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Magneto-Hydrodynamic Effects on Heat and Mass Transfer in Hybrid Nanofluid Flow over A Stretched Sheet with Cattaneo-Christov Model

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ABSTRACT

This study uncovered a numerical simulation of the Williamson hybrid nanofluid's MHD on "heat and mass transfer flow" over a porous stretched sheet. The model made use of Cattaneo-Christov heat and mass fluxes. The situation's underlying physics is modelled using governing equations. Using an appropriate similarity transformation, these equations were transformed into a system of ordinary differential equations. Methodology/Approach: MATLAB software along with BVC4C tool is used to find the numerical solution of the problem. The study's findings show that while boosting the mass relaxation flux increases concentration distributions, doing so also increases temperature distributions. Thermal radiation, heat generation, and an additional value to improve temperature and velocity distributions, the Eckert number was measured. Major findings: Higher magnetic field values are shown to result in an increase in the velocity distribution because of the applied electromagnetic force. Additionally, a rise in the thermal radiation parameter is seen to broaden the distributions of velocity and temperature. Astrophysics, geophysics, biological sciences, and biomedical engineering are all helpful to this study. The findings of this study are generally well supported by the literature.

1. Introduction

The interaction between thermal radiation, viscous dissipation, and heat transfer has drawn the attention of numerous researchers. Viscous dissipation and subsurface storage techniques are both used to capture geothermal energy. Thermal radiation is essential in nuclear power plants, gas turbines, satellites, and the alteration of high-temperature energy processes. This fluid was tested against ionizing radiation and chemical reactions by Kataria *et al.,* [1]. The Soret-Dufour process, the

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MHD buoyant force, and the significance of dissipative viscosity in a conducting fluid have all been illuminated by the use of electricity. The effects of radiation on stagnation flow were examined by Hayat *et al.,* [2] using second-order slip and melting heat transfer. A circulating disc with varying thicknesses may result in radiative flow, according to research by Ahmed Alsaedi *et al.,* [3]. Vedavathi *et al.,* [4] examined how radiation and mass transfer impacted the MHD unsteadiness convective flow across a vertical infinite plate. Chaio [5] was the first to create a colloidal nanoparticle suspension in a base fluid using a variety of chemical nanoparticles, including oxide ceramics, metal carbides (SiC), metal nitrides (AiN), metals (Al), and nonmetals (Graphite). There are several uses for nanofluids in the solar business, biomedical engineering, biological science, industrial cooling, and cancer therapy.

Murthy *et al.,* [6] used MHD boundary layer motion to explore Williamson nanofluid boundary layer motion in the passable zone. Hashim *et al.,* [7] investigated how a heated surface affects the Williamson fluid flow time. A dusty viscoelastic fluid is heated by MHD flow between two moving parallel plates in Reddy *et al.,* [8], which demonstrates the effects of radiation and thermal diffusion. Using a porous stretched sheet, Makinde *et al.,* [9] evaluated how chemical reactions affected the MHD flow of the Casson fluid. The computational solutions for unsteady MHD flow heat transfer across a stretched surface with suction or injection were shown by Krishna *et al.,* [10]. Reddy *et al.,* [11] examined these effects in their study on the impact of Soret and radiation on the erratic Casson fluid flow in a porous vertical conduit with expansion and contraction. A moving vertical porous plate was used in Sridevi *et al.,* [12] investigation of the impact of thermal radiation and chemical reactions on MHD flow. The impact of fluid movements, Numerous scholars have explored and investigated the effects of chemical interactions, both Newtonian and non-Newtonian [13–29]. Using restrictions that are not isothermal and not iso-solutal. Dawar *et al.,* [30] conducted research on the Williamson nanofluid convective flow across a cone and wedge. According to Srinivasacharya *et al.,* [30], heat radiation had an impact on the mixed convective flow of nanofluid on an inclined wavy surface. Utilizing mobile or stationary vertical plates, Gireesha *et al.,* [31] conducted research on chemically reacting nanofluid convective flow.

Ganesh Kumar *et al.,* [32] investigated the impact of a continuous heat source/sink on the nonlinear convective flow of nano Oldroyd-B fluid across a stretchable surface. A stretchy sheet of Maxwell viscoelastic MHD nanofluid was the subject of an investigation by Ahmad Farooq *et al.,* [33]. Nadeem *et al.,* [34] looked at how hazy nano-hybrid fluids were affected by natural convection motion and heat transmission in two upright plates. By varying viscosity and thermal conductivity, Idowu *et al.,* [35] looked at the Casson-Walters-B fluid's synchronous motion across a vertical porous plate.

