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Analysis of tangent hyperbolic nanofluid impinging on a stretching cylinder near the stagnation point

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A B S T R A C T

An analysis is executed to study the influence of heat generation/absorption on tangent hyperbolic nanofluid near the stagnation point over a stretching cylinder. In this study the developed model of a tangent hyperbolic nanofluid in boundary layer flow with Brownian motion and thermophoresis effects are discussed. The governing partial differential equations in terms of continuity, momentum, temperature and concentration are rehabilitated into ordinary differential form and then solved numerically using shooting method. The results specify that the addition of nanoparticles into the tangent hyperbolic fluid yields an increment in the skin friction coefficient and the heat transfer rate at the surface. Comparison of the present results with previously published literature is specified and found in good agreement. It is noticed that velocity profile reduces by enhancing Weissenberg number λ and power law index n. The skin friction coefficient, local Nusselt number and local Sherwood number enhances for large values of stretching ratio parameter A.

Introduction

The layer in which the effects of viscosity are significant in the close neighborhood of the surface is titled as boundary layer. Ludwig Prandtl presented the concept of boundary layer on August 12, 1904 at the third international conference in Germany. He divided the fluid equations into two categories, one inside the boundary layer where the influence of viscosity is maximum and second outside the boundary where the influence of boundary can be ignored. Boundary layers are pervasive in a great number of natural flows and fluid dynamics engineering applications, such as solicitations in liquid films in condensation procedure, polymer, extrusion of plastic sheets, glass blowing, spinning of fibers, cooling of elastic sheets, the aerodynamic extrusion of plastic sheets, paper manufacturing, the earth's atmosphere, the surface of car, ship and air vehicles, etc. Sakiadis [1] was the forerunner who elaborated the concept of two dimensional boundary layer of Newtonian fluid towards a continuous moving solid surface. Crane [2] extended this concept into two-dimensional steady flow of a linearly stretching sheet and got its exact solution in quiescent fluid. The boundary layer mixed convection flow of heated stretching surface was discussed by Chen [3]. He inspected the behavior different physical parameters and plotted graphs for local Nusselt number and skin friction coefficient. The effect of variable heat flux on two dimensional steady boundary layer flow was deliberated by Lin et al. [4]. They generate the solution in terms of hypergeometric functions and concluded that for smaller Prandtl number the boundary layer is larger. Ali [5] investigated the boundary layer flow of a continuously stretched surface with buoyancy effects. The boundary layer stagnation point flow towards a stretching sheet was discussed by Nadeem et al. [6]. Again, Nadeem et al. [7] investigated the boundary layer flow of second grade fluid towards a stretching sheet with temperature dependent viscosity. Rangi et al. [8] studied the heat transfer and boundary layer flow towards a stretching cylinder with variable thermal conductivity.

The boundary layer flow of pseudoplastic fluids has great importance due to its extensive uses in solutions and melts of high molecular weight polymers, emulsion coated sheets like photographic films, polymer sheets, etc. Nadeem et al. [9] examined the influence of magnetic field and temperature dependent viscosity on the peristaltic flow of Newtonian incompressible fluid. Again, Nadeem et al. [10] studied the peristaltic flow of a magnetohydrodynamic tangent hyperbolic fluid in a vertical asymmetric channel under long wavelength and low Reynolds number approximation. Akbar et al. [11] analyzed the effects of chemical reactions and heat transfer on tangent hyperbolic fluid treated through a tapered artery. Nadeem et al. [12] examined the peristaltic motion

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of tangent hyperbolic fluid in a curved channel. Naseer et al. [13] evaluated heat transfer and boundary layer flow of tangent hyperbolic fluid over a vertical exponentially stretching cylinder.

A base fluid comprises of nanoparticles deferred in conventional heat transfer basic fluid with the length scales of 1–100 nm is called nanofluid. The nanofluid enhances the convective heat transfer coefficient and thermal conductivity of the base fluids. Oil, water and ethylene glycol are poor conductors of heat. In order to increase the thermal conductivity of these fluids many techniques have been taken in description. One of these techniques is the addition of nano-sized material particles in the liquid. Choi et al. [14] found that with the addition of the nanoparticles the thermal conductivity of the base fluid enhances twice. Das [15] concluded that with the inclusion of nanoparticles the thermal conductivity becomes temperature dependent. Buongiorno et al. [16] evaluated the nanofluid coolants for advanced nuclear power plants. Malik et al. [17] analyzed the boundary-layer mixed convective flow of a nanofluid over a stretching plate. Khan et al. [18] investigated the numerical solution of nanofluid over a flat stretching surface. Akbar et al. [19] studied the MHD flow of nanofluid over a vertical stretching plate with exponential temperature-dependent viscosity and also considerd buoyancy effects. Vajravelu et al. [20] calculated the effects of the nanoparticle volume fraction and heat transfer characteristics with combined effects of temperature dependent internal heat generation/absorption and thermal buoyancy. Noghrehabadi et al. [21] examined the boundary layer and heat transfer flow of nanoparticles volume fraction with slip effects. Akbar et al. [22] Analyzed the magnetic field analysis past over a stretching sheet in a suspension of gyrotactic microorganisms and nanoparticles. Akbar et al. [23] investigated the Double-diffusive natural convective MHD boundary-layer flow of a nanofluid over a stretching sheet.

