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ORIGINAL ARTICLE

Q1 Magnetohydrodynamic (MHD) Jeffrey fluid over Q2 a stretching vertical surface in a porous medium

Kartini Ahmad[a,*], **Anuar Ishak**[b]

[a]*Department of Science in Engineering, Kulliyah of Engineering, IIUM, Gombak, Kuala Lumpur 50728, Malaysia*
[b]*School of Mathematical Sciences, Faculty of Science and Technology, UKM, UKM Bangi, Selangor 43600, Malaysia*

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Abstract This paper presents the study of steady two-dimensional mixed convection boundary layer flow and heat transfer of a Jeffrey fluid over a stretched sheet immersed in a porous medium in the presence of a transverse magnetic field. The governing partial differential equations are reduced to nonlinear ordinary differential equations with the aid of similarity transformation, which are then solved numerically using an implicit finite difference scheme. The effects of some of the embedded parameters, such as Deborah number β, magnetic parameter M, mixed convection parameter λ, porosity parameter γ and Prandtl number Pr, on the flow and heat transfer characteristics, are given in forms of tables and graphs.

1. Introduction

Flow of non-Newtonian fluid over stretching sheet has caught researchers' attention in the last few decades due to its important practical applications, mainly in manufacturing and industry processes. For instance, in the extrusion of polymer process, the extrudate from the die is generally drawn and simultaneously stretched into sheet of desired thickness, and is then solidified. The final quality of the sheet depends mainly on the extensibility of the sheet and rate of heat transfer. Therefore, the cooling procedure has to be monitored adequately. To the best knowledge of the authors, the boundary layer flow over a moving horizontal sheet was first initiated by Sakiadis [1], who developed the flow field due to a flat surface. His work was later extended by Crane [2] to a stretching sheet, for the two-dimensional problem where surface velocity is

*Corresponding author. Tel.: +603-6196 6528.
E-mail address: kartini@iium.edu.my (Kartini Ahmad).

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Nomenclature

a,b	constant
B_0	uniform magnetic field
C_f	skin friction coefficient
f	dimensionless stream function
g	acceleration to gravity
Gr_x	local Grashof number
k	thermal conductivity
M	magnetic parameter
Nu_x	local Nusselt number
Pr	Prandtl number
q_w	wall heat flux
Re_x	local Reynolds number
T	fluid temperature
$T_w(x)$	temperature of the stretching sheet
w	condition at the stretching sheet
T_∞	ambient temperature
u,v	velocity components along the x and y directions, respectively
u_e	velocity of the ambient fluid
x,y	Cartesian coordinates along the surface and normal to it, respectively

Greek symbols

α	thermal diffusivity
β	Deborah number
β_T	thermal expansion coefficient
ε	permeability coefficient
η	similarity variable
λ	buoyancy or mixed convection parameter
λ_1	ratio of the relaxation and retardation times
λ_2	relaxation time
θ	dimensionless temperature
μ	dynamic viscosity
γ	porosity parameter
ν	kinematic viscosity
ρ	fluid density
σ	electrical conductivity
τ_w	shear stress
ψ	stream function

Subscripts

w	wall

proportional to the distance from a fixed point. Since then, extensive research has been done capturing the various physical conditions and rheology of the fluids with different conditions, see for example Refs. [3–10].

Flow of an electrically-conducting fluid subject to a magnetic field has important applications, such as cooling nuclear reactors and magnetohydrodynamic (MHD) generators, plasma studies, oil exploration, geothermal energy extraction and boundary layer control in the field of aerodynamics [11]. In metallurgical processes, such as drawing, annealing and thinning of copper wires which involve cooling of continuous strips or filaments, the MHD effect is believed to improve the rate of cooling and hence, the properties of the final products. Mansur and Ishak [12] studied numerically magnetohydrodynamic (MHD) boundary layer flow of a nanofluid past a stretching/shrinking sheet with velocity, thermal, and solutal slip boundary conditions. Siddheshwar and Mahabaleshwar [13] examined analytically MHD flow of micropolar fluid over linear stretching sheet using regular perturbation technique and Ahmed et al. [14] applied the successive linearization method to study the effects of radiation and viscous dissipation on MHD boundary layer convective heat transfer with low pressure gradient in porous media. Other studies on the MHD flow in different fluids as well as different physical situations were considered for example in Refs. [15–22].

Due to its great range of applications in various fields, the investigation of convective heat transfer in fluid-saturated porous media has become a subject of interest, especially in geothermal energy recovery, food processing, fibre and granular insulation, design of packed bed reactors and dispersion of chemical contaminants in various processes in the chemical industry and environment [23]. Comprehensive studies can be found in Vafai [24], Nield and Bejan [25] and Vadasz [26]. There is an abundance of literature available which discusses fluid flow over stretching surfaces in porous medium. Some of them are Gbadeyan et al. [27] who investigated the effects of thermal diffusion and diffusion thermos effects on combined heat and mass transfer on mixed convection boundary layer flow over a stretching vertical sheet in a porous medium filled with a viscoelastic fluid in the presence of magnetic field, Imran et al. [28] studied the analysis of an unsteady mixed convection flow of a fluid saturated porous medium adjacent to heated/cooled semi-infinite stretching vertical sheet in the presence of heat source and Aly and Ebaid [29] investigated the mixed convection boundary-layer nanofluids flow along an inclined plate embedded in a porous medium using both analytical and numerical approaches. Dessie and Kishan [30] examined the MHD boundary layer flow and heat transfer of a fluid with variable viscosity through a porous medium towards a stretching sheet along with viscous dissipation and heat source/sink effects. Narayana [31] carried out a study on the effects of radiation and first-order chemical reaction on unsteady mixed convection flow of a viscous incompressible electrically conducting fluid through a porous medium of variable permeability between two long vertical non conducting wavy channels in the presence of heat generation, and to name a few.

Jeffrey fluid is a type of non-Newtonian fluid that uses a relatively simpler linear model using time derivatives instead of convected derivatives, which are used by most fluid models. Recently, this model of fluid has prompted active discussion. Some of the studies can be found in Shehzad et al. [32], Nallapu and Radhakrishnamacharya [33], Ahmad and Ishak [34] and Prasad et al. [35]. In view

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