

RESEARCH ARTICLE

Mixed convection flow of dusty viscoelastic fluid over a stretching sheet with modified magnetic field effect: Two-phase model

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ABSTRACT – The combination of elastic and viscous characteristics together with suspended dust particles in non-Newtonian fluids closely represents real-life fluids encountered in applications such as blood flow and food processing. Such fluids, known as dusty viscoelastic fluids, are important for understanding complex fluid dynamics in various industrial and biomedical fields. This paper presents a numerical analysis of two-phase mixed convection flow of dusty viscoelastic subject to the combined effects of mixed convection and an aligned magnetic over a vertical stretching sheet. The velocity and temperature profiles are examined over various parameters including viscoelastic, aligned angle, magnetic field, fluid-particle interaction, Prandtl number and buoyancy. The governing boundary layer partial differential equations (PDEs) are reduced to a system of ordinary differential equations (ODEs) through the application of suitable similarity transformations. The resulting ODEs are subsequently solved numerically using RKF45 method implemented in MAPLE Software. The validity of the present results is confirmed through favourable agreement with previously published results in the literature. The results indicate that as the viscoelastic parameter increases the velocity of both the fluid and dust phases increases, while the temperature profile for both phases decreases. The novelty of this study lies in the development of a two-phase model for dusty viscoelastic fluid flow, providing a more realistic mathematical representation for analysing non-Newtonian flows containing suspended particles.

Article History

Received : 23 June 2026
 Revised : 24 July 2026
 Accepted : 12 August 2026
 Published : 30 September 2026

Keywords

Two-phase flow
 Dusty viscoelastic fluid
 Aligned magnetic field
 RKF45 method
 Numerical solution

1. Introduction

Fluid mechanics is a branch of physical science concerned with the behaviour and characteristics of fluids under stationary and flowing conditions. Its theory serves as a fundamental basis for numerous scientific and engineering disciplines [1]. Based on their rheological characteristics, fluids can generally be classified into Newtonian and non-Newtonian fluids. For Newtonian fluids, the shear stress varies linearly with the rate of shear strain. In contrast, fluids that do not satisfy this linear stress-strain relationship are classified as non-Newtonian fluids, as their viscosity varies with the magnitude or duration of the applied shear.

In recent years, considerable research interest has been devoted to viscoelastic fluids because of their unique rheological characteristics, which cannot be sufficiently represented using conventional Newtonian fluid models. Consequently, these fluids are encountered in various conventional liquid systems, including oils, certain paints, polymeric solutions, organic liquids, and a variety of advanced materials with considerable industrial and commercial relevance [2]. Viscoelasticity is also crucial in a range of fields such as tribology, biomechanics, material science and engineering because of its distinct mechanical properties and time-dependent nature [3]. Driven by its broad range of practical applications, this research area has received increasing attention from the scientific community in recent years. Wahid et al. [4] investigated the flow characteristics of a viscoelastic fluid when subjected to heat radiation, viscous dissipation, porous medium, magnetohydrodynamic forces over a stretching sheet. In other geometrical surfaces, Singh and Vishwanath [5] examined buoyancy-induced viscoelastic fluid flow through an inclined porous channel under the influence of a moving magnetic field. Jafar et al. [6] investigated the hydromagnetic mixed convection flow of a viscoelastic fluid induced by a vertically stretching surface, taking into account the effects of viscous dissipation and thermal radiation on the heat transfer process. In a related study, the flow characteristics of a Brinkman viscoelastic fluid

over a horizontal circular cylinder have been investigated by Kanafiah et al. [7] and they employed the Keller–Box Method to obtain numerical solutions. Furthermore, a subsequent investigation by Kanafiah et al. [8] focused exclusively on the fluid flow and the wall shear stress characteristics associated with the same flow model. Several recent studies on viscoelastic in dissimilar situation have been treasured in literature [9–13].

The incorporation of suspended solid particles into viscoelastic fluids introduces additional complexity to their flow characteristics, giving rise to what is generally termed dusty viscoelastic fluid. Such fluid systems are relevant to a variety of industrial and biomedical processes, including polymer manufacturing, food processing, blood-flow applications, and aerosol transportation. The introduction of solid particles into a fluid, either naturally or deliberately in the form of dust, ash, or soot, can significantly modify the flow characteristics of the fluid in both the upper and lower flow regions. Owing to these practical significances, several studies have been carried out to better understand the dynamics of Newtonian and non-Newtonian fluids with the presence of solid particles under dissimilar conditions. Arifin et al. [13] numerically examined the flow behaviour of a dusty fluid past a stretching sheet in the presence of an aligned magnetic field. In the same year, Sharena et al. [14] investigated a dusty viscous quiescent fluid and concluded that the fluid–particle interaction parameters significantly influence the flow characteristics. Extending this work, a more recent study by Sharena et al. [15] incorporated the effects of thermal radiation and the Hall current on dusty fluid flow. Meanwhile, for non-Newtonian dusty fluid, Bilal et al. [16] focused on how free convection and a transversely applied uniform magnetic field affect the behaviour of a viscoelastic dusty fluid in a rotating frame. Kumar and Gupta [17] scrutinized the stability and behaviour of the system that are influenced by the combination of viscoelastic properties, suspended particles and fluctuations in the magnetic field. The study found that dusty particle addition affects the Nusselt number and skin friction, where these two parameters that are essential for comprehending the system's shear stresses and heat transfer rates. Furthermore, Shanthi and Hemamalini [18] studied viscoelastic conducting dusty fluid with free convection, influenced by an angled magnetic field and radiation, confined within a horizontal channel. Meanwhile, in the geometry of parallel plates, Ali et al. [19] studied the influence of heat generation and Newtonian heating on dusty Newtonian fluid flow. Recent studies on dusty viscoelastic fluids under magnetic field effects have been reported in the literature [21–23].

