Chapter 9

Heat and Mass Transfer Characteristics of Evaporating Falling Films: Application to Thermal Protection and Desalination

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ABSTRACT

This chapter presents a numerical investigation of heat and mass transfer characteristics during the evaporation of liquid films in vertical geometries. A two-phase model is developed to simulate laminar film evaporation into laminar gas flow. The liquid film evaporation is evaluated under adiabatic and heated wall conditions for both pure and binary liquid film. The model is based on a finite difference method to solve the governing equations of the two phases. The obtained results concerns two industrial processes. The first part of the chapter is devoted to the analysis of the thermal protection of vertical channel wall, while the second part is devoted to the desalination process by falling liquid film. The simulations results allowed the determination of the optimal operating conditions for both processes.

DOI: 10.4018/978-1-5225-7138-4.ch009
INTRODUCTION

A liquid film is a thin layer of a liquid flowing on a wall. The mechanisms for forming liquid films are diverse. In fact, they can simply appear under the effect of gravity, for example, falling films can be observed during a rainfall day on cars windows. Most of industrial processes today include the phenomenon of evaporation that generally occurs from falling liquid films. In particular, falling liquid film evaporation process is for cooling and desalination purposes.

For cooling purposes, the most common applications are the evaporative cooling, wall thermal protection and electronic devices cooling. To evaporate a liquid film, it is primordial to provide an equivalent energy to the latent heat of vaporization. Thus, this energy may be provided by two modes: direct contact evaporation or heterogeneous evaporation. For heated surfaces (microchips), the heat flux is firstly exchanged by conduction then by convection through the flowing liquid film. When the liquid film interface reaches the saturation conditions, evaporation begins, which consists on the heterogeneous evaporation process. In contrast, when the liquid film flows over an adiabatic wall (cooling tower for example), the hot gas flow exchanges thermal heat flux with the flowing liquid film directly throughout the interface. However, the heat flux absorbed from the hot gas is not sufficient to ensure the liquid film evaporation. Consequently, the liquid film contributes to the evaporation process by its own internal energy. The liquid film experiences a temperature drop. The previous phenomenon are largely highlighted and investigated in the literature. Early, Yan et al. (Yan, Lin, & Tsay, 1991) conducted an experimental study to examine the heat and mass transfer of the evaporative cooling of a falling liquid film. Water and ethanol liquid film were investigated in the study. The results showed an important drop of the wall and interface temperature for both liquids. The highest temperature reduction was observed with high inlet temperature and low inlet mass flow rate of the liquid films. Yan et Lin (Yan & Lin, 1991) have numerically reproduced the previous experimental study. The authors took advantage of the numerical simulation to deeply investigate the heat and mass exchange and provided the interfacial latent and sensible heat flux along with the evaporation rate. He et al. (He, An, Li, & Jackson, 1998) investigated experimentally and numerically the liquid film evaporation inside a vertical tube considering counter current flows. The authors identified two cooling modes of evaporation: namely evaporation and direct film cooling. It is shown that when the cooling liquid film temperature is relatively high the system operates at evaporation mode, while for low temperatures of the system operates at the direct film-cooling mode. Feddaoui et al. (Feddaoui, Belahmidi, Mir, & Bendou, 2001; Feddaoui, Meftah, & Mir, 2006) investigated numerically the evaporative cooling of falling liquid film in laminar and turbulent mixed convection inside a vertical tube. A significant liquid film cooling is reported
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