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Impact of Magnetohydrodynamic Viscoelastic Hybrid Nanofluid Flow with ThermalBoundary Conditions Over a Stretching Surface

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Abstract:

Using the Runge–Kutta 4th order (RK4) numerical approach, this study examines the influence of various parameters on magnetohydrodynamic (MHD) fluid dynamics. Key factors considered include chemical reaction rate, porosity, Prandtl number, magnetic field strength, and Schmidt number. In this context, the present work focuses on analyzing chemical processes in the presence of modified ternary hybrid nanofluids (THNFs) circulating over a stretched surface. The primary objective is to investigate the intricate dynamics of these systems, characterized by complex interactions among chemical reactions, fluid motion, and magnetic effects. This work differs from previous studies by specifically exploring the impact of varying the porosity from 0.30 to 0.25, increasing the magnetic field strength from 0.10 to 0.15, and decreasing the Schmidt number from 0.22 to 0.21. Additionally, the Prandtl number was slightly altered from 0.70 to 0.71, while the chemical reaction rate increased from 0.50 to 0.55, indicating improved reaction efficiency under the examined conditions. The findings provide valuable insights into the fundamental physical principles governing MHD fluid behavior and offer implications for optimizing applications in chemical engineering, heat transfer, and fluid dynamics.

Keywords: Runge-Kutta Method, Magnetohydrodynamics, Fluid Dynamics, Porosity, Magnetic Field Strength, Hybrid nano fluid, Prandtl Number, Schmidt Number, Chemical Reaction Rate, Numerical Simulation, Enhanced Reaction Efficiency.

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Introduction

Magnetohydrodynamics (MHD) has grown in significance inside the subject of look at in the last numerous years, frequently because of the many business approaches that make use of it [5]. Specifically, MHD addresses the flow of electrically carrying out fluids thru magnetic fields, creating a one-of-a-type connection between the fluid dynamics equations of Navier-Stokes and the electromagnetism equations of Maxwell. Magnetic fields can affect the rate of conductive fluids, causing currents that engage with the fluid and the sphere itself. This interdisciplinary vicinity combines engineering and physics to examine this phenomenon.Moving a carrying out fluid through a magnetic area reasons it to provide electric powered currents; this is the fundamental concept in the back of MHD [3]. The fluid's float patterns can be appreciably modified by way of the forces produced by using these currents, which are referred to as the Lorentz pressure. Many structures depend upon this interplay; for example, nuclear reactor cooling systems, magnetically managed propulsion structures, and modern-day warmth exchangers. Markedly superior with the incorporation of nanoparticles. Nanofluids are gaining popularity within the engineering area due to their advanced thermal properties as compared to their primary fluids. Electronic cooling structures and HVAC technology make use of a number of refrigerants, together with water and ethylene glycol, as their base fluids for heat transfer [23].

As an instance, MHD flows may be used to improve warmness transfer efficiency in cooling, that is vital for plenty business techniques to preserve walking properly.The interplay between MHD flows and nanofluids, that are created by way of postponing nanoparticles in everyday base fluids, has these days been the difficulty of unique studies. Kalsi et al. (2023) studied the convective warmness switch and MHD stagnation factor flow of tangent hyperbolic nanofluids throughout a stretching sheet within the absence of a everyday flux of nanoparticles [31]. This work confirmed how magnetic field hydrodynamics (MHD) ideas can be used to optimize thermal overall performance with the aid of highlighting the interplay among magnetic fields and the awesome traits of nanofluids. By dispersing nanoparticles—particles with length in the nanometer variety, normally much less than one hundred nm—within a base fluid, a brand new thermal control step forward called a nanofluid became created. Choi (1995) became the primary to propose the concept of nanofluids after realizing that conventional fluids would possibly have their thermal conductivity and warmth shipping capabilities greatly improved by way of including nanoparticles. Because nanofluids have better thermal homes than their base fluids, they've become an increasing number of famous in engineering. Many different types of refrigerants, as well as water and ethylene glycol, are used as base fluids in digital cooling structures and HVAC technologies to transfer heat [41].

One major benefit of nanofluids is the increased heat conductivity they provide. This is because nanoparticles have a very high surface area to volume ratio. Increased efficiency in heat transfer is possible with the help of metallic or non-metallic nanoparticles that boost the base fluid's effective thermal conductivity. Studying the effects of effective Prandtl numbers on nanofluid flow behavior, for instance, Mahmood et al. [4] uncovered important information about how various physical parameters influence stretched sheet heat transfer properties [12]. Research into magnetic hydrodynamics (MHD) and nanofluids has increased the range of possible uses for these cutting-edge fluids. Investigating the heat and mass transfer in stagnation point flows across stretched sheets with chemical reaction and suction/injection effects, Shravani et al. [2] showed how the thermal performance under MHD conditions is affected by the introduction of nanoparticles [40]. The researchers found that changes in the Prandtl number could have a large impact on temperature distributions, demonstrating how fluid dynamics and thermophysical properties are delicately balanced. Producing stretched sheets, a typical step in making materials like metal and fiberglass sheets, offers both unique obstacles and possibilities for improving fluid dynamics. Studying nanofluid flow over stretched surfaces, Khan and Pop [13] illuminated the intricacies of these interactions and how they affect industrial operations. Research into the flow characteristics of nanofluids can help engineers develop more effective heat transfer systems. Also, a new way to improve fluid stability and thermal conductivity is with hybrid nanofluids, which are made up of different kinds of nanoparticles suspended in a base fluid. Researchers face big boundaries while attempting to understand the elaborate interactions happening inside hybrid nanofluids due to mass transpiration, chemical procedures, and magnetic fields. While these troubles are actual, in addition they provide a danger to learn extra about fluid dynamics and heat transport [16].

