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Experimental investigation on the evaporation of a wet porous layer inside a vertical channel with resolution of the heat equation by inverse method

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ABSTRACT

In this paper, we realize an Experimental study of the evaporation of a wet porous layer inside a vertical channel. To develop this study, an experimental dispositive was realised. We measure the temperature along the plate and the evaporated flow rate using the test bed. From these measurements we note that the profiles of the temperature are divided into two areas: the heating and the evaporation zone. We also note that the use of the porous layer is more efficient for high heating flux and low liquid inlet flow. In addition, we studied different dimensionless numbers by solving the energy equation by inverse method. We note that the latent Nusselt number is more important than the sensible Nusselt Number, which proves that the flow dissipated by evaporation is greater than the one used by the film to increase its temperature.

1. Introduction

The phenomena of heat and mass transfer during the flow of a liquid film on a heated wall has a considerable interest in the engineering field, which was translated into many applications, such as the refrigeration [1], air conditioning [2], photovoltaic [3], energy-saving [4] and the cooling of electronic components. In order to understand the heat and mass transfer, different geometries were studied. Firstly, the flow of a liquid was examined on a horizontal flat plate [5]. We cite Siow et al. [6], who studied the evaporation of a laminar model within a horizontal channel. Yuan et al. [7] conducted a study on the coupled heat and mass transfer from a thin film of water subjected to a flow of moist air.

Thereafter, several studies addressed the case of a vertical plate in order to improve the flow of the liquid. Ben Jabrallah et al. [8] studied the coupled heat and mass transfer in a rectangular cavity that acts as a distillation cell. Cherif et al. [9] realised an experimental study on the natural and forced convection evaporation of a thin liquid film that flows on the inner faces of the plates of a vertical channel. Fahem et al. [10] conducted a numerical analysis on the heat and mass transfer within a distillation cell. Debbissi et al. [11] studied the evaporation of water by free and mixed convection into humid air and superheated steam. Min and Tang [12] conducted a theoretical study to analyze the characteristics of transient evaporation of a water film attached to an adiabatic solid wall.

Later on, other researchers have studied evaporation on an inclined plane [14–16,13], which affects gravitational forces and decreases the rate of fluid flow. We cite Zeghmati and Daguenet [17] who realised a study of transient laminar free convection over an inclined wet flat plate. Agunaoun and Daif [18] studied the evaporation of a thin film of water flowing on an inclined plate surface at a constant temperature that is higher than the air temperature.

From what was stated above, it is clear that researchers have studied different geometries and conducted parametric studies at almost all input parameters that may influence the heat and mass transfers.

On the other hand, alternative solutions, such as the use of binary fluids, have also been proposed to improve transfer. Cherif and Daif [19] conducted a numerical study on the heat and mass transfer between two vertical flat plates in the presence of a binary liquid film that flows on one heated plate. Debbissi et al. [20] studied the evaporation of a binary liquid film in a vertical channel.

However, obtaining a homogenous liquid film over the entire plate constitutes a major discrepancy between the theoretical and experimental studies. Despite efforts made in the field of modeling and numerical simulation, we still see a difference between calcu-

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Nomenclature

C_p	heat capacity at constant pressure [J kg^{-1} K^{-1}]
e	thickness of porous layer [m]
g	gravity acceleration [m s^{-2}]
h	heat transfer coefficient [W m^{-2} K^{-1}]
K	permeability [m^2]
L	length of the plate [m]
L_v	latent heat of water [J kg^{-1}]
m_{eV}	evaporating mass flow [kg s^{-1} m^{-2}]
Nu_L	latent Nusselt number [–]
Nu_s	sensible Nusselt number [–]
p	interne production [W m^{-3}]
q	heat flow [W m^{-2}]
T	temperature [K]
(x, y)	Cartesian coordinates [m]

Greek symbols

ρ	density [kg m^{-3}]
λ	thermal conductivity [W m^{-1} K^{-1}]
φ	heat flux density [W m^{-2}]

Subscripts

av	front
ar	back
eV	evaporated
in	entrance
T	total
L	latent
s	sensible
cd	conduction
p	plate
mes	measured
cal	calculated

lations and experiments. In a previous work, Cherif et al. [21], have studied the two aspects of the evaporation of a liquid film: experimental and numerical. A difference was reported. They believe that this difference is caused by the difficulty of making a falling film on a vertical plate. In fact, the film could not be controlled if it was directly adhered to the plate. To analyze the effect of dry zones on the plate, Debbissi et al. [22] realised a numerical study of the evaporation along an inclined plate. This plate is composed of two wet zones separated by a dry zone. The results of this study showed that the length of the dry zone plays an important role.

