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# Influence of heat source/sink on a Maxwell fluid over a stretching surface with convective boundary condition in the presence of nanoparticles

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**Abstract** In this article, heat source/sink effects on the steady boundary layer flow of a Maxwell fluid over a stretching sheet with convective boundary condition in the presence of nanoparticles are reported. An appropriate similarity transformation is employed to transform the governing equations in partial differential equations form to similarity equations in ordinary differential equations form. The resulting equations are then solved numerically using shooting technique. Results for the velocity, temperature and concentration distributions are presented graphically for different values of the pertinent parameters. It is found that the local Nusselt number is smaller and local Sherwood number is higher for Maxwell fluids compared to Newtonian fluids.
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## 1. Introduction

Prandtl's boundary layer theory proved to be great use in Newtonian fluids as the Navier–Stokes equations can be converted into much simplified equations which are easier to handle. The stretching sheet concept in Crane's [1] boundary layer flow of a Newtonian fluid over a stretching sheet has been investigated and extended by several authors [2–5] for different physical situations, due to its important applications to polymer industry. These studies restrict their analyses to non-Newtonian fluids. Flow due to a stretching sheet also occurs in thermal and moisture treatment of materials, particularly in processes involving continuous pulling of a sheet through a reaction zone, as in metallurgy, textile and paper industries, in the manufacture of polymeric sheets, sheet glass and crystalline materials. It is well known that a number of industrial fluids such as molten plastics, polymeric liquids, food stuffs or slurries exhibit non-Newtonian character. Therefore a study of flow and heat transfer in non-Newtonian fluids is of practical importance. Many models of non-Newtonian fluids exist. Maxwell model is one subclass of rate type fluids. This fluid model predicts the relaxation time effects. Such effects cannot be predicted by differential-type fluids. This fluid model is especially useful for polymers of low molecular weight. A review of non-Newtonian fluid flow problems may be found in [6–8].

The study of heat source/sink effects on heat transfer is very important because its effects are crucial in controlling the heat transfer. Postelnicu et al. [9] examined the effect of variable

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**Nomenclature**

| | | | |
|---|---|---|---|
| $c$ | stretching rate | $u$, $v$ | velocity components along $x$ and $y$ directions |
| $C_f$ | skin friction | $U_w$ | stretching sheet velocity |
| $c_p$ | specific heat | $x$ | coordinate along the stretching sheet |
| $C$ | nanoparticle volume fraction | $y$ | distance normal to the stretching sheet |
| $D_B$ | Brownian diffusion coefficient | | |
| $D_T$ | thermophoresis diffusion coefficient | *Greek symbols* | |
| $Nb$ | Brownian motion parameter | $\nu$ | kinematic viscosity |
| $Nt$ | thermophoresis parameter | $\phi$ | rescaled nanoparticle volume fraction |
| $Nu_x$ | local Nusselt number | $\rho_f$ | density of the base fluid |
| $Le$ | Lewis number | $\rho_p$ | density of the particles |
| Pr | Prandtl number | $\lambda$ | suction parameter |
| $S$ | heat source/sink parameter | $\beta$ | Maxwell parameter |
| $Sh_x$ | local Sherwood number | $\theta$ | dimensionless temperature |
| $T$ | temperature of the fluid | $\eta$ | similarity variable |
| $T_w$ | temperature at the wall | $\alpha$ | thermal diffusivity |
| $T_\infty$ | ambient fluid temperature | $\tau_w$ | wall shearing stress |

viscosity on forced convection flow past a horizontal flat plate in a porous medium with internal heat generation, but in heat generation part they considered only space dependent heat source. Abo-Eladahab and El Aziz [10] analyzed the effect of non-uniform heat source with suction/blowing, but confined to the case of viscous fluids only. Bataller [11] examined the effects of heat source/sink, radiation and work done by deformation on flow and heat transfer of a viscoelastic fluid over a stretching sheet. Abel and Nandeppanavar [12] investigated the effects of viscous dissipation and non-uniform heat source in a viscoelastic boundary layer flow over a stretching sheet. Tsai et al. [13] studied the unsteady stretching surface with non-uniform heat source. Hsiao [14] obtained the numerical solutions for the flow and heat transfer of a viscoelastic fluid over a stretching sheet with electromagnetic effects and non-uniform heat source/sink using the combination of finite difference method, Newton's method, and Gauss elimination method. In above cited papers they are shown that for effective cooling of stretching sheet, non-uniform heat source/sink should be used.

Aforementioned studies were primarily concerned with the laminar flow of a clear fluid (Newtonian/non-Newtonian fluid). In the recent past a new class of fluids, namely nanofluids has attracted the attention of the science and engineering community because of the many possible industrial applications of these fluids. Nanotechnology is an emerging science that is finding extensive use in industry due to the unique chemical and physical properties that the nano-sized materials possess. These fluids are colloidal suspensions, typically metals, oxides, carbides or carbon nanotubes in a base fluid. The term nanofluid was coined by Choi [15] in his seminal paper presented in 1995 at the ASME Winter Annual Meeting. It refers to fluids containing a dispersion of submicronic solid particles with typical length on the order of 1–50 nm. Kuznetsov and Nield [16] analytically studied the natural convective boundary layer flow of a nanofluid past a vertical plate. In a recent paper Khan and Pop [17] first time studied the problem of laminar fluid flow resulting from the stretching of a flat surface in a nanofluid. Alsaedi et al. [18] examine the influence of heat generation/absorption on the stagnation point flow of nanofluid toward a linear stretching surface. Rahman et al. [19] investigate the dynamics of the natural convection boundary layer flow of water based nanofluids over a wedge in the presence of a transverse magnetic field with internal heat generation or absorption with the help of Matlab software. Nandy and Mahapatra [20] analyze the effects of velocity slip and heat generation/absorption on magnetohydrodynamic stagnation-point flow and heat transfer over a stretching/shrinking surface and obtained the solution numerically using fourth order Runga–Kutta method with the help of shooting technique. Different from a stretching sheet, it was found that the solutions for a shrinking sheet are non-unique. Makinde and Aziz [21] investigate the effect of a convective boundary condition on boundary layer flow, heat transfer and nanoparticle fraction over a stretching surface in a nanofluid. Nadeem et al. [22] reported the numerical solutions of non-Newtonian nanofluid flow over a stretching sheet using the Maxwell fluid model. Hady et al. [23] studied the natural convection boundary-layer flow over a downward-pointing vertical cone in a porous medium saturated with a non-Newtonian nanofluid in the presence of heat generation or absorption and they used power-law model.

The objective of this study is to extend the work of Makinde and Aziz [21], by considering the Maxwell (non-Newtonian) fluid over a stretching sheet with the effect of heat source/sink. Similarity transforms are presented for this problem, and non-dimensionalized equations are addressed numerically. The results obtained are then compared with those of Makinde and Aziz. Graphical results for various values of the parameters are presented to gain thorough insight toward the physics of the problem. To the best of our knowledge, this problem has not been studied before.

## 2. Mathematical analysis

Consider a steady flow of an incompressible Maxwell fluid in the region $y > 0$ driven by a stretching surface located at $y = 0$ with a fixed stagnation point at $x = 0$. The sheet is coinciding with the plane $y = 0$, with the flow being confined to

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