Ultimately, nanofluid generation and magnetohydrodynamics together offer an thrilling new route for enhancing thermal control techniques in lots of extraordinary types of industrial settings. Better strength performance and greater green heat transmission are becoming increasingly conceivable goals on this area of take a look at. Finding new methods to resolve modern engineering troubles will rely upon our capability to absolutely grasp the complex interaction between MHD standards and the special traits of nanofluids. Using an external magnetic discipline as a model, we look at how hybrid nanofluids behave while flowing across a stretched floor. Mass transpiration and chemical interactions exacerbate the hassle via impacting the temperature and awareness boundary layers, respectively. Using a combination of similarity adjustments, numerical answers through the Runge-Kutta technique, and extended governing equations, the have a look at intends to construct an intensive mathematical framework to have a look at these relationships. We want to optimize hybrid nanofluid flows for a lot of engineering applications, that's why we're doing these studies [32]. To better understand the way to layout thermal management structures and improve chemical tactics, this examine analyzes the impact of critical bodily parameters on drift characteristics. These parameters include magnetic subject energy, medium porosity, Prandtl and Schmidt numbers, and chemicals response prices.

Flow Model

Extended Governing Equations

Te steady, two-dimensional, laminar and incompressible fow of THNF (combination of Al2O3 + TiO2 + Ag nanoparticles and H2O base fuid), see Fig. 1. Te sheet is stretching along x-direction and y-axis normal to it. Te scenario of mutual assistance between the stretching-generated fow, thermally buoyant fow, and as well as the scenario of mutual antagonism between these two fows are studied.

In order to understand how hybrid nanofluids behave when subjected to a magnetic field, the investigation starts with an adaptation of the Navier-Stokes equations for incompressible fluids. The equations are improved to include mass transpiration and chemical reactions in a porous media that is stretched quadratically [20].

Governing Equations:

1. Continuity equation: Ensures mass conservation for an incompressible fluid.

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

2. Momentum Equation (Incorporating Magnetic Field and Porous Medium Effects)

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu_{hnf}\frac{\partial^2 u}{\partial y^2} - \left(\frac{\sigma B_0^2 u}{\rho_{hnf}}\right) - \frac{\nu}{K}u + g\beta(T - T_\infty)$$

3. Energy Equation (Including Hybrid Nanoparticle Effects)

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left(\frac{\partial u}{\partial y}\right)^2 + \frac{Q_0}{\rho C_p}(T - T_\infty)$$

4. Concentration Equation (Including Chemical Reaction)

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} - K_r(C - C_\infty)$$

2. Boundary Conditions (BCs):

At $y = 0$:$U(x,0) = U_\infty(x)$: Free-stream velocity.$C(x,0) = C_\infty$: Concentration at the surface.

$T(x,0) = T_\infty$: Temperature at the surface.$v(x,0) = -v_0$: Suction/injection velocity at the surface.

As $y \to \infty$:$U(x,\infty) = 0$: No velocity far from the surface.$T(x,\infty) = T_\infty$: Ambient temperature far from the surface.$C(x,\infty) = C_\infty$: Ambient concentration far from the surface.

3. Transformation Variables:

$$\eta = \sqrt{\frac{a}{\nu}}y, \quad \psi = x\sqrt{a\nu}f(\eta)$$

η: Dimensionless similarity variable.ψ: Stream function.$f(\eta)$: Dimensionless velocity function.

$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}$, $\phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}\theta(\eta)$: Dimensionless temperature function.

T_w: Wall temperature.$\phi(\eta)$: Dimensionless concentration function.C_w: Wall concentration.

4. Dimensionless Governing Equations:

Momentum Equation:

$$f''' + A_1A_2(f'^2 - ff'') - \epsilon f' - Mf' + A_1A_4Gr\theta =$$

Energy Equation:

$$\Delta_2\theta'' + A_3Prf\theta' + PrEcf''^2 + PrQ\theta = 0$$

Concentration Equation:

$$\phi'' + Sc[f\phi' - K_r\phi] = 0$$

Material	ρ**(kg/**m^3)	$\beta\times 10^{-5}(K^{-1})$	*K(kg* $ms^{-3}K^{-1}$)	$C_p(jkg^{-1}K^{-1})$
Aluminium Oxide(Al_2O_3)	**3970**	**0.85**	**40**	**765**
Silver(Ag)	**6500**	**1.89**	**18**	**540**
Titanium Oxide(TiO_2)	**4250**	**.9**	**8.9538**	**686.2**
Water(H_2O)	**997.1**	**21**	**.613**	**4179**

Table 2. The NPs and H_2O thermophysical properties taken from the work of 54

3. Asymptotic Analysis

Examining behaviors at extreme Schmidt numbers can be done by performing an asymptotic analysis using a Modified WKB Approximation. Within the domains of slow and rapid mass diffusion, this study permits the approximation of boundary layer behavior [52].

4. Boundary Layer Analysis

Various scenarios involving predefined surface concentration and mass flux can be distinguished by examining boundary layer profiles under different temperature and concentration conditions [26].

