UNIVERSITY OF KWAZULU-NATAL

INYUVESI YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

EXAMINATIONS: NOVEMBER 2018

COURSE AND CODE: CHEMICAL ENGINEERING FUNDAMENTALS ENCH2EF

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINERS: PROF I GOVENDER, DR K MOODLEY

INTERNAL MODERATOR: DR J POCOCK

EXTERNAL MODERATOR: DR C NARASIGADU

INSTRUCTIONS:

1. **ALL** questions should be attempted.
2. **Two answer books are provided. Label them Book 1 and Book 2 respectively. Answer Section B in Book 1 and Section C in Book 2.**
3. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
4. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
5. This examination question paper, together with all associated diagrams **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

SECTION A

QUESTION 1 (Multiple Choice)

- Choose that answer which in your opinion is the correct or best answer and mark (with a "X") the appropriate block on the answer sheet provided.
- If you are *sure* of your answer, mark also the block containing the question mark.
- Use only a PEN on your answer sheet.

1.1 A gauge attached to a pressurised nitrogen tank reads a gauge pressure of 28 inches of mercury. If atmospheric pressure is 101 kPa, which of the following options best represents the absolute pressure in the tank?
1 inch = 2.54 cm and g = 9.81 m/s^2.

A. 196 kPa

B. 110 kPa

C. 195 kPa

D. 111 kPa

1.2 A liquid having a density ρ and viscosity μ is flowing through a horizontal straight pipe of diameter D at volumetric flowrate of Q. Which of the following statements best describes the relationship between the frictional head loss (H_f) and the pipe diameter?

A. $H_f \propto D^3$

B. $H_f \propto 1/D^3$

C. $H_f \propto D^5$

D. $H_f \propto 1/D^5$

1.3 The wall of an industrial furnace is constructed from fireclay brick of thickness h and thermal conductivity k. The steady-state operating temperature is maintained at T_1 and T_2 at the inner and out surfaces respectively. If the furnace material is replaced by one with a higher thermal conductivity, which of the following statements are false?

A. Heat flux increases

B. Power increases

C. Temperature gradient increases

D. Heat efflux increases

The following description applies to **Questions 1.4 and 1.5:**

A heat source emits radially outward from the main axis of a cylinder of diameter $D = 4.0$ m and length $L = 7$ m. The corresponding temperature profile as a function of radius (r) is given by:

$$T(r) = c + \frac{a}{k}\left[\frac{D^2}{4} - r^2\right],$$

where k denotes the constant thermal conductivity of the cylinder, $a = 1\frac{\text{J}}{\text{s·m}^3}$ is a fitting constant and $c = 85°\text{C}$.

1.4 The heat efflux through the boundary walls of the cylinder is:

A. 448π

B. 112π

C. 56π

D. 1190π

1.5 What is the best estimate (in SI units) of the convective heat transfer coefficient under steady-state operation at ambient room temperature?

A. 0.067

B. 0.047

C. 0.160

D. 0.167

1.6 In which of the following conditions will mass transfer occur spontaneously? C and z are concentration and distance respectively.

i. $dC/dz > 0$

ii. $dC/dz < 0$

iii. $dC/dz = 0$

iv. None of the above

A. i & ii

B. iii

C. All of the above (i, ii, iii)

D. iv

1.7 Which number forms the connecting link between the velocity and concentration profiles?

A. Schmidt number
B. Reynolds number
C. Stanton number
D. Fourier number

1.8 At which condition is the molar flux with respect to a stationary observer equal to the molar flux with respect to an observer moving with the molar average velocity?

A. In a very dilute solution
B. In a highly concentrated solution
C. At moderate concentration
D. Never

1.9 Under which of the following conditions is mass average velocity and molar average velocity equal?

A. In a very dilute solution
B. If molecular weights of all the species are equal
C. Always different
D. In dilute solutions as well as in solutions in which all components have same molecular weights

1.10 What is the physical significance of the Lewis number?

A. It is the ratio of bulk transfer mass and molecular diffusion
B. It is the ratio of thermal diffusivity to mass diffusivity
C. It is the ratio of conductive mass transfer to molecular diffusion
D. It is the ratio of mass transfer to mass capacity

TOTAL /50/

SECTION B

QUESTION 2

The *rotating-cylinder viscometer* comprises of a rotating, inner solid cylinder (radius, R and length L) and a fixed outer cylindrical shell as shown in figure 1. The narrow gaps (of thickness h and d as shown in the figure) are filled with a fluid. The solid cylinder is rotating at a constant angular velocity Ω about the main cylindrical axis. Assuming a Newtonian fluid of viscosity μ in the gaps:

2.1) State the no-slip boundary conditions in the h-gap and d-gap, and hence

(4)

2.2) Calculate the shear rates ($\dot{\gamma}_h$ *and* $\dot{\gamma}_d$) in the h-gap and d-gap respectively.