Although numerous studies have been reported, the influence of an aligned magnetic field has received comparatively limited attention, particularly in the context of two-phase mixed convection flow over a stretching surface. Motivated by these considerations, the present investigation examines the behaviour of a dusty viscoelastic fluid subjected to an aligned magnetic field, in which the magnetic field is applied at an acute angle relative to the stretching surface. To better represent practical engineering systems, a two-phase model is developed in which the fluid and dust particle phases are modelled independently and solved numerically to obtain the flow and thermal characteristics of the system. This approach extends previous studies that primarily considered a transverse magnetic field and single-phase formulation. The findings provide further insight into the fluid dynamics and heat transfer characteristics of complex dusty viscoelastic flows, while contributing to the advancement of numerical modelling techniques for non-Newtonian fluids containing suspended particles and supporting the design and optimisation of engineering systems.

2. Mathematical Formulation

The steady, incompressible, two-dimensional flow of a viscoelastic fluid containing suspended dust particles is induced by a stretching sheet, where the linear velocity is given by $u_w(x) = ax$. Figure 1 shows the physical configuration where an angle varies $0^\circ - 90^\circ$ denoted as α_1 is introduced between the magnetic field and the flow. The particulate phase is assumed to consist of spherical particles of uniform size that remain continuously and uniformly distributed throughout the flow domain. For fluid phase, the governing equations are given in Eq. (1) to Eq. (3), respectively. Meanwhile, similar type of equations in dusty phase are displayed in Eqs. (4) - (6). The boundary conditions in Eq. (7) serve to define the system of governing equations, which are expressed as PDEs [24–25].

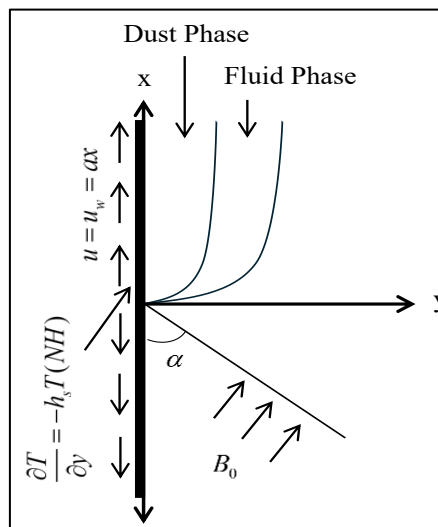


Fig. 1. The Dusty Viscoelastic fluid's flow structure

Fluid Phase:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad (1)$$

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = v \frac{\partial^2 y}{\partial y^2} + \frac{K_0}{\rho} \left(v \frac{\partial^3 u}{\partial y^3} + u \frac{\partial^3 u}{\partial x \partial y^2} + \frac{\partial u}{\partial y} \frac{\partial^2 v}{\partial y^2} + \frac{\partial u}{\partial x} \frac{\partial^2 u}{\partial y^2} \right) + \frac{\rho_p}{\rho \tau_v} (u_p - u) - \frac{\sigma u B_0^2}{\rho} \sin^2 \alpha_1 + g \beta^* (T - T_\infty). \quad (2)$$

$$\rho c_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k \left(\frac{\partial^2 T}{\partial y^2} \right) + \frac{\rho_p c_s}{\gamma_T} (T_p - T). \quad (3)$$

Dust Phase:

$$\frac{\partial u_p}{\partial x} + \frac{\partial v_p}{\partial y} = 0, \quad (4)$$

$$\rho_p \left(u_p \frac{\partial u_p}{\partial x} + v_p \frac{\partial u_p}{\partial y} \right) = \frac{\rho_p}{\tau_v} (u - u_p), \quad (5)$$

$$\rho_p c_s \left(u_p \frac{\partial T_p}{\partial x} + v_p \frac{\partial T_p}{\partial y} \right) = - \frac{\rho_p c_s}{\gamma_T} (T_p - T). \quad (6)$$

