UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:–

M.Sc.

Biochem Eng G21: Mass, Heat and Momentum Transfer and Bioprocess Material Properties

COURSE CODE	:	**BENGEG21**
DATE	:	**21-MAY-04**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

TURN OVER

*Answer **FOUR QUESTIONS. ALL** questions carry a total of **25 MARKS** each, distributed as shown [ ] Only the **FIRST FOUR ANSWERS** will be marked.*

1.

A cup-and-bob viscometer is used to measure the rheological properties of a mycelial fermentation broth. The inner cylinder rotates at a rotational speed (N) in revolutions per second and the torque (T) is measured. The inner cylinder has a radius (r_i) of 2.5 cm and length (L) 4 cm. The outer cylinder has a radius (r_o) 2.6 cm. The following measurements were recorded:

Rotational speed (s^{-1})	Torque (N m)
0.01	2.37×10^{-4}
0.05	5.72×10^{-4}
0.2	1.04×10^{-3}
1	1.97×10^{-3}

a) State the equations that relate the shear rate (γ) and shear stress (τ) to the rotational speed (N) and torque (T). Assume that the shear rate is constant over the annular gap in the cup-and-bob viscometer. [4]

b) Plot the rheogram for this fluid. [8]

c) Describe the type of rheological behaviour displayed by this broth and give the general equation for this behaviour. [4]

d) Describe limitations of this experiment. How can the equipment be modified to overcome these difficulties? [5]

e) Why is it important to be able to measure the rheology of fermentation broths? [4]

2.

a) Describe briefly the key differences between laminar and turbulent flow in a pipe. [6]

b) Explain why velocity profiles develop in pipes and illustrate with the aid of suitable diagrams how they change depending on the flow regime. Write down and comment on the ratio of the average velocity to the maximum velocity in each case. [10]

CONTINUED

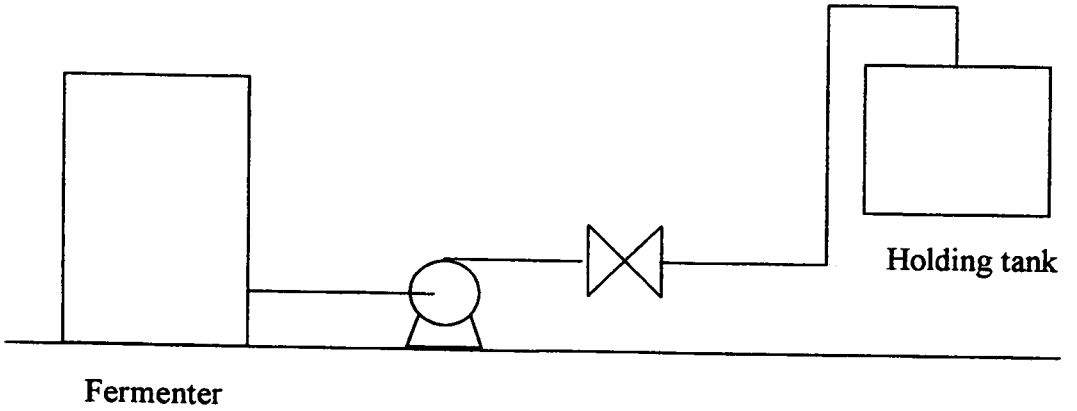
c) You are responsible for a fermentation suite with its associated pipework in a biopharmaceutical plant. Cleaning solution is passed through the pipes at the end of each batch. Calculate the minimum mass flow rate of the cleaning solution required in a 2.5 cm diameter stainless steel pipe and justify your answer. The cleaning solution has a density of 1050 kg/m^3 and a viscosity of 1x10^{-3} Pa.s. [5]

d) A syringe with a fine needle is used to deliver a biological drug to a patient. What type of flow do you expect in the syringe? What is the flowrate of the drug most sensitive to? Justify your answer. [4]

3.

a) State the Bernoulli equation and label each term. List the key limitations of the Bernoulli equation. [8]

b) At the end of a fermentation run, broth exits the fermenter through a harvest pipe on the side of the fermenter as shown in the diagram. The broth is transported through the pipe to a holding tank. Derive expressions for the velocity of the broth leaving the fermenter and the volumetric flowrate. [12]



c) Describe why the Bernoulli equation needs to be modified to calculate the pressure drop through the pipe. [3]

d) Write down the modified Bernoulli equation. [2]

TURN OVER

4.

a) What objectives are used when scaling-up/down stirred tank fermenters? How are they achieved? [4]

b) An *E.coli* fermentation broth is agitated in a 10L fermenter using a turbine impeller 0.058 m in diameter. Calculate the gassed power required for a stirrer speed of 240 rpm. You may assume that the ratio of ungassed power to gassed power is 1:0.4 and that the broth has a density and viscosity of 1000 $kg.m^{-3}$ and 10^{-3} Pa.s, respectively. The power number for a turbine impeller in the turbulent flow region is 5.7. [6]

c) You are asked to scale up the 10L fermenter to a 100L fermenter for pilot-scale runs. Determine the new stirrer speed for the 100L fermenter assuming that *E.coli* cells are robust and resistant to shear damage.

You are given the following information about the 100L fermenter:

Vessel aspect ratio = 2.5
Vessel volumetric space efficiency = 75%
Aeration rate = 0.75 vvm
Impeller diameter : Vessel diameter = 1:3 [15]

5.

a) A number of assumptions are made when deriving equations to describe the flow of liquid through a packed bed. List these assumptions and detail how each of these will also affect the values that are generated from the correlations and equations used. [10]

b) If you now decide to increase the diameter of the particles by a factor of two-fold how will this change the pressure drop in the system? [5]

c) Using these equations and correlations estimate the pressure drop that will result from the following conditions:

Flowrate: 20 L/h
Column radius: 5 cm
Particle radius: 30 micron
Bed height: 15 cm

List any assumptions that you make in addition to those covered in the first part of the question. [10]

CONTINUED

6.

This question concerns mass transfer in biocatalytic reactions.

a) Describe the uses of biocatalysis, using examples to illustrate your answer as appropriate. [5]

b) Under what circumstances can biocatalytic reactions become mass transfer limited? [8]

c) Define the Thiele Modulus and use it to describe graphically the effect of mass transfer limitation on an immobilised enzyme catalysed reaction. [7]

d) Describe a simple experimental test to establish whether there is diffusional limitation in a given system. [5]

END OF PAPER