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	:	**20-MAY-05**
TIME	:	**14.30**
TIME ALLOWED	:	**3 Hours**

05-C0179-3-80

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*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 horizontal cylinder with diameter d is kept at a constant temperature higher than that of the surrounding air. Show by dimensional analysis that the natural convection heat transfer coefficient, h, between the cylinder and the air, the cylinder diameter, d, the parameter βg, where β is the coefficient of thermal expansion for the air and g the acceleration of gravity, the temperature difference ΔT between the cylinder and the air properties density, ρ, viscosity, μ, specific heat, c_p, and thermal conductivity k can be related in the form of the following expression:

$$Nu = \mathrm{f}\,(Gr, Pr)$$

where $Nu = \dfrac{hd}{k}$ is the Nusselt number, $Gr = \dfrac{\beta g \rho^2 d^3 \Delta T}{\mu^2}$ is the Grashof number and $Pr = \dfrac{\mu c_p}{k}$ is the Prandtl number. Use as fundamental dimensions length L, mass M, time T, temperature θ and heat (energy) H. [10]

The heat transfer coefficient for a horizontal cylinder with $d = 0.2$ m in air at 294 K was measured experimentally and the following results were found:

Measurement 1: temperature of the cylinder = 400 K, $h = 6.545$ W m^{-2} K^{-1}.
Measurement 2: temperature of the cylinder = 500 K, $h = 7.732$ W m^{-2} K^{-1}.

Assuming that the experimental results obey an expression of the form:

$$Nu = a\,(Gr\,Pr)^b$$

where a and b are constants, calculate the heat transfer coefficient for a cylinder with diameter 0.3 m when the temperature of the cylinder is 470 K and that of the surrounding air is 294 K. [10]

For the above conditions the following values can be used for the air properties:

$\rho = 0.96$ kg m^{-3}, $\mu = 2.2\times10^{-5}$ Pa s, $c_p = 1.01\times10^{3}$ J kg^{-1} K^{-1},

$k = 3.2\times10^{-2}$ W m^{-1} K^{-1}, $\dfrac{\beta g \rho^2}{\mu^2} = 0.452\times10^{8}$ K^{-1} m^{-3}.

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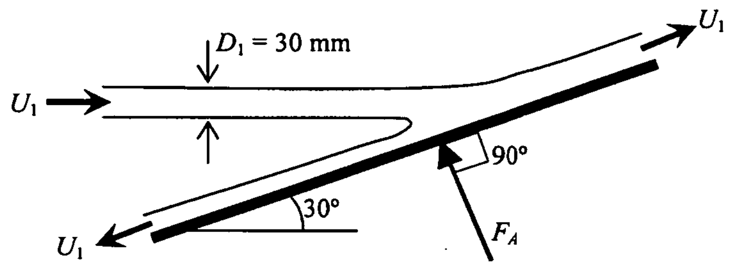
2.

What types of forces need to be taken into account in the momentum balance equation? Give an example of each type. [5]

A horizontal circular jet of air impinges on a stationary flat plate held at 30° to the horizontal and is split into the two directions as indicated in **Figure Q2** below.

Figure Q2 Impinging Jet



The jet velocity is 40 m s^{-1} and the jet diameter is 30 mm. If the air velocity magnitude remains constant and equal to that of U_1, as the air flows over the plate surface in the directions shown, determine:

(i) The magnitude of the force F_A required to hold the plate stationary. [7]

(ii) The fraction of mass flow along the plate surface in each of the two directions. [8]

You can assume that there are no frictional losses along the plate surface.

