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Effect of Chemical Reaction and Thermal Radiation on Bio-Magnetic Viscoelastic Fluid Flow Embedded in a Porous Medium

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The justification of our work is to describe the effects of bio-magnetic viscoelastic fluid flow. Here the study has been investigated with the companionship of a chemical reaction as well as thermal radiation. We consider the medium as a porous medium. By the two-dimensional fluid model, the blood flow is represented. The fluid is assumed as a viscoelastic fluid that consists of the core region suspension of all erythrocytes. By using a suitable method and proper mathematical analysis the model is developed. The velocity, temperature, and concentration coupled nonlinear PDEs are reformed into respective sets of nonlinear ODEs. Then the set of ODEs is solved analytically. The paper is authentic and it has been conducted by graphical representation for different profiles such as momentum, heat, and mass. The computation of skin friction, Nusselt number, and Sherwood number are presented through the tabular form. It has been noticed that the present work excellently agrees with previous work done by Misra & Adhikary[27] for some comparison and it has been treated as a particular case.

Keywords: Heat transfer; Thermal radiation; MHD; Chemical reaction; Viscoelastic fluid

1 Introduction

Now a day'sflow of blood under a common physiological state shows a vital role in the field of study (since disease condition of blood flow is very much dangerous). Due to the irregular flow of blood in arteries, cardiovascular diseases occur for which most deaths in human culture result. The major characteristic of the blood vessel disease is mainly three types according to physicians those are potentially needed treatment such as (1) a proliferative vasculopathy (thickening of blood vessels), (2) vasospasm (spasm of blood vessels), and (3) thrombosis (blood clots) or (blockage of blood vessels). To understand blood flow many researchers have put forward so many experimental, theoretical, and computational types of research.

Lee & Fung[1] have investigated Newtonian steady fluid flow passing through a locally constricted tube considered at a low Reynolds number. The blood flow in stenotic arteries has been investigated by Young[2] using an integral method. Further Young *et al.*[3] have extended their study area by investigating the elevated flow rate for Hemodynamics of arterial stenos is. Moreover, a good achievement by Charm & Kurland[4] they have concluded through their trial and findings. They found the best model (Casson model) that comes under blood flow and this model can be applied to human blood for research work. The magneto hydrodynamic boundary layer motion of non-Newtonian liquid past an exponentially accelerated shrinking surface was explored by Nadeem *et al*.[5]. They have adopted a suitable analytical method (Adomian decomposition method) to analyze this work. Further, Mishra *et al.*[6] have looked at overheat and concentration transport effects (for viscoelastic fluid) via the permeable medium. Sharma *et al.*[7] have examined3Dfluid motion (via a permeable medium) include in gin constant permeability for fluctuating mass and heat transfer. Hiremath & Patil[8] have reported the oscillatory motion over permeable media having a constant temperature. They considered the effects of natural convective currents. Nield & Bejan[9] have made another comprehensive review work on heat transfer (through porous media).

Because of the occupancy of protein, siderophilin in moist sordid plasma and fibrinogen blood cells

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look restraint similar construction. This is identified as rouleaux or aggregates. When the aggregates act comparable to a solid plastic, then there will be yield stress that container is recognized as constant yield stress in non-Newtonian liquid. This experiment was carried out by Fung[10]. The impacts of natural convective currents and concentration transport on an impulsively vertical sheet have been studied by Soundalgekar[11]. In his study, he ignored magneto hydrodynamic phenomena. In a saturated permeable media concentration and energy transport by free convective vertical surface and the impact of inconstant viscosity on convective heat transport have been investigated by Lai & Kulacki[12,13].

Recently a combination of concentration and energy transport with chemical reaction hasan important part innumerous aspects. In so various procedures like aeration, fading at the surfaces of the wet physique, cooling tower (heat transfer), energy, and concentration transport arise combinatorically. Chemical reactions can be classified such as heterogeneous or homogeneous procedures. The reaction is called first order if the reaction rate and species are directly proportional to each other. This has been investigated by Cussler[14] in his study diffusion concentration transport in liquid systems. The impacts of distribution in an isothermal boundary layer motion with a solvable horizontal sheet along with chemical reaction were examined by Wike[15]. Further mass transfer effect with chemical reaction impact on motion over an impulsively flat sheet reported by Das *et al*.[16].

So many authors[17–24] have gone through different studies on chemical reaction impacts on heat and mass transport (on laminar boundary layer) motion. The impact of a chemical reaction on a stirring isothermal perpendicular sheet under the presence of suction was reported by Muthucumarswamy[25]. Lately, Chemical reaction and thermal radiation impact on an isothermal perpendicular oscillating sheet under the influence of in constant concentration diffusion were reported by Manivannan *et al*.[26]. Misra *et al*.[27] surveyed the influence of chemical reaction on MHD oscillatory network flow, energy, and concentration transport in a biological fluid

Hence, the current examination aims to analyze effects on bio-magnetic viscoelastic liquid motion surrounded in a porous media with energy transport and chemical reaction. Using similarity variables the governing boundary layer equations were changed to a 2-point boundary value problem and the subsequent work is resolved analytically.

