OLDROYD-B FLUID FLOW OVER A STRETCHABLE SHEET WITHCATTANEO-CHRISTOV HEAT FLUX AND HETEROGENEOUS- HOMOGENEOUS CHEMICAL REACTIONS

E. ELANCHEZHIAN[1], K.M.PRABU[2*], S.TAMILSELVAN[3], K.LOGANATHAN[4]
[1 &2*]PG & Research Department of Physics, Sri VidyaMandir Arts & Science College (Autonomous), Katteri – 636 902, Uthangarai, Tamil Nadu, India.
[3] Assistant Professor, Department of Physics, Nandha Arts and Science College, Erode-638052, Tamilnadu, India.
[4]Assistant Professor, Department of Mathematics and Statistics, Manipal University, Jaipur-303007, Rajasthan, India.
Corresponding Author: svmprabu@gmail.com (K. M. Prabu)

ABSTRACT: This paper discusses the steady 2D hydro-magneticradiative flow, mass and heat transfers of an Oldroyd-B liquid towards a stretchy surface along with heterogeneous and homogeneous reactions including heat generation. The heat flux is established on Cattaneo-Christov concept. Appropriate similarity transformations are applied to transmute nonlinear PDE to ODE. The homotopy setup is helped to crack the nonlinear ordinary system. The contributions of several physical constants are examined and discussed. The Opposite trend is got in the velocity graph for growing values of Deborah numbers.

KEYWORDS:
Oldroyd-B liquid; Thermal radiation; Magneto hydrodynamics; Cattaneo-Christov heat flux; Heterogeneous-homogeneous reactions.

1. INTRODUCTION

The non-Newtonian liquids are important in boundary layer flow by reason of their industrial relevant applications. Instance of non-Newtonian liquids may contain sauce, lubricants, shampoos, pulps, ketchup, and sugar solutions. Few more research reports about non-Newtonian liquids are caught by Refs. [1]- [3]. The appearance of the Cattaneo-Christov heatflux (CCHF) and reaction rate effects in magneto-hydrodynamic flow of Oldroyd-B liquid was studied by Loganathan et al. [4]. Imtiaz et al. [5] considered CCHF model in the convection mass and energy transference of a 3^{rd}-grade liquid flow over an extending plate.

The hydromagneticnon-Newtonian liquid flow with radiative and heat source impacts over a stretchy surface was attracted by several scholars due to its industrial utilization. Pal [6] examined the impression of hydro-magnetic viscous fluid flow induced by a permeable extending plate with Hall current effects. Bhattacharyya et al. [7] presented the fluid flow of the micro polar liquid embedded in a porous reducing surface with heat transference rate and thermal radiation impressions. Suction/blowing impacts over a stretchy sheet of magneto convection flow of viscid fluid was detected by Mukhopadhyay [8]. Hayat et al. [9] performed the mixed conviction and convective boundary impacts of radiative Maxwell fluid flow along with nanoparticles a stagnation point flow. Shehzad et al. [10] considered the Maxwell liquid flow induced by porous extending sheet with variable thermal conductivity.

Several researchers studied heterogeneous-homogeneous responses with various types of fluids, such as a flow with micro-polar fluid by Shaw et al. [11], a flow with nano fluid by Kameswaran et al. [12], and a flow with viscoelastic fluid by Khan and Pop [13].Zhang et al. [14] inspected the upper-convected flow of Oldroyd-B non-Newtonian liquid over a time dependent extending sheet with the impressions of revised viscous dissipative impact, reaction rate, and Cattaneo-Christovduple diffusion concept. Oldroyd-B liquid flow with nanomaterials in an MHD stagnation point flow of was deliberated by Hayat et al. [15], in the existence of Cattaneo-Christov heat and mass fluxes, thermophoresis, and Brownian motion impacts. An investigation of energy transference of an unsteady Oldroyd-B liquid flow over an extending cylinder was investigated by Yasir et al. [16]. Shankaralingappa et al. [17] inspected the Oldroyd-B fluid flow of over a stretchy sheet with the Cattaneo–Christovduple diffusion, the relaxation reaction rate, heat source or sink, and thermophoretic element deposition.