The boundary conditions and similarity transformation that suit the considered model are shown in Eq. (7) and Eq. (8), respectively

$$u = u_w(x) = ax, \quad v = 0, \quad \frac{\partial T}{\partial y} = -h_s T \text{ at } y = 0, \quad (7)$$

$$u \rightarrow 0, u_p \rightarrow 0, v_p \rightarrow v, T \rightarrow T_\infty \text{ at } y \rightarrow \infty.$$

$$u = ax f'(\eta), \quad v = -(av)^{\frac{1}{2}} f(\eta), \quad \eta = \left(\frac{a}{v} \right)^{\frac{1}{2}} y, \quad \theta(\eta) = \frac{T - T_\infty}{T_\infty}, \quad (8)$$

$$u_p = ax F'(\eta), \quad v_p = -(av)^{\frac{1}{2}} F(\eta), \quad \theta_p(\eta) = \frac{T_p - T_\infty}{T_\infty}.$$

Where $u = \partial \varphi / \partial y$ and $v = -\partial \varphi / \partial x$ in which φ signifies stream function, η is non-dimensional similarity variables. The velocities and temperature components of fluid and dust particles along x and y axes are denoted by u, v, u_p, v_p, T, T_p , respectively while ρ and ρ_p are density for fluid and dust particles. γ_T and τ_v are thermal relaxation time and relaxation time of particles phase, h_s represents heat transfer parameter, B_0 is magnetic field and α is aligned angle. By substituting Eq. (8) into Eqs. (1) – (6), the governing equations are transformed and take the following form:

Fluid Phase:

$$K(2f'f''' - f''^2 - ff^{iv}) + \beta N(F' - f') - M \sin^2 \alpha_1 f' + \lambda \theta = 0 \quad (9)$$

$$\theta'' + \text{Pr} f \theta' + \frac{2}{3} \beta N(\theta_p - \theta) = 0. \quad (10)$$

Dust Phase:

$$F'^2 - FF'' + \beta(F' - f') = 0, \quad (11)$$

$$\theta'F + \frac{2}{3} \frac{\beta}{\text{Pr}\gamma} (\theta - \theta_\rho) = 0. \quad (12)$$

Transformed boundary conditions can be expressed as follows

$$\begin{aligned} f(0) = 0, f'(0) = 1, \theta'(0) = -b(1 + \theta(0)) \text{ at } \eta = 0, \\ f'(\eta) \rightarrow 0, f''(\eta) \rightarrow 0, F(\eta) \rightarrow 0, F(\eta) \rightarrow f(\eta), \theta(\eta) \rightarrow 0, \theta_\rho(\eta) \rightarrow 0 \text{ at } \eta \rightarrow \infty. \end{aligned} \quad (13)$$

The dimensionless parameters appearing in Eqs. (9) – (13), namely the buoyancy parameter λ , Grashof number Gr_x , Reynold number Re_x , magnetic field M , conjugate parameter for Newtonian Heating (NH) b , viscoelastic K , mass concentration of particle phase N , specific heat ratio of mixture γ , Prandtl number Pr and fluid-particle interaction β , are defined as follows:

$$\begin{aligned} \lambda = \frac{Gr_x}{Re_x^2}, \quad Gr_x = \frac{g\beta^*T_\infty x^3}{\nu^2}, \quad Re_x = \frac{ax^2}{\nu}, \quad M = \frac{\sigma\beta_0^2}{a\rho}, \quad b = -h_s \left(\frac{\nu}{a}\right)^{\frac{1}{2}}, \quad K = \frac{k_0 a}{\mu}, \\ N = \frac{\rho_p}{\rho}, \quad \gamma = \frac{c_s}{c_p}, \quad Pr = \frac{\nu(\rho c_p)}{k}, \quad \beta = \frac{1}{a\tau_v}. \end{aligned} \quad (14)$$

The dimensionless of skin friction coefficient, $C_f Re_x^{1/2}$ and Nusselt number, $Nu_x Re_x^{-1/2}$ are given as [11, 26]

$$C_f Re_x^{1/2} = (1 + K)f''(0), \quad Nu_x Re_x^{-1/2} = b \left(\frac{1}{\theta(0)} + 1 \right) \quad (15)$$

where $C_f = \mu(\partial u/\partial y)_{y=0}/\rho U_w^2(x)$ and $Nu_x = -kx(\partial T/\partial y)_{y=0}/k(T_w - T_\infty)$.

3. Numerical Procedure

The resulting ODEs (9) to (12) are solved numerically using the RKF45 method implemented in Maple software and subjected to the boundary conditions in Eq. (13). The numerical results are illustrated graphically, focusing on the velocity $f'(\eta)$ and temperature $\theta(\eta)$ profiles for viscoelastic fluid and dust particles, respectively. These resulting graphs are then analysed across the considered parameters.

The results obtained in this study are validated by comparison with those from the previously published studies, as shown in Table 1. Hence, the computed values from the present investigation under the limiting conditions without considering the dust, as the variables connecting the fluid and dust equations are assumed to be zero are compared with those from three published papers: Salleh et al. [26] applied the Keller–Box technique to obtain numerical solutions for a Newtonian fluid in the absence of dust particles. Turkyilmazoglu [28] derived an analytical solution for micropolar fluid flow without incorporating the material and wall permeability parameters, whereas Arifin et al. [27] adopted the RKF45 numerical scheme. The strong agreement between the current and previous analytical and numerical results is a noteworthy observation, thereby validating the numerical algorithm and graphical outputs.

