BioGecko Vol 12 Issue 03 2023
ISSN NO: 2230-5807

MHD Double Diffusive Radiative Jeffrey Fluid near Stagnation Point Flow towards a Stretching Sheet

M. Umamaheswar[1], S. Harinath Reddy[2], K. Kumaraswamy Naidu[3], D. Harish Babu[4], P. Chandra Reddy[5*]

[1,2,5*] *Dept. of Mathematics, Annamacharya Institute of Technology and Sciences (Autonomous), Rajampet - 516126, A.P, India*
[3] *Dept. of Mathematics, SreeVidyanikethan Engineering College, Tirupati-517102, A.P, India*
[4] *Dept. of Mathematics, SASL, VIT, Bhopal University, Bhopal-466114, Madhya Pradesh, India*

Email: [1]umasvu8@gmail.com
Corresponding Email: [5]chandramsc01@gmail.com*

Abstract
This research investigates the consequences of radiation on stagnation point flow of Jeffrey liquid in conducting field along an extended plane considering the variations in double diffusion. The governing expressions in nonlinear and coupled mode are turned to the combination of ordinary differential equations by employing similarity transformations. The set of non-linear equations and limit constraints are computationally solved using the shooting technique. It is shown and discussed in great detail how various flow field parameters affect momentum, heat measurement, diffusion, rate of heat transfer, skin friction coefficient and rate of mass transfer. Futher, the numerical outcomes of this study matched with previously published outcomes and the results were determined to be in coincidence.

Keywords: MHD, Jeffrey fluid, Thermal radiation, Similarity transformations, Stretching sheet.

1. INTRODUCTION

Scientists, engineers, and mathematicians explore heat and mass transfer flow inside the boundary layer in the existence of stretching, injection, shrinking and suction velocities. In industries, the defined modelled problems can be used in a variety of ways. Many technical processes, such as the fabrication of sheeting substantial in factories and the production of metallic sheets, the fabrication and cooling of huge metallic and polymer plates, glass design continuous casting, can all be directly linked to these types of flows. Motivated from the study presented by Sakiadis [1], number of researchers extends their works in this field with various physical aspects. Elbashbeshy [2] studied the effects due to diffusion of mass and heat under MHD over the fluid flow past an upright surface. Under MHD usual convection over a upright surface, Chen [3] investigated the impacts of heat and mass transmission. Nawaf et al. [4] carried out a numerical analysis of natural convection in a square porous cavity with one of its vertical walls heated differentially. Naidu et al. [5] considered Bingham liquid and analyzed its flow over a round tube with holey walls.

A non-Newtonian liquid demonstrate that has pulled in numerous analysts is Jeffrey liquid show, as usually utilized to represent a physiological liquid. Jeffrey liquid demonstrate may be a critical generalization of Newtonian liquid demonstrate as the afterward one can be concluded as a extraordinary case of the previous. A few analysts have examined almost Jeffrey liquid beneath distinctive conditions. Sreenadh et al. [6] studied the natural convection flow of a non-Newtonian Jeffrey fluid in a vertical channel with deformable porous layer. Maqbool et al. [7] explored the impact of ramping wall temperature and velocity of Jeffrey fluid over MHD convective flow through porous media. Raza [8] investigated thermic radiation as well as slip effects reacted on MHD stagnation point flow of Casson(non-Newtonian) liquid. Satyanarayana et al. [9] proposed the numerical solution of a Jeffery fluid flows under the consequences of thermal generation/sink over a stretching sheet. Odelu et al. [10] discussed the Soret and Dufour effects of free convective Jeffrey fluid between two parallel plates with that pressure with inducted magnetic field. Harish babu et al. [11] investigated melted heat transmit and radiation effects on Jefferey fluid over parallel stream of moving surface over a stretching sheet with pores.

In many technical and industrialist applications, such as the polymer extrusion process, non-linear surface temperature and concentration see ref. [13-18] play a critical role, according to the literature. There is a scarcity of research in this area. As a result, the consideration of the power-law surface temperature along with concentration near stagnation point flow is done and this mathematical model intends to examine the stagnation MHD point flow of Jeffrey liquid over a stretched surface with variable temperature ($\tilde{T}_w(x)=\tilde{T}_\infty+cx^n$) and concentration ($\tilde{C}_w(x)=\tilde{C}_\infty+cx^n$) is investigated in this paper.