Jangid et al. [18] examined a study on the Cattaneo-Christov heat flux theory of the Carreau liquid flow with ternary nanomaterials over a slopped reducing sheet. The steady MHD Casson fluid flow with between two similar plates over an extended porous wall along with radiation explored by Jangid et al. [19].Li et al. [20] inspected the entropy creation and stagnation point flow of Carreau liquid with nanoparticles along with the Cattaneo-Christov heat flux concept. The influence of MHD Darcy–Forchheimer3rd-grade fluid flow with nanoparticles near a linearly elastic sheet with the velocity slipping impact, Newtonian heating, and theory of the non-Fourier thermal and mass flux inspected by Loganathan et al. [21].Wahab et al. [22] discussed the heterogenous and homogenous reactions of inclined hydro-magnetic Carreau fluid flow with nanoscale heat transferences. Rehman et al. [23] explored the heterogenous and homogenous reactions of generalized Newtonian fluid flow insight of slopped hydromagnetic impression. A homogeneous and heterogeneous reactions of hydromagnetic mixed convection viscid flow in the company of heat source/sink between endless long concentric cylinders was considered by Abbas et al. [24]. Naveed et al. [25] explored the hydromagnetic coupled stress fluid flow over a porous oscillatory stretchy sheet with heterogenous/ homogenous reactions. Ramzan et al. [26] considered the nano fluid (graphene oxide/water) flow with homogeneous, heterogeneous reactions and heat generation/absorption impacts over a permeable channel. Sharma et al. [27] inspected the micro polar ternary hybrid nano fluid $(TiO_2 - CuO - SiO_2/blood)$ flow with homogeneous-heterogenous, Joule heating and dissipation impacts over a curved surface. Ahmed et al. [28] analyzed the MHD stagnation hybrid nano fluid $(Al_2O_3 - Cu/blood)$ flow passed through a sheet with homogenous-heterogenous reactions. Yasin et al. [29] explored the peristaltic radiative Carreau hybrid nano fluid$(Cu - Ag/blood)$flow in a symmetric channel in the company of the mixed convection, Joule heating, viscid dissipative, and heat source or sink impacts. Alsaedi et al. [30] inspected the thermal and solutal transfer and entropy creation in hydromagnetic radiation fluid flow with nanoparticles over heated stretched surface.

The mathematical outcomes of the nonlinear flow and heat transferences equations are derived by homotopy analysis method. This study is reported on Oldroyd-B fluid flow with CCHF model. The important effects MHD, heterogeneous-homogeneous chemical reactions and radiation are incorporated into the current work. Homotopy technique is working for the nonlinear ODE systems. Different flow parameters over various distributions are discussed and reported.

2 PROBLEM DEVELOPMENT

Consider the 2-D stretchy sheet flow of radiative Oldroyd-B flow (density is constant) with the heat generation impact. The velocity of surface is supposed as $u_{1_w} = cx, c > 0$. Wherec > 0 is the stretchy rate. The twice different temperatures on and far from the sheet are indicate by $T_w$and $T_\infty$with $T_w > T_\infty$. $B_m$is the magnetic strength, it is assigned erect to the stretchable surface. The effects of heterogeneous- homogeneous reactions for cubic autocatalysis surface are respectively stated by $A + 2B \rightarrow 3B$, rate $= k_c ab^2$ and $A \rightarrow B$, rate $= k_s a$. The governing relations are:

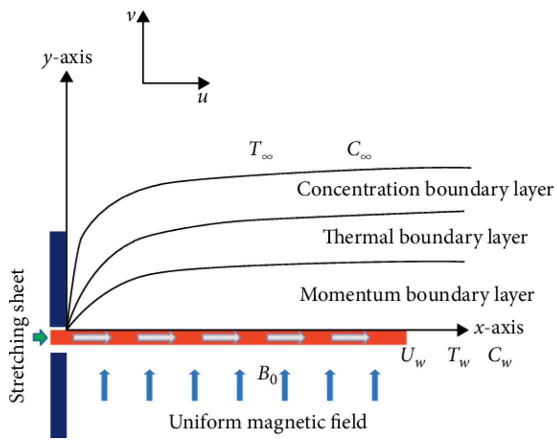


Fig. 1.Schematic diagram

$$\frac{\partial u_1}{\partial x} + \frac{\partial v_1}{\partial y} = 0 \quad --- \quad (1)$$

$$u_1 \frac{\partial u_1}{\partial x} + v_1 \frac{\partial u_1}{\partial y} + A_1 \left(u_1^2 \frac{\partial^2 u_1}{\partial x^2} + v_1^2 \frac{\partial^2 u_1}{\partial y^2} + 2u_1 v_1 \frac{\partial^2 u_1}{\partial x \partial y} \right) = \mu \frac{\partial^2 u_1}{\partial y^2}$$

$$-\mu A_2 \left(u_1 \frac{\partial^3 u_1}{\partial x \partial y^2} + v_1 \frac{\partial^3 u_1}{\partial y^3} - \frac{\partial u_1}{\partial x}\frac{\partial^2 u_1}{\partial y^2} - \frac{\partial u_1}{\partial y}\frac{\partial^2 v_1}{\partial y^2} \right) - \frac{\sigma B_m^2}{\rho}\left(u_1 + A_1 v_1 \frac{\partial u_1}{\partial y} \right) \quad ---- \quad (2)$$

$$u_1 \frac{\partial T}{\partial x} + v_1 \frac{\partial T}{\partial y} = \frac{\hat{k}}{\rho c_p}\frac{\partial^2 T}{\partial y^2} + \frac{Q}{\rho C_p}(T - T_\infty) - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} \quad (3)$$

$$u_1 \frac{\partial a}{\partial x} + v_1 \frac{\partial a}{\partial y} = D_A \frac{\partial^2 a}{\partial y^2} - k_c a b^2 \text{ ------- } (4)$$

$$u_1 \frac{\partial b}{\partial x} + v_1 \frac{\partial b}{\partial y} = D_B \frac{\partial^2 b}{\partial y^2} + k_c a b^2 \quad --- (5)$$

