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ORIGINAL ARTICLE

Chemically reacting micropolar fluid flow and heat transfer between expanding or contracting walls with ion slip, Soret and Dufour effects

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Abstract The aim of the present study is to investigate the Hall and ion slip currents on an incompressible free convective flow, heat and mass transfer of a micropolar fluid in a porous medium between expanding or contracting walls with chemical reaction, Soret and Dufour effects. Assume that the walls are moving with a time dependent rate of the distance and the fluid is injecting or sucking with an absolute velocity. The walls are maintained at constant but different temperatures and concentrations. The governing partial differential equations are reduced into nonlinear ordinary differential equations by similarity transformations and then the resultant equations are solved numerically by quasilinearization technique. The results are analyzed for velocity components, microrotation, temperature and concentration with respect to different fluid and geometric parameters and presented in the form of graphs. It is noticed that with the increase in chemical reaction, Hall and ion slip parameters the temperature of the fluid is enhanced whereas the concentration is decreased. Also for the Newtonian fluid, the numerical values of axial velocity are compared with the existing literature and are found to be in good agreement.

1. Introduction

The flow through porous channels has many important applications, in both engineering and biophysical flows. Examples of this include cosmetic industry, petroleum industry, soil mechanics, food preservation, the mechanics of the cochlea in the human ear, blood flow and artificial dialysis. Many researchers have investigated the numerical simulation of blood flow through curved geometries in the presence of a magnetic field by considering the effect of Dean number [1,2]. The theory of micropolar fluids was introduced by Eringen [3] which are considered as an extension of generalized viscous fluids with microstructure. Examples of micropolar fluids include lubricants, colloidal suspensions, porous rocks, aerogels, polymer blends, micro emulsions. Micropolar fluid flow in a porous channel was studied by Ashraf et al. [4] and drawn numerical solution using the finite difference scheme. Ojjela and Naresh Kumar [5] obtained a numerical solution by the quasilinearization method for the MHD flow and heat transfer of a micropolar fluid through a porous channel. Chamkha et al. [6] considered the transient free convective-radiative

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Nomenclature

t	time
$a(t)$	distance between the origin and lower/upper wall
V_1	injection/suction velocity
p	fluid pressure
$\overline{q}$	velocity vector
c	specific heat at constant temperature
$\bar{l}$	microrotation vector
N	microrotation component
Ec	Eckert number, $\frac{\mu V_1}{\rho ac(T_2-T_1)}$
k	thermal conductivity
k_1	viscosity parameter
k_2	permeability of the medium
k_3	chemical reaction rate
u	velocity component in x-direction
v	velocity component in y-direction
Pr	Prandtl number, $\frac{\mu c}{k}$
Re	suction/injection Reynolds number, $\frac{\rho V_1 a}{\mu}$
j	gyration parameter
$\overline{J}$	current density
J_1	nondimensional gyration parameter, $\frac{\rho ja V_1}{\gamma}$
$\overline{B}$	total magnetic field
$\overline{b}$	induced magnetic field
B_0	magnetic flux density
D	rate of deformation tensor
$\overline{E}$	electric field
Ha	Hartmann number, $B_0 a\sqrt{\frac{\sigma}{\mu}}$
D^{-1}	inverse Darcy parameter, $\frac{a^2}{k_2}$
R	nondimensional viscosity parameter, $\frac{k_1}{\mu}$
s_1	nondimensional micropolar parameter, $\frac{k_1 a^2}{\gamma}$
s_2	nondimensional micropolar parameter, $\frac{\gamma c}{a^2 k}$
T	temperature
T_1	temperature of the lower wall
T_2	temperature of the upper wall
T^*	dimensionless temperature, $\frac{T-T_1}{T_2-T_1}$
C	concentration
C^*	nondimensional concentration, $\frac{C-C_1}{C_2-C_1}$
C_1	concentration of the lower wall
C_2	concentration of the upper wall
D_1	mass diffusivity
Kr	nondimensional chemical reaction parameter, $\frac{k_3 a^2}{D_1}$
Sc	Schmidt number, $\frac{\upsilon}{D_1}$
Gr	thermal Grashof number, $\frac{\rho g\beta_T(T_2-T_1)a^3}{\upsilon^2}$
Gc	solutal Grashof number, $\frac{\rho g\beta_C(C_2-C_1)a^3}{\upsilon^2}$
Sh	Sherwood number, $\frac{\dot{n_A}}{a\upsilon(C_2-C_1)}$
$\dot{n_A}$	mass transfer rate
Sr	Soret number, $\frac{D_1 k_T \upsilon V_1}{cT_m \dot{n_A}}$
Du	Dufour number, $\frac{D_1 k_T n_A \dot{\rho} c}{\upsilon^2 V_1 c_s k}$
T_m	mean temperature
k_T	thermal-diffusion ratio
c_s	concentration susceptibility

Greek letters

λ	dimensionless y coordinate, $\frac{y}{a}$
α, β, γ	gyro viscosity parameters
ζ	dimensionless axial variable, $\frac{x}{a}$
υ	kinematic viscosity
ρ	fluid density
μ	fluid viscosity
μ'	magnetic permeability
σ	conductivity
η	wall expansion ratio, $\frac{a\dot{a}}{\upsilon}$

micropolar fluid flow over the vertical porous plate with the chemical reaction and Joule heating. Aurangzaib et al. [7] investigated the problem of thermophoresis effect on MHD micropolar fluid flow over a stretching surface with Soret and Dufour effects. Srinivasacharya and RamReddy [8] examined the steady convective flow of a micropolar fluid over a vertical plate in a non-Darcian porous medium with Soret and Dufour effects and a numerical solution was obtained by Keller-Box method. The MHD flow of micropolar fluid through concentric cylinders with the chemical reaction and cross diffusion effects was studied by Srinivasacharya and Shiferaw [9]. The Magnetohydrodynamic flow of a micropolar fluid with Hall and ion slip currents plays a great significance role in the real world applications in engineering. Ayano [10] considered the mixed convective micropolar fluid flow with heat and mass transfer in the presence of Hall and ion slip currents and the reduced governing equations are solved by the Keller-box method. The MHD flow of a micropolar fluid over a vertical plate with Hall and ion slip currents was investigated numerically by Anika et al. [11]. An analytical approximate solution HAM is applied to the effect of space porosity on mixed convection flow of micropolar fluid through a vertical channel with double diffusion and viscous dissipation was investigated by Muthuraj et al. [12]. Vedavathi et al. [13] illustrated the Soret and Dufour effects on the free convective flow of a viscous fluid past a vertical plate with radiation. The effects of Hall and ion slip on the mixed convection heat and mass transfer of second grade fluid with Soret and Dufour effects were investigated analytically by Hayat and Nawaz [14]. Chamkha and Ben-Nakhi [15] considered the mixed convection flow of a radiating viscous fluid along a permeable surface in a porous medium with Soret and Dufour effects. Soret and Dufour effects on free convective heat and mass transfer of incompressible viscous fluid from a vertical cone in a saturated porous medium with varying wall temperature and concentration were studied by Cheng [16]. The MHD flow of a viscous fluid over a vertical porous plate with Hall current has been considered by Anika et al. [17].

The study of magnetohydrodynamic flow, heat and mass transfer through porous expanding or contracting channels is attracted by many authors due to great applications in science and technology, such as transport of biological fluids through contracting or expanding vessels, the synchronous pulsating of porous diaphragms, the expanding or contracting jets, transpiration cooling and gaseous diffusion, the air circulation in the respiratory system, boundary layer control, and MHD pumps.