2. MATHEMATICAL MODEL AND FORMULATION:

A continuous MHD stagnation point flow in two-dimensional form is considered in reactive and electrically conducting field past a stretching sheet. Assume a homogenous magnetic field is supplied in the direction of the *x*-axis, which is normal to the *y* (>0)-direction. Figure 1 depicts the coordinated arrangement and physical representation.

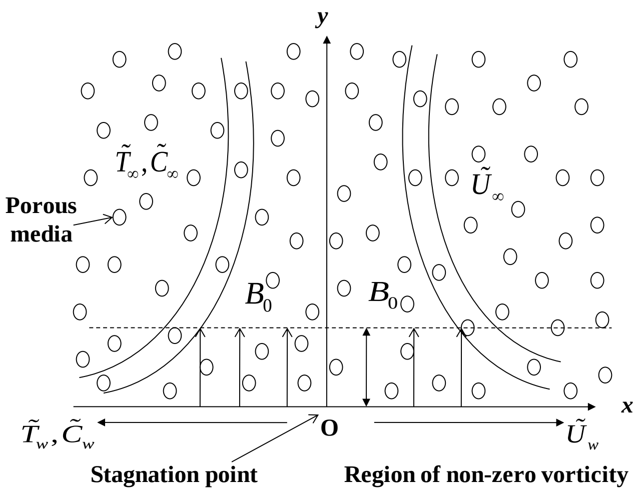

Fig.1. Geometrical model

The governed equations related to the flow and associated constraints are represented by based on the aforementioned physical assumptions. [12].

$$\frac{\partial p_1}{\partial x}+\frac{\partial p_2}{\partial y}=0 \tag{1}$$

$$p_1\frac{\partial p_1}{\partial x}=-p_2\frac{\partial p_1}{\partial y}+\tilde{U}_\infty\frac{\partial \tilde{U}_\infty}{\partial x}+\frac{\upsilon}{1+\lambda}\frac{\partial^2 p_1}{\partial y^2}-\frac{1}{\rho}B_0^2\sigma\left(p_1-p_{1\infty}\right) \quad (2)$$

$$p_1\frac{\partial q_1}{\partial x}+p_2\frac{\partial q_1}{\partial y}=\alpha\frac{\partial^2 q_1}{\partial y^2}+\frac{1}{\rho}\frac{Q}{c_p}\left(q_1-q_{1\infty}\right)-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} \quad (3)$$

$$p_1\frac{\partial q_2}{\partial x}+p_2\frac{\partial q_2}{\partial y}=D\frac{\partial^2 q_2}{\partial y^2}-Kr_1\left(q_{2\infty}-q_2\right) \quad (4)$$

and

At $y=0$:

$$p_1=\tilde{U}_w(x),\ p_2=\tilde{V}_w(x),\ q_{1w}(x)=q_{1\infty}+cx^n,\ q_{2w}(x)=q_{2\infty}+cx^n \quad (5)$$

As $y\to\infty$:

$$p_1\to\tilde{U}_\infty(x),\ q_1\to q_{1\infty},\ q_2\to q_{2\infty} \quad (6)$$

The radiative heat flux q_r is defined as $q_r=-\frac{4}{3}\frac{\sigma^*}{K_s}\frac{\partial q_1^{*4}}{\partial y}$ by utilizing the Rosseland approximation [15]. Use $-\frac{\partial q_r}{\partial y}=\frac{16}{3}\frac{\sigma^* q_{1\infty}^3}{K_s}\frac{\partial^2 q_1}{\partial y^2}$ such that eq. (3) becomes

$$p_1\frac{\partial q_1}{\partial x}+p_2\frac{\partial q_1}{\partial y}=\alpha\frac{\partial^2 q_1}{\partial y^2}+\frac{1}{\rho}\frac{Q}{c_p}\left(q_1-q_{1\infty}\right)+\frac{16}{3\rho}\frac{\sigma^* q_{1\infty}^3}{kc_p}\frac{\partial^2 q_1}{\partial y^2} \quad (7)$$

where $q_1^{*4}=4q_1q_{1\infty}^3-3q_{1\infty}^4$

Introducing subsequent similarity transformations [12]:

$$\eta=y.\sqrt{a/\upsilon},\ \theta(\eta)=\frac{\left(q_{1\infty}-q_1\right)}{\left(q_{1\infty}-q_{1w}\right)},\ \psi=x\sqrt{a\upsilon}\,f(\eta),\ \phi(\eta)=\frac{\left(q_{2\infty}-q_2\right)}{\left(q_{2\infty}-q_{2w}\right)} \quad (8)$$

