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The Significance of Cattaneo-Christov Heat Flux in the Presence of Joule Heating for Chemically Reactive Nanofluid Flow over an Extending Surface.

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Abstract

This study investigated the significance of applying Cattaneo-Christov's theories to the analysis of fluid flow with chemical reactions over a stretching surface, considering various thermophysical factors. The physical problem was mathematically modelled using a set of partial differential equations. To simplify this complex system, appropriate similarity variables were introduced, leading to a set of coupled nonlinear ordinary differential equations. These transformed equations were then solved using the spectral relaxation method, a technique rooted in Gauss-Seidel relaxation methods. The results were presented through visualizations and tabulated data. Interestingly, the thermal radiation parameter was observed to enhance both velocity and temperature distributions, while the magnetic field parameter had a dampening effect on the velocity profile.

Introduction

The Cattaneo-Christov thermal flux framework is employed to describe thermal transfer in viscoelastic flow induced by exponentially extending mass. Idowu et al., [1], demonstrated that altering viscosity and heat conductivity can communicate flow dissipation. Khan et al., [2], studied the MHD Falkner-Skan Sutterby nanofluid using the nanofluid model and Cattaneo-Christov heat flux theory. Williamson hybrid engine oil nanofluids were investigated alongside Cattaneo-Christov heat flux. Ali and Sandeep [3], numerically modelled the heat radiative transport of MHD Casson-Ferro fluid. Zhang and colleagues [4], examined melting heat reaction in von Karman circulating motion of hybrid nanofluids using Cattaneo-Christov heat flux. Hayat and Nadeem [5], applied the Cattaneo-Christov model and a chemical process to an exponentially stretchable surface, addressing the motion of 3D Eyring-Powell fluid. The Cattaneo-Christov model was used to analyse Carreau fluid flow over a thin sheet by Shihao et al. [6], connecting viscoelastic fluid flow with heat transport processes.

Within the realm of literature, investigations have delved into the realm of Cattaneo-Christov heat flux while considering factors like heat generation, viscous dissipation, and Brownian motion [7-9]. However, a notable gap in these studies lies in the omission of the electromagnetic force and permeability surface effects. Addressing this gap, the current research focuses on a physical setup where a porous medium coexists with a stretching surface, influenced by the presence of an electromagnetic force [10]. The resulting system of partial differential equations was tackled through numerical methods, and the resulting outcomes were visually represented in graphical form.

Mathematical formulation

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This paper investigates a scenario involving a constant, smooth, viscous, and incompressible nanofluid flow over a vertical porous plate (refer to Figure 1). The study delves into the heat transfer dynamics within this setup, taking into account heat generation and thermal radiation effects [11-13]. The boundary layer estimation is valid and the governing equations are:

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

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

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

The associated boundary conditions are:

$$u=bx,\qquad v=0,\qquad T=T_w,\quad at\quad y=0 \tag{4}$$

$$u=v=0,\qquad T\longrightarrow T_\infty,\quad as\quad y\longrightarrow\infty \tag{5}$$

The following suitable similarity transformations are defined to simplify the current model:

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

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

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

$$\begin{aligned}\frac{K_{hnf}}{k_f}\theta''+Pr\frac{(\rho c_p)_{hnf}}{(\rho c_p)_f}f\theta'+EcPr\left[M_q(E-f')^2+\frac{\mu_{hnf}}{\mu_f}(f'')^2\right]+QPr\theta-\alpha_1(ff'\theta'+f^2\theta'')\\ =0\end{aligned} \tag{8}$$

With the constraints:

$$f(0)=f_w,\qquad f'(0)=1,\qquad \theta(0)=1, \tag{9}$$

$$f(\infty)=0,\qquad \theta(\infty)=0 \tag{10}$$

Spectral relaxation method

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Through the employment of the SRM (Spectral Relaxation Method), the Gauss-Seidel relaxation technique is harnessed to decouple and linearize the system of equations. In this process, the current iteration denoted as r+1 is applied to the linear terms, while the preceding iteration denoted as r is applied to the nonlinear terms.

Going by the process of SRM on the transformed Eq. (7) & (8) subject to Eq. (9) to obtain:

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

$$b_{0,r}\theta''_{r+1} + b_{1,r}\theta'_{r+1} + b_{2,r} + b_{3,r} + b_{4,r} + b_{5,r}\theta'_{r+1} + b_{6,r}\theta''_{r+1} = 0$$

Results

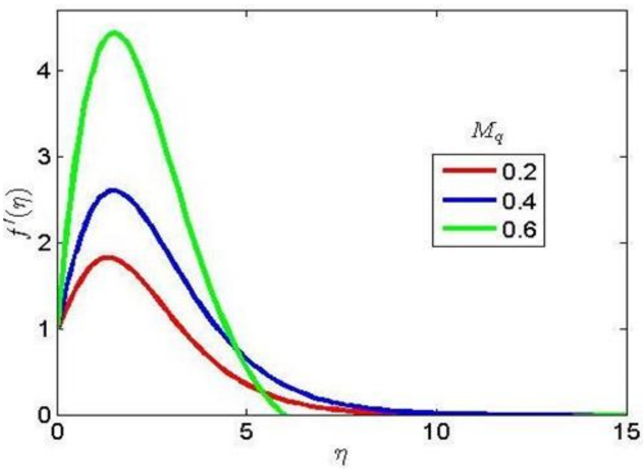

Fig 1: Effect of magnetic parameter on the velocity profile.

