APPENDIX C

A Calculation Example of The Mathematical Model

An example of the calculation of the proposed mathematical model is shown with selected operating conditions. Its operating conditions are shown in table C.1. The calculated properties were based on locations specified in figure 5.1.

Table C.1 Operating condition of the calculation example.

Helium charge pressure	6.1bar
Operating pressure	13.2bar
Solution concentration	0.23
Heat input	1.3kW
Rectification temperature	73.3°C
Cooling water temperature	31.8°C
Generator temperature	137.4°C
Solution temperature at generator inlet	109.2°C

At the operating pressure of 13.2bar and solution temperature in the generator of 137.4°C, which was considered as saturated state, its vapor concentration could be calculated as [Patek and Klomfar, 1995], x_4 = 0.762 and the concentration of liquid phase was, x_3 = 0.198. Thus, the calculated enthalpy of both vapor and liquid phase were as follows,

$h_4 = 1{,}819.2\ \mathrm{kJ{\cdot}kg^{-1}}$

$h_3 = 453.5\ \mathrm{kJ{\cdot}kg^{-1}}$

The specific volume of the liquid as well as vapor solution could be calculated by equation (5.6) and (5.7) respectively,

$$\upsilon_3 = (1 - X_3)\ \upsilon_{water-liq} + 0.85\ X_3\ \upsilon_{amm-liq},$$

properties in this equation were based on the operating temperature of the generator (saturated at temperature).

$$\upsilon_4 = (1 - X_4)\ \upsilon_{water-vap} + X_4\ \upsilon_{amm-vap},$$

properties in the prior equation were based on the operating pressure (saturated at pressure). The calculated $\upsilon_3 = 0.00158\ m^3 \cdot kg^{-1}$ and $\upsilon_4 = 0.00158\ m^3 \cdot kg^{-1}$.

Enthalpy of the liquid solution at the generator inlet, with x = 0.23, was calculated as, $h_1 = 308.2\ kJ \cdot kg^{-1}$. These values were substituted into equation (5.1) with $\dot{Q}_{in} = 1.3kW$. It was solved and the obtained volume flow rate of the vaporized solution was obtained as,

$$\dot{V}_4 = 2.184\ l\ min^{-1}.$$

It could be converted into mass flow rate by using specific volume υ_4 as,

$$\dot{m}_4 = 0.3303\ g \cdot s^{-1}$$

Mass flow rate of the pumped liquid could be obtained as,

$$\dot{m}_3 = 5.5118\ g \cdot s^{-1}$$

At this stage, the concentration was balanced by equation (5.8),

$$\dot{m}_1 x_1 = \dot{m}_3 x_3 + \dot{m}_4 x_4$$

If the value of x_1 was not valid, $x_1 \neq 0.23$, the calculation steps must be repeated with corrected x_1. However, in this calculation, the obtained balance was valid. Then, all obtained figures could be used for further calculations.

At the rectifier, the operating temperature was 73.3°C which could partially condense water vapor from the vaporized solution. The rectified vapor left the rectifier with concentration of, $x_7 = 0.984$. While the condensate that was partially condensed having concentration of, $x_5 = 0.505$. Enthalpies of both streams were calculated as,

$$h_7 = 1{,}421.6\ kJ \cdot kg^{-1}$$

$$h_5 = 83.2\ kJ \cdot kg^{-1}$$

Mass flow rate of the rectified vapor (7) could be calculated from equation (5.9),

$$\dot{m}_7 = \frac{(x_6 - x_5)}{(x_7 - x_5)} \dot{m}_4 = 0.1771\ g \cdot s^{-1}$$

and the condensate that was partially condensed was calculated as,

$\dot{m}_5 = 0.1532\ g{\cdot}s^{-1}$.

The pumped liquid (3) and condensate (5) were mixed as the strong solution (9). The concentration of the strong solution, x_9, could be calculated from equation (5.12),

$$x_9 = \frac{\dot{m}_3 x_3 + \dot{m}_5 x_5}{\dot{m}_3 + \dot{m}_5} = 0.206.$$

The rectified refrigerant vapor (7) was liquefied as liquid refrigerant (8) with mass flow rate, $\dot{m}_8 = \dot{m}_7$, and concentration, $x_8 = x_7$. Ammonia in the liquid solution was absorbed causing refrigerating effect in the evaporator. It was assumed that all of the obtained ammonia in the liquid refrigerant could be evaporated. Then its cooling capacity could be calculated from equation (5.14)

$$\dot{Q}_{evap} = \dot{m}_8 x_8 (h_{12-vap} - h_8)$$

Enthalpy of the evaporated ammonia in the evaporator could be calculated as,

$h_{12\text{-}vap} = 1264.9\ kJ{\cdot}kg^{-1}$

and the liquid refrigerant (8) enthalpy was calculated as $h_8 = 134.2\ kJ{\cdot}kg^{-1}$. Then the obtained cooling effect was calculated as,

$\dot{Q}_{evap} = 196.7\ W$.

When the absorption capability dropped, the combined evaporator-absorber effectiveness, ε, was included into consideration. It was defined as equation 5.18 as,

$$\varepsilon = \frac{\dot{m}_{11} x_{11} - \dot{m}_{10} x_{10}}{\dot{m}_8 x_8}$$

The effectiveness was varied from 1 down to 0.5 with a step of 0.1. In this example, it was assumed to be 0.7. With less absorption capability, the cooling effect was decreased as a result of less evaporated ammonia. Then the obtained cooling capacity could be estimated as,

$\dot{Q}_{evap} = 154.3\ W$.

Concentration of liquid refrigerant that was left in the evaporator could be calculated as,

$x_{12''} = 0.949$

With mass flow rate of,

$\dot{m}_{12'} = 0.0551\ g{\cdot}s^{-1}$

The concentration of the weak solution after absorption process (13) should be checked to verify the obtained results. Then, it was calculated by equation (5.23) as,

$x_{13} = 0.2299 \cong 0.23$

The calculated results are listed in table C2.

Table C2 Calculated results

$\varepsilon = 1.0$

location	T (°C)	X	h (kJ·kg⁻¹)	m (g·s⁻¹)	phase
1	109.7	0.229	308.2	5.842	liquid
2	137.4	0.229	530.7	5.842	mixture
3	137.4	0.198	453.5	5.512	sat liquid
4	137.4	0.762	1819.2	0.330	sat vapor
5	73.3	0.505	83.2	0.153	sat liquid
6	73.3	0.762	800.9	0.330	mixture
7	73.3	0.984	1421.6	0.177	sat vapor
8	31.8	0.984	134.2	0.177	liquid
9	136.0	0.206	443.5	5.665	liquid
10	68.5	0.206	138	5.665	liquid
11	43.0	0.229	11.8	5.839	liquid
12 liq	0.0	0.000	-0.04	0.003	liquid
12 vap	0.0	1.000	1264.9	0.174	vapor
13	43.0	0.229	11.8	5.842	liquid
$\varepsilon = 0.7$					
11	43.0	0.223	11.8	5.787	liquid
12 liq	0.0	0.949	-0.04	0.055	liquid
12 vap	0.0	1.000	1264.9	0.122	vapor
13	43.0	0.229	11.8	5.842	liquid