**BITS PILANI, DUBAI CAMPUS**

**FIRST SEMESTER 2011 – 2012**

**CHE C351 HEAT TRANSFER OPERATIONS**

**COMPREHENSIVE EXAMINATION**

**DATE: 9 – 1 – 2012**

**DURATION: 3 hours** **MAXIMUM MARKS: 35**

***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.*

**Question 1 [2 marks]**

A very long 5.5-mm diameter copper rod (k = 290W/mK) extends horizontally from a plane heated wall at 105 $^{O}$C. The temperature of the surrounding air is 22 $^{O}$C and convective heat transfer coefficient is 14 W/m$^2$K. Determine the heat loss.

**Question 2 [3 marks]**

The insulation boards for air conditioning purposes are made of three layers, middle being of packed glass 10 cm thick (k = 0.035 W/m.K) and the sides are made of plywood each of 6 cm thickness (k = 0.12 W/m.K). The outermost surface is at 45 $^{O}$C and the innermost surface is at 16 $^{O}$C. Determine the heat flow per unit area. Also calculate the interface temperatures.

**Question 3 [3 marks]**

A steel sphere [k = 24 W/m.$^{O}$C] of 4 cm diameter is exposed to a convection environment at 22 $^{O}$C, h = 15 W/m$^2$.$^{O}$C. Heat is generated uniformly in the sphere at the rate of 1.10 MW/m$^3$. Calculate the steady state temperature for the center of the sphere.

**Question 4 [4 marks]**

During a heat treatment process, spherical steel balls of 9 mm diameter are initially heated to 900 $^{O}$C in a furnace. Then they are cooled to 100 $^{O}$C by keeping them immersed in an oil bath at 30 $^{O}$C, with a convective heat transfer coefficient 30 W/m$^2$.$^{O}$C.

(a) Determine the time required for the cooling process.

(b) If it is desired to complete the cooling process in a period of 7 minutes, what will be the required value of convective heat transfer coefficient?

Properties of steel balls:

Density = 7750 kg/m$^3$, specific heat = 520 J/kg.$^{O}$C,

Thermal conductivity = 50 W/m.$^{O}$C

**Question 5 [4 marks]**

Air is flowing over a flat plate 7-m long and 2-m wide (maintained at 93 $^{O}$C) with a velocity of 1.25 m/s at 18 $^{O}$C. If Pr = 0.7, density = 1.27 kg/m$^3$, and kinematic viscosity = 1.45 X 10$^{-5}$ m$^2$/s, k = 0.025 W/m.K,

(a) Calculate the length of the plate over which the boundary layer is laminar,

(b) Calculate the laminar boundary layer thickness at the point of transition, using Blausius' exact solution,

(c) Calculate the thickness of the thermal boundary layer at this point, assuming that the plate is being heated over its entire length.

(d) Average heat transfer coefficient.

**Question 6 [4 marks]**

Consider two large parallel plates, one at 700 $^{O}$C with emissivity 0.8 and the other at 150 $^{O}$C having emissivity 0.5. A radiation shield is placed between them. The shield has emissivity 0.15 on the side facing hot plate and 0.35 on the side facing cold plate. Calculate the percent reduction in radiation heat transfer as a result of radiation shield.

**Question 7 [2 marks]**

Consider a system of concentric spheres of radius $r_1$ and $r_2$ ($r_2 > r_1$). If $r_1$ = 4.5 cm, determine the radius $r_2$ if it is desired to have the value of shape factor $F_{21}$ equal to 0.5.

**Question 8 [4 marks]**

A vertical plate 0.9 m high and maintained at 25 $^{O}$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.

The properties of water film at the mean temperature are:

Density = 985.0 kg/m$^3$, thermal conductivity = 66.4 X 10$^{-2}$ W/m.K,

Viscosity = 620 X 10$^{-6}$ kg/m.s, $h_{fg}$ = 2260 kJ/kg.

