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Analyzing Heat and Mass Transfer Flux in an Electrohydrodynamics Blood-Based Hybrid Nanofluid Subject to the Lorentz Force with the Application of the Cattaneo-Christov Model.

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Abstract

This study presents a unique approach by considering both the magnetic field and electromagnetic force in the flow direction. The application of a magnetic field slows down the fluid flow, while the electric force factor increases fluid velocity and temperature. The primary objective of this study is to investigate the behaviour of electro-hydrodynamic blood-based hybrid nanofluid as it passes through vertically stretchable areas. The Cattaneo-Christov model, with thermal radiation and heat generation, is employed in this investigation using partial differential equations. To simplify the system of coupled nonlinear differential equations, appropriate variables are introduced, and the Spectral Relaxation Method (SRM), a novel numerical technique, is employed to obtain the solutions.

Introduction

Currently, nanotechnology has captured the interest of numerous individuals. Its applications extend to various medical domains, such as biofluid mechanics, biological sensors, and pharmacology. The significance of nanofluids lies in their remarkable strength and composition, consisting of nano-sized particles. Magnetic nanofluids find utility in oscillators, optical pairs, optical switches, and tunable optical fiber filters. Several studies have been conducted in this area, each exploring different aspects of nanofluids. [1] focused on investigating magnetized Walter's-B nanofluid in a cylindrical disk. [2] examined nonlinear mixed convective hybrid nanofluid fluid flow with a specific emphasis on heat and mass transfer. [3] studied nanofluid and dusty particles concerning the Soret-Dufour mechanism. [4] delved into the study of couple stress hybrid nanofluid free stream with thermal effects. [5] conducted an examination of the Maxwell nanofluid flow analysis of an Ethylene Glycol/water mixture. [6] employed an effective thermal conductivity approach to study magnetite micropolar Casson ferrofluid. Lastly, [7] investigated the results of nanofluid passing a sheet with heat and mass flux constraints. In summary, nanotechnology is currently generating widespread interest, particularly in medical applications like biofluid mechanics, biological sensors, and pharmacology. The use of nanofluids, composed of nano-sized particles, is crucial in various fields, including optics and magnetic applications. A series of studies have been carried out to understand the behaviour and potential of nanofluids in

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different scenarios, covering a range of scientific interests [8]. To the best of our knowledge, there has been no prior research conducted on this particular model type. The current study holds significant promise due to its potential applications in power engineering, aerodynamics, engineering, agriculture, and other fields.

Methodology

In the scenario of an incompressible, steady, laminar flow of electro-hydrodynamic blood-based hybrid nanofluid over a stretching surface, the flow regime is influenced by both Lorentz force and electric current. At the wall of the surface, the concentration and temperature distribution are represented by C_w and T_w, respectively [9]. The situation involves a first-order chemical reaction and thermal radiation, with a visual representation shown in Figure 1. Utilizing the boundary layer approximation, the governing equations can be expressed as follows:

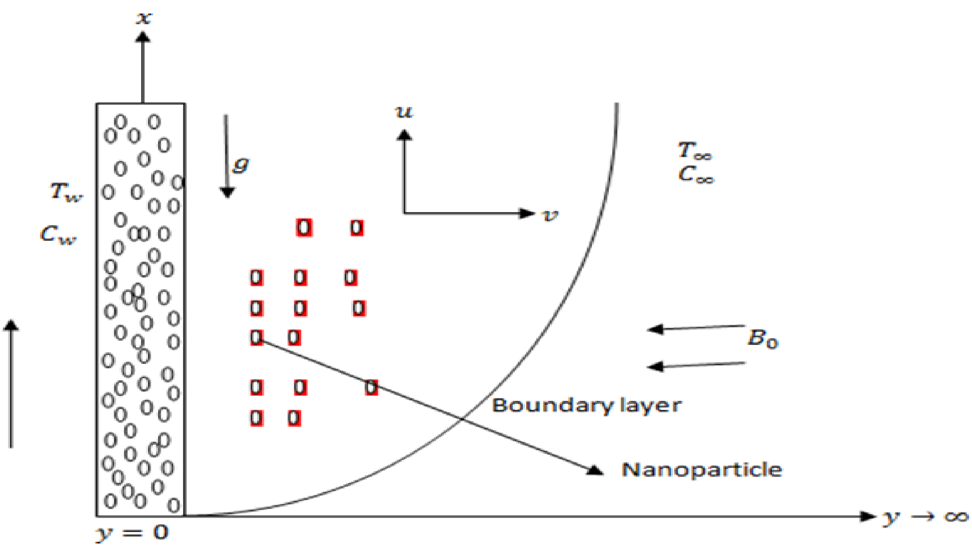

Fig. 1. Physical configuration

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu_{hf}\frac{\partial^2 u}{\partial y^2}+\frac{\sigma_{hnf}}{\rho_{hnf}}(E_0B_0-B_0^2u)-\frac{\eta_0}{\rho_{hnf}}\frac{\partial^3 u}{\partial y^3}-\frac{\nu}{K}u \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{hnf}\frac{\partial^2 T}{\partial y^2}+\frac{\mu_{nf}}{(\rho c_p)_{hnf}}\left(\frac{\partial u}{\partial y}\right)^2+\frac{\sigma_{hnf}}{(\rho c_p)_{hnf}}+\frac{Q_0}{(\rho c_p)_{hnf}}(T-T_\infty)+\tau\left[D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right]-$$
$$\beta_1\left[u\frac{\partial u}{\partial x}\frac{\partial T}{\partial x}+v\frac{\partial v}{\partial y}\frac{\partial T}{\partial y}+u\frac{\partial v}{\partial x}\frac{\partial T}{\partial y}+v\frac{\partial u}{\partial y}\frac{\partial T}{\partial x}+2uv\frac{\partial^2 u}{\partial x\partial y}+u^2\frac{\partial T}{\partial x^2}+v^2\frac{\partial^2 T}{\partial y^2}\right] \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}-k_l(C-C_\infty)-\beta_2\left[u\frac{\partial u}{\partial x}\frac{\partial C}{\partial x}+v\frac{\partial v}{\partial y}\frac{\partial C}{\partial y}+u\frac{\partial v}{\partial x}\frac{\partial C}{\partial y}+v\frac{\partial u}{\partial y}\frac{\partial C}{\partial x}+2uv\frac{\partial^2 u}{\partial x\partial y}+\right.$$
$$\left.u^2\frac{\partial C}{\partial x^2}+v^2\frac{\partial^2 C}{\partial y^2}\right] \tag{4}$$

the associated boundary conditions are:

$$u=bx=u_w(x),\quad v=0,\quad T=T_w,\quad C=C_w,\quad at\quad y=0$$
$$u=v=0,\ T\longrightarrow T_\infty,\ C\longrightarrow C_\infty,\quad as\quad y\longrightarrow\infty \tag{5}$$

The below similarity transformations are defined in demand to stream the current model

$$\eta=y\sqrt{\frac{b}{\nu}},\ \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\ \phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty},\ u=bxf'(\eta),\ v=-\sqrt{b\nu}f(\eta) \tag{6}$$

Using Eq. (6) on Eqs. (1)-(4) subject to (5) to obtain:

$$f'''+\frac{\mu_f\rho_{hnf}}{\mu_{hnf}\rho_f}\left[ff''-f'^2-Kf^v+M(E-f')+\frac{1}{Po}f\right]=0 \tag{7}$$

$$\frac{K_{hnf}}{k_f}\theta''+Pr\frac{(\rho c_p)_{hnf}}{(\rho c_p)_f}f\theta'+EcPr\left[M(E-f')^2+\frac{\mu_{hnf}}{\mu_f}(f'')^2\right]+QPr\theta+Nb\phi'\theta'+Nt(\theta')^2-$$
$$\beta_1(ff'\theta'+f^2\theta'')=0 \tag{8}$$

$$\phi''+Scf\phi'-Cr\phi+\frac{Nt}{LnNb}\theta''-\beta_2(ff'\phi'+f^2\phi'')=0 \tag{9}$$

With the constraints:

$$f(0)=0,\ f'(0)=1,\ \theta(0)=\phi(0)=1, f(\infty)=0,\ \theta(\infty)=\phi(\infty)=0 \tag{10}$$

Spectral Relaxation Method

In the context of the SRM (Selective Reduced Model), the Gauss-Seidel relaxation technique is employed to decouple and linearize the system of equations [10]. The current iteration, denoted by r+1, is applied to the linear terms, while the previous iteration, represented by r, is utilized for the nonlinear terms. Additionally, the Chebyshev collocation approach is applied to the iterated sequence of equations. By utilizing the SRM, the following set of equations is derived:

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$$f'''_{r+1} + a_{0,r}f''_{r+1} + a_{1,r} - a_{2,r}f^{v}_{r+1} + a_{3,r} + a_{4,r}f'_{r+1} + a_{5,r}f_{r+1} = 0 \tag{11}$$

$$b_{0,r}\theta''_{r+1} + b_{1,r}\theta'_{r+1} + b_{2,r} - b_{3,r} + b_{4,r} + b_{5,r} + QPr\theta_{r+1} + b_{6,r}\theta'_{r+1} + b_{7,r} + b_{8,r}\theta'_{r+1} + b_{9,r}\theta''_{r+1} = 0 \tag{12}$$

$$\phi''_{r+1} + c_{0,r}\phi'_{r+1} - Cr\phi_{r+1} + c_{1,r} + c_{2,r}\phi'_{r+1} + c_{3,r}\phi''_{r+1} = 0 \tag{13}$$

subject to:

$$f_{r+1}(0,\eta) = 0,\ f'_{r+1}(0,\eta) = 1,\ \theta_{r+1}(0,\eta) = \phi_{r+1}(0,\eta) = 1 \tag{14}$$

$$f_{r+1}(\infty,\eta) = 0,\ \theta_{r+1}(\infty,\eta) = \phi_{r+1}(\infty,\eta) = 0 \tag{15}$$

A starting guess is taken to satisfies the boundary constraints Eq. (14) and (15). The guess as used in this study are defined as follows:

$$f_0 = 1 - e^{-\eta},\ \theta_0 = \phi_0 = e^{-\eta} \tag{16}$$

Results

The spectral relaxation method was applied for the numerical solution of the transformed ordinary differential equations (Eq 7 to 9) together with the given boundary conditions (Eq. 10). The resulting diagrams illustrate the influence of flow parameters on velocity, concentration, and temperature profiles.

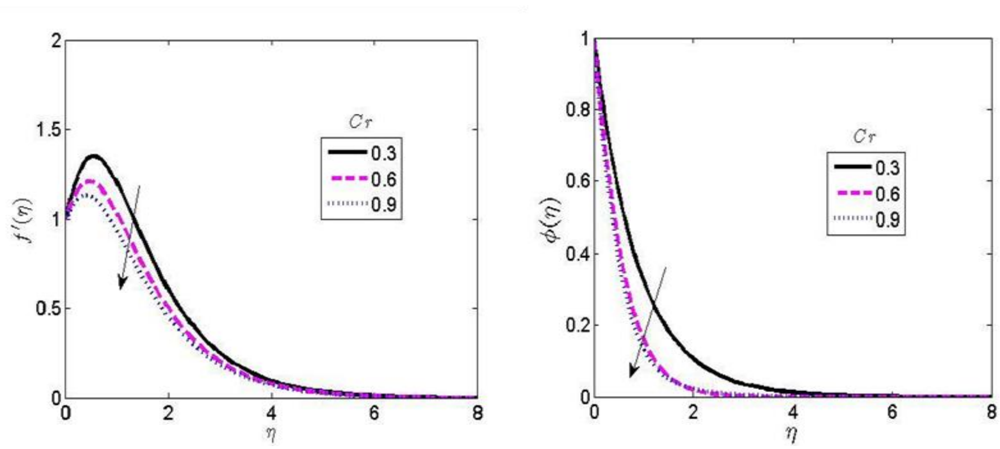

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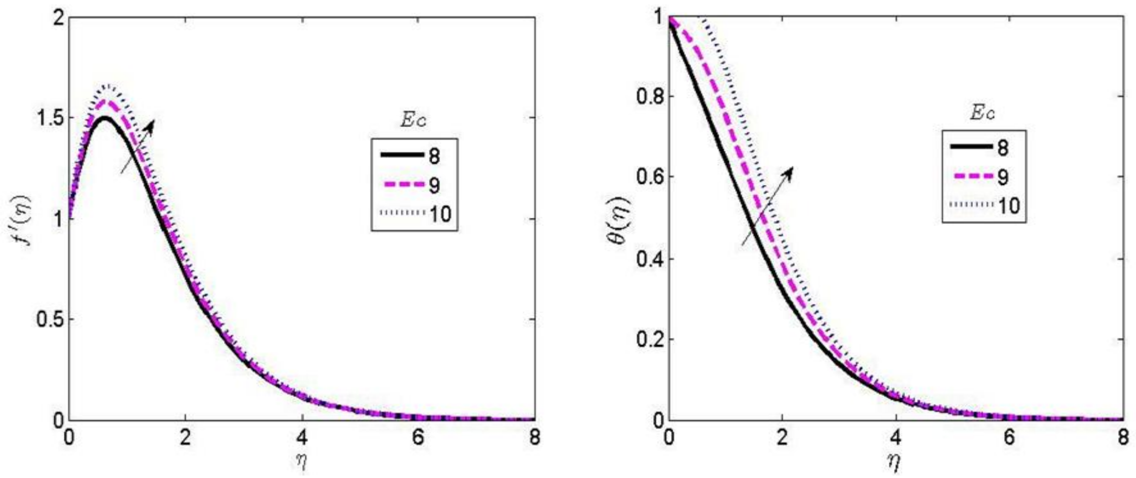
Fig. 2. Reaction of chemical reaction on the velocity and concentration