In view of Eq. (8), the Eqs. (2)- (6) are transformed to:

$$\frac{f'''}{1+\lambda}=-f\,f''+f'^2+\in^2-M\left(\in-f'\right)+\Omega f' \quad (9)$$

$$\left(1+4R/3\right)\theta''=-\Pr\left[\left(f\right)\theta'-nf'\theta+\gamma\theta\right] \quad (10)$$

$$\phi''=-Sc\left(f\phi'-n\phi f'-Kr\phi\right) \quad (11)$$

$$f'(0)=s,\ f'(\infty)=\in,\ f(0)=0,\ \theta(0)=1,\theta(\infty)=0,\phi(0)=1,\phi(\infty)=0 \quad (12)$$

Physical quantities are skin-friction C_{fx}, Nusselt number Nu_x and Sherwood number Sh_x (these are useful in numerous branches of engineering) represented as follows

$$C_{fx}=\frac{\tau_w}{\rho u_e^2}=\mathrm{Re}_x^{-0.5}\,f''(0) \quad (13)$$

$$Nu_x=\frac{1}{k}\frac{x.q_w}{\left(T_w-T_\infty\right)}=-\mathrm{Re}_x^{0.5}\left(1+\frac{4}{3}R\right)\theta'(0) \quad (14)$$

$$Sh_x=\frac{x.m_w}{D\left(C_w-C_\infty\right)}=-\mathrm{Re}_x^{0.5}\,\phi'(0) \quad (15)$$

Special case: Table 1. displays, comparison for $f''(0)$ while $Kr=Sc=S=M=R=\Omega=0$ with Agbaje et al. [12] , Ibrahim et al. [21] and Hayat et al. [22] by giving dissimilar values to $\in$. This table displays current results apparent good agreement with previous published results.

ISSN NO: 2230-5807

3. Solution by Numerical technique:

The nonlinear boundary values issue portrayed by Eqs.(9)-(11) subject to the boundaries given in Eq.(12) is fathomed by utilizing numerical procedure i.e. shooting strategy with R–K fourth arrange strategy [16].

In this strategy, the framework of conditions are decreased into begin with arrange ODE'S by utilizing: $\alpha_1 = f$, $\alpha_3 = f''$, $\alpha_5 = \theta'$, $\alpha_2 = f'$ $\alpha_6 = \phi$, $\alpha_7 = \phi'$, $\alpha_4 = \theta$ as follows

$$\begin{pmatrix} \alpha_1' \\ \alpha_2' \\ \alpha_3' \\ \alpha_4' \\ \alpha_5' \\ \alpha_6' \\ \alpha_7' \end{pmatrix} = \begin{pmatrix} \alpha_2 \\ \alpha_3 \\ (1+\lambda)(\alpha_2^2 + \Omega\alpha_2 - \alpha_1\alpha_3 - M(\in - \alpha_2) - \in^2) \\ \alpha_5 \\ \dfrac{-1}{1+\dfrac{4R}{3}}\left[Pr(\alpha_1\alpha_5 - n\alpha_2\alpha_4 + \gamma\alpha_4\right] \\ \alpha_7 \\ Sc\left[n\alpha_6\alpha_2 - \alpha_1\alpha_7 + k_r\alpha_6\right] \end{pmatrix} \text{with} \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \\ \alpha_7 \end{pmatrix} = \begin{pmatrix} S \\ 1 \\ x_1 \\ 0 \\ x_2 \\ 0 \\ x_3 \end{pmatrix}$$

The over framework of conditions is fathomed computationally with the assistance shooting procedure dependence upon the R–K fourth arrange strategy by preferring the reasonable lost conditions α_5, α_3 *and* α_7. In any case, the step estimate and merging criteria are settled 0.001 and 10^{-6} separately.

