Journal of Mines, Metals and Fuels, *71(12A): 168-176; 2023. DOI: 10.18311/jmmf/2023/43605*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Effects of Heat Generation and Radiation on Darcy Convective Non-Newtonian Power Law Liquid with Yield Stress over a Vertical Plate

R. Suresh Babu[1]*, B. Mallikarjuna[2], A. Sreevallabha Reddy[1] and M. V. Govindaraju[1]

[1]*Department of Mathematics, M S Ramaiah Institute of Technology, Bangalore - 560054, Karnataka, India; sureshbabur@msrit.edu,govindarajumv@msrit.edu, sreensiri@gmail.com*

[2]*Department of Mathematics, B M S College of Engineering, Bangalore - 560014, Karnataka, India*

Abstract

The effects of heat flux, and thermal buoyancy on mixed convective flow for a non-Newtonian power law liquid with yield stress via a vertical plate filled with a porous material under the influence of thermal radiation, and heat production are investigated in this topic. For this model, The PDE's that govern the flow are constructed and converted to a set of ODE's using appropriate transformation and the resultant ODEs are quantitatively determined using Shooting technique. The impacts of different flow regulating factors such as index parameter, yield stress, radiation, and heat generation are illustrated through graphical representation for fluid properties. This research shows that the velocity distribution, Nusselt and Sherwood numbers declines as the dimensionless rheological parameter rise, but temperature and concentration profiles exhibit the reverse tendency. Also, the velocity, temperature curves and mass flux grow as the radiation parameter rises, whereas the concentration curves and heat flux fall as the radiation parameter rises. For a specific case, a comparison with Lakshmi Narayana et al.,[13] was made, and a great agreement was established.

Keywords: *Heat Generation, Non-Newtonian Power-Law Fluid, Radiation Effect, Shooting Technique, Yield Stress*

1.0 Introduction

Non-Newtonian fluids have piqued the attention of several scientists because of their significance in the environmental and manufacturing techniques, particularly in the fields of electronic chips, fermentation, boiling, bubble columns, composite processing, paint application, food processing, polymer depolarization, and many others. Non-Newtonian fluids via channels have abundant functional applications in industries from a mathematical as well as engineering point of view. Because the shear stresses are not linearly proportionate to velocity gradient in non-Newtonian fluids and the relationship between them is always vary with time, so it is impossible to express as a unique equation. The mathematical formulation for such fluids is extremely irregular and almost impossible to solve analytically in nature. Several mathematical models are proposed for non-Newtonian fluids, still no detailed version available for large number of fluids under various flow situations. Hence, lot of researchers have drawn their attention towards non-Newtonian fluids owing to large scale applications and industrial uses, especially in the polymer industry. To characterise the non-Newtonian liquid action, the non- Newtonian liquid action, Mehta *et al*.,[1] deliberated the induced power law fluid over a non-isothermal flat plate. Masahiko *et al*.,[2] studied 3D experiments to observe the viscous, porous effects of inertia on the pressure droplet through a porous channel

*Author for correspondence

in a non-Newtonian liquid. A porous channel can be described as a solid or a series of solid materials (consists of pores or voids) with sufficient open space to allow a fluid to move through or around the solids in or around them. The structure of the porous channel completely depends upon the allocation of the pore size, the frequency of interconnectedness and inclination of pores, proportion of dead pores etc. at the microscopic level. Clearly, to understand the surface phenomena such as the absorption of macromolecules from polymer matrix and the restriction of pores etc., the microscopic definition is sufficient. The medium can be modelled in a solid matrix where fluid is in motion, penetrated by a network of channels or pores. Natural substances are referred to as permeable media, such as soils, rocks, bones, organic tissues and artificial materials such as cement, foams and stoneware. Saturated porous medium plays an important role in science and technology due to broad range of applications like underground spreading of chemical waste, thermal engineering, geothermal reservoirs, improved recovery of oil reservoirs, grain storage, nuclear waste repository, geothermal engineering etc. Hakiem *et al*.,[3] inspected the amount of mass transport on buoyancy induced power-law liquid over a plate. For the Eyring-Powell model, Nabil *et al*.,[4] investigated the motion of a nanofluid over a plate by an external uniform magnetic field. Idowu *et al*.,[5] explored the transfer characteristics of both Casson and viscoelastic (Walters-B) fluids like polymethyl, methacrylate, chromatography etc numerically. The flow of bi-viscous non-Newtonian liquid was modelled by Laurent *et al*.,[6] by a square lattice method. Literature associated with porous medium can be avail in recent book written by Wei[7].

