Hence, the temperature drops ΔT in a multiple-effect evaporator are approximately inversely proportional to the values of U. Calling $\sum \Delta T$ as follows for no boiling-point rise,

$$\sum \Delta T = \Delta T_1 + \Delta T_2 + \Delta T_3 = T_S - T_3 \tag{8.5-5}$$

Note that $\Delta T_1 \, °C = \Delta T_1 \, K$, $\Delta T_2 \, °C = \Delta T_2 \, K$, and so on. Since ΔT_1 is proportional to $1/U_1$, then

$$\Delta T_1 = \sum \Delta T \, \frac{1/U_1}{1/U_1 + 1/U_2 + 1/U_3} \tag{8.5-6}$$

Similar equations can be written for ΔT_2 and ΔT_3.

2. Capacity of multiple-effect evaporators. A rough estimate of the capacity of a three-effect evaporator compared to a single effect can be obtained by adding the value of q for each evaporator.

$$q = q_1 + q_2 + q_3 = U_1 A_1 \, \Delta T_1 + U_2 A_2 \, \Delta T_2 + U_3 A_3 \, \Delta T_3 \tag{8.5-7}$$

If we make the assumption that the value of U is the same in each effect and the values of A are equal, Eq. (8.5-7) becomes

$$q = UA(\Delta T_1 + \Delta T_2 + \Delta T_3) = UA \, \Delta T \tag{8.5-8}$$

where $\Delta T = \sum \Delta T = \Delta T_1 + \Delta T_2 + \Delta T_3 = T_S - T_3$.

If a single-effect evaporator is used with the same area A, the same value of U, and the same total temperature drop ΔT, then

$$q = UA \, \Delta T \tag{8.5-9}$$

This, of course, gives the same capacity as for the multiple-effect evaporators. Hence, the increase in steam economy obtained by using multiple-effect evaporators is obtained at the expense of reduced capacity.

8.5C Calculations for Multiple-Effect Evaporators

In doing calculations for a multiple-effect evaporator system, the values to be obtained are usually the area of the heating surface in each effect, the kg of steam per hour to be supplied, and the amount of vapor leaving each effect, especially the last effect. The given or known values are usually as follows: (1) steam pressure to first effect, (2) final pressure in vapor space of the last effect, (3) feed conditions and flow to first effect, (4) the final concentration in the liquid leaving the last effect, (5) physical properties such as enthalpies and/or heat capacities of the liquid and vapors, and (6) the overall heat-transfer coefficients in each effect. Usually, the areas of each effect are assumed equal.

The calculations are done using material balances, heat balances, and the capacity equations $q = UA \, \Delta T$ for each effect. A convenient way to solve these equations is by trial and error. The basic steps to follow are given as follows for a triple-effect evaporator.

8.5D Step-by-Step Calculation Methods for Triple-Effect Evaporators

1. From the known outlet concentration and pressure in the last effect, determine the boiling point in the last effect. (If a boiling-point rise is present, this can be determined from a Dühring line plot.)

Chap. 8   Evaporation

2. Determine the total amount of vapor evaporated by an overall material balance. For this first trial apportion this total amount of vapor among the three effects. (Usually, equal vapor produced in each effect, so that $V_1 = V_2 = V_3$ is assumed for the first trial.) Make a total material balance on effects 1, 2, and 3 to obtain L_1, L_2, and L_3. Then calculate the solids concentration in each effect by a solids balance on each effect.

3. Using Eq. (8.5-6), estimate the temperature drops ΔT_1, ΔT_2, and ΔT_3 in the three effects. Any effect that has an extra heating load, such as a cold feed, requires a proportionately larger ΔT. Then calculate the boiling point in each effect.

   [If a boiling-point rise (BPR) in °C is present, estimate the pressure in effects 1 and 2 and determine the BPR in each of the three effects. Only a crude pressure estimate is needed since BPR is almost independent of pressure. Then the $\sum \Delta T$ available for heat transfer without the superheat is obtained by subtracting the sum of all three BPRs from the overall ΔT of $T_S - T_3$ (saturation). Using Eq. (8.5-6), estimate ΔT_1, ΔT_2, and ΔT_3. Then calculate the boiling point in each effect.]

