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UNIVERSITY OF PETROLEUM
AND ENERGY STUDIES

Mid Semester Examination - May, 2019

Program/Course : M. Tech Chemical (Spl. in Process Design)
Subject: Process Modelling and Simulation
Code: CHPD7009
No. of pages: 2

Semester: II
Max. Marks: 100
Duration: 3 hrs

NOTE:

(A) **OPEN BOOK and OPEN NOTES EXAMINATION**

(B) Assume all missing data. **State your assumptions clearly.** Sketch wherever necessary.

ANSWER ALL QUESTIONS

1. A stainless-steel rod (18% Cr, 8% Ni) 6.4 mm in diameter is initially at a uniform temperature of 25°Cand is suddenly immersed in a liquid at 150°Cwith h = 120 W/m^2°C. Using the lumped-capacity method of analysis, calculate the time necessary for the rod temperature to reach 120°C. [20 marks]

   Also, write a MATLAB code for solving the above problem with the data provided. [10 marks]

2. A tubular chemical reactor of length L and cross section of 1 m^2 is employed to carry out a first order chemical reaction in which a material A is converted a product B with specific reaction rate constant k s^{-1}. The feed rate is u m^3/s, the feed concentration of A is c_0. The diffusivity of A is assumed to be constant at D m^2/s. If there is a volume change during the reaction, develop a mathematical model in the form of a differential equaion for the concentration of A as a function of length along the reactor. [20 marks]

   Also, write a MATLAB code for solving the above problem with the data provided. [10 marks]

3. Experimental setup of the batch vacuum distillation under total reflux condition in rotating packed bed (RPB) is shown in Fig. 1. The RPB was packed by wave thread stainless steel wire mesh, with a voidage of 0.95 and a specific surface area of 930 m^2/m^3, respectively. The inner diameter, outer diameter and the axial height of the rotor were 180, 285 and 310 mm respectively. The rotor speed varied between 275 and 700 rpm, and thus providing 20 - 130 times gravitational force at the arithmetic mean radius.

   The vapor entered axially into the RPB due to the pressure drop and left from the top of the rotor finally. The concentration of feeding ethanol was ranging from 70 to 95 wt%. The concentration of outlet ethanol was measured by gas chromatography (GC-S7900). The liquid flux was pumped from the effluent tank into the inner side of the rotor through a liquid distributor, and moved outward through the rotating packing under the centrifugal force. Thus, tiny droplets and thin films were formed at the surface of packing and resulted in large gas - liquid interfacial area, which was beneficial to the distillation. The vapor, containing high concentration of ethanol, was finally collected by condenser, and was then refluxed from the top of the RPB, while the water-rich liquid was discharged from the bottom and then returned to the reboiler. During the experiment, the operation pressure varied from 11.325 to 101.325 kPa and was controlled by a vacuum pump.

   Derive a complete balance model equations starting from overall mass balance. Also suggest some numerical techniques to solve your model equations. [40 marks]

