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INFLUENCE OF HEAT AND MASS TRANSMISSION ON THE MHD FLUID CIRCULATION IN CONJUNCTION WITH AN UPRIGHT SURFACE IN THE EMERGENCE OF RADIATION THERMOPHORESIS AND THE DUFOUR REPERCUSSIONS

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The current research simulates the mass and heat energy transmission model on MHD fluid flow under concentration and temperature deviations on a two-dimensional viscous fluid along an upright facet. Following boundary layer estimations, mathematical simulations for the movement of fluids, the conveyance of heat and mass exposed to radiation, thermophoresis, and Dufour consequences are generated as a set of partial differential equations. The surface's resilient suction was assessed. The built-in solver bvp4c in MATLAB is used for numerically debugging the aforementioned models. Through the inclusion of visualizations and tables, the detrimental effects of influencing variables are examined on the velocity, temperature as well as concentration gradients in conjunction with on the skin friction, Nusselt number, and Sherwood number. Excellent coherence may be shown when comparing between the most present findings and those that have previously been made available in the literature in specific limited circumstances. The Dufour effect, radiation, thermophoresis, and the Grashof number are all factors that influence fluid motion and heat transmission at the interface layer of dirt. Moreover, developments in the Shearing stress, Nusselt number, and Sherwood number coefficient are calculated. The findings are crucial for optimizing a variety of fluid-based technologies and systems, allowing developments in a number of industries including energy-effectiveness, electronics cooling, pursued medicine administration, and many more.
Keywords: *Chemical reaction; Dufour effect; Heat transfer; Mass transfer; Radiation; Thermophoresis*
PACS: 44.05.+e, 44.20.+b, 44.40.+a, 47.50.+d, 47.50.Cd

INTRODUCTION

The concomitant transpiration of both heat and mass remains an extremely important procedure that it has drawn a lot of interest because of its widespread use in STEM fields, including nuclear power facilities, crude oil processing, heat insulation, biological waste control, airflow, plasma analyses, geomagnetic turbines, subterranean industries, and thermal exchangers and many more. There is now a resurgence intriguing in the research of fluid flow, in tandem with the transmission of heat and mass, as an out-turn of these utilitarian processes' expanding uses. In this vein, M.B. Riaz et al. [1] conducted a thorough investigation on the consequences of mass transport along with the amalgamated heat displacement regarding convective fluid circulation with attribute concentration and temperature. R.D. Ene et al. [2] analyze the mass and heat transmission issue in a sticky substance flow to determine that the thickness of the boundary layer is dwindling. I. H. Qureshi et al. [3] performed a numerical simulation of the distribution of heat and mass caused by the infiltration of nanofluid into an impermeable medium to demonstrate that the ambient temperature rose when the frictional impact generated heat while heat is dispersed to the fluid's particle's surface. E.O. Fatunmbi and A. Adeniyan [4] examined heat and mass transition in Micropolar fluid movement across a prolong surface with velocity and thermal friction ambience and found that increasing the thickness attribute improved the exchange of thermal energy effect simultaneously. By using chaotic forced convection, J. E Salhi et al. [5] examined the heat and mass exchange of fluid carried over an even conduit. Some related works [6-10] are also found in the literature survey. Some other significant studies on heat and mass transmission with a variety of tangible characteristics are listed in [6–10].

Numerous important applications of magnetohydrodynamic (MHD) flow phenomena can be found in the fields of natural science, technology, and biomedicine. These applications include MHD power plants, MHD catalysts, blood flow extent, electrolytes, ionized substances, wave propagation tubes, propulsion systems. As a result, a lot of academics [11-15] are now paying more emphasis to how the magnetic field affects the movement of fluids and the conveyance of heat and mass. The adverse impacts of hesitant thermal emission on MHD convective slip propagation of viscoelastic fluid via a porous substrate encased within an opaque medium were explored by Choudhury and Dey [11]. Raju and Venkataramana [12] reviewed MHD and demonstrated viscous evaporation and thermal expansion when the convective flow was carried along permeable material in an elongated conduit with shielded and insurmountable bottom walls. The MHD boundary layer flow across a flat surface with diffuse dissipation has been elucidated by Kalita et al. [13]. It was quite well-explained by Das et al. [14] how magnetohydrodynamics affected entwined evaporative slip flow across an elevated perforated disc with diffuse viscosity and Joule radiation heating. Mahanthesh et al. [15] looked into the magnetohydrodynamic impact on a stochastic elastic sheet and the 3-dimensional propagation of nanofluids involving drift and thermal exposure.

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The least amount of energy required by reactants to initiate a chemical process is termed as energy for activation. Fluid motion combined with chemical processes and energy of activation encounters an enormous variety of applications, including crop damage arising from cooling, paper manufacture, food fabrication, porcelain, evaporation, crude oil, fluid emulsion, and so on. Magnetohydrodynamics (MHD), which is used in this work, is a phenomenon that deals with electrically stimulated flows of fluids that have enticing characteristics, which in turn govern the trajectory of flow and polarize the field's magnetism. Y.P. Lv [16] investigated the effect of chemical processes on the behavior of nanofluid motion in a twirling tube with a Hall current. A. M. Sedki [17] explored the consequences of chemical alteration on MHD-infused radiative conveyance of heat dissipation in tiny fluid flows owing to a stochastic lengthen interface via a permeable medium. N.N.W Khalili et al. [18] discuss the chemical retaliation impacts on MHD flow through an incrementally stretched surface with an insulation layer. Samuel and Fayemi [19] analyzed the effects of chemical reactions on harmonic dissipative fluid motion in an opaque medium over a stretched sheet combined with thermal radiation. Shah et al. [20] inquired about the detrimental impact of electromagnetic radiation on progressive heat transport in an MHD boundary region Carreau fluid involving a compound's reaction.

During the exchange of heat happens in a flowing fluid, as in chemical processing and geological mechanisms, it leads to a cross-diffusion phenomenon known as the Dufour effect. The Dufour effect is commonly seen in situations with both heat and concentration gradients, particularly multi-component fuel mixes or unifying mixtures of fluids. Such an effect is insurmountable in fluid flows with strong gradients of concentration and temperature in operations involving chemical manufacture, material acoustic, and numerous engineering projects. Extra variables in both the heat and transportation of mass equations define the Dufour effect numerically. Realizing this, numerous researchers were eager to explore the Dufour effect in diverse fluid movement situations. To mention a few, E. Seid et al. [21] inquired about various slips and Dufour consequences in fluid movement near an upright stretching surface in addition to the presence of magnetized nanoparticles. M. Hasanuzzaman et al. [22] assessed the significance of Dufour as well as thermal dispersion on erratic MHD natural convection and momentum flow over a perpetual stacked accessible surface. Ismail Filahi et al. [23] performed an empirical and quantitative analysis of the Dufour impact on thermosolutal flow in an axial brinkman translucent stack using a serene upper threshold.

Thermophoresis, commonly referred to as the Soret impact, is a physical phenomenon that occurs when tiny molecules or particles move through a fluid media in response to an alteration in temperature. In simple terms, throughout the action, substances in the hot atmosphere travel to a cooler one. In this regard, N. A. Shah et al. [24] performed a quantitative simulation of thermophoretic second-grade fluid motion across an upward slope with varying fluid properties and progressive scorching and shown that increased temperature-sensitive viscous factors improve velocity patterns. F. Mabooda et al. [25] discovered that having a combination of thermophoresis and Brownian motion in a fluid improves the transmission of heat. J. V. Tawade et al. [26] encountered that raising the amount of the Brownian motion attribute causes an increase in the thermal persona, and enhancing the magnitude of the Thermophoresis coefficient causes an increase in the thermal energy circulation. According to B. K. Jha and H. N. Sani [27] whenever thermophoretic readings escalate, it's possible to observe an accumulation of Sherwood number readings at the cooler plate. Furthermore, intriguing development concerning this [28-34] has developed some well-established models.

The contributors meticulously reviewed the existing literature and spotted multiple investigations on the implications of MHD on the transmission of heat and mass transport in the emergence of innumerable flow characteristics, but to their knowledge, there is no investigation regarding the inclusion of chemical reaction, thermophoresis, and the Dufour repercussions in conjunction with the amalgamated transfer of heat as well as mass effect on MHD fluid flow for the plate that is vertical. The inclusion of Thermophoresis and the Dufour effect, in tandem with additional significant flow characteristics, enhances the problem's originality. The proposed model is streamlined using boundary layer estimation and dimensionless transformations. The Numeric scheduling of bvp4c in MATLAB is then worn to solve the underlying combined nonlinear system of equations. The MATLAB quantitative analyzer of bvp4c provides a superb setting for dealing with entangled sets of conventional simultaneous equations. The mentioned approach has been utilized successfully to handle a range of issues pertaining to fluid flow. The aforementioned quantitative approach was most recently applied in the investigation of Dey et al. [35, 36] and Mirza et al. [37]. The insights gained from the results of the investigation will aid its designers in improving the efficacy of unifying mixtures of fluids and Particle Filtration, the combustion process and Burning Propagation, cooling techniques utilized in Bioprocessing and Biotechnology, and food extraction processes that incorporate Thermophoresis and Dufour effects.

MATHEMATICAL FORMULATION

In the instance of heat transmission, considering two-dimensional devoid convective incompressible fluid motion through a vertical plate. A homogenous magnetic gradient B is provided to the plate in the direction of transverse motion. The current investigation looks at the governing fluid's simultaneous heat and mass transmission approach when combined with chemical reactions, the Dufour effect, and thermophoresis. The x-axis advances upwards relative to the sheet, while the y-axis moves parallel to it. In the aforementioned scenario, the effect of the generated electromagnetic-field is neglected. Also, the Renolds number is considered to be very small. In the beginning, the plate and the fluid are kept at identical temperature and concentration. Suddenly, they rise to a temperature of $\overline{T}_w\ (> T_\infty)$ and concentration of $\overline{C}_w (> C_\infty)$Applying the boundary surface estimation, the governing equations are outlined in the following order

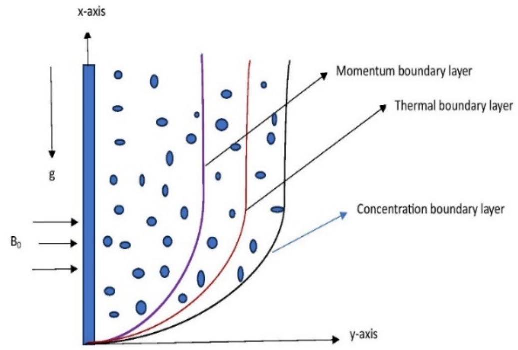

Figure1. Physical model of the flow scheme

Mass flow modeling:

$$\frac{\partial \bar{v}}{\partial \bar{y}} = 0 \tag{1}$$

$$\bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \nu\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{\sigma}{\rho}B_0^2\bar{u} + g\beta(\bar{T} - T_\infty) + g\bar{\beta}(\bar{C} - C_\infty) \tag{2}$$

$$\bar{v}\frac{\partial \bar{T}}{\partial \bar{y}} = \frac{\kappa}{\rho C_p}\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial \bar{y}} + \frac{1}{\rho C_p}\left[\frac{\rho D_m K_T}{C_s}\frac{\partial^2 \bar{C}}{\partial \bar{y}^2}\right] \tag{3}$$

$$\bar{v}\frac{\partial \bar{C}}{\partial \bar{y}} = D\frac{\partial^2 \bar{C}}{\partial \bar{y}^2} - k_r(\bar{C} - C_\infty) - \frac{\partial}{\partial \bar{y}}[V_T(\bar{C} - C_\infty)] \tag{4}$$

$$V_T = -\frac{k\nu}{T_r}\frac{\partial \bar{T}}{\partial \bar{y}}, \text{ stands for thermophoretic velocity,} \tag{5}$$

where k is the thermophoretic amount, T_r represents reference temperature.
Relevant boundary situations are:

$$\bar{y} = 0 : \bar{u} = U, \bar{v} = -v_0;\ \bar{T} = \bar{T}_w;\ \bar{C} = \bar{C}_w \tag{6}$$

$$\bar{y} \to \infty: \bar{u} \to 0;\ \bar{T} \to \bar{T}_\infty;\ \bar{C} = \bar{C}_\infty$$

Dimensionless parameters are:

$$f = \frac{\bar{u}}{U}, y = \frac{\bar{y}U}{\nu}, \theta = \frac{\bar{T} - T_\infty}{\bar{T}_w - T_\infty}, C = \frac{\bar{C} - C_\infty}{\bar{C}_w - C_\infty},$$

$$\lambda = \frac{v_0}{U},\quad M = \frac{\sigma B_0^2 \nu}{\rho U^2},\quad K = \frac{\nu K_r}{U^2},\quad Sc = \frac{\nu}{D},$$

$$Gr = \frac{\nu g\beta(\bar{T}_w - T_\infty)}{U^3},\quad Gm = \frac{\nu g\beta^*(\bar{C}_w - C_\infty)}{U^3},\quad Pr = \frac{\mu C_p}{\kappa}, \tag{7}$$

$$Ra = \frac{16a^*\nu^2\sigma T_\infty^3}{\kappa U^2},\quad Du = \frac{D_m k_T(\bar{C}_w - \bar{C}_\infty)}{C_S C_p(\bar{T}_w - T_\infty)},\quad \tau = -k\frac{(\bar{T}_w - T_\infty)}{\bar{T}_r}$$

Where f is dimensionless velocity, θ is dimensionless temperature, C is dimensionless concentration, y is dimensionless co-ordinate, λ is suction parameter, Gr is thermal Grashof number, Gm is solutalGrashof number, M is magnetic field limitations, Pr is Prandtl number, K is Chemical reaction specification, Sc is Schmidt number, Du is the amount of mass diffusivity (Dufour number), Ra is the radiation specification, τ is the thermophoretic constant.

Non-dimensional governing equation are

$$\frac{d^2 f}{dy^2} + \lambda\frac{df}{dy} - Mf + Gr\theta + GmC = 0 \tag{8}$$

$$\frac{d^2\theta}{dy^2} + Pr\lambda\frac{d\theta}{dy} - Ra\theta + PrDu\frac{d^2 C}{dy^2} = 0 \tag{9}$$

$$\frac{d^2 C}{dy^2} + \lambda Sc\left(1 - \tau\frac{d\theta}{dy}\right)\frac{dC}{dy} - KScC - \tau ScC\frac{d^2\theta}{dy^2} = 0 \tag{10}$$

with Modified boundary conditions

$$y = 0: f = 1;\ \theta = 1, C = 1$$

$$y \to \infty: f \to 0;\ \theta \to 0, C \to 0 \tag{11}$$

METHODOLOGY

The bvp4c quantitative algorithm in MATLAB is applied to the equations (8) to (10) due to the limitations (11). This bvp4c problem-solver is one of MATLAB's most recent extensions and produces excellent outcomes. Three crucial types of information are needed for this solver to function: the equation that needs to be solved, the given equation's boundary condition, and the initial estimate of the solution. Shampine et al. [38] was the first who initially presented the bvp4c methodology. In the present study, equations (8) to (10) along with the boundary condition (11) are transform into differential equation of first order applying MATLAB built in solver bvp4c as stated below:

Let, $f = y(1), \frac{df}{dx} = y(2), \theta = y(3), \frac{d\theta}{dx} = y(4), C = y(5), \frac{dC}{dx} = y(6)$ gives

```
dydx = [  y(2
          -λ*y(2)+M*y(1)-Gr*y(3)-Gm*y(5)
          y(4)
-Pr* λ *y(4)+Ra*y(3)-{Pr*Du*{- λ *Sc*( 1 - τ *y(4))*y(6)+K*Sc*y(5)- τ *Sc*y(5)*(Pr* λ *y(4)-Ra*y(3))}/(Pr*Du* τ*Sc*y(5))
          y(6)
     - λ*Sc*(1-τ*y(4))*y(6)+K*Sc*y(5)* -Pr* λ*y(4)+Ra*y(3)*{-{Pr*Du*{- λ*Sc*(1-τ*y(4))*y(6)+K*Sc*y(5)-τ*Sc*y(5)*(Pr* λ*y(4)-Ra*y(3))}/(Pr*Du* τ*Sc*y(5))}]
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VALIDATION OF THE CODE

The validity of the strategies adopted for this study is supported by Table. A comparison of Shearing stress (σ) and Nusselts'(Nu) number for radiation parameter (Ra) have been conducted with S. Ahmed [39].

Ra	Sahin et al. [39]		Present study	
	Shearing stress (σ)	Nusselts' number (Nu)	Shearing stress (σ)	Nusselts' number (Nu)
1	1.82981	1.52803	1.4857	1.3838
2	1.77918	1.82209	1.4851	1.3885
3	1.73423	2.17803	1.4845	1.3932

RESULTS AND DISCUSSION

In this survey, we looked at the influence of thermophoresis in viscous fluids, as well as chemical reactions and the Dufour effect. To assess the physical condition, for diverse fluid specifications, we examined the distinctive patterns for flow rate, temperature, and concentration. To begin, take a collection of arbitrary parameters with values, such as the Magnetic flux specification, M=1, Grashof number Gr=8, Solutal Grashof number Gm=3, Chemical reaction constant K=0.1, Radiation Parameter Ra=7, Thermophoresis parameter τ=2, Schimdt number Sc=0.6, Prandtl number Pr=0.71, Coefficient of mass diffusivity Du=0.75 unless otherwise stated. Figures 2–9 illustrate velocity curves tailored to different fluid properties. Figure 2 portray the velocity contour for different consequences of M. The graph shows that enhancing the magnetic value M mitigates the fluid velocity. The drop in fluid velocity is caused by the magnetic pull acting in the regular course of the flow of the fluid, creating aversion amongst fluid particles. For a conductive fluid, such aversion or resistance works as a drag or a form of "magnetic stiffness" that hinders fluid movement. As it turns out, fluid particles are subjected to extra constraints which tend to impede their trajectory along the pathway of how it flows. This drop in velocity results in antagonism in the entire flow rate of the fluid. Figure 3 depicts the unique velocity trends for various values of Du. We found a decrease in the velocity gradient as Du was enriched. It happens because an upsurge in Du can modify the temperature and intensity domains of the fluid, producing disturbances in a fluid's density and viscosity pattern and, as a result, variations in the velocity descent.

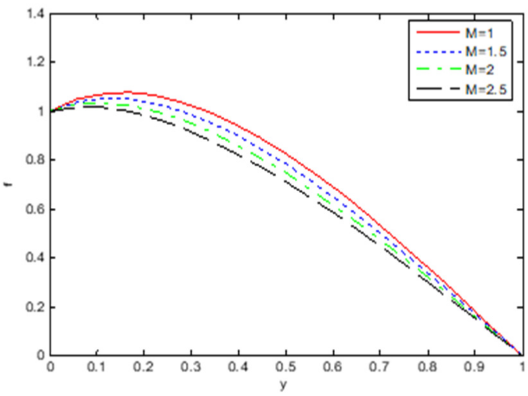

Figure 2. Velocity outline for varied values of M

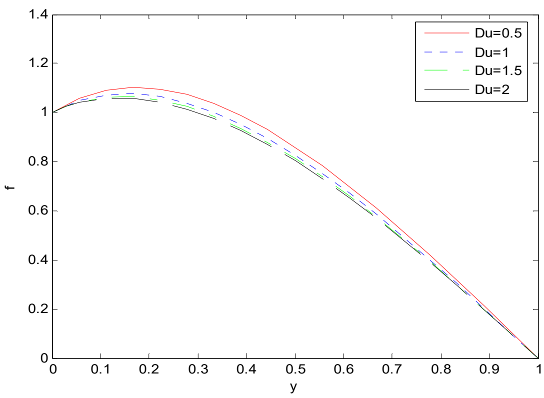

Figure 3. Velocity outline for varied values of Du

Figure 4 portrayed the attenuation character of the velocity curve with the growth of τ. The adverse impact of thermophoresis grows more corpulent as the thermophoretic coefficient elevates. As it turns out, the movement of the suspended objects in reaction to its temperature differential might impact the entire fluid motion and modify the velocity profile. This influence can cause changes in the velocity profile, resulting in higher velocities at certain regions within the fluid. The influence of radiation heat exchange on fluid properties rises as the radiation attribute Ra grows. This can cause variations in the fluid's variation in temperature, which influences its density and fluidity. Changes in the two parameters can influence the fluid's behaviour and, as a result, the velocity distribution. Figure 5 evokes the manner in which the velocity pattern lessened as Ra climbed.

However, Figure 6 depicts the rising character of the velocity depiction when Gr is increased. While the Grashof number escalates, the fluid's motion shifts from being regulated due to viscous pressure to having prevailed by buoyant factors. It culminates in an enormous boost in velocity portrayal. Figure 7 illustrates the developing nature of velocity portrait with the growth of solutal Grashof number (Gm).

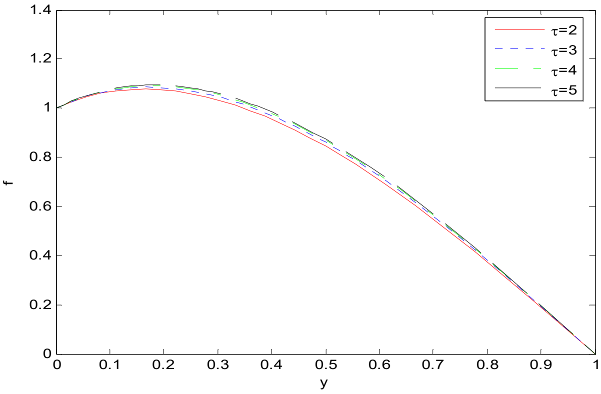

Figure 4. Velocity outline for varied values of τ

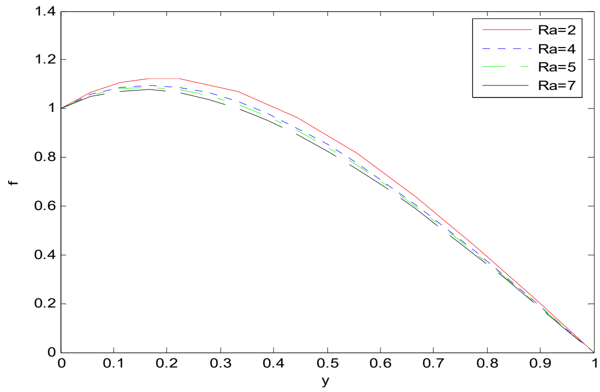

Figure 5. Velocity outline for varied values of Ra

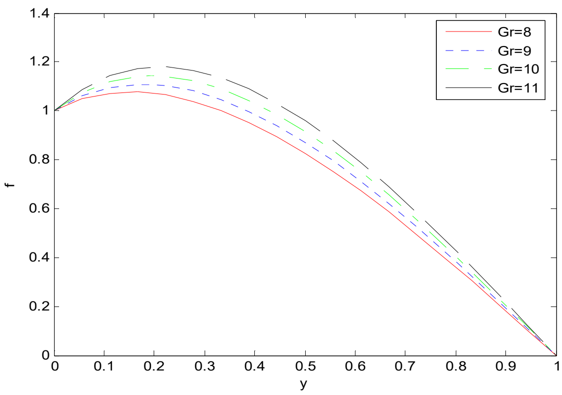

Figure 6. Velocity outline for varied values of Gr

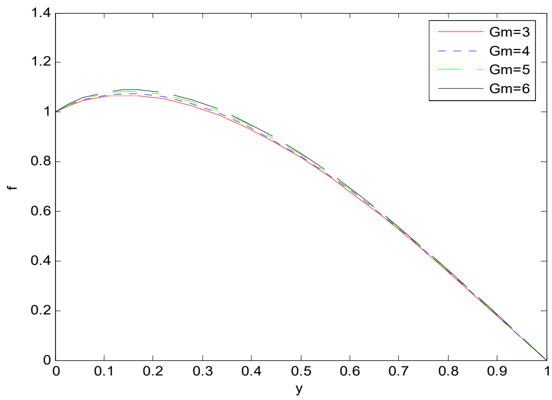

Figure 7. Velocity outline for varied values of Gm

Figure 8 delineates the velocity profile with the variation of Chemical reaction parameter (K). It has been seen that with the increasing of K, velocity decline. Figure 9 shows decreasing profile of velocity for increasing values of Prandtl number (Pr). It is displayed that high Prandtl number (Pr) values prompt the momentum boundary layer size to shrink, which minimizes velocity. Figure 10 demonstrates that with the hike of Schmidt number (Sc), velocity declined. Since the Schmidt number (Sc) indicates the relationship between molecular diffusivity and kinematic viscosity, velocity decreases as a result of this characteristic.

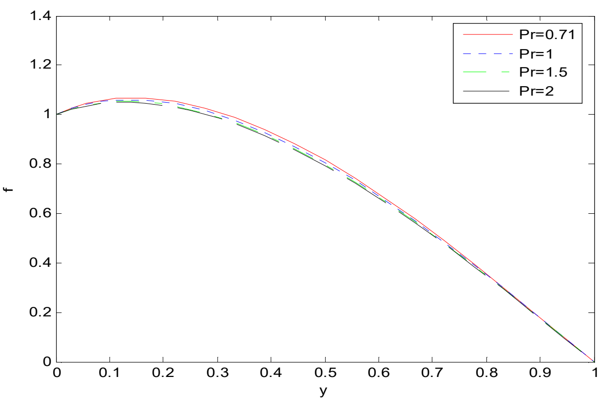

Figure 8. Velocity outline for varied values of Pr

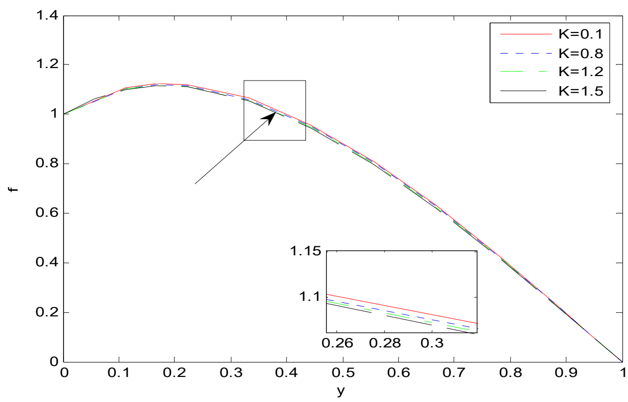

Figure 9. Velocity outline for varied values of K

Figures 11-16 depict a variety of temperature applicants suited to different characteristics of fluids. A rise through the thermophoretic coefficient τ promotes the motion of particles down the temperature variation. This transfer of energy can cause particles to accumulate in colder areas inside the fluid, thereby pulling heat aside from such regions. As this happens, the entire temperature gradient in locations where the particle buildup occurs is susceptible to decreases as seen in Figure 11.

The importance of radiation conveyance of heat grows with Ra. The impact of radiation exchange entails the transmission of energy by waves of electromagnetic radiation. The moment radiation develops more prevalent in all aspects of the heat transfer mechanism, the temperature gradient may fall, and this can be seen in Figure 12. The Dufour phenomenon is related to mass dispersion caused by a temperature distinctive in a fluid. In other acronyms, it encompasses an occurrence in which variations in temperature affect. The moment the Dufour effect gets large, it potentially impacts the whole heat transmission process as well. Figure 13 explains that phenomenon.

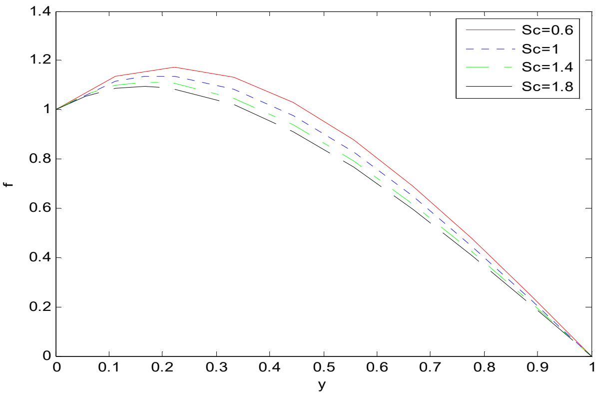

Figure 10. Velocity outline for varied values of Sc

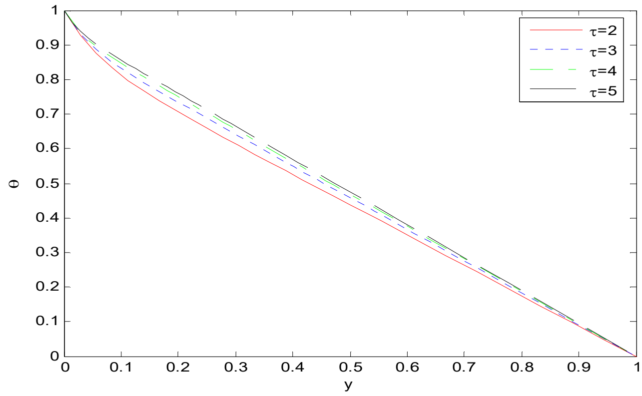

Figure 11. Temperature outline for varied values of τ

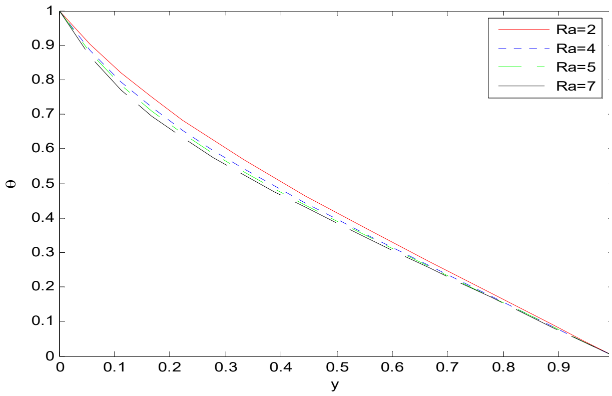

Figure 12. Temperature outline for varied values of Ra

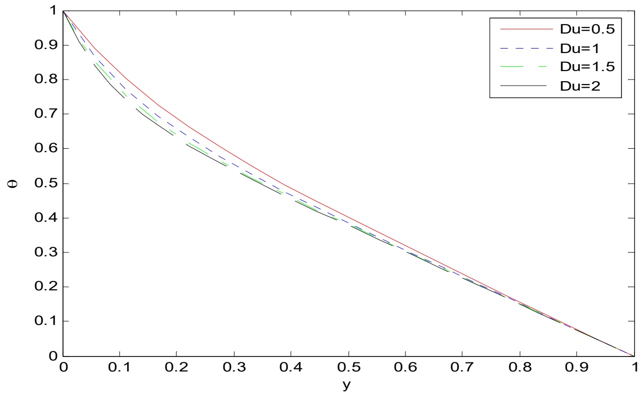

Figure 13. Temperature outline for varied values of Du

The Prandtl number serves as an unrestricted one that describes the relationship between a fluid's viscosity during motion to its thermal diffusion coefficient. It denotes the magnitude of the difference between the momentum propagation vs thermal propagation in a fluid's flow. When weighed against thermal diffusion, a greater Prandtl value suggests that momentum propagation is less important. In fluid motion conditions, especially through an opaque surface's interface layer, a greater Prandtl number might result in a lower temperature gradient as shown in Figure 14 owing to higher diffusion of heat than Momentum diffusion. It has also notice that with the enhanced of Chemical reaction parameter (K), temperature profile declined (Figure 15).

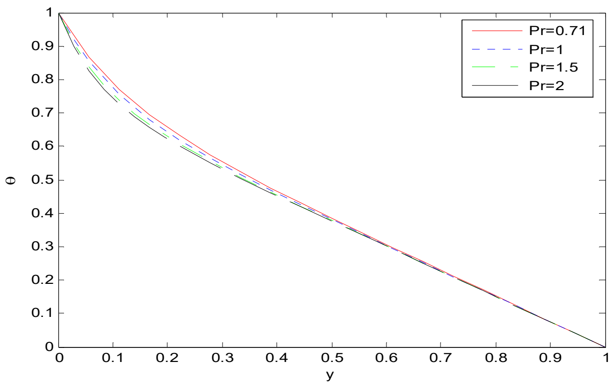

Figure 14. Temperature outline for varied values of Pr

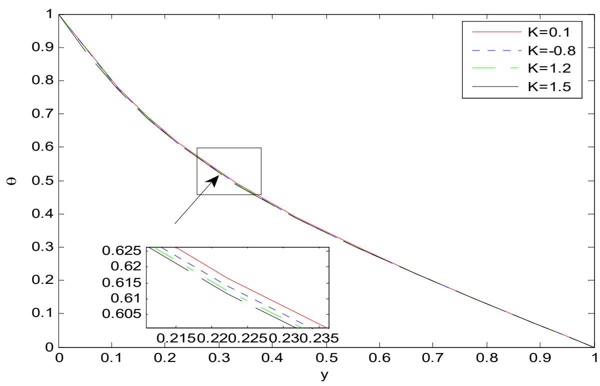

Figure 15. Temperature outline for varied values of K

A diminishing profile of temperature profile has been seen for the enhancement of Schmidt number (Sc) which is described in Figure 16. Figures 17–21 depict varying concentration patterns. The figure demonstrates that as, τ, K, and Du increase, the concentration profiles decrease in rates. The variation in temperature reduces owing to the reduced effectiveness of the wall's heat source, and this brings the concentration of the separation layer adjacent to the surface of the wall and so causes the distribution of concentration to diminish.

The acquisition of a chemical reaction factor is capable of having a considerable impact on the profile of concentration in a fluid motion. Figure 18 exhibits a downward shift in the concentration profile when the chemical reaction factor is increased. When the thermophoretic coefficient is increased, the thermophoretic pressure grows, forcing particles to disperse more forcefully toward cooler places. As a consequence, the distribution of concentrations falls as the thermophoretic characteristics increase, as particles aggregate in the cooler parts of the fluid flow, as seen in Figure 17.

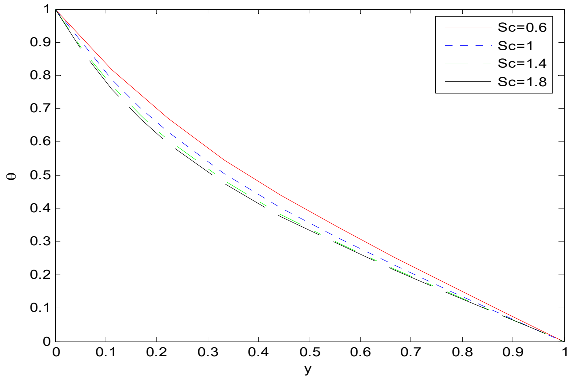

Figure 16. Temperature outline for varied values of Sc

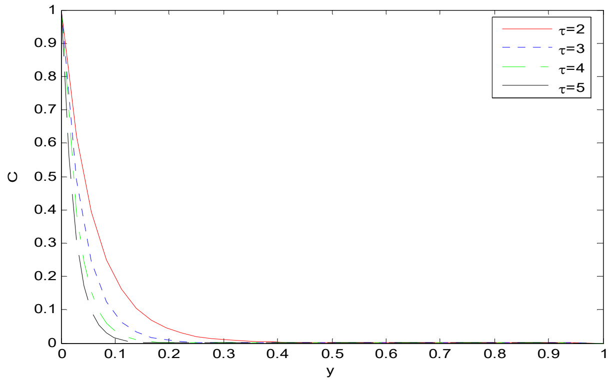

Figure 17. Concentration outline for varied values of τ

Figure 19 makes it apparent that as the Dufour number (Du) rises, the concentration falls. Whenever the Dufour number increases, there is a reduction in the temperature disparity between the fluid and the boundary layer. This ends up resulting in an increases transport of heat if the fluid, which in turn influences its viscosity. As a result, the concentration profile gets flatter.

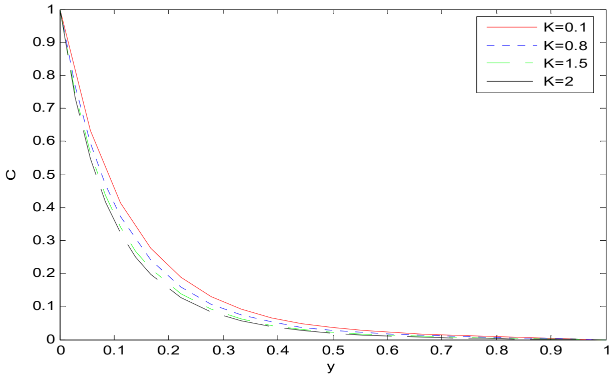

Figure 18. Concentration outline for varied values of K

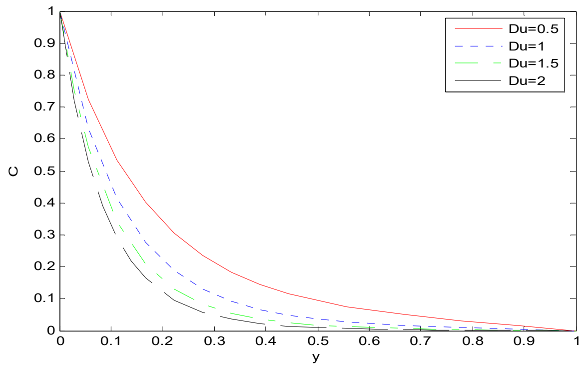

Figure 19. Concentration outline for varied values of Du

Figure 20 shows with the rise of radiation parameter (Ra), Concentration decline. Figure 21 reveals that as Schmidt number (Sc) grows the fluid concentration declines. In actually, the mass diffusivity of the fluid diminishes with increasing Sc, which in consequence lessens in fluid particle concentration.

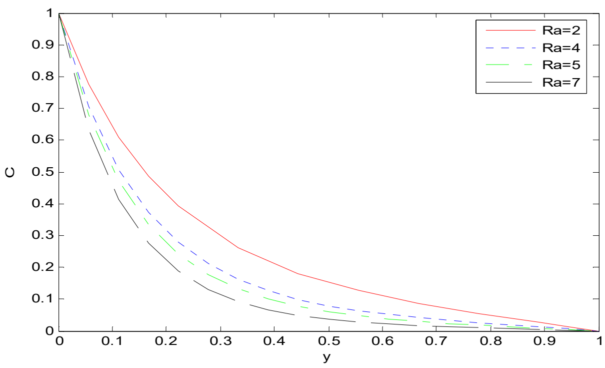

Figure 20. Concentration outline for varied values of Ra

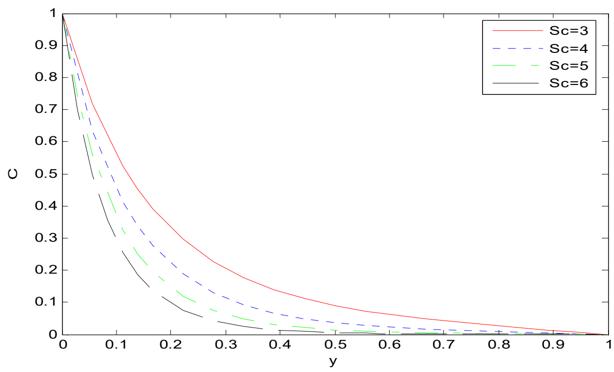

Figure 21. Concentration outline for varied values of Sc

Tables 2,3, and 4 highlight different values of Shearing stress, Nusselt number, and Sherwood number based on various flow attributes. Table 2 shows that shearing stress decreases with increasing magnetic field number, radiation parameter, Prandtl number, Schmidt number and chemical reaction factor but increases with increasing thermophoresis number, Thermal Grashof number and Solutal Grashof number respectively. Table 3 illustrates that the Nusselt number lowers with radiation, Prandtl number and the Dufour effect, but it enhanced for Thermophoretic parameter, Chemical reaction parameter and Schmidt number. Similarly, the Sherwood number enhances with thermophoresis parameter, Grashof number for heat transfer, Prandtl number, chemical reaction parameter and Schmidt number, as seen in Table 4.

Table 2. Shearing stress for different flow parameters

Gr	Gm	M	Pr	K	Sc	Ra	Du	τ	Shearing stress(σ)	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.1036	↓
		1.5							0.8963	
		2							0.706	
		2.5							0.579	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.1036	↑
								3	1.1408	
								4	1.1844	
								5	1.2343	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.2656	↓
				0.8					1.1622	
				1.2					1.0939	
				1.5					1.0285	
8	3	1	0.71	0.1	0.6	2	0.75	2	1.3710	↓
						4			1.1885	
						5			1.1331	
						7			1.0555	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.0555	↑
9									1.3150	
10									1.5745	
11									1.8341	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.0555	↓
			1						0.9845	
			1.5						0.9131	
			2						0.8704	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.0555	↑
	4								1.1530	
	5								1.2506	
	6								1.3481	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.7413	↓
					1				1.5361	
					1.4				1.3781	
					1.8				1.2622	

Table 3. Nusselt Number for different flow Parameters

Gr	Gm	M	Pr	K	Sc	Ra	Du	τ	Nusselt no. (Nu)	
8	3	1	0.71	0.1	0.6	2	0.75	2	1.4581	↓
						4			1.2702	
						5			1.2108	
						7			1.1258	
8	3	1	0.71	0.1	0.6	7	0.5	2	1.1909	↓
							0.75		1.1365	
							1		1.1036	
							1.35		1.0739	
8	3	1	0.71	0.1	0.6	7	0.75	2	2.3758	↑
				0.8					2.4179	
				1.2					2.4409	
				1.5					2.4576	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.5299	↓
			1						1.5098	
			1.5						1.4642	
			2						1.4138	

Gr	Gm	M	Pr	K	Sc	Ra	Du	τ	Nusselt no. (Nu)	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.8423	↑
					1				2.2295	
					1.4				2.2514	
					1.8				2.7164	
8	3	1	0.71	0.1	0.6	7	0.75	2	2.3758	↑
								3	2.7037	
								4	2.9071	
								5	3.0374	

Table 4. Sherwood number for different flow Parameters

Gr	Gm	M	Pr	K	Sc	Ra	Du	τ	Sherwood no. (Sh)	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.2036	↑
								3	1.308	
								4	1.4544	
								5	1.5443	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.1036	↑
9									1.3846	
10									1.6657	
11									1.9467	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.1258	↑
			1						1.6664	
			1.5						1.9856	
			2						2.1549	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.1258	↑
				0.8					2.1599	
				1.2					2.1707	
				1.5					2.2435	
8	3	1	0.71	0.1	0.6	7	0.75	2	1.5245	↑
					1				1.6492	
					1.4				2.5037	
					1.8				3.0886	

CONCLUSIONS

The effects of both concentration and temperature variations, thermophoresis along with a chemical reaction, and the significance of an applied extraneous electromagnetic field on the transmission of heat and mass over a heat-generating fluid are modeled as combined nonlinear situations with optimal boundary constraints. The aforementioned key points emerge based on the foregoing inquiry:

- Oscillating motions of the flow specifications cause the motion, temperature, and concentration domains in the motion of the fluid area to resemble radiation.
- Fluid mobility is slowed by the magnetic field influence, Dufour number, radiation, Chemical reaction parameter, Prandtl number and Schmidt number parameter applications, but it is accelerated by thermophoretic effect, thermal Grashof number and solutal Grashof number.
- The thermophoretic factor slows down the fluid's temperature, although the Prandtl number, the chemical reaction component, and mass diffusivity accelerate it.
- Fluid concentration diminishes with the growth of thermophoretic parameter, Chemical reaction parameter, Dufour number, radiation parameter and Schmidt number accordingly.
- The intensity of the drag force against a specific flow parameter has an effectible impression under the constraints of the various fluid specifications.
- The Sherwood number shows an increasing pattern under the repercussion of thermophoretic parameter, Thermal Grashof number, Prandtl number, chemical reaction parameter and Schmidt number respectively, but the Nusselt number slows down with elevated radiation parameter, Dufour effect and Prandtl number. Also, the Nusselt's number has increasing trend with the rises of chemical reaction parameter, Schmidt number and thermophoretic parameter.
- Shearing stress diminishes with rising magnetic, Chemical reaction, radiation and chemical reaction variation. Also, it diminishes with the enhancement of Prandtl and Schmidt number. But reverse nature is observed in the cases of thermophoretic parameter and both for Grashof number for heat as well as mass transfer.

FUTURE SCOPE

Other numerical techniques have also been used to solve this problem. The strategy for solving this problem can be employing to other complex geometrical arrangements. One could extend this problem to cover a wide range of non-

Newtonian models. Several important physical properties can be undertaken and their repercussions on the flow fluid spotted. There is an abundance of unrealized research potential as a result.

Nomenclature

$\bar{u}$ and $\bar{v}$ are the corresponding velocity of the fluid motion indices toward and tangential to the plate
g acceleration due to gravity
β heat transmission amount of volume growth
$\bar{\beta}$ amount of extension with species heat at persistent pressure
$\bar{T}$ fluid temperature
T_∞ far field temperature
$\bar{C}$ species concentration
C_∞ far field concentration
ρ fluid density
k_T thermal conductivity
C_p specific heat at persistent pressure
ν kinematic viscosity
σ thermal conductivity
C_s amount mass diffusivity
κ is the thermal conductivity
D chemical molecular diffusivity
D_m concentration susceptibility
k_r rate of chemical reaction

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REFERENCES

[1] M.B. Riaz, M. Asgir, A.A. Zafar, and S. Yao, "Combined effects of heat and mass transfer on MHD free convective flow of Maxwell fluid with variable temperature and concentration," Mathematical Problems in Engineering, **2021**, 1-36, (2021). https://doi.org/10.1155/2021/6641835
[2] R.D. Ene, N. Pop, and R. Badarau, "Heat and Mass Transfer Analysis for the Viscous Fluid Flow: Dual Approximate Solutions," Mathematics, **11**(7), 16-48 (2023). https://doi.org/10.3390/math11071648
[3] I.H. Qureshi, M. Nawaz, M.A. Abdel-Sattar, S. Aly, and M. Awais, "Numerical study of heat and mass transfer in MHD flow of nanofluid in a porous medium with Soret and Dufour effects," Heat Transfer, **50**(5), 4501-4515 (2021). https://doi.org/10.1002/htj.22085
[4] E.O. Fatunmbi, and A. Adeniyan, "Heat and mass transfer in MHD micropolar fluid flow over a stretching sheet with velocity and thermal slip conditions," Open Journal of Fluid Dynamics, **8**, 195-215 (2018). https://doi.org/10.4236/ojfd.2018.82014
[5] J.E. Salhi, K. Amghar, H. Bouali, and N. Salhi, "Combined heat and mass transfer of fluid flowing through horizontal channel by turbulent forced convection," Modelling and Simulation in Engineering, **2020**, 1-11 (2020). https://doi.org/10.1155/2020/1453893
[6] B.G. Agaie, S. Isa, A.S.A. Mai'anguwa, and A.S. Magaji, "Heat and mass transfer of MHD for an unsteady viscous oscillatory flow," Science World Journal, 16(2), 138-144 (2021). https://www.ajol.info/index.php/swj/article/view/212378/200285
[7] G.P. Vanitha, U.S. Mahabaleshwar, M. Hatami, and X. Yang, "Heat and mass transfer of micropolar liquid flow due to porous stretching/shrinking surface with ternary nanoparticles," Sci. Rep. **13**(1), 3011 (2023). https://doi.org/10.1038/s41598-023-29469-0
[8] B. Dey, J.M. Nath, T.K. Das, and D. Kalita, "Simulation of transmission of heat on viscous fluid flow with varying temperatures over a flat plate," JP Journal of Heat and Mass Transfer, **30**, 1-18 (2022). https://doi.org/10.17654/0973576322052
[9] B. Dey, and R. Choudhury, "Slip Effects on Heat and Mass Transfer in MHD Visco-Elastic Fluid Flow Through a Porous Channel," in: *Emerging Technologies in Data Mining and Information Security: Proceedings of IEMIS 2018*, vol. 1, (Springer Singapore, 2019). pp. 553-564. https://doi.org/10.1007/978-981-13-1951-8_50
[10] R. Kandasamy, K.K.S. Prabhu, and R. Periasamy, "Effects of chemical reaction, heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection," Int. J. Heat Mass Transfer, **48**, 1388-1396 (2005). https://doi.org/10.1016/j.ijheatmasstransfer.2004.10.008
[11] R. Choudhury, and B. Dey, "Unsteady Thermal Radiation Effects on MHD Convective Slip Flow of Visco-Elastic Fluid Past a Porous Plate Embedded in Porous Medium," International journal of applied mathematics and statistics, **57**(2), 215-226 (2018). http://www.ceser.in/ceserp/index.php/ijamas/article/view/5384/5439
[12] K.V.S. Raju, T.S. Reddy, M.C. Raju, P.V.S. Narayana, and S. Venkataramana, "MHD Convective flow through porous medium in a horizontal channel with insulated and impermeable bottom Walls in the presence of viscous dissipation and joule heating," Ain Shams Engineering Journal, **5**, 543-551 (2014). https://doi.org/10.1016/j.asej.2013.10.007
[13] B.K. Kalita, R. Choudhury, and P. Dhar, "Elucidation of MHD Boundary Layer Flow past a plate with Viscous Dissipation," International Journal of Engineering Research and Technology, **13**, 3321-3327 (2020). https://dx.doi.org/10.37624/IJERT/13.11.2020.3321-3327
[14] S. Das, R.N. Jana, and O.D. Makinde, "Magnetohydrodynamic mixed convective slip flow over an inclined porous plate with viscous dissipation and Joule heating," Alexandria Engineering Journal, **54**(2), 251-261 (2015). https://doi.org/10.1016/j.aej.2015.03.003
[15] B. Mahanthesh, B.J. Gireesha, R.S. Gorla, and O.D. Makinde, "Magnetohydrodynamic three-dimensional flow of nanofluids with slip and thermal radiation over a nonlinear stretching sheet: a numerical study," Neural Computing and Applications, **30**, 1557-1567 (2018). https://doi.org/10.1007/s00521-016-2742-5
[16] Y.P. Lv, N. Shaheen, M. Ramzan, M. Mursaleen, K.S. Nisar, and M.Y. Malik, "Chemical reaction and thermal radiation impact on a nanofluid flow in a rotating channel with Hall current," Scientific Reports, **11**(1), 19-47 (2021). https://doi.org/10.1038/s41598-021-99214-y
[17] A.M. Sedki, "Effect of thermal radiation and chemical reaction on MHD mixed convective heat and mass transfer in nanofluid flow due to nonlinear stretching surface," Results in Materials, **16**, 100334 (2022). https://doi.org/10.1016/j.rinma.2022.100334
[18] N.N.W. Khalili, A.A. Samson, A.S.A. Aziz, and Z.M. Ali, "Chemical reaction and radiation effects on MHD flow past an exponentially stretching sheet with heat sink," Journal of Physics: Conference Series, **890**(1), 12-25 (2017). https://doi.org/10.1088/1742-6596/890/1/012025
[19] D.J. Samuel, and I.A. Fayemi, "Impacts of variable viscosity and chemical reaction on Ohmic dissipative fluid flow in a porous medium over a stretching sheet with thermal radiation," Heat Transfer, **52**, 5022-5040 (2023). https://doi.org/10.1002/htj.22915

[20] S.A.G. A. Shah, A. Hassan, H. Karamti, A. Alhushaybari, S.M. Eldin, and A. M. Galal, "Effect of thermal radiation on convective heat transfer in MHD boundary layer Carreau fluid with chemical reaction," Scientific Reports, **13**(1), 4117 (2023). https://doi.org/10.1038/s41598-023-31151-4
[21] E. Seid, E. Haile, and T. Walelign, "Multiple slip, Soret and Dufour effects in fluid flow near a vertical stretching sheet in the presence of magnetic nanoparticles," International Journal of Thermofluids, **13**, 100136 (2022). https://doi.org/10.1016/j.ijft.2022.100136
[22] M. Hasanuzzaman, M.A.K. Azad, and M.M. Hossain, "Effects of Dufour and thermal diffusion on unsteady MHD free convection and mass transfer flow through an infinite vertical permeable sheet," SN Applied Sciences, **3**(12), 882 (2021). https://doi.org/10.1007/s42452-021-04842-8
[23] I. Filahi, M. Bourich, M. Hasnaoui, and A. Amahmid, "Analytical and numerical study of Soret and Dufour effects on thermosolutal convection in a horizontal Brinkman porous layer with a stress-free upper boundary," Mathematical Problems in Engineering, **2020**, 1-17 (2020). https://doi.org/10.1155/2020/4046570
[24] N.A. Shah, S.J. Yook, and O. Tosin, "Analytic simulation of thermophoretic second grade fluid flow past a vertical surface with variable fluid characteristics and convective heating," Scientific Reports, **12**(1), 5445 (2022). https://doi.org/10.1038/s41598-022-09301-x
[25] F. Mabood, M. D. Shamshuddin, and S. R. Mishra, "Characteristics of thermophoresis and Brownian motion on radiative reactive micropolar fluid flow towards continuously moving flat plate: HAM solution," Mathematics and Computers in Simulation, **191**, 187-202 (2022). https://doi.org/10.1016/j.matcom.2021.08.004
[26] J.V. Tawade, C.N. Guled, S. Noeiaghdam, U. Fernandez-Gamiz, V. Govindan, and S. Balamuralitharan, "Effects of thermophoresis and Brownian motion for thermal and chemically reacting Casson nanofluid flow over a linearly stretching sheet," Results in Engineering, **15**, 100448 (2022). https://doi.org/10.1016/j.rineng.2022.100448
[27] B.K. Jha, and H.N. Sani, "Role of thermophoresis on unsteady/steady mixed convective flow in a vertical channel having convective boundary conditions," SN Applied Sciences, **4**(4), 131 (2022). https://doi.org/10.1007/s42452-022-04971-8
[28] H.P. Mondal, and D.S. Chatterjee, "Thermophoresis and Soret-Dufour on MHD mixed convection mass transfer over an inclined plate with non-uniform heat source/sink and chemical reaction," Ain Shams Engineering Journal, **9**, 2111-2121 (2018). https://doi.org/10.1016/j.asej.2016.10.015
[29] P.S. Reddy, and J.C. Ali, "Soret and Dufour effects on MHD heat and mass transfer flow of micropolar fluid with thermophoresis," Journal of Naval Architecture and Marine Engineering, **13**(1), 39–50 (2016). https://doi.org/10.3329/jname.v13i1.23974
[30] F. Hussain, A. Hussain, and S. Nadeem, "Thermophoresis and Brownian model of pseudo-plastic nanofluid flow over a vertical slender cylinder," Mathematical Problems in Engineering, **2020**, 1-10 (2020). https://doi.org/10.1155/2020/8428762
[31] B. Deka, and R. Choudhury, "Impact of thermophoretic MHD Visco-elastic fluid flow past a wedge with heat source and chemical reaction," in: *Proceedings of IEMIS*, vol. 1, edited by A. Abraham, P. Dutta, J. Mandal, A. Bhattacharya, and S. Dutta, (Springer, Singapore, 2018), pp. 541-552. https://doi.org/10.1007/978-981-13-1951-8_49;
[32] R. Choudhury, and P. Dhar, "Diffusion Thermo effects of visco-elastic fluid past a porous surface in presence of magnetic field and radiation," International Journal of Innovative Research in Science, Engineering and Technology, **2**(3), (2013). https://www.ijirset.com/upload/march/45_DIFFUSION%20THERMO.pdf
[33] H. Upreti, A.K. Pandey, S.K. Rawat, and M. Kumar, "Modified Arrhenius and thermal radiation effects on three-dimensional magnetohydrodynamic flow of carbon nanotubes over bi-directional stretchable surface," Journal of Nanofluids, **10**(4), 538-551 (2021). https://doi.org/10.1166/jon.2021.1804
[34] J.B. Young, "Thermophoresis of a spherical particle: reassessment, clarification, and new analysis," Aerosol Science and Technology, **45**(8), 927-948 (2011). https://doi.org/10.1080/02786826.2011.569777
[35] Dey, B., Dukru, D., Das, T. K., & Nath, J. M. (2024). Modelling and Simulating the Heat Transference in Casson EMHD Fluid Motion Exacerbated by A Flat Plate with Radiant Heat and Ohmic Heating. East European Journal of Physics, (2), 172-180. https://doi.org/10.26565/2312-4334-2024-2-16
[36] B. Dey, B. Kalita, and R. Choudhury, "Radiation and Chemical reaction effects on unsteady viscoelastic fluid flow through porous medium," Frontiers in Heat and Mass Transfer (FHMT), **18**, 1-8 (2022). https://doi.org/10.5098/hmt.18.32
[37] A.H. Mirza, B. Dey, and R. Choudhury, "The detrimental effect of thermal exposure and thermophoresis on MHD flow with combined mass and heat transmission employing permeability," International Journal of Applied Mechanics and Engineering, **29**(1), 90-104 (2024). https://doi.org/10.59441/ijame/181556
[38] Shampine, Lawrence F., Jacek Kierzenka, and Mark W. Reichelt. "Solving boundary value problems for ordinary differential equations in MATLAB with bvp4c." Tutorial notes 2000 (2000): 1-27.
[39] S. Ahmed, "Study of thermal radiation and ohmic heating for steady magnetohydrodynamics natural convection boundary layer flow in a saturated porous regime," International Journal on Recent and Innovation Trends in Computing and Communication, **2**(9), 2796-2801 (2014). https://core.ac.uk/download/pdf/539907531.pdf

ВПЛИВ ТЕПЛОМАСОПЕРЕНОСУ НА МГД ЦИРКУЛЯЦІЮ РІДИНИ В ПОЄДНАННІ З ВЕРТИКАЛЬНОЮ ПОВЕРХНЕЮ ПРИ ВИНИКНЕННІ РАДІАЦІЙНОГО ТЕРМОФОРЕЗУ ТА РЕПЕРКУСІЇ ДЮФУРА

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Поточне дослідження моделює модель передачі маси та теплової енергії на МГД-потоці рідини за умов відхилення концентрації та температури на двовимірній в'язкій рідині вздовж вертикальної грані. Після оцінки граничного шару, математичного моделювання руху рідин, перенесення тепла та маси під дією випромінювання, термофорезу та реперкусії Дюфура генерується як набір диференціальних рівнянь у похідних. Було оцінено пружне всмоктування поверхні. Вбудований вирішувач bvp4c в MATLAB використовується для чисельного налагодження вищезгаданих моделей. За допомогою візуалізації та таблиць досліджується шкідливий вплив змінних на швидкість, температуру, а також градієнти концентрації в поєднанні з тертям шкіри, числом Нуссельта та числом Шервуда. Чудова узгодженість може бути продемонстрована при порівнянні між найсучаснішими висновками та тими, які раніше були доступні в літературі за конкретних обмежених обставин. Ефект Дюфура, випромінювання, термофорез і число Ґрасгофа – це всі фактори, які впливають на рух рідини та передачу тепла на межовому шарі бруду. Крім того, розраховуються зміни напруги зсуву, числа Нуссельта та коефіцієнта числа Шервуда. Отримані результати мають вирішальне значення для оптимізації різноманітних технологій і систем на основі рідини, що дозволяє розвивати низку галузей, включаючи енергоефективність, охолодження електроніки, медичне управління та багато іншого.
Ключові слова: *хімічна реакція; ефект Дюфура; теплопередача; масообмін; випромінювання; термофорез*