Table 1. Surface temperature, $\theta(0)$ when $M = \beta = N = 0, \gamma \rightarrow \infty$ and $b = 0.1$

Pr	Salleh et al. [26] (Keller-Box)	Turkyilmazoglu [28] (Exact values)	Arifin et al. [27] (RKF45)	Current Study (RKF45)
3	6.02577	6.05158546	6.05158577	6.0516393
7	1.76594	1.76039543	1.76039543	1.7605837
10	1.13511	1.11681524	1.11681523	1.1168217
100	0.76531	0.76452369	0.76455236	0.7646136

4. Research and Discussion

The computational analysis continues by considering specific values for several parameters, including $M = 0.2, \beta = \lambda = N = 0.5, K = 1, \alpha = \pi/6$ and $b = \gamma = 0.1$. These parameters remain constant throughout the study, except for those

deliberately varied to examine their effects. A detailed discussion of their influence on the velocity and temperature profiles is presented in the corresponding figures.

Figures 2 and 3 illustrate the influence of viscoelastic parameter, K on velocity and temperature distributions of fluid and dust phases, respectively. As shown in Figure 2, an increase in the values of K leads to a corresponding enhancement in the velocity profiles of both the viscoelastic fluid and dust particle phases throughout the boundary layer. The dust phase responds more gradually to variations in K than the fluid phase, owing to the drag interaction between the fluid and dust particles. Physically, a larger value of K strengthens the fluid's elastic behaviour, enabling it to store and release elastic energy during deformation. As a result, the fluid accelerates, and the drag interaction subsequently transfers momentum to the dust particles, causing their velocity to increase as well. The dust particles exhibit a slower response owing to their inertia. In contrast, Figure 3 shows that increasing K reduces the temperature profiles of both the fluid and dust phases. The accelerated flow enhances convective heat transfer from the stretching sheet, resulting in a thinner thermal boundary layer and lower temperatures in both phases. Accordingly, the temperature profile approaches its asymptotic value at a smaller similarity variable, indicating a thinner thermal boundary layer as compared to momentum boundary layer.

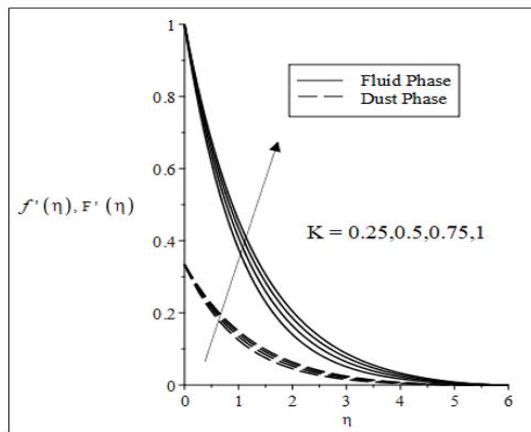


Figure 2. Effect of K on $f'(\eta)$

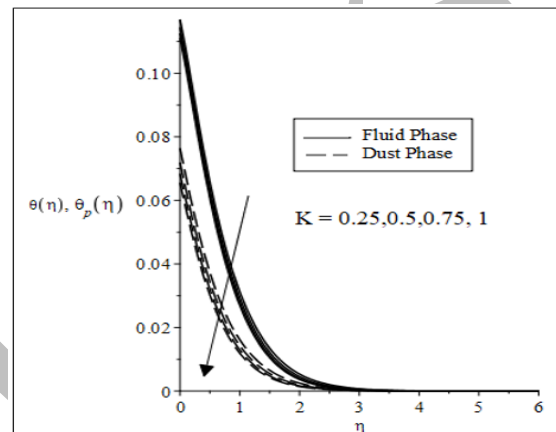


Figure 3. Effect of K on $\theta(\eta)$

Figures 4 and 5 depict the effect of the fluid-particle interaction parameter, β on the velocity and temperature distributions for fluid and dust phases, respectively. As β increases, the velocity of dust particles rises. This can be explained by the associated reduction in the particle velocity relaxation time, which enables the particles to respond more quickly to variations in the velocity of the surrounding fluid. Consequently, the dust particles accelerate and progressively approach the velocity of the fluid phase. This enhanced momentum exchange between the two phases causes a slight deceleration of the fluid motion. Additionally, the influence of β is more significant on dust phase as it exhibits noticeable changes. For temperature profile, a trend similar to that of the dust particles velocity is detected as β increases. Physically, a larger β strengthens the thermal coupling between the two phases, allowing heat to be transferred more efficiently from the warmer fluid to the cooler dust particles, resulting in higher temperature. Consequently, the dust temperature increases, while the enhanced thermal interaction also elevates the fluid temperature, indicating improved interphase heat exchange.