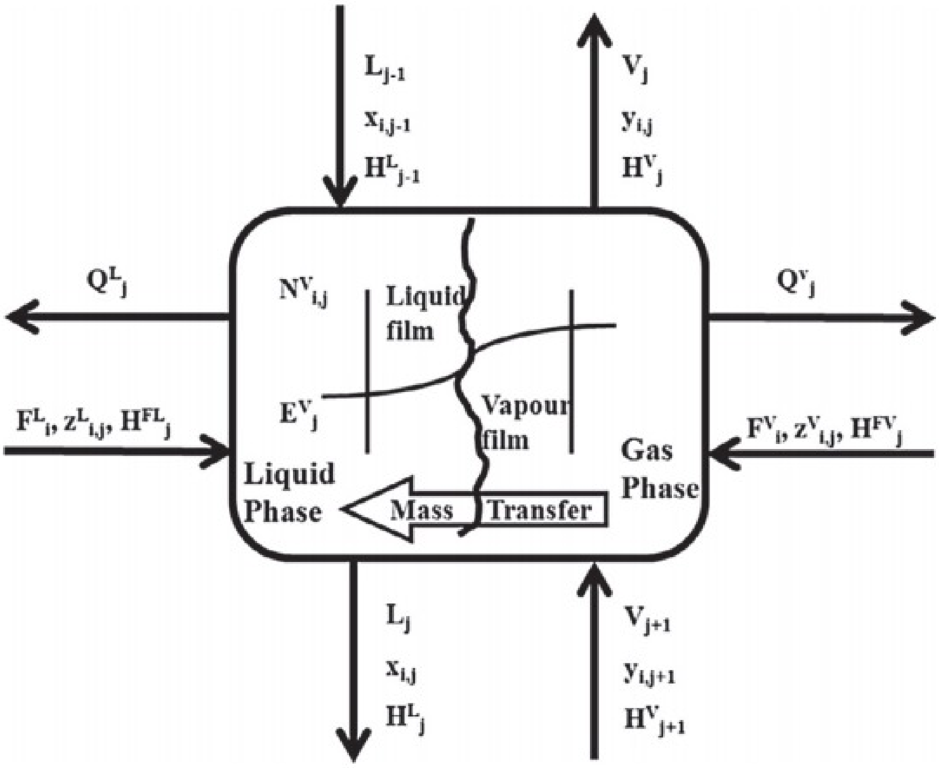
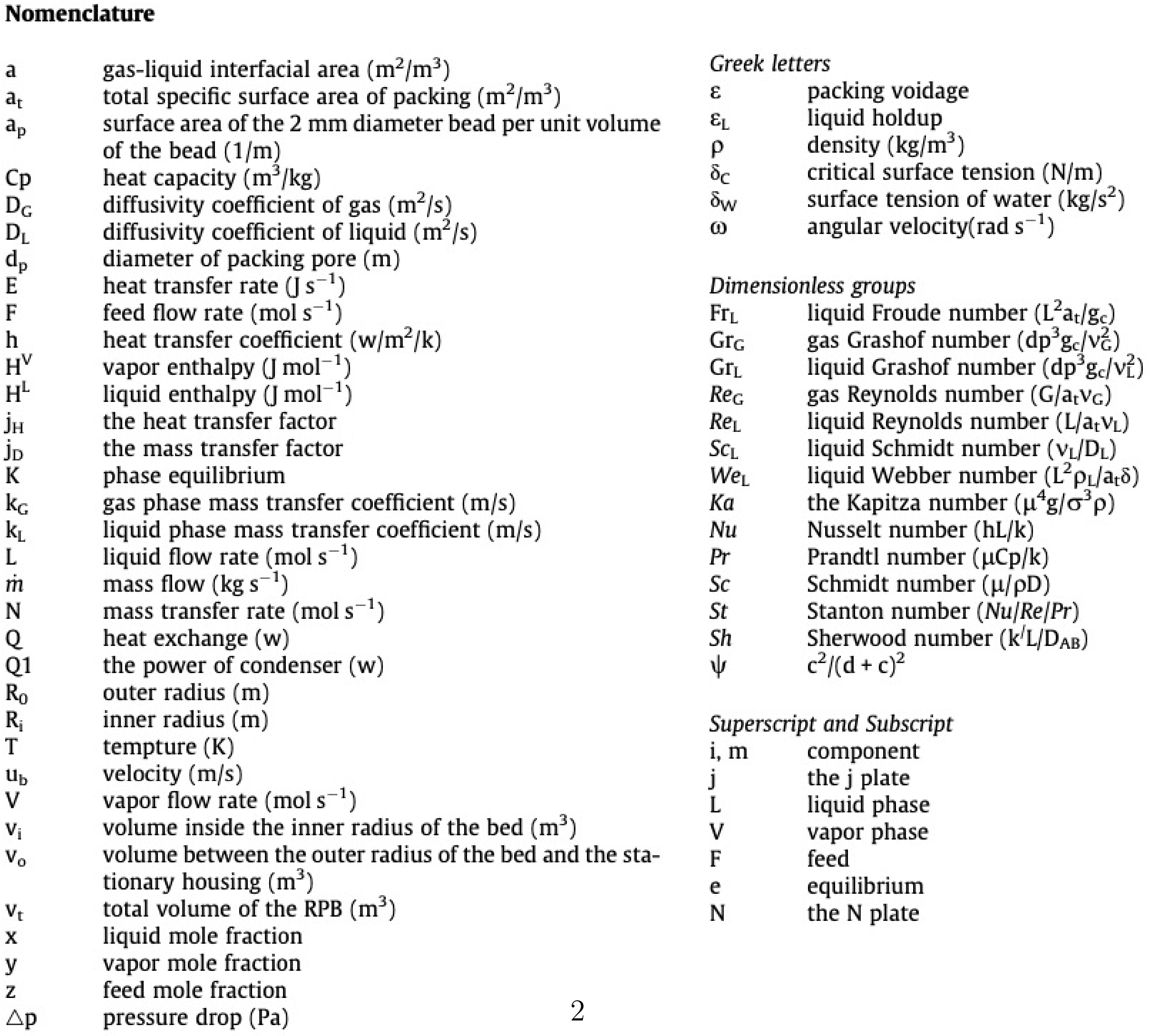