Then, the boundary conditions are

$$u_1 = u_{1_w},\ v_1 = 0,\ T = T_w, D_A \frac{\partial a}{\partial y} = k_s a,\ D_B \frac{\partial b}{\partial y} = -k_s a aty = 0$$

$$u_1 \rightarrow 0, v_1 \rightarrow 0, ,\ T \rightarrow T_\infty, a \rightarrow a_0, b \rightarrow 0 \text{ as } y \rightarrow \infty \quad --- (6).$$

where $(u_1, v_1), \rho, A_1, \sigma, A_2, \mu, , c_p, D_A, D_B$ and a_0 are the velocity components, density, relaxation time, electrical conductivity, retardation time, kinematic viscosity, specific heat and the corresponding diffusion types co efficient of Aand B and the '+ve' dimensional invariable. Using CCHF theory, we get the governing system of equation.

$$u_1 \frac{\partial T}{\partial x} + v_1 \frac{\partial T}{\partial y} + \lambda \left(u_1^2 \frac{\partial^2 T}{\partial x^2} + v_1^2 \frac{\partial^2 T}{\partial y^2} + \left(u_1 \frac{\partial u_1}{\partial x} + v_1 \frac{\partial u_1}{\partial y} \right) \frac{\partial T}{\partial x} + 2u_1 v_1 \frac{\partial T^2}{\partial x \partial y} \right) + \left(u_1 \frac{\partial v_1}{\partial x} + v_1 \frac{\partial v_1}{\partial y} \right) \frac{\partial T}{\partial y} \Big) = \frac{\hat{k}}{\rho c_p}\frac{\partial^2 T}{\partial y^2} + \frac{Q}{\rho C_p}(T - T_\infty) - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} \quad --- \quad (7)$$

Where Q is the internal heat source/sink. The radiative heat flux is taken as

$$q_r = -\frac{4\sigma_0}{3k^*}\frac{\partial T^4}{\partial y},$$

Consider the next similarity transmutations

$$\eta = \sqrt{\frac{c}{\mu}}y, u_1 = cxf'(\eta), v_1 = -\sqrt{c\mu}f(\eta),$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty},$$

$$a = a_0 \phi(\eta), b = a_0 h(\eta) \quad (8)$$

Replacing equation (8) in equations (2), (4), (5) and (7), we get

$$f''' + ff'' - f'^2 + \alpha(2ff'f'' - f^2f''') + \beta\left(f''^2 - ff^{iv}\right) - M(f' - \alpha ff'') = 0 \quad (9)$$

$$\left(1 + \frac{4}{3}Rd\right)\theta'' + Prf\theta' - Pr\gamma(f^2\theta'' + ff'\theta') + PrHg\theta = 0 \quad (10)$$

$$\frac{1}{Sc}\phi'' + f\phi' - k\phi h^2 = 0 \quad (11)$$

$$\frac{\delta^*}{Sc}h'' + fh' + k\phi h^2 = 0 \quad (12)$$

The resultant limitations are

$f(\eta) = 0, f'(\eta) = 1, \theta(\eta) = 1, \phi'(\eta) = K\phi(0), \delta^* h'(\eta) = -K\phi(0)$ at $\eta = 0$

$f'(\eta) \to 0, \theta(\eta) \to 0, \ \phi(\eta) \to 0, \ h(\eta) \to 0$ as $\eta \to \infty$ (13)

Where, $\alpha = A_1 c$ & $\beta = A_2 c$, $M = \frac{\sigma B_0^2}{\rho c}$, $Pr = \frac{\nu C_p}{\hat{k}}$, $Rd = \frac{4\sigma^* T_\infty^3}{kk^*}$, $\gamma = \lambda c$, $Hg = \frac{Q}{c\rho c_p}$, $Sc = \frac{\nu}{D_A}$, $k = \frac{k_c a_0^2}{c}$, $K = \frac{k_s\sqrt{\nu}}{D_A\sqrt{c}}$, $\delta^* = D_B/D_A$ are the non-dimensional relaxation & retardation time constants, magnetic parameter, Prandtl number, radiation constant, thermal relaxation time, heat generation constant, Schmidt number, effectiveness of the homogeneous chemical reaction, effectiveness of the heterogeneous chemical reaction and the ratio of the diffusion coefficient respectively.

Here, chemical classes B and A have concentrations b and a with rate constants K_s and K_c respectively. Because both reactants are of isothermal nature. With the hypothesis that diffusion coefficients of chemical classes B and A are of the equal consequence, it steers us to assume D_B and D_A are alike i.e., $\delta^* = 1$. Thus,

$$\phi(\eta) + h(\eta) = 1 \quad (14)$$

$$\frac{1}{Sc}\phi'' + f\phi' - k\phi(1-\phi)^2 = 0 \quad (15)$$

Then the equations (11) and (12) becomes

$$\phi'(0) = K\phi(0), \phi(\infty) \to 1 \quad (16)$$

The non-dimensional forms of local heat (Nu_x) and mass (Sh_x) transfer coefficients are defined as:

$$Re^{-\frac{1}{2}}Nu_x = -\left(1 + \frac{4}{3}Rd\right)\theta'(0), Re^{-\frac{1}{2}}Sh_x = -\phi'(0)$$

Order	$-f''(0)$		$-\theta'(0)$		$-\phi'(0)$	
	Ref. [1]	Extant	Ref. [1]	Extant	Ref. [1]	Extant
1	1.1833	1.1833	0.6111	0.6111	0.2186	0.2186
5	1.1439	1.1439	0.5484	0.5484	0.2002	0.2002
20	1.1435	1.1435	0.5464	0.5464	0.2018	0.2018
30	1.1435	1.1435	0.5464	0.5464	0.2021	0.2021
40	1.1435	1.1435	0.5464	0.5464	0.2021	0.2021

Table 1. Comparison of convergence of HAM solutions when $M = 0.5, \beta = 0.2, \alpha = 0.1, \gamma = 0.5, k = 0.7, K = 0.6, Pr = 0.9, Sc = 0.9, Hg = Rd = 0$.

3. SOLUTION METHODOLOGY

The primary conditions and auxiliary linear operators can be denoted in the procedure

$f_0 = 1 - e^{-\eta}, \theta_0 = e^{-\eta}, \phi_0 = 1 - \frac{1}{2}e^{-k\eta}$

$L_f = f'''(\eta) - f'(\eta),$

$$L_\theta = \theta''(\eta) - \theta(\eta)$$

$$L_\phi = \phi''(\eta) - \phi(\eta)$$

Which satisfy the property

$$L_f[E_1 + E_2 e^{\eta} + E_3 e^{-\eta}] = 0$$

$$L_\theta[E_4 e^{\eta} + E_5 e^{-\eta}] = 0$$

$L_\phi[E_6 e^{\eta} + E_7 e^{-\eta}] = 0,$

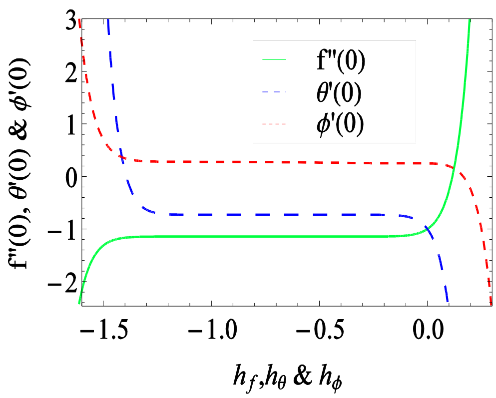


Fig. 2.h-curves for h_f, h_θ and h_ϕ.

The special explanations are

$$f_m(\eta) = f_m^*(\eta) + E_1 + E_2 e^{\eta} + E_3 e^{-\eta}$$

$$\theta_m(\eta) = \theta_m^*(\eta) + E_4 e^{\eta} + E_5 e^{-\eta}$$

$$\phi_m(\eta) = \phi_m^*(\eta) + E_6 e^{\eta} + E_7 e^{-\eta}$$

Here $E_j (j = 1 - 7)$

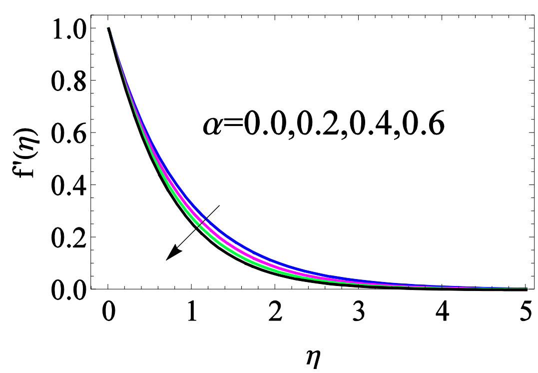
4. RESULTS AND DISCUSSION

The auxiliary constants working a substantial part for solutions of converging series. The h-lines are plotted with 15^{th}-order of similarity values in the Fig. 2. The acceptable range of the auxiliary constants are $-1.3 \leq h_f \leq -0.1$, $-1.2 \leq h_\theta \leq -0.1$ and $-1.3 \leq h_\phi \leq 0.0$. Furthermore, the serious results converge in the total section of $\eta(0 < \eta < \infty)$ when $h_f = h_\theta = -1$ and $h_\phi = -1.2$.

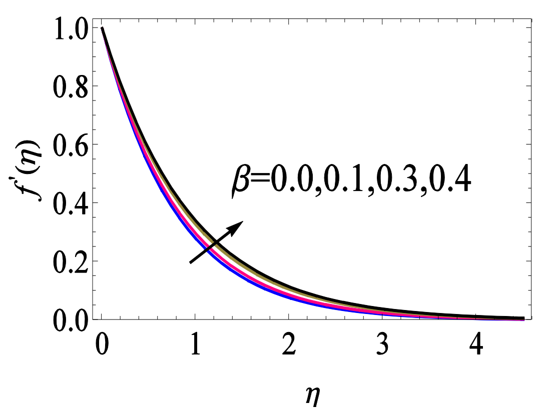
Table1. Displays the comparison of convergence of HAM solutions with Hayat et al. [1]. Our findings are found to be quite consistent. The movement, concentration and temperature profiles, surface drag force, local Sherwood and Nusselt numbers for various combinations of relaxation time invariable, retardation time constant, thermal relaxation time constant, radiation constant, heat generation constant, heterogeneous and homogeneous chemical reaction constants are analyzed for the fixed values of $M = 0.5, \beta = 0.2, \alpha = 0.1, \gamma = 0.5, Hg = -0.5, Rd = 0.3, k = 0.7, K = 0.6, Pr = 0.9$ and $Sc = 0.9$.

The outcomes of relaxation (α) and retardation (β) time invariants on the flow component $f'(\eta)$ are plotted in Fig. 3(a) and Fig. 3(b). These Figs evidently show that both α and β have opposite trend on the velocity field $f'(\eta)$. It is recognized evidence that a growth in relaxation time reduces the velocity, but velocity rises for higher retardation time. We have drawn Fig. 4(a) to see the discrepancy of radiation constant(Rd) on the temperature. It is distinguished that the momentum and thermal boundary layer fatness enhances upon growing the radiation constant. Fig. 4(b) determines the behavior of Hg on the temperature field $\theta(\eta)$ for $Hg > 0$, the energy creation phenomenon appears. This energy creation supplies additional energy to the liquid that agrees to an augment in the temperature boundary layer fatness. The effectiveness of heterogeneous-homogeneous reactions K and k on concentration field is designed in Figs. 5(a) & 5(b). For rising the energy of heterogeneous and homogeneous reaction, the concentration profile diminishes.

Figs. (6) & (7) present the numerical results for the local Nusselt number $\left(Re^{-\frac{1}{2}}Nu_x\right)$ and the local Sherwood number $\left(Re^{-\frac{1}{2}}Sh_x\right)$ for varied range of physical numbers. Figs. 6(a) & 6(b) exhibits the impact of α and βwith thermal relaxation time(γ) on heat transfer rate. It is perceived that α and β has reversal effects on heat transfer rate. From Fig. 7(c), it is evident that local Nusselt number reduces for rising the heat generation. Fig. 7(d) depicts those large values of radiation constant lead to higher Nusselt number. Figs.7(a)-7(c) show that the local Sherwood number diminishes on rising the heterogeneous-homogeneous chemical reaction and retardation time constants. Also, Sherwood number increases for relaxation time constant.

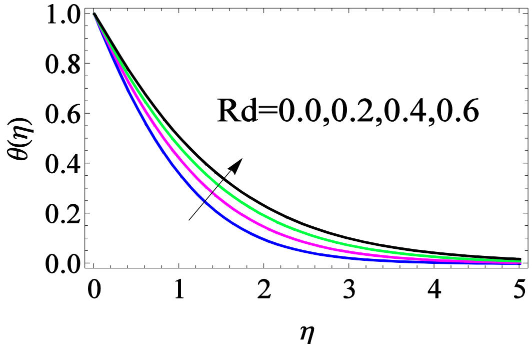


(a)

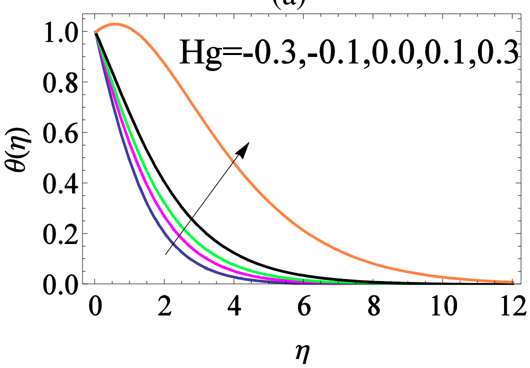


(b)

Fig. 3 Efficiacyof α and β on $f'(\eta)$.

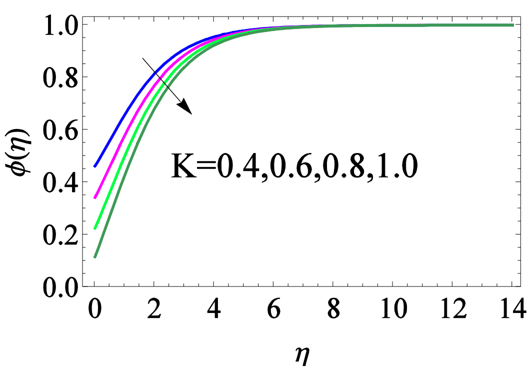


(a)

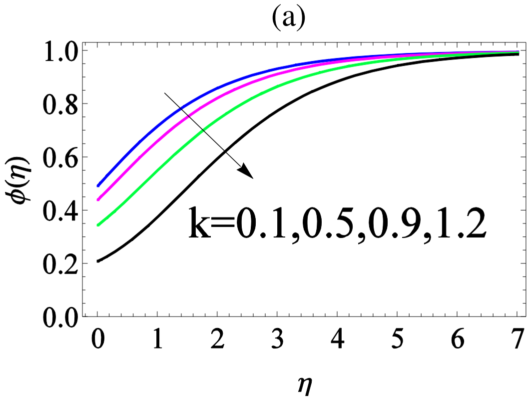


(b)