Khan *et al.,* [36] examined the MHD Falkner-Skan-Sutter via the nanofluid model and the "Cattaneo-Christov heat flux theory." Williamson hybrid engine oil with Cattaneo-Christov heat flux and nanofluids. Ali *et al.,* [37] quantitatively calculated the MHD Casson-Ferro fluid's heat radiative transport. The melting heat reaction in a von Karman circulating motion of hybrid nanofluids was investigated by Zhang Yan *et al.,* [38] by applying a Cattaneo-Christov heat flux. Hayat Tanzila *et al.,* [39] addressed the mobility of 3D Eyring-Powell using the 'Cattaneo-Christov model' and a chemical reaction on an exponentially stretchable surface. Shihao Han *et al.,* [40] used the Cattaneo-Christov model to link viscoelastic fluid flow with heat transfer mechanisms.

The magnetic and electric field-induced flow of highly conducting fluids is referred to as MHD. Astrophysicists and geophysicists use a variety of techniques to study these subjects as well as MHD power generation and heat exchanger construction. There has been a great deal of study done on MHD flows on non-Newtonian fluids on stretched surfaces. Plasma research, flow meters, aerodynamics, and solar energy equipment are a few examples of MHD processes. Due to the vast spectrum of MHD applications, the research mentioned below has explained the flow phenomena connected to MHD. Heat radiation is used, and the significance of Soret-Dufour is examined. Falodun *et al.,* [41] analyzed the flow of a chemically reactive fluid through a half-infinite upright plate. Khan *et al.,* [42] studied the implications of MHD and the non-Newtonian flow of nanofluids through a stretchy cylinder on many slides. Mishra A stretchable sheet was the subject of an investigation by Satya Ranjan *et al.,* [43] into the dissipation relevance of the Casson fluid's MHD stagnation-point motion. Mondal *et al.,* [44] investigated MHD mass transfer across a slanting plate with thermophoresis, a non-constant heat source/sink, chemical reaction, and Soret-Dufour significance. Ramzan *et al.,* [45] used heat transport analysis on a stretchable sheet with thermal and velocity slip restrictions to study MHD hybrid nanofluids with heat transmission. By Omowale *et al.,* [46] the MHD flow of a viscosity-elastic fluid across an accelerating penetrable surface was made clear. TiO2-water nanofluids and Al2O3-water were flowed past a stretched sheet in MHD convective flow, and Reddy *et al.,* [47] researched the Soret-Dufour effects. A thorough investigation of the energy analysis of shell and tube heat exchangers was done by Rashidi *et al.,* [48]. In a recent study, Farooq Umar *et al.,* [49] calculated the nonlinear thermal radiation in an entropy-producing magnetized nanofluid flow. Bhatti *et al.,* [50] explored natural convection non-Newtonian EMHD dissipative flow utilizing the Homotopy perturbation method using a microchannel containing a non-Darcy porous material. Therefore, mentioned above authors show that Cattaneo-Christov models are used to study magnetohydrodynamics with a distinct approach. To the absolute best of our insight, no concentration in the writing has considered MHD intensity and mass exchange stream of Williamson Half and half nanofluids over a permeable extending sheet with Cattaneo-Christov hypotheses. Subsequently, this paper zeroed in on intensity and mass exchange on Williamson mixture nanofluid stream by means of an extending penetrable surface with attractive and electromagnetic powers. This paper investigated the exploration on crossover nanofluid stream by means of an extended sheet by inspecting Cattaneo-Christov models and the Soret-Dufour system, as well as MHD Williamson stream by taking both attractive field and electromagnetic power importance on stream course into account. Tables and charts are utilized to delineate the effect of stream boundaries on speed, temperature, and fixation in a way that is straightforward.

2. Methodology

Consider steady, laminar, incompressible 2-D free convective flow of MHD Williamson hybrid nanofluids past a stretched sheet saturated in the passable zone is the main goal of this study. In Figure 1, the stretching surface's x-axis is treated, and the surface's y-axis is assessed. In order to coordinate the electric current, a uniform magnetization B0 is pushed while an electromagnetic force is applied to the stretched surface. The earliest research indicates that the induced magnetic field has no impact on magnetism. The stretching surface's concentration (Cw) and temperature (Tw) are both kept constant. The concentration C and temperature T are not close to the plate. Because there are no slip issues, a state of thermal equilibrium is kept. The water-based nanofluids are considered to have nonlinear viscous dissipative effects. Estimates of radiative heat flux are made using the Rosseland approximation Soret-Dufour mechanisms are also important because of the high concentrations of the compounds.

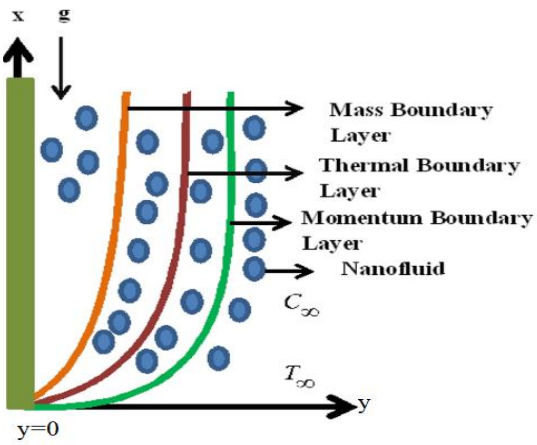


Fig. 1. The physical model of the problem

The governing equations are as follows in light of the assumptions.

