

Chebyshev spectral collocation analysis of electromagnetohydrodynamic fluid flow over an exponentially stretching cylindrical surface for enhanced material processing

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ABSTRACT: The present study investigates the electromagnetohydrodynamic (EMHD) boundary-layer flow, heat transfer, and mass transport of an electrically conducting viscous fluid over an exponentially stretching cylindrical surface with applications in advanced material processing systems. The mathematical model incorporates the combined effects of thermal radiation, chemical reaction, electromagnetic forces, and buoyancy-induced transport mechanisms. By employing suitable similarity transformations, the governing nonlinear partial differential equations are transformed into a coupled system of dimensionless ordinary differential equations. The resulting system is solved numerically using the Chebyshev Spectral Collocation Method (CSCM), which is renowned for its high accuracy, rapid convergence, and computational efficiency in solving nonlinear boundary-value problems. The influence of key physical parameters, including the Hartmann number, radiation parameter, Schmidt number, thermal Grashof number, solutal Grashof number, Reynolds number, electrical conductivity parameter, and chemical reaction parameter, on the velocity, temperature, and concentration distributions is examined in detail. Numerical results reveal that increasing the Hartmann number suppresses fluid velocity due to the enhanced Lorentz force generated by the applied magnetic field. Conversely, thermal radiation significantly elevates fluid temperature and increases the thickness of the thermal boundary layer. Furthermore, higher Schmidt number and chemical reaction parameters reduce species concentration within the boundary layer owing to diminished mass diffusivity and accelerated species consumption, respectively. The findings demonstrate that the Chebyshev Spectral Collocation Method provides stable and highly accurate solutions for complex EMHD transport problems involving cylindrical geometries. The developed model offers valuable theoretical insights for optimising electromagnetic control strategies in polymer extrusion, thin-film coating, metallurgical manufacturing, thermal processing, and other advanced material fabrication technologies.

Keywords: Chemical reaction, cylindrical stretching surface, electromagnetohydrodynamics, material processing, spectral collocation method, thermal radiation.

INTRODUCTION

Electromagnetohydrodynamic (EMHD) fluid flow has attracted considerable attention in recent years because of its wide range of applications in industrial and engineering processes such as polymer extrusion, electromagnetic casting, crystal growth, cooling of electronic devices,

nuclear reactors, and advanced material processing systems. The interaction between electrically conducting fluids and externally applied magnetic fields significantly modifies momentum, heat, and mass transfer characteristics within the fluid domain. Consequently, EMHD transport

phenomena have become an important research area in fluid mechanics and thermal engineering (Takhar *et al.*, 2000).

Boundary-layer flow over stretching surfaces has also gained substantial research interest due to its direct applications in industrial manufacturing processes, including wire drawing, continuous casting, glass-fibre production, extrusion of plastic sheets, and coating technologies. The pioneering work of Sakiadis initiated the theoretical study of moving surface boundary-layer flows, while Crane later extended the concept to linearly stretching surfaces, thereby stimulating extensive investigations on stretching surface transport phenomena. In recent years, exponentially stretching cylindrical surfaces have become increasingly important because of their relevance in cylindrical extrusion systems and industrial thermal processing applications (Mukhopadhyay, 2009).

The incorporation of magnetic field effects into transport systems has further increased the importance of magnetohydrodynamic flow analysis. Magnetohydrodynamic (MHD) transport mechanisms are widely employed in plasma confinement, metallurgical engineering, geothermal systems, electromagnetic pumps, and biomedical engineering applications. Fatunmbi and Are (2025) examined the numerical behavior of MHD nanofluid flow over an exponentially stretching porous sheet under the effects of activation energy and non-uniform heat source. Using similarity transformations and the Runge–Kutta–Fehlberg method, the study analyzed the impacts of magnetic and thermal parameters on fluid transport. The results showed that stronger magnetic fields reduce fluid velocity, while heat generation enhances temperature distribution within the boundary layer. Their findings are important for improving heat and mass transfer processes in industrial material processing and thermal engineering applications. Similarly, Kayalvizhi and Vijaya Kumar (2022) investigated the entropy generation characteristics of electromagnetohydrodynamic (EMHD) hybrid nanofluid stagnation-point flow over a porous stretching sheet in the presence of thermal radiation. The study demonstrated that thermal radiation and magnetic field parameters significantly influence fluid temperature, entropy generation, and heat transfer enhancement. Their results further revealed that hybrid nanoparticles improve thermal conductivity and overall thermal efficiency of the flow system. The research is highly relevant to advanced cooling technologies, energy systems, and enhanced industrial thermal processing applications. Shateyi (2013) studied chemically reactive MHD flow and reported that increasing chemical reaction parameters reduces concentration boundary-layer thickness due to stronger species consumption within the fluid domain.

