UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Eng. *M.Eng.*

Biochemical Eng E124: Biotransport Processes II

COURSE CODE : **BENGE124**

UNIT VALUE : **0.25**

DATE : **20-MAY-04**

TIME : **14.30**

TIME ALLOWED : **2 Hours**

*Answer ONE question from **Section A** and answer **TWO** questions from **Section B**.*
*ALL questions carry a total of **25 MARKS** each, distributed as shown* [ ].
*Only the **FIRST THREE ANSWERS** will be marked.*

SECTION A

1.

Fermentation medium is to be heated from 10°C to 37°C in a single pass countercurrent shell-and-tube heat exchanger before being passed into a fermenter. Medium passes through the tubes of the exchanger; the shell-side fluid is water. The change in the temperature of the water as it passes through the shell can be considered negligible.

The tube-side heat transfer coefficient can be determined using the following correlation:

$$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$$

You are given the following data:
Water:
Mass flowrate $= 3 \times 10^4\ kg\ h^{-1}$
Inlet and outlet temperature $= 60\ ^\circ C$
Thermal conductivity $= 0.6\ W\ m^{-1}\ K^{-1}$
Shell-side heat transfer coefficient $= 1165\ W\ m^{-2}\ K^{-1}$

Fermentation medium:
Volumetric flowrate $= 50\ m^3\ h^{-1}$
Inlet temperature $= 10\ ^\circ C$
Exit temperature $= 37\ ^\circ C$
Thermal conductivity $= 0.54\ W\ m^{-1}\ K^{-1}$
Density, viscosity and specific heat capacity are the same as water

Heat exchanger:
Number of tubes $= 30$
Inner diameter $= 5\ cm$
Pipe wall thickness $= 5\ mm$
Thermal conductivity of steel $= 50\ W\ m^{-1}\ K^{-1}$

Rate of heat transfer $= 1050\ kW$

a) Calculate the individual heat transfer coefficient for the tube-side fluid. State any assumptions that you have made. [12]

b) Calculate the overall heat transfer coefficient. [4]

c) Determine the heat transfer area. [4]

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d) What tube length is required? [2]

e) Why might the actual tube length required be larger than the calculated value? [3]

2.

You have just completed the design and construction of a fermenter. For purposes of temperature control you have equipped the fermenter with a cooling jacket. The design is such that the relative contributions to resistance to heat transfer are estimated at 1:4:1:3:1 for fermenter film: fermenter foul: metal wall: jacket foul: jacket film.
Your microbiology colleagues now tell you that with a change of fermenter broth composition they can achieve 20% extra cell density while maintaining the same cell growth rates. You quickly establish there is also a 60-fold increase in viscosity. Prepare a report detailing:

a) the impact of these two changes on the maximum cooling water temperature required to operate the fermenter satisfactorily. [10]

b) a potential design solution for the retrofit of the fermenter and/or ancillary equipment to allow you to maintain use of the existing cooling water supply without extra refrigeration. [15]

Some details of the fermenter design which you may find useful:
vessel height: 5 m
vessel diameter: 1.6 m
optimum fermenter broth temperature: 30 °C
designed maximum cooling water temperature: 20 °C

TURN OVER

SECTION B

3.

a) Define and give the physical interpretation of the Fourier number and Biot number for heat transfer. [8]

b) A solid food is being heated in a can by placing it in an autoclave and exposing it to steam at 120°C for 30 minutes. The product is assumed to heat and cool by conduction. The can has a diameter of 0.081 m and a height of 0.11 m. The initial uniform temperature of the product is 35°C. The properties of the food are thermal conductivity 0.34 W m^{-1} K^{-1}; specific heat 3.5 kJ kg^{-1} K^{-1}; and density 900 kg m^{-3}. The convective heat transfer coefficient for the boiling water is estimated to be 2000 W m^{-2} K^{-1}.

i) Estimate the temperature at the centre of the food after being exposed to steam for 30 minutes. Use the charts provided. [15]

ii) Comment on your answer [2]

Centreline temperature charts for an infinite slab and an infinite cylinder are provided.

