Exam: ***- Multiphase Reactors (MFR)***
- Mass Transfer and Reactions in Gas-Liquid Reactors

Date/Time: April 10th, 2018, 14.00 – 17.00 h

Location: A. Jacobshal 02

Please state the following on the first answer sheet:

- Name
- Address
- Postal code and place of residence
- Student number
- Date of birth

Please state your name on each subsequent answer sheet.

Credits:
1. 15
2. 20
3. 30
4. 25
5. 25
6. 10

Success!

Geert Versteeg

NB:

This exam is a so-called open book exam. The use of books and other course material is allowed!

Question 4 is only for *Multiphase Reactors*;
Also for Multiphase Reactors:
Indicate on the first page which bonus tutorials need to be taken into account. In total you can select three tutorials:
- one out of the series 1 and 2; 2 bonus points
- one out of the series 3 and 4; 4 bonus points
- one out of the series 5 and 6; 4 bonus points

Question 5 is only for *Mass Transfer and Reactions in Gas-Liquid Reactors*

Problem 1

A zero-order decomposition reaction of a reactant, $k_0 = 10^{-2}$ mol.l^{-1}.s^{-1}, is carried out in a CISTR.

- the feed stream consists of a solution with $[A]_{inlet}$ = 3,00 mol.l^{-1},
- $\Phi_V = 0{,}5 * 10^{-2}$ m^3.s^{-1},
- $V_{reactor}$ = 0,5 m^3,
- the density remains constant.

The reactant solution is kept in a storage vessel.

a) Calculate the concentration of A in the CISTR at steady state conditions.

The reactant solution pumped is from the storage vessel no.1 to the reactor; however, the storage vessel is at a certain moment in time empty. Therefore it is decided to switch to storage vessel no.2 with a concentration of 4000 mol.m^{-3}.

b) Calculate the concentration of A in the CISTR in the steady state that will be reached after the switch to storage vessel no.2.

c) After how many seconds, after starting pump at t=0, deviates the concentration of A in the reactor 5% of the steady state condition?

Problem 2

In a research laboratory the absorption rate from a single bubble in liquid is studied. A gaseous compound A (100% pure gas) is absorbed from a single bubble in liquid and A is subject to the following reaction:

$$A(G) \rightarrow P(L)$$

The reaction is second-order in A with k_2= 100 l.mol^{-1}. s^{-1}.

The experiments are carried out in a ideally mixed liquid phase and the concentration of A in the liquid is kept equal to zero (0). Only one bubble is present in the liquid and this liquid is fixed to a needle in order to be able to feed continuously A to the bubble. In this way the bubble size can be kept constant.

a) Give the absorption rate (mole.s^{-1}) for a bubble diameter of 10^{-2} m.

$Sh = 5 = (k_L, d_{bubble})/D_{AL}$

C_{AG} = 40 mol.m^{-3}

$D_{AL} = 10^{-9}$ m^2.s^{-1}

T = 298 K

$m_A = 0.50\ (C_{AG}/C_{AL})$

During one of the experiments the bubble suddenly was disconnected from the needle and rises upwards. The rise velocity of the bubble is 0.01 m.s^{-1} and can be assumed to be independent of the bubble diameter.

b) Calculate the distance this bubble has to travel to reduce the volume by 25%. It may be assumed that d_{bubble} remains constant!

Problem 3

In a stirred tank reactor gas compound A (very diluted in an N_2-stream) is absorbed into a liquid where the irreversible reaction $A + B \rightarrow C$ occurs. The reaction is first order in A, first order in B and has a reaction rate constant of $k_{1,1}=0.1\ m^3mol^{-1}s^{-1}$. The addition and withdrawal of liquid to the column is such that the concentration of B in the ideally mixed liquid always equals 2000 $mol.m^{-3}$. The concentration of A in the inlet gas flow equals 1 $mol.m^{-3}$. The gas phase in the reactor can be regarded as ideally mixed. The total pressure in the column equals 1 bar, the temperature 273 K: both pressure and temperature are independent of the position in the reactor. The gas throughput is equal to 10 m^3s^{-1}. The mass transfer coefficient in gas and liquid phase is 1.10^{-3} and $1*10^{-4}$ ms^{-1} respectively. The specific contact area in the column is 250 $m^2m^{-3}{}_{\text{reaction phase}}$. The volume of the reaction phase is 2.5 m^3. Additional data are given at the end of the question.

a) Give the relation for the flux.

b) Calculate the concentration of A leaving the reactor.

