UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:-

M.Sc.

M9: Transport Processes

COURSE CODE	:	**CENG00M9**
DATE	:	**30-APR-03**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

03-N0018-3-30

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Answer *FOUR QUESTIONS*. **Only the first four answers given will be marked.** *ALL* questions carry a total of ***20 MARKS*** each, distributed as shown [ ]

1. Oil occupies the concentric space between a long horizontal shaft of radius R_1 and an enveloping cylinder of radius R_2.

   a) If the inner shaft is rotated within the cylinder at an angular velocity ω, derive a steady state expression for:

      (i) The liquid velocity distribution within the annular space. [8]

   b) If the inner shaft is drawn axially, without rotating, through the cylinder at a linear velocity V, derive steady state expressions for:

      (i) The liquid velocity distribution within the annular space. [8]

      (ii) The shear stress on the inner cylinder. [4]

You may assume that the oil is Newtonian.

Continuity and Navier-Stokes equations:

$$\frac{\partial \rho}{\partial t}+\frac{1}{r}\frac{\partial}{\partial r}(\rho r v_r)+\frac{1}{r}\frac{\partial}{\partial \theta}(\rho v_\theta)+\frac{\partial}{\partial z}(\rho v_z)=0$$

r-component

$$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta^2}{r}+v_z\frac{\partial v_r}{\partial z}\right)=-\frac{\partial p}{\partial r}$$
$$+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_r)\right)+\frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}+\frac{\partial^2 v_r}{\partial z^2}\right]+\rho g_r$$

θ-component

$$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right)=-\frac{1}{r}\frac{\partial p}{\partial \theta}$$
$$+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta)\right)+\frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial \theta}+\frac{\partial^2 v_\theta}{\partial z^2}\right]+\rho g_\theta$$

z-component

$$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2}+\frac{\partial^2 v_z}{\partial z^2}\right]+\rho g_z$$

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2. *Discuss* the concept of *penetration distance* in relation to the unsteady state transfer of mass, momentum and heat into semi-infinite media. [5]

Derive an expression for the early-time contact temperature between two finite bodies brought together at initially different temperatures given that the transient temperature distribution in a semi-infinite slab is given by:

$$\frac{T - T_o}{T_s - T_o} = erfc\ \eta$$

where

$$\eta = y / \sqrt{4\alpha t}$$

and

$$erfc\ \eta = \frac{2}{\sqrt{\pi}} \int_{\eta}^{x} e^{-t^2}\, dt$$

T_s is the surface temperature, T_o the initial temperature and T the temperature at distance y from the surface, α is the thermal diffusivity and is $= k/C_p\rho$. [10]

Thus *explain* which feels colder to the touch: wood or metal at the same temperature. [5]

3. *Discuss* the conceptual differences between the film and penetration models of mass transfer respectively. *State* the appropriate boundary conditions and *derive* the corresponding transport equations. [4]

Using the film theory, *sketch* the form of the concentration profiles for a gas dissolving into liquid and undergoing a first order chemical reaction for (a) no reaction, (b) slow reaction and (c) fast reaction. [4]

Explain the significance of the Hatta number, *Ha*, defined by:

$$Ha = \sqrt{D_A k_1} / k_L^o$$

where D_A is the liquid phase diffusivity of component A, k_1 is the pseudo first-order reaction rate constant and k_L^o is the physical mass transfer coefficient. [3]

Traces of CO_2 in a gas stream are absorbed by a 0.5M aqueous solution of KOH. If the reaction rate constant k_1 is 8.0×10^3 s^{-1}, the mass transfer coefficient is 4×10^{-4} m s^{-1} and the diffusivity of KOH in water is 2×10^{-9} m^2 s^{-1}.

(i) To what extent is the rate of absorption enhanced by the use of alkali? [3]

(ii) To which case above (a, b or c) does the system correspond? [3]

(iii) What type of mass transfer device would you recommend for this duty, and why? [3]

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4. Derive an expression for the Reynolds analogy between heat and momentum transfer in a pipe. [9]

State *briefly* how the Reynolds analogy may be modified to produce (i) the Prandtl analogy and (ii) the von Kármán analogy. [4]

Why are the Prandtl and von Kármán analogies likely to be superior to the Reynolds analogy? [3]

A gas flows through a straight pipe at 300 kg m^{-2} s^{-1} and a Reynolds number of 120,000. At this Reynolds number $c_f = 0.079\ Re^{-0.25}$. Using the Reynolds analogy, estimate the corresponding value of the heat transfer coefficient. [4]

Data: gas property: $c_P = 1.4$ kJ kg^{-1} K^{-1}.

5. Discuss *briefly* Rushton's concept of shear and flow in a stirred tank. [7]

A bench-scale stirred tank is to be scaled up to full-scale whilst retaining geometric similarity. The bench-scale tank is 0.2 m in diameter with a 0.05 m diameter impeller that rotates at 15 Hz and consumes 3.1 W in power. Both tanks are filled to a depth equal to their diameter with a liquid of density 1350 kg m^{-3}. The full-scale tank is 1.6 m in diameter. Scale up is to be performed at constant mean energy dissipation rate. How much power is required by the full-scale impeller and what is its rate of rotation? [8]

By what factors would the shear and flow characteristics change in the full-scale tank if the impeller diameter were doubled in diameter at constant power input? [5]

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6. Describe *briefly* the *Weissenberg effect.* [5]

Starting from the r-component of the equations of motion expressed in terms of stresses:

$$\rho\left(\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta} - \frac{v_\theta^2}{r} + v_z\frac{\partial v_r}{\partial z}\right) =$$

$$-\frac{\partial p}{\partial r} - \left(\frac{1}{r}\frac{\partial (r\tau_{rr})}{\partial r} + \frac{1}{r}\frac{\partial \tau_{r\theta}}{\partial \theta} - \frac{\tau_{\theta\theta}}{r} + \frac{\partial \tau_{rz}}{\partial z}\right) + \rho g_r$$

show that for a viscoelastic fluid contained between long concentric cylinders the difference in total stresses exerted on the outer and inner cylinder walls, radii r_o and r_i respectively, is given by:

$$(\tau_{rr} + p)_{r_o} - (\tau_{rr} + p)_{r_i} = \int_{r_i}^{r_o} \frac{\rho v_\theta^2}{r} dr + \int_{r_i}^{r_o} \frac{(\tau_{rr} - \tau_{\theta\theta})}{r} dr$$ [8]

A dilute polymer solution in a Newtonian solvent is contained between two concentric cylinders, inner cylinder diameter 60 mm and outer cylinder diameter 65 mm. When the outer cylinder was rotated at a fixed speed a total stress difference of 27 Pa was observed between the outer and inner cylinder walls. When the polymer solution was replaced by the Newtonian solvent a total stress difference of 71 Pa was observed under the same conditions. Assuming that the rate of shear is constant across the gap between the cylinders and that the polymer solution and the Newtonian solvent exhibit similar velocity profiles, what was the first normal stress difference exerted by the viscoelastic fluid? [7]

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