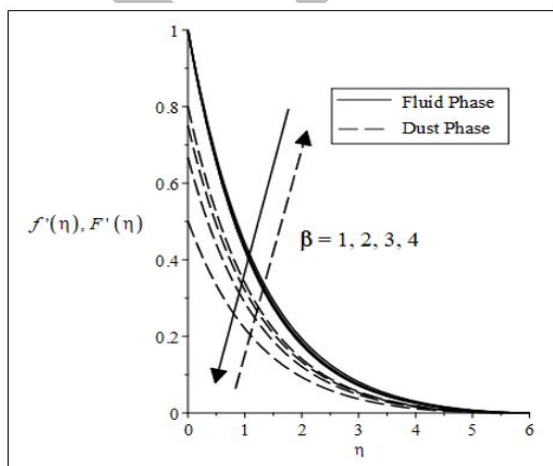


Figure 4. Effect of β on $f'(\eta)$

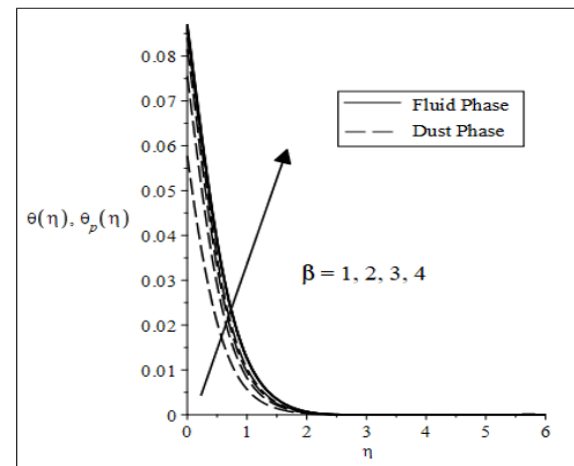
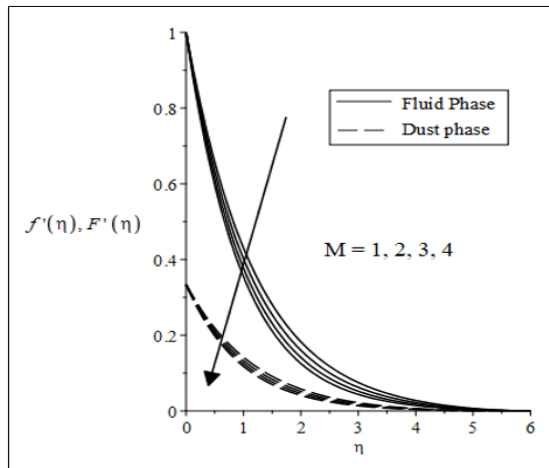
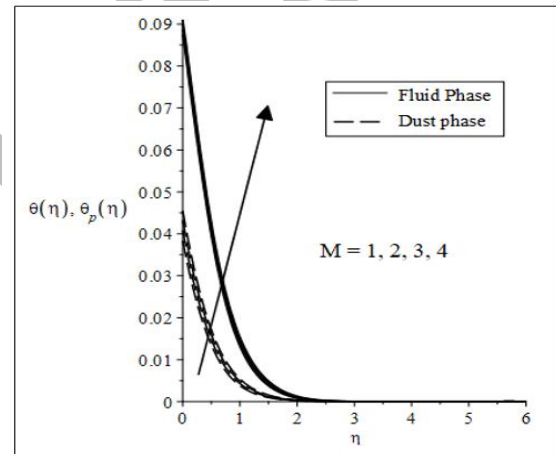
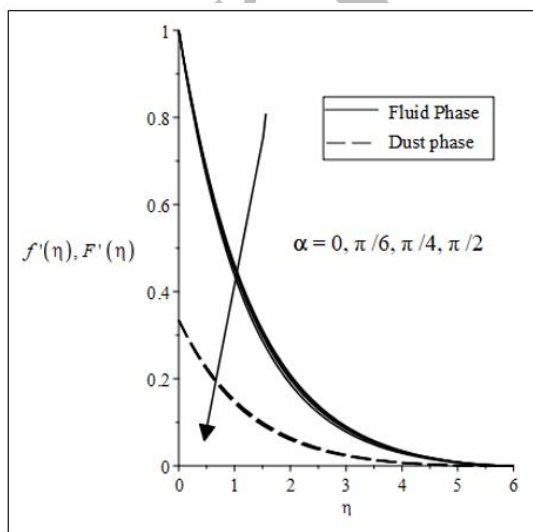
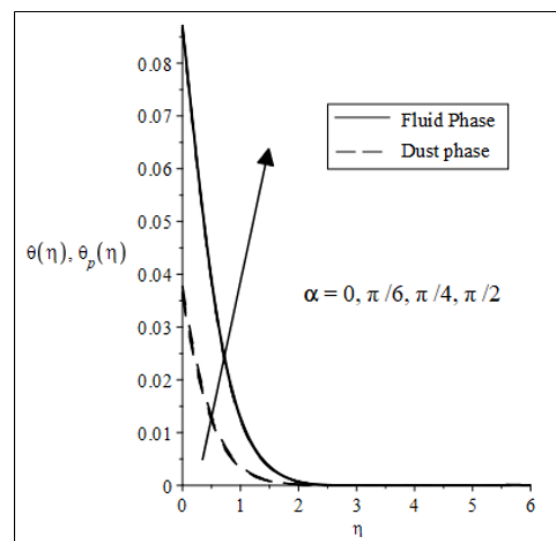
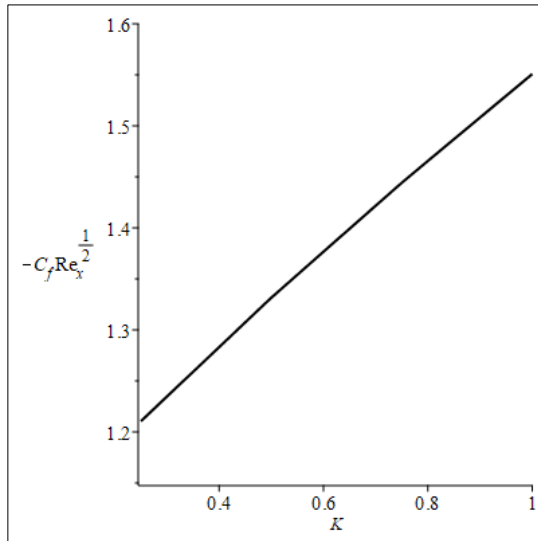
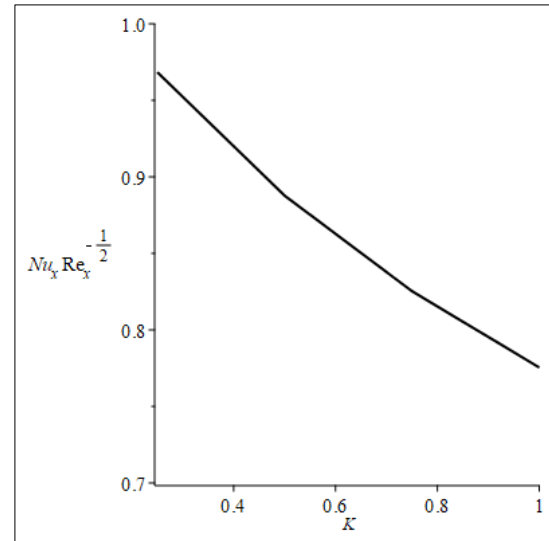


