24CGP083

Process Intensification and Integration

Semester 1 2024/25 | 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.

<u>Help during the exam</u>

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).

Answer **BOTH** questions. Each question carries 25 marks.

Candidates should show full working for calculations and derivations.

1. Immobilised enzymes are an effective strategy of intensifying some enzymatic reactions. The rate of enzymatic reaction: S → P can be expressed using the Michaelis-Menten equation:

$$V = \frac{V_m[S_b]}{K_m + [S_b]}$$

(a) Sketch the curve showing the reaction rate as a function of the bulk enzyme concentration and explain the physical meaning of V_m and K_m. Both axes need to be fully labelled. [4 marks]

(b) Explain how the values of V_m and K_m can be obtained experimentally using the Lineweaver-Burke ("double reciprocal") plot shown in Figure Q1. Write the equations for the line gradient, the x-intercept and the y-intercept shown on the plot below.

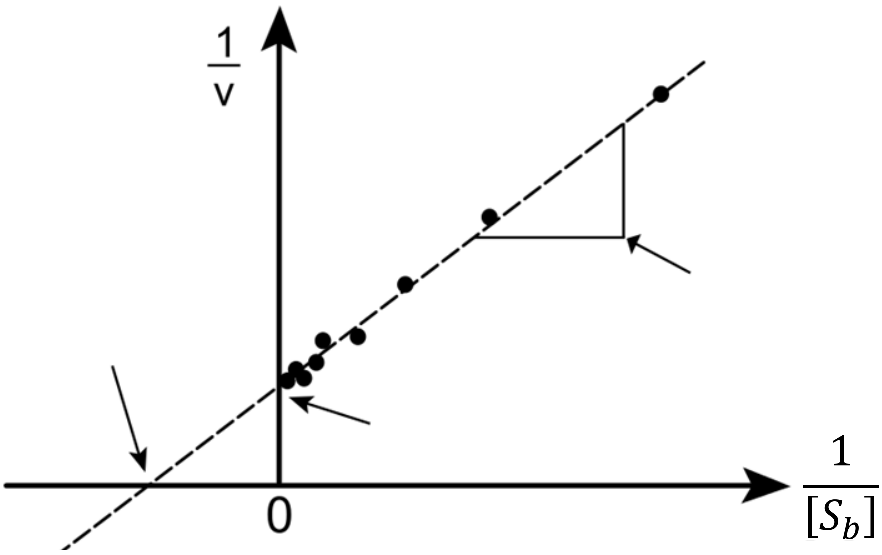

Figure Q1. Lineweaver-Burke plot for experimental determination of V_m and K_m.

[5 marks]

(c) Consider an immobilised enzyme reactor where spherical polymer beads with a diameter of 200 µm coated with enzyme are placed in a stirred tank. The amount of enzyme covalently bound to the beads is 1×10^{-4} mg enzyme/cm^2 and the particle loading in the tank is 5 vol%. Assuming V_m = 6×10^{-6} mol s^{-1} mg^{-1} enzyme, K_m = $2\times10^{--3}$ mol L^{-1}, $[C_b]$ = 7×10^{-3} mol L^{-1}, and a well-mixed system, calculate the rate of product formation in the reactor (in mol s^{-1} cm^{-2}). [3 marks]

Continued/…

Q1 Continued/…

(d) Explain why the reaction rate will decrease if the system is poorly mixed. [7 marks]

(e) Calculate the percentage increase of the reaction rate that can be achieved using immobilised enzyme compared to free enzyme. The solubility of free enzyme in the reaction mixture is 1 mg L^{-1}. [6 marks]

2. (a) (i) You are employed by a company manufacturing packaging material. A new packaging formulation comprising a nanoclay dispersion was developed at laboratory scale and exhibited improved barrier properties. Your colleague, who developed the formulation, explained that they first used a magnetic stirrer to mix for a while and subsequently used an ultrasonic processor for further processing. Explain why they may have taken this stepwise approach making use of two different process devices one after the other. [4 marks]

(ii) As the chemical engineer in charge of process development, you are tasked to propose a design for manufacture beyond laboratory scale, ensuring that the product from large scale has comparable properties to those obtained in the laboratory. Explain one significant challenge that you may face in accomplishing this task. [6 marks]

(iii) State what process equipment or series of process equipment you would consider for a delamination process performed at large scale, briefly explaining the reasoning for these choices. [2 marks]

