PROBLEMS

Heat-Transfer Coefficient in Single-Effect Evaporator. A feed of 4535 kg/h of a 2.0 wt % salt solution at 311 K enters continuously a single-effect evaporator and is being concentrated to 3.0%. The evaporation is at atmospheric pressure and the area of the evaporator is 69.7 m^2. Saturated steam at 383.2 K is supplied for heating. Since the solution is dilute, it can be assumed to have the same boiling point as water. The heat capacity of the feed can be taken as $c_p = 4.10$ kJ/kg · K. Calculate the amounts of vapor and liquid product and the overall heat-transfer coefficient U.

Ans. $U = 1823$ W/m^2 · K

Effects of Increased Feed Rate in Evaporator. Using the same area, value of U, steam pressure, evaporator pressure, and feed temperature as in Problem 8.4-1, calculate the amounts of liquid and vapor leaving and the liquid outlet concentration if the feed rate is increased to 6804 kg/h.

Ans. $V = 1256$ kg/h, $L = 5548$ kg/h, $x_L = 2.45\%$

Production of Distilled Water. An evaporator having an area of 83.6 m^2 and a $U = 2270$ W/m^2 · K is used to produce distilled water for a boiler feed. Tap water having 400 ppm of dissolved solids at 15.6°C is fed to the evaporator operating at 1 atm pressure abs. Saturated steam at 115.6°C is available for use. Calculate the amount of distilled water produced per hour if the outlet liquid contains 800 ppm solids.

Boiling-Point Rise of NaOH Solutions. Determine the boiling temperature of the solution and the boiling-point rise for the following cases.

(a) A 30% NaOH solution boiling in an evaporator at a pressure of 172.4 kPa (25 psia).

(b) A 60% NaOH solution boiling in an evaporator at a pressure of 3.45 kPa (0.50 psia).

Ans. (a) Boiling point = 130.6°C, boiling point rise = 15°C

Effect of Feed Temperature on Evaporating an NaOH Solution. A single-effect evaporator is concentrating a feed of 9072 kg/h of a 10 wt % solution of NaOH in water to a product of 50% solids. The pressure of the saturated steam used is 42 kPa (gage) and the pressure in the vapor space of the evaporator is 20 kPa (abs). The overall heat-transfer coefficient is 1988 W/m^2 · K. Calculate the steam used, the steam economy in kg vaporized/kg steam, and the area for the following feed conditions.

(a) Feed temperature of 288.8 K (15.6°C).

(b) Feed temperature of 322.1 K (48.9°C).

Ans. (a) $S = 8959$ kg/h of steam, $A = 295.4$ m^2

Heat-Transfer Coefficient to Evaporate NaOH. In order to concentrate 4536 kg/h of an NaOH solution containing 10 wt % NaOH to a 20 wt % solution, a single-effect evaporator is being used with an area of 37.6 m^2. The feed enters at 21.1°C (294.3 K). Saturated steam at 110°C (383.2 K) is used for heating and the pressure in the vapor space of the evaporator is 51.7 kPa. Calculate the kg/h of steam used and the overall heat-transfer coefficient.

Throughput of a Single-Effect Evaporator. An evaporator is concentrating F kg/h at 311 K of a 20 wt % solution of NaOH to 50%. The saturated steam used for heating is at 399.3 K. The pressure in the vapor space of the evaporator is 13.3 kPa abs. The overall coefficient is 1420 W/m^2 · K and the area is 86.4 m^2. Calculate the feed rate F of the evaporator.

Ans. $F = 9072$ kg/h

Surface Area and Steam Consumption of an Evaporator. A single-effect evaporator is concentrating a feed solution of organic colloids from 5 to 50 wt %. The solution has a negligible boiling-point elevation. The heat capacity of the feed is $c_p = 4.06$ kJ/kg · K (0.97 btu/lb_m · °F) and the feed enters at 15.6°C (60°F). Saturated steam at 101.32 kPa is available for heating, and the pressure in the vapor space of the evaporator is 15.3 kPa. A total of 4536 kg/h (10 000 lb_m/h) of water is to be evaporated. The overall heat-transfer coefficient is 1988 W/m^2 · K (350 btu/h · ft^2 · °F). What is the required surface area in m^2 and the steam consumption?

Evaporation of Tomato Juice Under Vacuum. Tomato juice having a concentration of 12 wt % solids is being concentrated to 25% solids in a film-type evaporator. The maximum allowable temperature for the tomato juice is 135°F, which will be the temperature of the product. The feed enters at 100°F. Saturated steam at 25 psia is used for heating. The overall heat-transfer coefficient U is 600 btu/h · ft² · °F and the area A is 50 ft². The heat capacity of the feed c_p is estimated as 0.95 btu/lb_m · °F. Neglect any boiling-point rise if present. Calculate the feed rate of tomato juice to the evaporator.

