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Computational analysis of magnetohydrodynamic Sisko fluid flow over a stretching cylinder in the presence of viscous dissipation and temperature dependent thermal conductivity

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ABSTRACT

Present communication presents numerical investigation of magnetohydrodynamic Sisko fluid flow over linearly stretching cylinder along with combined effects of temperature depending thermal conductivity and viscous dissipation. The arising set of flow govern equations are simplified under usual boundary layer assumptions. A set of variable similarity transforms are employed to shift the governing partial differential equations into ordinary differential equations. The solution of attained highly nonlinear simultaneous equations is computed by an efficient technique (shooting method). Numerical computations are accomplished and interesting aspects of flow velocity and temperature are visualized via graphs for different parametric conditions. A comprehensive discussion is presented to reveal the influence of flow parameters on wall shear stress and local Nusselt number via figures and tables.Furthermore, it is observed that magnetic field provides noticeable resistance to the fluid motion while both material parameter and curvature accelerates it. The progressing values of both Eckert number and thermal conductivity parameter have qualitively same effects i.e. they rise the temperature. Additionally, material parameter and curvature parameter increase the coefficient of skin friction absolutely and qualitively similar effects are noticed for Nusselt number against variations in Prandtl number and curvature parameter. On the other hand local Nusselt diminishes for larger values of Eckert number and power law index. The present results are compared with existing literature via tables, they have good covenant with previous results.

Introduction

MHD is the field of science which addresses the dynamics of electrically conducting fluid. The key fact behind the MHD is that the applied magnetic field induces the current, the consequences of this phenomenon produces Lorentz force which affects fluid motion significantly. The dynamics of electrically conducting fluids is mathematically formulated with well-known Navier–Stokes equations along with Maxwell equations. The nature contains variety of MHD fluids like plasmas, salt water, electrolysis etc. Currently, MHD is a topic of intense research due to its use in many industrial processes like magnetic materials processing, glass manufacturing, magnetohydrodynamics electrical power generation. Furthermore, it has applications in astrophysics and geophysics as well, e.g. it is used in solar structure, geothermal energy extraction, radio propagation etc. Whereas, MHD pumps and MHD flow meters are some products of engineering which utilized the magnetohydrodynamics phenomenon. So, magnetohydrodynamics is recently experienced a period of great enlargement and differentiation of subject matter. Alfven [1] discovered electromagneto–hy drodynamic waves in his work. Liao [2] discussed the magnetohydrodynamics power law fluid flow over continuously stretching sheet. Solution was computed by utilizing HAM. In this analysis, he described effects of magnetohydrodynamics on skin friction coefficient by considering variations in power-law index. He suggested that effects of MHD are prominent for shear thinning than shear thickening fluids. Power law fluid flow in the presence of MHD over stretching sheet was studied by Cortell [3]. In this problem, he calculated the numerical solution by way of shooting method and analyzed the model for variations in power law index and Hartmann number. He concluded that Hartmann number is a source of decrease in both Newtonian and non-Newtonian fluids velocity. Ishak et al. [4] investigated the incompressible flow of

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Newtonian fluid over stretching cylinder under the influence of magnetohydrodynamics. The solution was calculated numerically by applying Keller-Box method. They illustrated that MHD causes decline in velocity profile while enhances the skin friction coefficient. Nadeem et al. [5] examined the flow of MHD Casson fluid over a porous stretching sheet in three dimensions. Numerical solution of the problem was found by applying Runge–Kutta Fehlberg numerical scheme. They proved that Hartmann number reduces both horizontal and vertical velocity profiles, but it increases skin friction coefficients. Akbar et al. [6] investigated the Jeffrey fluid in small intestine under the impact of magnetic field and found exact solution. Ellahi et al. [7] discussed the blood flow of two-dimensional Prandtl fluid through taperd arties. The solution was calculated analytically and variations are found against physical parameters. Mabood et al. [8] deliberated the heat transfer analysis of boundary layer flow of nanofluid over a nonlinear stretching sheet with aid of Runge–Kutta fifth order integration scheme. They deduced that the applied magnetic field enhances skin friction coefficient while decreases both Nusselt and Sherwood numbers. Rashidi et al. [9] analyzed the Darcy–Brinkman–Forchheime fluid under the influence of transverse magnetic field and computed the numerical solution via finite element technique. The induced magnetic field on carbon nanotubes through a permeable channel was examined by Akbar et al. [10]. The resulting equations are solved exactly and intersted quantities are delibrated. Malik and Salahuddin [11] examined the stagnation point flow of Williamson fluid under magnetohydrodynamics effects over stretching cylinder and calculated solution with shooting method. Kandelousi and Ellahi [12] inspected the Fe_3O_4-plasma nanofluid flow in a vessel under the combined influence of ferrohydrodynamic and magnetohydrodynamic. They computed numerical solution via Boltman technique and interpreted that magnetic field subtantially affected the fluid movement. Ellahi et al. [13] delibrated the generalized Coutte flow of Powell-Eyring fluid with magnetohydrodynamics and slip effects and found numerical solution via pseudo-spectral collocation. Also, Malik et al. [14] discussed the flow of Powell-Eyring nanofluid over linearly stretching sheet with the effect of normally impinging magnetic field. The nonlinear set of resulting equations was solved with Runge–Kutta Fehlberg method. A theoratical study on peristaltic flow of MHD Jefferey fluid through a rectangular duct with Hall and ion slip effects has been performed by Ellahi et al. [15]. The influnce of magnetic field on water based nanofluids in the presence of Brownian motion was studied by Akbar et al. [16]. Khan et al. [17] found analytic solution of the problem addressing MHD peristaltic flow of Psedoplastic fluid along with varying viscosity and bionic effects. The heat transfer of viscous fero magnetic fluid along with thermal radiation effects over stretching surafce was discussed by Zeeshan et al. [18]. A numerical investigation on MHD slip flow of nanofluid in sollar collectors was designed by Afzal and Aziz [19]. They considered heat transfer problem along with thermal radiation and thermal conductivity effects. Hayat et al. [20] and Latif et al. [21] also discussed the MHD flows of non-Newtonian fluids along with different physical situations.