Fig. 4 Efficiacy of Rd and Hg on θ(η)

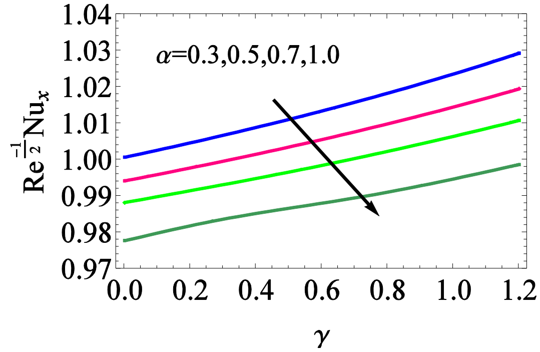


(a)

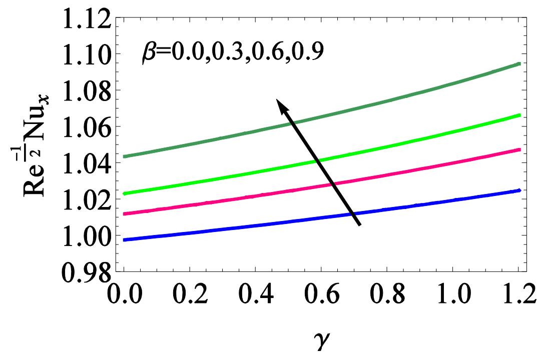


(b)

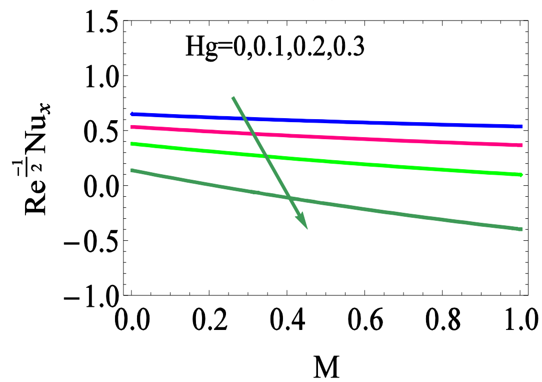
Fig. 5 Efficiacy of K and k on ϕ(η)



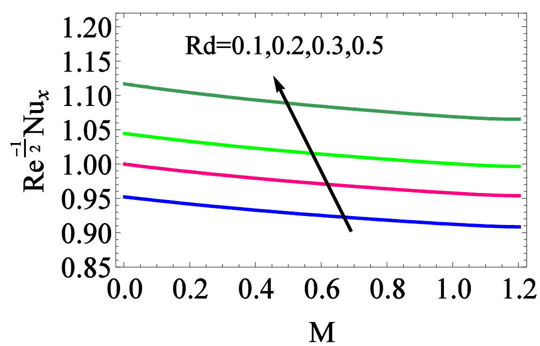
(a)



(b)

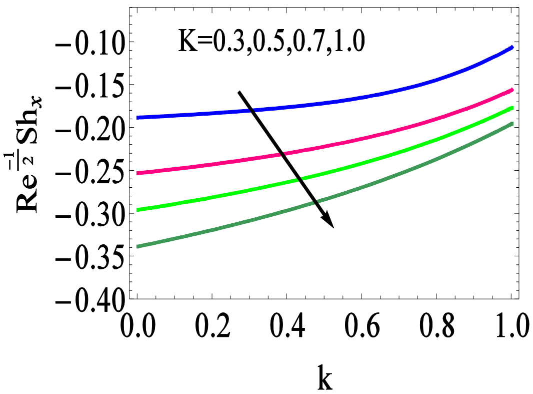


(c)

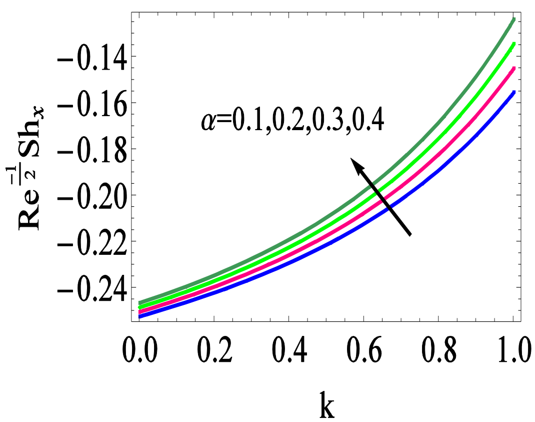


(d)

