UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Eng.   *M.Eng.*

Heat and Mass Transfer in Bioprocesses

COURSE CODE	:	**BENG2009**
UNIT VALUE	:	**0.50**
DATE	:	**02-MAY-06**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

06-C0108-3-60

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

1.

You are working in a company that has developed a process to produce DNA vaccines from *E.coli*. After the fermentation step a lysis step is used to release the DNA from the cells resulting in a sticky mixture. You find that an aggressive cleaning solution heated to 80°C is required to clean the sticky mixture off the inside of the lysis tank. A counter-current shell-and-tube heat exchanger containing 100 tubes is used to heat the cleaning solution from 10°C to 80°C at a mass flow rate of 8.6 kg s^{-1}. The tubes have external and internal diameters of 11 and 10mm, respectively, and a thermal conductivity of 17 W m^{-1} K^{-1}. Water enters the shell at 90°C at a mass flow rate of 22 kg s^{-1}. The shell side heat transfer coefficient is 2500 W m^{-2} K^{-1}.

You are given the following data:

The following correlation applies for turbulent flow in pipes:
$Nu = 0.023\, Re^{0.8}\, Pr^{0.4}$

Cleaning Solution:

Thermal conductivity	$= 0.5\ W\,m^{-1}\,K^{-1}$
Viscosity	$= 1 \times 10^{-3}\ Pa\ s$
Specific heat capacity	$= 3.68\ kJ\,kg^{-1}\,K^{-1}$
Density	$= 1{,}100\ kg\,m^{-3}$

Water

Specific heat capacity	$= 4.18\ kJ\,kg^{-1}\,K^{-1}$

a) Calculate the surface area available inside the heat exchanger. [23]

b) You notice that with time the aggressive cleaning solution causes corrosion in the heat exchanger resulting in a build up of layers of rust deposits. If you were to buy a new heat exchanger, suggest ways you could re-specify its design so as to limit the damage by corrosion? [2]

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2.

You are required to advise on the effect of major changes in fermentation broth properties on the ability to control temperature during microbial growth. The reported changes are the growth of the organism in a more filamentous form and to a higher final cell concentration but without any significant change in growth rate. These changes lead to:

i. a 10–fold increase in the viscosity of the final broth
ii. an increase in sensitivity of the microorganism to shear stress leading to a recommended requirement for a 2-fold decrease in stirrer speed
iii. a doubling of the final cell concentration.

a) Using the design assessment given below of the existing fermentation process define the cooling water temperature for the growth of the new strain. [14]

b) You decide to recommend that the fermentor is run at maximum cooling capacity and to adjust nutrient to limit cell growth. Assuming the viscosity of the broth remains at its new high level calculate the reduction in cell concentration which will occur. [11]

State all assumptions made in your calculations.

Existing fermentation process:

- *overall resistance to heat transfer ~ 0.002* $m^2\,K\,W^{-1}$
- *25% of this overall resistance is estimated to be attributed to a so-called fermentor broth liquid film*
- *temperature of available cooling water* 20^oC
- *fermentor broth temperature* 25^oC
- *minimum cooling water temperature during fermentor operation* 22^oC

CONTINUED

3.

You are working in a food company producing two products: canned tomato soup and canned tomato puree. You are responsible for designing the sterilisation stage for each of the canned products so as to destroy micro-organisms such as *Clostridium botulinum*. The cans of each product are stacked vertically in retorts and exposed to steam at 120°C.