Figure 5. Effect of β on $\theta(\eta)$

Figures 6 and 7 depict the effect of the magnetic field parameter, M on the distributions of velocity and temperature of the fluid and dust phases. An increase in M reduces the velocity profiles of both phases due to the enhanced Lorentz force, which opposes the fluid motion. Conversely, the temperature profiles increase with increasing M . The strengthening of M intensifies the Lorentz force, which resists the fluid flow and causes a deceleration of the fluid motion. Physically, the stronger magnetic field generates greater resistance to the flow, causing kinetic energy to be transformed into thermal energy. Consequently, the temperature of both the fluid and dust phases rise. The figures clearly demonstrate that the influence of M is more significant on the velocity profile than on the temperature profile, as it appears explicitly in the momentum equation only. Therefore, changes in M affect the flow field more significantly, while the temperature field is influenced indirectly. Figures 8 and 9 portray the influence of the aligned angle, α on the velocity and temperature distributions for viscoelastic fluid and dust particles, respectively. A similar trend to that observed in Figures 6 and 7 can be identified. This behaviour can be explained mathematically through the relationship between α and M , where the changes in α indirectly enhance the magnetic field effect. Thus, influencing both velocity and temperature distributions.

The magnitude skin friction coefficient $-C_f Re_x^{1/2}$ and Nusselt number $Nu_x Re_x^{-1/2}$ varies with viscoelastic parameter, K are presented in Figures 10 and 11, respectively. As K increases from 0.25 to 1.00, $-C_f Re_x^{1/2}$ increases from 1.2105 to 1.5508, representing an increase of approximately 28.1%. This trend suggests that the wall shear stress becomes more pronounced as a result of the increased elastic effects within the fluid. Consequently, accelerates the fluid motion as illustrated in Figure 2. In contrast, Figure 11 shows that $Nu_x Re_x^{-1/2}$ decreases from 0.9684 to 0.7754, corresponding to a reduction of approximately 19.9%. This reduction is attributed to the thickening of the thermal boundary layer, which decreases the wall temperature.


