# 4 Multiple-effect evaporation

Evaporation and vaporization are two separation processes carried out using the same procedure but to achieve different goals. They're both performed by the equipment called "evaporator" where a liquid solution is fed. Vaporization has the purpose of recovering the vapor phase, i.e. the solvent (usually water), while evaporation is aimed at separating the solid phase or concentrating emulsions and suspensions.

Every single effect requires an external heat duty to vaporize part of the solvent that exits from the top of the evaporator; therefore the higher the solvent flowrate to be vaporized is, the higher the heat duty consumption is.

However, the solvent should be recovered in liquid phase, i.e. it needs to be condensated downstream the evaporator, wasting this way its latent heat and paying for an additional cooling duty.

The multiple-effect evaporator principle is based on splitting the solvent vaporization in several steps, recovering this way the otherwise wasted enthalpy of the vapor phase leaving each step to provide the heat duty required by the next one, considerably reducing the system energy consumption.

Thus, by adding more effects, a higher COP and a decrease of the operating costs can be achieved at the expenses of the investment costs.

Therefore if the desired product is the concentrated solution, whose revenue doesn't depend on N (number of effects), the net income shows a maximum, i.e. there exists an optimal N value that is usually about 2-3.

On the other hand if the desired product is the vaporized solvent the optimal number of effects is the highest possible, where the "possibility" constraint is given by the feasibility of the heat exchange between vapor and liquid phases in each unit and by the viscosity increase of the liquid solution due both to concentration increase and to temperature decrease.

## 4.1 Multiple-effect evaporator design

A 15000 kg/h stream of seawater with a dissolved solid concentration of 3.6 % w/w has to be desalinated in a simple cocurrent three effects evaporator. The solution inlet temperature is 60.0 °C and the LP steam temperature in the first effect is 120.0 °C.

Evaluate flowrates, temperatures and concentrations of the system for 12000 kg/h solvent recovery.

The physical properties and design data are reported in Table 4.1, the solution specific heat is supposed to be constant despite the concentration increase.

The boiling-point elevation follows the correlation here below:

| | **Property** | **Value** | **Unit** |
|---|---|---|---|
| | $c_P^{solution}$ | 1 | $kcal/(kg \cdot \mathrm{K})$ |
| | $\Delta H_{ev}^{steam}$ | 526 | $kcal/kg$ |
| $1^{st}\, effect$ | | | |
| | $A_1$ | 200 | $m^2$ |
| | $\Delta H_{ev,1}^{vap}$ | 537.3 | $kcal/kg$ |
| | $U_1$ | 750 | $kcal/(m^2 \cdot h \cdot \mathrm{K})$ |
| $2^{nd}\, effect$ | | | |
| | $A_2$ | 200 | $m^2$ |
| | $\Delta H_{ev,2}^{vap}$ | 549 | $kcal/kg$ |
| | $U_2$ | 550 | $kcal/(m^2 \cdot h \cdot \mathrm{K})$ |
| $3^{rd}\, effect$ | | | |
| | $A_3$ | 200 | $m^2$ |
| | $\Delta H_{ev,3}^{vap}$ | 571.3 | $kcal/kg$ |
| | $U_3$ | 300 | $kcal/(m^2 \cdot h \cdot \mathrm{K})$ |

Table 4.1: Physical properties and design data

$$\Delta T_{eb}(^{\circ}\mathrm{C}) = 17.8 \cdot x(w/w) \tag{4.1.1}$$