The study of non-Newtonian liquids has grown in relevance from many years as industrial and technological needs have increased. The power law (Ostwald-de Waele) model is a popular non-Newtonian fluid model which is frequently used to guess the dynamics of shear thinning as well thickening fluids and may also duplicate the solutions of Newtonian fluids. There are several shear-independent viscosity non-Newtonian fluids like Casson, Oldroid-B, Couple stress, Viscoelastic, Micropolar and Ferrofluids etc., that still exhibit natural stress variations. The issue of heat, and mass transfer in porous channels for non-Newtonian liquids is essential due to real-world engineering implications such as food processing, materials processing, and oil recovery, among others. Because non-Newtonian liquids have non-linear properties, the characteristics of convective heat, and mass transportation in porous media differ considerably from those of Newtonian fluids in porous media. The power-law model idea was utilized to examine the different fluids and heat transfer difficulties connected with porous media setups including non-Newtonian fluids. Non-Newtonian power law fluid has rheological properties that are important for the study of various industrial fluids used in food preparation, bio-chemical and pharmaceutical industries etc. The power-law model is commonly used to study the dilatant and pseudoplastic properties of non-Newtonian fluids because finding an exact solution of power-law non-Newtonian fluids are difficult. Non-Newtonian power-law liquids were presented by various researchers like Schowalter[8], Chen *et al*.,[9] Nakayama *et al*.,[10] and Mehta *et al.,*[11] Jumah *et al*.,[12] and Lakshmi Narayana *et al*.,[13] investigated the Soret and Dufour impacts of a power law liquid with yield stress from a plate under changing wall temperature and concentration.

In recent years, researchers have focused on the heat generation and thermal radiation of non-Newtonian power-law fluids, and this has important roles in handling chemical reactions and dissociating fluids. The potential heat generation effects of combustion and nuclear reactor cores can change the temperature distributions, which can result in the formation of particle deposition rates. Several authors Kim and Hyun[14], Chamkha *et al*.,[15], Cheng[16], Patil and Kulkarni[17], Chen[18], Subhas Abel *et al*.,[19] and Suresh Babu *et al*.,[20] was examined theoretically the effect of internal heat generation of a Newtonian/ non-Newtonian liquids for different geometries by considering constant/variable fluid properties. Also, heat transmission through thermal radiation is an important component in many fields of industrial engineering and sciences such as chemical, aeronautical, environmental, space technology, and higher operating temperatures in fluid dynamics etc. Many studies involve free/forced/ mixed convective flows with thermal radiation through/ past a vertical surface in the literature. Very few authors like Cheng[21,25], Salem[22], Prabhu *et al*.,[23], Ibrahim *et al*.,[24], Mohammed Ibrahim[26] and Lavanya *et al*.,[27] are studied by considering both effects into the account for non-Newtonian power-law liquids in the literature. Swamy

Reddy *et al.*,[29] investigated the domino effect and radiation impacts in a Darcy convective power-law fluid immersed in a permeable material. Castaneda *et al.*,[30] investigated the potential of homogenization to develop a broad range of rheological models for non-colloidal particle mixtures experiencing finite deformations and revolutions under Stokes flow regime. Non-Darcy mixed convective flow of a non-Newtonian liquid in the presence of a volumetric heat source generated by electromechanical is studied by Ajaya Prasad *et al.*,[31]. Saleem *et al.*,[32] used a numerical technique to investigate the entropy analysis for coupled convective radiated non-linear power law liquid over an exponentially stretched plate. Falana *et al.*,[33] researched the power-law liquid from a continuously moving plate with slip effects in the presence of a transverse magnetic field.