4. Using heat and material balances in each effect, calculate the amount vaporized and the flows of liquid in each effect. If the amounts vaporized differ appreciably from those assumed in step 2, then steps 2, 3, and 4 can be repeated using the amounts of evaporation just calculated. (In step 2 only the solids balance is repeated.)

5. Calculate the value of q transferred in each effect. Using the rate equation $q = UA\,\Delta T$ for each effect, calculate the areas A_1, A_2, and A_3. Then calculate the average value A_m by

$$A_m = \frac{A_1 + A_2 + A_3}{3} \qquad (8.5\text{-}10)$$

If these areas are reasonably close to each other, the calculations are complete and a second trial is not needed. If these areas are not nearly equal, a second trial should be performed as follows.

6. To start trial 2, use the new values of L_1, L_2, L_3, V_1, V_2, and V_3 calculated by the heat balances in step 4 and calculate the new solids concentrations in each effect by a solids balance on each effect.

7. Obtain new values of $\Delta T_1'$, $\Delta T_2'$, and $\Delta T_3'$ from

$$\Delta T_1' = \frac{\Delta T_1 A_1}{A_m} \qquad \Delta T_2' = \frac{\Delta T_2 A_2}{A_m} \qquad \Delta T_3' = \frac{\Delta T_3 A_3}{A_m} \qquad (8.5\text{-}11)$$

The sum $\Delta T_1' + \Delta T_2' + \Delta T_3'$ must equal the original $\sum \Delta T$. If not, proportionately readjust all $\Delta T'$ values so that this is so. Then calculate the boiling point in each effect.

   [If a boiling point rise is present, then using the new concentrations from step 6, determine the new BPRs in the three effects. This gives a new value of $\sum \Delta T$ available for heat transfer by subtracting the sum of all three BPRs from the overall ΔT. Calculate the new values of $\Delta T'$ by Eq. (8.5-11). The sum of the $\Delta T'$ values just calculated must be readjusted to this new $\sum \Delta T$ value. Then calculate the boiling point in each effect.] Step 7 is essentially a repeat of step 3 but using Eq. (8.5-11) to obtain a better estimate of the $\Delta T'$ values.

8. Using the new $\Delta T'$ values from step 7, repeat the calculations starting with step 4. Two trials are usually sufficient so that the areas are reasonably close to being equal.

EXAMPLE 8.5-1. Evaporation of Sugar Solution in a Triple-Effect Evaporator

A triple-effect forward-feed evaporator is being used to evaporate a sugar solution containing 10 wt % solids to a concentrated solution of 50%. The boiling-point rise of the solutions (independent of pressure) can be estimated

from BPR°C $= 1.78x + 6.22x^2$ (BPR°F $= 3.2x + 11.2x^2$), where x is wt fraction of sugar in solution (K1). Saturated steam at 205.5 kPa (29.8 psia) [121.1°C (250°F) saturation temperature] is being used. The pressure in the vapor space of the third effect is 13.4 kPa (1.94 psia). The feed rate is 22 680 kg/h (50 000 lb$_m$/h) at 26.7°C (80°F). The heat capacity of the liquid solutions is (K1) $c_p = 4.19 - 2.35x$ kJ/kg·K (1.0 - 0.56x btu/lb$_m$·°F). The heat of solution is considered to be negligible. The coefficients of heat transfer have been estimated as $U_1 = 3123$, $U_2 = 1987$, and $U_3 = 1136$ W/m²·K or 550, 350, and 200 btu/h·ft²·°F. If each effect has the same surface area, calculate the area, the steam rate used, and the steam economy.

Solution: The process flow diagram is given in Fig. 8.5-1. Following the eight steps outlined, the calculations are as follows.