$$u_x + v_y = 0 \tag{1}$$

$$uu_x + vu_y = \frac{\mu_{nf}}{\rho_{nf}} u_{yy} + \sqrt{2}\nu\Gamma u_y u_{yy} - \frac{\sigma_{nf}}{\rho_{nf}} B_0^2 u - \frac{\sigma_{nf}}{\rho_{nf}} E_0 B_0 - \frac{\mu_{nf}}{\rho_{nf}} \frac{u}{K} \tag{2}$$

$$uT_x + vT_y = \begin{bmatrix} \alpha_{nf} T_{yy} - \frac{1}{(\rho Cp)_{nf}} q_{ry} + \frac{\mu_{nf}}{(\rho Cp)_{nf}} \left[u_y + \frac{\Gamma}{\sqrt{2}} u_y^2 \right] \\ + \frac{D_C}{(\rho Cp)_{nf}} C_{yy} + \frac{\sigma B_0^2}{(\rho Cp)_{nf}} u^2 \end{bmatrix} \tag{3}$$

$$uC_x + vC_y = \left[D_M C_{yy} + D_T T_{yy} - Kr * (C - C_\infty) \right] \tag{4}$$

The ideal boundary conditions for the model being considered are provided by:

$$\begin{gathered} T = T_w, C = C_w, u = bx, v = 0 \quad \text{at} \quad y = 0 \\ u \to 0, C \to C_\infty, T \to T_\infty \quad \text{as } y \to \infty \end{gathered} \tag{5}$$

Where, u and v are properties of velocity along x and y directions. b is stretching rate considered to be positive constant, C is concentration of fluid, T is temperature of fluid, Kr* is chemical rate of reaction, σ is electrical conductivity, ρnf is nanofluid density, αnf is nanofluid thermal diffusivity, μnf is nanofluid dynamic viscosity, K is permeability parameter, DM is diffusivity of species, (ρCp) is nanofluid heat capacitance, DT indicates mass flux in temperature gradient, DC indicates heat flux in concentration gradient.

The stretching sheet stretches on its plane with surface velocity (x) = bx where b is stretching rate considered to be positive constant. Rossel and approximation is considered.q_r is defined as

$$q_r = -\left(\frac{4\sigma^*}{3k_{nf}}\right)\left(\frac{\partial T^4}{\partial y}\right) \tag{6}$$

Where, k_{nf} stands for mean 'absorption coefficient' and σ^*stands for the 'Stefan-Boltzmann constant. According to the aforementioned hypotheses that there is little temperature change between the strata, the following connection is used:

$$T^4 \cong 4T_2^3 T - 3T_2^4 \tag{7}$$

The similarity transformations considered are:

$$\eta = \sqrt{(b/\nu_f)}, \psi = \sqrt{(b\nu_f)}xf(\eta), u = bxf'(\eta), v = -\sqrt{b\nu}f(\eta)$$
$$\zeta(\eta) = \frac{T-T_\infty}{T_w-T_\infty}, \varpi(\eta) = \frac{C-C_\infty}{C_w-C_\infty} \quad (8)$$

Employing the Eq. (7)-(8) on the governing Eq. (1)-(4), subject the boundary conditions (5):

$$f''' + K_1K_2\left[ff'' - \frac{M}{K_2}f' - f'^2 + E_0M\right] - A_1f' + Wef''f''' = 0 \quad (9)$$

$$\left(1+\frac{4}{3}R\right)\zeta'' + Pr\frac{K_3}{K_5}\begin{bmatrix} f\zeta' - 2f'\zeta + \frac{Ec}{K_4}f''^2 + 0.5Wef''^3 \\ +\frac{1}{K_3}(K_1f' + L_1\zeta + Du\varpi'') \end{bmatrix} \quad (10)$$

$$\varpi''Sc(f\zeta' - Kr\varpi + Sr\zeta'') = 0 \quad (11)$$

The associated boundary conditions are:

$$f' = 1, f = 0, \zeta = 1, \varpi = 1 \text{ at } \eta = 0 \quad \zeta \to 0, f' \to 0, \varpi \to 0 \text{ as } \eta \to \infty \quad (12)$$

Where,

$$M = \frac{\sigma B_0^2}{\rho_f}, Pr = \frac{\nu_f}{\alpha_f}, K = \frac{\nu_f}{K_p}, We = \Gamma x\sqrt{\frac{2b^3}{\nu_f}}, E_0 = \frac{E}{B_0U_w}, Kr = \frac{Kr*}{b}$$
$$Sc = \frac{\nu_f}{D_M}, So = \frac{D_T(T_w-T_\infty)}{\nu_f(C_w-C_\infty)}, Du = \frac{D_C(C_w-C_\infty)}{\nu_f(\rho C_p)_f(T_w-T_\infty)}, Ec = \frac{U_w^2}{(C_p)_f(T_w-T_\infty)}$$