Recently, researchers have shown increasing interest in cylindrical stretching surface problems because cylindrical geometries provide more realistic physical representations of industrial transport systems involving cylindrical pipes, fibers, and rotating cylindrical devices. Kalteh *et al.* (2016)

investigated magnetohydrodynamic flow and heat transfer over a stretching slender cylinder with thermal radiation effects and concluded that thermal radiation considerably enhances heat transfer characteristics. Furthermore, Mebarek-Oudina *et al.* (2024) examined thermal and flow dynamics of MHD Burgers' fluid induced by a stretching cylinder and highlighted the importance of electromagnetic transport in advanced thermal systems also Muzara and Shateyi (2023) studied the magnetohydrodynamic Williamson nanofluid flow over an exponentially stretching surface under the influence of chemical reaction and thermal radiation effects. The authors employed numerical techniques to analyze the nonlinear governing equations and evaluate the impacts of relevant flow parameters on velocity, temperature, and concentration profiles. Their findings indicated that thermal radiation enhances fluid temperature, while magnetic field intensity suppresses the velocity distribution due to resistive Lorentz forces. The study highlighted the significance of non-Newtonian nanofluid characteristics in improving heat and mass transfer processes in industrial manufacturing and thermal engineering systems.

Despite numerous investigations on MHD stretching surface flows, limited attention has been devoted to the combined effects of electromagnetohydrodynamic flow, thermal radiation, buoyancy force, and chemical reaction over exponentially stretching cylindrical surfaces using highly accurate spectral numerical techniques. Most previous investigations relied primarily on finite difference, shooting, and perturbation methods, which may suffer from convergence and stability limitations for strongly coupled nonlinear systems.

To overcome these limitations, the present study employs the Chebyshev Spectral Collocation Method to numerically investigate EMHD fluid flow over an exponentially stretching cylindrical surface. Spectral methods are well known for their excellent convergence properties and superior numerical accuracy when solving nonlinear boundary-value problems (Trefethen, 2000; Boyd, 2001). The effects of Hartmann number, radiation parameter, Schmidt number, thermal buoyancy force, and chemical reaction parameter on velocity, temperature, and concentration distributions are analysed comprehensively.

The novelty of the present investigation lies in the combined analysis of electromagnetohydrodynamic transport, thermal radiation, and chemically reactive species over an exponentially stretching cylindrical geometry using the highly accurate Chebyshev Spectral Collocation Method relevant to enhanced material processing applications.

MATHEMATICAL FORMULATION OF THE PROBLEM

Consider the steady, two-dimensional electromagnetohydrodynamic (EMHD) boundary-layer flow of an incompressible, viscous, and electrically conducting fluid

over an exponentially stretching cylindrical surface. The flow is subjected to a transverse magnetic field, thermal radiation, and a first-order chemical reaction. The cylindrical surface stretches exponentially along the axial direction, generating momentum, thermal, and concentration boundary layers within the fluid, which can be written as

Continuity equation

$$\frac{1}{r} \frac{\partial}{\partial r} (ru) = 0 \quad (1)$$

Momentum equation

$$u \frac{\partial u}{\partial r} = v \left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r} \frac{\partial u}{\partial r} \right) - \frac{\sigma B_0^2}{\rho} u + g\beta_T(T - T_\infty) + g\beta_C(C - C_\infty) \quad (2)$$

Energy equation

$$u \frac{\partial T}{\partial r} = \alpha \left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} \right) - \frac{1}{\rho C_p} \frac{\partial q_r}{\partial r} \quad (3)$$

Concentration equation

$$u \frac{\partial C}{\partial r} = D \left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r} \frac{\partial C}{\partial r} \right) - K_0(C - C_\infty) \quad (4)$$

Where u = velocity component, T = temperature, C = concentration, v = kinematic viscosity, σ = electrical conductivity, B_0 = magnetic field strength, ρ = density, D = molecular diffusivity, K_0 = chemical reaction parameter

Thermal radiation model

To account for radiative heat transfer within the fluid, the Rosseland diffusion approximation (q_r) is employed. This approximation is valid for optically thick fluids and is expressed as

$$q_{(r)} = -\frac{1}{3\alpha} 4K_B \frac{\partial}{\partial r} T^4 \quad (5)$$

Where K_B is the Stefan-Boltzmann constant and α is the absorption coefficient. It is assumed that the temperature difference within the flow is sufficiently small such that T^4 can be expressed as a linear function of temperature. This is accomplished by expanding T^4 in a Taylor series about T_∞ and neglecting higher-order terms, the expression results in:

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4 \quad (6)$$

Substituting equation (6) into equation (5)

$$q_r = -\frac{16\sigma^* T_\infty^3}{3k^*} \frac{\partial T}{\partial r} \quad (7)$$

Inserting equation (7) into the energy equation gives:

$$u \frac{\partial T}{\partial r} = \left(\alpha + \frac{16\sigma^* T_\infty^3}{3k^*} \right) \left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} \right) \quad (8)$$