(b) In order to evaluate the comparative performance of various low and high shear process devices used for dispersing nanoparticle clusters in a liquid, particle size measurements were made on samples taken during deagglomeration. Figure Q2 shows the mean diameters as a function of energy density with different equipment types. Different types of device are coded as 1, 2 … and for each type, the different configurations used (for example different impeller type of a stirred tank, nozzle diameter of a valve homogeniser…) are denoted as 1.1, 1.2…, 2.1, 2.2, 2.3, …

(i) What is the practical use of this comparative equipment performance evaluation? [3 marks]

(ii) What are the limitations arising from this approach to evaluate performance? [4 marks]

(iii) How do you propose to analyse the data from particle sizing to address the limitations you state in 2.(b)(ii)? [6 marks]

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Q2 Continued/…

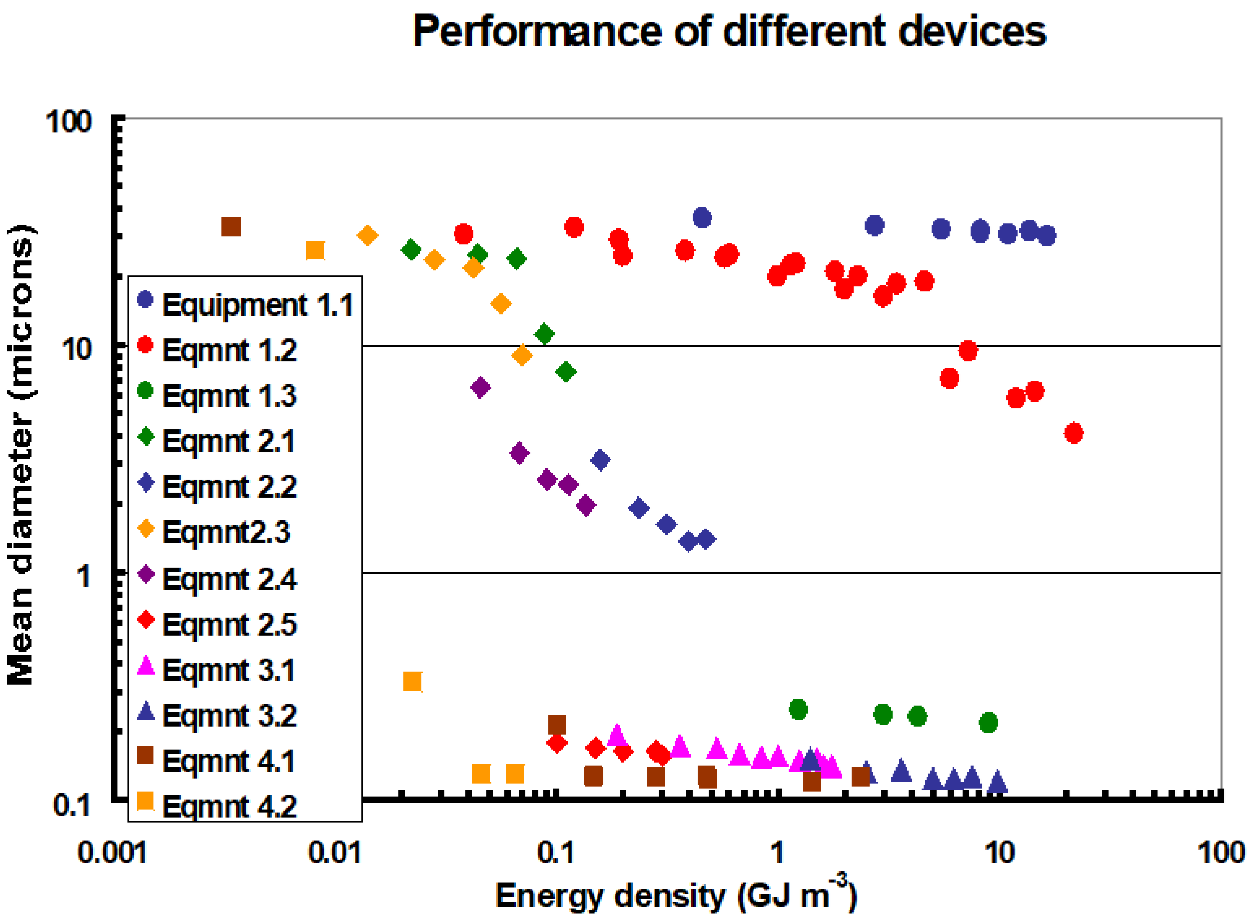

Figure Q2. Evaluation of the performance of 4 different process devices (denoted as 1, 2, 3, 4) with different configurations (denoted as 1.1, 1.2, ...) for the dispersion of nanoparticle clusters in a liquid.

END OF PAPER

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