Name ______________________

Student Number ______________________

University of Toronto
Faculty of Applied Science and Engineering
Final Examination, December, 1997

Third Year -- Program 5/Env, Biomed-chem
ChE393F Transport Phenomena

Fourth Year -- Program 5/Biomedical
ChE490 Biosystems III: Biotransport Processes

Examiner: Y.-L. Cheng

Instructions:

1. Type C Exam: One aid sheet allowed.
2. Calculator Type 2: Any non-programmable calculator allowed.
3. Do all problems.
4. Do all work on these sheets.

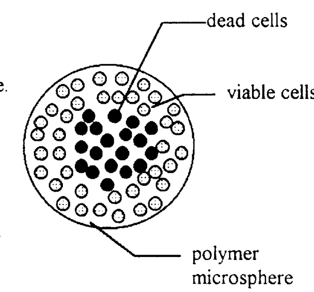
Problem 1	/10
Problem 2	/25
Problem 3	/25
Problem 4	/25
Problem 5	/15
Total	/100

Problem 1 [10 marks]

[Marks]

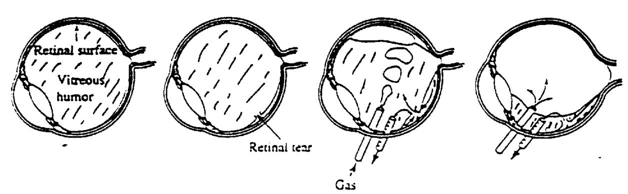
[5] (a) A solid object falling through the atmosphere is losing heat primarily by radiative heat transfer. Concurrently, some components of this object are evaporating into the gas phase and mass transfer away from the solid object takes place. Would you expect the Chilton-Colburn analogy between heat and mass transfer to apply in this situation? Explain.

[5] (b) Cells encapsulated in polymeric microspheres are being investigated in the treatment of a variety of diseases such as diabetes and Parkinsons disease. Essential nutrients such as oxygen diffuse from the surrounding fluid into the microsphere and are consumed by the encapsulated cells. It is observed that cells near the surface of the microspheres retain viability while cells in the interior core die. Explain this phenomenon, and discuss possible approaches to address this problem.



Problem 2 [25 marks]

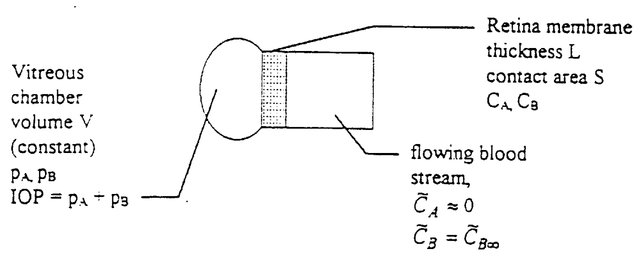
Tearing of the retina sometimes occurs, and may result in the detachment of the retina from the inner surface of the eye as shown. To re-attach the retina, the fluid in the vitreous chamber of the eye, the vitreous humour, is removed and replaced with a mixture of gases at high enough pressure to force the retina back against the inner eye surface.



The elevated intraocular gas pressure (IOP) must be maintained for a sufficiently long period of time to permit the retina to heal and re-attach. However, the IOP will decrease with time due to transport across the retina and into blood capillaries. Find an expression for IOP, as a function of time for the following model of this process. Clearly define any equilibrium partition coefficients, diffusion coefficients and mass transfer coefficients you require.

Model:

- The gas mixture can be treated as an ideal mixture of two components:
    - Component "A" is an inert gas that does not normally exist in the blood stream.
    - Component "B" is a mixture of components that normally exist in the blood stream.
- Immediately after injection of the gas mixture into the eye, the partial pressures of "A" and "B" are p_{Ao} and p_{Bo}, respectively. p_{Bo} is selected to be in equilibrium with blood stream concentrations of "B", $\tilde{C}_{B\infty}$.
- Transport from the vitreous chamber into the blood stream is limited by diffusion through the retinal membrane -- which you can treat as a solid membrane



Problem 3 [25 marks total]

Mass transfer coefficients from spheres into surroundng fluids are typically expressed in terms of Sherwood numbers **Sh** = $k_c d/D$, shere k_c is the convective mass transfer coefficient, d is the sphere diameter, and D is the diffusion coefficient of the solute "A" in the surrounding fluid.