Dimensionless transformation

Equation 1- is transformed into dimensionless parameters of the Schmidt number, Prandtl number, Grashof number, Radiation parameter, Heat function, Electroconductivity and Magnetic term. The dimensionless quantities used are:

$$Re^{-1} = \frac{\mu\rho}{\rho\mu'}$$

$$Pr = \frac{k(\rho C_p)}{k(\rho C_p)}$$

$$Sc = \frac{k(\rho C_p)}{D(\rho C_p)}$$

$$u = \frac{u}{U_0}, \eta = \frac{r}{a'}$$

$$k_0 = \frac{k_r^2(\rho C_p)}{(\rho C_p)v^{*2}}$$

$$Gr_\theta = \frac{g\beta(T - T_w)\mu}{u_r^2\beta}$$

$$Gr_\phi = \frac{g\beta^*(C - C_w)\mu}{u_r^2\beta^*}$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty}$$

$$\phi = \frac{C - C_\infty}{C_w - C_\infty}$$

$$\Re = \frac{16\zeta T_0^3 \rho}{3\alpha(C_p)}$$

$$Ha = \frac{\sigma B_0^2 u_r}{\rho}$$

$$\sigma_0 = \frac{\sigma_0}{v_r}$$

Rewriting equations (2), (4) and (8) in dimensionless form, the modelled equations are transformed into

$$\frac{\partial^2 u}{\partial \eta^2} + \frac{1}{\eta} \frac{\partial u}{\partial \eta} - H_a^2 u + Gr_\theta \theta + Gr_\phi \phi = 0 \quad (9)$$

$$\frac{\partial^2 \theta}{\partial \eta^2} + \left(\frac{1+r}{\eta} \right) \frac{\partial \theta}{\partial \eta} = 0 \quad (10)$$

$$\frac{\partial^2 \phi}{\partial \eta^2} + \frac{1}{\eta} \frac{\partial \phi}{\partial \eta} - ScK_0 \phi = 0 \quad (11)$$

Where: H_a = Hartmann number, $G_{r\theta}$ = thermal Grashof number, $G_{r\phi}$ = modified Grashof number, Sc = Schmidt number, R = radiation parameter

Boundary conditions

The boundary conditions are:

$$\begin{aligned} u(1) &= 0 \\ \theta(1) &= 1 \\ \phi(1) &= 1 \end{aligned} \quad (12)$$

$$\begin{aligned} \frac{\partial u}{\partial \eta}(0) &= 0 \\ \frac{\partial \theta}{\partial \eta}(0) &= 0 \\ \frac{\partial \phi}{\partial \eta}(0) &= 0 \end{aligned} \quad (13)$$

Chebyshev spectral collocation method

The transformed boundary-value problem defined by Equations (9) – (11) is solved numerically using the Chebyshev Spectral Collocation Method (CSCM). This method is selected for its superior convergence rate and spectral accuracy compared with conventional finite-difference techniques. The Chebyshev–Gauss–Lobatto collocation points are defined by:

$$x_j = \cos\left(\frac{j\pi}{N}\right), j = 0, 1, 2, \dots, N \quad (13)$$

The computational domain (-1, 1) is mapped into (0, 1) using

$$\eta = \frac{1+x}{2} \quad (14)$$

Approximation of unknown functions

The unknown functions are approximated as:

$$u(\eta) = \sum_{k=0}^N a_k T_k(x) \quad (15)$$

$$\theta(\eta) = \sum_{k=0}^N b_k T_k(x) \quad (16)$$

$$\phi(\eta) = \sum_{k=0}^N c_k T_k(x) \quad (17)$$

where: $T_k(x)$ are Chebyshev polynomials and a_k, b_k, c_k are unknown coefficients.

Chebyshev Differentiation Matrix

The first derivative matrix is:

$$D_{ij} = \begin{cases} \frac{c_i (-1)^{i+j}}{c_j x_i - x_j}, & i \neq j \\ -\frac{x_j}{2(1-x_j^2)}, & 1 \leq j \leq N-1 \\ \frac{2N^2+1}{6}, & i = j = 0 \\ -\frac{2N^2+1}{6}, & i = j = N \end{cases} \quad (18)$$

Where

$$c_0 = c_N = 2, c_j = 1 \quad (19)$$

The second derivative matrix becomes

$$D^{(2)} = D \times D \quad (20)$$

Discretization of governing equations

Utilizing equation (13) - (20) into equation (9) – (11)

The momentum equation becomes:

$$D^{(2)}U + \frac{1}{\eta} DU - H_a^2 U + G_{r\theta} \theta + G_{r\phi} \phi = 0 \quad (21)$$

The energy equation becomes:

$$D^{(2)}\theta + \left(\frac{1+R}{\eta}\right) D\theta = 0 \quad (22)$$

The concentration equation becomes:

$$D^{(2)}\phi + \frac{1}{\eta} D\phi - ScK_0 \phi = 0 \quad (23)$$

Implementation of boundary conditions

The boundary conditions are imposed directly into the matrix system.