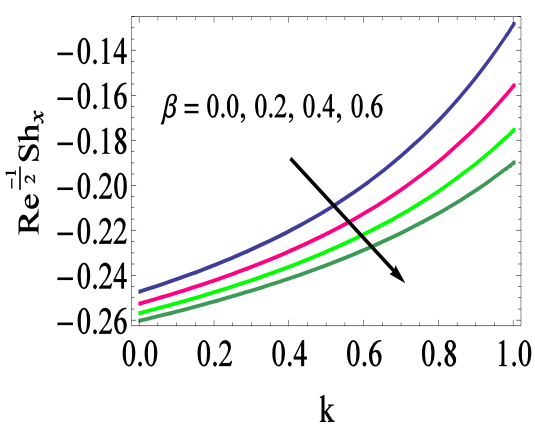
Fig. 6.Efficiacy of α, β, Hg and Rd on Nusselt number



(a)



(b)



(c)

Fig. 7. Efficiacy of K, α and β on Sherwood number

5. CONCLUSION

The extant work examines the impact of heat source and radiation using CCHF model on 2D Oldroyd-B fluid flow with heterogeneous and homogeneous chemical reactions. The present analysis has the following observations.

- Deborah numbers α and β have quite reverse impacts on the velocity field and mass transfer rate.
- Heat transfer rate improves for higher radiation and heat generation parameters and found the diminishing behavior for higher Hartmann number values.
- Heterogeneous and homogeneous reactions show inverse performance on mass transfer rate.
- **Conflicts of Interest:** The authors declare that they have no conflicts of interest.
- **Authors' Contributions:** All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.
- **Data Availability:** The data used to support the findings of this study are

made available by the corresponding author upon request.

- **Funding:** No funding received for this study.
- **Acknowledgments:** The authors sincerely acknowledge to Manipal University Jaipur, Rajasthan, India. For providing the research specialties for this research work.

REFERENCES

[1] Hayat, T., Imtiaz, M., Alsaedi, A., & Almezal, S. (2016). On Cattaneo–Christov heat flux in MHD flow of Oldroyd-B fluid with homogeneous–heterogeneous reactions. Journal of Magnetism and Magnetic Materials, 401, 296-303.

[2] Yao, S., Fang, T., & Zhong, Y. (2011). Heat transfer of a generalized stretching/shrinking wall problem with convective boundary conditions. Communications in Nonlinear science and Numerical simulation, 16(2), 752-760.

[3] Hayat, T., Asad, S., Qasim, M., & Hendi, A. A. (2012). Boundary layer flow of a Jeffrey fluid with convective boundary conditions. International Journal for Numerical Methods in Fluids, 69(8), 1350-1362.

[4] Loganathan, K., Sivasankaran, S., Bhuvaneswari, M., & Rajan, S. (2019). Second-order slip, cross-diffusion and chemical reaction effects on magneto-convection of Oldroyd-B liquid using Cattaneo–Christov heat flux with convective heating. Journal of Thermal Analysis and Calorimetry, 136, 401-409.

[5] Imtiaz, M., Alsaedi, A., Shafiq, A., & Hayat, T. (2017). Impact of chemical reaction on third grade fluid flow with Cattaneo-Christov heat flux. Journal of molecular liquids, 229, 501-507.

[6] Pal, D. (2013). Hall current and MHD effects on heat transfer over an unsteady stretching permeable surface with thermal radiation. Computers & Mathematics with Applications, 66(7), 1161-1180.

[7] Bhattacharyya, K., Mukhopadhyay, S., Layek, G. C., & Pop, I. (2012). Effects of thermal radiation on micro polar fluid flow and heat transfer over a porous shrinking sheet. International Journal of Heat and Mass Transfer, 55(11-12), 2945-2952.

[8] Mukhopadhyay, S. (2013). Slip effects on MHD boundary layer flow over an exponentially stretching sheet with suction/blowing and thermal

radiation. Aim Shams Engineering Journal, 4(3), 485-491.

[9] Hayat, T., Waqas, M., Shehzad, S. A., &Alsaedi, A. (2013). Mixed convection radiative flow of Maxwell fluid near a stagnation point with convective condition. Journal of Mechanics, 29(3), 403-409.

[10] Shehzad, S. A., Qasim, M., Alsaedi, A., Hayat, T., & Alsaadi, F. (2014). Radiative Maxwell fluid flow with variable thermal conductivity due to a stretching surface in a porous medium. Journal of Aerospace Engineering, 27(5), 04014023.

[11] Shaw, S., Kameswaran, P. K., & Sibanda, P. (2013). Homogeneous-heterogeneous reactions in micro polar fluid flow from a permeable stretching or shrinking sheet in a porous medium. Boundary value problems, 2013(1), 1-10.

[12] Kameswaran, P. K., Shaw, S., Sibanda, P. V. S. N., & Murthy, P. V. S. N. (2013). Homogeneous–heterogeneous reactions in a nano fluid flow due to a porous stretching sheet. International journal of heat and mass transfer, 57(2), 465-472.

[13] Khan, W.A.; Pop, I. Effects of homogeneous-heterogeneous reaction on the viscoelastic fluid towards a stretching sheet. ASME J. Heat Transf. 2012, 134, 064506.

[14] Zhang, Y., Yuan, B., Bai, Y., Cao, Y., & Shen, Y. (2018). Unsteady Cattaneo-Christov double diffusion of Oldroyd-B fluid thin film with relaxation-retardation viscous dissipation and relaxation chemical reaction. Powder Technology, 338, 975-982.

