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Magnetic field effect in three-dimensional flow of an Oldroyd-B nanofluid over a radiative surface

S.A. Shehzad [a,*], Z. Abdullah [a], F.M. Abbasi [b], T. Hayat [c,d], A. Alsaedi [d]

[a] Department of Mathematics, Comsats Institute of Information Technology, Sahiwal 57000, Pakistan
[b] Department of Mathematics, Comsats Institute of Information Technology, Islamabad 44000, Pakistan
[c] Department of Mathematics, Quaid-I-Azam University 45320, Islamabad 44000, Pakistan
[d] Nonlinear Analysis and Applied Mathematics (NAAM) Research Group, Faculty of Science, King Abdulaziz University, P. O. Box 80257, Jeddah 21589, Saudi Arabia

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ABSTRACT

This article investigates the convective heat and mass conditions in three-dimensional flow of an Oldroyd-B nanofluid. The stretched flow is electrically conducting in the presence of an applied magnetic field. Thermal radiation effects are accounted in the energy equation. The governing nonlinear problems are computed for the convergent approximate solutions. Influences of different parameters on the dimensionless temperature and nanoparticle concentration fields are shown and examined. Quantities of physical interest namely local Nusselt and Sherwood numbers are computed and analyzed numerically. Comparison in a limiting case is made with the previous published result and an excellent agreement is noted.

1. Introduction

The researchers at present are engaged to explore the properties of nanofluids under various aspects and flow configurations due to their importance in industry and technology. A colloidal mixture of small metal or metal oxide nanoparticles or carbon nanotubes into a base liquid is known as nanofluid. The physical properties of base fluids are dramatically change due to the addition of such nanoparticles. The interest of the researchers in this area is due to the higher thermal performance and potential role of nanofluids in high heat exchange and zero pressure drops. Further the role of nanofluids with biotechnological components has extensive applications in different biological sensors, agricultural and pharmaceutical processes etc. Buongiorno and Hu [1] explored that the nanofluids can be utilized in designing the waste heat removal systems and the standby systems like the emergency core cooling system. They also pointed out that the nanofluids may involve in the nuclear reactor applications. Some recent studies on nanofluids can be seen in the Refs. [2–8]. In addition the role of magneto nanofluids is quite important in manufacturing processes of industries due to its applications in gastric medications, sterilized devices, intelligent biomaterials etc. The manipulation of electrically conducting nanofluids is possible with the implementation of an applied magnetic field which is quite essential to achieve the desired quality of final product. The magneto nanoparticles have pivotal role in targeted drug release, magnetic resonance imaging, elimination of tumors with hyperthermia, synergistic effects in immunology, asthma treatment etc. [9]. Some recent investigations on magneto nanofluids can be consulted in the Refs. [10–18].

The energy conversion problems of non-Newtonian nanofluids induced by the stretching of surface through applied magnetic field and thermal radiation effects have prominent role in the industrial and engineering processes. Such problems arise in the extrusion of polymer sheet with very high radiation phenomenon that combines with magnetic field from a dye. In this procedure, film processing polymer melt has been stretched through a dye that is cooled via nanofluid in presence of radiation and magnetic field effects. The temperature distribution becomes the function of flow rate along the draw direction. The surface under consideration is a thin film type then the emission is strongly dependent upon the thickness of film and long wavelength of radiation. Magnetic liquid rotary seals perform with very low leakage and zero maintenance in abroad range of applications and it using the magnetic properties of magneto nanoparticles.

The present investigation is a combination of magnetic and radiative nanofluids which may be utilized in the extrusion manufacturing processing and other related fields. In this study,

* Corresponding author.
E-mail address: ali_qau70@yahoo.com (S.A. Shehzad).

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Nomenclature

u,v,w	velocity components
λ_1	relaxation time
λ_2	retardation time
B_0	applied magnetic field
T	Temperature
D_B	Brownian diffusion coefficient
ν	kinematic viscosity
C	nanoparticle concentration
σ^*	Steaffan-Boltzman constant
a,b	dimensional constant
h_2	mass transfer coefficient
T_f	ambient fluid temperature
T	radiative heat flux
η	similarity variable
Θ	dimensionless temperature
M	magnetic parameter
Le	Lewis number
Rd	radiation parameter
Nb	Brownian motion parameter
Nu	Nusselt number
Sh	Sherwood number
p	embedding parameter
$N_f, N_g, N_\theta, N\phi$	nonlinear operators
x,y,z	coordinate axes
σ	electrical conductivity
ρ_f	density of fluid
α	thermal diffusivity
τ	ratio of nanoparticle heat capacity
D_T	thermophoretic diffusion coefficient
c_f	specific heat capacity
u_w	stretching velocity
k^*	mean absorption coefficient
h_1	Heat transfer coefficient
k	thermal conductivity
C_f	ambient fluid concentration
f,g	dimensionless velocities
ϕ	dimensionless concentration
β_1, β_2	Deborah numbers
Pr	Prandtl number
Bi_1, Bi_2	Biot numbers
Nt	thermophoretic parameter
β	ratio parameter
Re_x	local Reynolds number
$L_f, L_g, L_\theta, L_\phi$	Linear operators
$\hbar_f$, $\hbar g$, $\hbar_\theta$, $\hbar_\varphi$	convergence control parameters

