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ScienceDirect
Desalination 201 (2006) 185–197
DESALINATION
www.elsevier.com/locate/desal

Numerical simulation of the behaviour of a distillation cell with influence of the characteristics of the heating wall

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Received 19 April 2004; accepted 11 February 2006

Abstract

In this paper, a numerical analysis of the coupled heat and mass transfer is proposed for a rectangular cell of form factor equal to 10. In particular, the heat and mass transfer are considered in the solid medium of the heated wall, in the liquid medium of the falling film and in the gaseous medium inside the cell. The solution of the transfer equations together with the appropriate boundary conditions allowed us to study in detail the evaporation and condensation mechanisms inside the cell. The study of the influence of the heated wall conductivity and of the heat distribution on the transfer phenomena allowed us to propose recommendations in order to improve the production of the cell.

Keywords: Desalination, evaporation, water film, natural convection.

1. Introduction

97.5% of the world water resources have a high salinity which renders them unavailable for human consumption. Furthermore, this situation is worsened by the pollution of several resources and by a continuous increase of consumption. This fact, accompanied by the constant increase of the energetic expenses, has pushed several researchers to propose desalting processes using renewable energies or industrial thermal discharge (cogeneration).

Presently, the processes of desalination by way of distillation seem to be the most appropriate to be coupled with the abundant solar energy in the arid regions or with the industrial thermal discharge. They consist in evaporating a liquid film of salted water and in condensing the vapor into pure water.

In order to remedy the drawbacks due to the low yield of the solar distillers of greenhouse type, Le Goff [1] proposed a multiple effects solar

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doi:10.1016/j.desal.2006.02.013

distiller with capillary film. The proposed configuration consists in evaporating a water film falling on a heated wall while reusing the condensation latent heat for the evaporation of another film in the adjacent cell. This author proposed global equations to describe the transfer phenomena inside the different cells, but these equations do not detail the transfer phenomena in the liquid film. This type of distiller has been studied by several researchers [2–5] concerned by applications related to the solar energy. These studies confirmed a neat increase of the production compared to a classical distiller of greenhouse type, but improvements are still necessary to make this system competitive.

To improve such processes, we need a better understanding of the transfer inside the cell which are mainly the thermosolutal convection in a cavity and the evaporation of a falling liquid film. Both phenomena have been studied independently in several research works.

Studies related to thermosolutal convection are abundant in literature. Trevisan and Bejan [6] proposed analytical and numerical solutions for coupled heat and mass transfer equations inside a vertical cavity. Beghein [7] proposed correlations between heat and mass transfer rates and their nondimensional numbers in case of a cavity submitted to horizontal temperature and concentration gradients.

In other applications, the evaporation of falling films on a heated wall was studied by many researchers because of the large interest in the industrial field. Indeed, several authors have studied the evaporation of falling films by adopting the approximation of a wetted plate for the thin films. Ben Nasrallah [8] and Vachon [9] published studies treating evaporation on a porous saturated plate to determine Nusselt and Sherwood numbers.

Other studies considered the transfer phenomena through the falling film. Tsay [10] and Yan [11] studied the evaporation of a liquid film falling on a vertical heated wall. They showed that when the film is very thin, a model that neglects the dynamic effects can be applied in a satisfactory way. Furthermore, they showed that the heat transfer between the liquid film and the surrounding medium is dominated by the evaporation latent heat and that it is very much influenced by the inlet temperature of the film.

In studies concerning the chemical industry, Agunaoun [12] and Cherif [13] treated the problem of a binary liquid film falling on a plate and mainly showed that the different transport phenomena are related to the composition of the binary mixture.

Ben Jabrallah et al [14] studied the distillation cells, in particular the evaporation of a thin film falling on the heated wall of a vertical cavity having a high form factor. A simulation model taking into account the change in film thickness and the operating parameters of the cell was proposed.

Most works on the falling and the evaporation of thin films assume that the effect of the plate on which the film falls is negligible. Indeed, it is widely admitted to suppose that the heat flux is directly applied to the liquid film. Moreover, most studies concerning the evaporation of the liquid films were performed by assuming that the thermal heat flux is uniformly distributed on the heated wall.

In this work, in order to be able to improve the yield of the distillers and to better understand their transfer mechanisms, we propose a study which takes into account the heat and mass transfer phenomena in the three different media that constitute a distiller under the form of a vertical rectangular cell: the solid medium of the heated plate, the liquid falling film and the gaseous medium represented by the air-vapor mixture that fills the cell. The influence of the conductivity of the heated plate and of a non homogeneous distribution of the heat flux on the production of the cell is also studied.

1. Description of the distillation cell

The distillation or desalting cell which is the object of this study is a vertical parallelepiped

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