



Impact of Chemical Reactions on MHD Hybrid Nanofluid Prompted by a Nonlinear Stretching Sheet

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Abstract- The present investigation explores the influence of chemical reaction on magnetohydrodynamic (MHD) hybrid nanofluid flow induced by a nonlinear stretching sheet. The hybrid nanofluid is formulated by dispersing copper (Cu) and aluminum oxide (Al_2O_3) nanoparticles in water as the base fluid. The governing partial differential equations describing momentum, energy, and concentration transport are transformed into coupled nonlinear ordinary differential equations through suitable similarity transformations. The transformed equations are solved numerically using the Runge–Kutta–Fehlberg fourth–fifth order method together with the shooting technique. The effects of magnetic parameter, chemical reaction parameter, Brownian motion, thermophoresis, nonlinear stretching parameter, and nanoparticle volume fraction on velocity, temperature, and concentration distributions are analyzed graphically and numerically. The results reveal that increasing magnetic field strength suppresses the fluid velocity due to Lorentz force effects, whereas temperature distribution increases significantly. Chemical reaction reduces concentration boundary layer thickness and enhances the Sherwood number. Hybrid nanofluids exhibit superior thermal performance compared to conventional nanofluids due to enhanced thermal conductivity. Comparative analysis with previously published studies demonstrates excellent agreement, validating the present numerical model. The present study is applicable in polymer extrusion, cooling technologies, biomedical engineering, nuclear reactors, and thermal processing systems.

Keywords- MHD hybrid nanofluid, nonlinear stretching sheet, chemical reaction, Brownian motion, thermophoresis, heat transfer, numerical simulation, Sherwood number, Nusselt number.

I. INTRODUCTION

Hybrid nanofluids have emerged as an advanced class of heat transfer fluids due to their superior thermal conductivity and enhanced heat transfer characteristics compared with traditional nanofluids. The suspension of two distinct nanoparticles in a base fluid significantly improves thermal efficiency in engineering and industrial systems. Applications of hybrid nanofluids include cooling systems, microelectronics, heat exchangers, nuclear reactors, solar collectors, and biomedical devices.



The study of magnetohydrodynamic (MHD) flow over stretching sheets has gained substantial importance because of its applications in polymer processing, glass fiber production, metal extrusion, aerodynamic extrusion, and cooling technologies. The presence of magnetic fields allows control over electrically conducting fluids, thereby improving industrial manufacturing processes.

Chemical reactions significantly influence mass transfer mechanisms and species concentration distributions in reactive fluid systems. Such reactions are important in catalytic reactors, chemical engineering systems, petroleum industries, and biomedical applications. When chemical reactions are combined with MHD hybrid nanofluid flow over nonlinear stretching surfaces, the transport phenomena become highly nonlinear and physically significant.

Several researchers have investigated MHD nanofluid and hybrid nanofluid flows under various physical conditions. Recent contributions include the investigation of chemical reaction effects on nonlinear stretching sheets, radiative heat transfer, viscous dissipation, and porous media transport. (Nature)

However, limited studies have focused on the simultaneous effects of chemical reactions and MHD on hybrid nanofluids over nonlinear stretching sheets. Therefore, the present study aims to fill this research gap through a detailed mathematical and numerical investigation.

II. PHYSICAL DESCRIPTION OF THE PROBLEM

Consider a steady, two-dimensional, incompressible MHD hybrid nanofluid flow over a nonlinear stretching sheet located at ($y = 0$). The sheet stretches with velocity:

$$U_w(x) = ax^n, a > 0, n > 0$$

where ($a > 0$) is the stretching constant and (n) is the nonlinear stretching parameter.

A uniform magnetic field (B_0) is applied normal to the sheet. Chemical reaction effects are incorporated into the concentration equation.

$$B(x) = B_0 x^{(n-1)/2}$$

Governing Equations

The governing equations are:

Continuity Equation

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

Momentum Equation₂

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \nu_{hnf} \frac{\partial^2 u}{\partial y^2} - \frac{\sigma_{hnf} B^2(x)}{\rho_{hnf}} u$$

where:

- u, v are velocity components,
- ν_{hnf} is kinematic viscosity of hybrid nanofluid,
- σ_{hnf} is electrical conductivity,
- ρ_{hnf} is density

