INDIAN SOCIETY OF THEORETICAL AND APPLIED MECHANICS (ISTAM 2024)

(International Conference)

Investigation of entropy analysis and convective heat transfer of a three-dimensional Casson nanofluid over a stretching sheet with suction

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ABSTRACT

This research looks at the substantial effect of non-linear thermal radiation and a non-uniform heat source/sink on the three-dimensional MHD convective flow of a Casson nanofluid with suction, incorporating Darcy-Forchheimer phenomena within a porous medium along a bidirectional stretched sheet. This study uses an irreversibility analysis to identify and eliminate causes of energy loss inside a system, thereby considerably increasing overall energy efficiency. The governing equations are formulated based on the assumptions and subsequently transformed from partial to ordinary differential equations using an appropriate transformation technique. The simplified equations are numerically solved using the MATLAB 'bvp4c' solver. The influence of physical parameters is meticulously explored and elegantly presented through insightful graphs and comprehensive tables. Furthermore, a good agreement is observed when comparing these results with existing data. This study reveals that increasing the permeability diminishes the velocity while amplifying the temperature profiles. Elevated Biot and Eckert numbers enhance the temperature profile, whereas suction effectively reduces the fluid temperature. Increasing the inertia coefficient parameter decreases the skin drag in both x- and y-directions. Elevating the non-linear radiation parameter from 0 to 1 leads to an impressive 32% rise in heat transfer and a notable 12% boost in mass transfer, as the chemical reaction parameter increases from 0 to 1. Rising Brinkmann and Reynolds numbers significantly boost the entropy generation. This research is crucial across engineering sectors like power generation, refrigeration, solar collectors, and chemical processing, where improved efficiency leads to significant cost savings and a reduced environmental footprint.

RESEARCH AIM

The basic motive of this research is to explore the characteristics of entropy generation in a three-dimensional MHD convective flow of a Casson nanofluid over a stretching surface. This study incorporates the effects of non-linear thermal radiation, non-uniform heat source, Joule heating, and Suction.

LITERATURE SURVEY

Yanala et al. [1] discussed the characteristics of heat and mass transfer in a Casson fluid over a permeable stretching sheet. Waseem et al. [2] studied the flow of a Micropolar nanofluid over an exponential stretching sheet, employing the Cattaneo-Chirstov heat model to analyze its thermal properties. Jawad et al. [3] examined the impact of mass and heat transfer on the convective Darcy-Forchheimer flow of Maxwell nanofluid via a stretched sheet with linear porosity. Jalili et al. [4] studied the nonlinear radiative heat transport in an electrically conducting non-Darcy fluid flow over a vertical porous stretching sheet.

MATHEMATICAL FORMULATION

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\upsilon\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial z^2}-u\left(\frac{\sigma B_o{}^2}{\rho_f}\right)-u\left(\frac{\upsilon}{k_1}\right)-\frac{C_b}{x\sqrt{k_1}}\mathrm{u}^2, \tag{2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=\upsilon\left(1+\frac{1}{\beta}\right)\frac{\partial^2 v}{\partial z^2}-v\left(\frac{\sigma B_o{}^2}{\rho_f}\right)-v\left(\frac{\upsilon}{k_1}\right)-\frac{C_b}{y\sqrt{k_1}}v^2, \tag{3}$$

$$\left.\begin{aligned}u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\frac{\partial^2 T}{\partial z^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial z}+\tau\left[D_B\frac{\partial T}{\partial z}\frac{\partial C}{\partial z}+\frac{D_T}{D_\infty}\left(\frac{\partial T}{\partial z}\right)^2\right]+\\ \frac{\mu}{\rho C_p}\left(1+\frac{1}{\beta}\right)\left[\left(\frac{\partial u}{\partial z}\right)^2+\left(\frac{\partial v}{\partial z}\right)^2\right]+\frac{\sigma B_o^2}{\rho C_p}\left(u^2+v^2\right)+\frac{q'''}{\rho c_p},\end{aligned}\right\} \tag{4}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial z^2}+\frac{D_T}{D_\infty}\frac{\partial^2 T}{\partial z^2}-k_r^*\left(C-C_\infty\right). \tag{5}$$

$$\left.\begin{aligned}E_G=\underbrace{\frac{k_f}{T_\infty^2}\left(1+\frac{16\sigma^* T^3}{3k_f k^*}\right)\left(\frac{\partial T}{\partial z}\right)^2}_{\text{Thermal Transfer Irreversiblity}}+\underbrace{\frac{\mu}{T_\infty}\left(1+\frac{1}{\beta}\right)\left[\left(\frac{\partial u}{\partial z}\right)^2+\left(\frac{\partial v}{\partial z}\right)^2\right]}_{\text{Viscous Dissipation Irreversibility}}+\underbrace{\frac{\mu}{k_1 T_\infty}\left(u^2+v^2\right)}_{\text{Porosity Irreversibility}}+\underbrace{\frac{\sigma B_0^2}{T_\infty}\left(u^2+v^2\right)}_{\text{Joule Heating Irreversibility}}\\ +\underbrace{\frac{RD_B}{T_\infty}\left[\left(\frac{\partial T}{\partial z}\right)\left(\frac{\partial C}{\partial z}\right)\right]+\frac{RD_B}{C_\infty}\left[\frac{\partial C}{\partial z}\right]^2}_{\text{MassTransfer Irreversibility}}.\end{aligned}\right\} \tag{6}$$

SOLUTION METHODOLOGY

The bvp4c function in MATLAB is a powerful and adaptable tool for solving boundary value problems, offering flexibility in handling complex and multipoint boundary conditions. Utilize Matlab ‘ bvp4c’ software to solve a set of ordinary differential equations and generate the graphs for the controlling parameters of velocity, temperature, concentration, and entropy. We discussed drag coefficient, heat transfer, and mass transfer for this specific problem.

CONCLUSIONS

Numerical solutions are obtained using the MATLAB software, specifically with the bvp4c solver. The physical impacts of various flow parameters on the flow field are depicted graphically and in tabular form.

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