In the literature to the best of our knowledge, the problem of radiation effect on mixed convective heat and mass transfer flow of a non-Newtonian power law fluid with yield stress in the presence of heat generation/absorption in the porous medium has not been investigated so far. Using similarity transformation, the mathematical model is converted into ODE's and then numerical solutions are computed by employing Shooting method with fourth order RK method. The consequences of the most important physical factors are explored through plots and comparison has been made with previously published work[13] in the absence of some non-dimensional parameters and found in good agreement. Such a study finds many industrial and engineering applications in solar collection systems, fire dynamics in insulations, catalytic reactors, nuclear waste repositories, several propulsion devices for aircraft, recovery of petroleum products and gases etc.

2.0 Materials and Methods

Consider a 2D mixed convective non-Newtonian power law fluid with yield stress through a vertical plate embedded in a saturated porous medium under the influence of heat generation, and radiation. The x-axis is measured from its leading edge of the vertical plate in the ascending direction and the y-axis is measured normal to the plate. The plate is maintained at the constant temperature T_w and constant concentration C_w which are greater than the ambient temperature T_∞ and concentration C_∞ respectively far away from the plate. The flow model and the physical co-ordinate system is shown is shown in Figure 1. Under the above assumptions and approximations, the flow equations and its associated conditions are defined as follows:

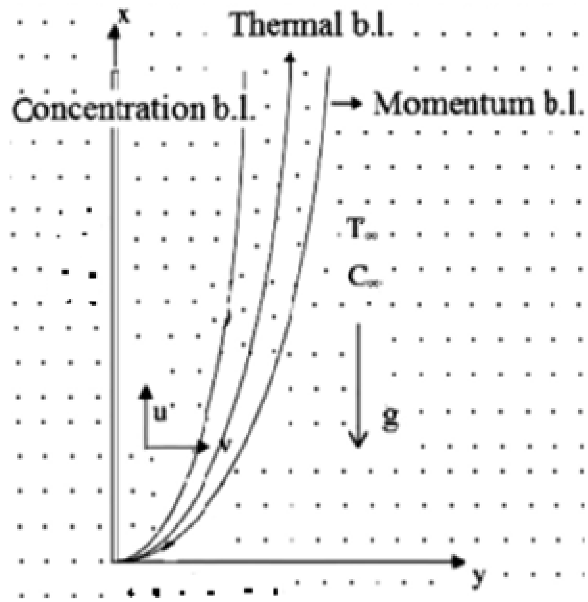

Figure 1. Sketch of the proposed co-ordinate system.

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

$$u^n=\frac{K}{\mu}\left\{-\frac{dP}{dx}-\rho g-\alpha_0\right\},\quad if\ \left\{-\frac{dP}{dx}-\rho g\right\}>\alpha_0,$$

$$u=0,\qquad if\ \left\{-\frac{dP}{dx}-\rho g\right\}\le\alpha_0, \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{Q_0}{\rho C_P}(T-T_\infty)-\frac{1}{\rho C_P}\frac{\partial q_r}{\partial y}, \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}, \tag{4}$$