Step 1. For 13.4 kPa (1.94 psia), the saturation temperature is 51.67°C (125°F) from the steam tables. Using the equation for BPR for evaporator number 3 with $x = 0.5$,

$$\text{BPR}_3 = 1.78x + 6.22x^2 = 1.78(0.5) + 6.22(0.5)^2 = 2.45°C \ (4.4°F)$$

$$T_3 = 51.67 + 2.45 = 54.12°C \ (129.4°F)$$

Step 2. Making an overall and a solids balance to calculate the total amount vaporized $(V_1 + V_2 + V_3)$ and L_3,

$$F = 22 680 = L_3 + (V_1 + V_2 + V_3)$$

$$Fx_F = 22 680(0.1) = L_3(0.5) + (V_1 + V_2 + V_3)(0)$$

$$L_3 = 4536 \ \text{kg/h} \ (10 000 \ \text{lb}_m/\text{h})$$

$$\text{total vaporized} = (V_1 + V_2 + V_3) = 18 144 \ \text{kg/h} \ (40 000 \ \text{lb}_m/\text{h})$$

Assuming equal amount vaporized in each effect, $V_1 = V_2 = V_3 = 6048$ kg/h (13 333 lb$_m$/h). Making a total material balance on effects 1, 2, and 3 and solving,

(1) $\quad F = 22 680 = V_1 + L_1 = 6048 + L_1, \quad L_1 = 16 632 \ \text{kg/h} \ (33 667 \ \text{lb}_m/\text{h})$

(2) $\quad L_1 = 16 632 = V_2 + L_2 = 6048 + L_2, \quad L_2 = 10 584(23 334)$

(3) $\quad L_2 = 10 584 = V_3 + L_3 = 6048 + L_3, \quad L_3 = 4536(10 000)$

Making a solids balance on effects 1, 2, and 3 and solving for x,

(1) $\quad 22 680(0.1) = L_1 x_1 = 16 632(x_1), \quad x_1 = 0.136$

(2) $\quad 16 632(0.136) = L_2 x_2 = 10 584(x_2), \quad x_2 = 0.214$

(3) $\quad 10 584(0.214) = L_3 x_3 = 4536(x_3), \quad x_3 = 0.500 \quad \text{(check balance)}$
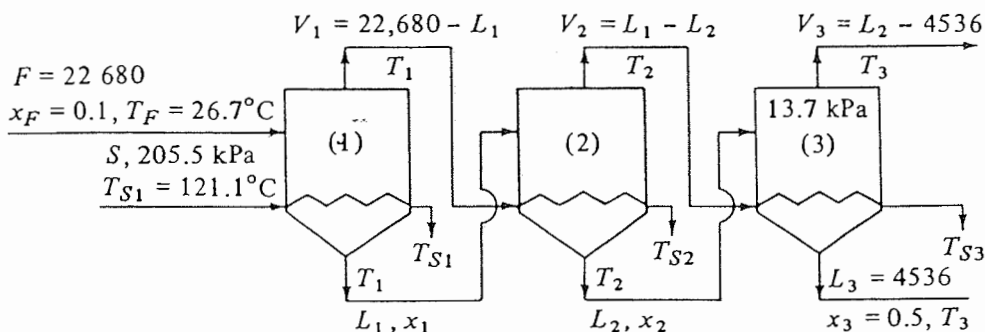

FIGURE 8.5-1. *Flow diagram for triple-effect evaporation for Example 8.5-1.*

Step 3. The BPR in each effect is calculated as follows:

(1) $BPR_1 = 1.78x_1 + 6.22x_1^2 = 1.78(0.136) + 6.22(0.136)^2 = 0.36°C\ (0.7°F)$