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

**Question 9 [6 marks]**

In a counter flow heat exchanger, process fluid is cooled from a temperature of 93 $^{O}$C with cooling water available at 27 $^{O}$C. The heat exchanger area is 150 m$^2$ and the overall heat transfer coefficient is 450 W/m$^2$.$^{O}$C. The flow rates are: process fluid = 45000 kg/h, cooling water = 97200kg/h. Heat capacity of process fluid is 1980 J/kg.$^{O}$C, and that of cooling water is 4180 J/kg.$^{O}$C. Calculate:

(a) The exit temperature of process fluid,

(b) The exit temperature of cooling water,

(c) The heat transfer rate.

**Question 10 [3 marks]**

In a 1-2 shell-and-tube heat exchanger oil ($C_p$ = 2.1 kJ/kg.$^{O}$C) at a rate of 90000 kg/h is cooled from 130 $^{O}$C to 60 $^{O}$C by water ($C_p$ = 4.2 kJ/kg.$^{O}$C) that enters at 20 $^{O}$C and leaves at 60 $^{O}$C. The overall heat transfer coefficient is 350 J/m$^2$.$^{O}$C. Calculate the effective temperature difference in the exchanger.

*** END OF PAPER ***

**BITS PILANI, DUBAI CAMPUS**
**ACADEMIC CITY, DUBAI**
**First SEMESTER 2011-2012**
**CHE C351: Heat Transfer Operations**
**<u>TEST – II (Open Book)</u>**

DATE: 11.12.2011

DURATION: 50 MINUTES MAXIMUM MARKS: 15

*Note: Attempt ALL questions.* Make suitable design decisions wherever necessary, and mention them clearly. Do not alter any given data.

**Question 1** [5 Marks]
Air at 20 $^{O}$C and at atmospheric pressure flows over a flat plate at a velocity of 3.1 m/s. the length of the plate is 1.15 m and it is maintained at 97 $^{O}$C. Calculate the heat transfer rate per unit width using Blasius' exact solution.
*Properties of air at mean temperature are:*
Density = 1.25 kg/m$^3$, heat capacity = 1.0 kJ/kg.K,
Thermal conductivity = 0.03 W/m.K, viscosity = 2.3 X 10$^{-5}$ kg.m/s

**Question 2** [5 Marks]
A vertical plate 600 mm high and maintained at 30 $^{O}$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.
The properties of water film at the mean temperature are:
Density = 985 kg/m$^3$, thermal conductivity = 0.7 W/m.K,
Viscosity = 43 X 10$^{-6}$ kg/m.s, $h_{fg}$ = 2257 kJ/kg.
Assume vapor density is small compared to that of the condensate.

**Question 3** [5 Marks]
2700 kg/h of water is heated from 25 $^{O}$C to 75 $^{O}$C by pumping it through a heated pipe of 25 mm diameter. If the surface of the heated pipe is maintained at 110 $^{O}$C, calculate:
a) heat transfer coefficient,
b) Length of the pipe, and
c) Rate of heat transfer from pipe to water.
*Thermo-physical properties of water at mean bulk temperature (50 $^{O}$C) are:*
Density = 985 kg/m$^3$, viscosity = 0.355 X 10$^{-3}$ kg/m.s
Thermal conductivity = 0.7 W/m.$^{O}$C, heat capacity = 4200 J/kg.$^{O}$C

*** END OF PAPER ***

**BITS, PILANI, DUBAI CAMPUS, ACADEMIC CITY, DUBAI**
**First SEMESTER 2011-2012**
**CHE C351: Heat Transfer Operations**
**<u>TEST – I (Closed Book)</u>**

DATE: 16.10.2011

**DURATION: 50 MINUTES** **MAXIMUM MARKS: 15**

*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.*

1 A flat wall is exposed to an environmental temperature of 32 $^{O}$C. The wall is covered with a layer of insulation 3.0 cm thick whose thermal conductivity is 1.2 W/m.$^{O}$C, and temperature of the wall on the inside of insulation is 415 $^{O}$C. The wall loses heat to the environment by convection. Compute the value of convection heat transfer coefficient which must be maintained on the outer surface of the insulation to ensure that the outer surface temperature does not exceed 41 $^{O}$C. [3]