(6)

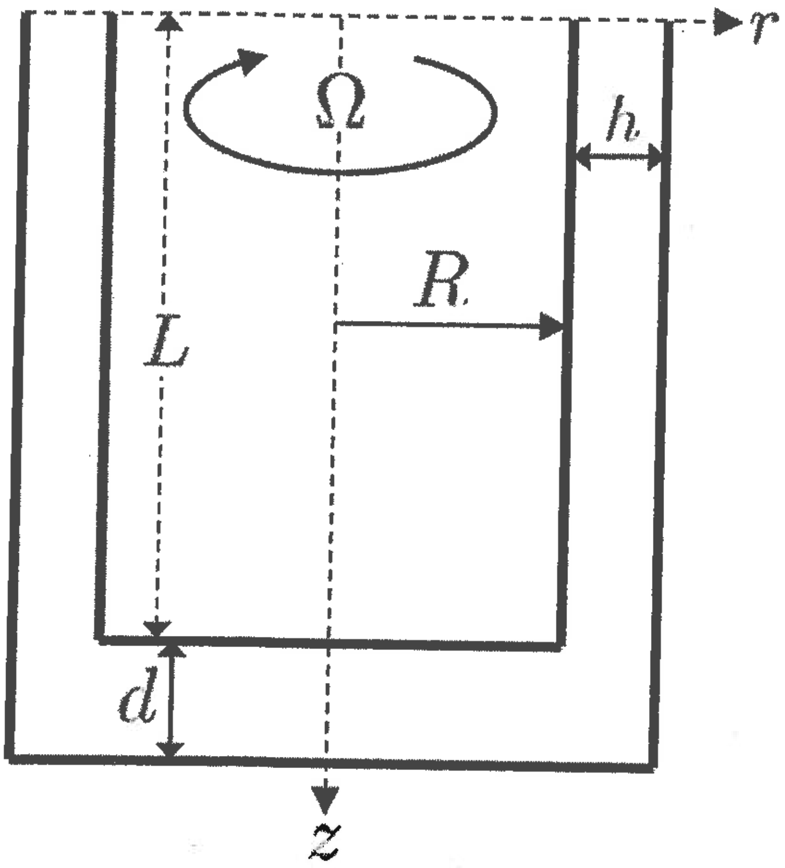

Figure 1

TOTAL /10/

QUESTION 3

Consider the steady-state heat flow (without generation) through a hollow cylindrical shell with inner and outer radii r_1 and r_2 respectively. The temperatures T_1 and T_2 at the inner and outer surfaces are such that $T_1 > T_2$.

3.1) Describe the heat efflux $q(r)$ in the solid region.

(2)

3.2) Describe the heat flux $\left[\frac{q(r)}{A(r)}\right]$ in the solid region.

(2)

3.3) Obtain an expression for the heat efflux mentioned in part (3.1) in terms of r_1, r_2, T_1, T_2, L, and a constant thermal conductivity, k.

(4)

3.4) If the thermal conductivity varies linearly with temperature as $k = a + bT$, re-derive the expression for the heat efflux.

(3)

3.5) By comparison of the results in question (3.3) and question (3.4), obtain an expression for the *effective* thermal conductivity, k_m, for question (3.4). What is the relationship between $k = a + bT$ and k_m?

(4)

TOTAL /15/

Formula Sheet

Reynolds Number:	$R_e = \frac{Dv\rho}{\mu}$
Newton's Law of Viscosity:	$\tau_{rx} = -\mu\frac{dv_x(r)}{dr}$
Mass balance:	$\int_{cs} \rho\vec{v}\cdot\overrightarrow{dA} + \int_{cv} \rho dV =$ Rate of mass generation
Momentum balance:	$\int_{cs} \vec{v}\rho\vec{v}\cdot\overrightarrow{dA} + \frac{\partial}{\partial t}\int_{cv} \rho\vec{v}dV = \sum$ Forces
Energy balance:	$\int_{cs} \overline{E'}\rho\vec{v}\cdot\overrightarrow{dA} + \frac{\partial}{\partial t}\int_{cv} \overline{E}\rho dV = q - \dot{W}$
Bernoulli's Equation:	$P + \frac{1}{2}\rho v^2 + \rho gh =$ constant
Continuity Equation:	$\rho Av =$ constant
Enthalpy balance:	$\overline{H}_1 + \frac{v_{1,av}^2}{2\alpha} + gy_1 \pm \overline{W}_s = \overline{H}_2 + \frac{v_{2,av}^2}{2\alpha} + gy_2 + \overline{Q}$
Mechanical energy balance:	$\frac{v_{1,av}^2}{2\alpha} + gy_1 + \frac{P_1}{\rho} \pm \overline{W}_s = \frac{v_{2,av}^2}{2\alpha} + gy_2 + \frac{P_2}{\rho} + \sum\overline{F}$
Head loss balance:	$\frac{v_{1,av}^2}{2\alpha g} + y_1 + \frac{P_1}{\rho g} \pm H_E = \frac{v_{2,av}^2}{2\alpha} + y_2 + \frac{P_2}{\rho g} + H_f$
Power:	ρgFH_E, where F is the volumetric flowrate
Hagen-Poiseuille Equation:	$\Delta P_f = \frac{32\mu(\Delta\ell)v_{av}^2}{D^2}$
Frictional pressure drop (any R_e):	$\Delta P_f = 2f\frac{\Delta\ell}{D}v_{av}^2$, where f is the Fanning friction factor
Fourier's Law:	$\frac{q_x}{A} = -k\frac{dT}{dx}$ In the x-direction
Newton's Law of Cooling:	$q = hA(T_s - T_e)$ $T_s > T_e$

SECTION C

QUESTION 4

A 20-cm-long, cylindrical graphite (pure carbon) rod is inserted into an oxidizing atmosphere at 1145 K and 1.013 x 10^5 Pa pressure. The oxidizing process is limited by the diffusion of oxygen counter-flow to the carbon monoxide (CO) that is formed on the cylindrical surface. Under the conditions of the combustion process, the diffusivity of oxygen in the gas mixture may be assumed to be 1.0 x 10^{-5} m^2/s.