The following definitions apply to nanofluid's thermal characteristics:

$$K_{nf} = k_f\frac{k_s + 2k_f - 2\phi(k_f - k_s)}{k_s + 2k_f + 2\phi(k_f - k_s)}, (\rho Cp)_{nf} = (1-\phi)(\rho Cp)_s + \phi(\rho Cp)_s,$$
$$\alpha_{nf} = \frac{K_{nf}}{(\rho Cp)_{nf}}, \mu_{nf} = (1-\phi)^{-2.5}\mu_f, \rho_{nf} = (1-\phi)\rho_f + \phi\rho_s, \nu_f = \frac{\mu_f}{\rho_f}. \quad (13)$$

3. Result and Discussion

Figure 2 shows the numerical approach of the present study. Eq. (9) through (11) of the boundary value issue were numerically resolved using MATLAB's bvp4c tool. This bvp4c function is created utilizing the finite difference technique and the three-stage Lobatto IIIa formula with fourth order precision. The tables and graphs presented in this section hereby correspond to these values except where it is otherwise stated.

Figure 3 illustrates the impact of the magnetic field (M) on the velocity profile. The velocity circulation and the whole hydrodynamic limit layer are worked on because of an expansion in M. Lorentz force is produced by a forced attractive field. Electrically conductive liquids are impacted by this power. For instance, Lorentz force significantly affects speed dissemination in figure 3, since electric component boundary is available in stream system.

The permeability parameter (K) affects the velocity appropriation, as displayed in Figure 4. The porousness boundary increments, bringing about a remarkable change in the velocity profile. The penetrability boundary in a limit layer stream permits liquids to venture out starting with one layer then onto the next genuinely. While expanding K builds the permeable system, it likewise permits more liquid particles to go through. Along these lines, the thickness of the hydrodynamic limit layer continues to rise. Prandtl (Pr) effect on velocity and temperature appropriations should be visible in Figures 5(a) and 4(b). The velocity and temperature diagrams degenerate emphatically when the Pr is expanded. Since any liquid with a bigger Prandtl will have an extremely high thickness, this outcome is sensibly right. As per the result displayed in Figure 5, the plate has started to cool from the wall up. Due to the low plate surrounding consistency, this is valid. Pr checks the stream conduct of liquid warm and energy boundaries during heat move. Truly, the thickness of the hydrodynamic and warm limit layer upgrades because of expansion in Pr.

On the velocity and fixation charts, Soret (Sr) has an impact displayed in Figure 6. Solutal and hydrodynamic limit layers seem to accelerate because of an expansion in Sr. To settle twofold diffusive stream, a more noteworthy Sr esteem has been found. For instance, on the off chance that the fixation inclination is more prominent than nothing, the thickness of the nanoparticles falls because of this slope, and they diffuse to a cooler medium. Nonetheless, when the liquid temperature climbs to Sr, the thickness of the liquid ascents and the nanoparticles spread to a hotter climate.

The influence of the Williamson boundary (Weissenberg number) (We) on the velocity profile is seen in Figure 7. The hydrodynamic layer and speed profile are upgraded by expanding We. With regards to speed, the effect of We is most perceptible when you're near the wall and nearly non-existent when you're a long way from the plate. Along these lines, liquid stream is impacted by the wall's thickness.

Figures 8(a) and 8(b) portrays the impact of Dufour (Du) on the velocity and temperature designs in the district. For the dispersion warm nature of the cycle, the meaning of Du should be visible. The energy transition inside the layer is dispersed by the focus inclinations depicted by the Du.

This outcomes in a synchronous decrease of the solutal and hydrodynamic limit layers. Eckert's (Ec) impact on temperature and velocity conveyances is found in Figures 9(a) and 9(b). The Eckert number is a proportion of the enthalpy and dynamic energy in the stream. In a high incompressible stream, Ec fundamentally affects the temperature, which is the reason it is significant at high rates in compressible streams. The final result, which indicates that the flow gains more energy and hence improves the thermal and hydrodynamic boundary layers.

To represent the effect of synthetic response term (Kr) on velocity and concentration circulations, Figures 10(a) and 10(b) was made. Destructive outcomes are gotten by decreasing the convergence of species and the energy limit layer at the pace of substance response. Species focus and rubbing coefficient are decreased by the destructive responsive cycle. The temperature and velocity profiles are displayed in Figures 11(a) and 11(b) for various values of the thermal radiation parameter (R). The electromagnetic radiation produced by the material medium in view of intensity energy is called warm radiation. The climb in temperature is a consequence of the energy delivered because of warm radiation. Nonetheless, convective stream is supported.

Table 1 compares the current study with that of Ramana Reddy *et al.,* [14]. When $E = We$ = 0. The current study was shown to be in strong agreement.

Key terms fundamentally affect designing amounts, as found in Table 2. Velocity up heat transmission and coefficient of skin contact by expanding Pr. Prandtl number importance stays consistent no matter what the rate at which mass is moved. The coefficient of skin rubbing diminishes with an expansion in the M boundary. At the point when M is expanded, the pace of intensity and mass transmission stays consistent. There is an expansion in the coefficient of skin grinding and the pace of intensity transmission with an expansion in Du, Ec and R. Table 2 shows that rising the worth of Kr, Sc diminishes skin erosion and the Sherwood coefficient.

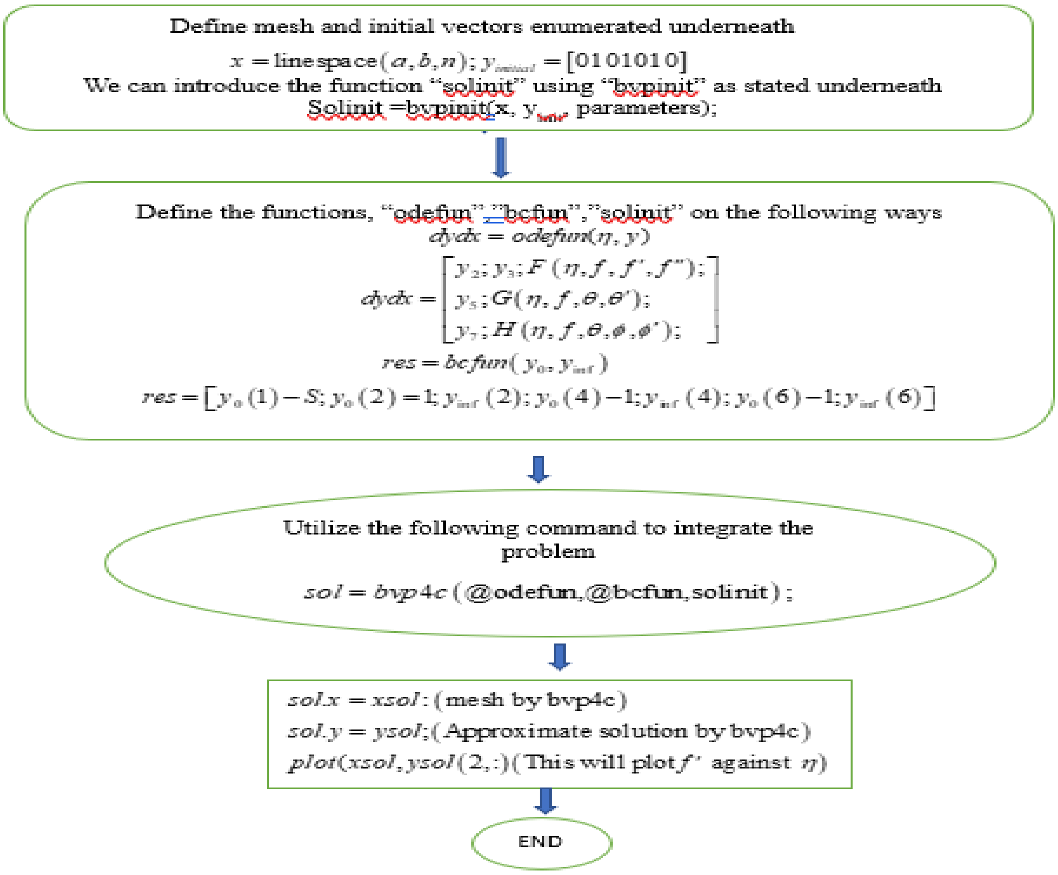


Fig. 2. Flow chart of numerical approach

Table 1
Comparison of the present study and the study of Ali Chamkha *et al.,* [47] when E=We = 0

M	ϕ	Ali chamkha *et al.,* [47]				Present study			
		$-f''(0)$		$-\theta'(0)$		$-f''(0)$		$-\theta'(0)$	
		Al_2O_3	TiO_2	Al_2O_3	TiO_2	Al_2O_3	TiO_2	Al_2O_3	TiO_2
0	0.05	1.00657	1.01167	1.62258	1.63832	1.00659	1.01169	1.62253	1.63829
	0.1	1.01002	1.01032	1.49187	1.51984	1.01001	1.01031	1.49185	1.51983
	0.15	0.98954	0.99666	1.37561	1.41387	0.98953	0.99665	1.37559	1.41385
0.5	0.05	1.20481	1.20961	1.57892	1.59484	1.20479	1.2096	1.57894	1.59486
	0.1	1.17592	1.18502	1.45312	1.48162	1.1759	1.18501	1.45312	1.48164
	0.15	1.13924	1.15183	1.34128	1.37981	1.13922	1.15181	1.3413	1.37981

Table 2
The significance of flow parameters on the skin friction, Nusselt and Sherwood numbers