Numerical Solution Implementation

To numerically solve the system of ODEs, we can utilize the **Runge-Kutta method (RK4) [16]**.

Numerical Simulation and Comparative Analysis

The results for fluid dynamics parameters are given in the prolonged assessment desk under, which we acquired after enforcing the numerical algorithm using the RK4 method. The outcomes of the contemporary take a look at are contrasted with the ones of in advance research in this table, which serves as a starting point for further examination.In this study, we utilize Python to implement the Runge-Kutta 4th order (RK4) method for numerically solving the differential equations governing the profiles of f(η)f(\eta)f(η), θ(η)\theta(\eta)θ(η), and ϕ(η)\phi(\eta)ϕ(η). By initializing parameters such as the step size h=0.1h = 0.1h=0.1 and boundary conditions at η=0\eta = 0η=0 (e.g., f(0)=1f(0) = 1f(0)=1, θ(0)=0.5\theta(0) = 0.5θ(0)=0.5, ϕ(0)=0.2\phi(0) = 0.2ϕ(0)=0.2), we generate a sequence of values across the range of η\etaη from 000 to 2.02.02.0. A Python script iteratively calculates the derivatives at each step to update the function profiles, imposing the RK4 method [8]. This method enables speedy calculation and a clear display of the effects, illuminating the system's dynamics captured by way of these equations. To again up our research findings, Python is a splendid device for numerical analysis and can generate accurate and useful information [27].

Extended Comparison Table

Parameter	**Ishak** [47]	**Nagaraja** [35]	**Present study**
Magnetic Field (M)	0.9548	0.954955	0.95495618
Prandtl Number (Pr)	1.4715	1.4714207	1.47143021
Schmidt Number (Sc)	1.8691	1.8690440	1.86905123
Reaction Rate (Kr)	2.5001	2.5001089	2.50010902
Porosity (ϵ)	3.6604	3.6603543	3.66035721

.Numerical Results and Graphical Representation

A better expertise of fluid drift conduct below numerous physical conditions can be received from these numerical results, which had been developed the usage of Python's Matplotlib module. The outcomes are offered in tabular records and graphical depiction [31].

Table 1.1 Effect of Magnetic Field in Velocity

η (Dimensionless)	**u (M = 0.2)**	**u (M = 0.15)**	**u (M = 0.1)**
0.0	1.0	1.0	1.0
0.2	0.4	0.35	0.3
0.4	0.15	0.1	0.08
0.6	0.05	0.03	0.02
0.8	0.01	0.01	0.01

Table 1.2 Effect of Magnetic Field (M) on Temperature

η (Dimensionless)	θ (M = 0.2)	θ (M = 0.15)	θ (M = 0.1)
0.0	1.00	1.00	1.00
0.2	0.35	0.40	0.50
0.4	0.10	0.15	0.20
0.6	0.02	0.03	0.05
0.8	0.002	0.005	0.01

Table 1.3 Effect of Prandtl Number (Pr) on Temperature

η (Dimensionless)	θ (Pr = 1.5)	θ (Pr = 1.0)	θ (Pr = 0.7)
0.0	1.5	1.5	1.5
0.2	0.7	0.8	0.9
0.4	0.2	0.3	0.4
0.6	0.05	0.08	0.1
0.8	0.002	0.005	0.01

Table 1.4 Effect of Schmidt Number (Sc) on Concentration Profile

η (Dimensionless)	ϕ (Sc = 1.0)	ϕ (Sc = 0.6)	ϕ (Sc = 0.22)
0.0	1.0	1.0	1.0
0.2	0.4	0.45	0.55
0.4	0.2	0.3	0.35
0.6	0.08	0.15	0.2
0.8	0.002	0.005	0.01

