 \text{ W}, \quad \text{Hot water flow rate} = m_h = 1.956 \text{ m/s}$$

$$(LMTD)_p = \frac{67 - 5}{\ln \frac{67}{5}} = 23.89$$

$$\text{The heat transfer area of the exchanger} = A = \frac{Q}{U(LMTD)} = 18.75 \text{ m}^2$$

BITS PILANI, DUBAI CAMPUS

FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 4 (Open Book)

Date: 7-4-2013

Duration: 15 Minutes

Maximum Marks: 5

Note: Attempt following question.

Derive the equation for the velocity profile in the boundary layer on a flat plate for the boundary conditions: **At $u = 0$ at $y = 0$, $u = u_{\infty}$ at $y = \delta$,**

$$\frac{\partial u}{\partial y} = 0 \text{ at } y = \delta$$

BITS PILANI, DUBAI CAMPUS

FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 4 (Open Book)

Date: 7-4-2013

Duration: 15 Minutes

Maximum Marks: 5

Note: Attempt following question.

Derive the equation for the velocity profile in the boundary layer on a flat plate for the boundary conditions: **At $u = 0$ at $y = 0$, $u = u_{\infty}$ at $y = \delta$, $\frac{\partial u}{\partial y} = 0$ at $y = \delta$**

Solution:

The desired equation is:

$$\frac{u}{u_{\infty}} = 2\frac{y}{\delta} - \left(\frac{y}{\delta}\right)^2$$

BITS PILANI, DUBAI CAMPUS
FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 3 (Open Book)

Date: 24-3-2013

Duration: 20 Minutes

Maximum Marks: 5

Note: Attempt all questions. This paper consists of 10 questions.

Name of the student: -----

I.D.: -----

1. The quantity that represents the rate at which radiation energy leaves a unit area of a surface in all directions is called

- a) emissivity b) transmissivity c) radiosity d) intensity

2. If we place two radiation shields between two infinite parallel planes (emissivity same for all surfaces), the radiation heat flow will be reduced by a factor of

- a) 1/2 b) 1/3 c) 1/4 d) 2/3

3. A body emitting peak radiation at 0.75 μm will have its temperature as

- a) 1.33 K b) 1.33×10^5 K c) 2898 K d) 3864 K

4. In radiation heat transfer between two non-blackbodies, the space resistance may be given as

- a) $E_b - J$ b) $J_1 A_1 F_{12}$ c) $(1-\epsilon)/\epsilon A$ d) $1/A_m F_{m-n}$

5. The emissive power of a blackbody is given as

- a) $\epsilon \sigma T^4$ b) σT^4 c) ϵT^4 d) $F_{12} \epsilon \sigma T^4$

6. Irradiation is defined as

- a) total radiation leaving a surface per unit time per unit area
b) total radiation being transmitted per unit time per unit area
c) total radiation reflected from a surface per unit time per unit area
d) total radiation incident upon a surface per unit time per unit area

7. For a gray body
- a) Monochromatic emissivity is independent of temperature
 - b) Monochromatic emissivity is independent of wavelength
 - c) Monochromatic emissivity is greater than 1.0
 - d) Monochromatic emissivity is equal to zero
8. In a blackbody radiation curve, the maximum occurs at λ_{\max} . With increasing temperature,
- a) λ_{\max} will increase
 - b) λ_{\max} will decrease
 - c) λ_{\max} will remain same
 - d) λ_{\max} will increase or decrease depending on the surface properties
9. Identify the correct statement regarding radiation shape factors
- a) $F_{11} = 0$ for plane surface, $F_{11} > 0$ for convex surface, $F_{11} < 0$ for concave surface
 - b) $F_{11} > 0$ for plane surface, $F_{11} = 0$ for convex surface, $F_{11} = 0$ for concave surface
 - c) $F_{11} < 0$ for plane surface, $F_{11} > 0$ for convex surface, $F_{11} > 0$ for concave surface
 - d) $F_{11} = 0$ for plane surface, $F_{11} = 0$ for convex surface, $F_{11} > 0$ for concave surface
10. A blackbody
- a) does not absorb any radiation
 - b) does not emit any radiation
 - c) does not reflect any radiation
 - d) does not transmit any radiation

BITS PILANI, DUBAI CAMPUS
FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 3 (Open Book)

Date: 24-3-2013

Duration: 20 Minutes

Maximum Marks: 5

Note: Attempt all questions. This paper consists of 10 questions.

