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Influence of surface mass transfer on mixed convection flows over non-isothermal horizontal flat plates

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Abstract

Non-similar solution of a steady mixed convection flow over a horizontal flat plate in the presence of surface mass transfer (suction or injection) is obtained when there is power-law variation in surface temperature. The surface temperature is assumed to vary as a power of the axial coordinate measured from the leading edge of the plate. A non-similar mixed convection parameter is considered which covers the whole convection regime, namely from pure free convection to pure forced convection. Numerical results are reported here to account the effects of Prandtl number, surface temperature, surface mass transfer parameter (suction or injection) on velocity and temperature profiles, and skin friction and heat transfer coefficients.

Keywords: Mixed convection; Horizontal plate; Mass transfer

1. Introduction

In the study of convective heat transfer, it is often found in literature that the problem is treated as either pure forced convection or pure free convection. In contrast, combined forced and free convection or "mixed" convection has applications in nature and in engineering devices such as atmospheric boundary layer flows, heat exchangers and electronic equipments etc. Mixed convection in laminar boundary layer flow has been studied for vertical plates [1–4], inclined plates [5,6] and horizontal plates [7]. In most of the cases, the studies have been done with forced convection dominated regime, that is forced convection under the influence of relatively weak to moderately strong buoyancy forces.

In early studies, Mori [7] and Sparrow and Minkowycz [8] did analysis of buoyancy force effect on forced convection over horizontal plates. They found $\frac{Gr_x}{Re_x^{5/2}}$ as the buoyancy force parameter. Later, Ramachandran

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Nomenclature

Roman letters

A	surface mass transfer parameter
f, F	dimensionless stream function and axial velocity component, respectively
g	acceleration due to gravity
G	dimensionless temperature
$Gr_x (= \frac{g\beta[T_w(x)-T_\infty]x^3}{\nu^2})$	local Grashof number
h	local heat transfer coefficient, $q_w/(T_w - T_\infty)$
k	thermal conductivity
n	exponent in the power-law variation of the surface temperature
Nu_x	local Nusselt number.
Pr	Prandtl number
$Re_x (= \frac{u_\infty x}{\nu})$	local Reynolds number
T	temperature
u, v	stream-wise and normal velocity components, respectively
x, y	axial and normal coordinates, respectively

Greek letters

β	volumetric coefficient of thermal expansion
ξ	mixed convection parameter
η	similarity variable
ν	kinematic viscosity
ρ	density
ψ	stream function

Subscripts

w, ∞	conditions at the wall and infinity, respectively
ξ, η	denote the partial derivatives w.r.t. to these variables, respectively

et al. [9] studied mixed convection over a horizontal plate under uniform wall temperature for the entire mixed convection regime, i.e., from pure forced convection to pure free convection. Two convection parameters have been used by Ramachandran et al. [9], one $\frac{Gr_x}{Re_x^{5/2}}$ to analyze the effect of buoyancy force on forced convection and another parameter $\frac{Re_x^{5/2}}{Gr_x}$ to analyze the effect of forced flow on free convection. To cover the entire regime of mixed convection along vertical and horizontal plates, Raju et al. [10] proposed new mixed convection parameter that is valid from pure forced convection to pure free convection regime. They have considered horizontal plate under uniform wall temperature and they used the new parameter $\frac{Re_x^5}{Re_x^5+Gr_x^2}$, which reduces to 0 for pure free convection and to 1 for pure forced convection. They have considered Pr number ranges from 0.1 to 10. Risbeck et al. [11] studied mixed convection flow over a horizontal flat plate using different single mixed convection parameter that covers the entire regime of mixed convection, from pure forced convection limit to pure free convection limit. Instead of uniform wall temperature they considered the wall temperature to be non-isothermal and has a power-law variation with the axial coordinate.

In many practical problems, there are several transport processes with surface mass transfer. Therefore as a step towards the eventual development on steady mixed convection flows, it is interesting as well as useful to investigate the combined effect of wall temperature variation and surface mass transfer on a horizontal flat plate. The objective of the present analysis is to obtain non-similar solution of a steady mixed convection flow over horizontal flat plate with surface mass transfer (injection or suction). Here same convection parameter $\frac{Re_x^{1/2}}{Re_x^{1/2}+Gr_x^{1/5}}$ as Risbeck [11] has been considered to cover the whole convection regime and wall temperature has been assumed to have a power-law variation with the axial distance.