10.302
Fall 2004
Exam 3
Wednesday, December 1, 2004

1. (60 points) A pure liquid is available from storage at its boiling point of 100°C. The material is to be fed to a reactor as a vapor at 200°C. The heating is to be achieved by using saturated high pressure steam at 230°C. Subcooling of the condensate will not be practiced. Relevant properties of the flow stream and of the steam are given below. The flow rate of the feed stream is 10kg/s.

A. What is the minimum flow rate of steam that can accomplish this task in an infinitely large, true counter-current exchanger? In an infinitely large true co-current exchanger?

B. Subject to the following assumptions, determine the area required for a true counter-current exchanger. The tube wall is very thin so the inside and outside areas are essentially equal.
   - (i) On the feed stream side of the tubes, h = 1000 $W/m^2 \cdot K$ when the feed stream liquid is in contact with the tubes;
   - (ii) On the feed stream side of the tubes, h = 300 $W/m^2 \cdot K$ when the feed stream vapor is in contact with the tubes;
   - (iii) On the steam side of the tubes, h = 5000 $W/m^2 \cdot K$;
   - (iv) The thermal resistance of the tube walls is negligible;

C. It has been suggested that it might be possible to use hot flue gas to replace the steam. Like the steam, it is available at 230°C. What is the minimum flue gas flow rate in an infinitely large counter-current exchanger? In an infinitely large co-current exchanger?

D. Re-work Part B if combustion gas is used at a rate of 100 kg/s and all conditions are as described in Part B except that the heat transfer coefficient on the combustion gas side of the tubes is 300 $W/m^2 \cdot K$ (rather than 5000 $W/m^2 \cdot K$ as it was if steam were used).

<u>Properties</u>

<u>Feed Stream</u>

Heat of Vaporization	=	0.6×10^6 J/kg
Heat Capacity of Vapor	=	3,000 J/kg·K
Heat Capacity of Liquid	=	2,000 J/kg·K

<u>Steam</u>

Heat of Condensation	=	1.8×10^6 J/kg

<u>Combustion Gas</u>

Heat Capacity	=	1000 J/kg·K

2. (40 points) A small aqueous waste stream is contaminated with a small amount (1 kg/m^3) of an organic species.

It has been suggested that this might be removed by the following procedure:

(a) Charge $5m^3$ of waste water to a tank as shown in the sketch.
(b) Charge $0.5m^3$ of solid beads to the tank. The beads will be chosen to have a strong affinity for the contaminant ($S_{bead/water} = 100$).
(c) Stir well for a specified period.
(d) Stop the stirrer, allow the beads to float, and drain off the water.

It is agreed that mass transfer external to the beads may be modeled as though the fluid around each bead were stagnant. The plan is to use beads with a diameter of 2mm.

A. What will the concentration be in the aqueous stream and in the beads if the vessel is stirred for an infinitely long time?
B. What is the value of the Biot Number?
C. Roughly (to within a factor of two) what duration of stirring would you recommend on the basis of engineering judgment? The idea is to select the shortest time consistent with effective use of the beads.
D. For the stirring period that you selected, roughly what contaminant concentration will be attained in the aqueous stream? Do you think that your answer is valid to ±10%? ±50%? ±100%?
E. Why do Parts C and D contain the word "roughly"?

<u>Properties</u>

Diffusivity of the contaminant in water = 10^{-5} cm^2/s

Diffusivity of the contaminant in the beads = 10^{-7} cm^2/s