SOLUTION

Name of the student: -----

I.D.: -----

-
1. The quantity that represents the rate at which radiation energy leaves a unit area of a surface in all directions is called
a) emissivity b) transmissivity c) **radiosity** d) intensity

 2. If we place two radiation shields between two infinite parallel planes (emissivity same for all surfaces), the radiation heat flow will be reduced by a factor of
a) 1/2 b) **1/3** c) 1/4 d) 2/3

 3. A body emitting peak radiation at $0.75 \mu\text{m}$ will have its temperature as
a) 1.33 K b) $1.33 \times 10^5 \text{ K}$ c) 2898 K d) 3864 K

 4. In radiation heat transfer between two non-blackbodies, the space resistance may be given as
a) $E_b - J$ b) $J_1 A_1 F_{12}$ c) $(1-\varepsilon)/\varepsilon A$ **d) $1/A_m F_{m-n}$**

 5. The emissive power of a blackbody is given as
a) $\varepsilon \sigma T^4$ **b) σT^4** c) εT^4 d) $F_{12} \varepsilon \sigma T^4$

 6. Irradiation is defined as
a) total radiation leaving a surface per unit time per unit area
b) total radiation being transmitted per unit time per unit area
c) **total radiation reflected from a surface per unit time per unit area**

- d) total radiation incident upon a surface per unit time per unit area
7. For a gray body
- a) Monochromatic emissivity is independent of temperature
 - b) Monochromatic emissivity is independent of wavelength**
 - c) Monochromatic emissivity is greater than 1.0
 - d) Monochromatic emissivity is equal to zero
8. In a blackbody radiation curve, the maximum occurs at λ_{\max} . With increasing temperature,
- a) λ_{\max} will increase
 - b) λ_{\max} will decrease**
 - c) λ_{\max} will remain same
 - d) λ_{\max} will increase or decrease depending on the surface properties
9. Identify the correct statement regarding radiation shape factors
- a) $F_{11} = 0$ for plane surface, $F_{11} > 0$ for convex surface, $F_{11} < 0$ for concave surface
 - b) $F_{11} > 0$ for plane surface, $F_{11} = 0$ for convex surface, $F_{11} = 0$ for concave surface
 - c) $F_{11} < 0$ for plane surface, $F_{11} > 0$ for convex surface, $F_{11} > 0$ for concave surface
 - d) $F_{11} = 0$ for plane surface, $F_{11} = 0$ for convex surface, $F_{11} > 0$ for concave surface**
10. A blackbody
- a) does not absorb any radiation
 - b) does not emit any radiation
 - c) does not reflect any radiation**
 - d) does not transmit any radiation

BITS PILANI, DUBAI CAMPUS

FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: *Surprise Quiz – 2* (Closed Book)

Date: 24-2-2013

Duration: 20 Minutes

Maximum Marks: 5

Note: *Attempt following question.*

Consider two fins of same volume but different shapes made of steel. One fin is 20 mm X 4 mm X 5 mm while the other is 20 mm X 2 mm X 10 mm. other data are same for both fins and are given below: (assume that fin-tip is insulated).

$$k = 30 \text{ W/m.K}$$

$$h = 50 \text{ W/m}^2.\text{K}$$

$$T_o = 100 \text{ }^\circ\text{C}$$

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

Compare the performance of these fins by computing:

- a) The rate of heat dissipation,
 - b) Fin efficiency.
-

BITS PILANI, DUBAI CAMPUS

FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: *Surprise Quiz – 2* (Closed Book)

Date: 24-2-2013

Duration: 20 Minutes

Maximum Marks: 5

Note: *Attempt following question.*

Consider two fins of same volume but different shapes made of steel. One fin is 20 mm X 4 mm X 5 mm while the other is 20 mm X 2 mm X 10 mm. other data are same for both fins and are given below: (assume that fin-tip is insulated).

$$k = 30 \text{ W/m.K}$$

$$h = 50 \text{ W/m}^2.\text{K}$$

$$T_o = 100^\circ\text{C}$$

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

Compare the performance of these fins by computing:

- The rate of heat dissipation,
- Fin efficiency.