More recent studies have explored various techniques to solve this problem. For example, several researchers used rough surfaces, or interposed obstacles [23]. For example, Zheng and Worek [24] realised numerical and experimental studies on the evaporation of a liquid film inside an inclined channel. They fixed glass rods on the plate to disrupt the flow of liquid, thus improving the heat and mass transfer.

We believe that the best way to achieve a falling film on a flat plate and control its characteristics is the application of a porous layer that plays the role of a support for the liquid film. Few studies have theoretically examined the effect of the presence of a porous medium during evaporation [25,26] and as far as we now here is not an experimental study that have examined the case of a liquid film evaporation along a vertical plate that is covered with a porous layer. As a result, this work focuses on the study of the evaporation of a wet porous layer inside a vertical channel. The main objective of this study is to evaluate the variation of the temperature and the evaporated flow rate as well as to determine the best operating conditions for a better performance of the system. We have also solved the heat equation by inverse method to determine the local variation of the evaporated flow rate and thereafter the local variation of the latent and sensible Nusselt numbers.

2. Experimental facility

2.1. Setup

To conduct the study we realised an experimental setup which we represent in Figs. 1 and 2. It is composed of:

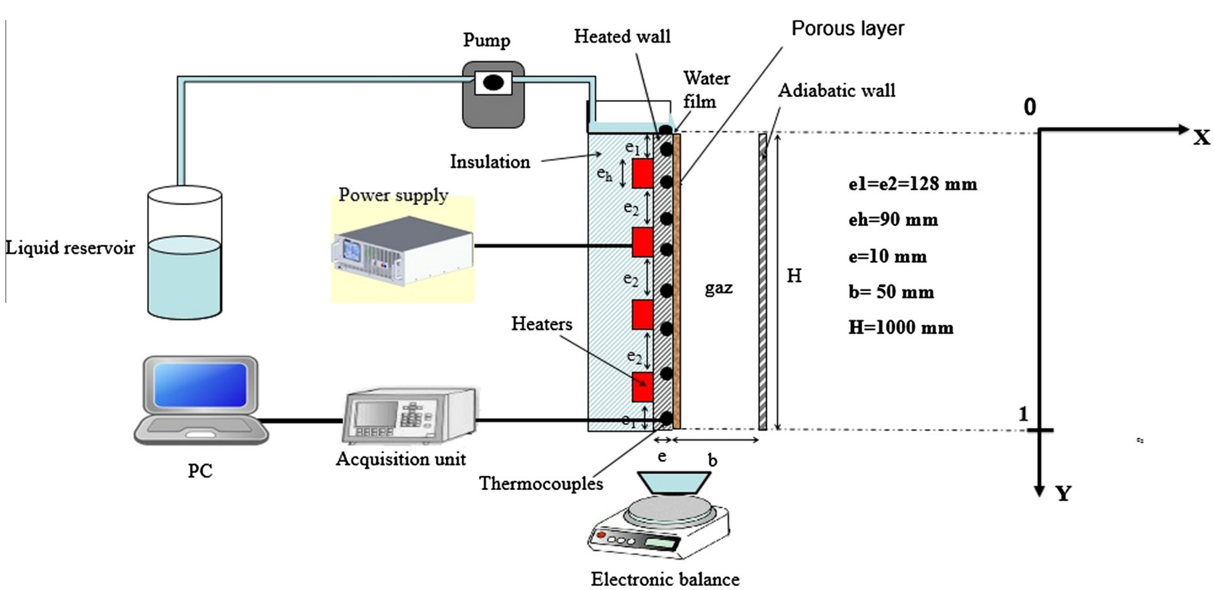

Fig. 1. Schematic presentation of the physical domain.