



**M.TECH DEGREE EXAMINATIONS: NOV/ DEC 2024**

(Regulation 2024)

First Semester

**BIOTECHNOLOGY**

24MBT501: Bioprocess Modelling and Simulation

**COURSE OUTCOMES**

- CO1:** Explain the fundamental principles of bioreactor design and scale-up in bioprocess engineering, including kinetic models and process optimization techniques.
- CO2:** Analyze material and energy balances in bioprocess systems to interpret the efficiency of bioprocesses.
- CO3:** Utilize numerical and machine learning techniques to solve optimization problems and improve bioprocess efficiency.
- CO4:** Apply principles of bioreactor operation and design to develop solutions for batch, semi-continuous, and continuous bioprocess systems.
- CO5:** Design sustainable and cost-effective bio-processes through economic and environmental impact analysis.

**Time: Three Hours**

**Maximum Marks: 100**

**PART A (4\*20 = 80 Marks)**

1. a) Our winery takes grain-in and puts wine into the market. The bottleneck of the operation is the fermenter operation. The fermenter is loaded with 10% sugar (assuming a density of  $1000 \text{ kgm}^{-3}$ ) and yeast before fermentation. This leads to a 5 h delay before fermentation starts. The fermentation takes 5 days to obtain a 4% alcohol mixture. Finally, unloading the fermenter contents, and clean the fermenter, requires another 3 h. Assume that the final product, wine (4% alcohol), also has a density of  $1000 \text{ kgm}^{-3}$ . Determine the fermenter size needed if a daily production of 240 L of wine is needed. 10 CO1 [K4]
- b) You are optimizing the citric acid production in a 5 L fermenter using the Plackett-Burman design. Six factors, including two dummy variables, are considered for screening their influence on citric acid yield. The factors and their levels are as follows: 8 CO1 [K5]

Factor	Low Level (-1)	High Level (+1)
Glucose concentration (g/L)	50	100
pH	4.5	6
Temperature (°C)	25	35

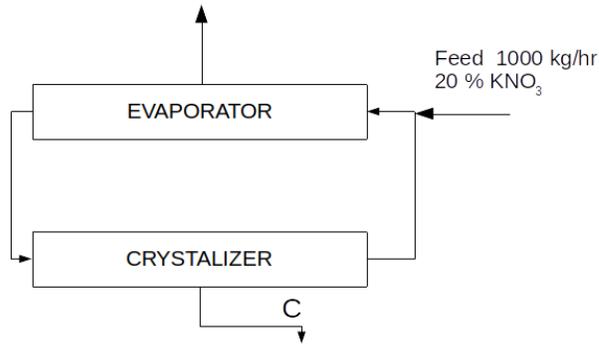
Agitation speed (rpm)	150	300
Aeration rate (vvm)	0.5	1
Dummy variable 1	-1	1
Dummy variable 2	-1	1

The citric acid yield (g/L) is recorded for each experimental run, and the design matrix is used to assess the main effects of each factor.

Formulate the design matrix for a Plackett-Burman experiment with 8 runs, considering the six factors and two dummy variables. Describe how you would analyze the experimental results to identify the significant factors influencing citric acid production. Assume the theoretical yield for runs be 85, 70, 90, 75, 80, 65, 88, 60.

Scenario:

- c) You are provided with glucose and glycerol as two carbon sources to be used in fermentation media. Discuss how choosing one over the other might affect the rate of microbial growth. 2 CO1 [K3]
2. a) A fermentation slurry containing *Streptomyces kanamyceticus* cells is filtered using a continuous rotary vacuum filter. The slurry is fed to the filter at a rate of 120 kg/h, where 1 kg of slurry contains 60 g of cell solids. To improve filtration rates, particles of diatomaceous earth filter aid are added at a rate of 10 kg/h. The concentration of kanamycin in the slurry is 0.05% by weight. Liquid filtrate is collected at a rate of 112 kg/h, and the concentration of kanamycin in the filtrate is 0.045% (w/w). The filter cake, containing cells and filter aid, is removed continuously from the filter cloth.  
(a) What percentage of the filter cake is water?  
(b) If the concentration of kanamycin dissolved in the liquid within the filter cake is the same as that in the filtrate, how much kanamycin is absorbed per kg of filter aid?  
(c) Present your solution in the form of Material Balance table. 10 CO2 [K4]
- b) Show below is a hybrid evaporator - crystallizer process to obtain potassium nitrate crystals. The fresh feed contains 20%  $\text{KNO}_3$ . The evaporator product contains 50%  $\text{KNO}_3$ , while the crystal product is 4% water. The mother liquor contains 600g  $\text{KNO}_3$  per kg  $\text{H}_2\text{O}$ . Determine the flowrate and composition of the input to the evaporator. 8 CO2 [K4]