Figure 1: Non-equilibrium stage for vacuum distillation



Nomenclature

a	gas-liquid interfacial area (m^2/m^3)
a_t	total specific surface area of packing (m^2/m^3)
a_p	surface area of the 2 mm diameter bead per unit volume of the bead (1/m)
Cp	heat capacity (m^3/kg)
D_G	diffusivity coefficient of gas (m^2/s)
D_L	diffusivity coefficient of liquid (m^2/s)
d_p	diameter of packing pore (m)
E	heat transfer rate (J s^{-1})
F	feed flow rate (mol s^{-1})
h	heat transfer coefficient (w/m^2/k)
H^V	vapor enthalpy (J mol^{-1})
H^L	liquid enthalpy (J mol^{-1})
j_H	the heat transfer factor
j_D	the mass transfer factor
K	phase equilibrium
k_G	gas phase mass transfer coefficient (m/s)
k_L	liquid phase mass transfer coefficient (m/s)
L	liquid flow rate (mol s^{-1})
$\dot{m}$	mass flow (kg s^{-1})
N	mass transfer rate (mol s^{-1})
Q	heat exchange (w)
Q1	the power of condenser (w)
R_0	outer radius (m)
R_i	inner radius (m)
T	tempture (K)
u_b	velocity (m/s)
V	vapor flow rate (mol s^{-1})
v_i	volume inside the inner radius of the bed (m^3)
v_o	volume between the outer radius of the bed and the stationary housing (m^3)
v_t	total volume of the RPB (m^3)
x	liquid mole fraction
y	vapor mole fraction
z	feed mole fraction
$\triangle p$	pressure drop (Pa)

Greek letters

ε	packing voidage
ε_L	liquid holdup
ρ	density (kg/m^3)
δ_C	critical surface tension (N/m)
δ_W	surface tension of water (kg/s^2)
ω	angular velocity(rad s^{-1})

Dimensionless groups

Fr_L	liquid Froude number ($L^2 a_t/g_c$)
Gr_G	gas Grashof number ($dp^3 g_c/\nu_G^2$)
Gr_L	liquid Grashof number ($dp^3 g_c/\nu_L^2$)
Re_G	gas Reynolds number ($G/a_t \nu_G$)
Re_L	liquid Reynolds number ($L/a_t \nu_L$)
Sc_L	liquid Schmidt number (ν_L/D_L)
We_L	liquid Webber number ($L^2 \rho_L/a_t \delta$)
Ka	the Kapitza number ($\mu^4 g/\sigma^3 \rho$)
Nu	Nusselt number (hL/k)
Pr	Prandtl number (μCp/k)
Sc	Schmidt number ($\mu/\rho D$)
St	Stanton number ($Nu/Re/Pr$)
Sh	Sherwood number ($k^l L/D_{AB}$)
ψ	$c^2/(d + c)^2$

Superscript and Subscript

i, m	component
j	the j plate
L	liquid phase
V	vapor phase
F	feed
e	equilibrium
N	the N plate