Applied Mathematics and Computation 217 (2010) 2356–2369

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Mixed convection heat transfer in the boundary layers on an exponentially stretching surface with magnetic field

Dulal Pal

Department of Mathematics, Visva-Bharati University, Santiniketan, West Bengal 731 235, India

ARTICLE INFO

Keywords:
Newtonian fluid
Heat transfer
Porous medium
Boundary-layer flow
Stretching sheet

ABSTRACT

An analysis has been carried out to describe mixed convection heat transfer in the boundary layers on an exponentially stretching continuous surface with an exponential temperature distribution in the presence of magnetic field, viscous dissipation and internal heat generation/absorption. Approximate analytical similarity solutions of the highly non-linear momentum and energy equations are obtained. The present results are found to be in excellent agreement with previously published work on various special cases of the problem. Numerical results for temperature distribution and the local Nusselt number have been obtained for different values of the governing parameters. The numerical solutions are obtained by considering an exponential dependent stretching velocity and prescribed boundary temperature on the flow directional coordinate. The effects of various physical parameters like Prandtl number, Hartman number, Grashof number on dimensionless heat transfer characteristics are discussed in detail. In particular, it has been found that increase in Prandtl number decreases the skin-friction coefficient at the stretching surface, while increase in the strength of the magnetic field leads to increase in the local Nusselt number.

1. Introduction

The problems of heat transfer in the boundary layers of a continuous stretching surface with a given temperature or heat-flux distribution moving in an otherwise quiescent fluid medium have attracted considerable attention during the last few decades due to their numerous applications in several industrial manufacturing processes. Few examples of such technological processes are the extrusion of plastic sheet, hot rolling, wire drawing, glass-fibre and paper production, drawing of plastic films and the cooling of a metallic plate in a cooling bath. A class of flow problems with obvious relevance to polymer extrusion is the flow induced by the stretching motion of a flat elastic sheet. For example, in a metal spinning process, the extradite from the die is generally drawn and simultaneously stretched into a filament or sheet, which is thereafter solidified through rapid quenching or gradual cooling by direct contact with water or chilled metal rolls. Annealing and thinning of copper wires is another example in which the final product depends on the rate of heat transfer at the stretching continuous surface with power-law and exponential variations of stretching velocity and temperature distribution. By drawing the strips in an electrically conducting fluid subjected to a magnetic field the rate of cooling can be controlled and the final products of desired characteristic might be achieved. Both the kinematics of stretching and the simultaneous heating or cooling during such processes have a decisive influence on the quality of the final products. After the pioneering works of Sakiadis [1], a rapidly increasing number of papers investigating the problem of flow induced by a surface moving with constant velocity have been published. With a bearing on the problem of a polymer sheet extruded from a dye, Erickson et al. [2] extended this problem to the case in which the transverse velocity at the moving surface is non-zero and obtained the

E-mail address: dulalp123@rediffmail.com

0096-3003/$ - see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.amc.2010.07.035

Nomenclature

a	parameter of the temperature distribution in the stretching surface
B_0	externally imposed magnetic field in the y-direction
C_f	local skin-friction coefficient
c_p	specific heat of the fluid at constant pressure
Ec	Eckert number
f	dimensionless stream function
Ha	Hartmann number
g	gravitational due to gravity
Gr	Grashof number
L	characteristic length of the plate
Nu_x	Nusselt number
Pr	Prandtl number
Q	internal heat generation/absorption coefficient
q	local surface heat flux
Re_x	local Reynolds number
T	fluid temperature
T_∞	ambient temperature
T_0	reference temperature
T_w	wall temperature
u	fluid axial velocity
U_0	reference velocity
U_w	velocity of the vertical surface
v	fluid transverse velocity
x, y	coordinates along and normal to the plate, respectively
X	dimensionless coordinate along the plate

Greek symbols

ν	kinematic viscosity
τ_{wx}	local shear stress
α	thermal diffusivity
β	coefficient of thermal expansion
η	non-dimensional transformed variable
λ	dimensionless heat generation/absorption parameter
μ	viscosity of the fluid
σ	fluid electrical conductivity
ψ	stream function
ρ	fluid density
θ	dimensionless temperature

subscripts

x	local
w	conditions on the wall
o	reference
∞	ambient or free stream condition

superscript

$'$	differentiation with respect to η

similarity solutions. They provided numerical results for different values of the parameters, with heat and mass transfer in the boundary layer being taken into account. The great majority of the theoretical investigators in this field have taken up the study of heat transfer in the vicinity of the continuous stretching surface with the aid of similarity solutions of the corresponding boundary layer equations. A combined analytical and experimental study of the flow and temperature fields in the boundary layer on a continuous moving surface has been carried out by Tsou et al. [3]. They found the measurements of the laminar velocity field were in excellent agreement with the analytical predictions. A papers by Ali [4] on the thermal boundary layer of a continuous stretching surface may also be referred. It is often argued that (Gupta and Gupta [5]) in reality the stretching of a sheet may not necessarily be linear. This situation has nicely been dealt by Kumaran and Ramanaiah [6] in their work on boundary layer flow considering quadratic stretching of a sheet.