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ORIGINAL ARTICLE

Heat transfer analysis of Jeffery fluid flow over a stretching sheet with suction/injection and magnetic dipole effect

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Jeffery fluid;
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Stretching surface;
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Abstract The purpose of the present paper was to investigate the flow and heat transfer of Jeffery fluid past a linearly stretching sheet with the effect of a magnetic dipole. The governing differential equations of motion and heat transfer are transformed into nonlinear coupled ordinary differential equations (ODEs) using appropriate similarity transformations. Then the ODEs are solved by adopting two different schemes, Runge–Kutta with shooting technique and series solution based on GA and NM. The effect of various physical parameters including ferromagnetic interaction parameter (β), Deborah number (γ_1), Prandtl number (Pr), suction/injection parameter (S), ratio of relaxation to retardation times (λ_2) on velocity and temperature profiles is illustrated graphically and in tabular form by considering two types of thermal process namely prescribed surface temperature (PST) and prescribed heat flux (PHF). Comparison with available results for particular cases is found an excellent agreement.

1. Introduction

Boundary layer flow and heat and mass transfer over a stretching surface have received spectacular attention due to their extensive applications in industry, engineering, and metallurgy process such as production of polythene and paper, polymer extrusion, cooling of elastic sheets, wire drawing, fiber technology, continuous stretching of plastic films, hot rolling, crystal growing and cooling of an infinite metallic plate in a cooling bath. Heat transfer is important because the rate of cooling can be controlled and final products of desired characteristics might be achieved. Flow over a flat plate with uniform free stream has been examined by Blasius [1]. The boundary layer flow over a continuous moving flat surface was initially investigated by Sakiadis [2]. Crane [3] established a simple closed form analytical solution for two-dimensional incompressible boundary layer flow over a linear stretching sheet with the velocity proportional to the distance from the origin. This problem was extended to heat and mass transfer with the effect of suction or blowing by Gupta and Gupta [4]. Ariel [5] considered the problem of boundary layer flow of a viscous fluid by a stretching sheet using homotopy perturbation method. Some of the collections of research papers existing in the open literature can be found in [6–11].

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Nomenclature

a	distance
c	stretching rate (s^{-1})
c_p	specific heat at constant pressure ($Jkg^{-1}\,K^{-1}$)
C_f	skin friction coefficient
f	dimensionless stream function
H	magnetic field (A/m)
k	thermal conductivity ($Wm^{-1}\,K^{-1}$)
K^*	pyromagnetic coefficient
κ	extra stress tensor
M	magnetization (A/m)
N_{ux}	local Nusselt number
Pr	Prandtl number
Re_x	local Reynolds number
R_1	Rivlin-Ericksen tensor
S	suction/injection parameter
T	temperature (K)
T_c	Curie temperature (K)
(u,v)	velocity components ($m\,s^{-1}$)
(x, y)	coordinates along and normal to sheet (m)
μ	dynamic viscosity ($Ns\,m^{-1}$)
μ_o	magnetic permeability
θ	dimensionless temperature

Greek symbols

α_1	dimensionless distance
β	ferromagnetic interaction parameter
γ	magnetic field strength (A/m)
γ_1	Deborah number
ρ	density ($kg\,m^{-3}$)
ε	dimensionless curie temperature
(η, ξ)	dimensionless coordinate
ψ	stream function ($m^2\,s^{-1}$)
ϕ	magnetic potential
τ	Cauchy stress tensor
λ	viscous dissipation parameter
$\lambda_1\ \lambda_2$	material parameters of Jeffrey fluid

However, all the above-mentioned researches are restricted to Newtonian fluid flows. Fluids that do not obey the Newton's law of motion are called non-Newtonian fluids. Study of non-Newtonian fluids has received great attention in modern technologies such as geothermal engineering, geophysical, astrophysical bio-fluid and petroleum industries, and some of the examples of non-Newtonian fluids are toothpaste, waste fluids, and food products. Many constituent relations of non-Newtonian fluids have been considered in the literature due to its versatile nature. Here we considered Jeffrey fluid model for non-Newtonian fluids. Sahoo [12] performed heat transfer analysis of non-Newtonian fluid over a stretching surface. He applied finite difference method with shooting technique to obtain simultaneous effects of the partial slip and the third-grade fluid parameter on velocity and temperature fields.

Sandeep et al. [13] investigated the stagnation point flow of MHD Jeffrey nanofluid over a stretching surface with induced magnetic field and chemical reaction. Raju et al. [14] analyzed the effects of nonlinear thermal radiation on 3D Jeffrey fluid flow over a stretching/shrinking surface in the presence of homogeneous-heterogeneous reactions, non-uniform heat source/sink, and suction/injection. Rashidi et al. [15] performed mixed convective laminar, incompressible flow and heat analysis transfer of viscoelastic fluid over a permeable wedge with thermal radiation by employing homotopy analysis method (HAM).

Hayat et al. [16] considered Jeffery fluid flow in a porous channel in the presence of a transverse magnetic field. They found a semi-analytical solution to the highly nonlinear problem by applying HAM. Hayat et al. [17] determined three-dimensional boundary layer flow of Jeffrey fluid past a stretching surface by employing HAM. Animasaun et al. [18] studied the motion of viscoelastic fluid toward a stretching sheet in the presence of induced magnetic field for the case of unequal diffusivities of homogeneous–heterogeneous reaction with thermal radiation. Nadeem et al. [19] investigated the effect of nanoparticles on two-dimensional steady flow of a Jeffrey fluid past a stretching surface. Rashidi and Erfani [20] analyzed thermal-diffusion and soret effect on steady MHD convective slip flow due to a rotating disk with viscous dissipation and Ohmic heating using the DTM-Padé technique.

Malik et al. [21] presented the Jeffrey fluid flow with a pressure-dependent viscosity. They considered two types of flow problem, Couette and Poiseulle flow for the Jeffrey fluid. Raju et al. [22] have discussed MHD chemically reacting boundary layer flow of Jeffrey nanofluid over a permeable cone in a porous medium with the effect of thermophoresis, Brownian motion, and thermal radiation. Sandeep et al. [23] studied heat and mass transfer of convective non-Newtonian nanofluids over a permeable stretching sheet with the effects of transverse magnetic field and suction/injection. Abolbashari et al. [24] examined entropy analysis for MHD nano-fluid past a permeable stretching surface. They considered four different types of nanoparticles with water as the base fluid. Narayana et al. [25] studied the flow of micropolar ferromagnetic fluid due to stretching of an elastic sheet in the presence of an applied magnetic field.

In view of all the above-stated application, the main objective of the present article was to explore the flow and heat transfer behavior of Jeffery fluid over a stretching surface with the influence of magnetic dipole. Effect of non-dimensional governing parameters such as ferromagnetic interaction parameter, suction/injection parameter, Deborah number, the ratio of relaxation to retardation times, Prandtl number on velocity and temperature fields is analyzed through the graph.

2. Mathematical formulation

2.1. Magnetic dipole

Magnetic liquid flow is influenced by the dipole field whose permanent magnetic scalar potential is taken as

$$\Phi = \frac{\gamma}{2\pi}\left(\frac{x}{x^2 + (y+a)^2}\right), \quad (1)$$

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