(2) $BPR_2 = 1.78(0.214) + 6.22(0.214)^2 = 0.65°C\ (1.2°F)$

(3) $BPR_3 = 1.78(0.5) + 6.22(0.5)^2 = 2.45°C\ (4.4°F)$

$\sum \Delta T$ available $= T_{S1} - T_3$ (saturation) $- (BPR_1 + BPR_2 + BPR_3)$

$$= 121.1 - 51.67 - (0.36 + 0.65 + 2.45) = 65.97°C\ (118.7°F)$$

Using Eq. (8.5-6) for ΔT_1 and similar equations for ΔT_2 and ΔT_3,

$$\Delta T_1 = \sum \Delta T \frac{1/U_1}{1/U_1 + 1/U_2 + 1/U_3} = \frac{(65.97)(1/3123)}{(1/3123) + (1/1987) + (1/1136)}$$

$$\Delta T_1 = 12.40°C \qquad \Delta T_2 = 19.50°C \qquad \Delta T_3 = 34.07°C$$

However, since a cold feed enters effect number 1, this effect requires more heat. Increasing ΔT_1 and lowering ΔT_2 and ΔT_3 proportionately as a first estimate,

$$\Delta T_1 = 15.56°C = 15.56\ K \qquad \Delta T_2 = 18.34°C = 18.34\ K$$
$$\Delta T_3 = 32.07°C = 32.07\ K$$

To calculate the actual boiling point of the solution in each effect,

(1) $\quad T_1 = T_{S1} - \Delta T_1$

$\qquad = 121.1 - 15.56 = 105.54°C$

$\quad T_{S1} = 121.1°C$ (condensing temperature of saturated steam to effect 1)

(2) $\quad T_2 = T_1 - BPR_1 - \Delta T_2$

$\qquad = 105.54 - 0.36 - 18.34 = 86.84°C$

$\quad T_{S2} = T_1 - BPR_1 = 105.54 - 0.36$

$\qquad = 105.18°C$ (condensing temperature of steam to effect 2)

(3) $\quad T_3 = T_2 - BPR_2 - \Delta T_3$

$\qquad = 86.84 - 0.65 - 32.07 = 54.12°C$

$\quad T_{S3} = T_2 - BPR_2$

$\qquad = 86.84 - 0.65 = 86.19°C$ (condensing temperature of steam to effect 3)

The temperatures in the three effects are as follows:

Effect 1	*Effect 2*	*Effect 3*	*Condenser*
$T_{S1} = 121.1°C$	$T_{S2} = 105.18$	$T_{S3} = 86.19$	$T_{S4} = 51.67$
$T_1 = 105.54$	$T_2 = 86.84$	$T_3 = 54.12$	

Step 4. The heat capacity of the liquid in each effect is calculated from the equation $c_p = 4.19 - 2.35x$.

$$F: \quad c_p = 4.19 - 2.35(0.1) = 3.955\ kJ/kg \cdot K$$

$$L_1: \quad c_p = 4.19 - 2.35(0.136) = 3.869$$

$$L_2: \quad c_p = 4.19 - 2.35(0.214) = 3.684$$

$$L_3: \quad c_p = 4.19 - 2.35(0.5) = 3.015$$

The values of the enthalpy H of the various vapor streams relative to water at 0°C as a datum are obtained from the steam table as follows:

Effect 1:

$T_1 = 105.54°C$, $T_{S2} = 105.18$ (221.3°F), $BPR_1 = 0.36$, $T_{S1} = 121.1$ (250°F)

$H_1 = H_{S2}$ (saturation enthalpy at T_{S2}) + 1.884 (0.36°C superheat)

$\quad = 2684 + 1.884(0.36) = 2685$ kJ/kg

$\lambda_{S1} = H_{S1}$ (vapor saturation enthalpy) $- h_{S1}$ (liquid enthalpy at T_{S1})