At $\eta = 0$:

$$DU(0) = 0 \quad (24)$$

$$D\theta(0) = 0 \quad (25)$$

$$D\phi(0) = 0 \quad (26)$$

At $\eta = 1$:

$$U(1) = 0 \quad (27)$$

$$\theta(1) = 1 \quad (28)$$

$$\phi(1) = 1 \quad (29)$$

Matrix formulation

The final algebraic systems become:

Momentum equation

$$A_1 U = B_1 \quad (30)$$

Energy equation

$$A_2 \theta = B_2 \quad (31)$$

Concentration equation

$$A_3 \Phi = B_3 \quad (32)$$

where:

$$A_1 = D^{(2)} + \frac{1}{\eta} D - H_a^2 I \quad (33)$$

$$A_2 = D^{(2)} + \left(\frac{1+R}{\eta}\right) D \quad (34)$$

$$A_3 = D^{(2)} + \frac{1}{\eta} D - ScK_0 I \quad (35)$$

ENGINEERING QUANTITIES OF INTEREST

The practical significance of the present electromagneto-hydrodynamic flow model is evaluated through three important engineering parameters: the skin friction coefficient, Nusselt number, and Sherwood number. These quantities provide valuable information regarding the momentum, thermal, and mass transport characteristics of the fluid during the material processing operation.

Skin friction coefficient

The skin friction coefficient (C_f) measures the wall shear stress generated by the fluid flow along the stretching cylindrical surface. It is directly proportional to the velocity gradient at the surface and is expressed as:

$$C_f = \frac{du}{d\eta} \Big|_{\eta=1} \quad (36)$$

A higher value of the skin friction coefficient indicates increased resistance to fluid motion at the surface, which is important in determining the drag force and energy requirements during industrial processing.

Nusselt number

The Nusselt number (Nu) characterizes the rate of heat transfer from the cylindrical surface to the fluid. It is defined as the negative temperature gradient at the wall:

$$Nu = -\frac{d\theta}{d\eta} \Big|_{\eta=1} \quad (37)$$

An increase in the Nusselt number signifies enhanced heat transfer performance, which is desirable in manufacturing processes involving cooling, heating, and thermal treatment of materials

Sherwood number

The Sherwood number (Sh) represents the rate of mass transfer at the surface and is given by the negative concentration gradient at the wall:

$$Sh = -\frac{d\phi}{d\eta} \Big|_{\eta=1} \quad (38)$$

Higher Sherwood number values indicate improved mass transport, which is crucial in applications such as coating, drying, chemical processing, and material deposition techniques.

Together, these engineering parameters serve as key indicators for assessing the effectiveness of electromagneto-hydrodynamic flow control in enhancing momentum transport, heat transfer, and mass transfer during advanced material processing operations.

RESULTS AND DISCUSSION

To investigate the influence of the governing physical parameters on electromagneto-hydrodynamic (EMHD) flow over an exponentially stretching cylindrical surface, the transformed governing equations together with the associated boundary conditions were solved numerically using the Chebyshev Spectral Collocation Method (CSCM). The computed velocity, temperature, and concentration distributions are presented in Figures 1–13. The obtained results provide valuable insights into the transport mechanisms relevant to advanced material processing applications through the selected realistic value of dimensionless hydrodynamic parameters in Table 1.

Figure 1 illustrates the effect of the chemical reaction parameter (k_0) on the concentration distribution. Increasing the chemical reaction parameter reduces the concentration profile throughout the boundary layer. This behaviour occurs because stronger chemical reactions accelerate the consumption of diffusing species, thereby diminishing concentration levels near the surface and within the fluid domain. Such a reduction is beneficial in material processing operations where controlled mass transport is required, including surface treatment, coating technologies, and chemical deposition processes. The findings conform with Ojo *et al.* (2025a), who stated that increase in temperature field enhances the rate of chemical reaction of energy transfer on MHD flow.

Figure 2 displays the concentration profile for various

Table 1. Selected realistic values of dimensionless hydrodynamic parameters.

Parameters	Value
Prandtl number (Pr)	3.5, 7.0, 10.5, 14.0, 17.5
Reynolds number (Re)	10, 20, 30, 40, 50
Schmidt number (Sc)	2.5, 4.5, 6.5, 8.5, 10.5
Radiation term (\mathfrak{R})	3.5, 6.5, 9.5, 12.5, 15.5
Grashof number (Gr_ϕ) due to concentration	3.2, 6.4, 9.6, 12.8, 16.0
Grashof number (Gr_θ) due to temperature	2.6, 5.2, 7.8, 10.4, 13.0
Magnetic Hartmann Number (Ha)	0.5, 1.5, 2.5, 3.5, 4.5
Chemical reaction term (k_0)	1.8, 3.6, 5.4, 7.2, 9.0
Electro-conductivity term (σ_0)	0.25, 0.50, 1.75, 1.00, 1.25

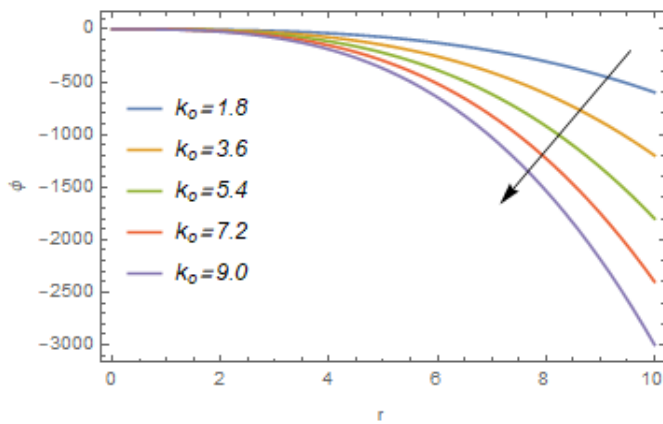


Figure 1. Concentration profile ϕ against boundary layer r for varying chemical reaction term k_0 .