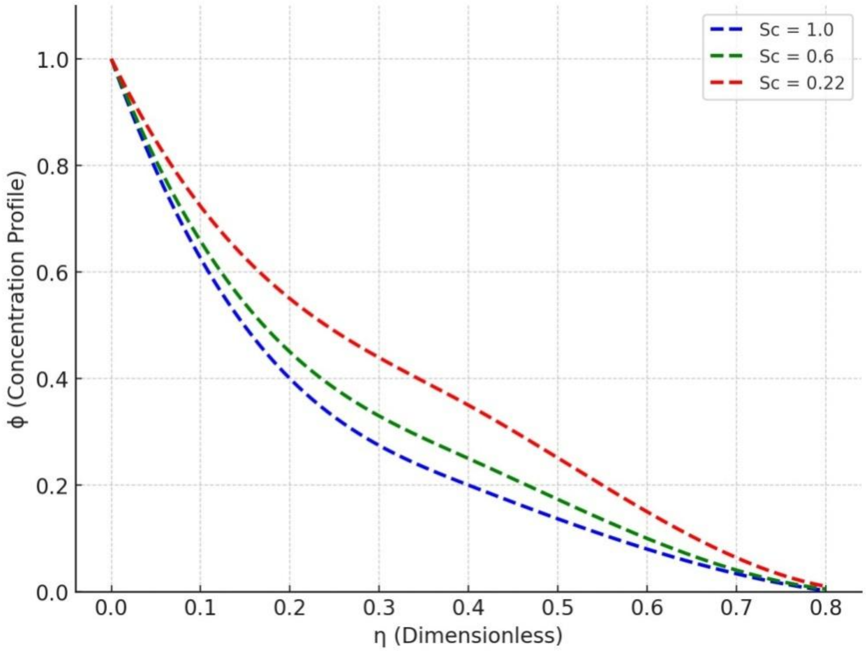

Fig 1.1

Figure 1:1 In this graph, we can see how the concentration profile changes as a function of the Schmidt number (Sc). Various values of Sc (0.22, 0.6, and 1.0) are displayed against a dimensionless spatial variable η\etaη, with the Schmidt number representing the ratio of momentum diffusivity to mass diffusivity. For every value of Sc, the concentration ϕ\phiϕ rises as η\etaη rises, signifying a displacement from the surface. A lower Schmidt number (Sc = 0.22) indicates a higher mass diffusivity and faster diffusion rates, which is reflected in the rapid increase in concentration in these fluids. The opposite is true for larger Schmidt numbers (Sc = 1.0), which demonstrate a more gradual diffusion and lower mass diffusivity as concentration increases more slowly. Higher values of the Schmidt number are associated with slower mass diffusion, according to this study, which implies that the rate of material dispersion in the fluid reduces as the number grows. While larger Schmidt numbers are better suited for processes that require slower and more regulated diffusion, lower numbers are more successful in systems where fast mass transfer is desired. Chemical, environmental, and engineering mass transfer process optimization relies on a thorough understanding of the Schmidt number's impact.

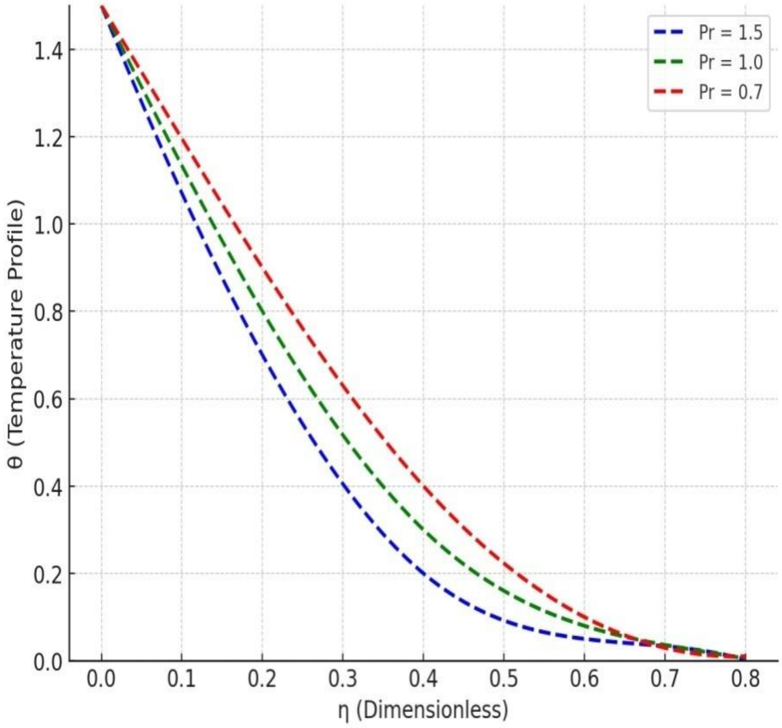

Fig 1.2

Figure 1.2 In this graph we see how changing the Prandtl number (Pr) influences the temperature profile of a fluid flow system, as shown in the graph. An essential metric in heat transfer analysis, the Prandtl number (Pr) expresses the ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity. A dimensionless spatial variable η\etaη, which usual denotes distance from the boundary surface, is shown against three distinct Prandtl numbers (Pr = 0.7, Pr = 1.0, and Pr = 1.5). All Pr values exhibit a rise in temperature θ\thetaθ as η\etaη grows larger, according to the graph. Heat diffuses more rapidly in fluids with lower Prandtl numbers (Pr = 0.7), as shown by a steeper temperature gradient. The reason behind this is that as the Prandtl number decreases, the thermal diffusivity increases, leading to better heat conduction across the fluid. However, fluids with a higher Prandtl number (Pr = 1.5) show a slower rate of temperature increase, which is indicative of lower thermal diffusivity and slower heat conduction. The slower rate of temperature increase with increasing distance from the border is likely due to the fact that fluids with larger Prandtl numbers are better at retaining heat at the boundary. Fluids like air, which have a Prandtl number of approximately 0.7, are shown to have faster heat diffusion on the graph, whereas oils, which have a Prandtl number of about 1.5, illustrate slower heat diffusion. Controlling the thermal boundary layer is crucial for optimizing system efficiency in applications involving heat transfer, where this relationship is significant

