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Radiative Effects on Mixed Convection in a Uniformly Heated Vertical Convergent Channel with an Unheated Moving Plate

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Abstract. Fluids engineering is extremely important in a wide variety of materials processing systems, such as soldering, welding, extrusion of plastics and other polymeric materials, Chemical Vapor Deposition (CVD), composite materials manufacturing. In particular, mixed convection due to moving surfaces is very important in these applications. Mixed convection in a channel, as a result of buoyancy and motion of one of its walls has received little research attention and few guidelines are available for choosing the best performing channel configuration, particularly when radiative effects are significant. In this study a numerical investigation of the effect of radiation on mixed convection in air due to the interaction between a buoyancy flow and an unheated moving plate induced flow in a uniformly heated convergent vertical channel is carried out. The moving plate has a constant velocity and moves in the buoyancy force direction. The principal walls of the channel are heated at uniform heat flux. The numerical analysis is accomplished by means of the commercial code Fluent. The effects of the wall emissivity, the minimum channel spacing, the converging angle and the moving plate velocity are investigated and results in terms of air velocity and temperature fields inside the channel and wall temperature profiles, both of the moving and the heated plates, are given. Nusselt numbers, both accounting and not for the radiative contribution to heat removal, are also presented.

AMS subject classifications: 80M12, 80A20
Key words: Mixed convection, moving surfaces, convergent channels, radiative effects.

1 Introduction

Mixed convection due to moving surfaces is very important in a wide variety of materials processing systems, such as soldering, welding, extrusion of plastics and other

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polymeric materials, hot rolling, cooling and/or drying of paper and textiles, Chemical Vapor Deposition (CVD), composite materials manufacturing, as reviewed in [1–3]. Mixed convection with continuously moving vertical surfaces in a quiescent fluid was mostly investigated with reference to a single moving plate, as reported in [4, 5].

An analytical investigation on forced, mixed and natural convection for vertical and inclined moving sheets was carried out in [6]. The investigation underlined a significant velocity overshoot within the boundary layer as the buoyancy parameter increased and the buoyancy effect was more pronounced at lower Prandtl numbers. Correlations for inclined moving surfaces in mixed convection either with uniform surface heat flux or with uniform surface temperature were developed in [7]. The effect of buoyancy forces on flow and heat transfer over a moving heated vertical or inclined surface in a fluid was studied in [8]. The surface moved at non-uniform velocity and both the uniform wall temperature and uniform wall heat flux conditions were considered. The Nusselt number increased with the buoyancy parameter, the Prandtl number and the stream-wise distance. Moreover, the Nusselt number for the uniform wall heat flux case was larger than that in the uniform wall temperature case.

The effects of the radiation in the numerical and analytical analysis of heat transfer from a moving surface to the environment are very important. Kuiken [9] studied the heat transfer from a small continuously moving isothermal electric resistance to a still fluid. Karwe and Jaluria [10, 11] investigated numerically the heat transfer from a continuously moving isothermal plate to a still environment and compared predictions obtained by solving boundary layer equations with those obtained by solving complete elliptic equations.

Heat transfer in a convergent channel with two uniformly heated flat plates is also an interesting problem. The determination of the thermal performance of these configurations is rather difficult because of the large number of thermal and geometric variables, such as the converging angle, the minimum channel spacing and the imposed wall heat flux. Some papers dealt with natural convection in air in convergent channels [12–17]. A numerical study of steady, laminar, mixed convection heat transfer from volumetrically heat generating converging, parallel and diverging channels was carried out in [18]. Air was the working fluid. The maximum angle of deviation of the channel plates from the vertical position for the converging and diverging channels was $2°$ and $-2°$, respectively. A parametric study was carried out for a wide range of physical and geometrical parameters to investigate their effect on the fluid flow and heat transfer characteristics. A universal correlation was presented to evaluate the non-dimensional maximum temperature occurring in converging, parallel or diverging channels. A numerical investigation of mixed convection in air in a convergent vertical channel, due to the interaction between a buoyancy flow and a moving plate induced flow, was presented in [19]. The plate was adiabatic and moved at a constant velocity in the buoyancy force direction whereas the principal inclined walls of the channel were heated at uniform heat flux. The numerical analysis was carried out by means of the finite volume method, using the commercial code Fluent. The effects of the minimum channel spacing, wall heat flux, moving plate