$\quad = (2708 - 508) = 2200$ kJ/kg latent heat of condensation

Effect 2:
$$T_2 = 86.84°C, \quad T_{S3} = 86.19, \quad BPR_2 = 0.65$$

$H_2 = H_{S3} + 1.884(0.65) = 2654 + 1.884(0.65) = 2655$ kJ/kg

$\lambda_{S2} = H_1 - h_{S2} = 2685 - 441 = 2244$ kJ/kg

Effect 3:
$$T_3 = 54.12°C, \quad T_{S4} = 51.67, \quad BPR_3 = 2.45$$

$H_3 = H_{S4} + 1.884(2.45) = 2595 + 1.884(2.45) = 2600$ kJ/kg

$\lambda_{S3} = H_2 - h_{S3} = 2655 - 361 = 2294$ kJ/kg

(Note that the superheat corrections in this example are small and could possibly have been neglected. However, the corrections were used to demonstrate the method of calculation.) Flow relations to be used in heat balances are

$$V_1 = 22\,680 - L_1, \quad V_2 = L_1 - L_2, \quad V_3 = L_2 - 4536, \quad L_3 = 4536$$

Write a heat balance on each effect. Use 0°C as a datum since the values of H of the vapors are relative to 0°C (32°F) and note that $(T_F - 0)°C = (T_F - 0)$ K and $(T_1 - 0)°C = (T_1 - 0)$ K,

(1) $\qquad Fc_p(T_F - 0) + S\lambda_{S1} = L_1 c_p(T_1 - 0) + V_1 H_1$

Substituting the known values,

$22\,680(3.955)(26.7 - 0) + S(2200) = L_1(3.869)(105.54 - 0)$
$$+ (22\,680 - L_1)(2685)$$

(2) $\qquad L_1 c_p(T_1 - 0) + V_1 \lambda_{S2} = L_2 c_p(T_2 - 0) + V_2 H_2$

$L_1(3.869)(105.54 - 0) + (22\,680 - L_1)(2244) = L_2(3.684)(86.84 - 0)$
$$+ (L_1 - L_2)(2655)$$

(3) $\qquad L_2 c_p(T_2 - 0) + V_2 \lambda_{S3} = L_3 c_p(T_3 - 0) + V_3 H_3$

$L_2(3.684)(86.84 - 0) + (L_1 - L_2)(2294) = 4536(3.015)(54.12 - 0)$
$$+ (L_2 - 4536)(2600)$$

Solving the last two equations simultaneously for L_1 and L_2 and substituting into the first equation,

$$L_1 = 17\,078 \text{ kg/h} \qquad L_2 = 11\,068 \qquad L_3 = 4536$$
$$S = 8936 \qquad V_1 = 5602 \qquad V_2 = 6010 \qquad V_3 = 6532$$

The calculated values of V_1, V_2, and V_3 are close enough to the assumed values so that steps 2, 3, and 4 do not need to be repeated. If the calculation were repeated, the calculated values of V_1, V_2, and V_3 would be used starting with step 2 and a solids balance in each effect would be made.

Step 5. Solving for the values of q in each effect and area,

$$q_1 = S\lambda_{S1} = \left(\frac{8936}{3600}\right)(2200 \times 1000) = 5.460 \times 10^6 \text{ W}$$

$$q_2 = V_1\lambda_{S2} = \left(\frac{5602}{3600}\right)(2244 \times 1000) = 3.492 \times 10^6 \text{ W}$$

$$q_3 = V_2\lambda_{S3} = \left(\frac{6010}{3600}\right)(2294 \times 1000) = 3.830 \times 10^6 \text{ W}$$

$$A_1 = \frac{q_1}{U_1 \, \Delta T_1} = \frac{5.460 \times 10^6}{3123(15.56)} = 112.4 \text{ m}^2$$

$$A_2 = \frac{q_2}{U_2 \, \Delta T_2} = \frac{3.492 \times 10^6}{1987(18.34)} = 95.8 \text{ m}^2$$

$$A_3 = \frac{q_3}{U_3 \, \Delta T_3} = \frac{3.830 \times 10^6}{1136(32.07)} = 105.1 \text{ m}^2$$

The average area $A_m \doteq 104.4 \text{ m}^2$. The areas differ from the average value by less than 10% and a second trial is not really necessary. However, a second trial will be made starting with step 6 to indicate the calculation methods used.