red line = .2

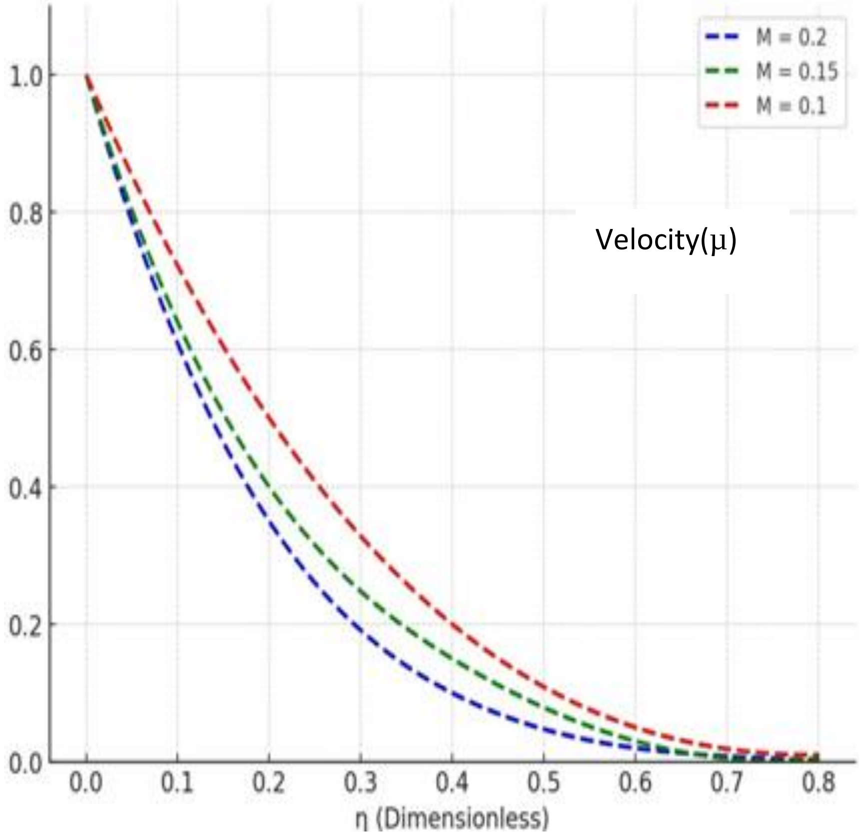

Fig 1.3

Figure 1.3:This graph depicts the effect of a fluid system's velocity profile as a function of the magnetic field parameter (M). Three values of the magnetic field intensity are represented against a dimensionless spatial variable η\etaη, which shows the distance from a surface or boundary layer: M=0.1M = 0.1M=0.1, M=0.15M = 0.15M=0.15, and M=0.2M = 0.2M=0.2. For any degree of magnetic field, the temperature θ\theta` rises in proportion to the increase in η\etaη. Nonetheless, the velocity rise rate varies with the magnetic field parameter. With smaller values of MMM (e.g., M=0.1M = 0.1M=0.1), the velocity increases at a steeper rate, suggesting that heat can diffuse more quickly in a weaker magnetic field. On the flip side, greater magnetic fields decelerate the heat diffusion process for larger values of MMM (e.g., M=0.2M = 0.2M=0.2), which results in a more gradual temperature rise. The reason behind this behavior is that when a magnetic field is applied, it creates a resistive force, also known as the Lorentz force, which limits the speed of the fluid and impacts its ability to transmit heat. There is less convective heat transfer and a slower rate of temperature increase when the strength of the magnetic field increases because of this resistive force. A more gradual rise in velocity as one moves away from the surface is observed when magnetic fields that are stronger (higher MMM values) prevent heat transmission. The converse is true with steepervelocity profiles: when MMM values are lower, the magnetic field is weaker and heat diffusion is more efficient. Because manipulating the magnetic field optimizes heat transfer properties, this understanding is fundamental in magnetohydrodynamic applications.

