Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

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

Full Length Article

Double dispersion effect on nonlinear convective flow over an inclined plate in a micropolar fluid saturated non-Darcy porous medium

D. Srinivasacharya *, Ch. RamReddy, P. Naveen

Department of Mathematics, National Institute of Technology, Warangal 506004, India

ARTICLE INFO

Article history:
Received 8 December 2017
Revised 3 July 2018
Accepted 17 July 2018
Available online xxxx

Keywords:
Nonlinear convection
Convective boundary condition
Double dispersion
Micropolar fluid
Successive linearization method

ABSTRACT

This article explores the influence of double dispersion on micropolar fluid flow past an inclined plate in a homogeneous and isotropic non-Darcy porous medium. Additionally, the effect of nonlinear Boussinesq approximation (i.e., also known as nonlinear convection) with the convective thermal condition is considered to address the heat and mass transfer phenomena in some thermal systems which are operated at moderate to very high temperatures. The governing partial differential equations are transformed into a system of ordinary differential equations using a local non-similarity method, and the resulting boundary value problem is solved using a novel successive linearization method (SLM). The accuracy of the SLM has been established by comparing the results with the shooting technique. This numerical study discusses the influence of pertinent parameters on the fluid flow characteristics through graphs and the salient features are discussed in detail. Heat and mass transfer varies extensively with the increase of nonlinear convection parameters, which depends on aiding and opposing flow situations. In the both aiding and opposing flows, thermal dispersion favors the heat transfer, whereas the solutal dispersion parameter benefits the mass transfer. This kind of investigation is useful in the mechanism of combustion, aerosol technology, high-temperature polymeric mixtures, solar collectors which are operated at moderate to very high temperatures.

1. Introduction

Analysis of thermal and solutal transport phenomena of micropolar fluid flow in porous media is a subject of incredible interest for researchers. Since various disciplines in geophysical and engineering industries are enforced to study the microscopic nature of the fluid elements, such as the cooling systems, petroleum reservoirs, agricultural fields, fiber insulation, ceramic processes, grain storage devices, coal combustors, etc. Eringen [1] initiated the theory of a micropolar fluid to describe fluids which contradict Newton's law of viscosity like liquid crystals, animal blood, polymeric fluids, lubricants, etc. The natural motion, body couples stress and microscopic effects of the fluid elements are conceptualized in this theory which are distinct features of micropolar fluids. The mathematical aspects of micropolar fluid theory and its applications are reported in the textbooks by Lukaszewicz [2] and Eremeyev et al. [3]. Many authors to mention few Beg et al. [4], Aurangzaib and Shafie [5], Srinivasacharya and Ramreddy [6], Noor et al. [7], Tripathy et al. [8], Mishra et al. [9], Gibanov et al. [10] are employed and exposed the above-mentioned theory in Darcy and/or non-Darcy porous medium under different circumferences, owing to its diverse applications in engineering, industrial and scientific fields like collecting devices, material processing, solar energy, etc. An exhaustive monograph on convective heat and mass transfer of various fluids in Darcy, and also the non-Darcy porous medium, can be found in the course reading by Nield and Bejan [11] and furthermore observe the references in that.

The double dispersion effects are more predominant in the flow region of a porous medium under the condition that the inertial effects are not negligible (refer Nield and Bejan [11] and citations therein). The double dispersion in a steady flow is due to the combined action of convection and molecular diffusion, and this concept helps to explain the differences often observed between transport parameters measured along and across the principal directions of fluid flow in the considered geometries. The development of double dispersion theory has been mainly related to miscible displacement and solute spreading in porous media. These areas are of major interest to ceramic processing, heat storage beds, secondary and tertiary oil recovery operations, and to pollution control in water resources engineering. In

* Corresponding author.
E-mail address: dsrinivasacharya@yahoo.com (D. Srinivasacharya).

https://doi.org/10.1016/j.jestch.2018.07.012
2215-0986/© 2018 Karabuk University. Publishing services by Elsevier B.V.