2 Mathematical Analysis

Let us consider the flow is symmetric about the axis of the channel and it is stretched towards the network partition such that the momentum of each partition is proportionate to the axial coordinate. To exam the second-order effect of unsteady magneto hydrodynamic motion of blood, let us study the motion of second-order liquid among 2 horizontal sheets at $y^*=0$ and $y^*=h$. Where the axis of $x^*$is drawn horizontal of sheets and y^* is perpendicular to the plate (Fig. 1). It is considered that blood is consistently thick. A magnetic description of persistent intensity B_0 is concerned in y^*-direction. Now the velocity, temperature, and concentration transport equations are taken in the system of

$$\partial_{t^*}u^* = -\frac{1}{\rho}\partial_{x^*}p^* + \nu\,\partial_{y^*y^*}u^* + \beta_0^*\partial_{y^*y^*}\partial_{t^*}u^* - \frac{\nu}{k^*}u^* - \frac{\sigma B_0^2}{\rho}u^*$$
$$+ g\beta(T-T_0) + g\beta_c(C^*-C_0) \quad \text{... (1)}$$

$$0 = -\frac{1}{\rho}\partial_{y^*}p^* \quad \text{... (2)}$$

$$\partial_{t^*}T = \frac{K'}{\rho c_p}\partial_{y^*y^*}T - \frac{1}{\rho c_p}\partial_{y^*}q_r \quad \text{... (3)}$$

$$\partial_{t^*}C^* = D\partial_{y^*y^*}C^* - K_c'(C^*-C_0) \quad \text{... (4)}$$

The corresponding boundary conditions are as follow

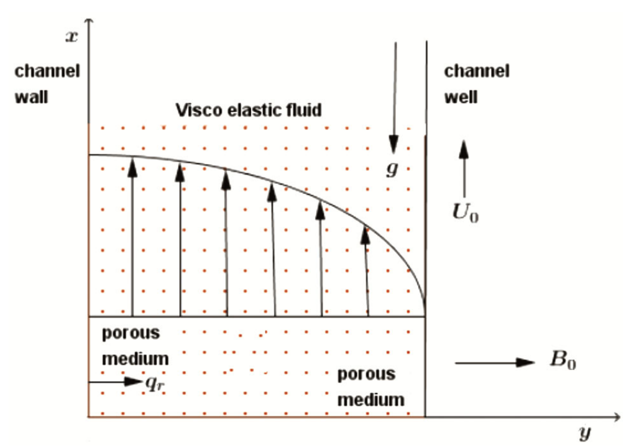

Fig. 1 — Flow configuration.

$$\left.\begin{array}{l} u^* = \lambda\,\partial_{y^*} u^*,\ T = T_0 + (T_w - T_0)e^{iw^*t^*}, \\ C^* = C_0 + (C_w - C_0)e^{iw^*t^*} \end{array}\right\} \quad at\ y^* = h,$$

$$u^* = \lambda\,\partial_{y^*} u^*,\ T = T_0,\ C^* = C_0 \qquad at\ y^* = 0, \qquad \text{... (5)}$$

3 Solution of the problem

In these equations, we have taken into account the temperature oscillation on the upper plate $y^* = h$ while the lower plate $y^* = 0$ is maintained at a flexible temperature T_0. In this case, the heat flux may be expressed as

$$\partial_{y^*} q = 4\alpha^2 (T - T_0) \qquad \text{... (6)}$$

Using heat flux equation (6), the governing Equations (1) to (4) are transformed to the ordinary differential equations and corresponding boundary conditions are as follows:

$$R_e \frac{\partial u}{\partial t} = -\frac{\partial p}{\partial x} + \frac{\partial^2 u}{\partial y^2} + \beta_0 \frac{\partial^3 u}{\partial y^2 \partial t} - \{\frac{1}{k} + M^2\}u + G_r\theta + G_c C \qquad \text{... (7)}$$

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial y} \qquad \text{... (8)}$$

$$\frac{\partial^2\theta}{\partial y^2} - p_r \frac{\partial\theta}{\partial t} + N^2\theta = 0 \qquad \text{... (9)}$$

$$\frac{\partial^2 C}{\partial y^2} - S_c \frac{\partial C}{\partial t} - K_c C = 0 \qquad \text{... (10)}$$

$$\left.\begin{array}{ll} u = \lambda \dfrac{\partial u}{\partial y}, \quad \theta = e^{i\omega t},\ C = e^{i\omega t} & at\quad y = 1 \\ u = \lambda \dfrac{\partial u}{\partial y}, \quad \theta = 0,\ C = 0 & at\quad y = 0 \end{array}\right\} \qquad \text{... (11)}$$