Pr	M	K	Sc	Du	Ec	Kr	R	We	Cf	Nu	Sh
0.71									0.0574	0.338	0.6779
3									1.2168	0.3447	0.6779
7									1.4571	0.3697	0.6779
	0								0.7676	0.6995	0.0559
	0.5								0.422	0.6995	0.0559
	1								0.1846	0.6995	0.0559
		0.3							0.8929	0.4111	0.5261
		0.6							0.1437	0.4111	0.5261
		1							1.1804	0.4111	0.5261
			0.61						1.2363	0.3377	0.5918
			1						0.3856	0.3377	0.6352
			3						0.1034	0.3377	0.6866
				1					0.1042	0.1066	0.3971
				2					1.1989	0.2226	0.3971
				3					2.2937	0.5518	0.3971
					0.2				0.5565	0.2584	0.6121
					0.4				1.7755	0.8541	0.6121
					0.6				2.9945	1.4498	0.6121
						0.1			0.4467	0.3141	0.7761
						0.3			0.777	0.3141	0.843
						0.5			1.2266	0.3141	1.0361
							0		0.0845	0.3427	0.812
							0.5		0.9431	0.3597	0.812
							1		1.8569	0.3777	0.812
								0	1.3434	0.524	0.6015
								0.5	2.706	0.524	0.6015
								1	3.0687	0.524	0.6015

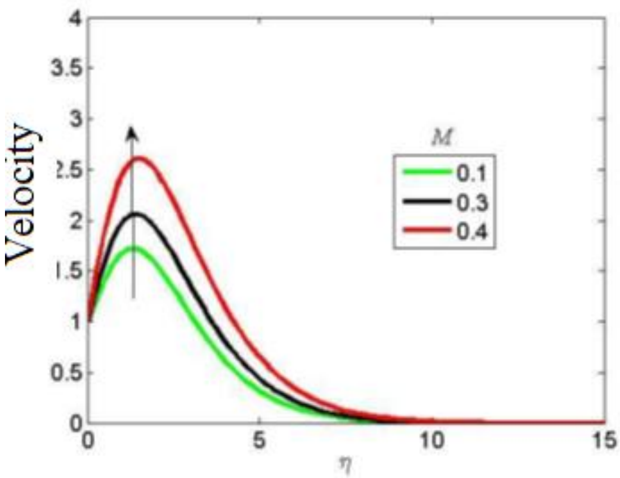


Fig. 3. Velocity profiles and the influence of the magnetic parameter

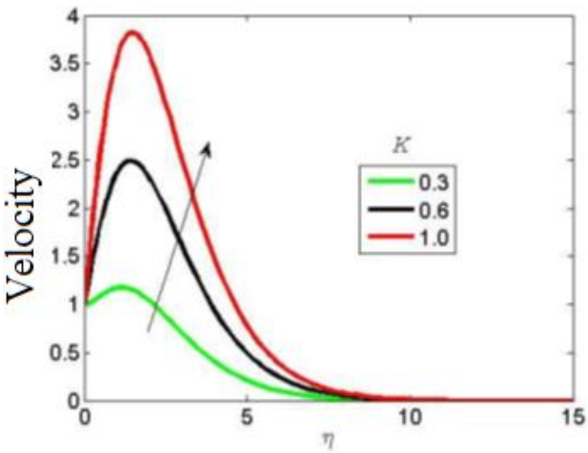
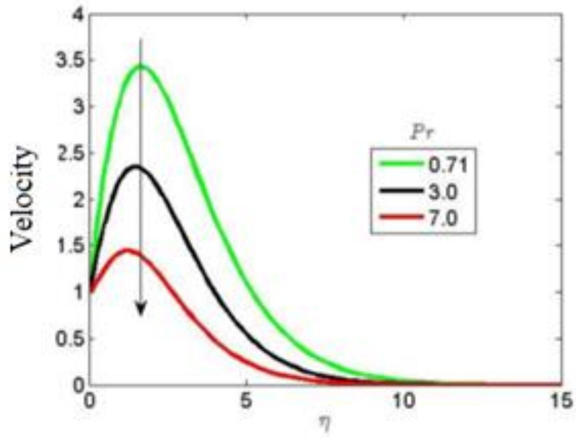
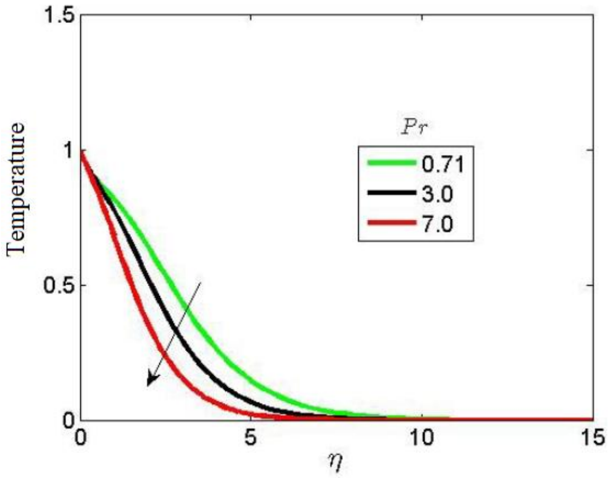


Fig. 4. Permeability parameter effects on velocity profiles



(a)



(b)