You are given the following data:

	Tomato Soup	*Tomato Puree*
Initial temperature, °C	*50*	*50*
Thermal conductivity, $W m^{-1}K^{-1}$	*0.55*	*0.836*
Density, $kg\ m^{-3}$	*980*	*1300*
Mean heat capacity, $kJ\ kg^{-1}\ K^{-1}$	*3.95*	*3.80*

Can:

Diameter = 7.5 cm
Height = 11.5 cm

The resistance to heat transfer caused by the metal wall of the can is assumed to be negligible. The heat transfer coefficient of the steam is 5000 $W\ m^{-2}K^{-1}$. The overall heat transfer coefficient for the canned tomato soup is 100 $W m^{-2}K^{-1}$.

a) For the sterilisation stage, sketch the shapes of the temperature profiles that you would expect across
   i) a can of tomato soup
   ii) a can of tomato puree
at time intervals t_0 and t_1.

State any assumptions used. [9]

b) Estimate the time taken for the centre of a can to reach 100°C for the case of
   i. a can of soup
   ii. a can of puree

In each case, assume the can is in the centre of a vertical stack of cans and is insulated on its two ends by the other cans.

Comment on your answers. [16]

Centreline temperature charts for an infinite cylinder are provided.

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4.

a) Describe all the stages from a prepared liquid formulated protein in a tank to a freeze-dried product in a vial suitable as the basis for an injectable therapeutic. Define precautions to be taken at each stage to avoid damage of the protein product. [10]

b) Show that the time taken to complete the primary drying phase may be described by

$$t = \frac{\Delta x^2 \rho_1 \phi}{2 k_p \Delta P}$$

Detail all assumptions in this derivation [15]

5.

a) Discuss why the outlet air temperature and the droplet size are the main determinants of how a heat labile protein may be spray dried with minimal damage. [10]

b) Using the design specifications given below calculate the change in drier throughput which might be required if a decrease in outlet air temperature to 60°C is to be implemented without any change in the final powder moisture content. Give full details of all assumptions. [10]

c) When testing out your calculations you find that the change in throughput is correctly predicted but the yield of active protein still remains low. Discuss why this may be the case. [5]

Moisture sorption isotherms and air-water enthalpy-humidity diagrams are provided.

Design specification of existing drier:

- *inlet air at 20 °C and 0.008 kg moisture / kg dry air*
- *outlet air at 80 °C*
- *final powder moisture content 0.1 kg moisture / kg dry solid*

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6.

The performance of a gel filtration chromatography column is tested after the first run (figure A) and 10th run (figure B) using a none binding pulse test to allow calculation of the number of theoretical plates.

Figure A

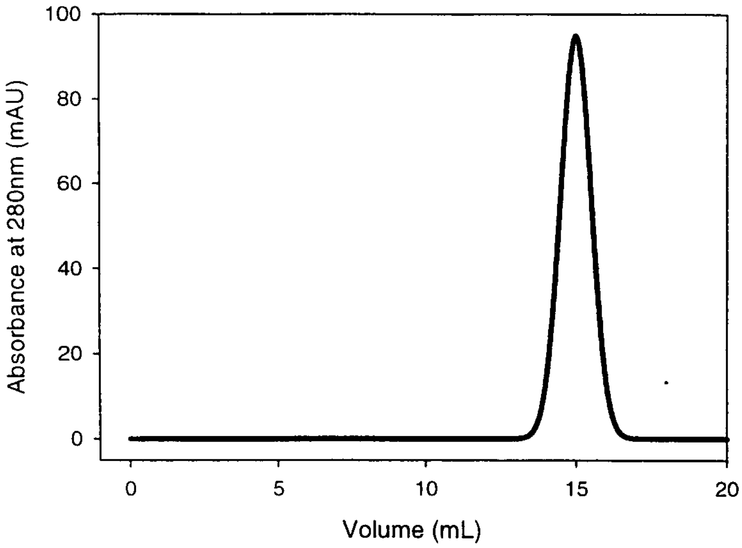
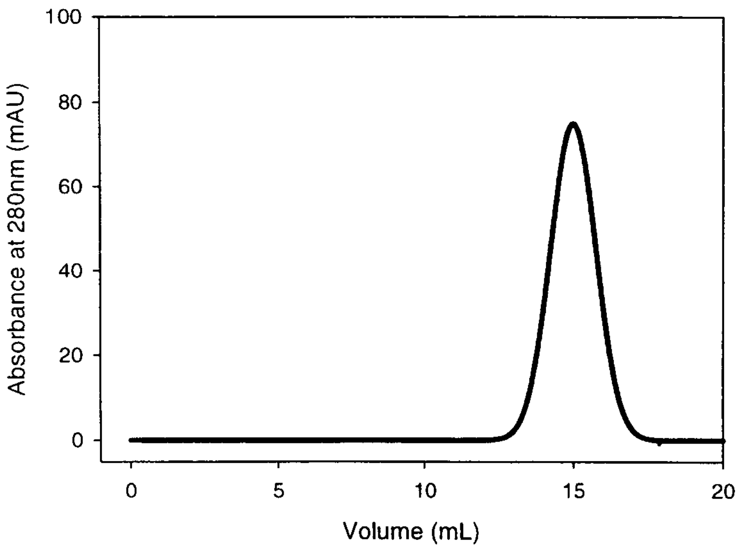