4.

a) Explain how an analysis of heat and mass transfer of a spray drying droplet leads to the conclusion that the outlet air temperature of a spray drier is the best determinant of the extent of damage to a heat labile protein. [10]

b) What other effects may also lead to damage of the protein? [5]

c) It is necessary to reduce the outlet air temperature of a spray drier from 80°C to 60°C. Estimate the reduction of throughput which will have to be accepted if the moisture content of the protein powder is to remain the same at 0.05 kg moisture / kg dried powder and the air inlet humidity is to remain constant at 0.008 kg moisture / kg dry air. [10]

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

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5.

a) Describe how combined heat and mass transfer occurs during freeze drying of a product in a vial for

   i) the primary drying phase [3]

   ii) the secondary drying phase [3]

b) Develop an expression to relate the time of drying with the depth of product in the vial. [10]

c) It is proposed to increase the depth of product in the vial from 1.0 to 1.1 cm. How might you maintain the same time for the primary drying phase to be completed? [9]

For the existing freeze drier the temperature of the frozen material in the vial is estimated at -30 °C. The pressure in the drying chamber is set at 12 N m $^{-2}$*.*

A vapour pressure diagram for ice is provided.

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CHARTS for Q3

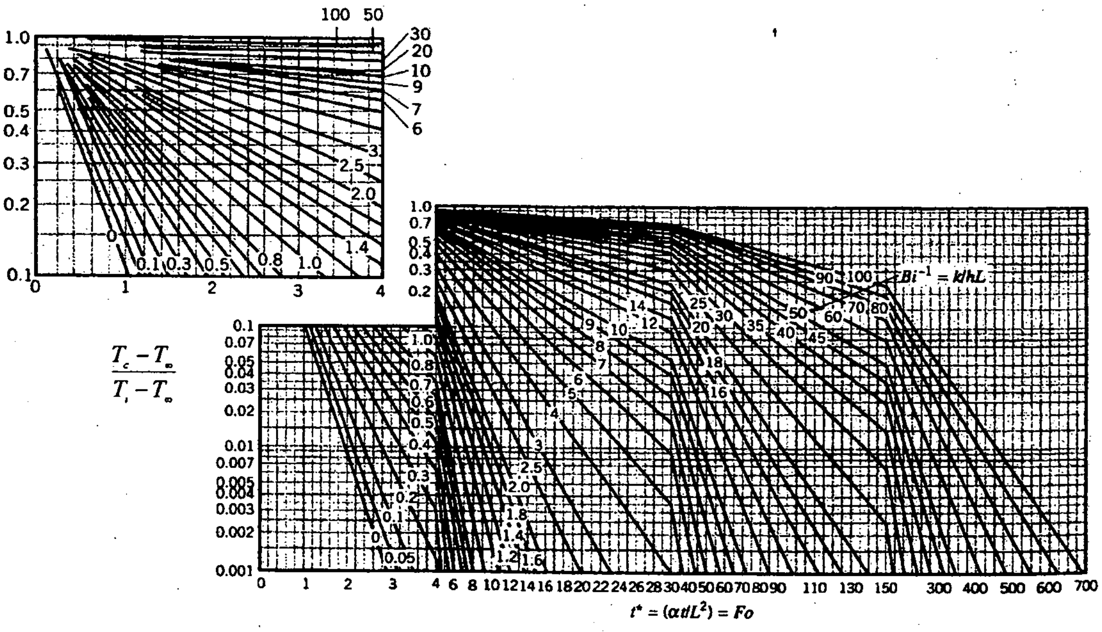

Figure 1. Midplane temperature for a plane wall of thickness 2L

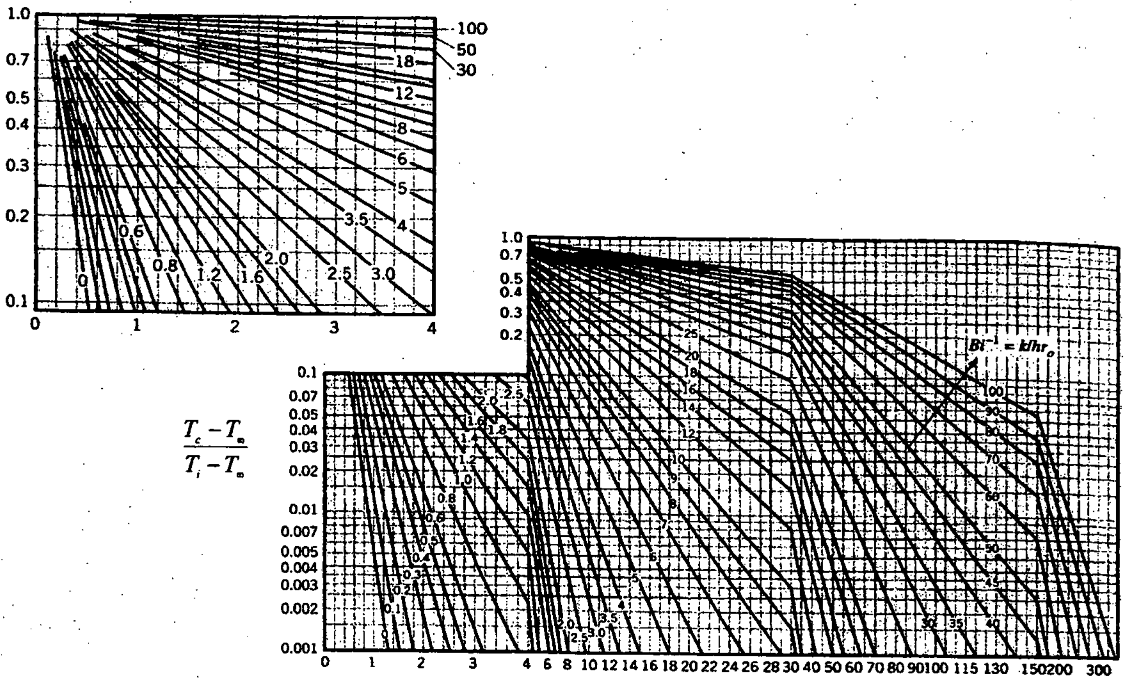

