International Journal of Thermal Sciences 50 (2011) 1996–2005

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Numerical study of evaporation in a vertical annulus heated at the inner wall

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ARTICLE INFO

Article history:
Received 13 December 2010
Accepted 4 March 2011
Available online 11 April 2011

Keywords:
Evaporation
Liquid film
Mixed convection
Annulus

ABSTRACT

Mixed convection during evaporation of a water falling film in a vertical concentric annulus was studied numerically. The water thin film falls on the inner tube and is subjected to a constant heat flux density, whereas the outer cylinder is assumed to be insulated and dry. An imposed air flow circulates within the gap between the two concentric tubes. The objective of this work is to understand the evaporation phenomenon in order to improve the average evaporated mass flux density and heat and mass transfer. Conservative equations governing the gas phase are solved numerically using the finite volume method. In the liquid phase, a method based on local heat and mass balances on each level is used. Thus, the following liquid film parameters, feed water mass flow, feed temperature and heat flux density, are taken into account. The obtained results are analyzed to emphasize and evaluate the influence of the previous operating parameters and the annulus curvature on the effective evaporation surface and on the mass flux density of evaporated water.

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1. Introduction

Evaporation in confined space occurs in many technological applications such as nuclear reactors, solar collectors, heat exchangers and distillation systems. Some systems used for desalination are based on evaporation and condensation phenomena. The limited yield of such processes incites the authors to investigate each basic phenomenon separately. The evaporation of falling liquid films on the wall has attracted the interest of several researchers. Despite great achievements in this field, due to the complexity of heat and mass transfer coupling at the liquid–gas interface, there remain shortcomings. The study of liquid film evaporation requires the solution of the transfer equations in two media, i.e. liquid film and ambient air in contact with film. The solution in the gas phase is almost controlled, but various works in this field differ by the manner of taking into account heat and mass transfer in the liquid film and its interactions with the neighboring gas. The studies can be classified in two groups:

- works which neglect the film thickness. The film is described by conditions of temperature and concentration on the wall. This is the method of the wet wall.
- works which proceed to the solution of the dynamic and thermal equations in film. The film is considered to possess a constant or variable thickness.

Works neglecting the film thickness are frequent where the mechanisms of flow and transfer in the liquid phase are neglected [1,2]. To simplify the problem, the liquid film on the wetted wall is considered to be extremely thin and at rest. Thus, the emphasis is mainly focused on gas flow and liquid film which is treated as boundary conditions to solve the gas phase equations. The case of vertical channels was widely studied [3–5]. The numerical study of film evaporation under laminar mixed convection in a vertical channel was conducted by Laaroussi et al. [6] who compared the approach of variable density and Boussinesq approximation for two binary mixtures air–water vapor and air–hexane. Salah El-Din [7] investigated the effect of different parameters on heat and mass transfer for many values of the buoyancy ratio. He demonstrated that the decrease of the heat flux ratio and the mass flux ratio increase heat and mass transfer between vertical parallel plates. Yan et al. [8] studied laminar mixed convection flows between vertical parallel plates with asymmetric heating. The effects of wetted wall temperatures and Reynolds number were investigated. It was shown that latent heat transfer is the dominant mode along the wetted walls. The cylindrical case was also treated numerically by Chang et al. [9]. Evaporation and condensation by natural convection in vertical annuli are analyzed [10,11].

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doi:10.1016/j.ijthermalsci.2011.03.007