Figure B



a) Calculate the number of theoretical plates for each column (answers should be given to two significant figures). [10]

b) Comment on possible reasons for this change. [5]

c) What are the process scale issues for this type of chromatography and what are the particular problems raised by the data shown? [10]

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7.

This question concerns the use of immobilised enzymes as biological catalysts.

a) List the main features (advantages and disadvantages) of using an immobilised rather than freely suspended enzyme as a biological catalyst. [5]

b) Qualitatively describe the diffusional limitations possible with such systems. [5]

c) Define the external effectiveness factor and the Damkohler number for a surface immobilised enzyme particle. [5]

d) Using a simple diagram, describe the relationship between effectiveness factor and Damkohler number for a surface immobilised enzyme particle, giving details of the magnitude of the parameters. [10]

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CHART for Q3

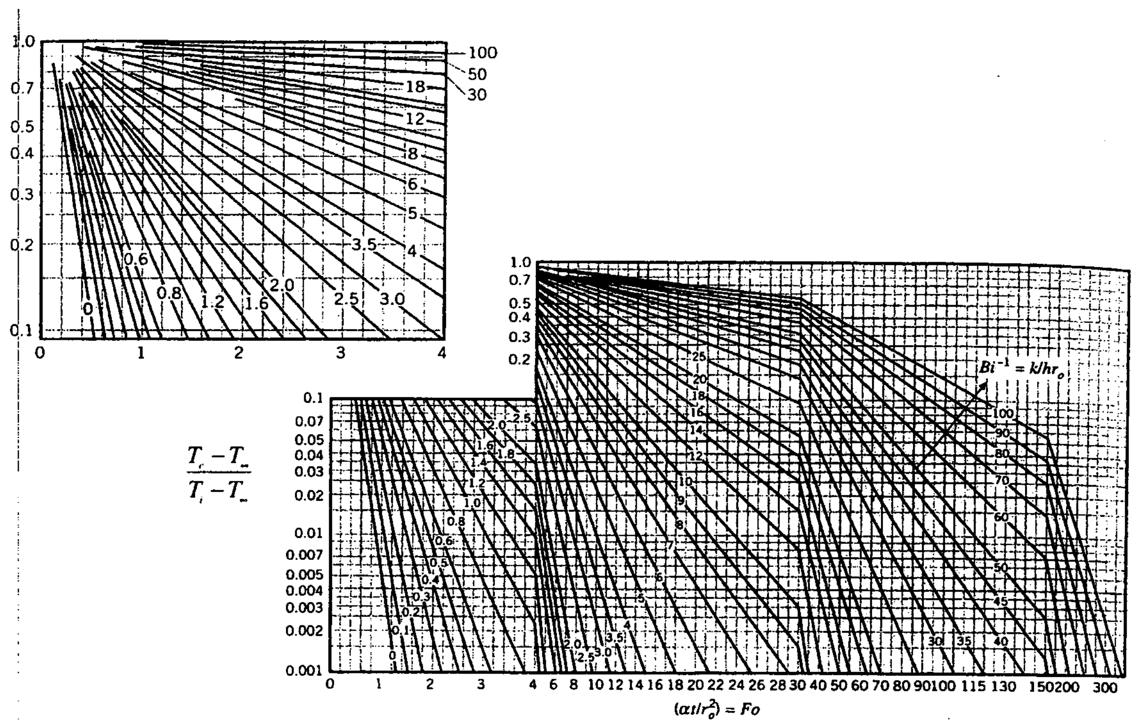

Figure 1. Centreline temperature for an infinite cylinder of radius r_o

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CHARTS for Q5

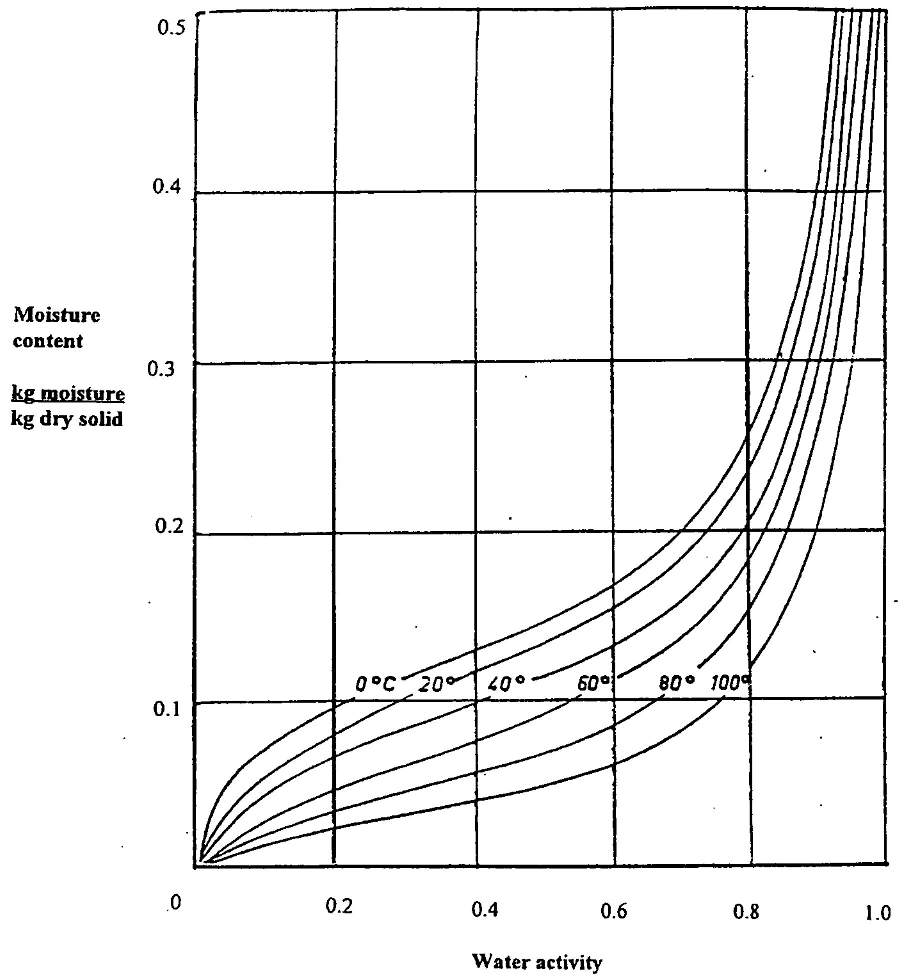

Figure 2. Moisture sorption isotherms

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CHARTS for Q5

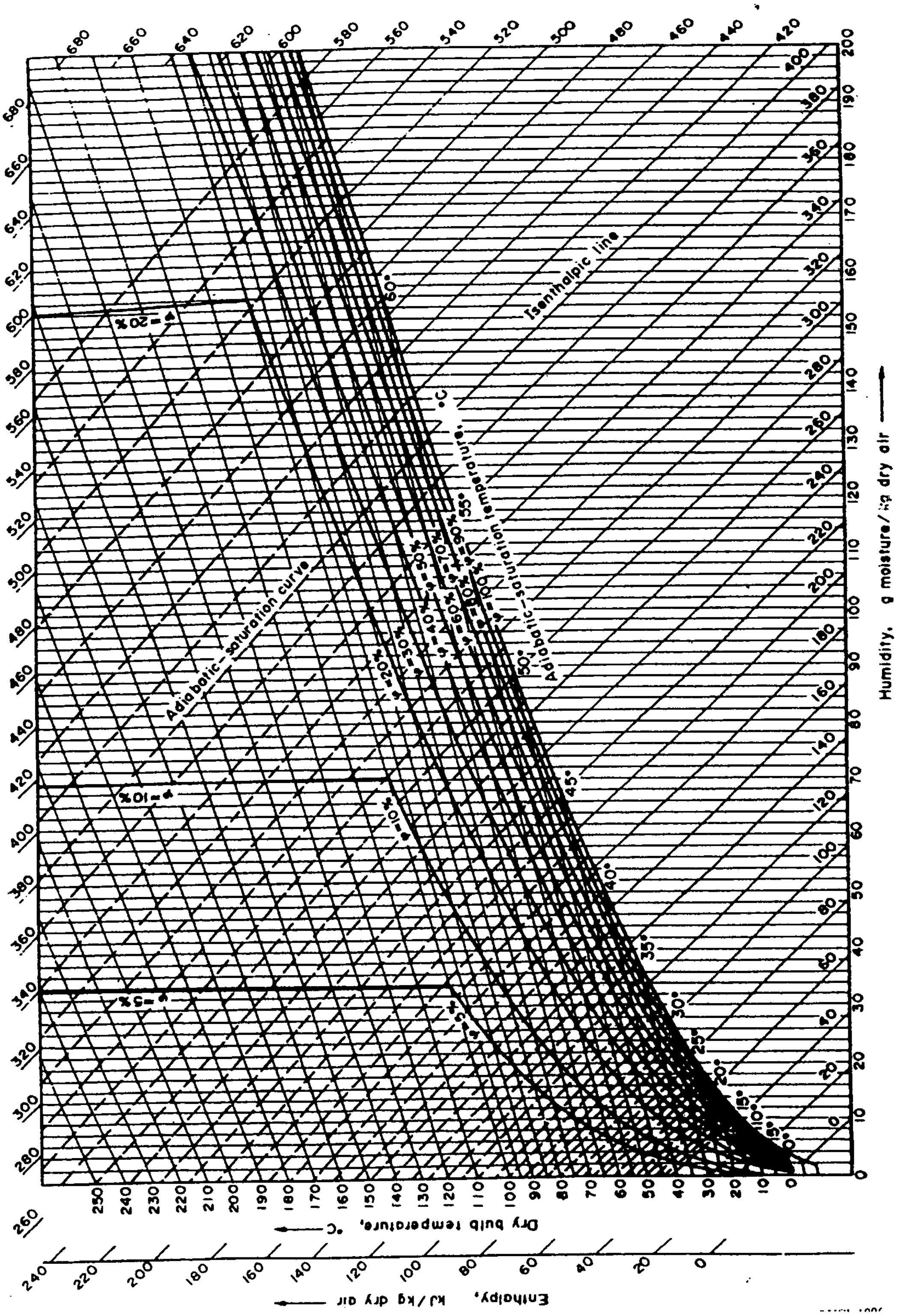

Figure 4. Enthalpy-humidity diagram for water vapour in air

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