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Entropy generation analysis for non-Newtonian nanofluid with zero normal flux of nanoparticles at the stretching surface

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ABSTRACT

The primary objective of the present analysis is to investigate the entropy generation via two important slip mechanism Brownian motion and thermophoresis diffusion in non-Newtonian nanofluid flow. These effects are analyzed by momentum equation along with a newly formed equation for nanoparticle distribution. Conventional energy equation is modified for the nanofluid by incorporation nanoparticles effects. The condition for zero normal flux of nanoparticles at the stretching sheet is defined to impulse the particles away from surface. To measure the disorder in the thermodynamic system an entropy generation analysis is discussed for present Jeffery nanofluid model. In order to solve the governing equations, compatible similarity transformations are used to obtain a set of higher order non-linear differential equations. An optimal homotopy analysis method (OHAM) and Keller Box Method are used to solve the given system of higher order nonlinear differential equations. Effect of emerging parameters such as Prandtl number, Schmidt number, Brownian motion and thermophoresis on temperature and concentration are shown through graphs. Variations in the entropy generation for different emerging parameters are discussed in detail with the help of graphical results. Also, the coefficient of skin friction, Nusselt number, Sherwood number and characteristic entropy generation rate are presented through graphs.

1. Introduction

During the last few decades, researchers have shown much interest in the boundary layer flows (Newtonian and non-Newtonian) along with the heat transfer over a stretching surface due to the wide range of applications in many industrial processes such as, materials manufactured by polymer extrusion, drawing of copper wires, glass fiber, cooling of metallic sheets and electronic chips.

Sakiadis [1] was the first who initiate the concept of boundary layer flow over a solid surface. This basic study of Sakiadis lay down a foundation for such problems over stretching surface, extensive literature is extended on boundary layer flow with the linear and nonlinear stretching surfaces for both Newtonian and non-Newtonian fluids [2–14]. The recent literature study concerning to the exponential stretching surface with respect to boundary layer flow still required, more intentions due to its practical applications in the industries. Magyari and Keller [15] were the first who considered the boundary layer flow and heat transfer analysis over an exponentially stretching sheet. After this several studies are discussed by many researchers for boundary layer flow over an exponentially stretching surface for different models some studies are mentioned here [16–18].

The term nanofluid was first introduced by Choi [19]. After the initial concept of nanofluid, Choi et al. [20] showed that the addition of small amount (less than 1% by volume) of nanoparticles in conventional heat transfer liquids increased the thermal conductivity of the base fluid up to 10–20%. In packaging and plastic industry, nanoparticles incorporation can play an important role on the quality and strength of final product. The packaging films can be made more reliable by introducing silicate nanoparticles. Zinc oxide nanoparticles incorporation into the plastic packaging films can block UV rays and provide anti-bacterial protection, while improving the strength and stability of the plastic film.

In 2006, Buongiorno [21] present the seven slip mechanism which are quite important as per requirement of turbulent and laminar flow. In this idea where he discovered that the nanoparticle absolute velocity can be viewed as a sum of the base fluid velocity and relative velocity. In his article he further described seven slip mechanisms namely: inertia, Brownian Diffusion, thermophoresis, diffusiophoresis, Magnus effect, fluid drainage and gravity settling for turbulent flow. But his idea was more compact for laminar flow where the effects of Brownian diffusion and thermophoresis were more significant. Study of boundary layer flow of nanofluid along a vertical surface is initially presented by

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Nield and Kuznetsav [22,23]. Recently, Khan and Pop [24] extend the idea of Kuznetsav and Nield for study of boundary layer flow of nanofluid past a stretching sheet prescribed a constant surface temperature. Narayana et al. [25] studied MHD nanofluid past a vertical plate in a rotating system with porous medium in the presence of thermal radiation and heat source effects. Venkateswarlu and Narayana [26] discussed heat transfer of a nanofluid in a rotating system in the presence of chemical reaction with radiation absorption effects. Nadeem and Lee [27] studied the two dimensional viscous boundary layer flow of nanofluid over an exponentially stretching surface analytically. Liu et al. [28] are the first who give the idea of three- dimensional boundary layer flow over an exponentially stretching surface. Nadeem et al. [29] presented numerical solution for water-based nanofluid over an exponential stretching surface. Sajjad et al. [30] discussed boundary layer Jeffrey fluid flow over bi-directional exponentially stretching surface and present series solution. Malik et al. [31] studied the three dimensional boundary layer flows over an exponentially stretching surface in the presence of thermal radiation. Mustafa et al. [32] consider flow of a nanofluid over exponentially stretched surface with convective boundary conditions. Dailr et al. [33] employed numerical solution for entropy generation analysis for magneto-hydrodynamic flow of Jeffery nanofluid over stretching surface. Bilal et al. [34] discussed analytic solution for Eyring–Powell nanofluid over exponentially stretched surface. Current study demands lot of attention in the field of nanofluid flow and heat transfer due to stretching sheet [35–39].

