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Effects of Hall current, radiation and rotation on natural convection heat and mass transfer flow past a moving vertical plate

G.S. Seth [a,*], S. Sarkar [a], S.M. Hussain [b]

[a] Department of Applied Mathematics, Indian School of Mines, Dhanbad 826004, India
[b] Department of Mathematics, OP Jindal Institute of Technology, Raigarh 496109, India

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Abstract An investigation of the effects of Hall current and rotation on unsteady hydromagnetic natural convection flow with heat and mass transfer of an electrically conducting, viscous, incompressible and optically thick radiating fluid past an impulsively moving vertical plate embedded in a fluid saturated porous medium, when temperature of the plate has a temporarily ramped profile, is carried out. Exact solution of the governing equations is obtained in closed form by Laplace transform technique. Exact solution is also obtained in case of unit Schmidt number. Expressions for skin friction due to primary and secondary flows and Nusselt number are derived for both ramped temperature and isothermal plates. Expression for Sherwood number is also derived. The numerical values of primary and secondary fluid velocities, fluid temperature and species concentration are displayed graphically whereas those of skin friction are presented in tabular form for various values of pertinent flow parameters.

1. Introduction

Natural convection flow induced by thermal and solutal buoyancy forces acting over bodies with different geometries in a fluid saturated porous medium is prevalent in many natural phenomena and has varied and wide range of industrial applications. For example, in atmospheric flows, the presence of pure air or water is impossible because some foreign mass may be present either naturally or mixed with air or water due to industrial emissions. Natural processes such as attenuation of toxic waste in water bodies, vaporization of mist and fog, photosynthesis, drying of porous solids, transpiration, sea-wind formation (where upward convection is modified by Coriolis forces), and formation of ocean currents [1] occur due to thermal and solutal buoyancy forces developed as a result of difference in temperature or concentration or a combination of these two. Such configuration is also encountered in several practical systems for industry based applications viz. heat exchanger devices, cooling of molten metals, insulation systems, petroleum reservoirs, filtration,

* Corresponding author. Mobile: +91 9006482450.
E-mail address: gsseth_ism@yahoo.com (G.S. Seth).

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Nomenclature

B_0	uniform magnetic field
c_p	specific heat at constant pressure
g	acceleration due to gravity
G_c	solutal Grashof number
K_1'	permeability of porous medium
k^*	Rosseland mean absorption coefficient
m	Hall current parameter
N	thermal radiation parameter
q_r'	radiative flux vector
T'	fluid temperature
U_0	uniform velocity of the plate
w'	fluid velocity in z' direction
C'	species concentration
D	chemical molecular diffusivity
G_r	thermal Grashof number
k	thermal conductivity of the fluid
K_1	permeability parameter
K^2	rotation parameter
M^2	magnetic parameter
P_r	Prandtl number
S_c	Schmidt number
t_0	characteristic time
u'	fluid velocity in x' direction

Greek symbols

β'	volumetric coefficient of thermal expansion
β^*	volumetric coefficient of expansion for species concentration
ρ	fluid density
σ^*	Stefan–Boltzmann constant
τ_e	electron collision time
Ω	uniform angular velocity
σ	electrical conductivity
ν	kinematic coefficient of viscosity
ω_e	cyclotron frequency

chemical catalytic reactors and processes, nuclear waste repositories, desert coolers, wet bulb thermometers, frost formation in vertical channels, etc. Considering the importance of such fluid flow problems, extensive and in-depth research works have been carried out by several researchers [2–10] in the past. Comprehensive reviews of natural convection boundary layer flow over various geometrical bodies with heat and mass transfer in porous and non-porous media are well documented by Eckert and Drake [11], Gebhart et al. [12], Nield and Bejan [13], Pop and Ingham [14] and Incropera et al. [15].

Investigation of hydromagnetic natural convection flow with heat and mass transfer in porous and non-porous media has drawn considerable attentions of several researchers owing to its applications in astrophysics, geophysics, aeronautics, electronics, meteorology, metallurgy, chemical and petroleum industries. Magnetohydrodynamic (MHD) natural convection flow of an electrically conducting fluid in a fluid saturated porous medium has also been successfully exploited in crystal formation. Oreper and Szekely [16] have found that the presence of a magnetic field can suppress natural convection currents and the strength of magnetic field is one of the important factors in reducing non-uniform composition thereby enhancing quality of the crystal. In addition to it, the thermal physics of hydromagnetic problems with mass transfer is of much significance in MHD energy generators, MHD flow-meters, MHD pumps, MHD accelerators, controlled thermo-nuclear reactors, etc. Keeping in view the importance of such study, Hossain and Mandal [17] investigated mass transfer effects on unsteady hydromagnetic free convection flow past an accelerated vertical porous plate. Jha [18] studied hydromagnetic free convection and mass transfer flow past a uniformly accelerated vertical plate through a porous medium when magnetic field is fixed with the moving plate. Elbashbeshy [19] discussed heat and mass transfer along a vertical plate in the presence of magnetic field. Chen [20] analyzed combined heat and mass transfer in MHD free convection flow from a vertical surface with Ohmic heating and viscous dissipation. Ibhrahim et al. [21] considered unsteady MHD micropolar fluid flow and heat transfer past a vertical porous plate through a porous medium in the presence of thermal and mass diffusions with a constant heat source. Chamkha [22] investigated unsteady MHD convection flow with heat and mass transfer past a semi-infinite vertical permeable moving plate in a uniform porous medium with heat absorption. Makinde and Sibanda [23] investigated MHD mixed convection flow with heat and mass transfer past a vertical plate embedded in a uniform porous medium with constant wall suction in the presence of uniform transverse magnetic field. Makinde [24] studied MHD mixed convection flow and mass transfer past a vertical porous plate embedded in a porous medium with constant heat flux. Eldabe et al. [25] discussed unsteady MHD flow of a viscous and incompressible fluid with heat and mass transfer in a porous medium near a moving vertical plate with time-dependent velocity.

Investigation of hydromagnetic natural convection flow in a rotating medium is of considerable importance due to its application in various areas of geophysics, astrophysics and fluid engineering viz. maintenance and secular variations in Earth's magnetic field due to motion of Earth's liquid core, internal rotation rate of the Sun, structure of the magnetic stars, solar and planetary dynamo problems, turbo machines, rotating MHD generators, rotating drum separators for liquid metal MHD applications, etc. It may be noted that Coriolis and magnetic forces are comparable in magnitude and Coriolis force induces secondary flow in the flow-field. Taking into consideration the importance of such study, unsteady hydromagnetic natural convection flow past a moving plate in a rotating medium is studied by a number of researchers. Mention may be made of research studies of Singh [26,27], Raptis and Singh [28], Kythe and Puri [29], Tokis [30], Nanousis [31] and Singh et al. [32].

In all these investigations, the effects of thermal radiation are not taken into account. However, thermal radiation effects on hydromagnetic natural convection flow with heat and mass transfer play an important role in manufacturing processes taking place in industries for the design of fins, glass production, steel rolling, casting and levitation, furnace design, etc.