Where the non-dimensional variables and the parameters are defined as:

$$y = \frac{y^*}{h}, x = \frac{x^*}{h}, u = \frac{u^*}{U_0}, p_r = \frac{\rho c_p}{K}, t = \frac{t^* U_0}{h}, R_e = \frac{U_0 h}{\nu}, p_r = \frac{p^* h}{\rho\nu U_0},$$

$$M^2 = \frac{\sigma B_0^2 h^2}{\rho\nu}, S_c = \frac{1}{D}, \beta_0 = \frac{U_0\beta_0^*}{\nu h}, \omega = \frac{\omega^* h}{U_0}, N^2 = \frac{4\alpha^2 h^2}{K},$$

$$\theta = \frac{T - T_0}{T_w - T_0}, C = \frac{C^* - C_0}{C_w - C_0}, G_r = \frac{g\beta(T_w - T_0)h^2}{\nu U_0}, G_c = \frac{g\beta_c(C_w - C_0)h^2}{\nu U_0}$$

From equations (7) and (8) $\frac{\partial p}{\partial x} = f(t)$. We take as

$$-\frac{\partial p}{\partial x} = Be^{i\omega t}$$

To solve Eqs. (7), (9) and (10) with boundary conditions (11) we write momentum, energy and mass descriptions as

$$u(y,t) = u_f(y)e^{i\omega t},\ \theta(y,t) = \theta_f(y)e^{i\omega t},\ C(y,t) = C_f(y)e^{i\omega t} \qquad \text{... (12)}$$

Using the above values equations (7), (9) and (10) becomes

$$(1 + \beta_0 i\omega)\frac{\partial^2 u_f}{\partial y^2} - \{R_e i\omega + \frac{1}{k} + M^2\}u_f = -B - G_r\theta_f - G_c C_f \qquad \text{... (13)}$$

$$\frac{\partial^2\theta_f}{\partial y^2} - \{p_r i\omega - N^2\}\theta_f = 0 \qquad \text{... (14)}$$

$$\frac{\partial^2 C_f}{\partial y^2} - \{S_c i\omega + K_c\}C_f = 0 \qquad \text{... (15)}$$

with

$$\left.\begin{array}{ll} u_f = \lambda\,\partial_y u_f, \quad \theta_f = 1,\ C_f = 1 & at\quad y = 1 \\ u_f = \lambda\,\partial_y u_f, \quad \theta_f = 0,\ C_f = 0 & at\quad y = 0 \end{array}\right\} \qquad \text{... (16)}$$

Resolving (13), (14) and (15) with boundary condition (16) and using (12) we get

$$\theta(y,t) = \frac{e^{i\omega t}}{e^{\lambda_1} - e^{\lambda_2}}(e^{\lambda_1 y} - e^{\lambda_2 y}),$$

$$C(y,t) = \frac{e^{i\omega t}}{e^{\lambda_3} - e^{\lambda_4}}(e^{\lambda_3 y} - e^{\lambda_4 y}),$$

$$u(y,t) = \left\{ A_6 e^{\lambda_5 y} + A_5 e^{\lambda_6 y} + \frac{1}{1 + \beta_0 i\omega}\left[\begin{array}{l} \dfrac{B}{\lambda_5^2} - \dfrac{G_r}{e^{\lambda_1} - e^{\lambda_2}}(\dfrac{e^{\lambda_1 y}}{\lambda_1^2 - \lambda_5^2} - \dfrac{e^{\lambda_2 y}}{\lambda_2^2 - \lambda_5^2}) \\ \qquad - \dfrac{G_c}{e^{\lambda_3} - e^{\lambda_4}}(\dfrac{e^{\lambda_3 y}}{\lambda_3^2 - \lambda_5^2} - \dfrac{e^{\lambda_4 y}}{\lambda_4^2 - \lambda_5^2}) \end{array}\right]\right\} e^{i\omega t} \qquad \text{... (17)}$$

The volumetric flow rate is calculated as

$$Q = \int_0^1 u\,dy = \left[\begin{array}{l} \dfrac{A_6(e^{\lambda_5} - 1)}{\lambda_5} + \dfrac{A_5(e^{\lambda_6} - 1)}{\lambda_6} + \\ \dfrac{1}{1 + \beta_0 i\omega}\left\{\begin{array}{l} \dfrac{B}{\lambda_5^2} - \dfrac{G_r}{e^{\lambda_1} - e^{\lambda_2}}\left(\dfrac{e^{\lambda_1} - 1}{\lambda_1(\lambda_1^2 - \lambda_5^2)} - \dfrac{e^{\lambda_2} - 1}{\lambda_2(\lambda_2^2 - \lambda_5^2)}\right) \\ - \dfrac{G_c}{e^{\lambda_3} - e^{\lambda_4}}\left(\dfrac{e^{\lambda_3} - 1}{\lambda_3(\lambda_3^2 - \lambda_5^2)} - \dfrac{e^{\lambda_4} - 1}{\lambda_4(\lambda_4^2 - \lambda_5^2)}\right) \end{array}\right\} \end{array}\right] e^{i\omega t} \qquad \text{... (18)}$$