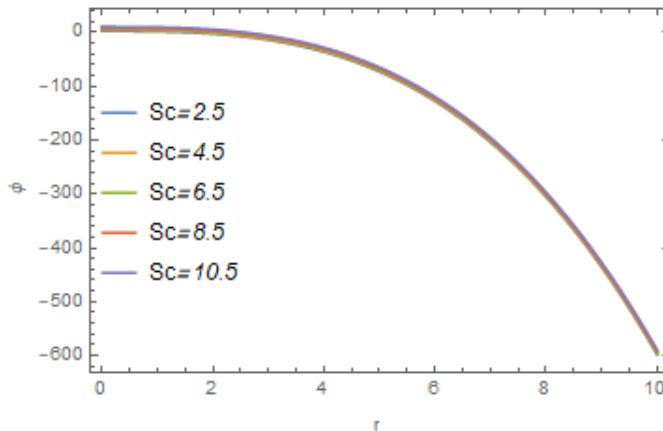


Figure 2. Concentration profile ϕ against boundary layer r for varying Schmidt number Sc .

values of the Schmidt number. Physically, the effect of the increasing Schmidt number is the decrease in mass diffusivity in comparison to momentum diffusivity, which affects the rate of diffusion of species away from the

stretching surface. Such effects have significant applications in the processing of advanced materials, where the rate of diffusion of species needs to be strictly regulated. The result is in agreement with Albuquerque *et al.* (2024), that displays decrease in mass diffusivity of flows increases the Schmidt number using the Fourier pseudospectral method and the immersed boundary method.

Figure 3 indicates that the temperature profiles of various values of the thermal radiation parameter show that there is an increase in temperature within the boundary layer as the radiation term increases. The results were able to demonstrate the high temperature levels due to the effect of the thermal radiation, which greatly affects the heat transfer characteristics and surface thermal controls. Especially in modern material processing, thermal coating, or surface treatments, the thermal radiation greatly dominates the heat transfer to control the temperature distribution. The result was consistent with the reference (Ojo and Egbo, 2025).

Figure 4 shows the temperature profile at different Pr values. It has been observed that the temperature of the fluids as well as the boundary layer, decreases with increasing values of the Pr number. This result shows that the decrease of the boundary layer at larger Pr values represents an increase in the rate of heat transfer. This has significant implications for advanced material processing techniques.

Figure 5 displays the plots of the velocity profile against the boundary layer coordinate for specified values of the Reynolds number, demonstrating that the Reynolds number has a major influence in governing the process of momentum transfer in the boundary layer flow. The physical significance of this is quite special owing to the fact that with an increase in the value of the Reynolds number, surface transport processes are enhanced and flow acceleration over the sheet is improved. This result agreed with Muhammad *et al.* (2023), who quantified that when there increase in Reynolds number it affects the momentum transfer in the boundary layer flow.

Figure 6 depicts a graph showing the velocity profile and the boundary layer coordinate for various values of solutal

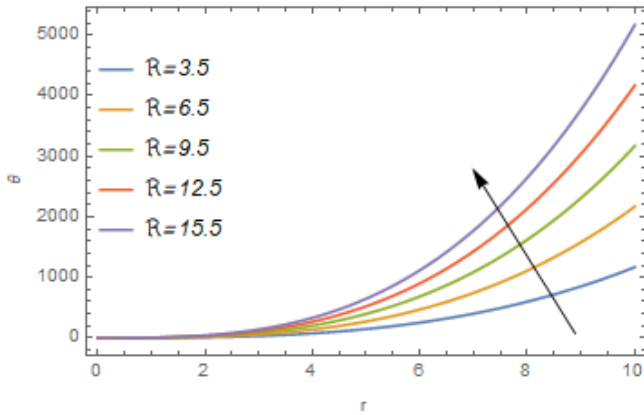


Figure 3. Temperature profile θ against boundary layer r for varying Radiation term (R).

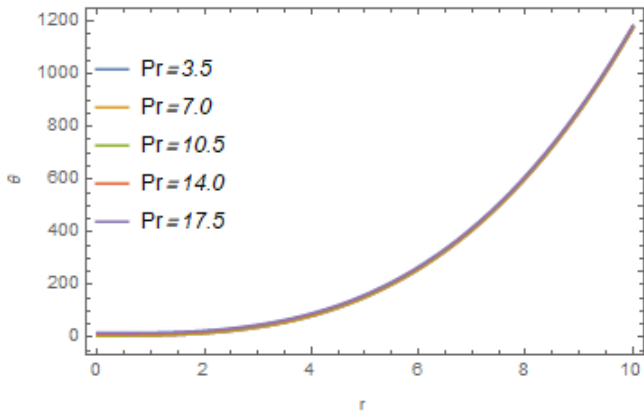


Figure 4. Temperature profile θ against boundary layer r for varying Prandtl number Pr

