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Radiative flow of micropolar nanofluid accounting thermophoresis and Brownian moment

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ABSTRACT

This article describes the Brownian motion and thermophoresis aspects in nonlinear flow of micropolar nanoliquid. Stretching surface with linear velocity creates the flow. Energy expression is modeled subject to consideration of thermal radiation phenomenon. Effect of Newtonian heating is considered. The utilization of transformation procedure yields nonlinear differential systems which are computed through homotopic approach. The important features of several variables like material parameter, conjugate parameter, Prandtl number, Brownian motion parameter, radiation parameter, thermophoresis parameter and Lewis number on velocity, micro-rotation velocity, temperature, nanoparticles concentration, surface drag force and heat and mass transfer rates are discussed through graphs and tables. The presented analysis reveals that the heat and mass transfer rates are enhanced for higher values of radiation and Brownian motion parameters. Present computations are consistent with those of existing studies in limiting sense.

Introduction

The concept regarding heat transport improvement via dispersing solid particles of nanometer dimensions was first introduced by Choi [1]. The traditional liquids like water, ethylene glycol and oils have poor heat transfer capability due to their low thermal conductivity. To increase the thermal conductivity of such liquids, the nano-scale solid particles are suspended in base liquids which change the thermophysical characteristics and increased the heat transfer rate remarkably. Several studies regarding the improvement of heat transfer through nanofluids have been reported. For illustration, the importance of entropy generation in MHD nanofluid flow with thermal radiation and convective boundary conditions by vertical microchannel is discussed by Lopez et al. [2]. Farooq et al. [3] analyzed nonlinear thermal radiation characteristics in flow of viscoelastic nanofluid. Analysis of magneto Casson nanoliquid flow with temperature dependent conductivity by a stretchable cylinder is reported by Hayat et al. [4]. Khan et al. [5] presented non-aligned oblique hydromagnetic stagnation region flow of nanofluid with variable viscosity and thermal radiation. Dissipation effects in magneto viscous nanoliquid induced by an exponentially

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Nomenclature

u, v velocity components
N microrotation
υ kinematic viscosity
J microinertia per unit mass
(γ^*) spin gradient viscosity
k, k_1 vortex viscosity, thermal conductivity
ρ, c_p density, specific heat
D_B Brownian diffusion
T temperature
α_m thermal diffusivity
D_T thermophoretic diffusion
T_∞ ambient temperature
τ ratio of effective heat capacity
C concentration
C_∞ ambient concentration
q_w wall heat flux
N_t thermophoresis parameter
N_b Brownian motion parameter
Le Lewis number
Nu_x heat transfer rate
τ_w shear stress
C_f skin friction coefficient
σ^* Stefan–Boltzmann constant
k^* mean absorption coefficient
h_s heat transfer coefficient
Pr Prandtl number
K micropolar parameter
R_d radiation parameter
η transformed variable
ψ stream function
$f_0(\eta)$, $g_0(\eta)$, $\theta_0(\eta)$, $\phi_0(\eta)$ initial approximations
Re_x Reynolds number
$\mathcal{L}_f$, $\mathcal{L}_g$, $\mathcal{L}_\theta$, $\mathcal{L}_\phi$ linear operators
C_i arbitrary constants
$f_m^*, f_g^*, f_\theta^*, f_\phi^*$ special solutions
h_f, h_g, h_θ, h_ϕ auxiliary parameters
Sh_x Sherwood number
γ conjugate parameter

stretchable surface are disclosed by Imtiaz et al. [6]. Three dimensional flow of aluminium oxide, copper and titanium dioxide nanoparticles by nonlinear stretched surface with Soret and Dufour effect is discussed by Mahanthesh et al. [7]. Combined effects of thermal radiation and convective heating in flow of variable viscosity nanoliquid by radially stretched surface are studied by Makinde et al. [8]. Shehzad et al. [9] modeled the three dimensional magneto Oldroyd-B nanoliquid flow with thermal radiation and convective condition. Afterwards extensive attempts on the topic are given (for detail see Refs. [10–20] and several studies therein).

Non-Newtonian materials are often encountered in several technical applications which comprise manufacturing crude soft elastic materials, performance of oils, greases, paints, processed food and movement of biological liquids. Blood, ketchup, liquid cosmetics, dyes, certain lubricants and puncturing sludge are few specimens of rheological liquids. In these liquids relationship between stress and strain is nonlinear in nature. In contrast to Newtonian liquids such liquids are much more difficult to analyze. Even Navier Stokes expressions are highly complicated involving number of constraints and the results of consequent equalities are more challenging to obtain [21]. Therefore several nonlinear models regarding non-Newtonian liquids have been presented (see Refs. [22–25] and several studies therein). Eringen [26] disclosed that theory of Navier–Stokes fails to interpret specifically the features of distinct liquids reveal with microscopic aspects developing from the micromotions and local structure of liquid elements. These kind of liquids are named micropolar liquids. These liquids are utilized to examine the characteristics of dirty oils, lubricants, polymeric suspensions, liquid crystals, animal blood with stiff cells and several other biological liquids [27]. Few studies related with flow of micropolar liquids can be addressed through [28–32] and several studies therein.

The characteristics of liquid flow by flat stretchable surface with heat/mass transfer are of much significance due to numerous applications in plastic and rubber sheets manufacturing, filaments and polymer sheets, glass blowing etc. Stretchable flow by flat surface is firstly explored by Crane [33]. Various researchers [34–37] thus discussed the heat/mass transfer characteristics in this direction with different flow geometries. Moreover the radiation phenomenon has increased much consideration of the researchers since it has multiple utilizations in industry and engineering. Such applications comprise polymer processing, nuclear reactors, glass production, gas cooled, solar power, satellites and in space technology like rocket, power plant and missiles etc. Olajuwon et al. [38] reported Hall current and magnetohydrodynamic impacts in thermally radiative micropolar liquid flow. Analytical solutions for radiative three-dimensional stretchable flow of magneto viscous nanoliquid with dissipation and convective heating condition are developed by Nayak [39]. Hayat et al. [40] developed numerical solutions for stagnation point flow of radiative viscous nanomaterial by a stretchable cylinder.

Flow of micropolar nanofluid due to stretchable surface with thermal radiation and Newtonian heating is the main concern of present study. Nanofluid modeling comprise the Brownian motion and thermophoresis aspects. The governing expressions are solved with the help of homotopy analysis method (HAM) [41–52]. Graphical results are used to elaborate the impacts of involved pertinent parameters on the velocity, micro-rotation velocity, temperature, concentration, surface drag force and heat and mass transfer rates. Results are compared with the previous limiting studies. To our knowledge such attempt even in absence of Brownian motion and thermophoresis does not exist.

Governing problems

Here Brownian motion and thermophoresis effects in stretchable flow of an incompressible micropolar nanoliquid are investigated. Stretching surface has linear velocity ($u_w(x) = cx$). Thermal radiation and Newtonian heating describe the heat transfer process. Viscous dissipation in energy expression is not considered. Detailed flow assumptions