FACULTY OF ENGINEERING

Final Examination
2024-2025

UNIVERSITY

Course Title: Mathematical Modeling
Department: Chemical Engineering
Course Code: KOU20451
Stage/ Year: Third
Time Allowed: 2 hr

Answer **All** Questions

1. Water containing 0.1 kg of salt per m^3 is poured into a tank at a rate of 2 L/s, and the tank is well-stirred. The tank is 2 m high, 2 m diameter and is initially ¾ full with pure water. Answer the following: **(30 Marks)**

5

a) If a 2 inch tube is installed at the bottom of the tank followed by a pump that discharges the solution at a rate 0.5m/s, write the model that describes the heigh and salt concentration in the tank. Also, find the amount of salt after 10 minutes from starting the process. [10 Marks]

10

b) If a nonlinear valve with a constant 5×10^{-4} m^2/s is installed at the outlet, find the height and concentration of salt after 4 minutes from starting the processusing finite difference method given that Δt is 0.5 min. 1 ft = 12 inch = 0.3048 m. [20 Marks]

2. For the reaction system below. Find the models for the concentrations of A, B, and C as a function of time, given that the reactions are elementary and these reactions are carried out in a constant volume vessel. **(15 Marks)**

10

$$2A + \frac{2}{5}B \rightleftharpoons 3\,C \longrightarrow D$$

3. Find the relation to predict the composition profile in a packed tube reactor undergoing isothermal linear kinetics with axial diffusion. The packed tube, heterogeneous catalytic reactor is used to convert species B by way of the reaction into products under (assumed) isothermal conditions. **(20 Marks)**

20

$$B \rightarrow \text{products}; \quad R_B = kC_B\left(\frac{\text{moles}}{\text{time-volume bed}}\right)$$

Diffusion along the axis is controlled by Fickian-like expression so that, in parallel with transport by convection due to superficial velocity v_o, there is also a diffusion-like flux represented by a Fickian relation

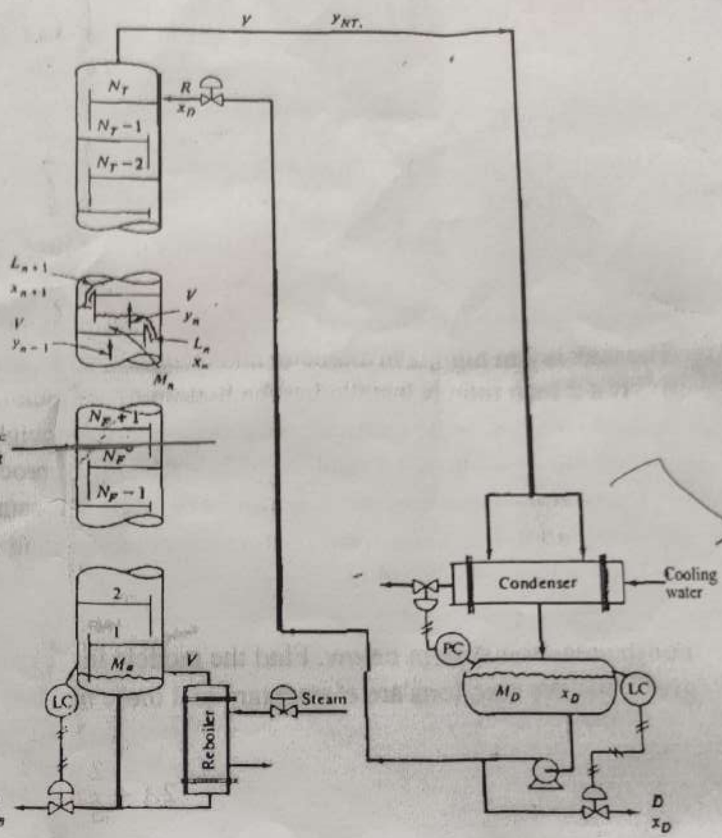
$$J_E = -D_E\frac{\partial C_B}{\partial z}\left(\frac{\text{mole}}{\text{area-time}}\right)$$

4. Consider an engine that generates heat at a rate of 5120 Btu/min. Suppose this engine is cooled with air, and the air in the engine housing is circulated rapidly enough so that the air temperature can be assumed uniform and is the same as that of the outlet air. The air is fed to the housing at 6.0 lbmol/min and 65°F. Also, an average of 0.50 lbmol of air is contained within the engine housing and its temperature variation can be neglected. If heat is lost from the housing to its surroundings at a rate of Q (Btu/min) = 33.0 (T − 65) and the engine is started with the inside air temperature equal to 65 °F:

10

a) Derive a differential equation for the variation of the outlet temperature with time.
b) Calculate the steady state air temperature if the engine runs continuously for an indefinite period of time, using C_v = 5.00 Btu/lbmol °F. **(20 Marks)**

Q5. For the binary distillation column shown in Fig below, derive the component and total balances for: Feed stage, condenser and reboiler. Assume any assumptions you find appropriate. **(15 Marks)**