Heat generation/absorption is reflected as a significant factor in numerous physical glitches such as fluids having endothermic and exothermic chemical reactions. Heat generation/absorption is assumed to be temperature-dependent or space dependent. Lawrence et al. [24] investigated the boundary layer flow of viscoelastic fluid over a stretching sheet with internal heat generation/absorption. Pavithra et al. [25] analyzed the heat transfer boundary layer flow of a dusty fluid over an exponentially stretching surface with combined effects of internal heat generation/absorption and viscous dissipation. Noghrehabadi et al. [26] studied the entropy generation of a nanofluid over an isothermal linear stretching plate with heat generation/absorption. Dessie et al. [27] examined the MHD boundary layer flow of Newtonian fluid with variable viscosity through a porous medium over a stretching sheet with viscous dissipation, heat source/sink and heat generation/absorption. Hakeem et al. [28] studied the effect of partial slip on hydromagnetic boundary layer flow in porous medium over a stretching surface with temperature and space dependent internal heat generation/absorption. Akbar et al. [29] examined the effects of thermal radiation and variable thermal conductivity on the flow of CNTS over a stretching sheet with convective slip boundary conditions. Akbar et al. [30] examined the two dimensional Magnetohydrodynamics flow of Eyring-Powell fluid. They noticed that by enhancing the intensity of the magnatic field as well as Eyring-Powell fluid parameter γ decrease the velocity profile. Mehmood et al. [31] depicted the Non Aligned point flow and heat transfer of an Ethylene–Glycol and nanofluid towards stretching sheet. They noticed that Ethylene-based nanofluids have higher local heat flux than water-based nanofluids. Rana et al. [32] invistigated the mixed convective oblique flow of a casson fluid with partial slip, internal heating and homogeneous–heterogeneous reactions.

The aim of the present analysis is to examine numerically, the stagnation point flow of tangent hyperbolic nanofluid over a stretching cylinder. Buongiorno model is used to examine the heat transfer due to nanoparticles. Moreover, heat generation/absorption effects are encountered for tangent hyperbolic nanofluid. For this persistence proper similarity transformations are used to diminish governing equations to ordinary differential equations. The effect of thermophoresis, Brownian motion and Lewis number for nanofluid are deliberated through graphs. The near wall quantities, such as Sherwood number due to nanoparticle concentration, Nusselt number due to heat transfer and local skin friction for velocity profile are discussed.

Mathematical formulation

Consider steady two-dimensional stagnation point flow of optically dense tangent hyperbolic nanofluid towards a stretching cylinder located at $r = R$, where r is the coordinate normal to cylinder. The cylinder is stretched with two equivalent and conflicting forces along x-axis with the velocity $u = \frac{ax}{l}$, by keeping the origin fixed as shown in Fig. 1. It is assumed that concentration and temperature at the wall is maintained at constant concentration C_w and temperature T_w. Where C_∞ and T_∞ are ambient concentration and temperature respectively. Under the boundary layer approximation, the governing equations of the mass, momentum, energy and nanoparticles in cylindrical coordinates x and r are written as Ref. [12]

$$\frac{\partial(ru)}{\partial x} + \frac{\partial(rv)}{\partial r} = 0, \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial r} = \nu\left((1-n)\frac{\partial^2 u}{\partial r^2} + (1-n)\frac{1}{r}\frac{\partial u}{\partial r} + n\sqrt{2}\Gamma\frac{\partial u}{\partial r}\frac{\partial^2 u}{\partial r^2} + \frac{n\Gamma}{\sqrt{2}r}\left(\frac{\partial u}{\partial r}\right)^2\right) + U_e\frac{dU_e}{dx}, \tag{2}$$

$$\rho c_p\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial r}\right) = \frac{K}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \tau\left\{D_B\left(\frac{\partial C}{\partial r}\frac{\partial T}{\partial r}\right) + \frac{D_T}{T_\infty}\left[\left(\frac{\partial T}{\partial r}\right)^2\right]\right\} + \frac{Q}{\rho c_p}(T - T_\infty), \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial r} = \frac{D_B}{r}\frac{\partial}{\partial r}\left(r\frac{\partial C}{\partial r}\right) + \frac{D_T}{T_\infty}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right), \tag{4}$$

the associated boundary conditions are

$$u = \frac{ax}{l},\ v = 0,\ T = T_w,\ C = C_w \quad \text{at } r = R,$$
$$u = U_e(x) = \frac{bx}{l},\ v = 0, T = T_\infty,\ C = C_\infty \quad \text{as } r \to \infty. \tag{5}$$

Here u and v are the velocity components along x and r directions respectively, Q is the temperature dependent volumetric rate of heat source when $Q > 0$ and heat sink when $Q < 0$, dealing with the situation of exothermic and endothermic chemical reactions respectively, ν is the kinematic viscosity, ρ is the density, A is the

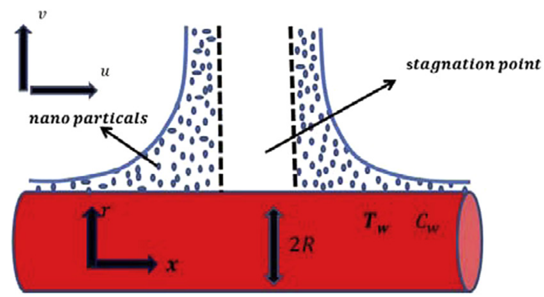

Fig. 1. Geometry of the problem.