Where the wall shear stress at the wall is found as

$$\tau_w = \left[\frac{\partial u}{\partial y} + \beta_0 \frac{\partial^2 u}{\partial y \partial t}\right]_{y=1} =$$

$$\left[A_6\lambda_5 e^{\lambda_5} + A_5\lambda_6 e^{\lambda_6} - \frac{1}{1 + \beta_0 i\omega}\left\{\begin{array}{l} \dfrac{G_r}{e^{\lambda_1} - e^{\lambda_2}}\left(\dfrac{\lambda_1 e^{\lambda_1}}{(\lambda_1^2 - \lambda_5^2)} - \dfrac{\lambda_2 e^{\lambda_2}}{(\lambda_2^2 - \lambda_5^2)}\right) \\ + \dfrac{G_c}{e^{\lambda_3} - e^{\lambda_4}}\left(\dfrac{\lambda_3 e^{\lambda_3}}{(\lambda_3^2 - \lambda_5^2)} - \dfrac{\lambda_4 e^{\lambda_4}}{(\lambda_4^2 - \lambda_5^2)}\right) \end{array}\right\}\right](1 + \beta_0 i\omega)e^{i\omega t} \qquad \text{... (19)}$$

$$\tau_w = \left[\frac{\partial u}{\partial y} + \beta_0 \frac{\partial^2 u}{\partial y \partial t}\right]_{y=0} =$$

$$\left[A_6\lambda_5 + A_5\lambda_6 - \frac{1}{1+\beta_0 i\omega}\left\{\begin{array}{l}\dfrac{G_r}{e^{\lambda_1}-e^{\lambda_2}}\left(\dfrac{\lambda_1}{(\lambda_1^2-\lambda_5^2)} - \dfrac{\lambda_2}{(\lambda_2^2-\lambda_5^2)}\right) \\ +\dfrac{G_c}{e^{\lambda_3}-e^{\lambda_4}}\left(\dfrac{\lambda_3}{(\lambda_3^2-\lambda_5^2)} - \dfrac{\lambda_4}{(\lambda_4^2-\lambda_5^2)}\right)\end{array}\right\}\right](1+\beta_0 i\omega)e^{i\omega t} \quad \text{... (20)}$$

The rate of heat transfer and mass transfer at the upper wall is calculated as

$$N_u = \left.\begin{array}{l} -\dfrac{\partial \theta}{\partial y}\Big]_{y=1} = -\dfrac{e^{i\omega t}}{e^{\lambda_1}-e^{\lambda_2}}\left(\lambda_1 e^{\lambda_1} - \lambda_2 e^{\lambda_2}\right) \\ -\dfrac{\partial \theta}{\partial y}\Big]_{y=0} = -\dfrac{e^{i\omega t}}{e^{\lambda_1}-e^{\lambda_2}}\left(\lambda_1 - \lambda_2\right)\end{array}\right\} \quad \text{... (21)}$$

$$Sh = \left.\begin{array}{l} -\dfrac{\partial C}{\partial y}\Big]_{y=1} = -\dfrac{e^{i\omega t}}{e^{\lambda_3}-e^{\lambda_4}}\left(\lambda_3 e^{\lambda_3} - \lambda_4 e^{\lambda_4}\right) \\ -\dfrac{\partial C}{\partial y}\Big]_{y=0} = -\dfrac{e^{i\omega t}}{e^{\lambda_3}-e^{\lambda_4}}\left(\lambda_3 - \lambda_4\right)\end{array}\right\} \quad \text{... (22)}$$

Here the expression of constants λ_i $(i = 1,2,3,4,5,6)$, A_i $(i = 1,2,3,4,5,6)$ is given in Apendix-1.

4 Results and Discussion

The current survey considers the model of the oscillatory magneto hydrodynamic motion of blood in a permeable medium in conjunction with the radiative heat, and chemical reaction that enhance the energy as well as solutal transfer profile respectively. The surveying argument aims to carry out the outcome of the porousness of the media, sheet energy, and chemical reaction on the motion phenomena. Thermal radiation contributes significantly to the energy transport case. Additional attention to the work is the impact of velocity slip. Permeable mediums are commonly practiced to isolate a heated physique to preserve energy. They are studied to use full in diminishing the free convective which would else arise strongly on the sheet.