3. RESULTS

Influences of radiation and chemical reaction on MHD flow with stagnation point of Jeffrey fluid with heat source over a stretchable area observed mathematically. Variations of skin friction, Sherwood number, rate of heat transfer, concentration and velocity under the influence of dissimilar physical parameter, through Figs. 2-12. Furthermore, the numerical variations of skin-friction factor, rate of heat transfer are tabulated in Table 1 and 2 under pertinent physical quantities.

Velocity profile differences due to the impact of Jeffrey fluid parameters are presented in Fig.2. It is detected that for emergent λ values fluid velocity declines. Fluid velocity cut downs for growing suction parameter (S>0), it is evident in Fig.3. The Fig. 4 exposed velocity profile for unlike values of *M*, velocity of the fluid declines for improving values in M. Due to the genuineness that, the presentation of the transversable magnetic field seems to give upswing with resistible form of energy well-known as Lorentz force which obstructs the fluid flow. Thus, the influence of *M* centrals to contract the velocity field. Fig. 5 portrays the result of velocity on permeability parameter **Ω**. It appears that velocity decays on enhancing Ω.

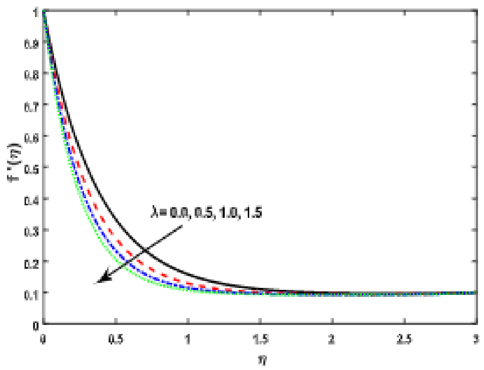

Fig.2 Change of Jeffrey parameter (λ) on $f'(\eta)$.

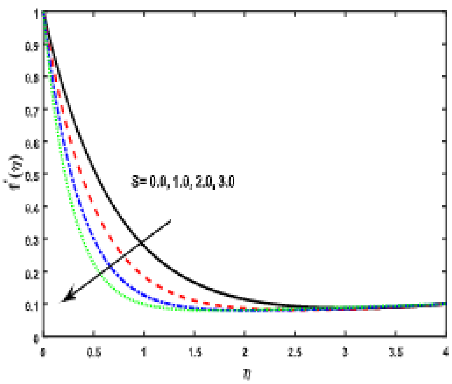

Fig.3 change of S (≥ 0) on $f'(\eta)$.

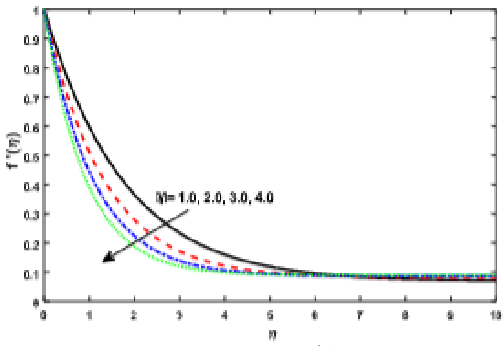

Fig. 4 Influence of M on $f'(\eta)$.

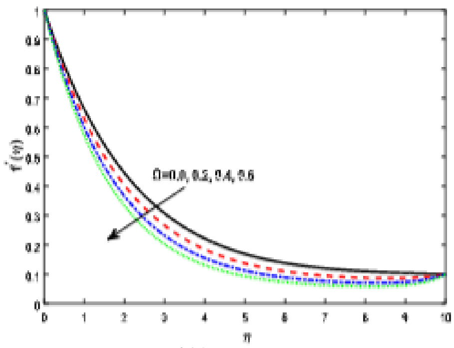

Fig. 5 Impact of Ω $f'(\eta)$

Fig. 6 illustrate the variation of temperature for the distinctive values of Jeffrey parameter λ and temperature boost on enhancing Jeffrey parameter λ. Fig.7 displays that the non-dimensional temperature decayed when γ rises. Physically, the temperature drops when the intensity of heat is reduced. The temperature of the Jeffrey fluid falls downcast for different values of Pr, it is evident in the Fig.8. From Fig.9 it is apparent that when R values rises, the temperature of the fluid boosts. This is done because greater thermal radiative numerals means a higher heat flux that upsurges the fluid temperature.