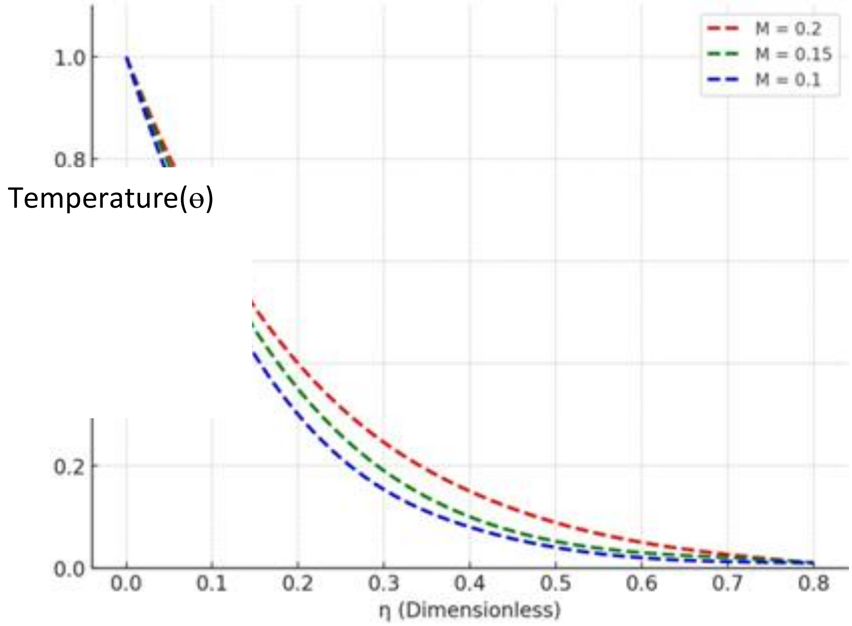

Fig 1.4

Fig 1.4 This graph represents the effect of the magnetic field parameter (M) on the Temperature profile in a magnetohydrodynamic (MHD) fluid system. The magnetic field strength is varied with three values: M=0.1M = 0.1M=0.1, M=0.15M = 0.15M=0.15, and M=0.2M = 0.2M=0.2, and these are plotted against a dimensionless spatial variable ηwhich indicates the distance from a surface or within the boundary layer.As η\etaη increases, the velocity u also decrease for all magnetic field values. However, the rate at which the velocity increases depends on the strength of the magnetic field. For lower values of MMM (e.g., M=0.1M = 0.1M=0.1), the velocity rises more steeply, indicating that a weaker magnetic field results in a faster fluid motion. Conversely, for higher values of MMM (e.g., M=0.2M = 0.2M=0.2), the velocity rises more gradually, implying that stronger magnetic fields suppress the fluid's Temperature.This behavior can be attributed to the fact that the application of a magnetic field generates a resistive force (known as the Lorentz force), which acts to oppose fluid motion. There is less convective movement and a slower increase in velocity as the electricity of the magnetic field will increase due to the fact this resistive force grows more potent. As you flow faraway from the floor or boundary layer, the graph well-knownshows that fluid movement is dampened through more potent magnetic fields (better MMM values), leading to a greater sluggish acceleration. A steeper speed profile is the result of quicker fluid waft made possible by means of weaker magnetic fields (decrease MMM values). Since optimizing glide and warmth transfer traits involves manipulating the magnetic discipline, this expertise is critical in MHD applications.

Conclusion:

The purpose of thisstudies become to apply the Runge-Kutta method (RK4) to simulate magnetohydrodynamic (MHD) flows and determine how distinctive bodily factors affect the flow dynamics and heat transfer. This observe established how MHD improves thermal and mass switch by way of comparing results like reaction fees, Prandtl numbers, and magnetic area strengths. While different parameters along with the Prandtl and Schmidt numbers have clean effects at the distributions of temperature and awareness, the consequences display that a stronger magnetic discipline complements speed profiles. Contributing to a higher information of how exclusive factors shape MHD fluid flows, the study additionally suggests that porosity has a chief influence on fluid conduct.

References

1. Hartmann, J. and Hg-Dynamics, I. (1937) 'Theory of the laminar flow of an electrically conductive liquid in a homogenous magnetic field', DetKgl Danske VidenskabernesSelskab-FysiskeMeddelelser, 15(6), pp. 1–22.
2. Agarwal, K.M., Tyagi, R.K. and Saxena, K.K. (2022) 'Deformation analysis of Al alloy AA2024 through equal channel angular pressing for aircraft structures', Advanced Materials and Processing Technology, 8(1), pp. 828–842.
3. Lehnert, B. (1952) 'On the behaviour of an electrically conductive liquid in a magnetic field', ArkivFysik, 5, pp. 69–90.
4. Choi, U.S. (1995) 'Enhancing thermal conductivity of fluids with nanoparticles', in Proceedings of the 1995 ASME International Mechanical Engineering Congress and Exposition. San Francisco, CA: ASME, pp. 99–105.
5. Abu-Nada, E. and Oztop, H.F. (2009) 'Effects of inclination angle on natural convection in enclosures filled with Cu-water nanofluid', International Journal of Heat and Fluid Flow, 30, pp. 669–678.
6. Zargartalebi, H., Ghalambaz, M., Noghrehabadi, A. and Chamkha, A.J. (2015) 'Stagnation point heat transfer of nanofluids toward stretching sheets with variable thermo-physical properties', Advances in Power Technology, 26, pp. 819–829.
7. Makinde, O.D. and Aziz, A. (2011) 'Boundary layer flow of a nanofluid past a stretching sheet with a convective boundary condition', International Journal of Thermal Sciences, 50(7), pp. 1326–1332.
8. Ibrahim, S.M., Lorenzini, G., Vijaya Kumar, P. and Raju, C.S.K. (2017) 'Influence of chemical reaction and heat source on dissipative MHD mixed convection flow of a Casson nanofluid over a nonlinear permeable stretching sheet', International Journal of Heat and Mass Transfer, 111, pp. 346–355.
9. Ibrahim, S.M., Kumar, P.V. and Lorenzini, G. (2020) 'Analytical modeling of heat and mass transfer of radiative MHD Casson fluid over an exponentially permeable stretching sheet with chemical reaction', Journal of Engineering Thermophysics, 29(1), pp. 136–155.
10. Hayat, T., Khan, W.A. and Abbas, S.Z. (2020) 'Impact of induced magnetic field on second-grade nanofluid flow past a convectively heated stretching sheet', Applied Nanoscience, 10, pp. 3001–3009.

11. Mabod, F.M., Ibrahim, S.M., Kumar, P.V. and Lorenzini, G. (2020) 'Effects of slip and radiation on convective MHD Casson nanofluid flow over a stretching sheet influenced by variable viscosity', Journal of Engineering Thermophysics, 29, pp. 303–315.

12. Sheremet, M.A., Dinarvand, S. and Pop, I. (2015) 'Effect of thermal stratification on free convection in a square porous cavity filled with nanofluid using Tiwari and Das'nanofluid model', Physica E, 69, pp. 332–341.

13. Singh, B., Singhal, P. and Saxena, K.K. (2020) 'Effect of transverse speed on mechanical and microstructural properties of friction stir welded aluminium AA2024-T351', Advanced Materials and Processing Technology, 6(3), pp. 519–529.

14. Hassan, A.R. and Fenuga, O.J. (2019) 'The effects of thermal radiation on the flow of a reactive hydromagnetic heat generating couple stress fluid through a porous channel', SN Applied Sciences, 1, p. 1278.