Figure 2 exhibits the effect of the viscoelasticity parameter β_0 on the velocity profiles in the nonappearance of slip variable and fixed values of other relevant constraints characterize the blood motion. It is to note that the rise in the viscoelastic variable increases the flow velocity near the plate under the influence of both magnetic and permeable medium (upto the middle of the channel, $y = 0.6$) and then decreases significantly. This is since the occurrence of permeable media (k = 1) acts as an insulator to the perpendicular sheet, avoiding temperature loss because of natural convective, for example, an outcome of which momentum rises by an enhance in the elastic parameter. Also, in the nonappearance of elasticity, the current outcome presents a good collaboration and shows a conformity with the work of Misra & Adhikary[27].

The slip parameter effect on the momentum description is discussed in Fig. 3. It is remarked that no flow separation occurs in the channel in the absenteeism of slip parameter ($\lambda = 0$) *i.e.* no-slip condition but when there is a velocity slip i.e. in the occurrence of slip variable flow separation takes place. It is noticed that the growth in slip parameter λ flow separation enhances.

Figure 4 shows the momentum distribution for various values of the magnetic and porous parameter and the fixed values of additional physical

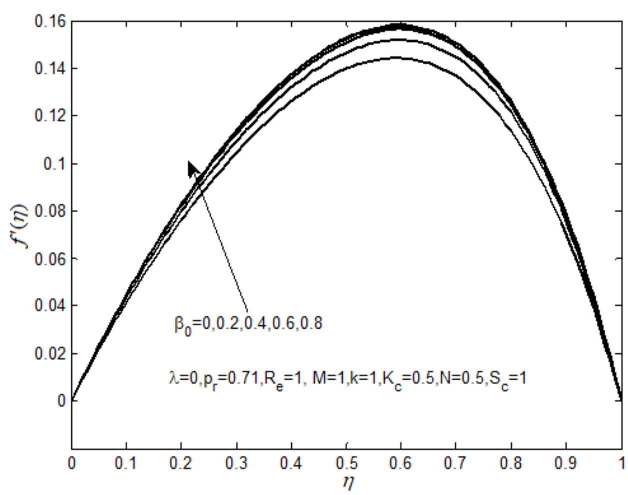

Fig. 2 Variation of on β_0 velocity profile.

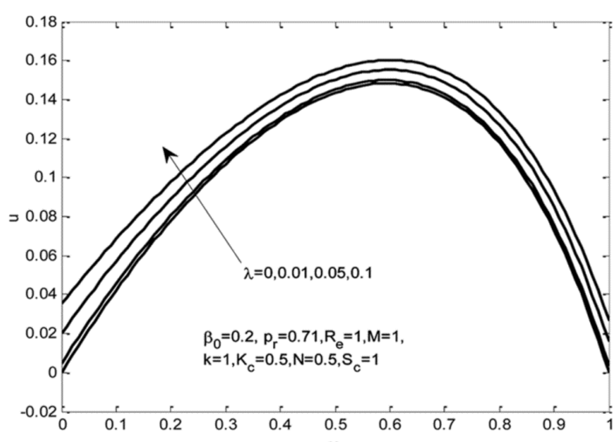

Fig. 3 — Variation of λ on velocity profile.

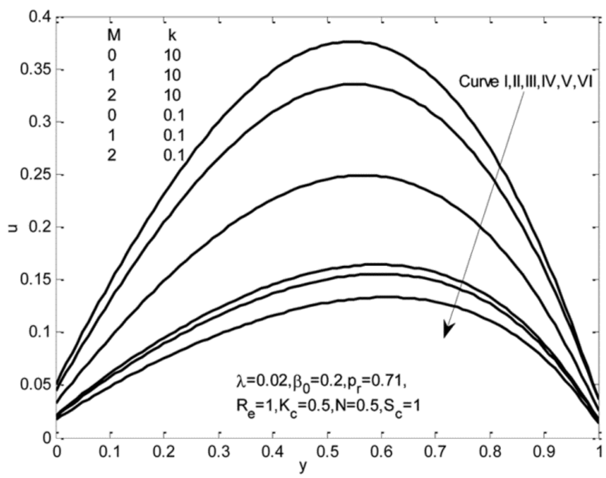

Fig. 4 — Velocity profile for different values of M and k.

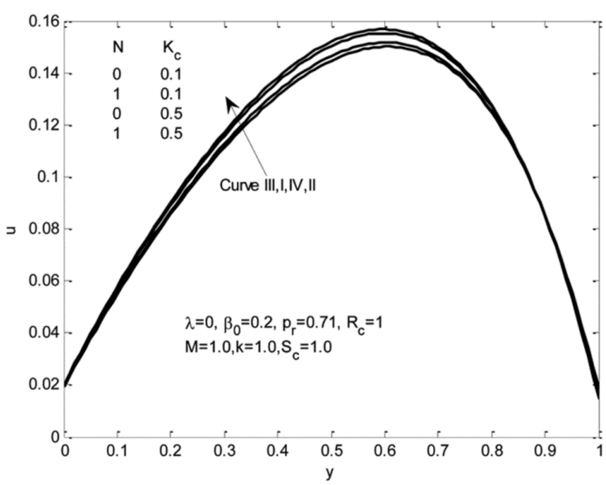

Fig. 5 — Velocity profile for different values of N and K_c.