Concentration of Cane Sugar Solution. A single-effect evaporator is being used to concentrate a feed of 10 000 lb_m/h of a cane sugar solution at 80°F and containing a sugar content of 15° Brix (degrees Brix is wt % sugar) to 30° Brix for use in a food process. Saturated steam at 240°F is available for heating. The vapor space in the evaporator will be at 1 atm abs pressure. The overall $U = 350$ btu/h · ft² · °F and the heat capacity of the feed is $c_p = 0.91$ btu/lb_m · °F. The boiling-point rise can be estimated from Example 8.5-1. The heat of solution can be considered negligible and neglected. Calculate the area required for the evaporator and the amount of steam used per hour.

Ans. Boiling-point rise = 2.0°F (1.1°C), $A = 667$ ft² (62.0 m²)

(Selected Topic) Boiling Points in a Triple-Effect Evaporator. A solution with a negligible boiling-point rise is being evaporated in a triple-effect evaporator using saturated steam at 121.1°C (394.3 K). The pressure in the vapor of the last effect is 25.6 kPa abs. The heat-transfer coefficients are $U_1 = 2840$, $U_2 = 1988$, and $U_3 = 1420$ W/m² · K and the areas are equal. Estimate the boiling point in each of the evaporators.

Ans. $T_1 = 108.6$°C (381.8 K)

(Selected Topic) Evaporation of Sugar Solution in a Multiple-Effect Evaporator. A triple-effect evaporator with forward feed is evaporating a sugar solution with negligible boiling-point rise (less than 1.0 K, which will be neglected) and containing 5 wt % solids to 25% solids. Saturated steam at 205 kPa abs is being used. The pressure in the vapor space of the third effect is 13.65 kPa. The feed rate is 22 680 kg/h and the temperature 299.9 K. The liquid heat capacity is $c_p = 4.19 - 2.35x$, where c_p is in kJ/kg · K and x in wt fraction (K1). The heat-transfer coefficients are $U_1 = 3123$, $U_2 = 1987$, and $U_3 = 1136$ W/m² · K. Calculate the surface area of each effect if each effect has the same area, and the steam rate.

Ans. Area $A = 99.1$ m², steam rate $S = 8972$ kg/h

(Selected Topic) Evaporation in Double-Effect Reverse-Feed Evaporators. A feed containing 2 wt % dissolved organic solids in water is fed to a double-effect evaporator with reverse feed. The feed enters at 100°F and is concentrated to 25% solids. The boiling-point rise can be considered negligible as well as the heat of solution. Each evaporator has a 1000-ft² surface area and the heat-transfer coefficients are $U_1 = 500$ and $U_2 = 700$ btu/h · ft² · °F. The feed enters evaporator number 2 and steam at 100 psia is fed to number 1. The pressure in the vapor space of evaporator number 2 is 0.98 psia. Assume that the heat capacity of all liquid solutions is that of liquid water. Calculate the feed rate F and the product rate L_1 of a solution containing 25% solids. (*Hint*: Assume a feed rate of, say, $F = 1000$ lb_m/h. Calculate the area. Then calculate the actual feed rate by multiplying 1000 by 1000/calculated area.)

Ans. $F = 133\,800$ lb_m/h (60 691 kg/h), $L_1 = 10\,700$ lb_m/h (4853 kg/h)

(Selected Topic) Concentration of NaOH Solution in Triple-Effect Evaporator. A forced-circulation triple-effect evaporator using forward feed is to be used to concentrate a 10 wt % NaOH solution entering at 37.8°C to 50%. The steam used enters at 58.6 kPa gage. The absolute pressure in the vapor space of the third effect is 6.76 kPa. The feed rate is 13 608 kg/h. The heat-transfer coefficients are $U_1 = 6246$, $U_2 = 3407$, and $U_3 = 2271$ W/m² · K. All effects have the same area. Calculate the surface area and steam consumption.

Ans. $A = 97.3$ m², $S = 5284$ kg steam/h

(Selected Topic) Triple-Effect Evaporator with Reverse Feed. A feed rate of 20 410 kg/h of 10 wt % NaOH solution at 48.9°C is being concentrated in a triple-effect reverse-feed evaporator to produce a 50% solution. Saturated steam at 178.3°C is fed to the first evaporator and the pressure in the third effect is 10.34 kPa abs. The heat-transfer coefficient for each effect is assumed to be 2840 W/m² · K. Calculate the heat-transfer area and the steam consumption rate.