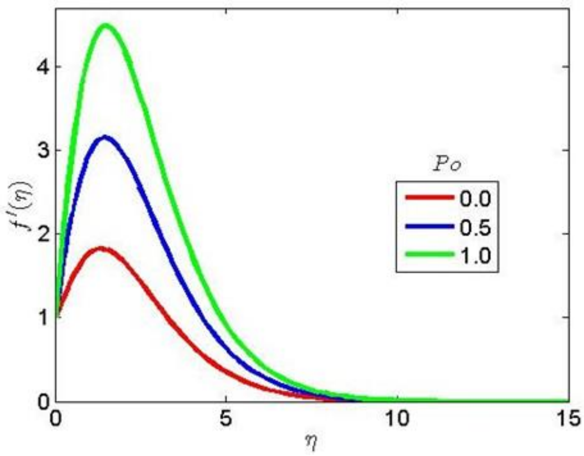

Fig 2: effect of permeability parameter.

Conclusion

The principal findings of the study are as follows:

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1. Elevating the magnetic parameter results in an augmented velocity profile. This phenomenon arises due to the significant influence of the electromagnetic force on the Lorentz force, leading to a reduction in strength and subsequent velocity increase;

2. The fluid's velocity within the boundary layer experiences augmentation owing to the expansion in the holes caused by an increase in the permeability parameter;

3. An increase in the Prandtl number is shown to enhance both the hydrodynamic and thermal boundary layer thickness;

4. An upsurge in the Eckert number (Ec) corresponds to an increased heat energy, thereby augmenting both the hydrodynamic and thermal boundary layer thickness;

References

1. Idowu, A. S., and B. O. Falodun. "Variable thermal conductivity and viscosity effects on non-Newtonian fluids flow through a vertical porous plate under Soret-Dufour influence." Mathematics and Computers in Simulation 177 (2020): 358-384.
2. Khan, Umair, Anum Shafiq, A. Zaib, Abderrahim Wakif, and Dumitru Baleanu. "Numerical exploration of MHD falkner-skan-sutterby nanofluid flow by utilizing an advanced non-homogeneous two-phase nanofluid model and non-Fourier heat-flux theory." Alexandria Engineering Journal 59, no. 6 (2020): 4851-4864.
3. Ali, M. E., and N. Sandeep. "Cattaneo-Christov model for radiative heat transfer of magnetohydrodynamic Casson- ferrofluid: A numerical study." Results in physics 7 (2017): 21-30.
4. Hayat, Tanzila, and S. Nadeem. "Flow of 3D Eyring-Powell fluid by utilizing Cattaneo-Christov heat flux model and chemical processes over an exponentially stretching surface." Results in Physics 8 (2018): 397-403.
5. Han, Shihao, Liancun Zheng, Chunrui Li, and Xinxin Zhang. "Coupled flow and heat transfer in viscoelastic fluid with Cattaneo–Christov heat flux model." Applied Mathematics Letters 38 (2014): 87-93.
6. Tanveer, A., S. Hina, T. Hayat, M. Mustafa, and B. Ahmad. "Effects of the Cattaneo–Christov heat flux model on peristalsis." Engineering applications of computational fluid mechanics 10, no. 1 (2016): 373-383.
7. Upadhya, S. Mamatha, C. S. K. Raju, S. Saleem, and A. A. Alderremy. "Modified Fourier heat flux on MHD flow over stretched cylinder filled with dust, graphene and silver nanoparticles." Results in Physics 9 (2018): 1377-1385.
8. Alao, F. I., A. I. Fagbade, and B. O. Falodun. "Effects of thermal radiation, Soret and Dufour on an unsteady heat and mass transfer flow of a chemically reacting fluid past a semi-infinite vertical plate with viscous dissipation." Journal of the Nigerian mathematical Society 35, no. 1 (2016): 142-158.
9. Tlili, I., W. A. Khan, and Ilyas Khan. "Multiple slips effects on MHD SA-Al2O3 and SA-Cu non-Newtonian nanofluids flow over a stretching cylinder in porous medium with radiation and chemical reaction." Results in physics 8 (2018): 213-222.
10. Salawu, S. O., and M. S. Dada. "Radiative heat transfer of variable viscosity and thermal conductivity effects on inclined magnetic field with dissipation in a non-Darcy medium." Journal of the Nigerian Mathematical Society 35, no. 1 (2016): 93-106.

ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 10, Spl Iss 2, 2021

11. Saba, S. S., Sreelakshmi, D., Kumar, P. S., Kumar, K. S., & Saba, S. R. (2020). Logistic regression machine learning algorithm on MRI brain image for fast and accurate diagnosis. International Journal of Scientific and Technology Research, 9(3), 7076-7081.
12. Saikumar, K. (2020). RajeshV. Coronary blockage of artery for Heart diagnosis with DT Artificial Intelligence Algorithm. Int J Res Pharma Sci, 11(1), 471-479.
13. Saikumar, K., Rajesh, V. (2020). A novel implementation heart diagnosis system based on random forest machine learning technique International Journal of Pharmaceutical Research 12, pp. 3904-3916.