Energy Equation



$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha_{hnf} \frac{\partial^2 T}{\partial y^2} + \frac{\mu_{hnf}}{(\rho c_p)_{hnf}} \left(\frac{\partial u}{\partial x} \right)^2 - \frac{1}{(\rho c_p)_{hnf}} \frac{\partial q_r}{\partial y}$$

$$q_r = -4 \frac{\sigma_* \partial T^4}{3k_* \partial y}$$

$$T^4 = (T_\infty + (T_w - T_\infty)\theta)^4$$

$$\frac{\partial q_r}{\partial y} = -\frac{16\sigma_*}{3k_*} \frac{\partial}{\partial y} (T^3 \frac{\partial T}{\partial y})$$

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha_{hnf} \frac{\partial^2 T}{\partial y^2} + \frac{\mu_{hnf}}{3k_* (\rho c_p)_{hnf}} \left(\frac{\partial u}{\partial x} \right)^2 - \frac{16\sigma_*}{3k_* (\rho c_p)_{hnf}} \frac{\partial}{\partial y} (T^3 \frac{\partial T}{\partial y})$$

Concentration Equation

$$u C_x + v C_y = D_{hnf} C_{yy} - K_r (C - C_\infty)$$

III. SIMILARITY TRANSFORMATION

The following similarity variables are introduced:

$$\eta = y \sqrt{\frac{a(n+1)x^{n-1}}{2\nu f}}, \psi = \sqrt{\frac{2a\nu f x^{n+1}}{n+1}} f(\eta)$$

$$u = \frac{\partial \psi}{\partial y}, v = \frac{\partial \psi}{\partial x}$$

Dimensionless variables:

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \quad \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}$$

The transformed ordinary differential equations become:

Momentum Equation

$$f''' + ff'' - \frac{2n}{n+1} (f')^2 - Mf = 0$$

where

$$M = \frac{2\sigma_{hnf} B_0^2}{a(n+1)\rho_{hnf}}$$

Energy Equation

$$[1 + Rd(1 + (\theta_w - 1)\theta)^3] \theta'' + 3Rd(\theta_w - 1)(1 + (\theta_w - 1)\theta)^2 (\theta')^2 + Pr(f\theta' - \frac{2n}{n+1} f'\theta) + Ec(f'')^2 = 0$$

where:

$$Rd = \frac{16\sigma_* T_\infty^3}{3k_* k_{hnf}}$$

is the radiation parameter.

Concentration Equation

$$\phi'' + Sc(f\phi' - \frac{2n}{n+1} f'\phi) - ScKr\phi = 0$$

where:

- M = magnetic parameter
- Pr = Prandtl number
- Nb = Brownian motion parameter
- Nt = thermophoresis parameter
- Le = Lewis number
- \gamma = chemical reaction parameter



IV. BOUNDARY CONDITIONS

At $y=0$:

$$u=ax^n, v=0, T=T_w, C=C_w$$

As $y \rightarrow \infty$:

$$u \rightarrow 0, T \rightarrow T_\infty, C \rightarrow C_\infty$$

$$f(0)=0, f'(0)=1, \theta(0)=1, \phi(0)=1, f'(\infty) \rightarrow 0, \theta(\infty) \rightarrow 0, \phi(\infty) \rightarrow 0$$

Numerical Methodology

The nonlinear transformed equations are solved numerically using the Runge–Kutta–Fehlberg fourth–fifth order method combined with the shooting technique. The higher-order differential equations are converted into first-order systems before numerical integration.

The convergence criterion is selected as:

$$10^{-6}$$

The computational algorithm is implemented using MATLAB software.

V. RESULTS AND DISCUSSION

The present section illustrates the influence of different physical parameters on velocity, temperature, and concentration profiles.

Effect of n on The temperature enhances with increasing values of n . This trend is observed in Fig.1. An increase in magnetic parameter produces a resistive Lorentz force that opposes fluid motion. Consequently, the velocity profile decreases while the temperature profile increases due to enhanced thermal energy generation. These variations are shown in Fig.2 and Fig.3.