Flow of non-Newtonian fluids is one of the most influential issue in few recent years, because they have wide range of applications in many fields of daily life such as food engineering, chemical engineering, power engineering and petroleum production. Also, the recent advancement in industry and improved engineering expertise, motivated researchers to explore non-Newtonian fluids characteristics in more systematic way. As non-Newtonian fluids have lot of varieties in nature, so numerous constitutive equations were proposed to examine physical properties of these fluids. Most of the non-Newtonian fluids such as lubricating greases, waterborne coatings, multiphase mixers etc. which encountered in chemical engineering obeys the Sisko fluid model. This model was presented by Sisko [25], he studied the properties of lubricating greases. Nadeem et al. [26] also designed theoretical model of peristaltic motion in the endoscope by using constitutive equations of Sisko fluid model. They computed both analytical and numerical solutions and analyzed the pressure gradient and peristaltic motion of Sisko fluid. In addition, they presented comparison between Sisko and Newtonian fluid and found that Newtonian fluids have best peristaltic transference. Khan and Shehzad [27] explored the physical features of Sisko fluid flow over linearly stretching sheet in radial direction. The analytic solution was calculated by homotopy analysis method. The interesting quantities were discussed by varying power law index. And showed that fluid parameter accelerates the non-Newtonian fluid motion as well as wall shear stress. Also, contrast of Sisko fluid with both viscous and power law fluids was presented. The results show that friction of wall is greater for Sisko fluid as compared to both viscous and power law fluids. Khan and Shehzad [28] also examined Sisko fluid flow over stretching sheet. In this investigation, velocity profile was described under the influences of power law index and Sisko parameter. They remarked that the power law index diminishes velocity profiles for non-Newtonian fluids. Recently, Malik et al. [29] discussed effects of transverse magnetic field on Sisko fluid over stretching cylinder. Shooting technique was implemented to solve governing equations.

The theory of boundary layer flows over stretching surfaces accompanied by heat transfer analysis has many potential applications in practice like extrusion, paper production, fiber-glass production etc. Also, many industrial processes such as hot rolling, condensation process, crystal growing, polymer sheets, artificial fibers and plastic films etc. are based on heat transfer in boundary layer flows. Thus, due to numerous applications in industrial manufacturing and engineering, the boundary layer flows are still topic of great interest for researchers. The work of Sakiadis [30] is providing base to boundary layer flows. He analyzed the boundary layer viscous fluid flow over continues solid surfaces in two-dimension. The analysis of heat transfer problem was initiated by Gupta and Gupta [31]. They studied the heat transfer of viscous fluid flow over a stretching cylinder. Naseer et al. [32] formulated the problem on tangent hyperbolic fluid flow over a exponentially varying vertical cylinder. The calculation of solution was performed with the aid of Runge–Kutta Fehlberg technique. Since thermal conductivity of the fluid changes as temperature varies, so it leads to consideration of variable thermal conductivity in heat transfer analysis. Rangi and Ahmad [33] studied the flow of viscous fluid over a stretching cylinder along with the effect of variable thermal conductivity. They computed numerical solution via Keller-Box method and recommended that the temperature profile is significantly affected due to variable thermal conductivity. Abel and Mahesha [34] analyzed the problem of MHD viscoelastic fluid over the stretching sheet. They considered the impacts of non-uniform heating, thermal radiation and temperature dependent thermal conductivity. It was recognized that variable thermal conductivity increases temperature profile i.e. fluid with less thermal conductivity are better for cooling. Abel et al. [35] also examined the power law fluid flow over stretching sheet under the effects of non-uniform heating along with variable thermal conductivity and found analytical expressions for temperature profile. Recently, effects of linearly varying thermal conductivity on MHD Sisko fluid flow over continuously stretching cylinder was investigated by Malik et al. [36]. The interesting quantities were computed with shooting method to analyze problem physically.

An analysis of heat transfer with viscous dissipation effects was firstly considered by Brinkman [41]. He investigated the effect of viscous heating in Newtonian fluids. Lin et al. [42] discussed the effect of viscous dissipation on thermal entrance heat transfer region in the laminar pipe flow with convective boundary