MANICALAND STATE UNIVERSITY OF APPLIED SCIENCES

FACULTY OF ENGINEERING

DEPARTMENT: CHEMICAL AND PROCESSING ENGINEERING

MODULE: TRANSPORT PHENOMENA

CODE: CHEP 211

SESSIONAL EXAMINATIONS
DECEMBER 2022

DURATION: 3 HOURS

EXAMINER: MISS N. T. MADZIWA

INSTRUCTIONS

1. *Answer **all** questions.*
2. *Start a new question on a fresh page*
3. *Total marks 100*
4. *Formulae sheet is given at the end of the paper.*

Additional material(s): *Calculator and Lennard-Jones Constants Tables*

QUESTION 1

a) State Fick's law of molecular diffusion and define each term. [3]

b) Show that for diffusion in gases, the diffusivities of species **A** and **B**, D_{AB} and D_{BA} are equal. [6]

c) Describe how heat transfer by conduction occurs. [4]

d) Give ***two*** differences between forced convection and free convection in heat transfer. [2]

e) Under what conditions does the Navier-Stokes equation reduce to:

  i. Stoke's or Creeping flow. [1]

  ii. Euler equation. [1]

f) By performing a mass balance on a volume element $(\Delta x)(\Delta y)(\Delta z)$, show that for a fluid of constant density, the equation of continuity reduces to:

$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0$ or $\nabla \cdot v = 0$ [8]

QUESTION 2

A thin film of liquid of density ρ and viscosity μ flows down a vertical wall of length L and width W. The film thickness is δ. By performing a shell momentum balance on the z-component of momentum,

a. derive an equation for the velocity profile of the film. [20]

b. hence, determine the maximum velocity. [5]

QUESTION 3

a) An uninsulated steel pipe in a building transports steam at 450 °C. The walls of the building and the surrounding air are both at 25 °C. State and explain the heat transfer mechanisms that occur in this system. [6]

b) A furnace wall consists of 30 cm of fire brick (k = 1 W/m·K), 25 cm of insulating brick (k = 0.12 W/m·K) and a 35 cm of red brick (k = 0.75 W/m·K). The inner wall of fire brick is exposed to furnace gas at 1200K whilst air at 310 K is adjacent to the outside wall of red brick. The inside and outside convective heat transfer coefficients are 95 and 20 W/m^2·K, respectively. Determine:

i. the heat loss per square metre of the composite wall. [7]

ii. the temperature of the innermost wall surface. [2]

c) Calculate the rate of cooling of an aluminium plate (1.5 m by 1.5 m) at 580 K when it is suspended horizontally in stagnant air at 300 K. The heat transfer coefficient is estimated using the following correlation:

$$Nu_L = 0.14\, Gr_L^{\frac{1}{3}}\, Pr^{\frac{1}{3}}$$

where $Gr_L = \dfrac{L^3 \rho^2 g \beta \Delta T}{\mu^2}$

The properties of air, evaluated at the film temperature of 440 K are:

ρ = 0.8021 kg/m^3 ; c_p = 1.0197 × 10^3 J/kg·K ; μ = 2.4453 × 10^{-5} Pa·s ;

k = 3.6427 × 10^{-2} W/m·K ; β = 2.2681 × 10^{-3} K^{-1} [10]

QUESTION 4

a) Outline the mass transfer of a component between two immiscible phases using the Two-Resistance Theory, clearly stating the assumptions. [5]

b) Using the Two-Resistance Theory, show that for steady state mass transfer from a gas phase to a dilute liquid phase, the overall mass transfer coefficient in the liquid phase, K_L is related to the individual mass transfer coefficients of the gas phase and liquid phase, k_G and k_L respectively, by the following expression:

$$\frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{Hk_G}$$

Where H is the Henry's Law constant [7]

c) In the absorption of component A from an air stream into an aqueous stream, the composition of the two adjacent streams were $C_{AL} = 4$ kgmol/m^3 and $P_{AG} = 1.013 \times 10^4$ Pa. The Henry's law constant for this system is 1.674×10^3 Pa/(kgmol/m^3). The overall liquid phase mass transfer coefficient, K_L was equal to 1.26×10^{-6} kgmol/m$^2\cdot$s$\cdot$(kgmol/m^3). If 60% of the total resistance to mass transfer is encountered in the liquid film, determine the individual film mass transfer coefficients, k_G and k_L, the molar flux of **A** and the interfacial concentration C_{Ai}. [13]

END OF EXAMINATION

FORMULAE SHEET

Diffusional molar flux in the z-direction: $N_{A_z} = -cD_{AB}\frac{\partial y_A}{\partial z} + y_A N_{total}$

Diffusional molar flux of A in the z-direction: $N_{A_z} = -CD_{AB}\frac{\partial y_A}{\partial z} + y_A\left(N_{A_z} + N_{B_z}\right)$

Navier-Stokes equation: $\rho\frac{D\boldsymbol{v}}{Dt} = -\nabla\boldsymbol{P} + \mu\nabla^2\boldsymbol{v} + \rho\boldsymbol{g}$

Navier-Stokes equation in the *x*-direction:

$$-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 \mathrm{v}_x}{\partial x^2}+\frac{\partial^2 \mathrm{v}_x}{\partial y^2}+\frac{\partial^2 \mathrm{v}_x}{\partial z^2}\right)+\rho g_x=\rho\left[\frac{\partial \mathrm{v}_x}{\partial t}+\mathrm{v}_x\frac{\partial \mathrm{v}_x}{\partial x}+\mathrm{v}_y\frac{\partial \mathrm{v}_x}{\partial y}+\mathrm{v}_z\frac{\partial \mathrm{v}_x}{\partial z}\right]$$

Equation of Continuity: $\frac{\partial \mathrm{v}_x}{\partial x}+\frac{\partial \mathrm{v}_y}{\partial y}+\frac{\partial \mathrm{v}_z}{\partial z}=0$

Stoke's flow or Creeping flow: $-\nabla \boldsymbol{P}+\mu\nabla^2\boldsymbol{v}+\rho\boldsymbol{g}=0$

Euler equation: $\rho\frac{D\boldsymbol{v}}{Dt}=-\nabla\boldsymbol{P}+\rho\boldsymbol{g}$

Grad function: $\nabla=\frac{\partial}{\partial x}i+\frac{\partial}{\partial y}j+\frac{\partial}{\partial z}k$

Velocity in vector notation: $\boldsymbol{v}=v_x i+v_y j+v_z k$

Gravitational acceleration in vector notation: $\boldsymbol{g}=g_x i+g_y j+g_z k$

z-component of momentum flux in x-direction: $\phi_{xz}=\tau_{xz}+\rho v_x v_z$

z-component of momentum flux in y-direction: $\phi_{yz}=\tau_{yz}+\rho v_y v_z$

z-component of momentum flux in z-direction: $\phi_{zz}=P+\tau_{zz}+\rho v_z v_z$

General formula for viscous stress tensors: $\tau_{ij}=-\mu\left(\frac{\partial v_i}{\partial j}+\frac{\partial v_j}{\partial i}\right)$ where $i,j=x,y,z$