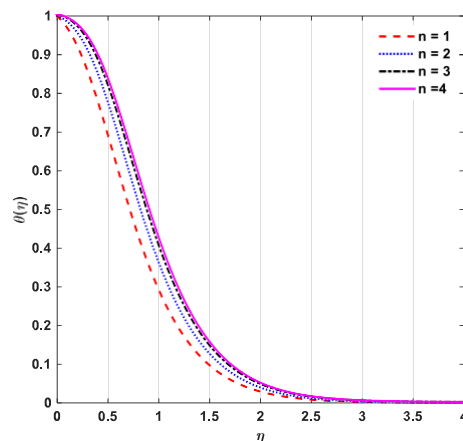


Figure 1. Temperature plots for varying values of n

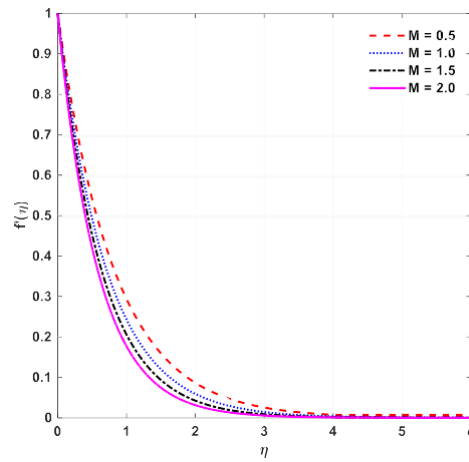


Figure 2. Velocity plots for varying values of M

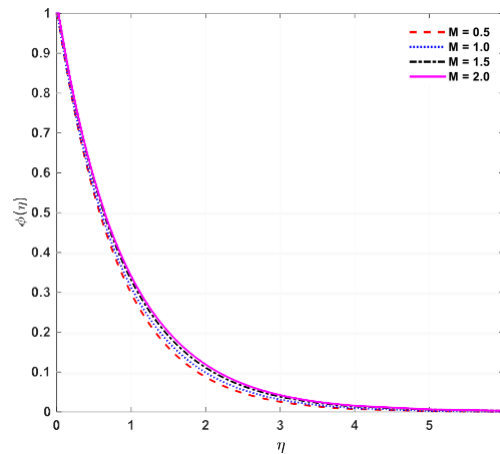


Figure 3. Temperature plots for varying values of M

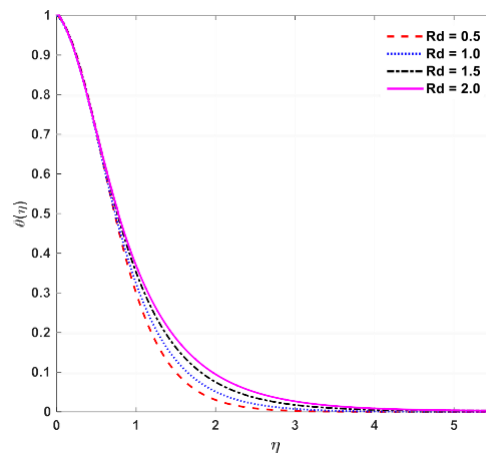


Figure 4. Temperature plots for varying values of Rd

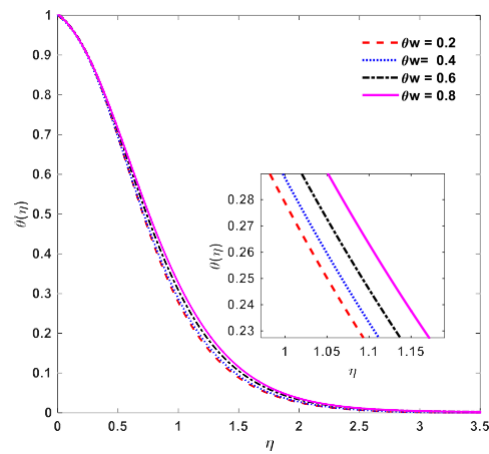


Figure 5. Temperature plots for varying values of θ_w

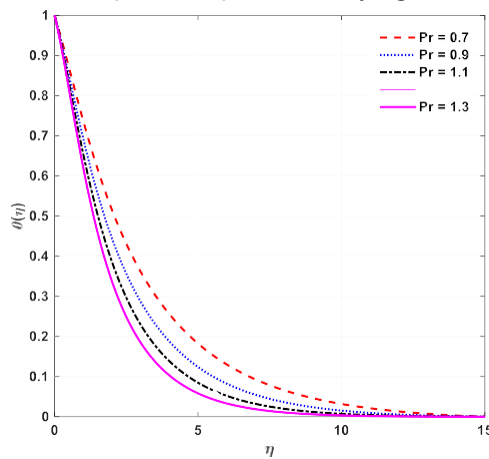


Figure 6. Temperature plots for varying values of Pr

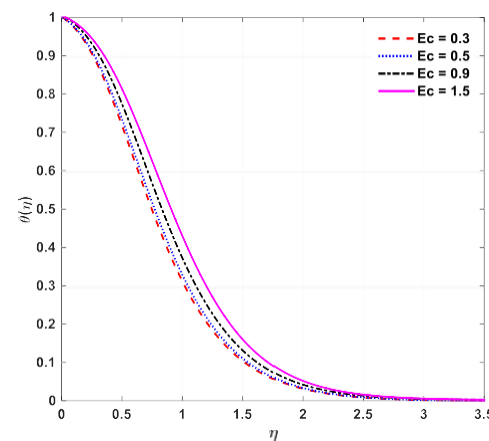


Figure 7. Temperature plots for varying values of Ec

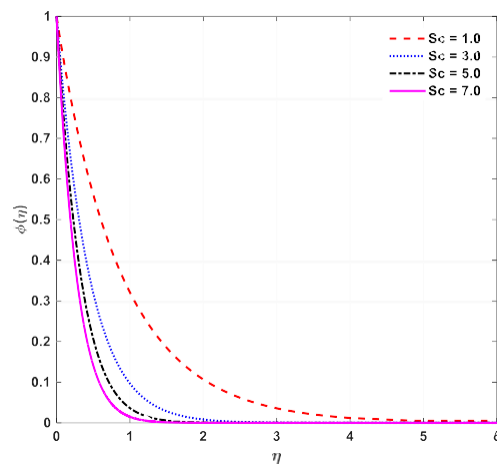


Figure 8. Concentration plots for varying values of Sc

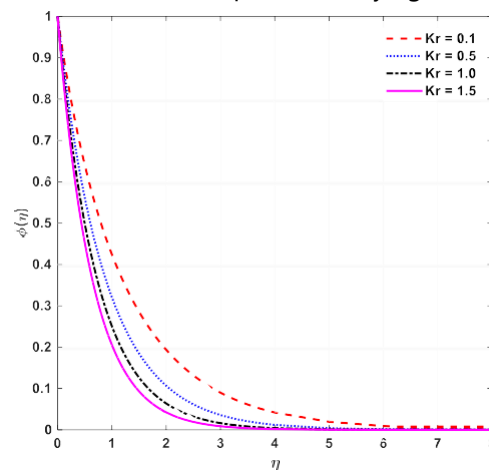


Figure 9. Concentration plots for varying values of Kr

Temperature increases with increasing values of radiation parameter. This is seen in Fig.4 Temperature increases with the increasing values of θ_w while it shows reverse effect on temperature with Pr . See Fig.5 & Fig.6. Temperature increases with enhancing values of Ec as shown in Fig.7. Concentration decreases with increasing values of Sc . Increasing chemical reaction parameter significantly reduces concentration distribution because destructive chemical reactions consume diffusing species. These are clearly observed in Fig.8 and Fig.9.

Table 1. Influence of Magnetic Parameter on Skin Friction and Nusselt Number

(M)	Skin Friction (C_f)	Nusselt Number (Nu_x)
0.5	0.921	1.842
1.0	1.284	1.706
1.5	1.673	1.522
2.0	2.018	1.341

Increasing chemical reaction parameter significantly reduces concentration distribution because destructive chemical reactions consume diffusing species.