[15] Hayat, T., Khan, S. A., Khan, M. I., Momani, S., &Alsaedi, A. (2020). Cattaneo-Christov (CC) heat flux model for nanomaterials stagnation point flow of Oldroyd-B fluid. Computer Methods and Programs in Biomedicine, 187, 105247.

[16] Yasir, M., Ahmed, A., Khan, M., Alzahrani, A. K., Malik, Z. U., & Alshehri, A. M. (2023). Mathematical modelling of unsteady Oldroyd-B fluid flow due to stretchable cylindrical surface with energy transport. Aim Shams Engineering Journal, 14(1), 101825.

[17] Shankaralingappa, B. M., Prasannakumara, B. C., Gireesha, B. J., & Sarris, I. E. (2021). The impact of Cattaneo–Christov double diffusion on Oldroyd-B Fluid flow over a stretching sheet with thermophoretic

particle deposition and relaxation chemical reaction. Inventions, 6(4), 95.

[18] Jangid, S., Alessa, N., Mehta, R., & Thamaraikannan, N. (2022). Numerical Study of Cattaneo–Christov Heat Flux on Water-Based Carreau Fluid Flow over an Inclined Shrinking Sheet with Ternary Nanoparticles. Symmetry, 14(12), p. 2605.

[19] Jangid, S., Mehta, R., Mehta, T., & Sushila. (2023). Mathematical modeling of steady MHD Casson fluid flow with stretching porous walls in existence of radiation, chemical reaction, and thermal diffusion effect. Mathematical Methods in the Applied Sciences, 46(7), 8243-8262.

[20] Li, S., Ali, F., Zaib, A., Loganathan, K., Eldin, S. M., & Ijaz Khan, M. (2023). Bioconvection effect in the Carreau nano fluid with Cattaneo–Christov heat flux using stagnation point flow in the entropy generation: Micro machines level study. Open Physics, 21(1), 20220228.

[21] Loganathan, K., Alessa, N., Tamilvanan, K., & Alshammari, F. S. (2021). Significances of Darcy–Forchheimer porous medium in third-grade nanofluid flow with entropy features. The European Physical Journal Special Topics, 230, 1293-1305.

[22] Wahab, H. A., Shah, S. Z. H., Ayub, A., Sabir, Z., Sadat, R., & Ali, M. R. (2023). Heterogeneous/homogeneous and inclined magnetic aspect of infinite shear rate viscosity model of Carreau fluid with nanoscale heat transport. Arabian Journal of Chemistry, 16(5), 104682.

[23] Rehman, S., Alqahtani, S., Alshehery, S., & Moussa, S. B. (2023). A comprehensive physical insight of inclined magnetic field on the flow of generalized Newtonian fluid within a conduit with Homogeneous-heterogeneous reactions. Arabian Journal of Chemistry, 16(5), 104633.

[24] Abbas, Z.; Mehdi, I.; Hasnain, J.; Alzahrani, A.K.; Asma, M. Homogeneous-heterogeneous reactions in MHD mixed convection fluid flow between concentric cylinders with heat generation and heat absorption. Case Stud. Therm. Eng. 2023, 42, 102718.

[25] Naveed, M., Imran, M., &Gul, S. (2023). Heat transfer analysis in hydromagnetic flow of couple stress fluid in presence of homogeneous and heterogeneous chemical reactions over

a porous oscillatory stretchable sheet. Advances in Mechanical Engineering, 15(2), 16878132231155823.

[26] Ramzan, M., Chaudhry, H., Ghazwani, H. A. S., Kadry, S., Shahmir, N., Abbas, M., & Saleel, C. A. (2023). Impact of homogeneous–heterogeneous reactions on nanofluid flow through a porous channel–A Tiwari and Das model application. Numerical Heat Transfer, Part A: Applications, 1-14.

[27] Sharma, B. K., Sharma, P., Mishra, N. K., Noeiaghdam, S., & Fernandez-Gamiz, U. (2023). Bayesian regularization networks for micro polar ternary hybrid nanofluid flow of blood with homogeneous and heterogeneous reactions: Entropy generation optimization. Alexandria Engineering Journal, 77, 127-148.

[28] Ahmed, S., Chen, Z. M., & Ishaq, M. (2023). Multiple solutions in magneto hydrodynamic stagnation flow of hybrid nanofluid past a sheet with mathematical chemical reactions model and stability analysis. Physics of Fluids, 35(7).

[29] Yasin, M., Hina, S., & Naz, R. (2023). Influence of inclined magnetic field on peristaltic flow of Ag–Cu/blood hybrid nanofluid in the presence of homogeneous–heterogeneous reactions with slip condition. Arabian Journal for Science and Engineering, 48(1), 31-46.

[30] Alsaedi, A., Khan, S. A., & Hayat, T. (2023). A model development for thermal and solutal transport analysis in radiating entropy optimized and magnetized flow of nanomaterials by convectively heated stretched surface. Chaos, Solutions & Fractals, 171, 113424.