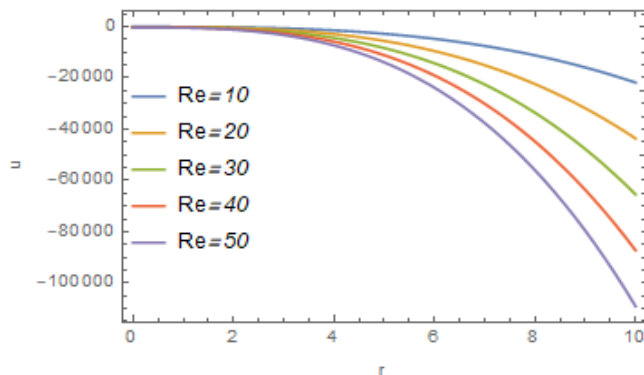


Figure 5. Velocity profile u against boundary layer r for varying Reynolds number (Re).

Grashof number, thus exemplifying that velocity profile enhances significantly due to the effect of buoyancy forces caused by the concentration of the solution, this being

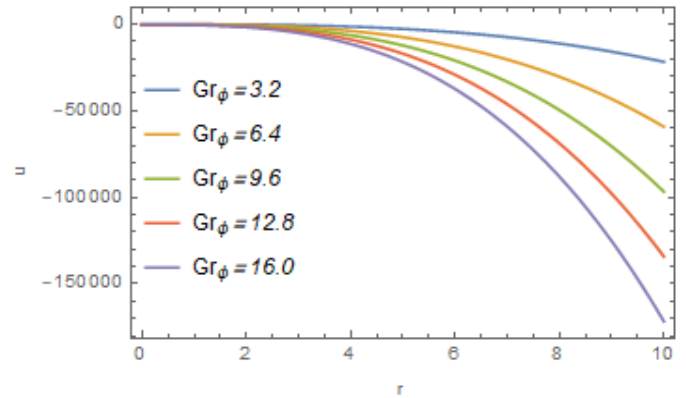


Figure 6. Velocity profile u against boundary layer r for varying Grashof number in term of concentration (Gr_ϕ).

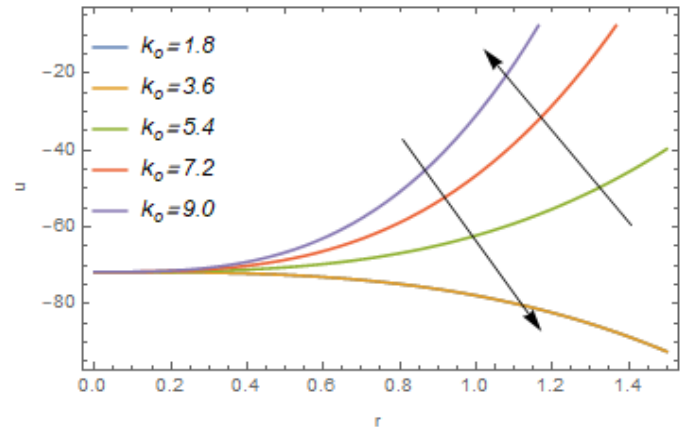


Figure 7. Velocity profile u against boundary layer r for varying chemical reaction term (k_0).

more material when it comes to issues of improvement of velocity, as this particular flow is utilizable in improving various transport phenomena like diffusion of any particular species, coating distribution, etc.

Figure 7 is the graph of the velocity profile against the boundary layer coordinate for different values of the chemical reaction parameter, and it is seen that chemical reactions have a significant effect on the momentum transport of the flow field due to their association with mass diffusion and buoyancy forces. The physical implications of this are important with regard to advanced material processing, with chemical reaction effects providing a means of regulation for transport mechanisms, as well as coating dynamics and flow performance, for reactive manufacturing operations.

Figure 8 implies the graph of the velocity profile against the boundary layer coordinate for different values of the Schmidt number highlights the strong influence of mass diffusivity on the momentum transform in the flow. This explained the behaviour is particularly important because

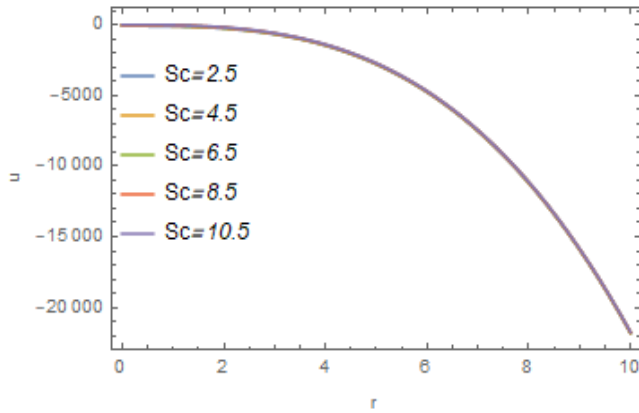


Figure 8. Velocity profile u against boundary layer r for varying Schmidt number (Sc).

