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Numerical analysis for magnetohydrodynamic chemically reacting and radiating fluid past a non-isothermal uniformly moving vertical surface adjacent to a porous regime

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Abstract A mathematical model is conducted for the unsteady magnetohydrodynamic viscous, incompressible free convective flow of an electrically conducting Newtonian fluid over an impulsively-started semi-infinite vertical plate adjacent to saturated porous medium in the presence of appreciable thermal radiation heat transfer and chemical reaction of first order taking transverse magnetic field into account. The fluid is assumed optically thin gray gas, absorbing-emitting radiation, but a non-scattering medium. The governing non-linear partial differential equations are non-dimensionalized and are solved by an implicit finite difference scheme of ***Crank–Nicholson*** type. It is found that, increasing magnetic parameter serves to decelerate the flow, but increased temperatures and concentration values. An increase in the porosity parameter (K) is found to escalate the local skin friction (τ_x), Nusselt number (Nu_x) and the Sherwood number (Sh_x). Applications of the model include fundamental magneto-fluid dynamics, MHD energy systems and magneto-metallurgical processing for aircraft materials.

1. Introduction

Magnetohydrodynamics deals with the dynamics of an electrically conducting fluid, which interacts with a magnetic field. The study of heat transfer and flow, through and across porous media, is of great theoretical interest because it has been applied to a variety of geophysical and astrophysical phenomena. Practical interest of such study includes applications in electromagnetic lubrication, boundary cooling, bio-physical systems and in many branches of engineering and science. In engineering, it finds its application in MHD pumps, MHD bearings, nuclear reactors, geothermal energy extraction and boundary layer control in the field of aerodynamics. In porous media applications such as packed beds, to sustain a given flow rate of the electrically conducting liquid in the bed, the pres-

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Nomenclature

$\bar{a}$	absorption coefficient
$\overline{C}$	species concentration (kg m^{-3})
C_P	specific heat at constant pressure (J kg^{-1} K)
$\overline{C}_\infty$	species concentration in the free stream (kg m^{-3})
$\overline{C}_W$	species concentration at the surface (kg m^{-3})
D	chemical molecular diffusivity (m^2 s^{-1})
E_C	Eckert number
g	acceleration due to gravity (m s^{-2})
Gr	thermal Grashof number
Gr_m	mass Grashof number
K	permeability parameter
n	surface temperature power law exponent
m	surface concentration power law exponent
M	Hartmann number
Nu_x	Nusselt number
$\bar{p}$	pressure (Pa)
Pr	Prandtl number
q_r	radiation parameter
Sh_x	Sherwood number
Sc	Schmidt number
$\overline{T}$	temperature (K)
$\overline{T}_w$	fluid temperature at the surface (K)
$\overline{T}_\infty$	fluid temperature in the free stream (K)
u	dimensionless velocity component in x-direction (m s^{-1})
u_0	plate velocity (m s^{-1})
v	dimensionless velocity component in y-direction (m s^{-1})

Greek symbols

α	thermal diffusivity
β	coefficient of volume expansion for heat transfer (K^{-1})
$\bar{\beta}$	coefficient of volume expansion for mass transfer (K^{-1})
θ	dimensionless fluid temperature (K)
κ	thermal conductivity (W m^{-1} K^{-1})
μ	coefficient of viscosity (kg m^{-3})
υ	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})
σ	electrical conductivity
$\bar{\sigma}$	Stefan–Boltzmann constant
τ_x	shearing stress (N m^{-2})
ϕ	dimensionless species concentration (kg m^{-3})

Subscripts

w	conditions on the wall
∞	free stream conditions

sure drop and the liquid holdup will be increased under magnetohydrodynamic conditions compared with the case of *non-conducting* fluids. In crystal growth applications in porous media, the external magnetic field imposed has been successfully exploited to suppress unsteady flow and also reduce composition non-uniformity. Recent monographs by Nield and Bejan [1] and Ingham and Pop [2] provide an excellent summary of the work on the subject.

Thermal radiation effects on the boundary layer may play important role in controlling heat transfer in polymer processing industry where the quality of the final product depends on the heat controlling factors to some extent. Actually, many processes in new engineering areas occur at high temperatures and knowledge of radiation heat transfer besides the convective heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas. England and Emery [3] have studied the radiation effects of an optically thin gray gas bounded by a stationary plate. Again Raptis and Perdikis [4] studied the effects of thermal radiation on moving vertical plate in the presence of mass diffusion. The governing equations were solved by the Laplace transform technique. The thermal radiation effects in a steady free convective flow through a porous medium bounded by a vertical infinite porous plate have been considered by Raptis [5]. Hussain and Pop [6] studied the radiation effects on stationary free convection of an optically thin dense fluid along an isothermal vertical surface embedded in a porous medium with highly porosity using Brinkman–Forchheimer–Darcy extended model, by means of two different numerical techniques, the Keller-box method and the local non-similarity scheme. Jaiswal and Soundalgekar [7] obtained an approximate solution to the problem of an unsteady flow past an infinite vertical plate with constant suction and embedded in a porous medium with oscillating plate temperature.

An analysis of the thermal radiation effects on stationary mixed convection from vertical surfaces in saturated porous media for both a hot and a cold surface has been presented by Bakier [8]. The unsteady flow through a highly porous medium in the presence of radiation was studied by Raptis and Perdikis [9]. The effects of radiation and viscous dissipation on the transient natural convection–radiation flow of viscous dissipation fluid along an infinite vertical surface embedded in a porous medium, by means of network simulation method, investigated by Zueco [10]. The effects of radiation and chemical reaction on natural convection flows of a Newtonian fluid along a vertical surface embedded in a porous medium presented by Mahmoud and Chamkha [11]. Sahin [12] investigated the effect of transverse periodic permeability oscillating with time on the heat transfer flow of a viscous incompressible fluid through a highly porous medium bounded by an infinite vertical porous plate, by means of series solution method. Sahin [13] studied the effect of transverse periodic permeability oscillating with time on the free convective heat transfer flow of a viscous incompressible fluid through a highly porous medium bounded by an infinite vertical porous plate subjected to a periodic suction velocity.

Chamkha [14] investigated the chemical reaction effects on heat and mass transfer laminar boundary layer flow in the presence of heat generation/absorption effects. Muthucumaraswamy and Kulaivel [15] presented an analytical solution to