# UNIVERSITY COLLEGE LONDON

University of London

## EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

*B.Eng.* *M.Eng.*

**Chemical Eng E802: Transport Processes I**

COURSE CODE : **CENGE802**

UNIT VALUE : **0.50**

DATE : **28-APR-06**

TIME : **14.30**

TIME ALLOWED : **3 Hours**

06-C0216-3-80



**TURN OVER**

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

1. A turbine flowmeter consisting of a rotating propeller mounted coaxially in a circular pipe is used to measure volumetric flowrates. Use Buckingham's Π theorem to show that the volumetric flowrate, $Q$, the rate of rotation, $N$, and diameter, $d$, of the impeller, the diameter of the pipe, $D$, and the density, $\rho$, and viscosity, $\mu$, of the flowing fluid are related by [7]

$$\frac{Q}{ND^3} = f\left(\frac{\rho N D^2}{\mu},\ \frac{D}{d}\right)$$

What is the physical significance of each of these groups? [3]

A 20 mm diameter propeller in a 40 mm diameter pipe carrying water at 50 l $s^{-1}$ rotates at 1000 rpm. A geometrically similar 0.15m diameter propeller is installed in a 0.3m diameter pipe carrying carbon dioxide at 200 °C and 8 bar, which may be assumed to be ideal. At what rotational speed of the second propeller is dynamic similarity with the first achieved? [6]

What is the carbon dioxide volumetric flowrate at this speed? [4]

*Data:*
Carbon dioxide: $\mu = 2.5 \times 10^{-2}$ m Pa s; molar mass = 44.
Water: $\mu = 1$ m Pa s; $\rho = 1000$ kg $m^{-3}$.

2. 200 kg $h^{-1}$ of liquid at 15 °C flows through a well-stirred vessel where it is heated by condensing steam fed at 15 kg $h^{-1}$ flowing through heating coils immersed in the liquid.

If the hold up of liquid in the vessel at any time is 100 kg of liquid, what is the steady state temperature of the liquid? The walls of the vessel may be assumed to be well insulated. [6]

On start up the vessel contents are at 15 °C. Neglecting the thermal capacity of the vessel and the heating coil, what is the time taken for the temperature of the liquid to rise to within 5 °C of its steady state value? [14]

Data:
Liquid specific heat 3.3 kJ $kg^{-1}$ $K^{-1}$;
Steam specific enthalpy = 2800 kJ $kg^{-1}$;
Condensate specific enthalpy = 600 kJ $kg^{-1}$.

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3. The general form of the steady-state macroscopic momentum balance equation is:

$$\begin{matrix}\text{Rate of input} \\ \text{of momentum}\end{matrix} - \begin{matrix}\text{Rate of output} \\ \text{of momentum}\end{matrix} + \begin{matrix}\text{Sum of forces on} \\ \text{control volume}\end{matrix} = 0$$

Replace each of the terms in the above form with appropriate mathematical expressions. Define carefully any symbols that you use. [8]

Water, density 1000 kg $m^{-3}$, is to be pumped from a subterranean collection tank into a drain at a rate of 5 kg $s^{-1}$ through a 50 mm internal diameter pipe. The water exits the pump vertically through a short pipe and then horizontally via a sharp 90° bend. If the pressure at the inlet to the bend is 3 bar and the head loss across the bend is one velocity head, estimate the horizontal force exerted by the water on the bend. [12]

4. Discuss *briefly* two of the following:
   (i) Mechanism of viscosity in gases and liquids. [10]
   (ii) Advantages and disadvantages of Venturi meters with respect to orifice plate meters. [10]
   (iii) Colburn j-factors for heat and mass transfer. [10]

5. A shell and tube heat exchanger with one shell pass and one tube pass contains 88 tubes, each of 17.5 mm internal diameter, 22.3 mm outside diameter and 4.55 m long. Benzene flows through the tube-side at 21 kg $s^{-1}$. Given that for the tube-side, $Nu = 0.023 Re^{0.8} Pr^{0.4}$, where the symbols have their usual meaning, calculate the tube-side film heat transfer coefficient. [8]

The tube walls have a thermal conductivity of 48 W $m^{-1}$ $K^{-1}$ and the shell-side heat transfer coefficient is 4500 W $m^{-2}$ $K^{-1}$. Assuming that there is no thermal resistance due to fouling, calculate the overall heat transfer coefficient based upon the outside area of the tubes. [8]

What are the relative thermal resistances of both the outside and the inside films relative to that of the tube walls? [4]

Data:
Benzene: $\rho = 812$ kg $m^{-3}$; $\mu = 0.352$ mPa s; $c_p = 1.75$ kJ $kg^{-1}$ $K^{-1}$;
$k = 0.128$ W $m^{-1}$ $K^{-1}$.

