# UNIVERSITY COLLEGE LONDON

*University of London*

## EXAMINATION FOR INTERNAL STUDENTS

*For The Following Qualifications:-*

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

**Biochemical Eng E102: Introduction to Biotransport Processes**

| | | |
|---|---|---|
| COURSE CODE | : | **BENGE102** |
| UNIT VALUE | : | **0.50** |
| DATE | : | **19-MAY-03** |
| TIME | : | **10.00** |
| TIME ALLOWED | : | **3 Hours** |

03-C0100-3-60


**TURN OVER**

*Answer 5 QUESTIONS.* **Only the first 5 answers given will be marked.**
*ALL questions carry a total of 20 each, distributed as shown* [ ]

**1.**

Dimensional analysis showed that the following relation describes the mixing of a liquid in a stirred unbaffled tank:

$$\frac{P}{\rho N^3 D^5} = f\left[\frac{\rho N D^2}{\mu}, \frac{N^2 D}{g}\right]$$

where P is the power consumption, N is the impeller rotation speed, D is the impeller diameter, g is the acceleration due to gravity and ρ and μ are the liquid density and viscosity respectively.

Water is mixed in a stirred unbaffled tank which has diameter $D_L$. The rotating speed is $N_l$ and the power consumption is $P_L$. It is planned to design a small model of this tank that is physically similar to the large scale prototype. Describe the steps which should be followed for the design of the model tank.

a) What problems can appear during the design of the model tank if water is used as the liquid in both systems. How can you overcome them? [12]

b) What is the meaning of physical similarity between a model and a prototype and what applications does it find? [5]

c) How can dimensionless groups be used in order to ensure similarity between a model and a prototype? [3]

**PLEASE TURN OVER**

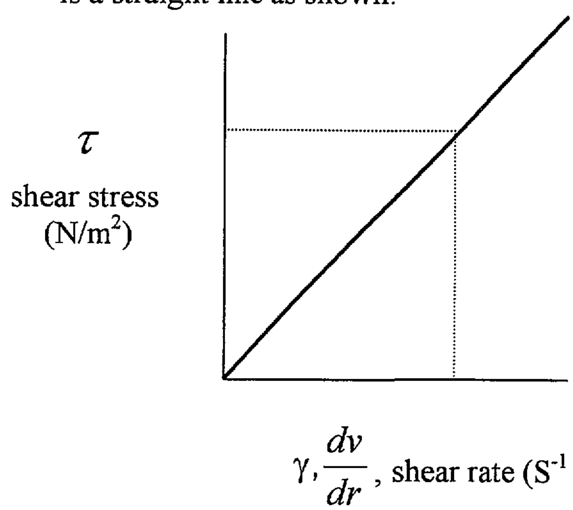
**2.**

A viscous liquid is pumped through a pipe of diameter, D and length, L. If flow is steady, laminar and fully developed, obtain the radial distribution of shear stress and show that its value at the wall of the pipe is given by:

$$\tau_W = -\frac{D}{4}\frac{\Delta P}{\Delta L}$$ [6]

Where ΔP is the pressure drop across a section of the pipe with length ΔL.

The liquid is Newtonian and the shear stress, τ, and the shear rate, γ, is a straight line as shown:




Show that the velocity of the liquid as a function of the radial position, r, from the centre of pipe is:

$$U = \frac{1}{\mu}\left(\frac{\Delta P}{\Delta L}\right)\left(\frac{D^2}{16} - \frac{r^2}{4}\right)$$ [8]

Briefly comment on:

i) The shape of the velocity profile given by equation [2]

ii) What happens to the velocity distribution when flow changes from laminar to turbulent. [2]

iii) When flow remains laminar but the fluid becomes shear thinning (pseudoplastic). [2]

iv) As (iii) but shear thickening (dilatant). [2]

**PLEASE TURN OVER**

**3.**

What is meant by the terminal velocity of particles settling in a liquid medium?

Show that for laminar flow, terminal settling velocity, of a spherical particle is given by

$$U_t = \frac{D^2 g(\rho_s - \rho_f)}{18\mu}$$ [10]

Where $\rho_s$ and $\rho_f$ are the density of the solid and fluid respectively, $\mu$ in the liquid viscosity which is assumed to be Newtonian, g is the acceleration due to gravity and D is particle diameter.

A mixture of two materials, A and B is to be separated into fractions of materials A and B by making use of the different terminal velocities of the particles. The ratios of the density of material A, and material B to the suspending liquid are 1.9 and 1.35 respectively.

For complete separation of the two materials $(U_t)_A > (U_t)_B$. Show that for complete separation the ratio of the maximum diameter, $D_B$ of particles of material B to the minimum diameter, $d_A$, of particles of material A must not exceed about 1.6. [10]

**4.**

A Newtonian liquid of viscosity 0.00056 $Ns/m^2$ is flowing through a smooth 2 cm inside diameter tubing which is 20 m long. Assuming that flow is laminar and fully developed, calculate the volumetric flow rate and velocity of the liquid if flow is achieved by a pump having a total head (pressure) of 0.6 $N/m^2$. [15]

Verify your solution and comment on the applicability of the equations used. [5]