Consider a situation where the concentration of "A" in the fluid at the sphere surface is maintained at C_{AS}, and the concentration in the bulk of the surrounding fluid is $C_{A\infty}$. "A" can be considered to be dilute in the surrounding fluid.

[Marks]

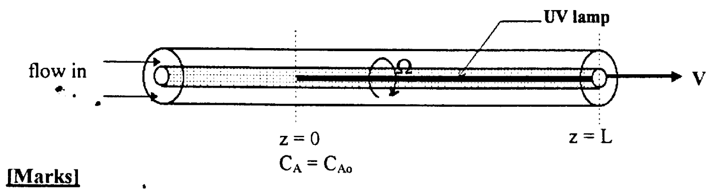
[10] (a) Find an expression for the Sherwood number when the surrounding fluid is stagnant.

[10] (b) If the surrounding fluid is undergoing forced convective flow, and the effect of convection on mass transfer is equivalent to a stagnant layer of thickness δ such that C_A drops from the surface concentration C_{AS} to the bulk concentration from $r = R$ to $r = R+\delta$, where R is the sphere radius, find an expression for the Sherwood number.

[5] (d) Is δ the same as a concentration boundary layer thickness around the sphere? Explain.

Problem 4 [25 marks total]

An incompressible Newtonian fluid flows laminarly between two concentric hollow cylinders as shown. The outer cylinder (radius R) is stationary while the inner cylinder (radius αR) is being pulled in the z-direction at velocity V, and rotated in the θ-direction at angular velocity Ω.



[Marks]

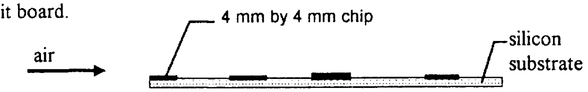
[12] (a) The flow is steady, and for $z \geq 0$ fully developed. Write the governing equations and associated boundary conditions that would permit you to solve for the point to point velocity profile in the region $z \geq 0$ and $\alpha R \leq r \leq R$. Justify any simplifications to the governing equations you make. Qualitatively sketch the velocity profiles you expect (use more than one sketch if necessary). Do not solve.

[8] (b) The flowing fluid is made up of a solvent as well as components "A" and "B" in dilute concentrations. The fluid at z = 0 contains "A" at concentration C_{Ao}. The inner cylinder is made of a UV-transparent material, and encloses a UV lamp in the region $z \geq 0$. The UV source catalyzes a chemical reaction $A \rightarrow B$ that occurs at the surface of the inner rod with the reaction kinetics rate expression $r_A = k\,C_A$ where k is the reaction rate constant, and r_A is the rate at which A is reacted per unit surface area per unit time (mols A $m^{-2}\,s^{-1}$). Write the governing equation and boundary conditions that would allow you to solve for the steady state point to point C_A profile in the annular region for $z \geq 0$ and $\alpha R \leq r \leq R$. Justify any simplifications you make. Do not solve.

[5] (c) Assuming you've found the expression for the C_A profile. Write an expression that would allow you to calculate the total rate of reaction W_A (mols A/s) in the region between z = 0 and z = L.

Problem 5 [15 marks]

Forced air at T_∞ of 25 °C and velocity V_∞ of 10 m/s is used to cool electronic elements on a circuit board. One such element is a chip, 4 mm by 4 mm, located at the leading edge of the circuit board.



Convection heat transfer for this situation has been found to be correlated by

$$Nu_x = 0.04\,Re_x^{0.85}\ Pr^{1/3}$$

The chip dissipates 30 mW when it is operational. The silicon substrate can be considered to be totally insulating. Data for air at the temperature of interest: thermal conductivity = 0.0262 W/(m K), Pr = 0.708, kinematic viscosity = 1.57×10^{-5} m^2/s. Assuming that the surface temperature of the chip reaches a steady state value which can be considered constant across the chip, estimate the surface temperature.

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