Nomenclature

b	coefficient of Forchheimer term
Bi	Biot number
$\mathcal{B}$	Buoyancy ratio
C	concentration
C_f	skin friction coefficient
C_w	wall concentration
C_∞	ambient concentration
d	pore diameter
D	molecular solutal diffusivity
Da	Darcy number
D_e	effective solutal diffusivity
D_c	solutal dispersion parameter
D_s	thermal dispersion parameter
f	dimensionless stream function
Fs	Forchheimer number
g	dimensionless microrotation
g^*	gravitational acceleration
Gr	thermal Grashof number
h_f	convective heat transfer coefficient
j	micro-inertia density
k_f	thermal conductivity
K_p	permeability
L	characteristic length
M_w	dimensionless wall couple stress
N	coupling number
Nu_x	local Nusselt number
Pr	Prandtl number
Re	global Reynold's number
Ri	mixed convection parameter
Sc	Schmidt number
Sh_x	local Sherwood number
T	temperature
T_f	convective wall temperature
T_∞	ambient temperature
u_∞	free stream velocity,
u, v	Darcy velocity components in the x and y directions

Greek symbols

α	molecular thermal diffusivity
α_e	effective thermal diffusivity
α_1	nonlinear density-temperature (NDT) parameter
α_2	nonlinear density-concentration (NDC) parameter
β_0, β_1	coefficients of thermal expansion of first and second orders
β_2, β_3	coefficients of solutal expansion of first and the second order
$\mathcal{J}$	dimensionless micro-inertia density
η	similarity variable
γ	spin-gradient viscosity
ε	porosity
κ	vortex viscosity
χ	thermal dispersion coefficient
λ	dimensionless spin-gradient viscosity
ω	component of microrotation
Ω	inclination of angle
θ	dimensionless temperature
ϕ	dimensionless concentration
μ	dynamic viscosity
ζ	solutal dispersion coefficient
ν	kinematic viscosity
ρ_∞	density
ψ	stream function
ξ	dimensionless stream wise coordinate

Superscripts

w	wall condition
∞	ambient condition

Superscripts

$'$	differentiation with respect to η

unusual geometry, likely in the packed beds, the transportation of fluid through convoluted paths will lead to double dispersion effects at pore level in the porous media. Given the applications as mentioned earlier, many authors have analyzed the effects of thermal and solutal dispersion on convective heat and mass transfer through porous media. Murthy [12] has investigated effects of double dispersion on mixed convection heat and mass transfer in the non-Darcy porous medium. El-Amin et al. [13] studied the effects of chemical reaction and double dispersion on non-Darcy free convective heat and mass transfer in a porous medium. The effects of thermal and solutal dispersion on natural convection about an isothermal vertical cone with a fixed apex half angle, pointing downwards in a Newtonian fluid are analyzed by RamReddy [14]. Recently, Bouaziz [15] investigated the double dispersion on the double-diffusive convective boundary layer between a vertical plate immersed into a non-Darcy saturated porous medium with a nanofluid. Several attempts have been made in recent years to investigate the problem of convective flow over an inclined plate in various Newtonian and non-Newtonian fluids due to its geophysical and industrial applications. These applications include chemical processing, electrical systems, iron removal, brine clarification, etc. Chamka et al. [16], Rahman et al. [17], Murthy et al. [18], Pal and Chatterjee [19] and Sui et al. [20] considered fluid flow characteristics along an inclined plate with different Newtonian/non-Newtonian fluid under various physical conditions.

Heat transfer analysis with convective thermal boundary condition is an essential and useful consideration in the gas turbines, nuclear plants, heat exchangers related industries, due to its realistic nature. Also, it occurs when a solid substrate is in contact with the fluid at a different temperature and involves relative motion between the fluid and the substrate. In many practical applications involving cooling or heating of the surface, the presence of convective heat exchange between the surface and the surrounding fluid cannot be neglected, and this is a very crucial aspect in thermal materials processing industries. In this mechanism, heat is supplied to the convecting fluid through a bounding surface with a finite heat capacity, which provides a convective heat transfer coefficient. Given these applications, Makinde and Aziz [21] considered the convective thermal condition for the analysis of magnetohydrodynamic cold fluid flow along a vertical surface, whereas Hayat et al. [22] analyzed the effect of thermal radiation in mixed convection stagnation point flow over a moving surface subject to the convective boundary condition. Poonia and Bhargava [23] developed a theoretical model to analyze mixed convective Eyring-Powell fluid flow along a semi-infinite horizontal flat plate with the convective thermal condition. In the recent times, the influence of Joule heating and thermal radiation on MHD micropolar fluid has been discussed by Ramzan et al. [24] by taking the partial slip and convective surface boundary condition.

Some of the thermal systems such as those encountered in reactor safety, combustion and solar collectors are operate at very high