Step 6. Making a new solids balance on effects 1, 2, and 3 using the new $L_1 = 17\,078$, $L_2 = 11\,068$, and $L_3 = 4536$ and solving for x,

(1) $22\,680(0.1) = 17\,078(x_1)$, $x_1 = 0.133$

(2) $17\,078(0.133) = 11\,068(x_2)$, $x_2 = 0.205$

(3) $11\,068(0.205) = 4536(x_3)$, $x_3 = 0.500$ (check balance)

Step 7. The new BPR in each effect is then

(1) $BPR_1 = 1.78x_1 + 6.22x_1^2 = 1.78(0.133) + 6.22(0.133)^2 = 0.35°C$

(2) $BPR_2 = 1.78(0.205) + 6.22(0.205)^2 = 0.63°C$

(3) $BPR_3 = 1.78(0.5) + 6.22(0.5)^2 = 2.45°C$

$\sum \Delta T$ available $= 121.1 - 51.67 - (0.35 + 0.63 + 2.45) = 66.00°C$

The new values for ΔT are obtained using Eq. (8.5-11).

$$\Delta T_1' = \frac{\Delta T_1 A_1}{A_m} = \frac{15.56(112.4)}{104.4} = 16.77 \text{ K} = 16.77°C$$

$$\Delta T_2' = \frac{\Delta T_2 A_2}{A_m} = \frac{18.34(95.8)}{104.4} = 16.86°C$$

$$\Delta T_3' = \frac{\Delta T_3 A_3}{A_m} = \frac{32.07(105.1)}{104.4} = 32.34°C$$

$$\sum \Delta T = 16.77 + 16.86 + 32.34 = 65.97°C$$

These $\Delta T'$ values are readjusted so that $\Delta T'_1 = 16.77$, $\Delta T'_2 = 16.87$, $\Delta T'_3 = 32.36$, and $\sum \Delta T = 16.77 + 16.87 + 32.36 = 66.00°C$. To calculate the actual boiling point of the solution in each effect,

(1) $T_1 = T_{S1} - \Delta T'_1 = 121.1 - 16.77 = 104.33°C$, $T_{S1} = 121.1°C$

(2) $T_2 = T_1 - BPR_1 - \Delta T'_2 = 104.33 - 0.35 - 16.87 = 87.11°C$

$T_{S2} = T_1 - BPR_1 = 104.33 - 0.35 = 103.98°C$

(3) $T_3 = T_2 - BPR_2 - \Delta T'_3 = 87.11 - 0.63 - 32.36 = 54.12°C$

$T_{S3} = T_2 - BPR_2 = 87.11 - 0.63 = 86.48°C$

Step 8. Following step 4, the heat capacity of the liquid is $c_p = 4.19 - 2.35x$.

$$F: \quad c_p = 3.955 \text{ kJ/kg} \cdot \text{K}$$
$$L_1: \quad c_p = 4.19 - 2.35(0.133) = 3.877$$
$$L_2: \quad c_p = 4.19 - 2.35(0.205) = 3.708$$
$$L_3: \quad c_p = 3.015$$

The new values of the enthalpy H are as follows in each effect.

(1) $H_1 = H_{S2} + 1.884(°C \text{ superheat}) = 2682 + 1.884(0.35) = 2683 \text{ kJ/kg}$