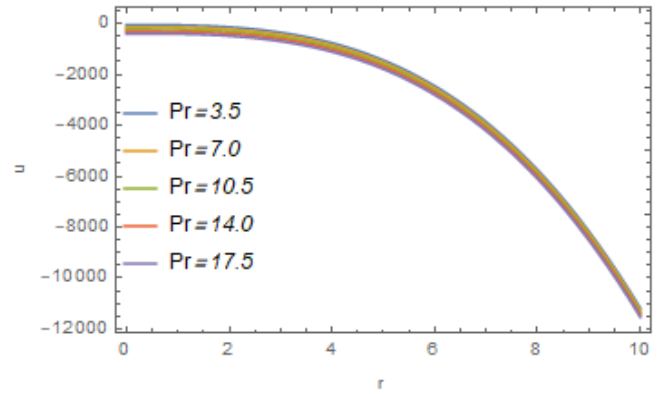


Figure 11. Velocity profile u against boundary layer r for varying Prandtl number (Pr).

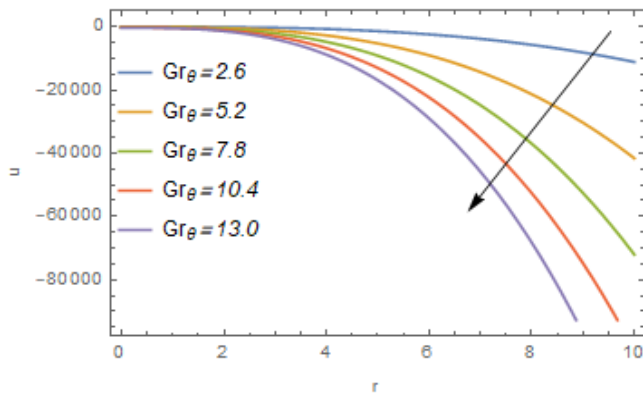


Figure 9. Velocity profile u against boundary layer r for varying Grashof number in term of temperature (Gr_{θ}).

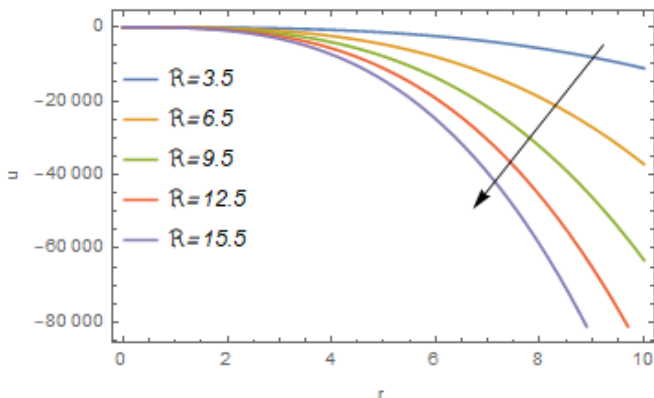


Figure 10. Velocity profile u against boundary layer r for varying Radiation term (\mathfrak{R}).

controlling Schmidt number effects helps regulate mass transport, coating diffusion rates, and the uniformity of material deposition in a chemically reactive manufacturing

system.

Figure 9 displays the graph of the velocity profile against the boundary layer coordinate for different values of the thermal Grashof number, demonstrating the significant impact of temperature-induced buoyancy forces on the fluid motion. The enhancement of velocity with increasing thermal Grashof number is crucial as thermal buoyancy effects can be effectively utilised to regulate momentum transport, improve heat transfer efficiency and optimise processing over an exponentially stretching sheet.

Figure 10 is the graph of the velocity profile against the boundary layer coordinate for different values of the thermal radiation parameter illustrates the important role of radiative heat transfer in modifying the momentum transport within the boundary layer flow, since radiation effect is highly significant therefore radiative heating can be employed to control surface temperature, improve transport efficiency and optimize the quality of thermally sensitive material fabrication over an exponentially stretching sheet. The outcome is in line with Nascimento et al. (2024), who showcased that increase in radiation enhances thermally sensitive of boundary layer.

Figure 11 gives the graph of the velocity profile against the boundary layer coordinate for different values of the Prandtl number, demonstrating the influence of thermal diffusivity on the momentum transport in the boundary layer flow. Thus, controlling the Prandtl number effect is essential for regulating coupled heat and momentum transport, improving surface coating processes and ensuring thermal stability over an exponentially stretching sheet.

Figure 12 represents the graph of the velocity profile against the boundary layer coordinate and demonstrates the effect of different Hartmann numbers on the flow. The Hartmann number is representative of the ratio of electromagnetic (Lorentz) forces that act upon the fluid compared to the viscous forces. The significance of this is theoretically and physically of major consequence to hydrodynamics since, by altering the intensity of the magnetic field, flow stability can be controlled. The

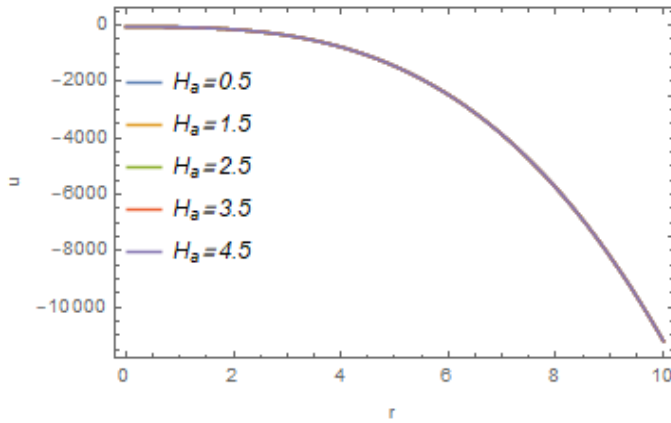


Figure 12. Velocity profile u against boundary layer r for varying Magnetic Hartmann number (H_a).

