Commun Nonlinear Sci Numer Simulat 15 (2010) 1485–1493

Contents lists available at ScienceDirect

Commun Nonlinear Sci Numer Simulat

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

Effect of variable density on hydromagnetic mixed convection flow of a non-Newtonian fluid past a moving vertical plate

Ahmed M. Salem, Mohamed Abd El-Aziz *, Emad M. Abo-Eldahab, Ibrahim Abd-Elfatah

Department of Mathematics, Faculty of Science, Helwan University, 11795 Cairo, Egypt

ARTICLE INFO

Article history:
Received 4 December 2008
Received in revised form 2 June 2009
Accepted 4 June 2009
Available online 9 June 2009

PACS:
47.50.−d
44.20.+b

Keywords:
Power-law fluid
Mixed convection
Variable density
Magnetic field

ABSTRACT

The effect of temperature-dependent density on MHD mixed convection flow of power-law fluid past a moving semi-infinite vertical plate for high temperature differences between the plate and the ambient fluid is studied. The fluid density is assumed to decrease exponentially with temperature. The usual Boussinesq approximations are not considered due to the large temperature differences. The surface temperature of the moving plate was assumed to vary according to a power-law form, that is, $T_w(x) = T_\infty + Ax^\gamma$. The fluid is permeated by a uniform magnetic field imposed perpendicularly to the plate on the assumption of small magnetic Reynolds number. A numerical shooting algorithm for two unknown initial conditions with fourth-order Runge–Kutta integration scheme has been used to solve the coupled non-linear boundary value problem. The effects of various parameters on the velocity and temperature profiles as well as the local skin-friction coefficient and the local Nusselt number are presented graphically and in the tabular form. The results show that application of Boussinesq approximations in a non-Newtonian fluid subjected to high temperature differences gives a significant error in the values of the skin-friction coefficient and the application of an external magnetic field reduces this error markedly in the case of shear-thickening fluid.

1. Introduction

The transfer of heat and momentum from a heated moving surface in an otherwise ambient medium occurs in many manufacturing processes such as rolling sheet drawn from a die, cooling and/or drying of paper and textile, manufacturing of polymeric sheets, sheet glass and crystalline materials, etc. [1,2]. When the material emerges from the die or roller, its temperature is higher than that of the surroundings. Generally, this high temperature is due to the external heating as in the case of hot extrusion. Plastic deformation of the material and the friction between the flowing material and the die also contribute to the heating. In the case of cold extrusion, a portion of heat generated is lost to the die and the remaining heat is dissipated to the environment. In many practical applications, the extruded material passes through a cooling bath as in the case of wire cutting discussed by Fisher [2]. Sakiadis [3] was the first to study the flow due to a solid surface moving with a constant velocity in an otherwise ambient fluid. Due to the entrainment of ambient fluid, this problem represents a different class of boundary layer problem which has a solution different from that of boundary layer flow over a stationary surface. The corresponding heat transfer problem was studied theoretically and experimentally by Tsou et al. [4], theoretically by Erickson et al. [5] and experimentally by Griffin and Thorne [6]. Jeng et al. [7] considered the flow and heat transfer characteristics over a moving surface in an ambient fluid. Moutsoglou and Chen [8] and Takhar et al. [9] examined the effect of buoyancy forces on an inclined surface moving in an ambient fluid.

* Corresponding author.
E-mail addresses: ah_marei@hotmail.com (A.M. Salem), m_abdelaziz999@yahoo.com (M. Abd El-Aziz).

1007-5704/$ - see front matter
doi:10.1016/j.cnsns.2009.06.005

Nomenclature

A	prescribed constant
B_o	magnetic field
°C	degree centigrade
C_f	coefficient of skin friction
c_p	specific heat at constant pressure
f	dimensionless stream function
g	acceleration due to gravity
Gr_x	local Grashof number
k	thermal conductivity
K	dynamic viscosity coefficient
M	magnetic field parameter
m	density/temperature parameter
n	power-law index
Nu	Nusselt number
Pr	generalized Prandtl number
Re_x	local Reynolds number
Re_n	generalized Reynolds number
q_w	wall heat flux
T	temperature
u	x-component of velocity
υ	y-component of velocity
x, y	axial and normal coordinates

Greeks

α	thermal diffusivity
β	coefficient of volume expansion
δ	boundary layer thickness
η	dimensionless normal distance
θ	dimensionless temperature
λ	buoyancy parameter
μ	dynamic viscosity
ν	kinematical viscosity
σ	electrical conductivity
ρ	density
ψ	stream function
τ	shear stress

Subscripts

w	properties of the wall
∞	free stream condition

Superscript

$'$	differentiation with respect to η

In recent years, the non-Newtonian fluids in the presence of a magnetic field find increasing applications in many areas such as chemical engineering, electromagnetic propulsion, nuclear reactors, etc. Sarpakaya [10] has given many possible applications of non-Newtonian fluids in various fields. The flow of non-Newtonian power-law fluids in the presence of a magnetic field over two-dimensional bodies was investigated by Sarpakaya [10], Sapunkov [11], Vujanovic et al. [12], Djukic [13,14] and Andersson et al. [15]. Recently, Abo-Eldahab and Salem [16–18] have studied the MHD flow of a non-Newtonian power-law fluid over moving boundary.

Most studies of convective flow past a semi-infinite vertical plate were restricted, in general, to the case where the temperature difference between the plate and the ambient fluid is small. In this case, the Boussinesq approximations [19] can be used to treat the fluid density as a variable only in buoyancy term of the momentum equation. In situation where there is large temperature difference between the plat and the ambient fluid, the Boussinesq approximations can no longer be used or it can give erroneous results. Recently, Abd El-Aziz [20] studied the mixed convection flow of a micropolar fluid over a continuously moving plate due to high temperature differences in the presence radiation.

The present paper deals with the study of the MHD mixed convection flow of a non-Newtonian power-law fluid past a moving semi-infinite vertical plate for high temperature differences, the fluid is assumed to be electrically conducting in