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A correlation for mixed convection heat transfer from converging, parallel and diverging channels with uniform volumetric heat generating plates ☆

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Abstract

A numerical study of steady, laminar, mixed convection heat transfer from volumetrically heat generating converging, parallel and diverging channels is carried out. Air is considered as the working fluid. The maximum angle of deviation (ϕ) of the channel plates from the vertical position for the converging and diverging channels is 2° and −2°, respectively. A parametric study has been carried out for a wide range of Re_S, Gr_S^*, γ and ϕ to investigate their effect on the fluid flow and heat transfer characteristics. A universal correlation, to estimate the non-dimensional maximum temperature occurring in the converging, parallel or diverging channels is presented.

Keywords: Mixed convection; Heat generation; Inclined channels; Correlation; Maximum temperature

1. Introduction

Natural and mixed convection heat transfer from vertical channels with constant temperature or constant heat flux boundary conditions have been extensively studied to model heat transfer from electronic circuit boards, solar energy devices and nuclear applications. A detailed survey of literature on mixed convection in internal flows has been presented in Aung [1]. However, studies on natural and mixed convection from converging or diverging channels are limited. Sparrow et al. [2] presented the results of an experimental and numerical study on natural convection from isothermal converging channels. The maximum half angle of inclination of the plates considered for their study was 15°. Water was considered as the working fluid. Sparrow and Ruiz [3] carried out an experimental study of natural convection from a diverging channel and presented a universal correlation for converging, parallel and diverging channel, based on the maximum inter-wall spacing. Kaiser et al. [4] carried out a numerical study of natural convection from isothermal converging channels. The angles of inclination considered for the converging channel varied from 1° to 30°. Gau et al. [5] performed an experimental study of both buoyancy assisting and buoyancy opposing mixed convection heat transfer

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from a converging channel. In their study, one of the channel walls was placed vertically and was uniformly heated and the other wall was adiabatic, with an inclination of 3°.

From a review of literature, it is clear that comprehensive studies on conjugate mixed convection from converging and diverging channels with uniform volumetric heat generation are scarce. Hence, the above problem has been taken up for investigation, with a view to develop a correlation for the maximum temperature in the channel.

2. Mathematical formulation and solution procedure

2.1. Mathematical formulation

Fig. 1 a and b show the geometric configuration of the channel with symmetric and uniform heat generation along both the walls. The flow is assumed to be laminar, incompressible, hydrodynamically and thermally developing. The medium is assumed to have constant properties, outside of density, for which Boussinesq approximation is assumed to hold good. A psuedo-transient approach is used to obtain steady state solutions. In view of this, the governing equations in dimensionless form are

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \tag{1}$$

$$\frac{\partial U}{\partial \tau}+U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{1}{Re_S}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \tag{2}$$

$$\frac{\partial V}{\partial \tau}+U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{1}{Re_S}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+\frac{Gr_S^*}{Re_S^2}\theta \tag{3}$$

$$\frac{\partial \theta}{\partial \tau}+U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{1}{Re_S Pr}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right). \tag{4}$$

The non-dimensional parameters are defined as follows:

$$X=x/S, Y=y/S, U=u/V_\infty, V=v/V_\infty, \theta=(T-T_\infty)/\Delta T_{\mathrm{ref}}, P=p/(\rho V_\infty^2), \tau=V_\infty t'/S$$

where x, y and S denote the horizontal distance, vertical distance and spacing between the channel wall in meters at the entrance, respectively. u, v and V_∞ are the velocity components in the x, y directions and the entry velocity of the fluid in m/s, respectively. p and T are the dimensional pressure and temperature inside the computational domain and t' is the

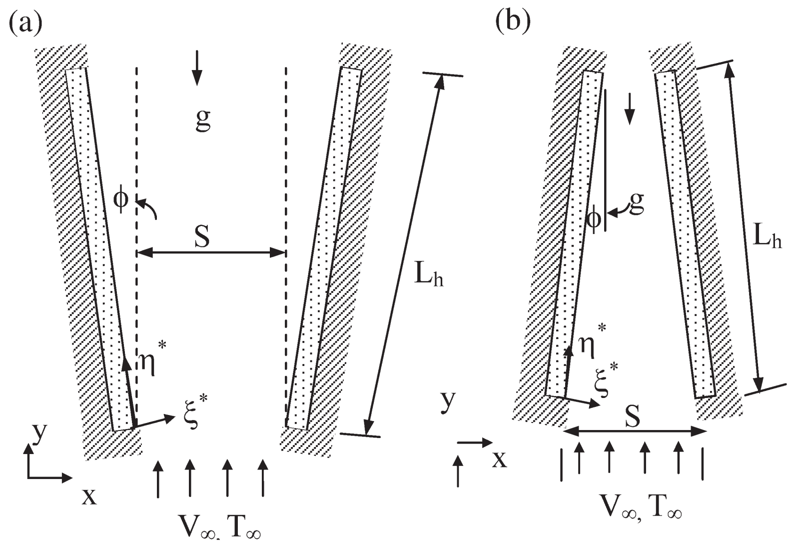

Fig. 1. Geometry under consideration. (a) Diverging channel, (b) converging channel.