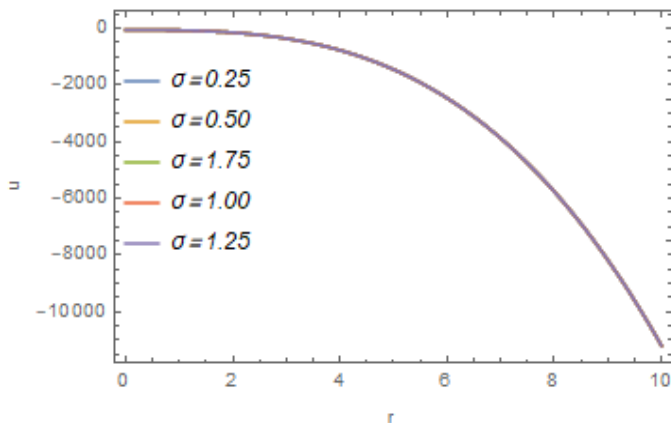


Figure 13. Velocity profile u against boundary layer r for varying Electroconductivity parameter (σ).

precision in coating is also enhanced significantly via optimum material fabrication schemes in the presence of an exponentially stretching sheet. The findings conform with Ojo *et al.* (2025b), who reported that increase in MHD fluid flow also enhances Lorentz forces.

Figure 13 demonstrates a graph showing the velocity profile against the boundary layer coordinate with different values of the electroconductivity parameter. This analysis has confirmed the important role of electrical conductivity in the flow transport of electromagnetohydrodynamic (EMHD) flow. This is a major milestone in our analysis, especially because electrical conductivity can efficiently act as a turning parameter for flow control, material coating, and material fabrication processes over an exponentially stretching sheet with enhanced stability. This result is in good compliance with the findings of Nikodijević Đorđević *et al.* (2025), who stated that the enhancement of electroconductivity also enhances the flow rate of MHD fluid flow.

Conclusion

This study employed the Chebyshev Spectral Collocation Method (CSCM) to investigate the electromagnetohydrodynamic (EMHD) boundary-layer flow, heat transfer, and mass transport over an exponentially stretching cylindrical surface relevant to advanced material processing applications. The numerical results demonstrate that the adopted spectral technique provides high computational accuracy and efficiency in capturing the complex interactions among electromagnetic forces, thermal effects, and species diffusion within the flow domain.

The analysis revealed that electromagnetic parameters significantly influence the transport characteristics of the fluid. In particular, the application of a magnetic field generates Lorentz forces that oppose fluid motion, thereby suppressing the velocity profile and modifying the momentum boundary layer. Furthermore, thermal radiation and buoyancy forces were found to enhance thermal transport and alter the temperature distribution, while concentration-related parameters strongly affected mass transfer characteristics.

The present findings provide valuable theoretical insights into the optimisation of EMHD-controlled manufacturing processes, including polymer extrusion, thin-film deposition, surface coating, metallurgical processing, and other advanced material fabrication technologies. The study further establishes the effectiveness of the Chebyshev spectral framework as a reliable numerical tool for analysing complex transport phenomena in electrically conducting fluids subjected to electromagnetic fields.

Future investigations may extend the current model to hybrid nanofluids, non-Newtonian fluids, unsteady three-dimensional flow configurations, and experimentally validated industrial systems to further enhance its applicability in modern manufacturing technologies.

Based on the numerical results, the following major conclusions are drawn:

1. The Chebyshev Spectral Collocation Method proved to be an efficient and accurate numerical technique for analysing EMHD fluid flow over an exponentially stretching cylindrical surface.
2. Reynolds number, thermal and solutal Grashof numbers, Prandtl number, Schmidt number, and chemical reaction parameter exert significant influence on the velocity, temperature, and concentration distributions within the boundary layer.
3. Increasing the Hartmann number and electrical conductivity parameter strengthens the electromagnetic Lorentz force, leading to a suppression of fluid velocity and a reduction in momentum boundary-layer thickness.
4. Thermal radiation and buoyancy effects enhance thermal energy transport, resulting in higher fluid

- temperatures and thicker thermal boundary layers.
5. Higher chemical reaction and Schmidt number parameters reduce concentration levels within the boundary layer, thereby providing effective control of mass transfer processes.
 6. The combined effects of electromagnetic control, heat transfer, and mass diffusion can be strategically utilised to optimise transport performance, process stability, and product quality in advanced material processing and manufacturing systems.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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