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Exploring the Influence of Thermophoresis and Brownian Motion on Radiative Chemically-Reacting MHD Hiemenz Flow over a Nonlinear Stretching Sheet with Nanoparticle-Induced Heat Generation.

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Abstract

In this research, we investigate the characteristics of radiative magnetohydrodynamic (MHD) stagnation point flow over a nonlinear stretching sheet, taking into account the influences of thermophoresis and Brownian motion of nanoparticles. Employing a similarity transformation technique, the governing partial differential equations are transformed into a set of ordinary differential equations (ODEs). Additionally, the Homotopy Analysis Method (HAM) is employed to elucidate the associated mechanisms. Our findings reveal that enhanced magnetic and velocity exponent parameters lead to a dampening effect on the fluid velocity, while the presence of thermophoresis and Brownian motion intensifies specific thermal influences.

Introduction

Nanofluids comprise particles at the nanoscale, measuring less than 100 nanometers, which are introduced into base fluids like oil, water, biofluids, ethylene, and lubricants. Despite their profound significance across industries, medicine, and various scientific and technological domains, researchers have predominantly directed their attention towards nanofluids rather than other fluids. Nevertheless, nanofluids continue to hold a pivotal role in medical applications, such as the utilization of gold nanoparticles for cancer tumor detection and the development of tiny therapeutic agents used for targeting cancerous growths. The concept of nano materials was introduced by Choi [1], who deduced that infusing these particles enhances the thermal conductivity of the fluid. Hayat et al. [2] derived analytical solutions for magnetohydrodynamic (MHD) nanofluid squeezing flow between parallel plates. In a study by Hussain et al. [3], the dynamics of Jeffery nanofluid flow over an exponentially stretched sheet were investigated, incorporating radiation effects. Abbas et al. [4] explored thermal radiation and chemical reaction effects in a magnetized nanofluid flow. Hayat et al. [5] delved into heat and mass transfer characteristics under convective conditions. Ganesh Kumar et al. [6] studied boundary layer flows and melting heat transfer of a Prandtl fluid over a stretching surface with suspended fluid particles. Jalali et al. [7] numerically examined the interplay between viscosity and thermal conductivity in heat transfer involving Al_2O_3-water nanofluid. Further insights on this topic can be found in references [8–10].

Contemporary metallurgical and metalworking technologies heavily rely on understanding the magnetohydrodynamic (MHD) flow of electrically conducting fluids. [11] investigated Laplace transform solutions for unsteady natural convective motion driven by rotating

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magnetohydrodynamics in a permeable medium above an oscillating sheet. [12] analyzed the impact of chemical reactions on magnetohydrodynamic free convective motion of a mobile liquid over a vertical sheet. [13] numerically tackled the Marangoni mixed convection problem in a nanofluid subjected to an inclined magnetic field of uniform strength.

Mathematical Formulation

We review a non-linear continuously stretched horizontal plate impinging on a steady, two-dimensional, incompressible stagnation-point flow. Fig. 1 describes the flow model. The relevant interpretations have been developed in this study [14].

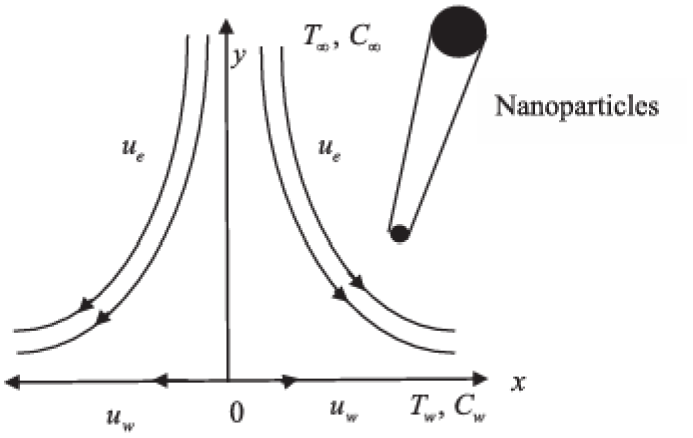

Figure 1: Physical model of the flow

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

$$\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \bar{u}_e\frac{d\bar{u}_e}{d\bar{x}} + v\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{\sigma B^2(\bar{x})}{\rho}(\bar{u} - \bar{u}_e), \tag{2}$$

$$\bar{u}\frac{\partial T}{\partial \bar{x}} + \bar{v}\frac{\partial T}{\partial \bar{y}} = \alpha\frac{\partial^2 T}{\partial \bar{y}^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial \bar{y}} + \tau\left(\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial \bar{y}}\right)^2 + D_B\frac{\partial T}{\partial \bar{y}}\frac{\partial C}{\partial \bar{y}}\right) + \frac{Q_0}{\rho C_p}(T - T_\infty), \tag{3}$$

$$\bar{u}\frac{\partial C}{\partial \bar{x}} + v\frac{\partial C}{\partial \bar{y}} = D_B\left(\frac{\partial^2 C}{\partial \bar{y}^2}\right) + \frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial \bar{y}^2}\right) - k_0(C - C_\infty). \tag{4}$$

The appropriate boundary conditions are

$$\begin{aligned} &\bar{u} = \bar{u}_w(\bar{x}), \quad \bar{v} = 0, \quad T = T_w, \quad C = C_w \quad \text{at} \quad \bar{y} = 0 \\ &u = \bar{u}_e(\bar{x}), \quad T = T_\infty, \quad C = C_\infty \quad \text{as} \quad \bar{y} \to \infty, \end{aligned} \tag{5}$$