$$v=0,\quad T=T_w,\quad C=C_w\ \text{ at } y=0$$

$$u\to 0,\quad T\to T_w,\quad C\to C_w\ \text{ at } y\to\infty. \tag{5}$$

Where, u and v are the velocity components along x and y directions respectively, T and C are the temperature and concentration respectively, K is the permeability of the porous medium, g is the gravitational acceleration, k is the thermal conductivity, μ is the kinematic viscosity of the fluid, η is the power-law index, ρ is the fluid density, T_w and C_w are the plate temperature and concentration, T_∞ and C_∞ are the free stream temperature and concentration far away from the plate, Q_0 is the temperature dependent volumetric heat generation, q_r is the radioactive heat flux and C_p is the specific heat at constant pressure, α is the thermal diffusivity, α_0 is the threshold pressure gradient of the non-Newtonian power-law fluid and D is the mass diffusivity. For the free stream, Eq. (2) gives

$$-\frac{dP}{dx}-\rho_\infty g=0 \tag{6}$$

Eliminating pressure term between Eqs. (2) and (6), we have

$$u^n=\frac{K}{\mu}\{(\rho_\infty-\rho)g-\alpha_0\}, \quad if\ \{(\rho_\infty-\rho)g\}>\alpha_0,$$

$$u=0, \qquad if\ \{(\rho_\infty-\rho)g\}\le\alpha_0, \tag{7}$$

Taking the Boussinesq approximation into the density, we have

$$\rho=\rho_\infty\{1-\beta_T(T-T_\infty)-\beta_C(C-C_\infty)\} \tag{8}$$

where, β_T and β_C are coefficients of thermal expansion, and concentration expansion. Substituting Eq. (8) in Eq. (7) and rewriting, we get

$$u^n=\frac{\rho_\infty gK}{\mu}\left\{\beta_T(T-T_\infty)+\beta_C(C-C_\infty)-\frac{\alpha_0}{\rho_\infty g}\right\},$$

$$if\ \{\beta_T(T-T_\infty)+\beta_C(C-C_\infty)\}>\frac{\alpha_0}{\rho_\infty g},$$

$$u=0, \quad if\ \{\beta_T(T-T_\infty)+\beta_C(C-C_\infty)\}\le\frac{\alpha_0}{\rho_\infty g}, \tag{9}$$

In order to non-dimensionalize the above equations, the stream function $\psi(x,y)$ is introduced, followed by a similarity transformation.

$$\psi(\eta)=\alpha\,Ra_x^{1/2}f(\eta), \quad \eta=\frac{y}{x}Ra_x^{1/2}, \quad \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}, \quad \phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty},$$

$$\eta=\frac{y}{x}Ra_x^{1/2}, \tag{10}$$

Substituting Eqs.(10) in to Eqs. (9), (3) and (4), we have

$$f'=(\theta+N\phi-\Omega)^{1/n}, \qquad if\ \ (\theta+N\phi)>\Omega$$

$$f'=0, \qquad if\ \ (\theta+N\phi)\le\Omega \tag{11}$$

$$\left(1+\frac{4}{3}R_d\right)\theta''+\frac{1}{2}f\theta'+Q\theta=0, \tag{12}$$

$$\frac{1}{Le}\phi''+\frac{1}{2}f\phi'=0, \tag{13}$$

The relevant boundary conditions (5) are transformed into

$$\begin{aligned} &f=0,\quad \theta=1,\quad \phi=1 \quad at\ \eta=0\\ &f'\to0,\ \theta\to0,\ \phi\to0 \quad as\ \eta\to\infty. \end{aligned} \tag{14}$$

Where $Ra_x=\frac{x}{\alpha}\left[\frac{\rho Kg\beta_T(T_w-T_\infty)}{\mu}\right]^{1/n}$, $\Omega=\frac{\alpha_0}{\rho_\infty g\beta_T(T_w-T_\infty)}$, is the rheological parameter,

$Q=\frac{Q_0\,x^2}{\rho_\infty C_p\,\alpha\,Ra_x}$ is the heat source, and $Le=\frac{\alpha}{D}$ is the Lewis number, $N=\frac{\beta_C(C_w-C_\infty)}{\beta_T(T_w-T_\infty)}$ is the Buoyancy ratio, and the Radiation parameter is $R_d=\frac{4\sigma T_\infty^{\,3}}{\rho_\infty C_p\,\alpha K}$.