Figure 2. Centreline temperature for an infinite cylinder of radius r_o

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CHARTS for Q4

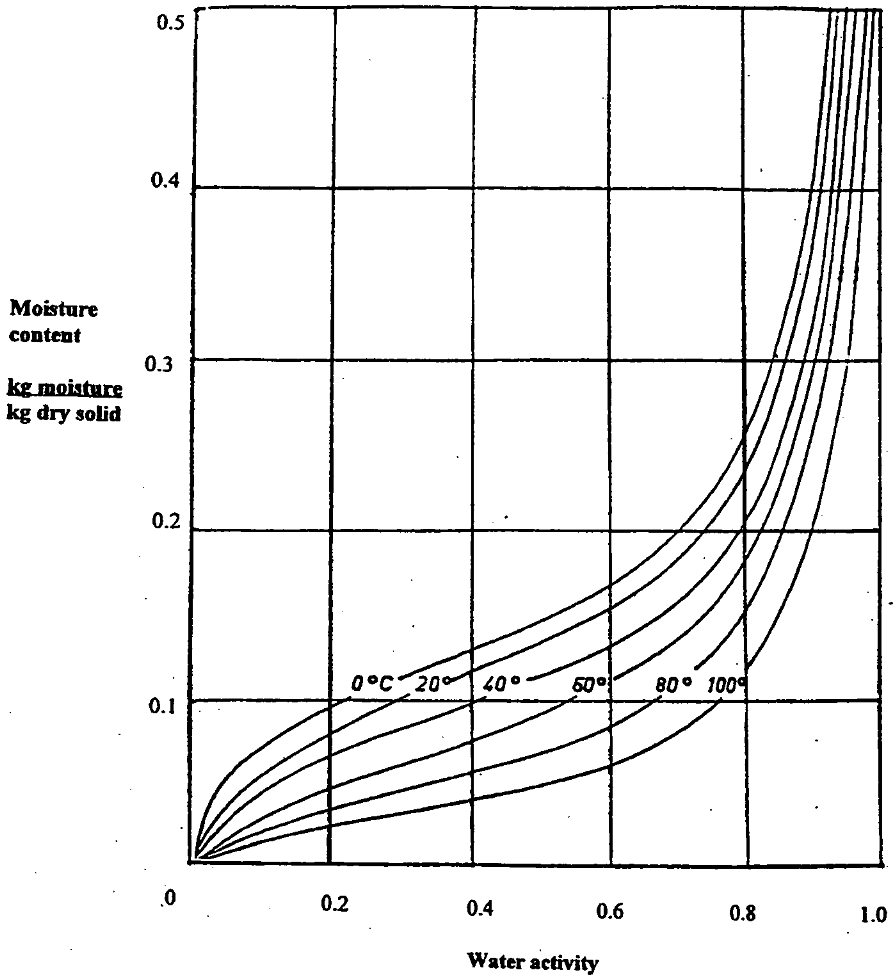

Figure 3. Moisture sorption isotherms

TURN OVER

CHARTS for Q4

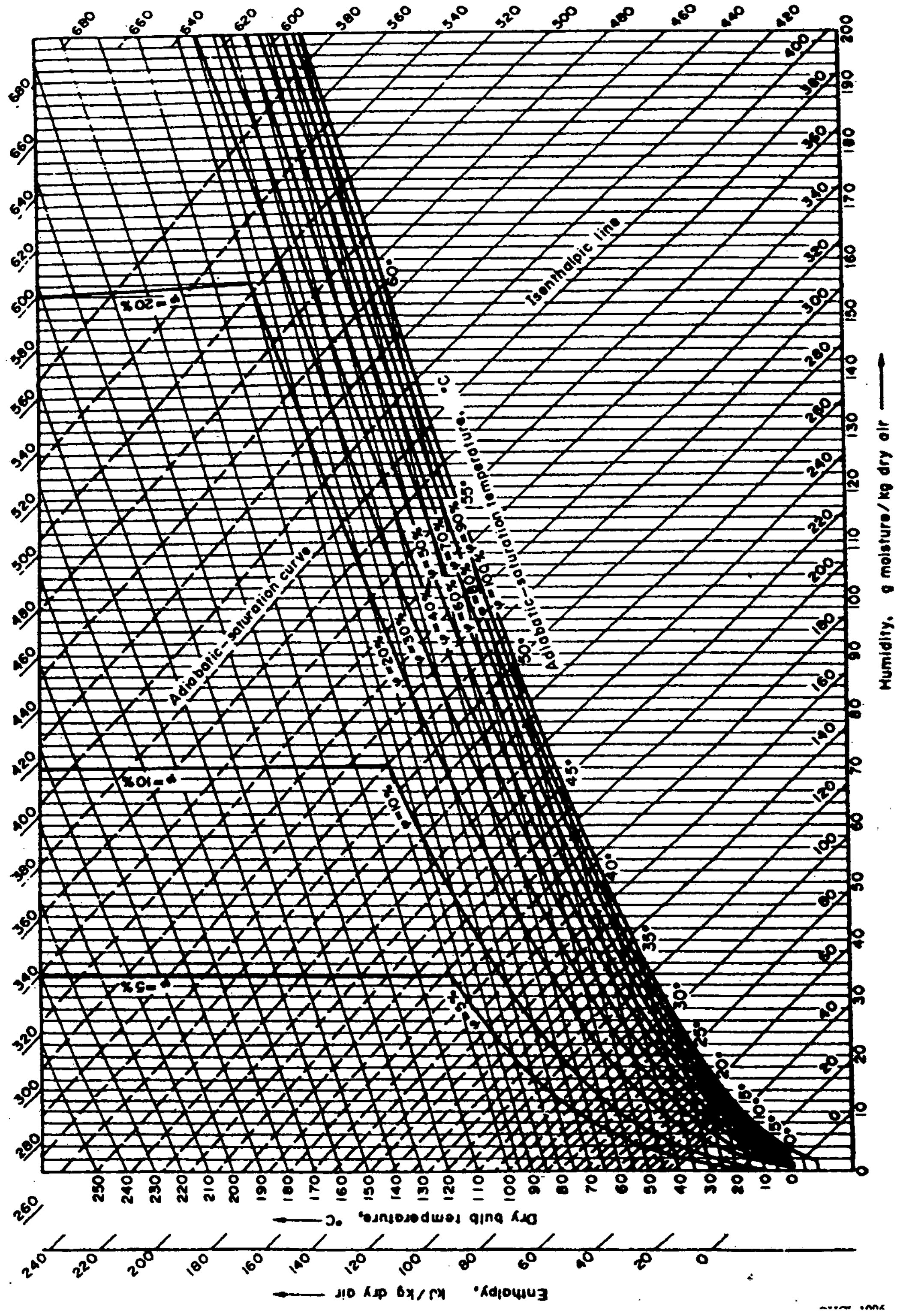

Figure 4. Enthalpy-humidity diagram for water vapour in air

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CHART for Q 5

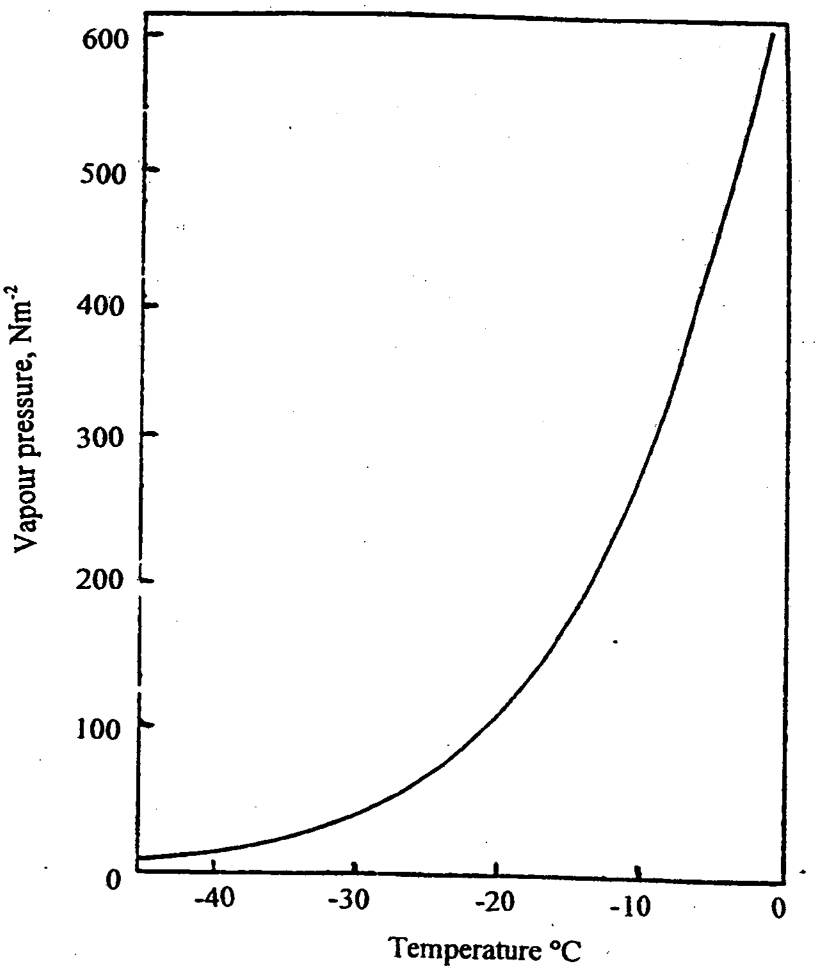

Figure 5. Vapour pressure of ice. (10^5 N m^{-2} = atmosphere)

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