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Simulation of heat and mass transfer in a multi-effect distillation plant for seawater desalination

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Abstract

In the European project EasyMED an innovative, multi-effect distillation plant for seawater desalination has been developed. The basic elements of each effect are vertical plates. On one side of a plate, seawater is distributed as a falling film, whereas on the other side, the plate is heated by condensing vapour generated in the previous effect. Our Institute is concerned with the heat and mass transfer in a system based on numerical experiments. Good agreement was achieved between a one-dimensional (1D) and a two-dimensional (2D) model capturing the evaporating falling film. Being less computationally expensive and sufficient for practical requirements, a 1D model was adopted for conjugate heat transfer between condensing and evaporating cells.

Keywords: Falling seawater film; Condensation; Evaporation; Conjugate heat transfer; Mass transfer; Nusselt

1. Introduction

In the European project EasyMED [1], an innovative, multi-effect distillation plant for seawater desalination has been developed. Involved are partners from France, Italy, and Germany. The objective was to develop a prototype plant which is easy to operate and which makes efficient use of energy.

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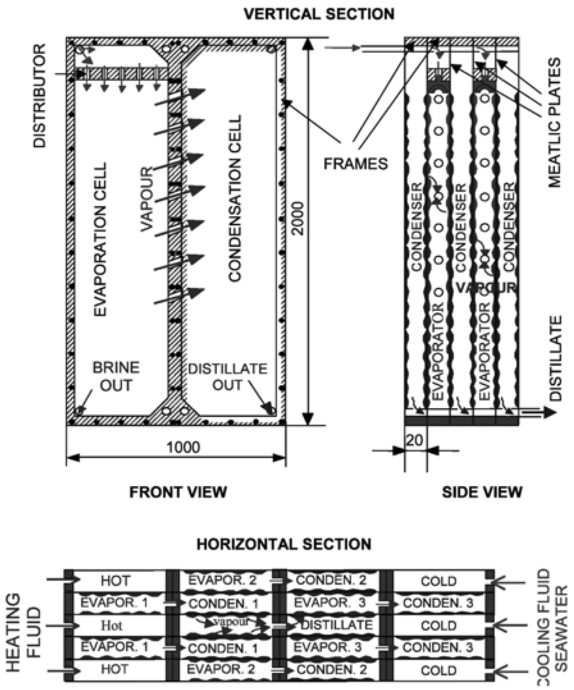

Fig. 1. Cross-sectional views of the EasyMED desalination unit as provided by our French partner from Nancy.

the plate is heated by condensing vapour generated in the previous effect (Fig. 1). In the evaporating cell, the seawater film immerses horizontal wires. On the one hand, these wires homogenise the film, preventing it from breaking up and leaving dry patches on the heating plate. On the other hand, they promote turbulence also at lower Reynolds numbers, thus augmenting the heat transfer across the falling film. This is the reason why they are called turbulence wires.

Our Institute is concerned with the heat and mass transfer in the system based on numerical experiments. In a previous publication [2], much of our results obtained in the project were summarised. This publication deals mainly with the improvement of the heat transfer by means of the turbulence wires. A 1D model was formulated that ignores the wires but captures the heat and mass transfer of the entire film. In the present work, the 1D model is further developed and compared to a 2D model. As will be shown, the 1D description of the system is sufficient for practical needs. Therefore, a 1D program has been written that treats simultaneously vapour condensation and falling film evaporation, mass transport inside the saltwater film, and conjugate heat transfer through the conducting metallic plate.

2. Nusselt's water–skin theory

For thin liquid films, evaporating as well as condensing, there is already a theory [3], which shall be briefly outlined here. Further improvements that are possible with the aid of computers are pointed out below.

For an evaporating film, Nusselt's theory gives a parabolic velocity profile

$$v = \frac{g \cdot \delta^2}{\nu}\left[\frac{x}{\delta} - \frac{1}{2}\left(\frac{x}{\delta}\right)^2\right] \tag{1}$$

and a linear temperature distribution

$$T = T_W - \left(T_W - T_I\right)\frac{x}{\delta} \tag{2}$$

where x denotes the distance from the heating plate; T_W is the wall temperature; and T_I the saturation temperature of the vapour, which is assumed to be equal to the temperature of the liquid–gas interface (Fig. 2). Then the film thickness δ at distance y from the inlet is given by

$$\delta(y) = \left[\delta_{IN}^4 - 4\frac{\lambda\nu\left(T_W - T_I\right)}{\rho \cdot g \cdot \Delta h}\right]^{1/4} \tag{3}$$

where δ_{IN} denotes the initial (inlet) film thickness, Δh the evaporation enthalpy, λ the thermal conductivity, and ρ the density of the liquid phase.

For a condensing film, the velocity profile obeys Eq. (1). The temperature distribution