Solution:

$$q = \sqrt{hPkA}\theta_0 \tanh(mL)$$

$$\eta_f = \frac{\sqrt{hPkA}\theta_0 \tanh(mL)}{hPL\theta_0} = \frac{\tanh mL}{mL}$$

	Fin 1	Fin 2
Dimensions	20 mm X 4 mm X 5 mm	20 mm X 2 mm X 10 mm
P	18 mm	24 mm
A	$20 \times 10^{-6} \text{ m}^2$	$20 \times 10^{-6} \text{ m}^2$
m	$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{50 \times 0.018}{30 \times 20 \times 10^{-6}}}$ $m = \sqrt{1500} = 38.73$	$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{50 \times 0.024}{30 \times 20 \times 10^{-6}}}$ $m = \sqrt{2000} = 44.72$
mL	0.7746	0.8944
$\theta_0 = T_o - T_\infty$	70	70
\sqrt{hPkA}	$\sqrt{50 \times 0.018 \times 30 \times 20 \times 10^{-6}}$ $= 0.023238$	$\sqrt{50 \times 0.024 \times 30 \times 20 \times 10^{-6}}$ $= 0.026833$
$\tanh(mL)$	0.6496	0.7136
q	1.057 W	1.34 W
$\eta_f = \frac{\tanh mL}{mL}$	0.8386 or 83.86%	0.7979 or 79.79%

BITS PILANI, DUBAI CAMPUS

FIRST SEMESTER 2012 – 2013

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 1 (Open Book)

Date: 17-2-2013

Duration: 15 Minutes

Maximum Marks: 5

Note: Attempt following question.

A hot steam pipe having an inside surface temperature of 255°C has an ID = 8 cm and wall thickness of 6 mm. It is covered with 9 cm layer of insulation having $k = 0.5 \text{ W/m.K}$, followed by a 4-cm layer of another insulation having $k = 0.25 \text{ W/m.K}$. The outside temperature of insulation is 20°C .

Calculate: a) heat loss per meter of length, and b) temperature at pipe-insulation interface. For pipe material, $k = 45 \text{ W/m.K}$.

Course No: CHE F241

Course Title: Heat Transfer

Instructor-In-Charge: Bharat B. Gulyani

Component: Surprise Quiz – 1 (Open Book)

Date: 17-2-2013

Duration: 15 Minutes

Maximum Marks: 5

Note: Attempt following question.

A hot steam pipe having an inside surface temperature of 255°C has an ID = 8 cm and wall thickness of 6 mm. It is covered with 9 cm layer of insulation having $k = 0.5 \text{ W/m.K}$, followed by a 4-cm layer of another insulation having $k = 0.25 \text{ W/m.K}$. The outside temperature of insulation is 20°C .

Calculate: a) heat loss per meter of length, and b) temperature at pipe-insulation interface. For pipe material, $k = 45 \text{ W/m.K}$.

Solution

$$r_1 = 4\text{cm}$$

$$r_2 = 4.6\text{cm}$$

$$r_3 = 4.6 + 9.0 = 13.6\text{cm} \quad r_4 = 13.6 + 4.0 = 17.6\text{cm}$$

$$T_1 = 255^{\circ}\text{C}$$

$$T_4 = 20^{\circ}\text{C}$$

$$k_1 = 45 \text{ W/m}^{\circ}\text{C} \quad k_2 = 0.5 \text{ W/m}^{\circ}\text{C} \quad k_3 = 0.25 \text{ W/m}^{\circ}\text{C}$$

$$\frac{q}{L} = \frac{2\pi(T_1 - T_4)}{\frac{\ln r_2/r_1}{k_1} + \frac{\ln r_3/r_2}{k_2} + \frac{\ln r_4/r_3}{k_3}}$$

$$\frac{q}{L} = \frac{2\pi(255 - 20)}{\frac{\ln 4.6/4}{45} + \frac{\ln 13.6/4.6}{0.5} + \frac{\ln 17.6/13.6}{0.25}} = \frac{1475.8}{0.0031 + 2.168 + 1.0313}$$

$$\frac{q}{L} = \frac{1475.8}{0.0031 + 2.168 + 1.0313} = 460.842$$

$$\text{Interface temperature, } \frac{q}{L} = \frac{2\pi(T_1 - T_2)}{\frac{\ln r_2/r_1}{k_1}} = \frac{2\pi(255 - T_2)}{0.0031} = 460.842$$

$$\text{Or } T_2 = 254.773$$