Density of air: 1.23 kg m^{-3}

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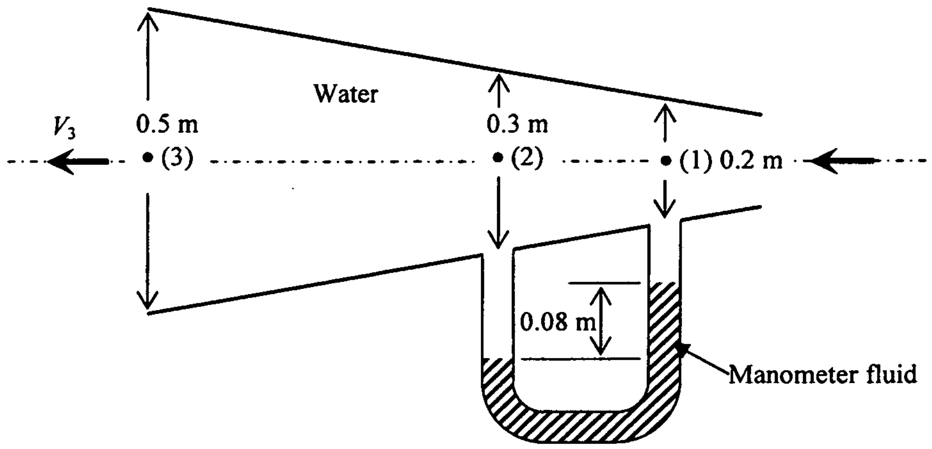
3.

What are the main assumptions in the derivation of the Bernoulli equation? [5]

Water flows steadily through a diverging tube as shown in the figure below. Determine the velocity V_3 at the exit of the tube if frictional effects are negligible. [15]

Density: water = 1000 kg m^{-3}, manometer liquid = 2000 kg m^{-3}

Figure Q3: Diverging Tube



4.

Answer *briefly* TWO of the following

(i) What are the mechanisms of heat and mass transfer by molecular diffusion? [10]

(ii) What are the methods for the measurement of liquid viscosity. [10]

(iii) Compare and contrast laminar and turbulent flows. [10]

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5.

The defining equation for the Fanning Friction Factor, c_f, in a pipe is $\tau_0 = c_f \frac{1}{2}\rho\bar{u}^2$, where τ_0 is the pipe wall shear stress, ρ the fluid density and $\bar{u}$ the mean fluid velocity. Using a momentum balance on a section of pipe, diameter d and length L, show that the pressure loss due to friction, Δp_f, is given by

$$\Delta p_f = 2c_f \frac{L}{d}\rho\bar{u}^2$$ [10]

State carefully any assumptions that you make. [2]

2600 kg min^{-1} of a liquid, density 1170 kg m^{-3} and viscosity 2.3 mPa s, flows through a long horizontal pipeline. If the pipeline has a diameter of 150 mm, a length of 560 m and is made of commercial steel, estimate the pressure loss due to friction. [8]

Data:

Table Q5: Absolute roughness of pipes

Pipe material	*Roughness* e (mm)
Drawn tubing	0.0015
Commercial Steel & wrought iron	0.05
Cast iron	0.25
Concrete	0.3 ~ 3
Riveted Steel	1 ~ 10

The Fanning friction factor is given by:

$$c_f = 0.001375\left[1+\left(20{,}000\frac{e}{d}+\frac{10^6}{Re}\right)^{1/3}\right]$$

6.

The radial heat flux, q_r [W m^{-2}], at radius r in a long cylinder of circular cross-section with internal energy generation of $\dot{q}$ [W m^{-3}] is given by $\frac{d(rq_r)}{dr} = \dot{q}r$. Show that the radial temperature profile is given by

$$T - T_o = \frac{\dot{q}r_o^2}{4k}\left[1-\left(\frac{r}{r_o}\right)^2\right]$$

where T is the temperature at radius r, T_o is the temperature at radius r_o, the outside radius, and k is the thermal conductivity of the cylinder. [12]

A nuclear fuel element is in the form of a long circular cylinder. If the rate of internal energy generation is 50 MW m^{-3}, calculate the maximum diameter of the element such that the maximum temperature within the rod is no more than 250 K above the element's outer surface temperature. [8]

The thermal conductivity of the fuel element is 30 W m^{-1} K^{-1}.

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7\.