Figure 6. Effect of M on $f'(\eta)$

Figure 7. Effect of M on $\theta(\eta)$

Figure 8. Effect of α on $f'(\eta)$

Figure 9. Effect of α on $\theta(\eta)$


Figure 10. Effect of K on $C_f Re_x^{1/2}$

Figure 11. Effect of K on $Nu_x Re_x^{-1/2}$

5. Conclusion

The study investigates the fluid-particle interaction of viscoelastic fluid with the magnetic field and mixed convection impacts. The findings of this study are applicable in engineering processes such as polymer processing, coating technology, electromagnetic flow control, and thermal management systems. The main findings of this study are:

- For viscoelastic parameter, K , the results show that the velocity for the fluid and dust phases is increased and the temperature profile for both phases are decreased.
- The magnetic field parameter, M exhibits an opposite trend, where increasing its value results in a reduction of the velocity profiles for both the viscoelastic fluid and dust particle phases, while enhancing the temperature profiles of both phases.
- The fluid-particle interaction, β and aligned angle, α influence the two phases differently. An increase in these parameters leads to a reduction in the velocity of the fluid phase but an enhancement in the velocity of the dust phase. In contrast, the temperature profiles of both phases increase as these parameters are increased.

The present study is limited to steady, two-dimensional boundary layer flow of dusty viscoelastic fluid. Future studies may consider other types of non-Newtonian fluid such as Eyring Powell fluid, as well as additional effects including thermal radiation, porous media and nanoparticles to improve the applicability of the model.

Acknowledgement

The authors express their gratitude to Universiti Teknologi MARA, for their support and assistance.

Declaration of Competing Interest

The authors declare no conflict of interest.

CRediT Authorship Contribution Statement

Nur Syamilah Arifin (Writing – original draft)
 Syazwani Mohd Zokri (Mathematical Formulation)
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 Norbaiti Tukiman (Writing – review & editing)

Generative Artificial Intelligence Declarations

The authors have not utilised any AI resources or tools in the preparation of this article.

References

- [1] Granger RA. Fluid mechanics. New York: Dover Publications; 1995.
- [2] Biswas PK, Nandy KC, Das RK. Study of dusty viscoelastic fluid (Kuvshinski type) using Lighthill technique. Acta Ciencia Indica. 2022;[volume(issue)]:[pages].
- [3] Wang D, de Boer G, Neville A, Ghanbarzadeh A. A review on modelling of viscoelastic contact problems. Lubricants. 2022;10(12):358. <https://doi.org/10.3390/lubricants10120358>
- [4] Wahid NS, Hafidzuddin MEH, Arifin NM, Turkyilmazoglu M, Abd Rahmin NA. Magnetohydrodynamic (MHD) slip Darcy flow of viscoelastic fluid over a stretching sheet and heat transfer with thermal radiation and viscous dissipation. CFD Letters. 2020;12(1):1–12.