- c) In a continuous reactor, a feed stream contains 80 kg/h of component A and 20 kg/h of component B. After the reaction, 60 kg/h of component A and 10 kg/h of component B are converted into products. The unreacted streams are sent to a recycle line. If 40 kg/h of the recycled stream is returned to the feed, calculate the mass balance for component A. 2 CO2 [K3]
3. a) Solve using Heun's method:  $dy/dx = 3e^{-x} - 0.4y$ ,  $y(0) = 5$ , Find  $y(3)$ , where  $h = 1.5$ . 10 CO3 [K3]
- b) The concentration of the salt  $x$  in a home-made soap maker is given as a function of time by  $dx/dt = 37.5 - 3.5x$ . At the initial time,  $t=0$  the salt concentration in the tank is 50g/L, using bisection method and the step size of  $h = 1.5$  min. What is the salt concentration after 3 mins? 8 CO3 [K3]
- c) How do you overcome class imbalance in machine learning? 2 CO3 [K2]
4. a) Fucoxanthin, a xanthophyll compound vital for photosynthesis, has gained interest due to its potential health benefits. To explore its industrial potential, answer the following: Design a detailed process flow diagram (flowsheet) outlining all essential unit operations and processes for the industrial-scale production of fucoxanthin. Provide a brief explanation for each step. 10 CO4 [K4]
- b) You are operating a 10 L fermenter to study the oxygen transfer rate in a microbial fermentation process. The oxygen transfer coefficient (kLa) is being determined using the dynamic gassing-out method. During the experiment, dissolved oxygen (DO) concentrations are measured using a DO probe, which occasionally gives fluctuating readings due to probe lag and sensor noise. Other process variables like agitation speed, aeration rate, and temperature are recorded, but inconsistencies are observed in the data due to minor sensor calibration errors. Apply data reconciliation techniques to correct measurement inconsistencies and obtain reliable results. 8 C4 [K4]
- c) Justify why mass balance is a perfect method for data reconciliation? 2 CO5 [K2]

**Answer any ONE Question**

**PART B (1\*20 = 20 Marks)**

5. a) A Biotechnology company is developing an industrial process for enzyme production using *Aspergillus niger* in solid-state fermentation (SSF). The fermentation substrate consists of agricultural waste, and the company aims to optimize the media components to maximize enzyme yield. They have identified key factors influencing enzyme production: moisture content, nitrogen source, carbon source, and pH. The research team decides to apply Response Surface Methodology (RSM) to optimize the media components. They design an experiment involving the following variables: Moisture content: 50–70% (w/w); Nitrogen source: Urea, with concentrations between 0.5–2.0% (w/w); Carbon source: Molasses, with concentrations between 2.0–6.0% (w/w); pH: 4.5–6.5. Using Response Surface Methodology (RSM), the research team performs a central composite design (CCD) with the enzyme yield as the response variable. Explain how Response Surface Methodology (RSM) aids in identifying the optimum levels of media constituents for SSF. Include the role of central composite design (CCD) in your answer. 14 CO1 [K4]
- b) The empirical formula of *Pseudomonas* 5401 is given as:  $\text{CH}_{1.83}\text{O}_{0.55}\text{N}_{0.25}$ . The final cell concentration is 25 g/L, and we are tasked to determine the maximum concentration of  $(\text{NH}_4)_2\text{SO}_4$  required, assuming it is the sole nitrogen source. 6 CO1 [K3]

**OR**

6. a) A bioprocess engineer is optimizing the production of ethanol using *Saccharomyces cerevisiae*. The yield of ethanol depends on three uncertain input parameters: 14 CO5 [K4]
- a) Glucose concentration in the feed (G): Normally distributed with a mean of 100 g/L and a standard deviation of 10 g/L.
  - b) Temperature (T): Uniformly distributed between 30°C and 40°C.
  - c) pH (P): Log-normal distribution with a median of 5.5 and a geometric standard deviation of 0.2.

Using the ethanol yield equation:

where Y is the ethanol yield in g/L, analyze the uncertainty in ethanol yield

$$Y = 0.5 \cdot G \cdot \exp\left(-\frac{(T-35)^2}{50}\right) \cdot (1 - |P - 5.5|)$$

using Monte Carlo Simulation.

Describe the steps involved in performing Monte Carlo Simulation for this problem.

- b) Considering the above situation in 6 (a) - Analyze the impact of variability in glucose concentration, temperature, and pH on ethanol yield. 6 CO5 [K3]

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