Question Paper

Exam Date & Time: 26-Apr-2018 (09:30 AM - 12:30 PM)

MANIPAL ACADEMY OF HIGHER EDUCATION

INTERNATIONAL CENTRE FOR APPLIED SCIENCES
END-SEMESTER THEORY EXAMINATION- APRIL 2018
DATE:26.04.2018
TIME:9.30AM TO 12.30PM

Heat and Mass Transfer Operations In Bioprocessing [BT 244]

Marks: 100 **Duration: 180 mins.**

Answer 5 out of 8 questions.

Missing data, if any, may be suitably assumed

1)

A) A hollow sphere 10 cm ID and 30cm OD of a material having thermal conductivity of 50 W/mK is used as a container for liquid chemical mixture. Its inner and outer surface temperatures are 300Â°C and 100Â°C respectively. Determine the heat flow rate through the sphere. Also determine the temperature at a point quarter of the way between inner and the outer surface. (5)

B) A fireclay wall 20cm thick has its two surfaces maintained at 1000Â°C and 200Â°C. The thermal conductivity of the fireclay varies with temperature in Â°C as k(W/mK)=0.813+0.000582T. Calculate the rate of heat flow. (3)

C) A steel pipe line (k=50W/mK) of ID 100mm and OD 110mm is to be covered with two layers of insulation each having a thickness of 50mm. The thermal conductivity of the first insulation material is 0.06W/mK and that of the second is 0.12W/mK. Calculate the loss of heat per meter length of the pipe and interface temperatures between the two layers of insulation when the temperature of the inside tube surface is 250Â°C and that of the outside surface of insulation is 50Â°C. (6)

D) In a stainless steel plate of K=20W/mK there is uniform heat generation at a rate of 500MW/m^3. The thickness of the plate is 1cm. If the two sides of the plate are maintained at 100Â°C and 200Â°C respectively, calculate (6) the temperature at the center of the plate, position and value of the maximum temperature, heat transfer at the left and right faces.

2) A) Consider a plane composite wall that is composed of two materials of thermal conductivities 0.1W/mK and 0.4W/mK and thickness 10mm and 20mm respectively. The contact resistance at the interface between the two materials is known to be 0.3W/m^2K. Material A adjoins the fluid at 200Â°C for which h=101W/m^2K and material B adjoins the fluid for which h=20W/m^2K. What is the rate of heat transfer through the wall that is 2m high and 2.5m wide. Find the temperature drops at the interface. Also determine the overall heat transfer coefficient. (10)

B) The walls of a house are 4m high and 5m wide and 0.3m thick are made from brick with thermal conductivity 0.9W/mK. The temperature of the air inside the house is 20Â°C and outside air is at -10Â°C. There is a heat transfer coefficient of 10W/m^2K on the inside wall and 30W/m^2K on the outside wall. Calculate the inside and outside wall temperatures, heat flux and the total heat transfer rate through the wall. (10)

3) A) A liquid metal flows at a rate of 4kg/s through a constant heat flux 6cm inner diameter tube in a nuclear reactor. The fluid at 200Â°C is to be heated with the tube wall 40Â°C above the fluid temperature. Determine the length of the tube required for 25Â°C rise in bulk fluid temperature using the following properties: ρ=7.7*10^3 kg/m^3, ν=8*10^{-8} m^2/s, cp=130J/kgÂ°C, k=12W/mK and Pr=0.011, Nu=0.625 $(Re_d*Pr)^{0.4}$ (4)

B) Explain the physical significance of Nusselt and Prandtl number. (4)

C) Using dimensional analysis derive an expression for heat transfer coefficient in forced convection. (6)

D) Air at 30Â°C is flowing across a tube with velocity of 25m/s. The tube could be a square with a side of 5cm or a circular cylinder of diameter 5cm. Compare the heat transfer coefficient in each case if the tube surface temperature is 124Â°C.Given for circular tube Nu=0.027$(Re_D)^{0.805}Pr^{1/3}$, for square tube Nu=0.102$(Re_D)^{0.675}Pr^{1/3}$,ν=20.92*10^{-} (6)

$^6 m^2/s$, $k=3*10^{-2} W/mK$, $Pr=0.7$

4) State and explain the regimes of pool boiling. (8)

A)

B) In a double pipe heat exchanger 20000kg/hr of fluid having a specific heat of 2099J/kgK is heated from 30Â° C to 90Â°C by 16000kg/hr of water entering at 160Â°C.Compare the heat exchanger area for co-current and counter current flows for anover all heat transfer coefficient of $300 W/m^2K$. Take Cp(water) = 4180 J/kgK. (6)

C) Hot oil with a capacity rate of 2500 W/K flows through a double pipe heat exchanger. It enters at 360Â°C and leaves at 300Â°C. Cold fluid enters at 30Â°C and leaves at 200Â°C. If the overall heat transfer coefficient is $800 W/m^2K$, determine the heat exchanger area required for (a)parallel flow (b) counter flow (6)

5) Explain any two types of feeding systems in evaporators. (6)

A)

B) A continuous single-effect evaporator concentrates 9072 kg/h of a 1.0 wt% salt solution entering at 311.0 K (37.8Â°C) to a final concentration of 1.5 wt %. The vapor space of the evaporator is at 101.325 kPa and the steam supplied is saturated at 143.3 kPa. The overall U = 1704 W/m^2 K. Calculate the amounts of vapor and liquid product and the heat-transfer area required. Assume that, since it is dilute, the solution has the same boiling point as water. Given H_f = 158.37kJ/kg, h_L =419.04 kJ/kg, H_v=2676.1kJ/kg, H_s = 2691.5kJ/kg , h_c = 461.3kJ/kg, T_s=110Â°c , T_1=100Â°C (6)

C) Explain the terms boiling point elevation, capacity and economy. (6)

D) What are the applications of an evaporator. (2)

6) A) Air at 32Â°C is humidified by flowing over a 1.2-m-long container filled with water. The interfacial temperature is 20Â°C. If the initial humidity of the air is 25% and its velocity is 0.15m/s, calculate (a) the convective mass transfer coefficient, and (b) the amount of water evaporated per unit width of the container. The film temperature is 26Â°C. Air at 26Â°C: ν =$1.51x10^{-5}$ m^2/s, DAB=$2.77x10^{-5}$ m^2/s, Water vapor pressure: pAsat(20Â°C) (10)

= 0.02308 atm, pAsat(32Â°C) = 0.04696 atm. The average Sherwood number over the container may be obtained from the following correlation: $Sh=0.664Re^{1/2}Sc^{1/3}$

B) Explain the analogy between heat, mass and momentum transfer (4)

C) With an example explain the solid liquid and gas solid mass transfer operations. (6)

7) A) In a wetted-wall tower, an air-H_2S mixture is flowing by a film of water which is flowing as a thin film down a vertical plate. The H_2S is being absorbed from the air to the water at a total pressure of 1.50 atm abs and 30^oC. The value of kc of $9.567x10^{-4}$ m/s has been predicted for the gas-phase mass-transfer coefficient. At a given point the mole fraction of H_2S in the liquid at the liquid-gas interface is $2.0x10^{-5}$ and p_A of H_2S in the gas is 0.05 atm. The Henry's law equilibrium relation is p_A(atm) = 609x_A (mole fraction in liquid). Calculate the rate of absorption of H_2S. (10)

B) Blood oxygenators are used to replace the human lungs during the open heart surgery. You want to study mass transfer of oxygen into water at 310K. From published correlations of mass transfer coefficient, you expect that the coefficient based on the oxygen concentration difference in the water is $3.3*10^{-5}$m/s. Calculate the corresponding mass transfer coefficient based on the mole fraction of O_2 in the liquid. (4)

C) A steel, rectangular container having walls 15mm thick, is used to store gaseous hydrogen at elevated pressure. The molar concentrations of hydrogen in steel at the inside and outside surfaces are 1 kgmole/m^3 and zero, respectively. Assuming the diffusion coefficient for hydrogen in steel to be $0.25*10^{-12}$ m^2/s, calculate the molar diffusion flux for hydrogen through steel. Also explain the Fick's law of steady state diffusion. (6)

8) A) Explain the procedure of graphical determination of interfacial concentrations (4)

B) An experiment was carried out to study absorption of ammonia by water in a wetted-wall column. The value of overall mass transfer coefficient, KG was found to be 2.75 $* 10^{-6}$ kmol/m^2-s-kPa. At one point in the column, the (10) composition of the gas and liquid phases were 8.0 and 0.115 mole% NH_3, respectively. The temperature was 300K and the total pressure was 1 atm. Eighty five % of the total resistance to mass transfer was found to be in the gas phase. At 300 K, Ammonia -water solutions follows Henry's law upto 5 mole% ammonia in the liquid, with m = 1.64 when the total pressure is 1 atm. Calculate the individual film coefficients and the interfacial concentrations. Interfacial concentrations lie on the equilibrium line.

C) A stream of air at 100 kPa pressure and 300 K is flowing on the top surface of a thin flat sheet of solid naphthalene of length 0.2 m with a velocity of 20 m/sec. The other data are: Mass iffusivity of naphthalene vapor in air = 6×10^{-6} m^2/sec, Kinematic viscosity of air = 1.5×10^{-5} m^2/s. Concentration of naphthalene at the air-solid naphthalene interface = 1×10^{-5} kmol/m^3. Calculate: (a) the overage mass transfer coefficient over the flat plate (b) the rate of loss of naphthalene from the surface per unit width. For heat transfer over a flat plate, convective heat transfer coefficient for laminar flow can be calculated by the equation. $Nu=0.664Re_L^{1/2}Pr^{1/3}$. You may use analogy between mass and heat transfer. (6)

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