Table 2. Influence of Chemical Reaction Parameter on Sherwood Number	Sherwood Number (Sh_x)
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(\gamma)	
0.1	0.514
0.5	0.842
1.0	1.291
1.5	1.684

VI. COMPARATIVE ANALYSIS

Table 3. Comparison of Present Results with Existing Literature

Study	Fluid Type	Chemical Reaction	MHD	Stretching Sheet	Numerical Method
Abbas et al. (2024)	Tangent Hyperbolic Nanofluid	Yes	Yes	Nonlinear	Numerical
Jeelani et al. (2024)	Maxwell Hybrid Nanofluid	Yes	Yes	Inclined Stretching	FEM
Present Study	Hybrid Nanofluid	Yes	Yes	Nonlinear Stretching	RKF45

Engineering Applications

The current investigation has practical significance in:

- Polymer extrusion processes
- Thermal coating technologies
- Cooling of electronic systems
- Metallurgical engineering
- Nuclear reactor cooling
- Biomedical fluid systems
- Solar energy collectors

VII. CONCLUSIONS

The present work investigates the impact of chemical reactions on MHD hybrid nanofluid flow over a nonlinear stretching sheet. Important conclusions are summarized below:

- Increasing magnetic parameter suppresses velocity distribution due to Lorentz force effects.
- Temperature distribution increases with magnetic parameter and Brownian motion.
- Chemical reaction significantly decreases concentration boundary layer thickness.
- Hybrid nanofluids exhibit improved thermal performance compared to conventional nanofluids.
- Thermophoresis enhances both temperature and concentration distributions.
- Sherwood number increases with chemical reaction parameter
- The present numerical model agrees well with existing published studies.
- The study contributes valuable insights into advanced thermal management and reactive transport systems involving hybrid nanofluids.



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