Fig. 5. (a) Influence of velocity profiles for different values of Prandtl number (b) Influence of temperature profiles for different values of Prandtl number

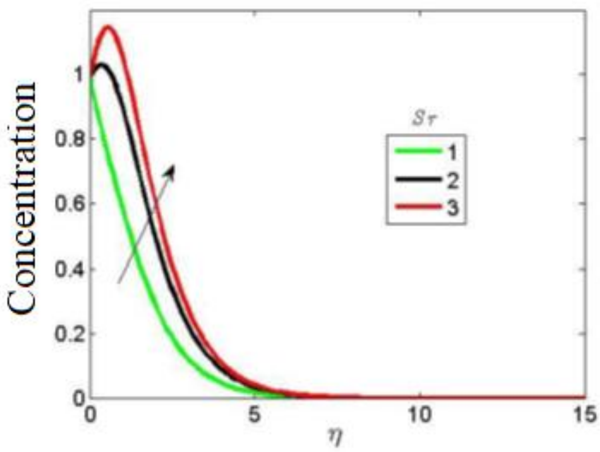


Fig. 6. Soret number effects on Velocity profiles

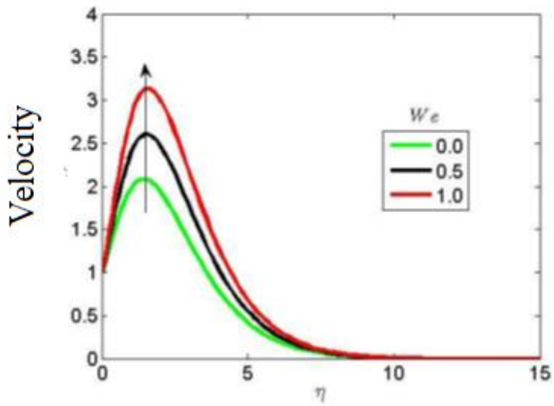
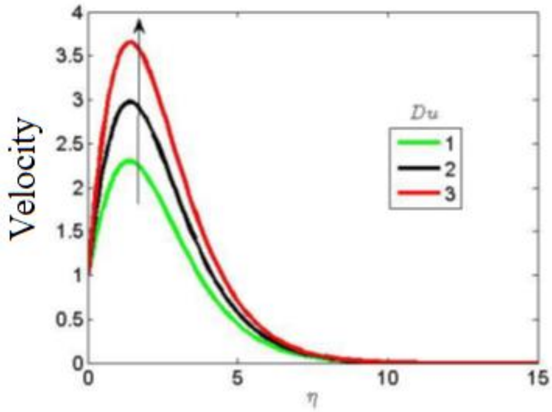
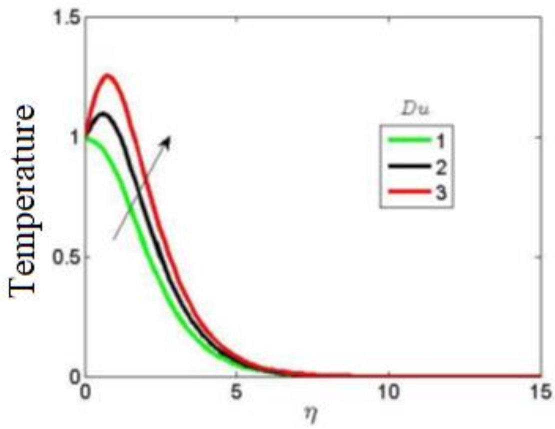


Fig. 7. Velocity profiles are affected by the Weissenberg number

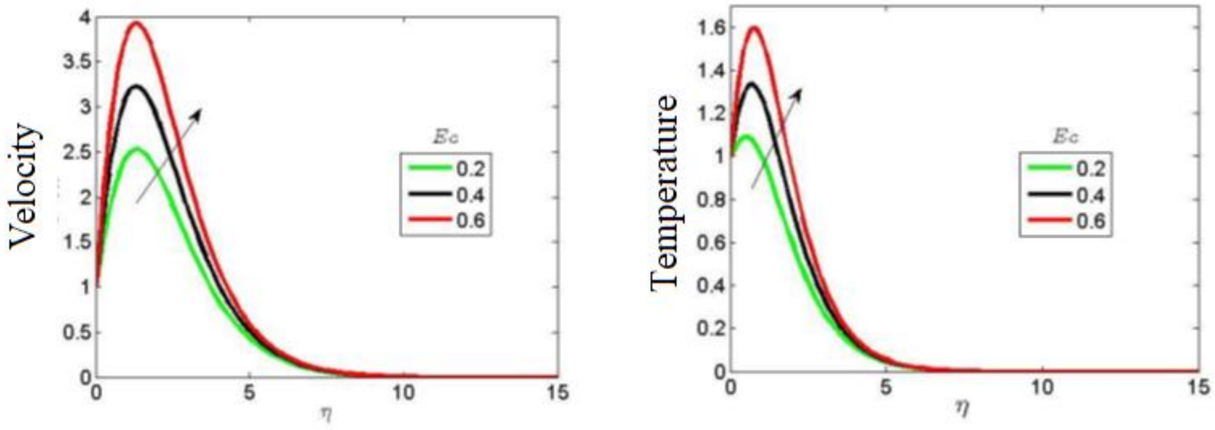


(a)



