Homework 9 (Group) Due date: 26-Mar-2007

1. (Chapter 8, Prob. 8.87) A 0.1 mole% caustic soda (NaOH) solution is to be concentrated in a continuous evaporator. The solution enters the unit at 25°C at a rate of 150 mol/min and is concentrated to 5 mole% at 50°C. Hot dry air at 200°C and 1.1 bar absolute is bubbled through the evaporator and leaves saturated with water at 50°C and 1 atm. Calculate the required volumetric flow rate of the entering air and the rate at which heat must be transferred to or from the unit. Assume that the heat capacity per unit mass of all liquid solutions is that of pure water. Refer to Table B.11 for heats of solution for NaOH solutions.

2. (Chapter 8, Prob. 8.99) An ammonia solution at a high pressure is flash vapourized at a rate of 200 lb_m/h. The solution contains 0.7 lb_m NH_3/lb_m, and its enthalpy relative to H_2O (l, 32°F) and NH_3 (l, -40°F) is -50 Btu/lb_m. Liquid and gas streams emerge from the unit at 1 atm and 80°F. Use Figure 8.5-2 to determine the mass flow rates and ammonia mass fractions of the vapour and liquid product streams and the rate (Btu/h) at which heat must be transferred to the vapourizer.

3. (Chapter 9, Prob. 9.60) In the preliminary design of a furnace for industrial boiler, methane at 25°C is burned completely with 20% excess air, also at 25°C. The feed rate of methane is 450 kmol/h. The hot combustion gases leave the furnace at 300°C and are discharged to the atmosphere. The heat transferred from the furnace (Q) is used to convert boiler feedwater at 25°C into superheated steam at 17 bar and 250°C. Use the following approximate heat capacities [kJ/ (mol °C)] in your solution of this problem: CH_4 (g) = 0.0431, CO_2 (g) = 0.0423, H_2O (g) = 0.0343, O_2 (g) = 0.0312, N_2 (g) = 0.0297.
   a) Draw and label a flowchart of this process [the chart should look like the one shown in part (b) without the preheater] (see at the end of problems) and calculate the composition of the gas leaving the furnace. Then, using the given constant heat capacities, calculate the average molar heat capacity of the gas. Finally, calculate Q (kJ/h) and the rate of steam production in the boiler (kg/h).

   b) In the actual boiler design, the air feed at 250C and the combustion gas leaving the furnace at 300oC pass through a heat exchanger (the *air preheater*). The combustion (flue) gas is cooled to 150°C in the preheater and is then discharged to the atmosphere, and the heated air is fed to the furnace. Calculate the temperature of the air entering the furnace (a trial-and-error solution is required) and the rate of steam production.

   c) Explain why preheating the air increases the rate of steam production. (*Suggestion*: Use the energy balance on the furnace in your explanation.) Why does it make sense economically to use the combustion gas as the heating medium?

4. (Chapter 9, Prob. 9.28) Ethyl benzene is converted to styrene in the catalytic dehydrogenation reaction

$$C_8H_{10}\ (g) \longrightarrow C_8H_8 + H_2: \quad \Delta H^o_r(600^oC) = +124.5\ kJ/mol$$

A flowchart of a simplified version of the commercial process is shown at the end of the problems. Fresh and recycled liquid ethylbenzene combine and are heated from 25°C to 500°C (A), and the heated ethylbenzene is mixed adiabatically with steam at 700°C (B) to produce the feed to the reactor at 600°C. (the steam suppresses undesired side reactions and removes carbon deposited on the catalyst surface.) A once-through conversion of 25% is achieved in the reactor (C), and the products emerge at 560°C. The product stream is cooled to 25°C (D), condensing essentially all of the water, ethylbenzene, and styrene and allowing hydrogen to pass out as a recoverable by-product of the process.

The water and hydrocarbon liquids are immiscible and are separated in a settling tank decanter (E). The water is vapourized and heated (F) to produce the steam the mixes with the ethylbenzene feed to the reactor. The hydrocarbon stream leaving the decanter is fed to distillation column (G) (actually, a series of towers), which separates the mixture into essentially pure styrene and ethylbenzene, each at 25°C after cooling and condensation steps have been carried out. The ethylbenzene is recycled to the reactor preheater, and the styrene is taken off as a product.

a) Calculate on the basis of 100 kg/h styrene produced, the required fresh ethylbenzene fee rate, the flow rate of recycled ethylbenzene, and the circulation rate of water, all in mol/h. (Assume P = 1 atm.)

b) Calculate the required rates of heat input or withdrawal in kJ/h for the ethylbenzene preheater (A), steam generator (B) and the reactor (C).

c) Suggest possible ways to improve the energy economy of this process.

