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ORIGINAL ARTICLE

Numerical investigation on heat and mass transfer effect of micropolar fluid over a stretching sheet through porous media

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Abstract The present paper deals with the study of unsteady heat and mass transfer characteristics of a viscous incompressible electrically conducting micropolar fluid. The flow past over a stretching sheet through a porous medium in the presence of viscous dissipation. A uniform magnetic field is applied transversely to the direction of the flow. Similarity transformations are used to convert the governing time dependent non-linear boundary layer equations into a system of non-linear ordinary differential equations that are solved numerically by Runge–Kutta fourth order method with a shooting technique. The influence of unsteady parameter (A), Eckert number (E_c), porous parameter (K_p), Prandtl number (P_r), Schmidt number (S_c) on velocity, temperature and concentration profiles are shown graphically. The buoyancy force retards the fluid near the velocity boundary layer in case of opposing flow and is favorable for assisting flow. In case of assisting flow, the absence of porous matrix enhances the flow. The impact of physical parameters on skin friction co-efficient, wall couple stress and the local Nusselt number and Sherwood number are shown in tabular form.

1. Introduction

The boundary layer flow, heat and mass transfer in a quiescent Newtonian and non-Newtonian fluid driven by a continuous stretching sheet are of significance in a number of industrial engineering processes such as the drawing of a polymer sheet or filaments extruded continuously from a die, the cooling of a metallic plate in a bath, the aerodynamic extrusion of plastic sheets, the continuous casting, rolling, annealing and thinning of copper wires, the wires and fiber coating, etc. The final product of desired characteristics depends on the rate of cooling in the process and the process of stretching. Mohammadi and Nourazar [1] studied on the insertion of a thin gas layer in micro cylindrical Couette flows involving power-law liquids. The analytical solution for two-phase flow between two rotating cylinders filled with power-law liquid and a micro layer of gas has been investigated by Mohammadi et al. [2]. The dynamics of the boundary layer flow over a stretching surface originated from the pioneering work of Crane [3]. Later on,

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Nomenclature

A	unsteadiness parameter
a	positive constant with dimension per time
B	non-dimensional parameter
B_0	applied magnetic field
b	constant with dimension temperature over length
C	concentration of the solute
C_{fx}	local skin friction co-efficient
C_p	specific heat at constant pressure
C_{sx}	local couple stress co-efficient
C_ω	concentration of the solute at the sheet
C_∞	concentration of the solute far from the sheet
D'	molecular diffusivity
E_c	Eckert number
e	positive constant
f	dimensionless stream function
g	acceleration due to gravity
G_c	solutal Grashof number
G_r	thermal Grashof number
h	non-dimensional variable
j	micro inertia density
K_p	local porous parameter
k	thermal conductivity
K_p^*	permeability of the porous medium
M	magnetic field parameter
M_{wx}	local wall couple stress
N	micro-rotation component
N_{ux}	local Nusselt number
P_r	Prandtl number
R_{ex}	local Reynold number
S_c	Schmidt number
Sh_x	local Sherwood number
T	non-dimensional temperature
t	non-dimensional time
T_ω	wall temperature of the fluid
T_∞	temperature of the fluid far away from the sheet
U_ω	sheet velocity
(u, v)	velocity components
(x, y)	cartesian co-ordinates

Greek symbol

α	stretching rate
α_0	thermal diffusivity
β	coefficient of thermal expansion
β'	coefficient of concentration expansion
Δ	micropolar parameter
υ	kinematics coefficient of viscosity
κ	kinematics micro-rotation viscosity
λ_0	non-dimensional material parameter
μ	coefficient of viscosity
γ	spin gradient viscosity
σ	electrical conductivity
ρ	density of the fluid
τ_w	wall shear stress
ϕ	non-dimensional concentration
θ	non-dimensional temperature
η	similarity variable

Subscripts

ω	condition at wall
∞	condition at free stream

various aspects of the problem have been investigated such as Gupta and Gupta [4], Chen and Char [5], and Dutta et al. [6] extended the work of Crane [3] by including the effect of heat and mass transfer analysis under different physical situations.

Micropolar fluids are fluids with microstructure and asymmetrical stress tensor. Physically, they represent fluids consisting of randomly oriented particles suspended in a viscous medium. These types of fluids are used in analyzing liquid crystals, animal blood, fluid flowing in brain, exotic lubricants, the flow of colloidal suspensions, etc. The theory of micropolar fluids, is first proposed by Eringen [7,8]. In this theory the local effects arising from the microstructure and the intrinsic motion of the fluid elements are taken into account. The comprehensive literature on micropolar fluids, thermomicropolar fluids and their applications in engineering and technology was presented by Ariman et al. [9], Prathap Kumar et al. [10]. Kelson and Desseaux [11] studied the effect of surface conditions on the micropolar flow driven by a porous stretching sheet. Srinivasacharya et al. [12] analyzed the unsteady flow of micropolar fluid between two parallel porous plates. Bhargava et al. [13] investigated by using a finite element method the flow of a mixed convection micropolar fluid driven by a porous stretching sheet with uniform suction.

Gorla and Nakamura [14] discussed the combined convection from a rotating cone to micropolar fluids with an arbitrary variation of surface temperature. Takhar et al. [15] examined the bouncy effects in a forced flow in the three dimensional non-steady motion of an incompressible micropolar fluid in the vicinity of the forward stagnation point of a blunt nosed body. Ibrahim et al. [16] discussed the case of mixed convection flow of a micropolar fluid past a semi-infinite, steadily moving porous plate with varying suction velocity normal to the plate in the presence of thermal radiation and viscous dissipation. Damseh Rebhi et al. [17] have investigated natural convection heat and mass transfer adjacent to a continuously moving vertical porous infinite plate for incompressible, micropolar fluid in the presence of heat generation or absorption effects and a first-order chemical reaction. Ali and Magyari [18] have studied the unsteady fluid and heat flow by a submerged stretching surface while its steady motion is slowed down gradually. Mukhopadhyay [19] extended it by assuming the viscosity and thermal diffusivity are linear functions of temperature and studied unsteady mix convection boundary layer flow of an incompressible viscous liquid through porous medium along a permeable surface, and the thermal radiation effect on heat transfer was also considered.