**PLEASE TURN OVER**

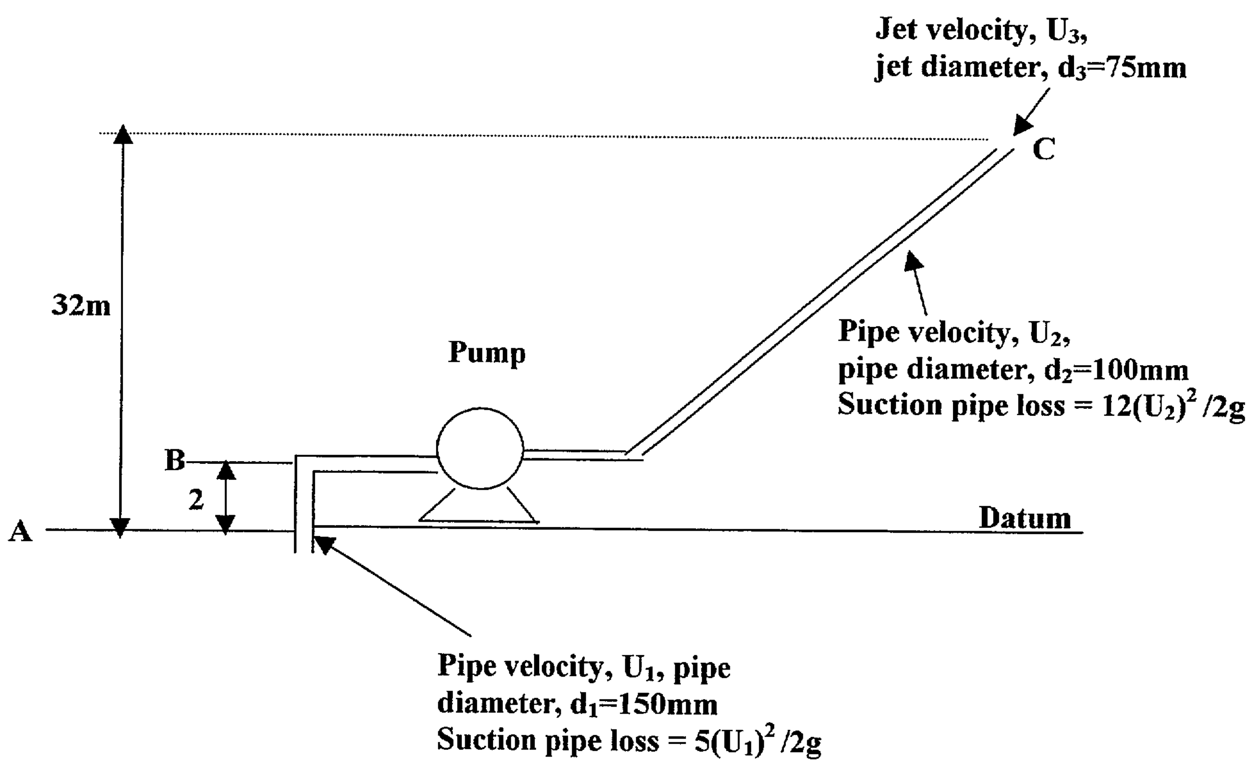
5.

A pump develops a head of 50m. The pump draws water from a pump at A (figure below) through a 150mm diameter pipe in which there is a loss of energy per unit weight due to friction, $h_1 = 5\frac{U_1^2}{2g}$ varying with the mean velocity $U_1$ in the pipe, and discharges it through a 75mm nozzle at C, 30m above the pump, at the end of 100mm diameter delivery pipe in which there is a loss of energy per unit weight $h_2 = 12\frac{U_2^2}{2g}$.

Applying Bernoulli's equation calculate:

a) The velocity of the jet issuing from the nozzle at C. [12]

b) The pressure in the suction pipe at the inlet to the pump at B. [8]




**PLEASE TURN OVER**

6.

What do you understand by dynamic similarity between two particles flowing through two different fluids. [5]

A drag force of 20N is experienced by a spherical particle flowing through water at 2 m/s. A second particle having a diameter twice that of the first is placed in a wind tunnel. The air pressure and temperature in the wind tunnel are maintained constant. What air velocity is required to maintain dynamic similarity between the two systems? [10]

What is the corresponding drag force on the sphere in the wind tunnel. [5]

Data for the two systems are as follows:

| | WATER | AIR |
|---|---|---|
| Density | $1000 kg/m^3$ | $1.19 kg/m^3$ |
| Viscosity | $10^{-3} Ns/m^2$ | $1.7 \times 10^{-5} Ns/m^2$ |

7.

Dimensional analysis shows the relationship for the power input to a Newtonian fermentation broth agitated by a turbine impeller in fully baffled bioreactor is given by:

$$\frac{P}{\rho N^3 D^5} = f\left[\frac{\rho D^2 N}{\mu}\right]$$

where the group on the left-hand-side is the impeller power number, $P_o$ and that on the right-hand-side is the impeller Reynolds number, Re. Using the following experimental data:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Re | 2 | 3 | 5 | 10 | 20 | 40 | 50 | 100 | 200 | 500 | 1000 |
| $P_o$ | 100 | 67 | 40 | 20 | 11 | 7.0 | 6.0 | 5.0 | 4.5 | 4.0 | 4.0 |

i) Plot the graph of $P_o$ versus Re [10]

ii) Obtain the relationship between $P_o$ and Re for laminar and turbulent regimes. [5]

iii) Specify where laminar flow stop and turbulent flow regime begins. [5]

**PLEASE TURN OVER**

**8.**

i) Describe the mechanisms of momentum, heat and mass transfer by molecular diffusion. [8]

ii) Write in differential form the one-dimensional equations which describe the above mechanisms of momentum, heat and mass transfer. Explain all the symbols you are using. [5]

iii) Discuss the similarity of the three molecular diffusion processes. [8]

**END OF PAPER**