$\lambda_{S1} = H_{S1} - h_{S1} = 2708 - 508 = 2200 \text{ kJ/kg}$

(2) $H_2 = H_{S3} + 1.884(0.63) = 2654 + 1.884(0.63) = 2655 \text{ kJ/kg}$

$\lambda_{S2} = H_1 - h_{S2} = 2683 - 440 = 2243 \text{ kJ/kg}$

(3) $H_3 = H_{S4} + 1.884(2.45) = 2595 + 1.884(2.45) = 2600 \text{ kJ/kg}$

$\lambda_{S3} = H_2 - h_{S3} = 2655 - 362 = 2293 \text{ kJ/kg}$

Writing a heat balance on each effect,

(1) $22\,680(3.955)(26.7 - 0) + S(2200) = L_1(3.877)(104.33 - 0)$
$$+ (22\,680 - L_1)(2683)$$

(2) $L_1(3.877)(104.33 - 0) + (22\,680 - L_1)(2243) = L_2(3.708)(87.11 - 0)$
$$+ (L_1 - L_2)(2655)$$

(3) $L_2(3.708)(87.11 - 0) + (L_1 - L_2)(2293) = 4536(3.015)(54.12 - 0)$
$$+ (L_2 - 4536)(2600)$$

Solving,

$$L_1 = 17\,005 \text{ kg/h} \quad L_2 = 10\,952 \quad L_3 = 4536 \quad S = 8960 \text{ (steam used)}$$
$$V_1 = 5675 \qquad V_2 = 6053 \qquad V_3 = 6416$$

Note that these values from trial 2 differ very little from the trial 1 results. Following step 5, and solving for q in each effect and A,

$$q_1 = S\lambda_{S1} = \frac{8960}{3600}(2200 \times 1000) = 5.476 \times 10^6 \text{ W}$$

$$q_2 = V_1\lambda_{S2} = \frac{5675}{3600}(2243 \times 1000) = 3.539 \times 10^6 \text{ W}$$

$$q_3 = V_2 \lambda_{S3} = \frac{6053}{3600}(2293 \times 1000) = 3.855 \times 10^6 \text{ W}$$

$$A_1 = \frac{q_1}{U_1 \, \Delta T'_1} = \frac{5.476 \times 10^6}{3123(16.77)} = 104.6 \text{ m}^2$$

$$A_2 = \frac{q_2}{U_2 \, \Delta T'_2} = \frac{3.539 \times 10^6}{1987(16.87)} = 105.6 \text{ m}^2$$

$$A_3 = \frac{q_3}{U_3 \, \Delta T'_3} = \frac{3.855 \times 10^6}{1136(32.36)} = 104.9 \text{ m}^2$$

The average area $A_m = 105.0 \text{ m}^2$ to use in each effect. Note that this value of 105.0 m^2 is quite close to the average value of 104.4 m^2 from the first trial.

$$\text{steam economy} = \frac{V_1 + V_2 + V_3}{S} = \frac{5675 + 6053 + 6416}{8960} = 2.025$$

8.6 CONDENSERS FOR EVAPORATORS

8.6A Introduction

In multiple-effect evaporators the vapors from the last effect are usually leaving under vacuum, i.e., at less than atmospheric pressure. These vapors must be condensed and discharged as a liquid at atmospheric pressure. This is done by condensing the vapors using cooling water. The condenser can be a surface condenser, where the vapor to be condensed and the cooling liquid are separated by a metal wall, or a direct contact condenser, where the vapor and cooling liquid are mixed directly.

8.6B Surface Condensers

Surface condensers are employed where actual mixing of the condensate with condenser cooling water is not desired. In general, they are shell and tube condensers with the vapor on the shell side and cooling water in multipass flow on the tube side. Noncondensable gases are usually present in the vapor stream. These can be air, CO_2, N_2, or another gas which may have entered as dissolved gases in the liquid feed or occur because of decomposition in the solutions. These noncondensable gases may be vented from any well-cooled point in the condenser. If the vapor being condensed is below atmospheric pressure, the condensed liquid leaving the surface condenser can be removed by pumping and the noncondensable gases by a vacuum pump. Surface condensers are much more expensive and use more cooling water, so they are usually not used in cases where a direct-contact condenser is suitable.

8.6C Direct-Contact Condensers

In *direct-contact condensers* cooling water directly contacts the vapors and condenses the vapors. One of the most common types of direct-contact condensers is the counter-current barometric condenser shown in Fig. 8.6-1. The vapor enters the condenser and is condensed by rising upward against a shower of cooling water droplets. The condenser is located on top of a long discharge tail pipe. The condenser is high enough above the discharge point in the tail pipe so that the water column established in the pipe more than compensates for the difference in pressure between the low absolute pressure in the