Journal of the Egyptian Mathematical Society (2016) **24**, 108–115

Egyptian Mathematical Society

Journal of the Egyptian Mathematical Society

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www.elsevier.com/locate/joems

ORIGINAL ARTICLE

Chemical reaction and radiation effects on mixed convection heat and mass transfer over a vertical plate in power-law fluid saturated porous medium

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Received 27 April 2013; revised 28 August 2014; accepted 21 October 2014
Available online 11 February 2015

KEYWORDS

Mixed convection;
Porous media;
Chemical reaction effects;
Radiation effects;
Power law fluid;
Heat and mass fluxes

Abstract Mixed convection heat and mass transfer along a vertical plate embedded in a power-law fluid saturated Darcy porous medium with chemical reaction and radiation effects is studied. The governing partial differential equations are transformed into ordinary differential equations using similarity transformations and then solved numerically using shooting method. A parametric study of the physical parameters involved in the problem is conducted and a representative set of numerical results is illustrated graphically.

2010 MATHEMATICS SUBJECT CLASSIFICATION: 76A05; 76E06; 80A20

1. Introduction

The analysis of mixed convection boundary layer flow along a vertical surface embedded in porous medium has received considerable theoretical and practical interest. A number of studies have been reported in the literature focusing on the problem of mixed convection about different surface geometries in porous media. A review of convective heat transfer in porous medium is presented in the book by Nield and Bejan [1]. It is well known that most fluids which are encountered in chemical and allied processing applications do not satisfy the classical Newton's law and are accordingly known as non-Newtonian fluids. Due to the important applications of non-Newtonian fluids in biology, physiology, technology, and industry, considerable efforts have been directed toward the analysis and understanding of such fluids. A number of mathematical models have been proposed to explain the rheological behavior of non-Newtonian fluids. Among these, a model which has been most widely used for non-Newtonian fluids, and is frequently encountered in chemical engineering processes, is the power-law model. Although this model is merely an empirical relationship between the stress and velocity gradients, it has been successfully applied to non-Newtonian fluids experimentally.

The prediction of heat or mass transfer characteristics for mixed or natural convection of non-Newtonian fluids in porous media is very important due to its practical engineering

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Peer review under responsibility of Egyptian Mathematical Society.

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http://dx.doi.org/10.1016/j.joems.2014.10.001
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Nomenclature

A, B	dimensional constants
a, b	constants
l	temperature variation index at wall
T	temperature
C	concentration
g	gravitational acceleration
T_∞	ambient temperature
K	Darcy permeability
k_1	rate of chemical reaction
k	thermal conductivity
q_y^r	radiative heat flux
$q_w(x)$	heat flux
$q_m(x)$	mass flux
C_p	specific heat at constant pressure
C_s	concentration susceptibility
α_m	thermal diffusivity
D_m	mass diffusivity
γ	chemical reaction parameter
R	radiation parameter
σ	Stefan–Boltzman constant
Le	Lewis number
N	buoyancy ratio
n	power-law index
β_T	coefficient of thermal expansion
β_C	coefficient of concentration expansion
Nu_x	Nusselt number
Sh_x	Sherwood number
v	kinematic viscosity
ϕ	dimensionless concentration
θ	dimensionless temperature
u, v	Darcian velocity components in x and y directions
x, y	co-ordinates along and normal to the plate
η	similarity variable
ψ	stream function

applications. Abo-Eldahab and Salem [2] studied the problem of laminar mixed convection flow of non-Newtonian power-law fluids from a constantly rotating isothermal cone or disk in the presence of a uniform magnetic field. Kumari and Nath [3] considered the conjugate mixed convection conduction heat transfer of a non-Newtonian power-law fluid on a vertical heated plate which is moving in an ambient fluid. Degan et al. [4] presented an analytical method to investigate transient free convection boundary layer flow along a vertical surface embedded in an anisotropic porous medium saturated by a non-Newtonian fluid. Chamkha and Al-Humoud [5] studied mixed convection heat and mass transfer of non-Newtonian fluids from a permeable surface embedded in a porous medium under uniform surface temperature and concentration species. Chen [6] considered the problem of magnetohydrodynamic mixed convective flow and heat transfer of an electrically conducting, power-law fluid past a stretching surface in the presence of heat generation/absorption and thermal radiation. Elgazery and Abd Elazem [7] analyzed numerically a mathematical model to study the effects of a variable viscosity and thermal conductivity on unsteady heat and mass transfer in a non-Newtonian power-law fluid flow through a porous medium past a semi-infinite vertical plate with variable surface temperature in the presence of magnetic field and radiation. Effect of double dispersion on mixed convection heat and mass transfer in a non-Newtonian fluid-saturated non-Darcy porous medium has been investigated by Kairi and Murthy [8]. Chamkha et al. [9] studied the effects of melting, thermal radiation and heat generation or absorption on steady mixed convection from a vertical wall embedded in a non-Newtonian power-law fluid saturated non-Darcy porous medium for aiding and opposing external flows. Hayat et al. [10] investigated the Magnetohydrodynamic (MHD) mixed convection stagnation-point flow and heat transfer of power-law fluids toward a stretching surface using the homotopy analysis method.

Radiative convective flows are very important in many industrial and environment processes that are operating at high temperature. Since the solution for convection and radiation equation is very complicated, there are few studies about simultaneous effect of convection and radiation for internal flows. Salem [11] considered the coupled heat and mass transfer in Darcy–Forchheimer mixed convection from a vertical flat plate embedded in a fluid saturated porous medium under the effects of radiation and viscous dissipation. Damseh [12] studied magnetohydrodynamics-mixed convection from radiate vertical isothermal surface embedded in a saturated porous media. The radiation effect on MHD mixed convection flow about a permeable vertical plate was studied by Orhan Aydn [13]. Hayat et al. [14] analyzed the effects of radiation and magnetic field on the mixed convection stagnation point flow over a vertical stretching sheet in a porous medium.

On the other hand, chemical reaction effects on heat and mass transfer are of considerable importance in hydrometallurgical industries and chemical technology. Several investigators have examined the effect of chemical reaction on the flow, heat and mass transfer past a vertical plate. Further, chemical reaction effects on heat and mass transfer with radiation are of considerable importance in hydrometallurgical industries and chemical technology such as polymer production and food processing. Chamkha et al. [15] studied MHD mixed convection radiation interaction along a permeable surface immersed in a porous medium in the presence of Soret and Dufour effects. Prabhu et al. [16] considered the effects of chemical reaction, heat and mass transfer on MHD flow over a vertical stretching surface with heat source and thermal stratification effects. Postelnicu [17] studied the influence of chemical reaction on heat and mass transfer by natural convection from vertical surfaces in porous media by considering Soret and Dufour effects. Ibrahim et al. [18] analyzed the effects of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction. Unsteady natural convective power-law fluid flow past a vertical plate embedded in a non-Darcian porous medium in the presence of a homogeneous chemical reaction was studied by Chamkha [19]. Recently Pal and Mondal [20] studied the influence of chemical