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Repercussions of diffusion-thermo and thermo-diffusion with chemically reacting MHD mixed convective flow past a plate

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ABSTRACT A perusal of mixed convective MHD stream past a permeable upright flat plate inundated in a pervious medium has been dispensed. Accentuation has been specified to the interpretation of thermo-diffusion (Soret) and diffusion-Thermo (Dufour) sequels in companionship with chemical reaction. For solving non-dimensional forms of governing equations, a numerical technique has been employed. The consequences of relevant physical parameters are sensational. The profiles of velocity, temperature, and concentration are manifested graphically for disparate values of flow parameters. The enhancement of the magnetic parameter diminishes the velocity curve which exhibits conformity with the physical situation. Also, the relevant substantial quantities have been graphically discussed for possible cases.

KEYWORDS Porous medium; Shearing stress; Nusselt number; Sherwood number

1. Introduction

The problems of synchronous heat and mass transmission in companionship with magnetic field in the porous medium have fascinated numerous analyzers in current times owing to its application in varied sectors of engineering and technology. But in several problems, the Dufour and Soret upshots are ignored upon the basis that both are of lower rank of dimensions than the results designated by Fourier's and Fick's law. Although some objections are observed. As for isotope separation, the sequel of Soret has been exploited and the Dufour effects in a mixture of gases with very light molecular weight like H_2, He and of moderate molecular mass like N_2, the air was of the order of sufficient magnitude so that this effect cannot be neglected. Moreover, Soret and Dufour's repercussions are prominent in many areas viz. drying processes, hydrology, chemical reactors, geosciences, petrology, etc. The contribution of the investigators in this area is appreciable and is enlightened here.

The expeditions of few explorers viz. Alam and Rahman (2006), Alam et al. (2006), Agbaje et al. (2020), Davika et al. (2013), Gbadeyan et al. (2018), Hayat et al. (2015), Imtiaz et al. (2020), Jagadha et al. (2017), Kaladhar et al. (2019), Makinde (2011), Malapati and Dasari (2017), Niranjan et al. (2017), Olanrewaju and Makinde (2011), Postelnicu (2004, 2007), Pravin et al. (2020), Tripathy et al. (2015), Venkateswarlu et al. (2013, 2019) are praiseworthy.

This problem aims to examine the synchronous transmission of heat and mass by mixed convection past an upright pervious plate implanted in a permeable medium in the existence of cataclysmic chemical reaction and magnetic field accompanied with Soret as well as Dufour sequels by using the Boussinesq model.

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2. Mathematical formulation

Here the steady two-dimensional mixed convective flow of a viscous incompressible fluid past a semi-infinite vertical porous flat plate in a permeable medium is accounted and the flow is taken along the plate. The x-axis is along with the plate in the upright direction and the y-axis is normal to it. A uniform magnetic flux of strength B_0 is applied in the direction of the y-axis. The exterior section of the plate is maintained at a constant temperature T_w and a constant concentration C_W with the temperature & concentration far off the plate T_∞ and C_∞ where $T_w > T_\infty$ and $C_w > C_\infty$. The free stream velocity U_∞ is presumed as constant which is parallel to the vertical plate. The physical model along with the reference frame of the problem is revealed in Fig. 1.

The governing Eqs. under the boundary layer and Darcy-Boussinesq approximations are given as follows: Equation of continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

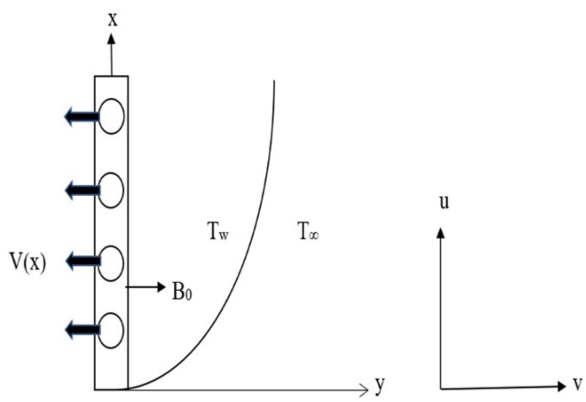

Figure 1: Physical model and coordinate system.

Equation of momentum:

$$u\left(\frac{\partial u}{\partial x}\right)+v\left(\frac{\partial u}{\partial y}\right)=\nu\left(\frac{\partial^2 u}{\partial y^2}\right)+g\beta\left(T-T_\infty\right)+ g\beta^*\left(C-C_\infty\right)-\left(\frac{\sigma B_0^2}{\rho}\right)u-\frac{\nu u}{K_p} \quad (2)$$

Equation of energy:

$$u\left(\frac{\partial T}{\partial x}\right)+v\left(\frac{\partial T}{\partial y}\right)=\alpha\left(\frac{\partial^2 T}{\partial y^2}\right)+\frac{D_m\kappa_T}{C_sC_p}\frac{\partial^2 C}{\partial y^2} \quad (3)$$

Equation of concentration:

$$u\left(\frac{\partial C}{\partial x}\right)+v\left(\frac{\partial C}{\partial y}\right)=D_m\left(\frac{\partial^2 C}{\partial y^2}\right)+\frac{D_m\kappa_T}{T_m}\left(\frac{\partial^2 T}{\partial y^2}\right) -K_r\left(C-C_\infty\right) \quad (4)$$

The boundary conditions are:

$$\begin{aligned} &\text{At } y=0: u=0,\ v=-V(x) \\ &\qquad T=T_w,\ C=C_w \\ &\text{At } y\to\infty: u\to\infty,\ T\to\infty \\ &\qquad C\to C_\infty \end{aligned} \quad (5)$$

where u and v are velocity components along x and y-axis respectively, ν is kinematic viscosity, g is the acceleration due to gravity, ρ is the density, β is the coefficient of thermal expansion, β^* is the coefficient of concentration expansion, K_p is the Darcy permeability, α is the thermal diffusivity, D_m is the coefficient of mass diffusivity, C_p is the specific heat at constant pressure, T_m is the mean fluid temperature, κ_T is thermal diffusion ratio, C_s is the concentration susceptibility, B_0 is magnetic parameter, σ is magnetic permeability, K_r is chemical reaction parameter.

The following dimensionless quantities and physical parameters are introduced for convenience:

$$\begin{aligned} &\eta=y\sqrt{\frac{u_\infty}{\nu x}},\ \Psi=\sqrt{\nu x U_\infty}f(\eta) \\ &\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\ \phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty} \\ &K=\frac{K_r\nu}{U_\infty^2},\ M=\frac{\sigma B_0^2\nu}{\rho U_\infty^2} \end{aligned} \quad (6)$$

where Ψ is the stream function defined as $u=\frac{\partial\Psi}{\partial y}$ and $v=-\frac{\partial\Psi}{\partial x}$, $f(\eta)$ is dimensionless stream function, $\theta(\eta)$ is dimensionless temperature, $\phi(\eta)$ is dimensionless concentration, η is similarity variable, M is the magnetic parameter, and K is chemical reaction parameter.

Now, using non-dimensional quantities from 6 in the Eqs. 2 - 4, we get the following local similarity equations:

$$f'''+\frac{1}{2}ff''+g_s\theta+g_c\phi-\left(M\,Re+\frac{1}{DaRe}\right)f'=0 \quad (7)$$

$$\theta''+\frac{1}{2}Prf\theta'+PrDu\phi''=0 \quad (8)$$

$$\phi''+\frac{1}{2}Scf\phi'+ScSr\theta''-K\phi ScRe=0 \quad (9)$$

where Gr, Gm, g_s, g_c, Da, Re, Pr, Sc, Sr and Du are local Grashof number, local modified Grashof number, temperature buoyancy parameter, mass buoyancy parameter, local Darcy number, local Reynolds number, Prandtl number, Schmidt number, Soret number and Dufour number respectively and are defined as

$$\begin{aligned} &Gr=\frac{g\beta\left(T_w-T_\infty\right)x^3}{\nu^2},\ Gm=\frac{g\beta^*\left(C_w-C_\infty\right)x^3}{\nu^2} \\ &g_s=\frac{Gr}{Re^2},\ g_c=\frac{Gm}{Re^2},\ Da=\frac{K_p}{x^2},\ Re=\frac{U_\infty x}{\nu},\ Pr=\frac{\nu}{\alpha} \\ &Sr=\frac{D_m\kappa_T\left(T_w-T_\infty\right)}{\nu T_m\left(C_w-C_\infty\right)},\ Sc=\frac{\nu}{D_m},\ Du=\frac{D_m\kappa_T\left(C_w-C_\infty\right)}{C_sC_p\nu\left(T_w-T_\infty\right)} \end{aligned}$$

The transmuted boundary conditions are

$$\begin{aligned} &\text{At } \eta=0:\ f=f_w,\ f'=0,\ \theta=1,\ \phi=1 \\ &\text{As } \eta\to\infty:\ f'=1,\ \theta=0,\ \phi=0 \end{aligned} \quad (10)$$

where f_w is the dimensionless suction velocity and defined as $f_w=\left(2xv(x)/\nu\right)Re^{-1/2}$.

3. Method of solution

For the coupled ordinary non-linear differential equations, the solution is not achievable in closed form. Therefore, the Eqs. 7 - 9 under the boundary conditions 10 are interpreted in the numerical method under the aegis of the bvp4c solver of MATLAB. The non-dimensional velocity, temperature, and concentration are represented in graphical forms and by the process of numerical calculations skin friction, Nusselt number, and Sherwood number are worked out and described in tabular forms.

The non-dimensional skin friction, Nusselt number and Sherwood number at the wall of the plate at $\eta=0$ are defined as $\tau=\left(\frac{d^2f}{d\eta^2}\right)_{\eta=0}$, $Nu=\left(\frac{d\theta}{d\eta}\right)_{\eta=0}$, $Sh=\left(\frac{d\phi}{d\eta}\right)_{\eta=0}$ respectively.

4. Results and discussion

A study has been executed to perceive and analyze the numerical results for a divergent range of several physical variables like Prandtl number (Pr), chemical reaction parameter (K), Schmidt number (Sc), Dufour number (Du), Reynolds number (Re), Soret number (Sr), magnetic parameter (M), suction parameter (f_w), mass buoyancy parameter (g_c), temperature buoyancy parameter (g_s), local Darcy number (Da). The behavior of fluid velocity, temperature, and mass disposition along with skin friction coefficient, rate of heat transmission, and rate of mass transmission are inscribed in this portion. The solution is acquired for variables with values $Pr=6.9$, $K=0.1$, $Sc=0.22$, $Du=0.15$, $g_s=5$, $g_c=5$, $Da=5$, $Re=2$, $Sr=0.4$, $M=2$, $f_w=0.2$ unless otherwise stated.

Figures 2 and 3 refer to the deviation of velocity distribution for divergent values of M and f_w, respectively.

Figure 2 displays the influence of magnetic parameter (M) on fluid velocity. In an electrically conducting fluid, the existence of magnetic parameter introduces a resistive force called Lorentz force which has a tendency to slow down the fluid motion in the boundary layer when

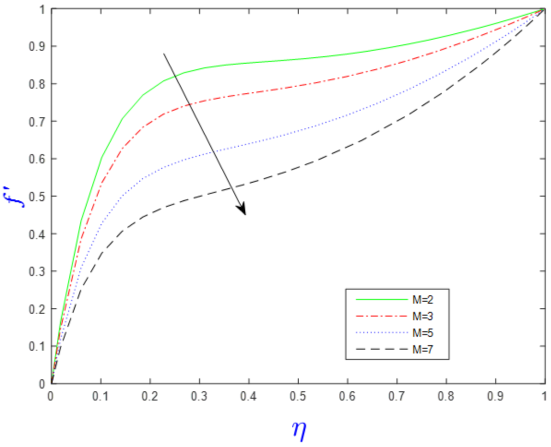

Figure 2: Velocity field for different values of M (2, 3, 5, 7).

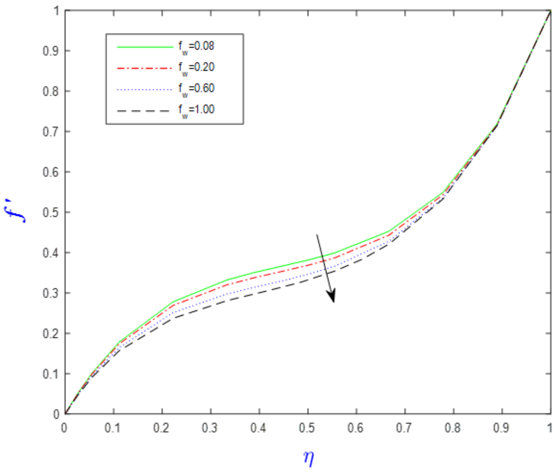

Figure 3: Velocity field for different values of f_w (0.08, 0.20, 0.60, 1).

the magnetic field is acted in the normal direction. The obtained result is in agreement with physical situation.

Velocity due to suction parameter (f_w) is displayed in Fig. 3. Apparently, velocity allocations are lessened via larger f_w. Physically, it is noticeable that suction balances the growth of the boundary layer and eventually fluid velocity diminishes.

Figures 4 - 6 describe the impressions of f_w, Du and Sr on temperature propagations. Figure 4 delineates the effect of suction parameter f_w on temperature profiles. Physically it is demonstrated that the growth of the thermal boundary layer is reduced due to the sucking retardant fluid particles through the porous wall and thereafter temperature field reduces.

The impact of Du and Sr on temperature allocations is observed in Figs. 5 and 6, respectively. Here, we witness that the temperature diminishes with the increase of the fore-said parameters.

The variations of concentration profile for divergent

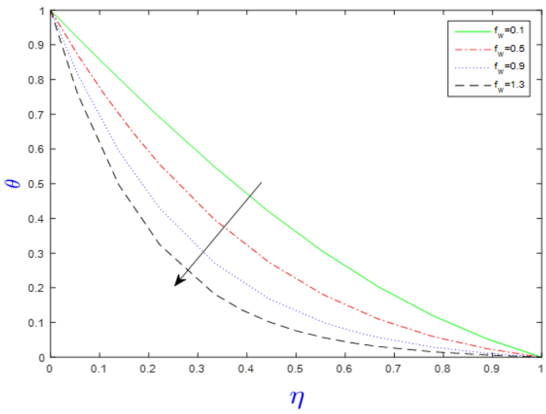

Figure 4: Temperature field for different values of f_w (0.1, 0.5, 0.9, 1.3).

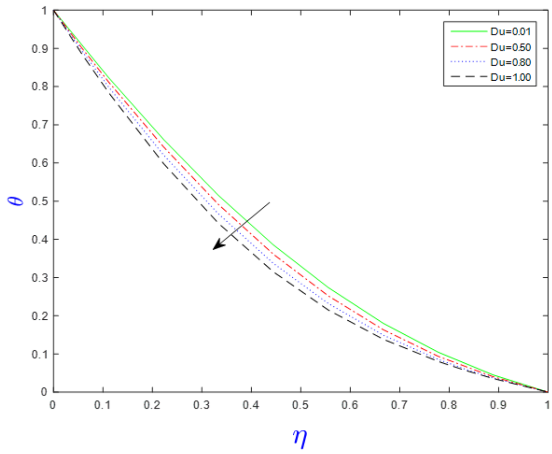

Figure 5: Temperature field for different values of Du (0.01, 0.5, 0.8, 1).

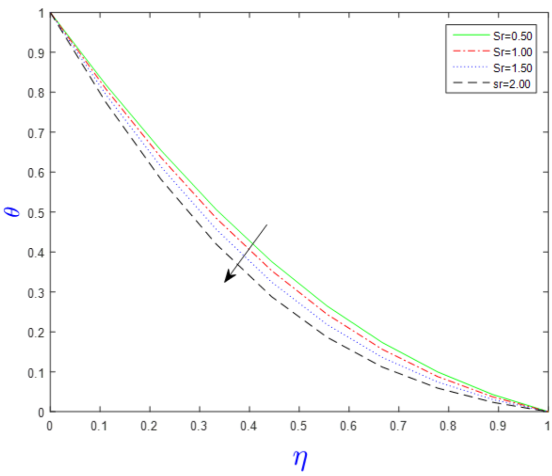

Figure 6: Temperature field for different values of Sr (0.5, 1, 1.5, 2).

Table 1: Skin friction (τ) against changes in various parameters:

Pr	K	Sc	Du	g_s	g_c	Da	Re	Sr	M	f_w	τ
									2		8.8789
6.9	.1	.22	.15	5	5	5	2	.5	3	.2	7.8306
									5		6.1807
									7		4.9709
							3				2.3345
6.9	.1	.22	.15	5	5	.7	4	.4	2	.2	2.0896
							5				1.9074
							6				1.7663

Table 2: Nusselt number (Nu) against changes in various parameters.

Pr	K	Sc	Du	g_s	g_c	Da	Re	Sr	M	f_w	τ
								.5			-1.5968
6.9	.1	.22	.15	5	.1	5	2	1	2	.2	-1.6897
								1.5			-1.816
								2			-1.9969
									1		-1.7368
6.9	.1	.22	.15	5	5	.7	2	.5	3	.2	-1.6579
									5		-1.6087
									10		-1.5418

Table 3: Sherwood number (Sh) against changes in various parameters.

Pr	K	Sc	Du	g_s	g_c	Da	Re	Sr	M	f_w	τ
	.7										-1.0851
5	1.6	.22	.15	5	5	5	2	.4	2	.2	-1.2183
	2.5										-1.3449
	3.5										-1.4787
										10	1.502
6.9	.1	.22	.15	5	5	5	2	.4	1	14	2.4922
										16	2.9771
										18	3.4557

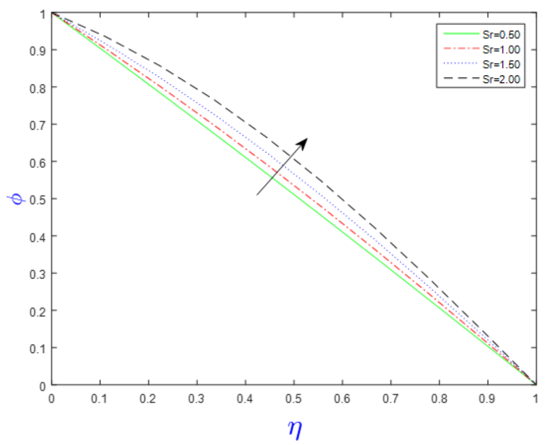

Figure 7: Concentration field for different values of Sr (0.5, 1, 1.5, 2).

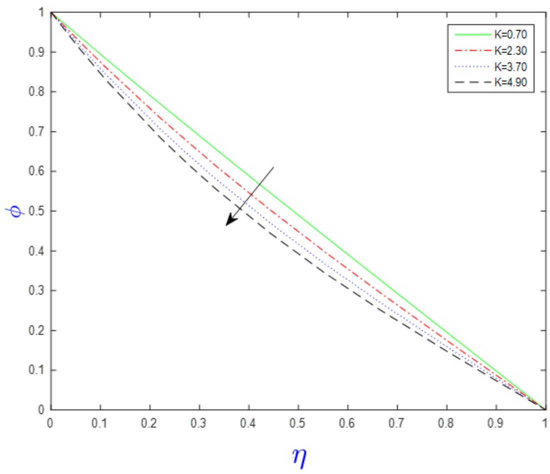

Figure 8: Concentration field for different values of K (0.7, 2.3, 3.7,4.9).

values of flow parameters viz. Sr and K are illustrated in Figs. 7 and 8, respectively.

Figure 7 displays the behavior of concentration for various values of Sr. The concentration profile accelerates with the rise in the numerical values of Sr.

The epilogues of K on concentration propagations are represented in Fig. 8. It is seen that with the shoot-up of K, concentration allocations are reduced.

Table 1 to Table 3 display the variations of skin friction τ, Nusselt number Nu and Sherwood number Sh, respectively, for numerous values of pertinent physical parameters.

5. Conclusions

In this article, we have examined inferences regarding chemically reacting MHD mixed convective stream past a permeable vertical plate considering Soret and Dufour's effects through a pervious medium. The details of flux, heat, and mass transmission characteristics and their faith in some physical variables are manifested graphically.

The suction parameter has a straight relationship with fluid mobility and temperature distributions i.e. wall suction balances the growth of velocity and thermal boundary layer. Also, the velocity profile decelerates when the magnetic parameter, Prandtl number, and Reynolds number increase. An increase in the chemical reaction parameter reduces the concentration profile along with the coefficient of skin friction and mass transfer coefficient. However, temperature as well as heat transfer coefficient is inversely proportional to the chemical reaction parameter.

Due to the influence of Soret number, velocity and concentration of the fluids along with mass transfer coefficient enhance, but the coefficient of skin friction, heat transfer coefficient and temperature of the fluids decrease. It is found that the Dufour number imposes hindrance to the temperature field and the Schmidt number behaves in an opposite manner on the concentration profile.

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