Now, we introduce the following similarity transformations

$$x=\frac{\overline{x}}{l},\quad y=\frac{\overline{y}\sqrt{\mathrm{Re}}}{l},\quad u=\frac{\overline{u}}{u_\infty},\quad v=\frac{\overline{v}\sqrt{\mathrm{Re}}}{u_\infty},\quad u_e=\frac{\overline{u}_e}{u_\infty},\quad \zeta=\frac{\overline{y}\sqrt{\mathrm{Re}}}{l}x^{\frac{1-m}{2}},\quad \theta=\frac{T-T_\infty}{T_w-T_\infty},$$
$$\phi=\frac{C-C_\infty}{C_w-C_\infty},\quad \psi=x^{\frac{m+1}{2}}f(\zeta),\quad u=x^m f'(\zeta),\quad v=-\left[\frac{m+1}{2}x^{\frac{m-1}{2}}f(\zeta)+\frac{m-1}{2}yx^{m-1}f'(\zeta)\right] \tag{6}$$

Substituting Eq. (6) in Eqs. (2)–(5), we obtain

$$f'''+\frac{m+1}{2}ff''+m(1-f'^2)+M(1-f')=0, \tag{7}$$

$$\frac{1}{\mathrm{Pr}}\left(1+\frac{4}{3}R\right)\theta''+\frac{m+1}{2}f\,\theta'+Nb\theta'\phi'+Nt\theta'^2+Q\,\theta=0, \tag{8}$$

$$\phi''+\frac{m+1}{2}\,Lef\,\phi'+\frac{Nt}{Nb}\theta''-Le\,\gamma\,\phi=0, \tag{9}$$

We now adopt a fore mentioned initial guesses and linear operators to encapsulate the homotopic solutions

$$(1-p)\,L_1(f(\zeta;\ p)-f_0(\zeta))=p\,\hbar_1\,N_1[f(\zeta;\ p)]\,,$$
$$(1-p)\,L_2(\theta(\zeta;\ p)-\theta_0(\zeta))=p\,\hbar_2\,N_2[f(\zeta;\ p),\ \theta(\zeta;\ p),\ \phi(\zeta;\ p)]\,,$$
$$(1-p)\,L_3(\phi(\zeta;\ p)-\phi_0(\zeta))=p\,\hbar_3\,N_3[f(\zeta;\ p),\ \theta(\zeta;\ p),\ \phi(\zeta;\ p)],$$

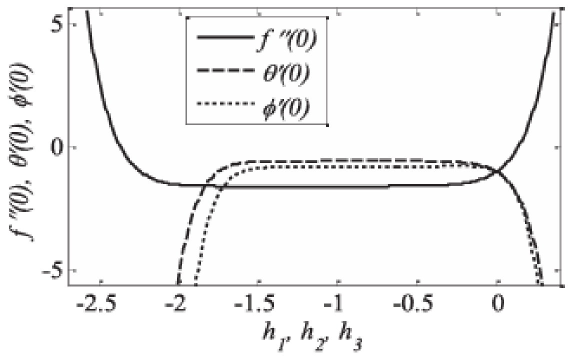

Figure 2: $\hbar$-curves for $f''(0)$, $\theta'(0)$ and $\phi'(0)$ at 15th order approximations

Results

For a wide range of physical characteristics, tables and charts are often performed to ascertain and describe the nature of flow, temperature, concentration, skin friction coefficient, and local Nusselt and Sherwood numbers. We check out the following values all across the exploration, apart from renovated quantities as revealed in the tables and charts.

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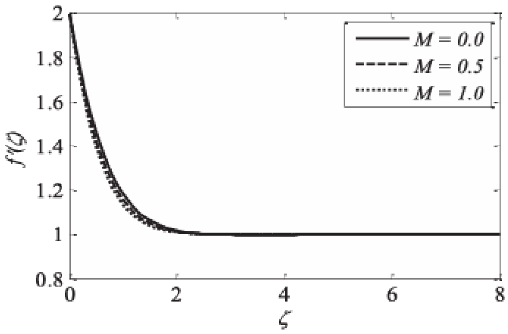

Figure 3: Effect of M on $f'(\zeta)$

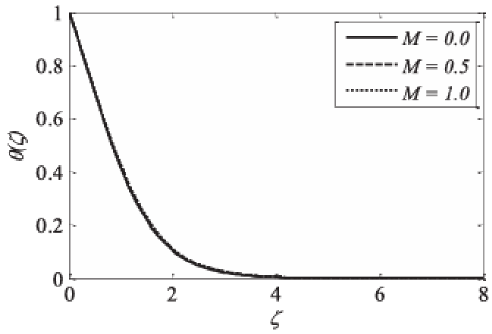

Figure 4: Effect of M on $\theta(\zeta)$

Conclusion

This study examines the analytical investigation of a two-dimensional steady forced convective flow involving a Newtonian fluid adjacent to a convectively heated vertically moving plate. The flow is directed toward the surface of a variable magnetic field while considering the influence of radiation, all analyzed through the Homotopy Analysis Method (HAM). The following key findings emerge from the graphical and numerical solutions presented in this study:

1. The temperature profile experiences a substantial increase due to variations in the heat source parameter.

2. Thermal radiation and thermophoresis parameters contribute to an enhancement in the temperature distribution.

3. The concentration profile decreases as the Lewis number and chemical reaction parameters increase.

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