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6. The mechanical Energy Balance Equation is:

$$\Delta\left(\frac{p}{\rho}+\frac{1}{2}\bar{u}^2+gz\right)+w_x+g\Delta h_f=0$$

where the symbols have their usual meaning. Describe *briefly* the significance of each of the five terms in this equation. [6]

Crude oil from an offshore platform arrives at a land pumping station with a pressure of 5 bar. From there it is to be delivered to a refinery at 2 bar through a 100 km pipeline, at an elevation of 70 m above the pumping station. The pipeline is of 0.5 m internal diameter, equivalent roughness 0.45 mm and includes fittings equivalent to 2000 pipe diameters. If oil is to be pumped through the pipeline at a rate of 12 $m^3$ $min^{-1}$, determine the head required by a pump to achieve this flowrate. [10]

What is the power required by the pump? [4]

Data: Crude oil properties: density = 800 kg $m^{-3}$, viscosity = 5 mPa s.

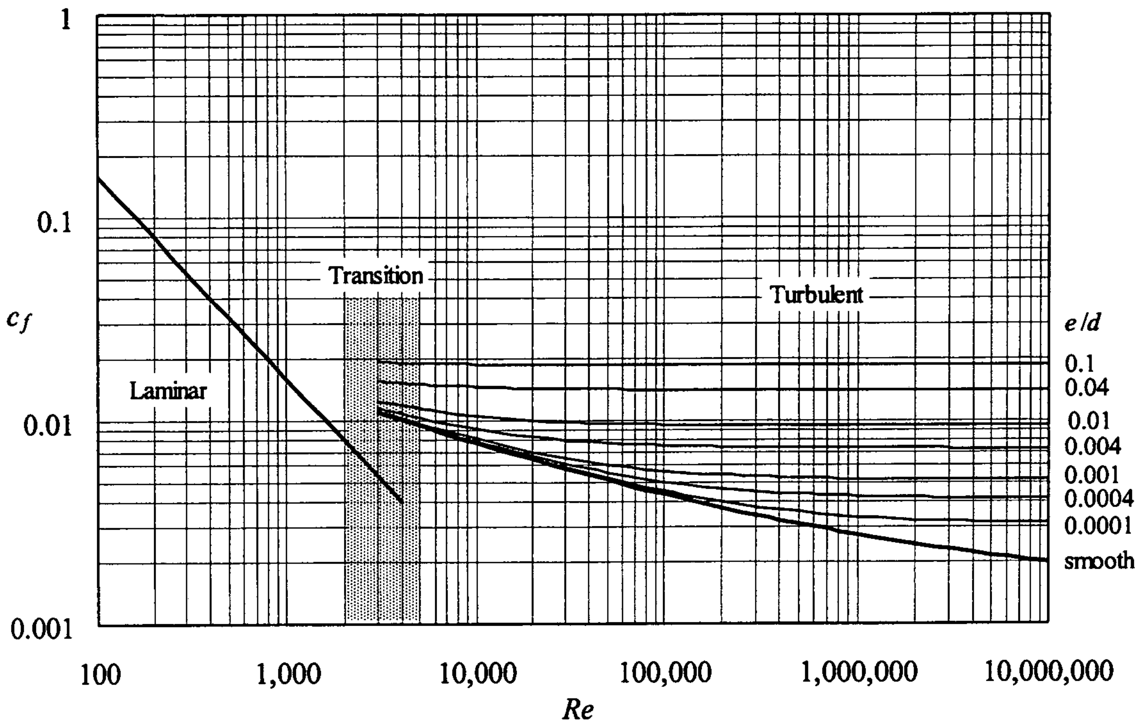


**Figure Q5:** Fanning Friction Factor versus Reynolds Number for Straight Pipes

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7. Starting from a steady-state microscopic mass balance show that in the case of one-dimensional diffusion in a stagnant gas film the molar flux of $A$ in the y-direction, $N_{A_y}$, between two points 1 and 2, is given by:

$$N_{A_y} = \frac{cD_{AB}}{y_2 - y_1} \ln\left[\frac{1 - x_{A_2}}{1 - x_{A_1}}\right]$$

where $c$ is the molar density, $D_{AB}$ the diffusivity of $A$ in B and $x_A$ the mole fraction of $A$. [10]

Stefan's method is used to determine the vapour-phase diffusivities of volatile liquids in air. In this method, the liquid is placed in an open-ended vertical cylinder and air is passed gently across the open end. The rate of evaporation is measured by weighing the cylinder and its contents. From the data given below obtained in such an experiment, evaluate the diffusion coefficient. [10]

Data:
Internal diameter of cylinder, 5 mm
Temperature, 15 °C
Total pressure, 1 bar
Weight loss in 30 minutes, 5 mg
Vapour pressure of liquid, 0.48 bar
Molar mass of liquid, 74 kg $kmol^{-1}$
Depth of liquid interface below the open end of the cylinder, 120 mm

**END OF PAPER**