we consider the three-dimensional flow of an Oldroyd-B nanofluid with thermal radiation and magnetic field effect. Robin's type conditions for heat and mass transfer [19–22] are imposed at the boundaries of stretching surface. No attempt has been presented yet in the literature to investigate such flow analysis. The homotopy analysis method (HAM) [23–29] has been implemented to compute the series solutions of velocities, temperature and nanoparticle concentration. Impacts of important physical parameters on dimensionless temperature and nanoparticle concentration profile are plotted and discussed carefully.

2. Governing problems

We consider the steady three-dimensional flow of an incompressible Oldroyd-B fluid over a stretched surface at $z = 0$. The flow takes place in the domain $z > 0$ (see Fig. 1). The ambient fluid temperature and ambient nanoparticle concentration are taken as T_∞ and C_∞ while the surface temperature and surface nanoparticle concentration are maintained by convective heat transfer and convective nanoparticle concentration at a certain value T_f and C_f. The thermal radiation term is retained via Rosseland's approximation. The fluid is conducting through constant applied magnetic field. Induced magnetic field is neglected for small magnetic Reynolds number assumption. Electric field effect is taken zero. The governing boundary layer equations for an incompressible three-dimensional flow of an Oldroyd-B fluid are:

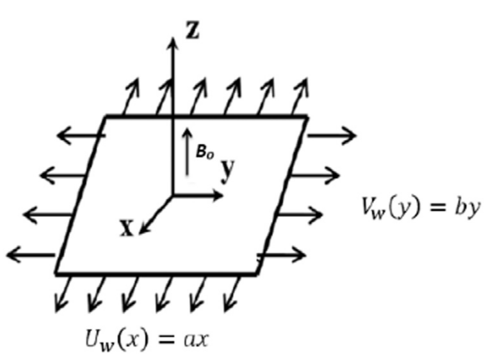

Fig. 1. Geometry of the problem.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0, \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}+\lambda_1\left(\begin{array}{c} u^2\frac{\partial^2 u}{\partial x^2}+v^2\frac{\partial^2 u}{\partial y^2}+w^2\frac{\partial^2 u}{\partial z^2}+2uv\frac{\partial^2 u}{\partial x\partial y}\\ +2vw\frac{\partial^2 u}{\partial y\partial z}+2uw\frac{\partial^2 u}{\partial x\partial z}\end{array}\right)$$
$$=\nu\left(\frac{\partial^2 u}{\partial z^2}+\lambda_2\left(\begin{array}{c} u\frac{\partial^3 u}{\partial x\partial z^2}+v\frac{\partial^3 u}{\partial y\partial z^2}+w\frac{\partial^3 u}{\partial z^3}-\frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial z^2}\\ -\frac{\partial u}{\partial y}\frac{\partial^2 v}{\partial z^2}-\frac{\partial u}{\partial z}\frac{\partial^2 w}{\partial z^2}\end{array}\right)\right)-\frac{\sigma B_0^2}{\rho_f}\left(u+\lambda_1 w\frac{\partial u}{\partial z}\right), \tag{2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+\lambda_1\left(\begin{array}{c} u^2\frac{\partial^2 v}{\partial x^2}+v^2\frac{\partial^2 v}{\partial y^2}+w^2\frac{\partial^2 v}{\partial z^2}+2uv\frac{\partial^2 v}{\partial x\partial y}+\\ 2vw\frac{\partial^2 v}{\partial y\partial z}+2uw\frac{\partial^2 v}{\partial x\partial z}\end{array}\right)$$
$$=\nu\left(\frac{\partial^2 v}{\partial z^2}+\lambda_2\left(\begin{array}{c} u\frac{\partial^3 v}{\partial x\partial z^2}+v\frac{\partial^3 v}{\partial y\partial z^2}+w\frac{\partial^3 v}{\partial z^3}-\frac{\partial v}{\partial x}\frac{\partial^2 v}{\partial z^2}\\ -\frac{\partial v}{\partial y}\frac{\partial^2 v}{\partial z^2}-\frac{\partial v}{\partial z}\frac{\partial^2 w}{\partial z^2}\end{array}\right)\right)-\frac{\sigma B_0^2}{\rho_f}\left(v+\lambda_1 w\frac{\partial v}{\partial z}\right), \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\frac{\partial^2 T}{\partial z^2}+\tau\left(D_B\frac{\partial C}{\partial z}\frac{\partial T}{\partial z}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial z}\right)^2\right)+\frac{1}{(\rho c)_f}\frac{16\sigma^* T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial z^2}, \tag{4}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial z^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial z^2}, \tag{5}$$