Loughborough University

23CGB021
Food Engineering

Semester 2 2023/24 | In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Attempt **FOUR** questions in total. Each question carries 25 marks.

Candidates should show full working for all calculations and derivations.

Graph paper is provided and should be submitted with the answer booklet.

1. (a) An industrial food engineer is required to maintain the exponential growth phase of a foodborne pathogen for months to study its physiology. What special device would you recommend to achieve this purpose? Explain the working principle of this device.

[5 marks]

(b) Define what is meant by specific growth rate (*k*) and generation time (*g*) for an exponentially growing microbial population. [2 marks]

(c) Derive an expression showing the relationship between the specific growth rate (*k*) and generation time (*g*) of an exponentially growing microbial population if the specific growth rate is mathematically represented via:

$$\frac{dN}{dt} = kN$$

where *N* is the microbial cell number at time *t*. [5 marks]

(d) Name the three major microbial metabolic pathways that are important for food fermentation. Show with a schematic diagram the overall ATP yields, main substrates, and products of these pathways. [9 marks]

(e) Explain the reasons for referring to the oxidation of ethanol and lactic acid as 'scavenging' or 'salvaging' metabolism. Provide appropriate examples for each case.

[4 marks]

2. In canned green peas, the decimal reduction time for *C. botulinum* spores is 0.2 min at 121.1°C and the *z*-value is 10°C. To achieve commercial sterility in this product, the number of spores of this microorganism must be reduced by 12 orders of magnitude. Before sterilisation, on average one spore of *C. botulinum* was found in 20 cans. During sterilisation, the temperature in the centre of the can varied with time as shown in the table below.

Time from start of process, *t* (min)	Temperature in the centre of the can, *T* (°C)
27	91.3
37	101.4
47	107.2
57	111.0
67	114.3
77	113.1
82	98.2

Determine:

(a) The F_0 value for the above sterilisation process. [8 marks]

(b) Whether or not the product will become commercially sterile with respect to *C. botulinum* after this sterilisation process. [4 marks]

(c) The average number of spores of *C. botulinum* in a sterilised can. [4 marks]

(d) The expected number of cans infected by *C. botulinum* in a batch consisting of 10^7 cans. [5 marks]

(e) The lethal rate of *C. botulinum* at 125°C. Provide also the physical meaning of this value. [4 marks]

3. (a) Briefly describe what is meant by the terms “constant rate period”, “critical moisture content” and “falling rate period” in the drying of foods. How and why does the rate of drying differ in the constant and falling rate periods? [6 marks]

(b) Some food in the shape of thin layers is to be dried in a tray drier by blowing excess air parallel to the upper surface only (see data below).

(i) If the surface heat transfer coefficient (h) between the air and the food can be correlated by the following expression, calculate the rate of convective heat transfer (in Watts) to the food from the air.

$$h = 15.4U^{0.8} \text{ W m}^{-2} \text{ K}^{-1}$$

where U is the air velocity (m s^{-1}). [5 marks]

(ii) Hence calculate the drying rate (kg s^{-1}) in the constant rate period, and the time taken to reach the critical moisture content. [7 marks]

(iii) If the falling rate period kinetics are characterised by the equation

$$-\frac{dm}{dt} = k\left(m - m_{eq}\right)$$

where m is the dry basis moisture content, m_{eq} is the equilibrium dry basis moisture content and k is a constant, estimate the value of k. [3 marks]

(iv) Hence determine the time taken to further reduce the moisture content to 6% (dry basis). [4 marks]

Data

Surface area of each tray:	1.8 m^2
Initial (wet) mass of food in each tray:	5 kg
Initial moisture content:	150% (dry basis)
Critical moisture content:	50% (dry basis)
Latent heat of evaporation:	2 500 kJ kg^{-1}
Equilibrium moisture content:	3% (dry basis)
Dry bulb temperature of air:	75°C
Wet bulb temperature of air:	30°C
Air velocity:	5 m s^{-1}

4. (a) Describe the essential features of a freeze drier and how they contribute to an effective process. [6 marks]

(b) A food product is to be freeze-dried from a moisture content of 80 wt% (wet basis) to 4 wt% (wet basis). The product is composed of 25 mm thick slices, which are laid on trays. It can be assumed that all heat and mass transfer occurs via the upper surface which is exposed to a radiant heater.

(i) By considering the rate of movement of the sublimation front, derive the following expression for the freeze-drying time:

$$t = \frac{\rho\left(m_{ice} - m_{dry}\right)}{2b\left(p_i - p_s\right)} L^2$$

where the symbols have their usual meaning (with moisture contents as dry basis). [8 marks]

(ii) Hence estimate the freeze-drying time (see data below). [4 marks]

(iii) By first deriving an appropriate equation relating heat and mass transfer variables, evaluate the required surface temperature of the product for these drying conditions to be achieved. [7 marks]

<u>Data</u>

Thermal conductivity of icy material	2.0 W m^{-1} K^{-1}
Thermal conductivity of freeze dried material	0.05 W m^{-1} K^{-1}
Permeability of the dry layer	2.8 x 10^{-8} s m^{-2}
Mass of dry solids per unit volume	950 kg m^{-3}
Latent heat of sublimation of ice	3 MJ kg^{-1}
Ice interface temperature	-28˚C
Vapour pressure of ice at -28°C	46.9 Pa
Chamber pressure	12 Pa

5. (a) Two new formulations, A and B, were developed as sauces to be used on steaks. These will be marketed in small packaging to be used in fast-food and take-away restaurants. Analysis of the data from rheology measurements have given the following constitutive equations for these products:

Steak sauce A: $\tau = 25 + 5.2\,\dot{\gamma}^{0.45}$

Steak sauce B: $\tau = 0.07\,\dot{\gamma}^{0.95}$

(i) State the flow behaviour of each product. [2 marks]

(ii) Which of the two newly developed products would you recommend taking to market? Explain why you make this recommendation. [5 marks]

(iii) As the process engineer in this production unit, state one challenge that you foresee with your recommended product from the point of view of processing or transport based on its rheological profile. [2 marks]

(b) Rheological properties of a food product were determined before and after the introduction of an additive. Data obtained are given below.

Shear rate (s^{-1})	Shear stress **before** addition (Pa)	Shear stress **after** addition (Pa)
30	34.5	24.0
100	210.0	80.0
200	594.0	160.0
350	1375.1	280.0
575	2895.5	460.0
725	4099.5	580.0
900	5670.0	720.0

(i) Plot the flow curves for the data before and after the addition, using the graph paper provided. [5 marks]

(ii) Propose constitutive equations (with the constants/ parameters for these equations) that best describe the flow behaviour before and after the addition so you can explain how this addition has affected the rheological behaviour. [11 marks]

END OF PAPER

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