2 A thick-walled tube of stainless steel (k = 19 W/m.$^{O}$C) with 3-cm inner diameter and 5-cm outer diameter is covered with a 4-cm layer of insulation (k = 0.2 W/m.$^{O}$C). If the inside wall temperature of the pipe is maintained at 600 $^{O}$C, and outside of insulation is to be at 100 $^{O}$C, calculate the heat loss per meter of length. [3]

3 A 3-kW resistance heater wire (k = 12 W/m.K) has a diameter of 4 mm and a length of 0.5 m, and is used to boil water. If the outer surface temperature of the resistance wire is 104 $^{O}$C, determine the temperature at the center of the wire. [3]

4 A very long 25-mm diameter copper rod (k = 300 W/m.$^{O}$C) extends horizontally from a plane heated wall at 120 $^{O}$C. The temperature of the surrounding air is 25 $^{O}$C and convective heat transfer coefficient is 9.0 W/m$^2$K. Determine the heat loss. [3]

5 Stainless steel ball bearings ( $\rho$ = 8085 kg/m$^3$, k = 15.1 W/mK, $C_p$ = 0.480 kJ/kgK, $\alpha$ = 3.91 X 10$^{-6}$ m$^2$/s) having a diameter of 1.2 cm are to be quenched in water. The balls leave the oven at a uniform temperature of 900 $^{O}$C and are exposed to air at 30 $^{O}$C for a while before they are dropped into the water. If the temperature of the balls is not to fall below 850 $^{O}$C prior to quenching and the heat transfer coefficient in the air is 125 W/m$^2$K, determine how long they can stand in the air before being dropped in the water. [3]

**BITS PILANI, DUBAI CAMPUS, ACADEMIC CITY, DUBAI**
**FIRST SEMESTER 2011-2012**
**CHE UC351 Heat Transfer Operations**
**QUIZ – II**
(Closed Book)

**DATE: 30-11-2011**

**DURATION: 20 MINUTES** **MAXIMUM MARKS: 7**

Name of the student: --------------------- I.D.: -----------------

**Note: Attempt all questions. This quiz consists of 6 questions. Question 1 to 5 carry 1 mark each, and question 6 carries 2 marks.**

1. Prandtl number is defined as;

 a) $\Pr = \frac{\mu}{\rho}$ b) $\Pr = \frac{hd_0}{k}$ c) $\Pr = \frac{k}{\rho c_p}$ d) $\Pr = \frac{\rho v C_p}{k}$

2. Reynolds analogy is expressed as:

 a) $St = \frac{f}{8}$ b) $\frac{\tau}{\rho} = \left(\frac{\mu}{\rho} + \varepsilon_M\right)\frac{du}{dy}$

 c) $f = \frac{0.316}{\mathrm{Re}_d^{0.25}}$ d) $St_x \Pr^{2/3} = \frac{C_{fx}}{2}$

3. The empirical expression for calculation of heat transfer in fully developed turbulent flow in smooth tubes is:

 a) $Nu_d = 0.0395 \mathrm{Re}_d^{3/4}$ b) $Nu_d = 0.036 \mathrm{Re}_d^{0.8} \Pr^{1/3}\left(\frac{d}{L}\right)^{0.055}$

 c) $Nu_d = 0.023 \mathrm{Re}_d^{0.8} \Pr^{n}$ d) $Nu_d = 4.364$

4. $\frac{\theta}{\theta_\infty} = \frac{3}{2}\frac{y}{\delta_t} - \frac{1}{2}\left(\frac{y}{\delta_t}\right)^3$ is the equation of thermal boundary layer:

 a) Of laminar flow on a plate
 b) Of turbulent flow on a flat plate
 c) Of laminar flow in a tube
 d) Of turbulent flow in a tube.

5. Stanton number is defined as

 a) $St = \frac{Nu_d \mathrm{Re}_d}{\Pr}$ b) $St = 0.381 \mathrm{Re}_x^{-0.2}$

 c) $St = 1.64\sqrt{\Pr}$ d) $St = \frac{h}{\rho c_p u_m}$

6. Inside the tube of an exchanger, Re = 20 000, and Pr = 5.0. If Sieder-Tate equation coefficient, C = 0.023, and viscosity correction is neglected, what is the value of Nu?