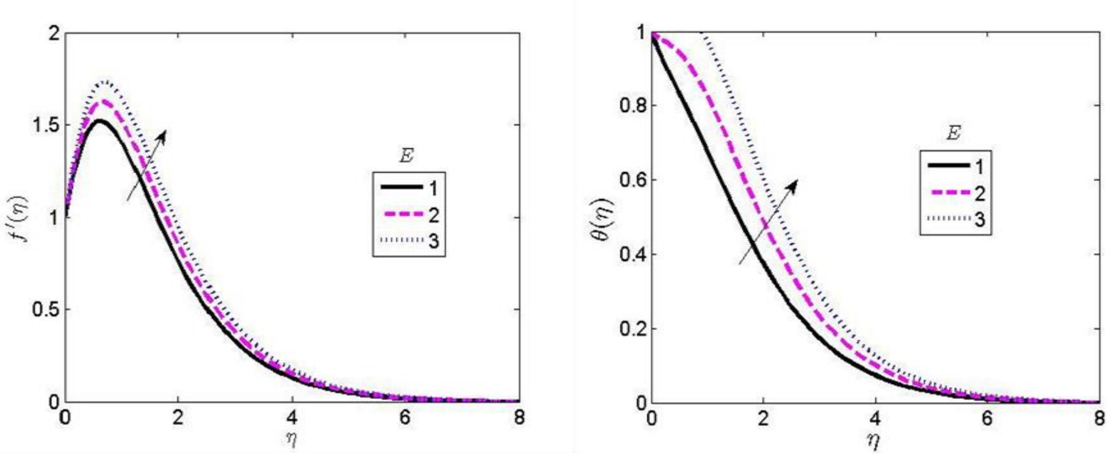


Fig.3. reaction of Eckert number and electric field factor on velocity, temperature

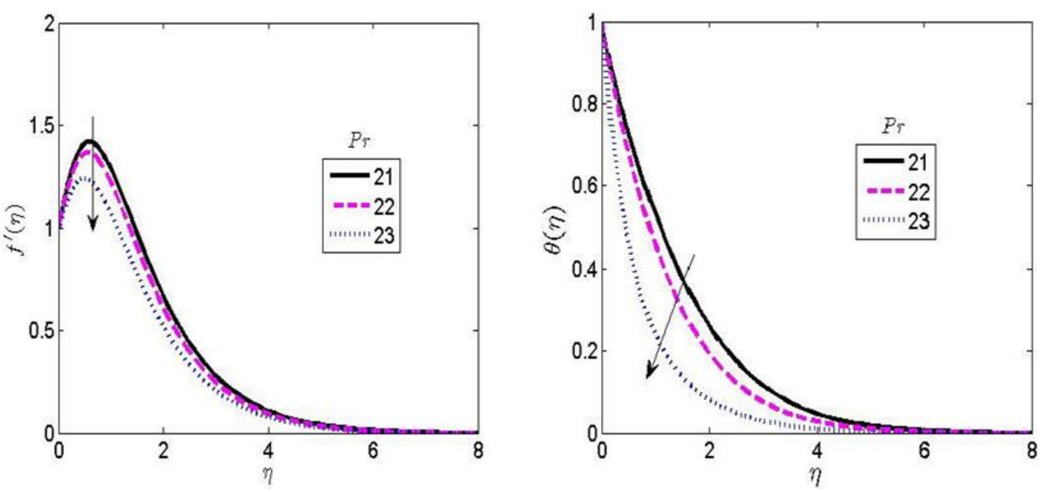


Fig.4. Reaction of Prandtl and Thermal radiation on velocity, temperature

Conclusions

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It is observed that a higher electric field factor enhances both the velocity and temperature profiles. An increase in the Eckert number leads to augmentation in both the thermal and hydrodynamic boundary layer thickness. A higher value of K elongates the aperture, promoting increased fluid flow by enhancing the fluid velocity. An increase in Pr results in a reduction of both velocity and temperature profiles. A higher value of Sc decreases the skin friction and Sherwood number.

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