The dimension-less heat, and mass transfer coefficients are given by

$$\frac{Nu_x}{Ra_x^{1/2}}=-\theta'(0), \quad \frac{Sh_x}{Ra_x^{1/2}}=-\phi'(0) \tag{15}$$

where Nu_x and Sh_x are the local Nusselt, and Sherwood numbers respectively.

3.0 Results and Discussion

The Runge-Kutta based shooting technique is used to solve the equations (11) - (13) subject to the BC's (14). To understand the science of the problem, a numerical examination was conducted, and the findings are shown using graphical representations for various non-dimensional factors from Figures 2 to 11. Here, if the index parameter is less than one, then the fluid is pseudo-plastic, for equal to one the fluid is Newtonian and more than one, then the fluid is dilatant. To validate our study, present outcomes are compared with Jumah *et al.*,[5] and Lakshmi Narayana *et al.*,[6] for a particular case and establish an excellent agreement.

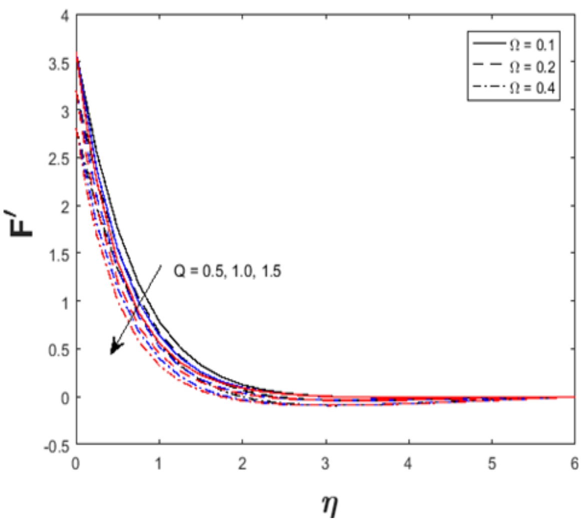

Figure 2. Outcome of Q and Ωon velocity.

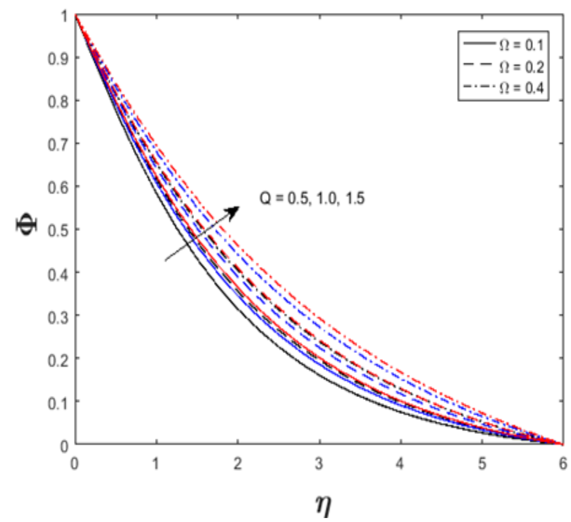

Figure 4. Outcome of Q and Ωon concentration.

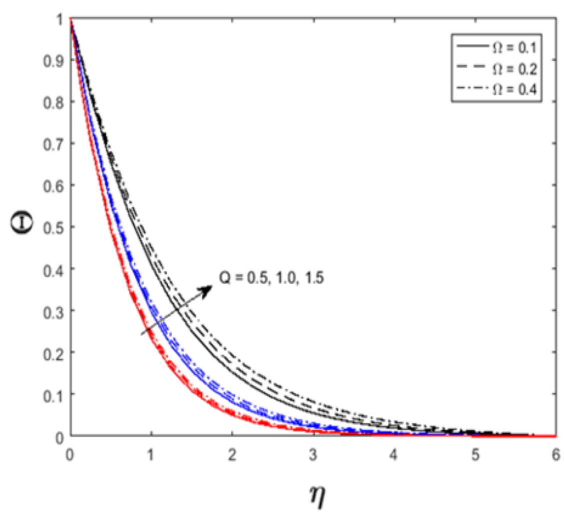

Figure 3. Outcome of on temperature.