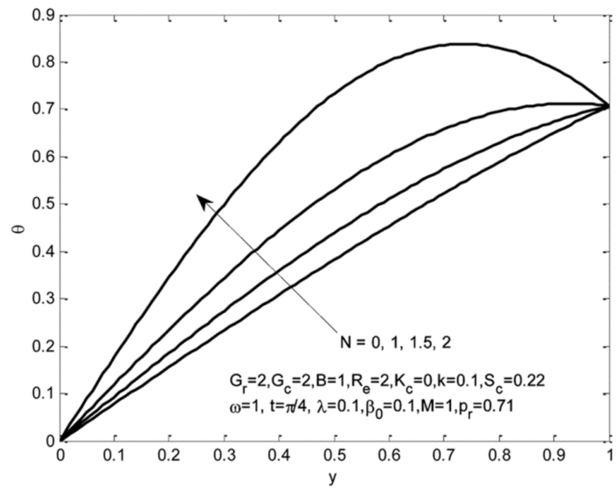

Fig. 6 — Temperature profile for different values of N.

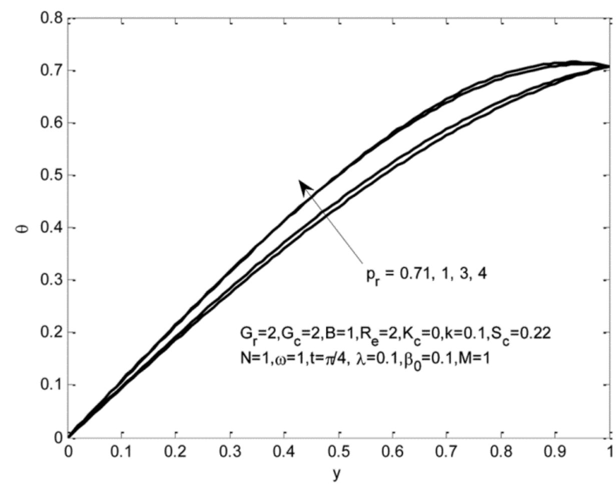

Fig. 7 — Temperature profile for different values of p_r.

parameters. From the figure, it is realized that as the strength of the magnetic parameter rises the momentum decelerates significantly in both the nonappearance of the permeable medium $(k = 10)$ and the occurrence of the permeable medium $(k = 0.1)$. This reveals that the occurrence of a magnetic field yields Lorentz force, a resistive force grounds a significant reduction in liquid velocity.

Figure 5 shows the impacts of thermal radiation and chemical reaction on velocity descriptions. It is noted that an enhance in thermal radiation raises the velocity profile (Curves I and II) also a similar effect is marked with an enhancement in a destructive chemical reaction $(Kc > 0)$ *i.e*., velocity profile enhances with an enhance in chemical reaction parameter.

Figure 6 exhibits the impact of thermal radiation on heat profiles. It is detected that with the rise in thermal radiation the energy of the liquid enhances significantly. The present observation coincides with the results of Misra & Adhikary[27]. This is because of the occurrence of elastic elements might remain accredited to the statistic that once a viscoelastic liquid is in motion, a positive quantity of temperature is stocked up in the substantial as strain temperature in the calculation to a magnetic parameter which resists the velocity, as an outcome, the energy enhances.

The characteristic of Pr for the presence of other pertinent parameters on energy description is depicted through Fig. 7. It exposes that fluid temperature augments significantly with an enhance in Pr and consequently the thermal bounding surface thickness retards. From the mathematical expression of Pr suggest that the increase in Pr is due to the slow thermal diffusion. Therefore, thermal bounding surface thickness decelerates that resulted in the fluid temperature retards significantly throughout the domain.

Figure 8 presents the mass profile for several values of the Schmidt number describing the mass profile. It exposes that an enhance in Sc leads to an increase in mass with the permeable medium. Therefore, heavier species subsidize to increasing the level of mass in the entire domain that reveals the bounding surface thickness retards. Fig. 9 displays the impacts of reactive agents associated to this study. Here, Kc>0 indicates the destructive reaction, Kc =0 suggests no chemical reaction, and Kc<0 represents the constructive chemical reaction. The observation reveals that the solutal profile overshoots for the destructive chemical reaction within the permeable medium whereas the case of constructive chemical reaction opposes it significantly.