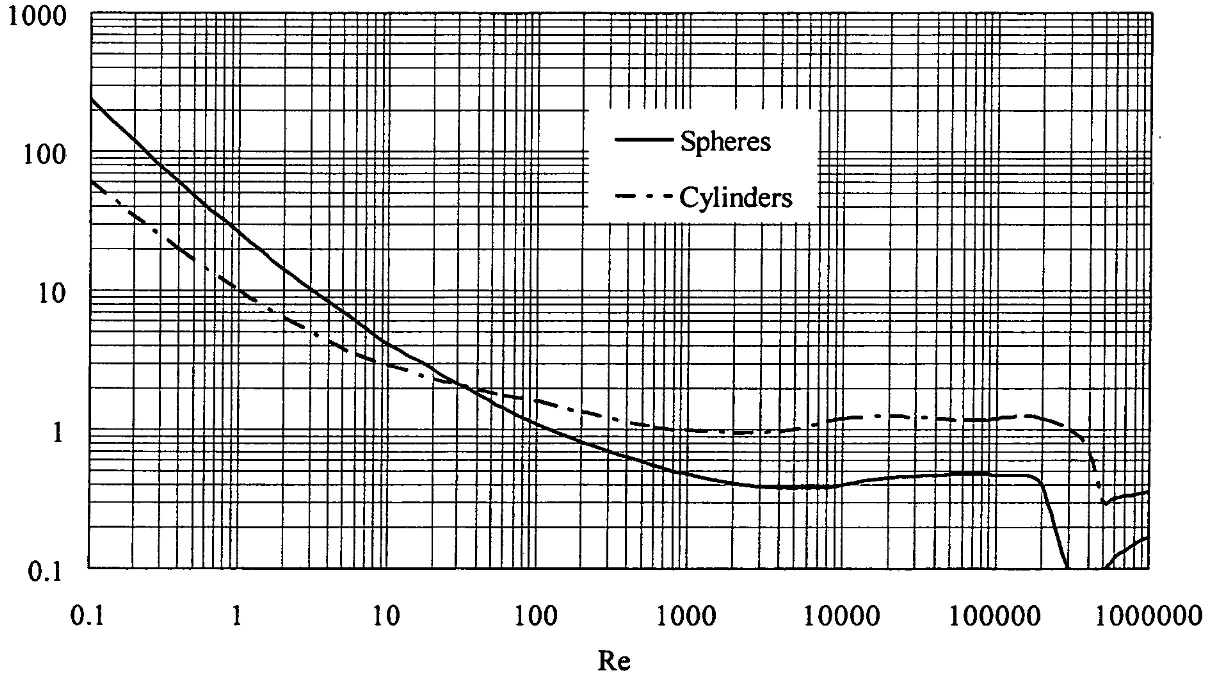
Using the information given below, estimate the mass transfer coefficient of a 7 mm diameter sphere of solid sucrose as it falls through water at its terminal velocity. [20]

The terminal velocity of a sphere, diameter d, is given by $u_t = \sqrt{\frac{4d(\rho_s - \rho)g}{3c_{D_S}\rho}}$, where ρ_s is the density of the sphere, ρ is the density of the fluid, g is gravitational acceleration and c_{D_S} is the drag coefficient of the sphere. The chart below shows how drag coefficients for spheres and cylinders vary with Reynolds number, *Re*. Liquid mass transfer film coefficients k_L from a sphere to a flowing fluid are correlated by $\frac{k_L d}{D_{AB}} = 2 + 0.6\left(\frac{\rho u_t d}{\mu}\right)^{0.5}\left(\frac{\mu}{\rho D_{AB}}\right)^{0.33}$ where D_{AB} is the mass diffusivity of the solute, μ the fluid viscosity, other symbols are defined as above.

Data:-

Mass diffusivity of sucrose in water 0.45×10^{-9} m^2 s^{-1}
Density sucrose solid 1580 kg m^{-3}
Density of water 997 kg m^{-3}
Viscosity of water 0.5 mPa s

Chart Q7: Drag coefficients for spheres and cylinders



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