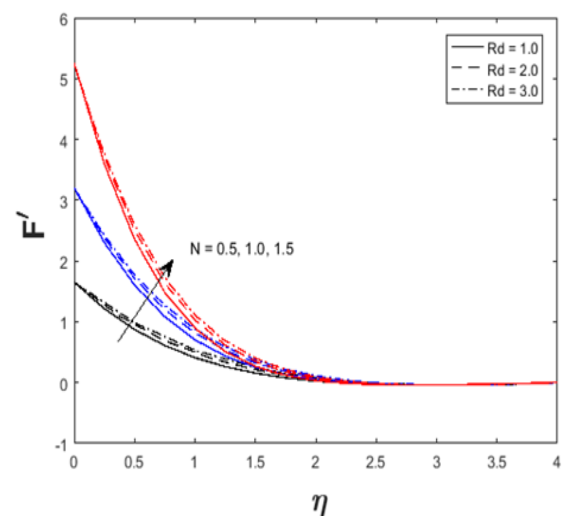

Figure 5. Outcome of Rd and N on velocity.

The effects of dimensionless rheological as well as heat generation parameters are depicted on flow fields velocity $f'(\eta)$, temperature $\theta(\eta)$, and concentration $\phi(\eta)$ in Figures 2-4. The velocity distribution falls as the rheological parameter raises in Figure 2, but the temperature, and concentration gradients in Figures 3 and 4 exhibit the opposite pattern because flow doesn't really start in a porous material until the buoyancy forces are strong enough to create shear stress in the liquid greater than the yield stress or pressure difference. As it turns out, free convection will produce certain inequalities that are significantly dependent on the yield stress. In addition, as seen in Figure 2, the velocity drops as Q increases. The influence of heat producing parameters on temperature is depicted in Figure 3, and it is seen that the temperature profile increases by increasing because the role of internal heat production is to enhance the rate of heat transmission to the fluid, thereby raising the temperature. A similar type of tendency is noticed in the concentration profile as given by Figure 4.

The flow fields velocity $f'(\eta)$, temperature $\theta(\eta)$, and concentration $\phi(\eta)$ for distinct values of radiation

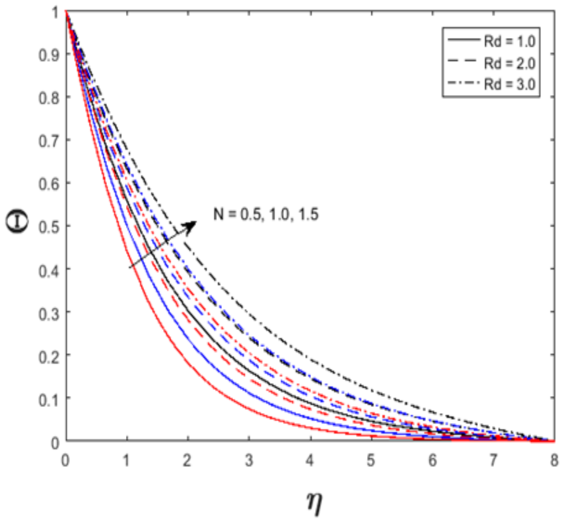

Figure 6. Outcome of *Rd* and *N*on temperature.