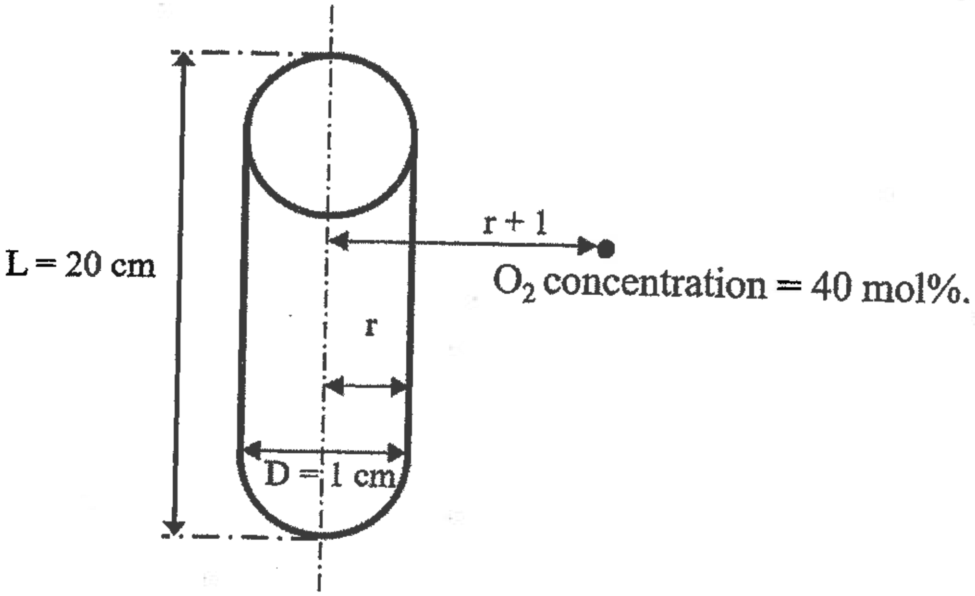

Figure 2

The combustion reaction is: $2C + O_2 \rightarrow 2CO$

4.1) Referring to figure 2, determine the moles of CO that are produced at the surface of the rod per second at the time when the diameter of the rod is 1.0 cm and the oxygen concentration that is a 1.0 cm distance from the rod [(1 + rod radius) cm from centre of the rod] is 40 mol%. Assume a steady-state process.

(10)

4.2) What would be the composition of oxygen 1.0 cm from the centre of the rod?

(7)

Question 4 continued ...

Useful equations for Question 4:

General equation for diffusion over generic distance x:

$$N_{Ax} = (N_{Ax} + N_{Bx})C_A/C - D_{AB}dC_A/dx,$$

where:

- N_{Ax} is the mass flux of A in the x direction,
- N_{Bx} is the mass flux of B in the x direction,
- C_A is the concentration of A diffusing,
- C is the concentration of the bulk fluid, and
- D_{AB} is the diffusion coefficient.

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QUESTION 5

McAdams presented the heat-transfer equation for the turbulent flow of gases past a single sphere.

$$Nu = \frac{hd_p}{k} = 0.37\left(Re_{dp}\right)^{0.6}\left(Pr^{1/3}\right),$$

where $Re_{dp} = \frac{d_p v_\infty}{\nu}$ with d_p the diameter of the sphere.

5.1) Propose the equation you would use to correlate the mass-transfer coefficient from a single sphere into a turbulent gas stream.

(3)

5.2) How would you modify your equation to cover a very low Reynolds number range?

(5)

Useful equations for Question 5:

General equation for diffusion over generic distance x:

$$N_{Ax} = (N_{Ax} + N_{Bx})C_A/C - D_{AB}dC_A/dx,$$

where N_{Ax} is the mass flux of A in the x direction,

N_{Bx} is the mass flux of B in the x direction,

C_A is the concentration of A diffusing,

C is the concentration of the bulk fluid, and

D_{AB} is the diffusion coefficient.

Chilton-Colburn analogy:

For heat	For mass
$\frac{f}{2} = St\,Pr^{\frac{2}{3}}$, where	$\frac{f}{2} = \frac{k_c}{\bar{v}}\left(Sc^{\frac{2}{3}}\right)$, where
f is the friction factor	f is the friction factor
St is the Stanton number	$\bar{v}$ is the average velocity
Pr is the Prandtl number	Sc is the Schmidt number

TOTAL /8/