Finally, the mathematical computation of rate of shear stress, rate of mass, and heat transfer at both the lower sheet (y= 0) and the upper sheet (y =1) are obtained and presented in Tables 1 to 3 for numerous values of physical constraints characterizes the flow phenomena. Table 1 reveals that the rate of shear stress decreases for the enhance in elasticity and magnetic constraint but it increases significantly for the Reynolds number, porous matrix, thermal buoyancy, and mass buoyancy parameters for fixed values of $P_r = 0.71,\ K_c = 1,\ N = 1,\ S_c = 1, \lambda = 0.05$ at both the plate in magnitude. Table 2 presents the impacts of the Prandtl numeral and thermal radiation on the Nusselt number. It is noticed that an enhance in Prandtl number and thermal radiation increases the Nusselt number at the lower plate whereas the impact is reversed at the upper sheet and for higher value s of thermal radiation at the

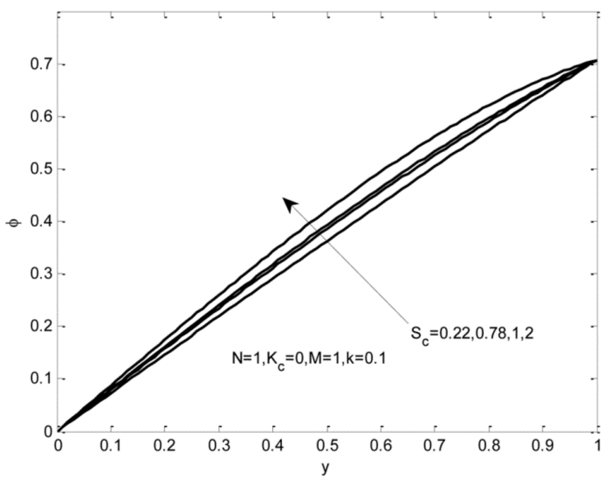

Fig. 8 — Variation of concentration profile for different values of S_c.

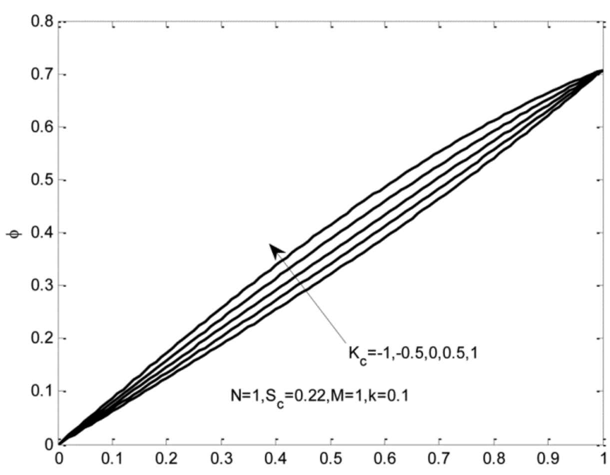

Fig. 9 — Variation of concentration profile for different values of K_c.

Table 1 — Values of τ_w for several values of parameters with $p_r = 0.71, K_c = 1,\ N = 1, S_c = 1, \lambda = 0.05$.

β_0	R_e	M	k	G_r	G_c	$\tau_w]_{y=0}$	$\tau_w]_{y=1}$
0	1	0	10	0.5	0.5	0.5132	-0.653
0.2						0.5026	-0.6346
	2					0.523	-0.6537
	3					0.5277	-0.6564
	1	1				0.4488	-0.5704
		2				0.3307	-0.4494
			0.1			0.1803	-0.2807
			0.5			0.2841	-0.3983
				2		0.3941	-0.6941
				5		0.6142	-1.2856
				0.5	2	0.3721	-0.6433
					5	0.5482	-1.1332

Table 2 — Values of N_u for several values of parameters with $t = \frac{5\pi}{2}$

p_r	$N_u]_{y=0}$	$N_u]_{y=1}$	N	$N_u]_{y=0}$	$N_u]_{y=1}$
0.1	-0.8403	-0.454	0	-0.7834	-0.5482
0.5	-0.9105	-0.3235	1	-0.9367	-0.2722
0.71	-0.9367	-0.2722	2	-1.7818	0.969
1	-0.9696	-0.205	3	-16.4429	16.4106

Table 3 — Values of S_h for several values of parameters with $t = \frac{5\pi}{2}$

S_c	$S_h]_{y=0}$	$S_h]_{y=1}$	K_c	$S_h]_{y=0}$	$S_h]_{y=1}$
0.22	-0.674	-0.7733	-1	-0.8725	-0.3952
0.3	-0.6819	-0.7562	-0.5	-0.7981	-0.5305
0.78	-0.7258	-0.6577	0	-0.7324	-0.656
1	-0.7437	-0.6149	0.5	-0.674	-0.7733
2	-0.8072	-0.4415	1	-0.6219	-0.8832

upper plate it becomes unstable. Table 3 exhibits the impacts of the Schmidt number and chemical reaction parameter on the Sherwood number at both lower and upper plates. It is seen that the Sherwood number enhances at the lower sheet and reduces at the upper sheet due to an enhance in Schmidt number but the impact is reversed in case of the chemical reaction. Therefore, the rate of solutal transfer encouraged by the inclusion of heavier species.

5 Conclusion

The major contribution of the parameters is laid down here as;

- Flow separation takes place with the slip parameter on the velocity profiles.
- The fluid momentum as well as the temperature distribution enhance with the rise in thermal radiation and the chemical reaction.
- Heavier species subsidize to increasing the level of concentration.
- Heavier species are also favorable to increase the rate of concentration transfer.

Apendix-1

$$\lambda_1=\sqrt{p_r i\omega-N^2},\ \lambda_2=-\lambda_1,\ \lambda_3=\sqrt{S_c i\omega+K_c},\ \lambda_4=-\lambda_3,\ \lambda_5=\sqrt{\frac{R_e i\omega+\frac{1}{k}+M^2}{1+\beta_0 i\omega}},$$

$$\lambda_6=-\lambda_5,\quad A_1=\frac{1}{1+\beta_0 i\omega}\left\{\begin{array}{l}\frac{B}{\lambda_5^2}-\frac{G_r}{e^{\lambda_1}-e^{\lambda_2}}\left(\frac{e^{\lambda_1}}{\lambda_1^2-\lambda_5^2}-\frac{e^{\lambda_2}}{\lambda_2^2-\lambda_5^2}\right)\\ -\frac{G_c}{e^{\lambda_3}-e^{\lambda_4}}\left(\frac{e^{\lambda_3}}{\lambda_3^2-\lambda_5^2}-\frac{e^{\lambda_4}}{\lambda_4^2-\lambda_5^2}\right)\end{array}\right\},$$

$$A_2=\frac{1}{1+\beta_0 i\omega}\left\{\begin{array}{l}-\frac{G_r}{e^{\lambda_1}-e^{\lambda_2}}\left(\frac{\lambda_1 e^{\lambda_1}}{\lambda_1^2-\lambda_5^2}-\frac{\lambda_2 e^{\lambda_2}}{\lambda_2^2-\lambda_5^2}\right)\\ -\frac{G_c}{e^{\lambda_3}-e^{\lambda_4}}\left(\frac{\lambda_3 e^{\lambda_3}}{\lambda_3^2-\lambda_5^2}-\frac{\lambda_4 e^{\lambda_4}}{\lambda_4^2-\lambda_5^2}\right)\end{array}\right\},$$

$$A_3=\frac{1}{1+\beta_0 i\omega}\left\{\begin{array}{l}\frac{B}{\lambda_5^2}-\frac{G_r}{e^{\lambda_1}-e^{\lambda_2}}\left(\frac{1}{\lambda_1^2-\lambda_5^2}-\frac{1}{\lambda_2^2-\lambda_5^2}\right)\\ -\frac{G_c}{e^{\lambda_3}-e^{\lambda_4}}\left(\frac{1}{\lambda_3^2-\lambda_5^2}-\frac{1}{\lambda_4^2-\lambda_5^2}\right)\end{array}\right\},$$

$$A_4=\frac{1}{1+\beta_0 i\omega}\left\{\begin{array}{l}-\frac{G_r}{e^{\lambda_1}-e^{\lambda_2}}\left(\frac{\lambda_1}{\lambda_1^2-\lambda_5^2}-\frac{\lambda_2}{\lambda_2^2-\lambda_5^2}\right)\\ -\frac{G_c}{e^{\lambda_3}-e^{\lambda_4}}\left(\frac{\lambda_3}{\lambda_3^2-\lambda_5^2}-\frac{\lambda_4}{\lambda_4^2-\lambda_5^2}\right)\end{array}\right\},$$

$$A_5=\frac{(A_1-\lambda A_2)(1-\lambda\lambda_5)-(A_3-\lambda A_4)(e^{\lambda_5}-\lambda\lambda_5)}{(e^{\lambda_5}-\lambda\lambda_5)(1-\lambda\lambda_6)-(e^{\lambda_6}-\lambda\lambda_6)(1-\lambda\lambda_5)},\ A_6=\frac{\lambda A_4-A_3-(1-\lambda\lambda_6)A_5}{1-\lambda\lambda_5}$$

Nomenclature

B_0	magnetic field intensity	N_u	Nusselt number
C	concentration	Sh	Sherwood number
C_p	specific heat at constant pressure	S_c	Schmidt number
g	acceleration due to gravity	M	magnetic parameter
G_r	Grashof number	u^*	axial velocity
G_c	modified Grash of number	t^*	time
K_c	chemical reaction parameter	(x^*, y^*, z^*)	space coordinator
P_r	Prandtl number	N	thermal radiation parameter
R_e	Reynolds number	p^*	pressure
T	fluid temperature	k	permeability medium

Greek symbols

β_0	viscoelastic coefficient	λ	slip parameter
ω^*	angular frequency	μ	dynamic viscosity
ν	kinematic fluid viscosity	ρ	fluid density
σ	conductivity of medium	β_c	volume expansion coefficient

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