16-CHEM-A3, HEAT and MASS TRANSFER

DECEMBER 2017

Three Hours Duration

NOTES:

1) If doubt exists as to the interpretation of any question, you are urged to submit a clear statement of any assumptions made along with the answer paper.

2) Property data required to solve a given problem are provided in the problem statement or are available in the recommended texts. If you are unable to locate the required data, do not let this prevent you from solving the rest of the problem. Even in the absence of property data, you still have the opportunity to provide a solution methodology.

3) This is an **open-book exam**. One textbook of your choice with notations listed on the margins etc., but no loose notes are permitted into the exam. Candidates may use any **non-communicating** scientific calculator.

4) All problems are worth **25 points**. At least **two problems** from **each part** must be attempted.

5) **Only the first two** questions as they appear in the answer book from each section will be marked.

PART A – HEAT TRANSFER

1) Water in a tank at 15 °C is heated by passing steam through a 60-cm long, 40-mm diameter pipe placed in water. The surface temperature of the pipe is maintained at 85 °C. The following empirical correlations for Nusselt number (Nu) as a function of Grashoff number (Gr) and Prandtl number (Pr) may be used:

$$Nu = C\,(Gr\,Pr)^m$$

where C and m are constants. The values of C and m are as follows:

$$C = 0.53 \text{ and } m = 0.25 \text{ for } 10^4 < Gr\,Pr < 10^9$$

$$C = 0.13 \text{ and } m = 0.33 \text{ for } Gr\,Pr > 10^9$$

(a) **[13 points]** Find the heat loss from the pipe if it is kept horizontal.

(b) **[12 points]** Find the heat loss from the pipe if it is kept vertical.

DATA:

Density of water = 988 kg/m^3
Thermal conductivity of water = 0.647 W/m.K
Viscosity of water = 5.493 x 10^{-4} kg/m.s
Specific heat capacity of water = 4.178 kJ/kg.K
Coefficient of volume expansion of water = 5.1 x 10^{-4} K^{-1}

2) A pipe (outside diameter = 30 cm) is covered with two layers of insulation. The thermal conductivity of the first layer, which is on the outside, is 0.105 W/m.K and 40 mm thick. The thermal conductivity of the second layer, which is on the inside, is 0.105 W/m.K and 50 mm thick. The inner and outer surface temperatures of the insulation are 350 °C and 50 °C, respectively.

(a) **[10 points]** Estimate the heat loss per meter length of the pipe.

(b) **[5 points]** Estimate the heat loss per m^2 of outer insulation surface.

(c) **[10 points]** Estimate the temperature of the surface between the two layers of insulation.

3) A heat exchanger is to be designed to heat water flowing at a rate of 1720 kg/hr from 20 °C to 45 °C using steam condensing at 110 °C on the outside surface of 4-meter long brass tubes (thermal conductivity = 111.65 W/m.K, outside diameter = 25 mm, inside diameter = 22.5 mm). The velocity of water is 61.2 m/min and the weight of steam condensed is 1.25 kg/s. Find the number of brass tubes required to heat water from 20 °C to 45 °C.

DATA:
Density of water = 995.7 kg/m^3
Thermal conductivity of water = 0.617 W/m.K
Kinematic viscosity of water = 6.59×10^{-7} m^2/s
Specific heat capacity of water = 4.174 kJ/kg.K
Latent heat of vaporization of water = 2230 kJ/kg
Steam side film heat transfer coefficient = 4650 $W/m^2.K$

PART B – MASS TRANSFER

1) It is desired to separate a mixture containing benzene and toluene at a constant pressure of 101.32 kPa absolute using the following vapor pressure data:

Temperature, in °C	**Vapor Pressure of Benzene,** in kPa	**Vapor Pressure of Toluene,** in kPa
80.0	101.32	-
82.9	108.12	41.86
85.0	117.60	46.00
87.0	127.60	50.40
90.5	138.25	55.20
93.3	149.72	60.26
96.1	161.85	65.86
99.0	174.65	71.73
101.6	188.25	78.00
104.5	202.65	84.66
107.2	216.65	91.86
110.0	234.11	99.59
110.1	-	101.32

(a) **[15 points]** Compute the vapor-liquid equilibrium data at 101.32 kPa absolute.

(b) **[10 points]** Find an empirical relation between liquid and vapor phase composition.

2) An air-ammonia mixture flowing at a rate of 20 mol/hr and containing 5% NH_3 by volume is being scrubbed in a countercurrent manner with 2N sulfuric acid in a wetted wall column (internal diameter = 15 mm, length = 70 cm) operating at 20 °C and 101.3 kN/m^2. Under these conditions, 90% of NH_3 is absorbed, and the change in acid concentration can be neglected.

(a) **[12 points]** Calculate the value of mass transfer coefficient, k_G.

(b) **[13 points]** If the value of the heat transfer coefficient (h) in a similar setup with identical operating conditions is 75.2 kcal/hr.m^2.°C, then estimate the value of mass transfer coefficient (k_G) from Chilton-Colburn analogy.

DATA: Diffusity of NH_3 in air at 20 °C = 2.2 x 10^{-5} m^2/s
Specific heat capacity of air at 20 °C = 238 cal/kg.°C
Scmidt number (Sc) of air-NH_3 mixture at 20 °C = 0.67
Prandtl number (Pr) of air at 20 °C = 0.70

3) Air is flowing at a velocity of 2.5 m/s over a horizontal water surface 2 meters long. The total pressure is 0.98 kg$_f$/m^2 and the partial pressure of water vapor in the air is 10 mm Hg. The relative humidity of air is 33.3%. Calculate the loss of water per hour per unit area from the horizontal water surface.

DATA: Diffusion coefficient of water vapor in air = 7.0 cm^2/hr
Kinematic viscosity of air = 1 x 10^{-3} cm^2/hr

The Periodic Table of the Elements