*** END OF PAPER ***

**BITS PILANI, DUBAI CAMPUS, ACADEMIC CITY, DUBAI**
**FIRST SEMESTER 2011-2012**

# CHE UC351 Heat Transfer Operations

## QUIZ – I

(Closed Book)

**DATE: 02-11-2011**

**DURATION: 20 MINUTES** **MAXIMUM MARKS: 8**

Name of the student: -------------------- I.D.: -----------------

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**Note: Attempt all questions. This quiz consists of 16 questions.**

1. Thermal radiation lies in the wavelength range

 a) 0.1 – 100 cm b) 0.1 – 100 μm

 c) 0.1 – 100 nm d) 0.1 – 100 mm

2. The equation $E_b = \sigma T^4$ is known as

 a) Wein's law b) Stefan-Boltzmann law

 c) Kirchhoff's law d) Planck's law

3. The relationship between irradiation and radiosity can be expressed as

 a) $J = \varepsilon E_b - \rho G$ b) $J = \varepsilon E_b + \rho G$

 c) $J = \rho E_b + \varepsilon G$ d) $G = \frac{J + \varepsilon E_b}{(1 - \varepsilon)}$

4. The speed of electromagnetic radiation in vacuum is given as

 a) $c = 3 \times 10^8 \, km/s$ b) $c = 3 \times 10^6 \, km/s$

 c) $c = 3 \times 10^6 \, m/s$ d) $c = 3 \times 10^8 \, m/s$

5. For a black body

 a) space resistance is equal to zero
 b) space resistance is equal to unity
 c) surface resistance is equal to zero
 d) surface resistance is equal to unity

6. 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

7. A gray body is defined such that

e) a) Its monochromatic emissivity $\varepsilon_\lambda$ is *independent* of wavelength
f) b) Its total emissivity $\varepsilon$ is *independent* of wavelength
g) c) Its total emissivity $\varepsilon$ is *independent* of direction
h) d) Its absorptivity is *independent* of direction

8. The emissive power of a blackbody is given as

a) $\varepsilon\sigma T^4$    b) $\varepsilon T^4$    c) $\sigma T^4$    d) $F_{12}\varepsilon\sigma T^4$

9. If the angle of incidence of radiation is equal to the angle of reflection, it is called

a) Black body radiation
b) Gray body radiation
c) Diffuse radiation
d) Specular radiation

10. In a blackbody radiation curve, the maximum occurs at $\lambda_{\max}$. With increasing temperature,

a) $\lambda_{\max}$ will decrease

b) $\lambda_{\max}$ will increase

c) $\lambda_{\max}$ will remain same

d) $\lambda_{\max}$ will increase or decrease depending on the surface properties

11. 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

12. The reciprocity relation for radiation shape factors is given as,

a) $E_{b1}/A_1 = E_{b2}/A_2$ b) $F_{12} = F_{21}$

c) $A_1 F_{12} = A_2 F_{21}$ d) $F_{12}/A_1=F_{21}/A_2$

13. The intensity of radiation is defined as

a) the radiation emitted per unit time per unit area

b) the radiation emitted per unit area and per unit of solid angle in a certain specified direction

c) total radiation incident upon a surface per unit time per unit area

d) total radiation which leaves a surface per unit time per unit area

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

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

15. Heat transfer between two infinite parallel planes is given as

a) $q_{1-2} = \dfrac{(J_1 - J_2)}{1/A_1 F_{12}}$

b) $q = \dfrac{\sigma A(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$

c) $q = \dfrac{\sigma A_1(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2} - 1\right)}$

d) $q = \sigma A_1 \varepsilon_1 (T_1^4 - T_2^4)$

16. Which among the following has the shortest wavelength?

a) shortwave radiation b) infrared radiation

c) ultraviolet radiation d) X-ray radiation

*** END OF PAPER ***