Entropy generation analysis in flow and heat transfer is investigated by many researchers. In thermodynamical system, diffusion, chemical reactions, friction force between solid surfaces and fluid viscosity within a system give rise to energy loses, which induces entropy generation in the system. Due to this entropy generation has been of great interest in the fields such as heat exchangers, turbomachinery, and electronic cooling. Aiboud and Sauoli [40] studied entropy generation analysis in viscoelastic MHD flow over a stretching surface. Butt et al. [41] presented the effects of velocity slip on entropy generation in the boundary layer flow over a vertical sheet with convective boundary conditions. Noghrehabadi et al. [42] discussed entropy generation for nanofluid over a stretching sheet with heat generation/absorption. Abolbashari et al. [43] used HAM to discuss entropy generation in an unsteady MHD nanofluid flow adjacent to a stretching surface with the water as base fluid and different type of nanoparticles. Further literature survey reveals that there is no study available for entropy generation analysis for three dimensional boundary layer flow of Jeffery nanofluid over bi-directional exponentially stretching surface.

The main objective of the present study is to investigate analytically and numerically, the zero normal flux boundary condition for nanoparticle and entropy generation analysis for Jeffery nanofluid over an exponentially stretching surface. Buongiorno model is used to investigate the heat transfer due to nanoparticles. Entropy generation analysis is carried out in the presence of viscous dissipation for Jeffrey nanofluid. For this purpose proper similarity transformations are used to reduce governing equations to ordinary differential equations. The effect of Lewis umber, Brownian motion and thermophoresis for nanofluid are discussed through graphs. Moreover entropy generation due to heat transfer, viscous dissipation and for mass transfer is considered. The near wall quantities, such as local skin friction for velocity profile, Nusselt number due to heat transfer and Sherwood number due to nanoparticle concentration are discussed.

2. Problem formulation

Consider steady, three dimensional incompressible flow of Jeffrey nanofluid past over an exponentially stretching surface coinciding with the plane at $z = 0$ and flow is confined to upper half plane at$z > 0$. The problem is considered by using Buongiorno [21] model which deals nanofluid as two-component mixture (base fluid + nanoparticles). The flow is generated, due to exponential stretching of the surface in two directions one is along $x-$axis and other is along $y-$axis by keeping origin fixed. The wall surface stretching velocities are $U_w = U_0 e^{\frac{x+y}{L}}$ and $V_w = V_0 e^{\frac{x+y}{L}}$ where U_0, V_0 are constants. Moreover temperature and concentration of nanoparticles are distributed exponentially. The wall temperature T_w and concentration C_w are greater than the ambient temperature and concentration, T_∞ and C_∞ respectively (Fig. 1).

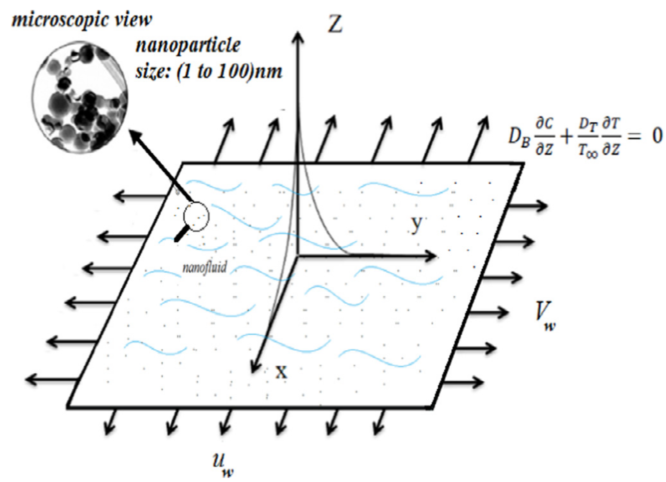

Fig. 1. Geometry of the problem.

3. Governing equations for Jeffery nanofluid

3.1. Momentum equation

The governing equations of motion for present problem in the presence of boundary layer approximation are, as reported in [30]

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = \frac{\nu}{1+\lambda_1} \times \left[\frac{\partial^2 u}{\partial z^2} + \lambda_2\left(\begin{array}{c}\frac{\partial u}{\partial z}\frac{\partial^2 u}{\partial x\partial z} + \frac{\partial v}{\partial z}\frac{\partial^2 u}{\partial y\partial z} + \frac{\partial w}{\partial z}\frac{\partial^2 u}{\partial z^2}\cdots \\ +u\frac{\partial^3 u}{\partial x\partial z^2} + v\frac{\partial^3 u}{\partial y\partial z^2} + w\frac{\partial^3 u}{\partial z^3}\end{array}\right)\right], \tag{2}$$

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = \frac{\nu}{1+\lambda_1} \times \left[\frac{\partial^2 v}{\partial z^2} + \lambda_2\left(\begin{array}{c}\frac{\partial u}{\partial z}\frac{\partial^2 v}{\partial x\partial z} + \frac{\partial v}{\partial z}\frac{\partial^2 v}{\partial y\partial z} + \frac{\partial w}{\partial z}\frac{\partial^2 v}{\partial z^2}\cdots \\ +u\frac{\partial^3 v}{\partial x\partial z^2} + v\frac{\partial^3 v}{\partial y\partial z^2} + w\frac{\partial^3 v}{\partial z^3}\end{array}\right)\right], \tag{3}$$

3.2. Heat transfer and nanoparticle concentration equation

The modified form of thermal energy equation with viscous dissipation [44] and nanoparticle concentration equation for a nanofluid can be written as

$$(\rho c_p)_f\left[\frac{\partial T}{\partial t} + V.\nabla T\right] = \nabla.(k\nabla T) + S.\mathbf{L} + (\rho c_p)_p \times \left[D_B \nabla C.\nabla T + D_T\frac{\nabla T.\nabla T}{T_\infty}\right], \tag{4}$$