Physical Property Data

Ethylbenzene: $(C_p)_{liquid}$ = 182 J/(mol °C), ΔH_v = 36.0 kJ/mol at 136°C

$(C_p)_{vapour}$ [J/(mol °C)] = 118 + 0.30T(°C)

Styrene: $(C_p)_{liquid}$ = 209 J/(mol °C), ΔH_v = 37.1 kJ/mol at 145°C

$(C_p)_{vapour}$ [J/(mol °C)] = 115 + 0.27T(°C)

5. (Chapter 9, Prob. 9.28) Methane is burned with 25% excess air in a continuous adiabatic reactor. The methane enters the reactor at 25°C and 1.10 atm at a rate of 5.50 L/s and the entering air is at 150°C and 1.1 atm. Combustion in the reaction is complete, and the reactor effluent gas emerges at 1.05 atm. Calculate (a) the temperature and (b) the degrees of superheat of the reactor effluent. (Consider water to be the only condensable species in the effluent.)

Figure for Problem 3.

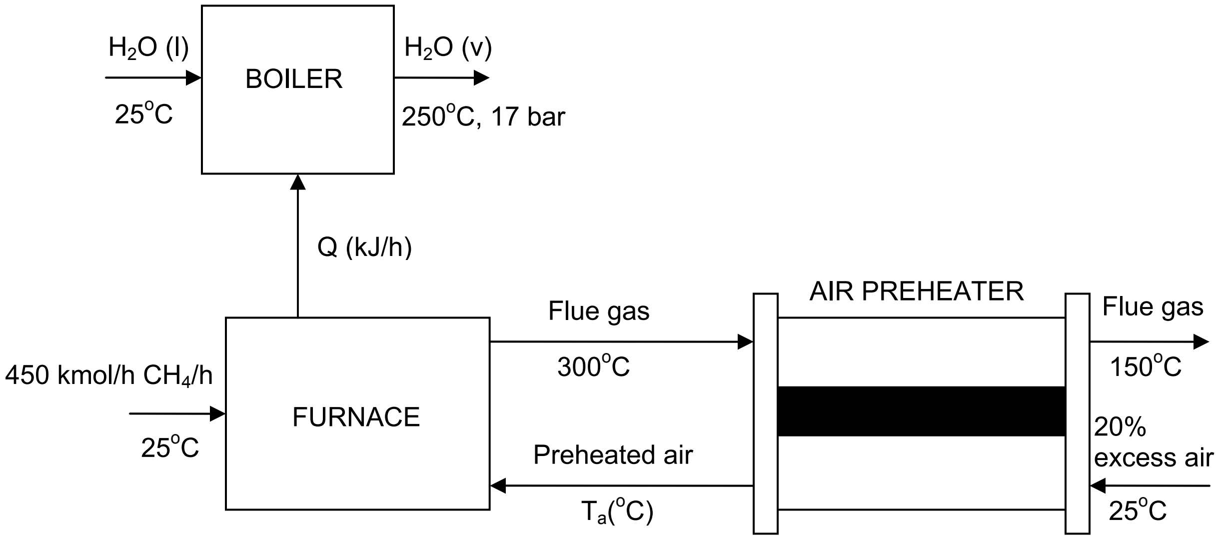
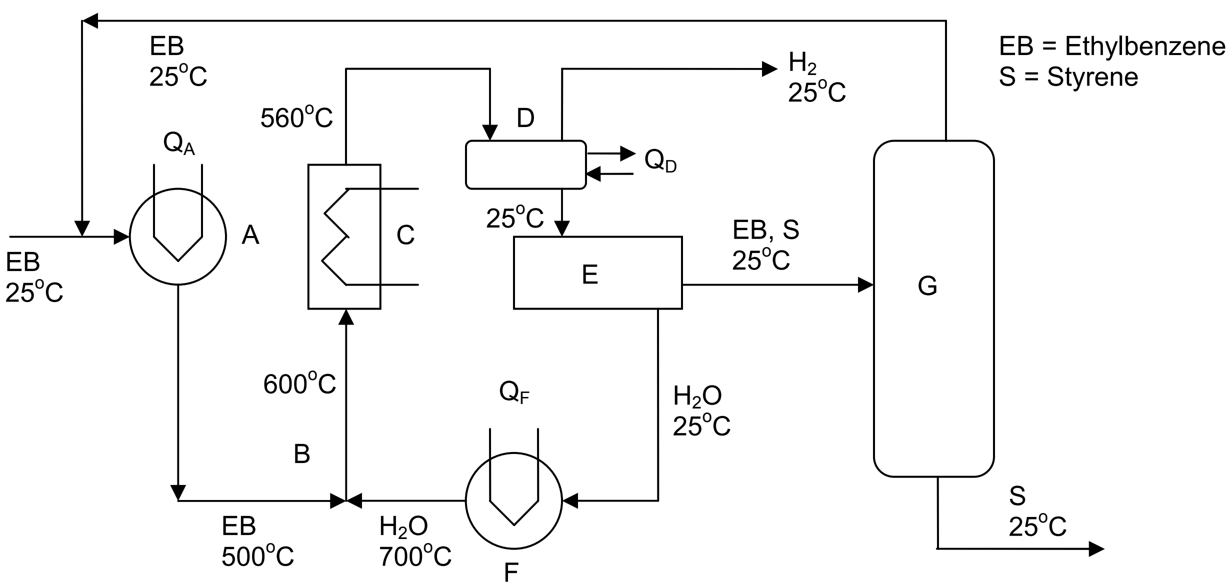


Figure for Problem 4



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