A First Course on Kinetics and Reaction Engineering
Activity 30.1

Problem Purpose

This problem will allow you to practice the general approach for analyzing an integrated heat exchanger and PFR. It also illustrates a problem where the cold approach is specified and used as one of the heat exchanger design equations instead of the heat transfer equation.

Problem Statement

An acid, A, is to be hydrolyzed according to the reaction A + W → P, where W represents water and P, the product. The acid will be fed to an adiabatic, steady state PFR at 0.07 kmol s^{-1} and water will be fed at 1.67 kmol s^{-1}. This gives a total feed flow of 0.04 m^3 s^{-1}; the density of the fluid may be considered to be constant. The feed temperature is 300 K. The reaction volume in the PFR is 0.5 m^3. The rate expression is given in equation (1), with the rate coefficient given in equation (2) and the equilibrium constant in equation (3). The heat of reaction is -86,000 kJ $kmol^{-1}$ at 298 K. The heat capacities of A, W, and P are 412, 76, and 512 kJ $kmol^{-1}$ K^{-1}, respectively, and may be taken to be independent of temperature. Compare the conversions and final temperatures when (a) the feed enters the PFR directly and (b) when the product stream is used to heat the feed (assume a 5 K cold approach).

$$r_1 = kC_AC_W\left[1-\frac{C_P}{KC_AC_W}\right] \tag{1}$$

$$k = \left(1.2\ \times\ 10^{12}\ \text{m}^3\ \text{kmol}^{-1}\ \text{s}^{-1}\right)\exp\left\{\frac{-13000K}{T}\right\} \tag{2}$$

$$K = \left(4.2\ \times\ 10^{-15}\ \text{m}^3\ \text{kmol}^{-1}\right)\exp\left\{\frac{11300K}{T}\right\} \tag{3}$$

Worksheet

1. Make a sketch of the system, labeling each flow stream.

2. Read through the problem statement. Each time you encounter a quantity, write it down and equate it to the appropriate variable. When you have completed doing so, if there are any additional constant quantities that you know will be needed and that can be calculated from the values you found, write the equations needed for doing so.

3. Generate the design equations needed to model the PFR by simplification of the general PFR design equations found in Unit 17 or on the AFCoKaRE Exam Handout.

4. Identify the specific set of equations that needs to be solved and within those equations identify the independent and dependent variables, if appropriate, and the unknown quantities to be found by solving the equations.

5. Assuming that the PFR design equations will be solved numerically, specify the information that must be provided and show how to calculate any unknown values.

6. Set up the heat exchanger design equations (energy balance and either heat transfer equation or specified approach).

7. Identify the specific set of equations that needs to be solved and within those equations identify the independent and dependent variables, if appropriate, and the unknown quantities to be found by solving the equations.

8. Assuming that the heat exchanger design equations will be solved numerically, specify the information that must be provided and show how to calculate any unknown values.

9. Solve the design equations and use the results to answer the questions asked.