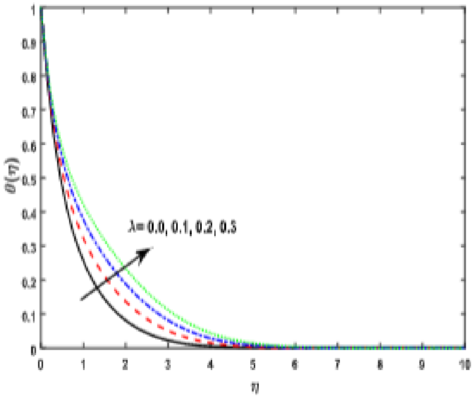

Fig.6 Influence of λ on on $\theta(\eta)$.

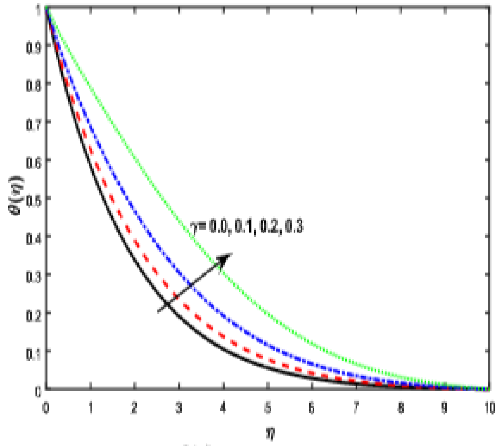

Fig. 7 Impact of γ on $\theta(\eta)$.

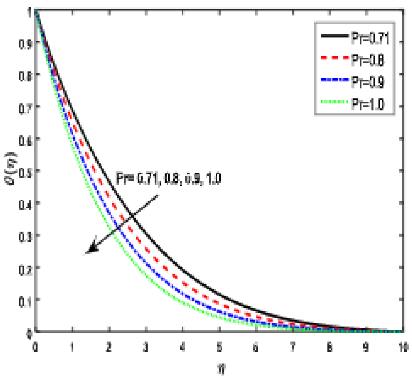

Fig.8 Change of Pr on on .

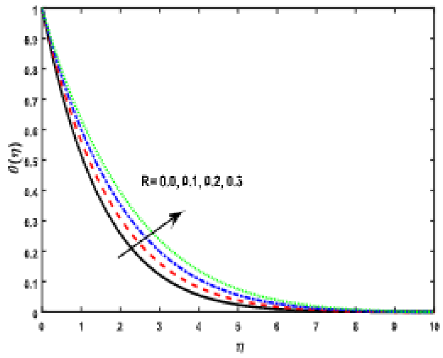

Fig. 9 Change of R on .

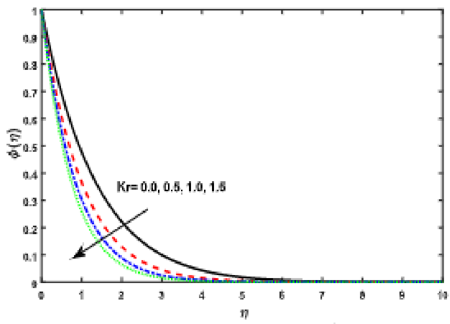

Fig. 10 Change of Kr on $\phi(\eta)$.

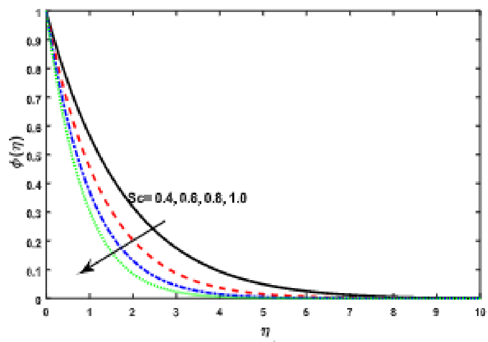

Fig.11 Change of Sc on $\phi(\eta)$.