A homogenous catalyst is added so that the reaction now occurs instantaneously with respect to mass transfer. The mass transfer coefficient in the liquid phase decreases to 10^{-5} $m.s^{-1}$ as a consequence of increased viscosity of the liquid. The mass transfer coefficient in the gas phase, the specific contact area are not affected.

c) Is the concentration of A leaving the reactor higher or lower compared to the value calculated in b)?

d) Calculate the concentration of A in the leaving gas.

Additional data

$D_A = 2*10^{-9}\ m^2s^{-1}$

$D_B = 1*10^{-9}\ m^2s^{-1}$

$D_C = 5*10^{-10}\ m^2s^{-1}$

$m_A = 0.2$ [-] $(= [C_{A,G}/C_{A,L}]_{\text{equilibrium}})$

Problem 4

A layer of Insoluble Unwanted Product (UP) is formed on the wall of an ideal mixer during a process. Once a month UP is removed of the wall via washing with an aqueous solution of ED (Everything Disappears). UP is not soluble in water. The reaction product of UP and ED however, is very soluble in water. Therefore, it can be stated that the reaction between UP and ED is a surface reaction, which occurs on the outside of the UP layer.

The reaction rate equation is:

$R'' = -k_{1,1}C_{UP}C_{ED}$ kmol. $m^{-2}.s^{-1}$

with: C_{ED} = concentration ED near the layer, $kmol.m^{-3}$
$C_{ED,0}$ = concentration ED in the inlet stream, $kmol.m^{-3}$
C_{UP} = concentration ED in layer (note the concentration of UP is constant in the layer, it consists of pure UP!), $kmol.m^{-3}$
A = wall surface of the reactor, m^2
Φ_v = liquid flowrate ED, $m^3.s^{-1}$
k_{LS} = mass transfer coefficient liquid to layer, $m.s^{-1}$

a) What is the dimension of $k_{1,1?}$

b) Give a relationship that can be used to calculate the conversion. Work as much as possible from using the data and symbols.

c) Give the three asymptotic solutions are possible and what is their physical meaning?

Problem 5

A new air refresher type developed is consisted of a big box in which along one of the walls water runs (in plug flow!) as a laminar film downward. The air in the restaurant is well-mixed.
Through the inlet of the box a constant inflow of air ($\Phi_{G,1}$) enters the box, containing 15 ppm NH_3 ($15{\cdot}10^{-4}$ vol%). The airstream leaves the box via the outlet. The target is to reduce the NH_3 level in the air to a concentration of 0.3 ppm. Additional data are presented below the questions.

a) Which mass transfer model is most suitable describing the absorption of NH_3 in the water film running over the plate ?
b) Give an expression for the NH_3 flux to the wall (in mole/m^2 s)
c) Calculate the steady state NH_3 concentration in the air leaving the box

DATA

Length of box	10 m	Height of box	2.5 m
Depth of box	1 m	Pressure P	1.10^5 Pa
$\Phi_{G,1}$	$1.0 \cdot 10^{-4}$ $m^3 \cdot s^{-1}$	$\Phi_{v,\ water}$	$2.5 \cdot 10^{-3}$ $m^3 \cdot s^{-1}$
δ	$2.0 \cdot 10^{-3}$ m (thickness of water film)		
$D_{NH3,water}$	$1 \cdot 10^{-9}$ m^2/s (diff. coefficient of NH_3 in water)		
$M_{NH3,water}$	500 (distribution coefficient m = $[NH_3]_{water}$ / $[NH_3]_{air}$ at equilibrium		
Temperature T	298 K	Universal gas constant	8.314 J mol^{-1} K^{-1}
air	ideal gas		
k_g	1.10^{-3} $m.s^{-1}$ (mass transfer coefficient gas phase)		

Problem 6

I. Under which conditions is the absorption rate for the reaction $A(g) + B(l) \rightarrow P(liq.)$ with $R_A = -k_{1,1} \cdot C_A . C_B$ limited by mass transfer:

A. $Ha < 0.2$ and $(AL-1)Ha^2 >> 1$
B. $Ha < 0.2$ and $(AL-1)Ha^2 << 1$
C. $Ha > 2$
D. $Ha = 1$ and $AL=1$

It must be noted, however, that $Ha >> E_{A,inf}$

II. The degree of conversion in an absorption process of A(g) from an ideally mixed gas phase into a liquid in which the 3th order reaction $A \rightarrow P$ takes place ($R_A = -k_3 C_{AL}^3$) is dependent of the outlet concentration $C_{A,out}$.

This implies:
A. $Ha < 0.2$ and $(AL-1)Ha^2 >> 1$
B. $Ha < 0.2$ and $(AL-1)Ha^2 << 1$
C. $Ha > 2$
D. The reaction order is wrong: it must be first order in C_A