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International Communications in Heat and Mass Transfer 32 (2005) 685–694

International Communications in HEAT and MASS TRANSFER

www.elsevier.com/locate/ichmt

A study of the liquid evaporation with Darcian resistance effect on mixed convection in porous media ☆

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Available online 19 March 2005

Abstract

A problem of the evaporation of liquid with Darcian resistance effect on mixed convection flow over a vertical plate in an isotropic porous medium has been studied. Two flow models, aiding and opposing flows, are considered. The boundary layer equations are integrated numerically to obtain the non-similar solutions for the velocity, temperature and concentration distributions for several values of the Darcian resistance and buoyancy force parameters. The results show that the evaporation of liquid on the wall increases when the buoyancy force Ra_K/Pe_x is gradually increased and the overall heat transfer rate will be pronounced when the Darcian resistance ζ is very small.

Keywords: Mixed convection; Liquid evaporation; Porous media

1. Introduction

In recent years a great deal of research on the liquid evaporation onto a vertical plate in porous media has been studied due to the increasingly practical applications. Examples include electronic equipment cooling systems, geothermal operations, heat exchangers, chemical catalytic reactors, skin evaporation in biology and chemical vapor deposition (CVD), etc.

A number of researchers have focused on the porous media problem with mathematical assumptions based on Darcy law or non-Darcy law. Bejan and Poulikakos [1] used the similarity

☆ Communicated by J.P. Hartnett and W.J. Minkowycz.

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0735-1933/$ - see front matter
doi:10.1016/j.icheatmasstransfer.2004.10.020

technique to simplify the parameters to be a Darcy's flow index in natural convection. Ranganathan and Viskanta [2] neglected the variety of permeability, and found the velocity and temperature profiles have a large change when the wall boundary posses the suck or blowing flow in mixed convection. Hong et al. [3] and Chen and Ho [4] studied the high permeability in a natural convection over a vertical plate. The result showed that the boundary effect is prominent on the leading edge and the energy boundary layer of non-Darcy's law is less than that of Darcy's law. Lauriat and Prasad [5] analyzed an enclosed square in non-Darcy's flow, the heat transfer rate at the permeability and conductivity of porous media is more than that of the liquid. Takhar et al. [6], Lai [7], Shenoy [8], and Takhar and Beg [9] presented the comparison between the experiment data and numerical results and found them in a very good agreement. Chandrasekhara et al. [10] used a power series function to the wall temperature profile based on Forchheimer model [11]; the results were proposed that the heat transfer is increased, and the flow rate is decreased as the boundary effects are increased in a heated vertical plate. Rees and Pop [12] studied the vertical wave plate over the natural convection in a porous medium. Yih [13] presented the result of magnetohydrodynamic (MHD) in laminar mixed convection, and indicated the local Nusselt number becomes nearly constant when the permeability parameter is very small and large.

In the aspect of liquid evaporation, Schröppel and Thiele [14] presented a numerical method for the momentum, heat, and mass transfer of benzene in laminar and turbulent boundary layer along a vaporizing liquid film, and the results were found in a good agreement with the measurement in terms of flow profiles. Chow and Chung [15] studied the evaporation of water under a laminar stream of air and superheated steam, which showed that below the inversion temperature, liquid evaporation decreases as the humidity of air increases, and above the inversion temperature, liquid evaporation increases as the humidity of air increases. Yan and Lin [16] analyzed the film thickness could not be neglected in the performance of ethanol film evaporation when the liquid mass flow rate was large. Yan [17] pointed out that the magnitude of the evaporative latent heat flux might be five times greater than that of sensible heat flux and noted that the higher the inlet temperature, the lower the liquid flow rate or a higher gas flow Reynolds number is necessary in a better liquid cooling system.

Most of the analytical studies in porous media are based on the model of Darcy's law or only considered the momentum and energy equation. Therefore, the purpose of this study is to numerically present the mixed convection liquid evaporation in porous media with non-Darcy effects.

2. Analysis

Consider a steady, two-dimensional laminar mixed convection flow over an isothermal, vertical plate in a porous medium. The flow model and physical coordinate system is illustrated in Fig. 1 with the aiding and opposing flows. T_w, T_∞ and U_∞ are the wall temperature, free stream temperature and velocity, respectively. For facilitating the analysis, the following assumptions are made.

(1) Steam, air and mixed steam exhibit perfect gas law behavior.
(2) The liquid film is extremely thin and can be neglected.
(3) The velocity of air is static on the wall.