Figs. 10 and 11 displays deviations in species concentration for dissimilar values of Sc in addition to Kr. The profile of concentration slows down on growing Kr . It's factual is since the greater numerals of chemical reaction mark tumble inside the chemical molecular diffusivity. Species concentration declines for dissimilar values of Sc. This can be due to the truth that the atomic diffusivity diminishes with increment in Schmidt number. In this manner, the species concentration is giant for littler values of Sc and squat for prevalent values of Sc. Figs. 12 and 13 parades that Nusselt number rises for budding values of Pr and n against R.

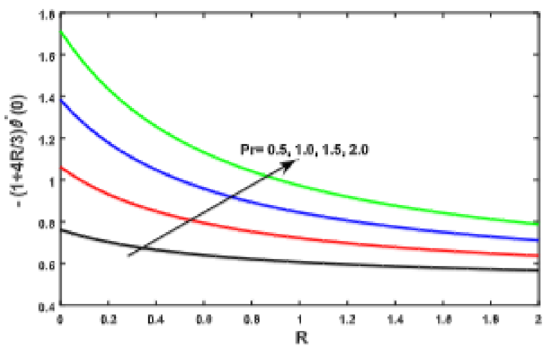

Fig.12 Deviations of *Pr* on Nusselt number against *R*.

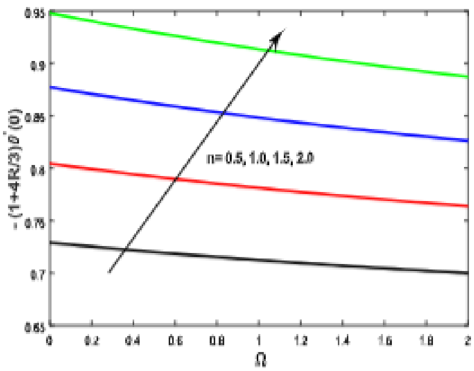

Fig.13 Deviations of n on Nusselt number against *R*.

Table. 1. A mathematical correlation for $f''(0)$ dissimilar those of Agbaje et al. [12], Ibrahim et al. [17] and Hayat et al. [18] for assorted values of $\in$, when $Kr = Sc = S = M = R = \Omega = 0$.

$\in$	Ibrahim et al. [17]	Hayat et al. [18]	Agbaje et al. [12]		Present
			SPM	SQLM	
0.01	-0.9980	-0.99702	-0.9980	-0.9980	-0.998043
0.02	--	-0.99578	-0.9958	-0.9958	-0.996083
0.05	--	-0.98757	-0.9876	-0.9876	-0.987729
0.10	-0.9694	-0.96938	-0.9694	-0.9694	-0.969436
0.20	-0.9181	-0.91810	-0.9181	-0.9181	-0.918112
0.50	-0.6673	-0.66732	-0.6673	-0.6673	-0.667260
1.00	--	0.00000	--	0.0000	0.000000

Table. 2. A mathematical correlation for $-\left(1+\frac{4}{3}R\right)\theta'(0)$ dissimilar those of Agbaje et al. [12] , Ibrahim et al.[17] and for dissimilar values of Pr and $\in$ when $M = Kr = Sc = \gamma = n = \Omega = R = 0$..

$\in$	Pr	Ibrahim et al. [17]	Agbaje et al. [12]		Present
			SPM	SQL	
0.1	1.0	0.6022	0.6022	0.6022	0.602213
0.2	1.0	0.6245	0.6245	0.6245	0.624656
0.5	1.0	0.6924	0.6924	0.6924	0.692455
0.1	1.5	0.7768	0.7768	0.7768	0.776815
0.2	1.5	0.7971	0.7971	0.7971	0.797129
0.5	1.5	0.8648	0.8648	0.8648	0.864800

4. CONCLUSION

The significance of radiation mass and heat transfer on MHD Jeffery fluid near to stagnation point flow towards a stretching sheet is examined. The typical mathematical equations of concentration and temperature are shown in the form of power law. The flow related equations are formulated and cracked. The crucial outcomes in the presented research are recorded as follows:

1. Momentum of the fluid amplified when velocity ratio parameter values are increased. and suction and magnetic parameters shows opposite movement.
2. Fluid velocity drops for differential values of Jefferey parameter, but temperature of the same fluid rises.
3. Temperature on the dimensionless fluid hastens when thermal radiation parameter upturns and slow down by means of the heat absorption constraint.
4. For growing values of Schmidt number in addition chemical reaction parameter species concentration hinders.
5. Nusselt number rises with upward Prandtl number, opposite behavior observed in radiation parameter.