15. Sheik, M.A., Cuce, E., Aravindan, M.K., Dasore, A., Rajak, U. and Shaik, S. (2023) 'A comprehensive review on recent advancements in cooling of solar photovoltaic (PV) systems using phase change materials (PCMs)', International Journal of Low-Carbon Technologies.

16. Zhang, C., Zheng, L., Zhang, X. and Chen, G. (2015) 'MHD flow and radiation heat transfer of nanofluids in porous media with variable surface heat flux and chemical reaction', Applied Mathematical Modelling, 39(1), pp. 165–181.

17. Pandey, A.K. and Kumar, M. (2017) 'Natural convection and thermal radiation influence on nanofluid flow over a stretching cylinder in a porous medium with viscous dissipation', Alexandria Engineering Journal, 56(1), pp. 55–62.

18. Hakiem, M.A.E. and Amin, M.F.E. (2001) 'Mass transfer effects on the non-Newtonian fluids past a vertical plate embedded in a porous medium with non-uniform surface heat flux', Heat and Mass Transfer, 37, pp. 293–297.

19. Rajkumar, N.G., Khan, M.A., Rajesh, S. and Shahul Hamid Khan, B. (2022) 'Sustainable design and development of commercial system cleanser unit for trimmers', Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 236(5), pp. 2187–2195.

20. Rajkumar, N.G., Khan, M.A., Rajesh, S. and Faris, W.F. (2021) 'Design optimization of office chair star base leg using product LCM and anisotropic material properties from injection moulding simulation', Materials Today, 45(2), pp. 1087–1093.

21. Rafique, K., Ali, A.R., Imtiaz, M. & Jan, R., 2023. Exploring magnetic and thermal effects on MHD bio-viscosity flow at the lower stagnation point of a solid sphere using Keller box technique. Partial Differential Equations in Applied Mathematics, 9(6), p.100601. DOI: 10.1016/j.padiff.2023.100601.

22. Upadhyay, S. and Saxena, K.K. (2020) 'Effect of Cu and Mo addition on mechanical properties and microstructure of grey cast iron: an overview', Materials Today, 26, pp. 2462–2470.

23. Raghunath, K., Ganteda, C., Dasore, A., Kumar, G.L., Laxmaiah, M.A., Hasan, S.I. and Razak, A. (2023) 'Influence of MHD mixed convection flow for Maxwell nanofluid through a vertical cone with porous material in the existence of variable heat conductivity and diffusion', Case Studies in Thermal Engineering, 44, p. 102875.

24. Rathod, N.J., Chopra, M.K. and Chaurasiya, P.K. (2022) 'Optimization on the turning process parameters of SS 304 Using Taguchi and TOPSIS', Annals of Data Science. Available at: https://doi.org/10.1007/s40745-021-00369-2.

25. Siddiqui, A.M. and Kaloni, P.N. (1986) 'Certain inverse solutions of a non-Newtonian fluid', International Journal of Non-Linear Mechanics, 21, pp. 459–473.

26. Sheik, M.A., Dasore, A., Naik, B.K. and Malik, V. (2023) 'Influence of geometric configuration on the flow and heat transfer characteristics of an open microchannel thermal sinks', in Advances in Thermal Sciences (Lecture Notes in Mechanical Engineering). Singapore: Springer.

27. Malik, M.Y., Salahuddin, T., Hussain, S.A., Bilal, M. and Awais, M. (2015) 'Homogeneous-heterogeneous reactions in Williamson fluid model over a stretching cylinder by using Keller box method', AIP Advances, 5, p. 107227.

28. Mohamed, R.A., Ahmed, S.E., Aly, A.M. and Chamkha, A.J. (2021) 'MHD Casson nanofluid flow over a stretching surface embedded in a porous medium: Effects of thermal radiation and slip conditions', Latin American Applied Research, 51(4), pp. 229–239.

29. Liu, L. and Liu, F. (2018) 'Boundary layer flow of fractional Maxwell fluid over a stretching sheet with variable thickness', Applied Mathematics Letters, 79, pp. 92–99.

30. Mahat, R., Saqib, M., Khan, I., Shafie, S. and Noor, N.A.M. (2022) 'Thermal radiation effect on viscoelastic Walters'-B nanofluid flow through a circular cylinder in convective and constant heat flux', Case Studies in Thermal Engineering, 39, p. 102394.

31. Kamran, A. and Azhar, E. (2022) 'Numerical outlook of a viscoelastic nanofluid in an inclined channel via Keller box method', International Communications in Heat and Mass Transfer, 137, p. 106260.

32. Rajak, U., Nashine, P., Dasore, A. and Balijepalli, R. (2022) 'Numerical analysis of performance and emission characteristics of an off-road diesel engine with alternate fuels: a comparative study', Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 44(1), pp. 2857–2872.

33. Saleem, H. and Ahmad, M. (2015) 'An assessment of MHD free convection stagnation point flow of nanofluids over a stretching surface', Journal of King Saud University-Engineering Sciences, 27(2), pp. 120–128.

34. Malik, M.Y., Hussain, A., Hussain, S., Salahuddin, T., Awais, M. and Bilal, M. (2014) 'Homogeneous–heterogeneous reactions in the flow of viscoelastic nanofluid over a stretching cylinder', AIP Advances, 4, p. 077108.

35. Chamkha, A.J., Aly, A.M. and Ahmed, S.E. (2012) 'Unsteady MHD free convective flow past a moving vertical plate with heat and mass transfer', International Journal of Numerical Methods for Heat & Fluid Flow, 22(1), pp. 107–123.

