# Introduction to Chemical Engineering

## Problem Sheet Review on Mass and Energy Balances

**Problem 1 (mass balance; not reactive)** Midterm exam 2020

In the four-stage evaporation system shown in Fig. 1, a 50% by weight sugar solution is concentrated to 65% (by weight) by evaporating water in each stage. An input stream of 50 000 kg/h is feed to the system.

a. Perform degree-of-freedom analysis for each subsystem as well as for the overall system.
b. Determine the flow and composition of all the streams. Please fill a similar table as given below and report your results in the table.

Assumptions:

- Stages I and II evaporate equal amount of water, i.e. W1=W2.
- Stages III and IV evaporate equal amount of water, i.e. W3=W4.
- Stage III evaporates 10% of the total water entering the system.

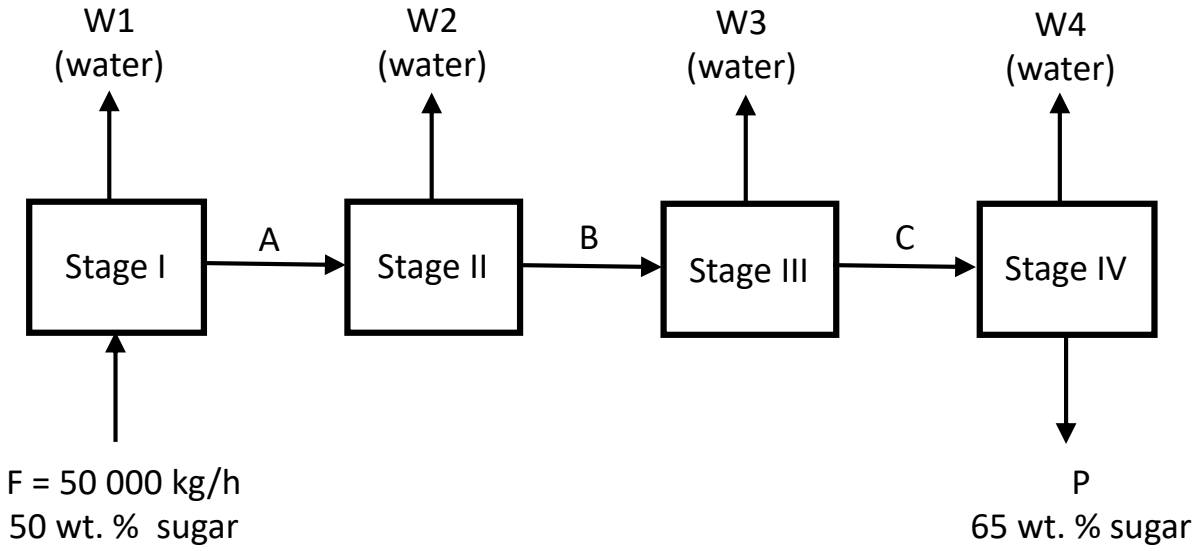



Fig. 1. Four-stage evaporation system.

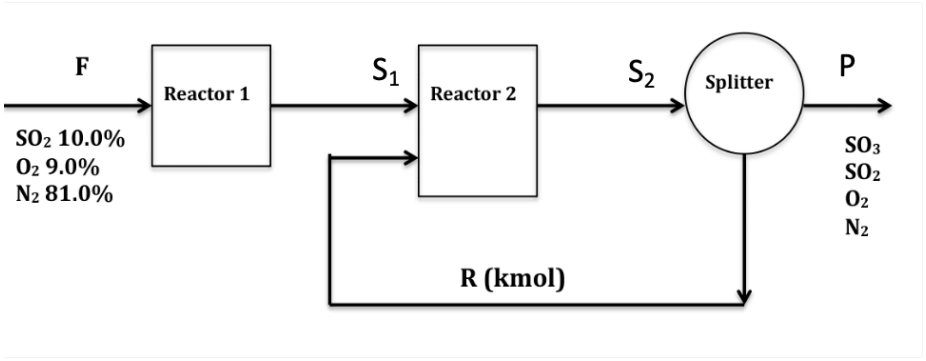
| | F | P | W1 | W2 | W3 | W4 | A | B | C |
|---|---|---|---|---|---|---|---|---|---|
| Flow (kg/h) | | | | | | | | | |
| Composition Sugar (%w/w) | | | 0 | 0 | 0 | 0 | | | |
| Composition | | | 1 | 1 | 1 | 1 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| water (%w/w) | | | | | | | | | |

**Problem 2 (Mass balances on reactive systems)** **Final exam 2013**

Sulfur dioxide ($SO_2$) that is a toxic gas can be converted to $SO_3$, which has many uses in industry. A gas stream having the composition shown in figure below is to be passed through a two-stage reactor. To increase the overall conversion to 95 %, some of the exit gas from stage 2 is recycled back to the inlet of stage 2 using a splitter. The conversion of the $SO_2$ to $SO_3$ (on one pass though) in the first stage is 75 % and in the second stage 65 %.

**All the fractional compositions are in mol%**




Knowing that $N_2$ is an inert, write and balance the reaction that takes place in the reactors.

a) Taking F=100 kmol/h as basis, find the molar flow rate and the molar compositions of the streams $S_1$ and P.
b) How much must be recycled per 100 kmol/h of inlet gas (stream F)? (What is the molar flow rate of R, for F=100 kmol/h)

**Problem 3 (Energy balances on non-reactive systems)** **Final exam 2019**

Toluene ($C_7H_8$) is condensed and cooled in a process consisting of two units operating at 1atm, such as below. In the first unit, a specific compound (C) is used for condensing vapor mixture of Toluene. For every 100 kg of C charged into the system, 27.5 kg of a vapor mixture of toluene and water (9.1wt%) enter the condenser and are condensed by the C stream. In the second unit, water is used to reduce the temperature of liquid Toluene and water. Please note that the phase of C is solid, and it does not change in this process.

Calculate:

a) The temperature of the C stream after it leaves the condenser.

b) The mass flow rate (kg/h) of cooling water required.

| Stream | Cp [kJ $kg^{-1}$ $°C^{-1}$] | $T_b$ [°C] | $\Delta H_{vap}$ ($T_b$) [kJ $kg^{-1}$] |
|---|---|---|---|
| $H_2O$ (l) | 4.2 | 100 | 2260 |
| $H_2O$ (g) | 2.1 | - | - |
| $C_7H_8$ (l) | 1.7 | 111 | 230 |
| $C_7H_8$ (g) | 1.3 | - | - |
| C(s) | 2.1 | - | - |