- [5] Singh JK, Vishwanath S. Hall and ion-slip effects on MHD free convective flow of a viscoelastic fluid through porous regime in an inclined channel with moving magnetic field. *Kragujevac Journal of Science*. 2020;42[(issue)]:[pages]. [doi]
- [6] Jafar AB, Shafie S, Ullah I, Safdar R, Jamshed W, Pasha AA, et al. **Retracted article:** Mixed convection flow of an electrically conducting viscoelastic fluid past a vertical nonlinearly stretching sheet. *Scientific Reports*. 2022;12(1):14679. <https://doi.org/10.1038/s41598-022-18761-0>. **Retraction in: Scientific Reports**. 2025. <https://doi.org/10.1038/s41598-025-02616-5>, **Please replace it with others**
- [7] Kanafiah SFHM, Kasim ARM, Zokri SM, Arifin NS. Non-similarity solutions of non-Newtonian Brinkman–viscoelastic fluid. *Mathematics*. 2022;10(12):2023. <https://doi.org/10.3390/math10122023>
- [8] Kanafiah SFHM, Kasim ARM, Zokri SM, Arifin NS, Manaf ZIA. Flow analysis of Brinkman-viscoelastic fluid in boundary layer region of horizontal circular cylinder. *CFD Letters*. 2022;14(12):27–37. <https://doi.org/10.37934/cfdl.14.12.2737>
- [9] Fauzi F, Kasim ARM, Kanafiah SFHM, Zokri SM, Taofeeq AA, Yasin SHM. Advancing heat transfer: exploring nanofluids and regression analysis on lower stagnation point of a horizontal circular cylinder for Brinkman-viscoelastic fluid. *Semarak Engineering Journal*. 2024;7(1):1–10. [doi]
- [10] Benaissa M, Rafiq MY, Shahzad H, Zayani HM, Khedher NB, et al. — **verify full author list**. Boundary layer formation over a stretchable cylinder in a viscoelastic fluid with partial slip and viscous dissipation effects. *Case Studies in Thermal Engineering*. 2025;74:[article number]. [doi]
- [11] Ramadevu S, Kumar PV, Lorenzini G, Ibrahim SM, Jyothsna K. Viscoelastic flow analysis with Buongiorno nanofluid model over a nonlinear stretching sheet: a homotopy approach. *Frontiers in Heat and Mass Transfer*. 2025;23(3):857–79. [doi]
- [12] Akbar NS, Zamir T, Habib MB, Bilal S, Muhammad T, Farooq M. Thermal predictive modelling of viscoelastic MHD nano fluid over a stretching sheet in a porous medium using neural network technique. *ZAMM – Journal of Applied Mathematics and Mechanics*. 2026;106(4):e70413. <https://doi.org/10.1002/zamm.70413>
- [13] Medhi K, Debnath K, Sarma K. Thermal, mass, and flow analysis of time-dependent hydromagnetic viscoelastic fluid over a porous stretching sheet with radiation and heat flux. *Heat Transfer*. 2026;55(1):670–82. [doi]
- [14] Arifin NS, Zokri SM, Kasim ARM, Salleh MZ, Mohammad NF. The aligned magnetic field of a dusty fluid flow over a stretching sheet. *AIP Conference Proceedings*. 2017;1870(1):040033. [doi]
- [15] Isa SM, Mohammad NF. Boundary layer flow of dusty fluid on a stretching sheet of another quiescent fluid. *Journal of Physics: Conference Series*. 2017;819(1):012027. <https://doi.org/10.1088/1742-6596/819/1/012027> ‡
- [16] Isa SM, Mahat R, Katbar NK, [authors 4–6], et al. Thermal radiative and Hall current effects on magneto-natural convective flow of dusty fluid: numerical Runge–Kutta–Fehlberg technique. *Numerical Heat Transfer, Part B: Fundamentals*. 2025;86(6):1599–621. [doi]
- [17] Bilal M, Khan S, Ali F, Arif M, Khan I, Nisar KS. Couette flow of viscoelastic dusty fluid in a rotating frame along with the heat transfer. *Scientific Reports*. 2021;11(1):506. <https://doi.org/10.1038/s41598-020-79795-w>
- [18] Kumar P, Gupta S. Hydromagnetic instability of two viscoelastic dusty-fluids in porous medium. *WSEAS Transactions on Heat and Mass Transfer*. 2021;16:137–44. [doi]
- [19] Shanthi M, Hemamalini P. The study of inclined magnetic field and thermal radiation on MHD oscillatory convective flow of heat absorbing visco-elastic dusty fluid confined in horizontal channel. *Journal of Mechanical Engineering[publisher/country — several journals share this title]*. 2022;7(5):114–6. [doi]
- [20] Ali F, Ali G, Khan A, Khan I, Eldin ET, Ahmad M. Effects of Newtonian heating and heat generation on magnetohydrodynamics dusty fluid flow between two parallel plates. *Frontiers in Materials*. 2023;10:1120963. <https://doi.org/10.3389/fmats.2023.1120963> ‡
- [21] El-Dib YO, *Elgazery NS* ‡, Gad NS. Insights into nonlinear stability of dusty viscoelastic overlaid magnetic fluids: impact of a periodic magnetic field. *Journal of Applied and Computational Mechanics*. 2026;[volume(issue)]:1–16. [doi]
- [22] Kalita H, Devi K, Nag A, Karmakar PK. Nonlinear pulsations in self-gravitating multi-species viscoelastic dusty plasmas. *Discover Space*. 2026;130[(issue) or article number — **Springer Discover journals use article numbers**]:1–24. [doi]
- [23] Sarma N, Paul A. Thermal and flow transfer characteristic of two-phase dusty viscoelastic Maxwell hybrid nanofluid over a porous radiative cylinder. *International Journal of Computational Materials Science and Engineering*. 2026[**verify year: ID 2450019 denotes a 2024 article sequence**];15(2):2450019. [doi]
- [24] Kasim ARM, Othman ZS, Shafie S, Pop I. Generalized Blasius problem for a viscoelastic fluid with viscous dissipation and suction/injection effects. *International Journal of Numerical Methods for Heat & Fluid Flow*. 2013;23(7):1242–55. <https://doi.org/10.1108/HFF-02-2011-0022>
- [25] Rashidi MM, Ali M, Rostami B, Rostami P, Xie GN. Heat and mass transfer for MHD viscoelastic fluid flow over a vertical stretching sheet with considering Soret and Dufour effects. *Mathematical Problems in Engineering*. 2015;2015:861065. <https://doi.org/10.1155/2015/861065>
- [26] Salleh MZ, Nazar R, Pop I. Boundary layer flow and heat transfer over a stretching sheet with Newtonian heating. *Journal of the Taiwan Institute of Chemical Engineers*. 2010;41(6):651–5. <https://doi.org/10.1016/j.jtice.2010.01.013> ‡
- [27] Arifin NS, Zokri SM, Kasim ARM, Salleh MZ, Mohammad NF. Two-phase mixed convection flow of dusty Williamson fluid with aligned magnetic field over a vertical stretching sheet. In: **[Editor surnames and**

- initials]**, editors. Proceedings of the Third International Conference on Computing, Mathematics and Statistics (iCMS2017); 2017 **[dates]**; **[city, country]**. *Singapore: Springer* ‡; 2019. p. 209–16. **[doi]**
- [28] Turkyilmazoglu M. Flow of a micropolar fluid due to a porous stretching sheet and heat transfer. *International Journal of Non-Linear Mechanics*. 2016;83:59–64. <https://doi.org/10.1016/j.ijnonlinmec.2016.04.004>

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