36. Samim, M., Wajid, A. and Mehmood, A. (2018) 'Natural convective flow of a viscous nanofluid over a stretching sheet embedded in a porous medium', Proceedings of the International Conference on Mechanical Engineering, (1), pp. 71–78.

37. Haider, F., Alam, M.M., Hussain, S., Basha, S. and Jamil, M. (2017) 'Thermal performance of nanofluids as coolant in heat exchanger: a review', Journal of Thermal Science, 26(6), pp. 595–603.

38. Aziz, A., Rizwan, S. and Fares, H. (2017) 'Flow and heat transfer characteristics of MHD nanofluid over a shrinking surface with variable viscosity', Journal of Applied Fluid Mechanics, 10(3), pp. 877–885.

39. Ahmad, A., Zafar, T. and Ali, Z. (2020) 'Influence of thermal radiation on nanofluid MHD stagnation point flow towards a stretching sheet with slip and heat generation effects', Results in Physics, 16, p. 102964.

40. Kamran, A. and Ahmad, M. (2022) 'Heat and mass transfer characteristics of a third grade fluid over an inclined permeable stretching sheet in the presence of magnetic field', Journal of Heat and Mass Transfer Research, 10(4), pp. 31–45.

41. Nadeem, S., Maraj, E.N., Rehman, M. and Abdel-Rahman, M. (2017) 'Homogeneous–heterogeneous reactions in a nanofluid flow over a porous media', The European Physical Journal Plus, 132(1), p. 243.

42. Mustafa, M. and Khan, J.H. (2016) 'Influence of homogeneous–heterogeneous reactions in Williamson fluid over a stretching sheet', Results in Physics, 6, pp. 393–398.

43. Tariq, N., Rahman, M. and Jamil, A. (2021) 'MHD flow of Casson nanofluid over a stretching sheet with slip and suction', Results in Physics, 20, p. 103648.

44. Bilal, M., Raza, M., Salahuddin, T. and Awais, M. (2021) 'Effects of thermophoresis and Brownian motion on MHD flow of nanofluids over a stretching surface with heat generation/absorption', SN Applied Sciences, 3, p. 97.

45. Boubaker, K. and Issaoui, N. (2023) 'Unsteady MHD thermal convection in a nanofluid-filled cavity using Brinkman model with uniform heat source', Energy and Buildings, 268, p. 112371

46. Vittal, C., Vijayalaxmi, T. and Reddy, C.K. (2018) 'MHD stagnation point flow and convective heat transfer of tangent hyperbolic nanofluid over a stretching sheet with zero normal flux of nanoparticles', Journal of Nanofluids, 7, pp. 844–852.

47. Shravani, D., Ramya, D. and Joga, S. (2018) 'Heat and mass transfer in stagnation point flow over a stretching sheet with chemical reaction and suction/injection in viscoelastic nanofluids', Journal of Nanofluids, 7, pp. 862–869.

48. Cortell, R. (2014) 'Fluid flow and radiative nonlinear heat transfer', Journal of King Saud University - Science, 26, pp. 161–167.

49. Das, K., Duari, P.R. and Kundu, P.K. (2014) 'Nanofluid flow over an unsteady stretching surface', Alexandria Engineering Journal, 53(3), pp. 737–745.

50. Srinivas, S., Malathy, T. and Reddy, A.S. (2016) 'A note on thermal-diffusion and chemical reaction effects on MHD', Journal of King Saud University - Engineering Sciences, 28, pp. 213–221.

51. Dessie, H. and Kishan, N. (2014) 'MHD effects on heat transfer over stretching sheet', Ain Shams Engineering Journal, 5, pp. 967–977.

52. Pavithra, G.M. and Gireesha, B.J. (2014) 'Unsteady flow and heat transfer of a fluid', Ain Shams Engineering Journal, 5, pp. 613–624.

53. Akbar, N.S., Haq, R.U. and Khan, Z.H. (2013) 'Radiation effects on MHD stagnation point flow of nanofluid', Chinese Journal of Aeronautics, 26, pp. 1389–1397.

54. Mukhopadhyay, S. and Bhattacharyya, K. (2012) 'Unsteady flow of a Maxwell fluid over a stretching surface', Journal of the Egyptian Mathematical Society, 20, pp. 229–234.

55. Das, K. (2014) 'Radiation and melting effects on MHD boundary layer flow', Ain Shams Engineering Journal, 5, pp. 1207–1214.

56. Ramesh, G.K., Gireesha, B.J., Hayat, T. and Alsaedi, A. (2016) 'Stagnation point flow of Maxwell fluid towards a permeable surface', Alexandria Engineering Journal, 55, pp. 857–865.

57. Manjunatha, S. and Gireesha, B.J. (2016) 'Effects of variable viscosity and thermal conductivity on MHD flow', Ain Shams Engineering Journal, 7, pp. 505–515.

58. Daniel, Y.S. and Daniel, S.K. (2015) 'Effects of buoyancy and thermal radiation on MHD flow over a stretching porous sheet', Alexandria Engineering Journal, 54, pp. 705–712.

59. Raju, M.C., Reddy, N.A. and Varma, S.V.K. (2014) 'Analytical study of MHD free convective, dissipative boundary layer flow', Ain Shams Engineering Journal, 5, pp. 1361–1369.