15

V L

for A

$$\frac{V\,dC_A}{dt} = C_{Ai}F_i - C_A F - Vk\,C_A C_B$$

$$\frac{V\,dC_B}{dt}$$

Best wishes

Assistant Prof. Dr. Saif T. Manji

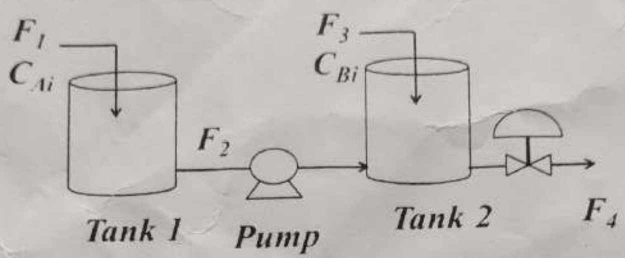
Midterm Examination
2024-2025

Department: Chemical Engineering
Stage/ Year: Third

Course Title: Mathematical Models
Course Code: KOU20451
Time Allowed: 90 minutes

Answer **Q1** + Any Two Other Questions

Q1. Consider the blending system shown with the following assumptions: **[40 marks]**

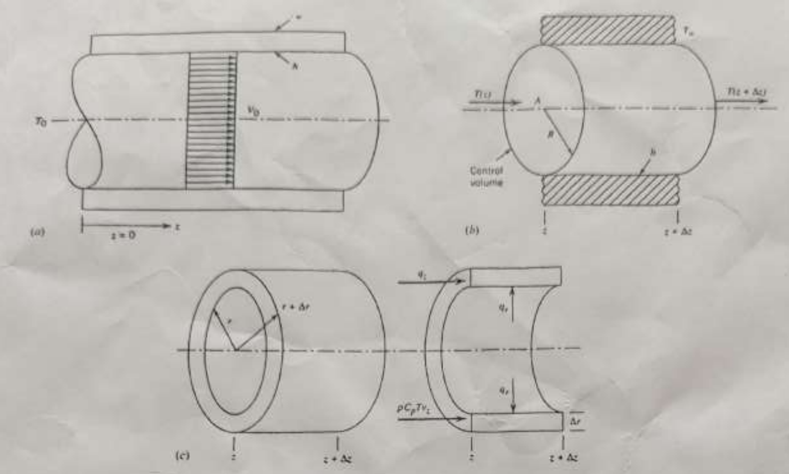


1. Tanks 1 & 2 are on the same level and each has different cross-sectional area.
2. F_1, F_2 are the volumetric flowrates of pure water.
3. Two different solutes (A & B) are added in this process and their concentrations are expressed as C_A and C_B (kg solute/m^3 water).
4. Physical properties can be assumed to be constant everywhere.
5. The valve is nonlinear such that $F \propto \sqrt{h}$ and the proportionality constants β.
6. No reaction is taking place.

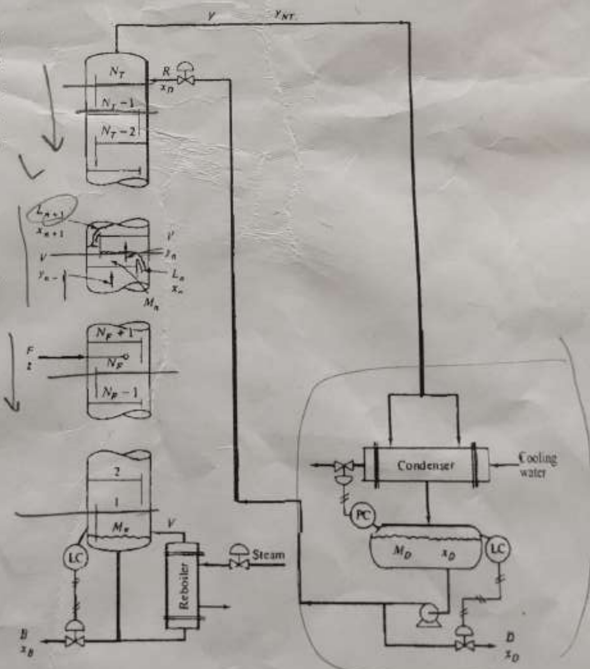
Write mathematical models to describe the liquid height and the concentrations in each tank.

Q2. For the case of plug flow with heat transfer, derive a mathematical model for the temperature distribution in the pipe assuming: **[30 marks]**

a. A steady-state conditions.
b. The physical properties (density, specific heat, thermal conductivity, etc.) of the fluid remain constant.
c. The wall temperature is constant and uniform (i.e., does not change in the z or r direction) at a value Tw.
d. The inlet temperature is constant and uniform (does not vary in r direction) at a value T_0, where $T_0 >$ Tw.
e. The velocity profile is plug shaped or flat, hence it is uniform with respect to z or r.
f. The fluid is well mixed (highly turbulent), so the temperature is uniform in the radial direction.
g. Thermal conduction of heat along the axis is small relative to convection.



Q3. For the binary distillation column shown in Fig below, derive the component and total balances for: Feed stage, Top stage and Bottom stage. Assume any assumptions you find appropriate. **[30 marks]**



Q4. For the reaction system below. Find the concentrations of A, B, C, and D as a function of time, given that the reactions are elementary and these reactions are carried out in a constant volume vessel. **[30 marks]**

$$A + 2B \rightleftharpoons C \longrightarrow D$$