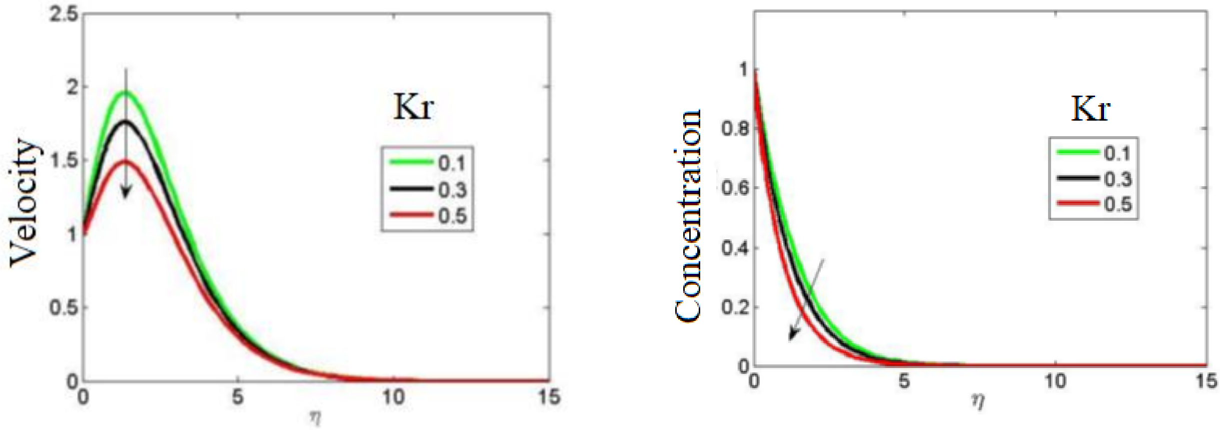
(b)

Fig. 8. (a) Dufour number influences velocity profiles (b): Dufour number influences temperature profiles



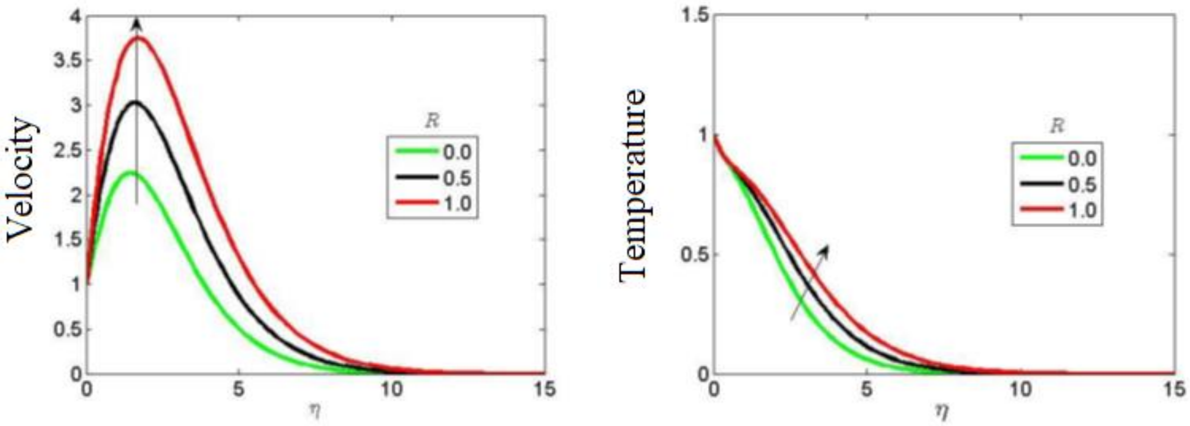
(a) (b)

Fig. 9. (a) Eckert number effects on velocity profiles (b) Eckert number's impact on temperature profiles



(a) (b)

Fig. 10. (a) Chemical reaction's impact on velocity profiles (b): Chemistry-related reaction's effects on concentration profiles



(a) (b)

Fig. 11. (a) The effect of a radiation parameter on velocity profiles (b): Temperature profiles are affected by a radiation parameter

4. Conclusion

Here is the conclusion that can be drawn from this study

i. The study's most important conclusions are as follows:
ii. Thermal radiation and heat generation parameters were identified to enhance fluid temperature and warm fluid particles by raising fluid velocity.
iii. A factor in the energy equation known as the viscous dissipation term is responsible for dissipating heat energy into the flow of a fluid. So, heat energy makes the hydrodynamic and thermal layers thicker.
iv. It has been shown that a chemical reaction increases local mass transfer and friction between the skin. As the thermal layer thickens, a higher heat relaxation flow and a higher mass relaxation flux were shown to improve fluid particle concentrations and the overall concentration layer.

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