5. REFERENCES

1. Sakiadis, B.C, Boundary layer behavior on continuous solid surfaces: I. Boundary layer equations for two-dimensional and axisymmetric flow, AIChE J., 5 (1961), 26-28
2. Elbashbeshy, E.M.A.., Heat and mass transfer along a vertical plate with variable surface temperature and concentration in the pressure of the magnetic field, Int. J. Eng.Sc., 34(1997), 515-522.
3. Chen, C. H, Combined heat and mass transfer in MHD free convection from a vertical surface with Ohmic heating and viscous dissipation, Int. J. Eng. Science, 42(2004) 699-713.
4. Nawaf, H.S., and Pop, I., Natural convection from a discrete heater in a square cavity filled with a porous medium, Journal of porous media, 8(2005) 55-63.
5. Kumaraswamy Naidu K & Sreenadh, S.," Fully developed free convective flow of a Bingham fluid in a circular pipe with permeable wall, International Journal of Ambient Energy, 2022, DOI: 10.1080/01430750.2022.2037459
6. Sreenadh, S., Rashidi., M.M., Kumaraswamy Naidu, K., and Parandhama, A., Free convection flow of a Jeffrey fluid through a vertical deformable porous stratum. Journal of Applied Fluid Mechanics, vol. 9 (5) (2016) , 2391-2401.
7. Maqbool, K A.B.Mann, M.H.Tiwana, Unsteady MHD convective flow of a Jeffery fluid embedded in a porous medium with ramped wall velocity and temperature, Alexandria Engineering Journal, 57(2) (2018), 1071-1078.
8. Raza J, Thermal radiation and slip effects on magnetohydrodynamic (MHD) stagnation point flow of Casson fluid over a convective stretching sheet. *Propulsion and Power Research*, 8(2), (2019), 138-146
9. Narayana, P. V. S, Babu, D.H., Babu, M. S., Numerical study of a Jeffrey fluid over a porous stretching sheet with heat source/sink- *International Journal of Fluid Mechanics Research*, 46(2) (2019).
10. Odelu Ojjela, Adigoppula Raju, Naresh Kumar, N., Influence of Induced Magnetic Field and Radiation on Free Convective Jeffrey Fluid Flow between two Parallel Porous Plates with Soret and Dufour Effects, *Journal of Mechanics*, 35(5) (2019), 657–675, https://doi.org/10.1017/jmech.2018.68

11. Harish Babu, D, Satya Narayana, P. V., " Melting heat transfer and radiation effects on Jeffrey fluid flow over a continuously moving surface with a parallel free stream, *Journal of Applied and Computational Mechanics*, 2019, 5(2),468-76.
12. Agbaje TM, Mondal S, Makukula ZG, Motsa SS, 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.
13. Xu H, Liao S, Laminar flow and heat transfer in the boundary-layer of non-Newtonian fluids over a stretching flat sheet. Computers& Mathematics with Appl. 57(9), (2009), 1425-1431.
14. Nadeem S, Rashid M, Akbar NS, Non-orthogonal stagnation point flow of a nano non-Newtonian fluid towards a stretching surface with heat transfer. Int J Heat and Mass Transfer.57(2), 2013, 679-689.
15. Pal D, Mandal G, Vajravelu K, Flow and heat transfer of nanofluids at a stagnation point flow over a stretching/shrinking surface in a porous medium with thermal radiation, Applied Mathematics and Computation. 238(1), 2014, 208-224.
16. Fenuga O.J., Hassan A.R., Olanrewaju P.O., Mixed convection in MHD flow and heat transfer rate near a stagnation-point on a non-linear vertical stretching sheet, Int. J. of Applied Mechanics and Engineering 25(1),2020, 37-51.
17. Ibrahim W, Shankar B, Naneppanavar M., M., MHD stagnation point flow heat transfer due to nanofluid towards a stretching sheet. Int. J Heat and Mass transf. 56,2013, 1-9.
18. Hayat T, Javed T, Abbas Z, MHD flow of micropolar fluid near stagnation point towards non-linear stretching surface. Nonlinear Anal: Real-world appl. 10(3),2009, 1514-26.