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Numerical study of humid air condensation in presence of non-condensable gas along an inclined channel

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Abstract

The purpose of this study is to analyse the combined heat and mass transfer of liquid film condensation from vapour-gas mixtures flowing downward along an inclined channel. Both the liquid and mixture regions are approached by two-coupled laminar boundary layer. The model uses an implicit finite difference method to solve the coupled governing equations for liquid film and gas flow together with the interfacial matching conditions. The effects of the inlet to the wall temperature difference, the inlet Reynolds number, the inlet relative humidity and the angle of declination on the condensation process are examined.

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Keywords: Condensation, Liquid film, inclined channel, non-condensable gas, humid air

1. Introduction

The Condensation occurs when vapour is cooled below its saturation temperature. This phenomenon occurs in numerous thermal engineering applications such as refrigeration engineering, heat exchangers, desalination etc. A vast amount of work related to liquid film condensation have been conducted by many authors. Siow et al. [1] studied numerically the condensation of steam-air mixtures inside horizontal channel. Oh et al. [2] studied experimentally liquid film condensation with non-condensable gas in a vertical tube. Siow et al. [3, 4] developed a model to study laminar film condensation from steam-air mixtures in vertical and declining parallel-plate channels. Other studies of liquid film condensation in different geometries are also available in literature [5- 8].

This paper presents the results from a complete two-phase model for laminar film condensation of water vapour-air mixtures in inclined channel.

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Nomenclature

D	Mass diffusivity, $m^2 s^{-1}$	Re	Reynolds number
j''_{vI}	Steam diffusive mass flux $kg.m^{-2}s^{-1}$	RH_0	inlet relative humidity, %
h_{fg}	Latent heat of vaporisation, J/kg	ΔT	Inlet-to-wall temperature difference, $(T_0 - T_w)$ °C
m_0	Inlet mass flow rate, $kgm^{-1}s^{-1}$	θ	Angle of declination, °

2. Analysis and modelling

The problem of condensation by mixed convection in inclined channel was numerically analysed for vapour-gas mixtures. The right plate of channel is adiabatic, while the other is assumed to be dry and isothermal. A humid air enters the channel with uniform velocity u_0, temperature T_0, relative humidity RH_0, and pressure p_0. The flow is considered to be laminar, incompressible and two-dimensional. The channel is declining at an angle θ from the horizontal and the gravitational acceleration acts vertically downward (Fig. 1).

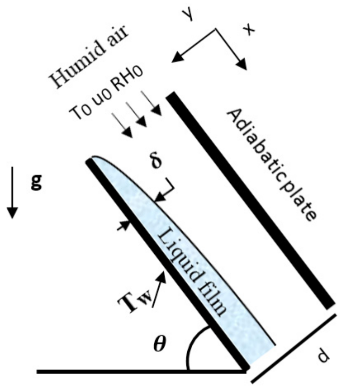

Fig. 1. Physical model.

2.1. Liquid phase equations

The governing equations for the conservation of mass, momentum and energy respectively in the liquid region are written as:

$$\frac{\partial}{\partial x}(\rho_L u_L)+\frac{\partial}{\partial y}(\rho_L v_L)=0 \tag{1}$$

$$\frac{\partial}{\partial x}(\rho_L u_L u_L)+\frac{\partial}{\partial y}(\rho_L v_L u_L)=-\frac{dp_d}{dx}+\frac{\partial}{\partial y}\left[\mu_L\frac{\partial u_L}{\partial y}\right]+(\rho_L-\rho_0)g\sin\theta \tag{2}$$

$$\frac{\partial}{\partial x}(\rho_L c_{PL} u_L T_L)+\frac{\partial}{\partial y}(\rho_L c_{PL} v_L T_L)=\frac{\partial}{\partial y}\left[\lambda_L\frac{\partial T_L}{\partial y}\right] \tag{3}$$

2.2. Gas phase equations

Similarly, the governing equations for gas flow region are: