ADV MATH SCI JOURNAL
Advances in Mathematics: Scientific Journal **10** (2021), no.2, 855–868
ISSN: 1857-8365 (printed); 1857-8438 (electronic)
https://doi.org/10.37418/amsj.10.2.15

ANALYSIS OF RADIATION, CHEMICAL REACTION, SORET AND DUFOUR EFFECTS NEAR STAGNATION POINT ON MHD FLOW THROUGH A STRETCHING SHEET

Krishnandan Verma[1], Sanjit Basfor, and Bishwaram Sharma

ABSTRACT. The current investigation aims to study Soret and Dufour effects on MHD flow near stagnation point through a heated stretching sheet including the impact of radiation and chemical reaction. Similarity transformations are adopted to covert the governing equations to nonlinear ODE's. Numerical approach has been adopted to solve the equations using MATLAB's solver bvp4c. The graph of velocity, temperature, and concentration distributions are obtained for different parameters. In order to know the precision of the numerical solution, comparison has been made between the current outcomes and the outcomes present in the literature and the outcomes show fair agreement. Soret and Dufour effects affect the species concentration and fluid temperature to a significant extent as the former raises the species concentration close to the surface of the stretching sheet and the latter increases the temperature of the fluid.

[1]*corresponding author*

2020 *Mathematics Subject Classification.* 76D05, 76S05.
Key words and phrases. Chemical reaction, Dufour effect, radiation, stretching sheet, Soret effect, bvp4c.
Submitted: 11.01.2021; *Accepted:* 26.01.2021; *Published:* 21.02.2021.

1. Introduction

Heat and mass transfer processes have become increasingly important in engineering sectors. Many engineering applications involve the process of transfer of heat past an extending sheet like metallurgical process, glass production, purification of crude oil, drawing of wires etc. So the study of stretching sheet has gathered significant attention at the present time by modern researchers due to its valuable applications. Ishak et al. [1] studied the transfer of heat over an extending surface on MHD flow near stagnation point and found that magnetic parameter and stretching velocity affect significantly the heat transfer process.Mishra et al. [2] investigated numerically boundary layer MHD flow in porous media through an expanding sheet under the influence of external heat. Nandy [3] analysed MHD non-Newtonian flow of Casson fluid past an extending surface and acquired analytic solution adopting Homotopy Analysis Method. Ali et al. [4] carried numerical investigation due to an expanding surface on steady, viscous, MHD flow close to stagnation point under magnetic environment. Alavi et al. [5] adopted Keller box method to analyse numerically the effect on an exponentially extending surface due to stagnation point MHD flow. Rashidi et al. [6] examined analytically, transfer of heat past a vertical extending surface by using two auxiliary parameters. Vajravelu and Nayfeh [7] studied numerically transfer of heat over an infinite stretching sheet in present of external heat.

Ahmed et al. [8] studied analytically MHD Jeffrey fluid through an expanding surface considering heat generation, thermal radiation and Joule heating. Noghrehabadi et al. [9] investigated partial slip conditions on nanofluid flow with heat as well as mass transfer past an extending surface. Yasmin et al. [10] analysed the transfer of heat in MHD non-Newtonian micropolar fluid through a curl-extended sheet. Ibrahim [11] investigated micropolar boundary layer slip flow of second order fluid past an expanding sheet with magnetic effects. Mohanty et al. [12] investigated, in porous medium, unsteady transfer of heat and mass due to micropolar fluid through an extending surface. Das et al. [13] investigated numerically unsteady nanofluid flow through a heated expanding surface considering radiation and found that the Brownian motion parameter remarkably affect the rate of heat transfer. Razi et al. [14] carried out numerical study in porous medium of Williamson nanofluid through an extending surface considering the impact of slip parameters and magnetic effects.Important investigations on stretching sheet, porous media and nanofluid can be looked in the literatures [15–19].

The applications of chemical reaction on flow problems are seen in many engineering sectors viz. chemical industries, petrochemical industries, cooling of nuclear reactors etc. Jonnadula et al. [20] studied the effect of chemically reacting fluid in porous medium with the transfer of heat and mass on MHD flow through an extending sheet. Numerical solution of Casson fluid flow with slip through an extending surface with thermal diffusion and diffusion thermo effects was obtained by Ullah et al. [21].

The present work aims to examine the impact of chemical reaction, Soret and Dufour effect with the transfer of heat and mass on MHD flow over a stretching sheet. The solution is obtained numerically using MATLAB's built in solver bvp4c and graphs are obtained for different parameters involved in the study.

2. Problem Formulation

Consider MHD flow near stagnation point in porous medium through a heated stretching sheet in a two dimensional system as shown in Figure 1. Fluid mixture is incompressible, chemically reacting and electrical conducting and the fluid is assumed steady. The x-axis is considered in horizontal direction while y-axis is taken perpendicular to it. Normal to x-axis a uniform weak magnetic field of strength B_0 is applied, and the induced magnetic field is neglected. Let the velocity of the free stream, stretching velocity, and temperature of the sheet be denoted by $U_\infty(x)$,$U_w(x)$ and $T_w(x)$, respectively.

Considering the assumptions mentioned above, the governing equations of the problem [22] are:

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}=0,$$

$$U\frac{\partial U}{\partial x}+V\frac{\partial V}{\partial y}=U_\infty\frac{\partial U_\infty}{\partial x}+\upsilon\frac{\partial^2 U}{\partial y^2}-\frac{1}{\rho}B_0^2\sigma(U-U_\infty)-\frac{\upsilon}{K}U, \tag{2.1}$$

$$U\frac{\partial T}{\partial x}+V\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2}+\frac{1}{\rho}\frac{Q}{c_p}(T-T_\infty)-\frac{1}{c_p\rho}\frac{\partial q_r}{\partial y}, \tag{2.2}$$

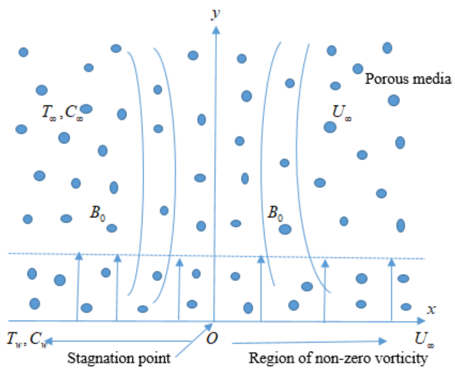

FIGURE 1. Geometric configuration

$$U\frac{\partial C}{\partial x} + V\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} + \frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2} - K_{c_1}(C - C_\infty). \tag{2.3}$$

The relevant conditions on the boundaries are

$$y = 0 : U = U_w(x), V = V_w(x), T = T_w(x), C = C_w(x), \tag{2.4}$$

$$y \to 0 : U = U_\infty(x), T = T_\infty(x), C = C_\infty(x), \tag{2.5}$$

where $V_w(x) = -(av)^{\frac{1}{2}}s_0, C_w(x) = cx^m + C_\infty, U_w(x) = ax, U_\infty(x) = bx$ and $T_w(x) = cx^m + T_\infty; a, c > 0, b \geq 0$.

Heat flux due radiation,

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

where $T^4 \approx 4T_\infty^3 T - 3T_\infty^4$

When we introduce stream function ψ as $U = \frac{\partial \psi}{\partial y}$ and $V = -\frac{\partial \psi}{\partial x}$, then the equation of continuity is satisfied automatically.

The following similarity transformations are employed to make equations (2.1)-(2.3) dimensionless:

$$\psi = x\sqrt{av}f(\eta), \eta = y\sqrt{\frac{a}{v}}, \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}. \tag{2.6}$$

The dimensionless equations obtained using (2.6) are given by:

$$f''' - f'^2 + ff'' + v_0^2 - M(f' - v_0) - k_p f' = 0, \tag{2.7}$$

$$(1 + \frac{4}{3}R)\theta'' + Pr(f\theta' - mf'\theta + \delta\theta + D_f\phi'') = 0, \tag{2.8}$$

$$\phi^{''} + Sc(f\phi^{'} - mf^{'}\phi + Sr\theta^{''} - k_c\phi) = 0, \tag{2.9}$$

where $Pr = \frac{\upsilon}{\alpha}$, $D_f = \frac{D_m k_T (C_w - C_\infty)}{\upsilon c_s c_p (T_w - T_\infty)}$, $Sr = \frac{D_m k_T (T_w - T_\infty)}{\upsilon T_m (C_w - C_\infty)}$, $k_c = \frac{K_{c_1}}{a}$, $Sc = \frac{\upsilon}{D_m}$, $R = \frac{4\sigma^* T_\infty^3}{k^* k}$, $\delta = \frac{Q}{\rho c_p a}$, $v_0 = \frac{b}{a}$, $k_p = \frac{\upsilon}{aK}$ and $M = \frac{\sigma B_0^2}{a\rho}$.

The boundary conditions (2.4) and (2.5) are transformed to

$$\eta = 0 : f(0) = s_0, f^{'}(0) = 1, \theta(0) = 1, \phi(0) = 1, \tag{2.10}$$

$$\eta \to \infty : f^{'}(\infty) = v_0, \theta(\infty) = 0, \phi(\infty) = 0, \tag{2.11}$$

$$Skin - friction, C_{fx} = \frac{\tau_w}{\rho U_e^2} = Re_x^{-0.5} f^{''}(0),$$

$$NusseltNumber, Nu_x = \frac{1}{k}\frac{xq_w}{(T_w - T_\infty)} = -Re_x^{0.5}(1 + \frac{4}{3}R)\theta^{'}(0),$$

$$SherwoodNumber, Sh_x = \frac{xm_w}{D_m(C_w - C_\infty)} = -Re_x^{0.5}\phi^{'}(0).$$

2.1. **Methodology.** The equations (2.7)-(2.9) along with boundary restrictions (2.10) and (2.11) are solved using MATLAB's solver bvp4c. The numerical solutions are represented by graphs for different parameters affecting the problem.

3. Results and Discussions

The graphs for temperature, concentration, and velocity are obtained numerically in the form of graphs for R, M, Sr, D_f and k_c. In the computational procedure, the parameters affecting the problems are assigned the following values viz. $s_0 = 0.5, k_c = 0.1, v_0 = 0.1, k_p = 0.5, R = 0.5, Pr = 0.71, \delta = 0.2, m = 0.5, Sc = 0.62, M = 0.5, Sr = 0.2$ and $D_f = 0.2$. The values of the parameter for which the graph is obtained are changed according to the convenience whereas the values of the remaining parameters are kept fixed. The numerical precision of the current study is confirmed by comparing the present result for $f^{''}$(0)and $-\theta^{'}(0)$ in Table 1 and Table 2, with the outcomes in the literatures [22–24] and the current outcomes are in fair agreement.

The consequence of Radiation parameter R on temperature, and concentration distribution are depicted in Figure 2 and Figure 3. From the figures, it is spotted that the rise in the values of radiation parameter raises the temperature of the fluid but decreases the species concentration. The rise in temperature

TABLE 1. Comparison between the present result and previous works [22–24] of $f''(\theta)$ for different values of v_0 and $Pr = 0.71, m = 0.5, \delta = 0.2, M = s_0 = k_p = R = k_c = Sc = D_f = Sr = 0$.

v_0	Hayat et al. [24]	Ibrahim et al. [23]	Agbaje et al. SPM [22]	Agbaje et al. SQLM [22]	Present study
0.01	-0.99802	-0.9980	-0.9980	-0.9980	-0.9980
0.02	-0.99578	-	-0.9958	-0.9958	-0.9958
0.05	-0.98757	-	-0.9876	-0.9876	-0.9876
0.10	-0.96938	-0.9694	-0.9694	-0.9694	-0.9694
0.20	-0.91810	-0.9181	-0.9181	-0.9181	-0.9181
0.50	-0.66732	-0.6673	-0.6673	-0.6673	-0.6673
1.00	0.00	-	-	0.00	0.00

TABLE 2. Comparison $-(1+\frac{4}{3}R)\theta'(0)$ of the present result with [23] and [22] for different values of v_0 and Pr when the values of other parameters are $M = s_0 = Sr = D_f = k_p = R = k_c = Sc = m = \delta = 0$.

v_0	Pr	Ibrahim et al. [23]	Agbaje et al. SPM [22]	Agbaje et al. SQLM [22]	Present study
0.1	1.0	0.6022	0.6022	0.6022	0.6022
0.2	1.0	0.6245	0.6245	0.6245	0.6245
0.5	1.0	0.6924	0.6924	0.6924	0.6925
0.1	1.5	0.7768	0.7768	0.7768	0.7768
0.2	1.5	0.7971	0.7971	0.7971	0.7971
0.5	1.5	0.8648	0.8648	0.8648	0.8648

of the fluid is due to the increase in heat flux associated with the larger values of thermal radiation. Mathematically radiation parameter is inversely proportional to Rosseland absorption coefficient k^*, i.e., increasing the values of R will simultaneous decreases k^*. Therefore decrease in the value of k^* will imply high radiative heat flux thereby increasing the fluid temperature.

The distribution of velocity, temperature, and concentration for various values of magnetic parameter M are portrayed in Figures 4, 5 and 6. It is seen in Figure 4 that the magnetic field have a retarding effect on the fluid velocity as the higher values of M reduces the velocity of the fluid. The magnetic field give rise to an opposing force known as Lorentz force which is responsible for decay of the velocity field. From Figure 5 and Figure 6, it is noticed that the temperature and concentration increases when the value magnetic parameter is raised. Both the temperature and species concentration is more near the surface of the sheet but as we go away from the sheet in the y-direction the temperature as well as concentration drops.

The impact of Soret number Sr on temperature and concentration profiles are depicted in Figure 7 and Figure 8 respectively. The effect of Soret number is profoundly seen on the species concentration of the fluid. The rise in Soret number increases the species concentration. There is negligible increase in temperature with the increasing values of Soret number as depicted in Figure 7. Soret number is ratio of temperature difference $(i.e.T_w - T_\infty)$ and concentration difference $(i.e.C_w - C_\infty)$, so raising the value of Sr simultaneously increases the temperature difference and decreases the concentration difference which ultimately raises the species concentration and decreases the fluid temperature as evident from the graphs.

The impact of Dufour number D_f on fluid temperature and concentration are represented in Figure 9 and Figure 10 respectively. It is spotted that the

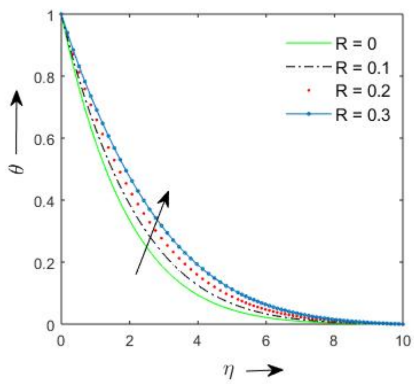

FIGURE 2. Variation of temperature due to R

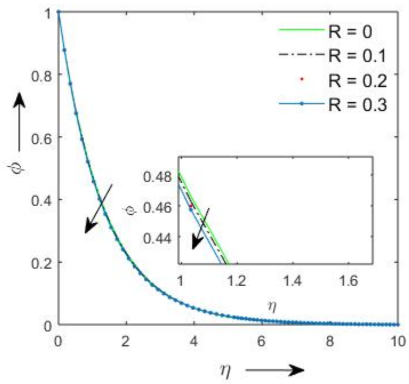

FIGURE 3. Variation of concentration due to R

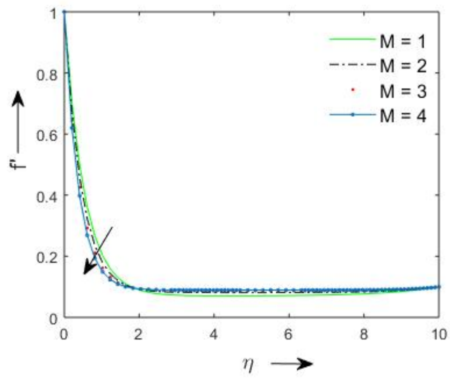

FIGURE 4. Variation of velocity due to M

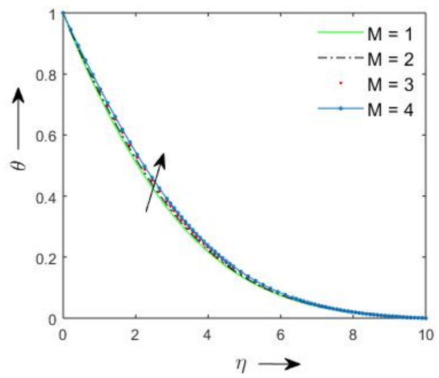

FIGURE 5. Variation of temperature due to M

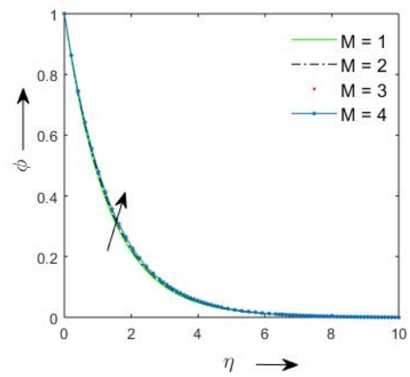

FIGURE 6. Variation of concentration due to M

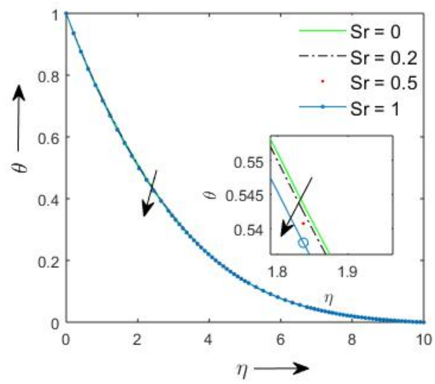

FIGURE 7. Variation of temperature due to Sr

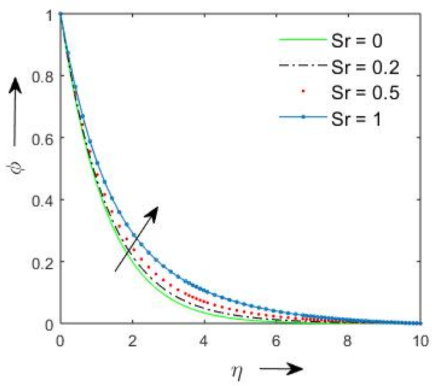

FIGURE 8. Variation of concentration due to Sr

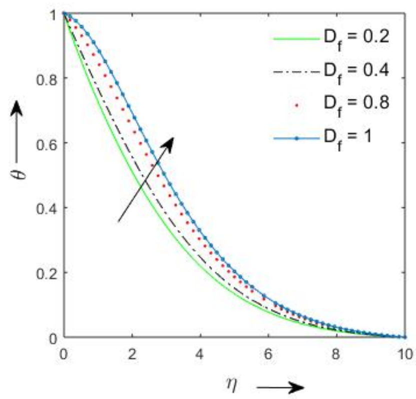

FIGURE 9. Variation of temperature due to D_f

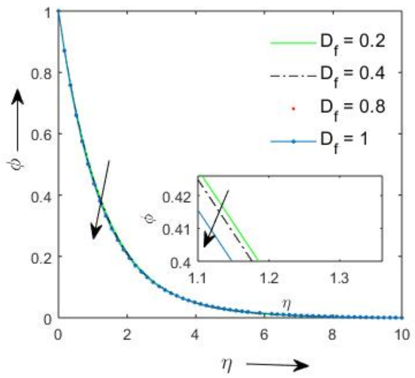

FIGURE 10. Variation of concentration due to D_f

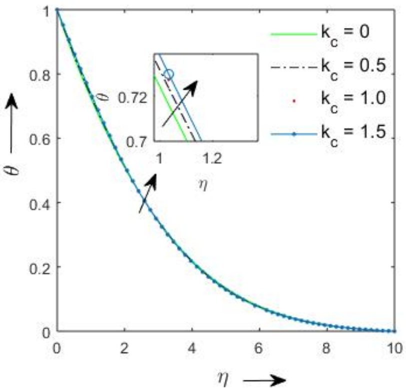

FIGURE 11. Variation of temperature due to k_c

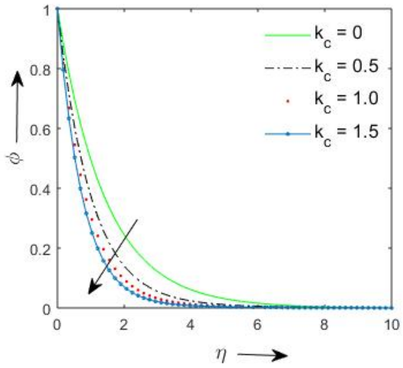

FIGURE 12. Variation of concentration due to k_c

rise in Dufour number boosts the fluid temperature but decreases the species concentration. Dufour number is the ratio between concentration difference $(i.e.C_w - C_\infty)$ and temperature difference $(i.e.T_w - T_\infty)$, so raising the Dufour number will increase the concentration difference and decrease the temperature difference which ultimately decreases the species concentration and increases the temperature of the fluid as evident from the graphs.

The influence of dimensionless chemical reaction k_c on temperature, and concentration distribution are represented in Figure 11 and Figure 12 respectively. From Figure 11, it is spotted that growth in the value of increases the temperature close to the surface of the sheet but the rise in temperature is very small. From Figure 12, it is spotted that the rise in value of k_c decreases the species concentration of the fluid because molecular diffusivity decreases with the rise in k_c.

The effect of R,Sr,D_f and k_c on the transfer of heat and mass have been presented in Table 3. The rise in Sr enchances the rate of heat transfer and retards the rate of mass transfer but a reverse case is observed in case of D_f, K_c, and R.

TABLE 3. Numerical values of $-\theta^{'}(0)$ and $-\phi^{'}(0)$ for Sr, D_f, k_c and R when the values of other parameters are taken as $M = 0.5, v_0 = 0.1, k_p = 0.5, m = 0.5, Pr = 0.71, Sc = 0.62$ and $\delta = 0.2$.

Sr	D_f	k_c	R	$-\theta^{'}(0)$	$-\phi^{'}(0)$
0	0.2	0.1	0.5	0.3195	0.7953
0.2	0.2	0.1	0.5	0.3216	0.7718
0.5	0.2	0.1	0.5	0.3247	0.7357
1.0	0.2	0.1	0.5	0.3301	0.6730
0.2	0.2	0.1	0.5	0.3216	0.7718
0.2	0.4	0.1	0.5	0.2540	0.7790
0.2	0.8	0.1	0.5	0.1154	0.7938
0.2	1.0	0.1	0.5	0.0443	0.8014
0.2	0.2	0	0.5	0.3268	0.7064
0.2	0.2	0.5	0.5	0.3054	0.9723
0.2	0.2	1.0	0.5	0.2903	1.1595
0.2	0.2	1.5	0.5	0.2779	1.3131
0.2	0.2	0.1	0	0.5312	0.7416
0.2	0.2	0.1	0.1	0.4625	0.7489
0.2	0.2	0.1	0.2	0.4074	0.7547
0.2	0.2	0.1	0.3	0.3627	0.7594

4. CONCLUSION

The present investigation analyses the importance of transfer of heat and mass past a heated stretching sheet with Soret and Dufour effects near stagnation point on MHD flow. Important results derived from the study are listed below:

(1) Magnetic parameter retards the growth of the fluid velocity.

(2) Fluid temperature grows when the values of radiation parameter, magnetic parameter, chemical reaction parameter and Dufour number are raised whereas Soret number retards the growth of fluid temperature.
(3) Larger values of magnetic parameter and Soret number boosts the fluid concentration whereas rise in the values of chemical reaction parameter, Dufour number and radiation parameter decreases the fluid concentration.

TABLE 4. Nomenclature

a,b,c,m	Constants	T_∞	Fluid temperature far away from the sheet
B_0	Magnetic Field	$T_w(x)$	Temperature of the sheet
C_{fx}	Skin-friction coefficient	U, V	Velocity in x and y directions
c_p	Specific heat at constant pressure	$U_w(x)$	Stretching velocity
$C_w(x)$	Concentration near the sheet	$U_\infty(x)$	Free stream velocity
f'	Dimensionless velocity	$V_w(x)$	Mass flux velocity
k	Thermal conductivity	s_0	Suction/injection velocity
k_c	Chemical reaction parameter	α	Thermal diffusivity
k^*	Rosseland absorption coefficient	δ	Dimensionless heat generation /absorption coefficient
R	Radiation parameter	η	Similarity Variable
Nu_x	Nusselt number	v_0	Velocity ratio parameter
M	Magnetic parameter	k_p	Permeability parameter
Pr	Prandtl number	μ	Dynamic viscosity
q_r	Radiative heat flux	ν	Kinematic viscosity
q_w	Surface heat flux	ρ	Density of the fluid
Re_x	Local Reynolds number	σ^*	Stefan-Boltzman constant
Sh_x	Sherwood number	θ	Non-dimensional temperature
T	Fluid Temperature	ψ	Stream function

(4) Rate of heat transfer enhances with the growth in Soret number but it falls with the growth in Dufour number, chemical reaction parameter and radiation parameter.

(5) Mass transfer rate enhances, when the values of Dufour number, Chemical reaction parameter and radiation parameter are raised but it decreases with the rise in Soret number.

REFERENCES

[1] A. ISHAK, K. JAFAR, R. NAZAR, I. POP: *MHD stagnation point flow towards a stretching sheet*, Phys. A Stat. Mech. its Appl., **388**(17) (2009), 3377-3383.

[2] S. R. MISHRA, B. NAYAK, R. P. SHARMA: *MHD stagnation point flow past over a stretching sheet in the presence of non-Darcy porous medium and heat source/sink*, Defect and Diffusion Forum, **374** (2017), 92-105.

[3] S. K. NANDY: *Analytic solution of MHD stagnation point flow and heat transfer of Casson fluid over a stretching sheet with partial slip*, Hindawi, **2013** (2013), Article ID 108264.

[4] F. MD. ALI, R. NAZAR, N. M. ARIFIN: *MHD stagnation point flow and heat transfer towards stretching sheet with induced magnetic field*, Applied Mathematics and Mechanics, **32**(4) (2011), 409-418.

[5] S. Q. ALAVI, A. HUSSANAN, A. R. MD. KASIM, N. ROSLI, MD. Z. SALLEH: *MHD stagnation point flow towards an exponentially stretching sheet with prescribed wall temperature and Heat flux*, International Journal of Applied and Computational Mathematics, **3** (2017), 3511-3523.

[6] M. M. RASHIDI, M. ALI, B. ROSTAMI, P. ROSTAMI, G. XIE: *Heat and Mass transfer for MHD viscoelastic fluid flow over a vertical stretching sheet with considering Soret and Dufour effects*, Modeling and Analysis in Thermodynamics and heat transfer, **2015** (2015), Article ID 861065.

[7] K. VAJRAVELU, J. NAYFEH: *Convective heat transfer at a stretching sheet*, Acta Mechanica, **96** (1993), 47-54.

[8] J. AHMED, A. SHAHZAD, M. KHAN, R. ALI: *A note on convective heat transfer of an MHD Jeffrey fluid over a stretching sheet*, AIP Advances, **5**(11) (2015), art.id 117117.

[9] A. NOGHREHABADI, R. POURRAJAB, M. GHALAMBAZ: *Flow and heat transfer of nanofluds over a stretching sheet taking into account partial slip and thermal convective boundary conditions*, Heat and Mass Transfer, **49**(9) (2013), 1357-1366.

[10] A. YASHMIN, K. ALI, M. ASHRAF: *Study of heat and mass transfer in MHD flow of Micropolar fluid over a stretching surface*, Scientific Reports, **10** (2020), Article no. 4581.

[11] W. IBRAHIM: *MHD boundary layer flow and heat transfer of micropolar fluid past a stretching sheet with second order slip*, Journal of Brazilian Society of Mechanical Sciences and Engineering, **39** (2017), 791-799.

[12] B. MOHANTY, S. R. MISHRA, H. B. PAATTANAYAK: *Numerical investigation on heat and mass transfer effect of micropolar fluid over a stretching sheet through porous media*, Alexandria Engineering Journal, **54**(2) (2015), 223-231.

[13] K. DAS, P. R. DUARI, P. K. KUNDU: *Nanofluid flow over an unsteady stretching surface in presence of thermal radiation*, Alexandria Engineering Journal, **53**(3) (2014), 737-745.

[14] S. MD. RAZI, S. K. SOID, A. S. ABD AZIZ, N. ADLI, Z. MD. ALI: *Williamson nanofluid flow over a stretching sheet with varied wall thickness and slip effects*, Journal of Physics: Conference Series, **1366** (2019), art. id. 01227.

[15] P. S. REDDY, A. J. CHAMKA: *Soret and Dufour effects on MHD convective flow of Al_2O_3 water and TiO_2 water nanofluids past a stretching sheet in Porous media with heat generation/absorption*, Adv Power Technol, **27**(4) (2016), 1207-1218.

[16] D. DEY, R. BORAH: *Dual solutions of boundary layer flow with heat and mass transfer over an exponentially shrinking cylinder*, Latin American Applied Research, **50**(4) (2020), 247-253.

[17] O. D. MAKINDE, F. MABOOD, S. M. IBRAHIM: *Chemically reacting on Boundary layer flow of nanofluids over a nonlinear stretching sheet with heat source/sink and thermal radiation*, Thermal Sci, **22**(1B) (2018), 495-506.

[18] K. VERMA, D. BORGOHAIN, B. R. SHARMA: *Soret effect through a rotating porous disk of MHD fluid flow* , International Journal of Innovative Technology and Exploring Engineering, **9**(10) (2020), 21-28.

[19] B. R. SHARMA, R. N. SINGH: *Baro-diffusion and Thermal-diffusion in a binary fluid mixture confined between two parallel discs in presence of small axial magnetic field*, Latin American Applied Research, **38**(4) (2008), 313-320.

[20] M. JONNADULA, P. POLARAPU, M. G. REDDY, M. VENAKATESWARLU: *Influence of thermal radiation and chemical reaction on MHD flow, Heat and Mass transfer over a stretching surface*, Procedia Engineering, **127** (2015), 1315-1322.

[21] I. ULLAH, I. KHAN, S. SHAFIE: *Soret and Dufour effects on unsteady mixed convection slip flow of Casson fluid over a nonlinearly stretching sheet with convective boundary conditions*, Scientific Reports, **7** (2017), Article no 1113.

[22] T. M. AGBAJE, S. MONDAL, Z. G. MAKUKULA, S. S. MOTSA, P. SIBANDA: *A new numerical approach to MHD stagnation point flow and heat transfer towards a stretching sheet*, Ain Shams Engineering Journal, **9** (2018), 233-243.

[23] W. IBRAHIM, B. SHANKAR, M. M. NANEPPANAVAR: *MHD stagnation point flow heat transfer due to nanofluid towards a stretching sheet*, Int. J. Heat Mass Transfer, **56** (2013), 1-9.

[24] T. HAYAT, T. JAVED ABBAS: *MHD flow of micropolar fluid near stagnation point towards non-linear stretching surface*, Nonlinear Real World Appl., **10**(3) (2009), 1514-1526.

DEPARTMENT OF MATHEMATICS
DIBRUGARH UNIVERSITY
DIBRUGARH, ASSAM, INDIA
Email address: verma.kisu@gmail.com

DEPARTMENT OF MATHEMATICS
ARUNODOI ACADEMY
SIVASAGAR, ASSAM, INDIA
Email address: zitnas.sb@gmail.com

DEPARTMENT OF MATHEMATICS
DIBRUGARH UNIVERSITY
DIBRUGARH, ASSAM, INDIA
Email address: bishwaramsharma@yahoo.com