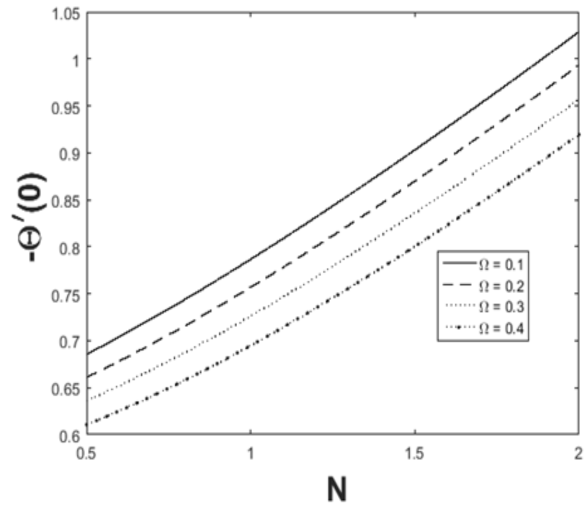

Figure 8. Outcome of Ω on Nusselt number.

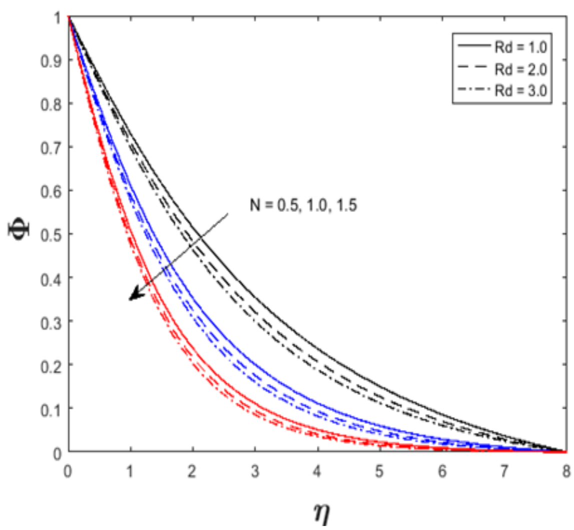

Figure 7. Outcome of *Rd* and *N*n concentration.

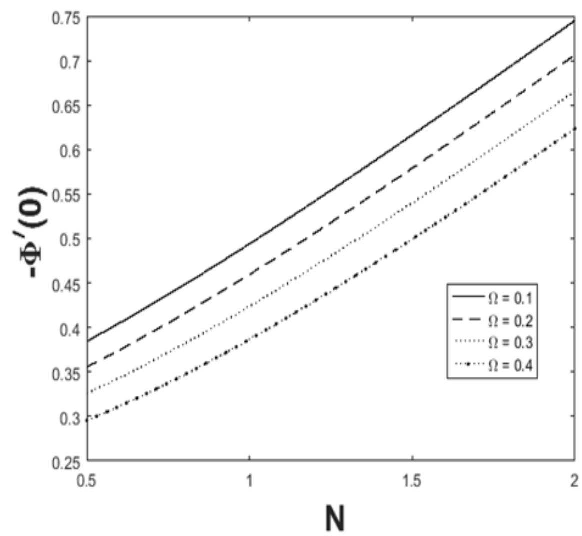

Figure 9. Outcome of Ω on Sherhood number.

parameter as well as buoyancy ratio are depicted in Figures 5-7. The velocity $f'(\eta)$ and temperature $\theta(\eta)$ of the liquid raised when the amount of the radiation parameter is increased, as seen in Figures 5 and 6. Figure 6 depicts the effect of the radiation parameter on the plate's power law fluid temperature. By raising the value of the radiation parameter, the release of extra heat energy from the flowing zone is enhanced, resulting in a rise in the power law liquid temperature at a particular distance from the surface. Furthermore, Figure 7 shows that the concentration of the liquid falls down as the amount of radiation parameter grows. The science underlying this is that as the rate of radiative heat transmitted to the fluid rises, so does the fluid temperature, and subsequently, the fluid velocity. Also the effect of buoyancy ratio on velocity $f'(\eta)$ and temperature $\theta(\eta)$ profiles is observed from Figures 5 and 6, and as N enhances the velocity, temperature profiles increases. As seen in Figure 7, concentration profiles exhibit the reverse tendency as N grows.

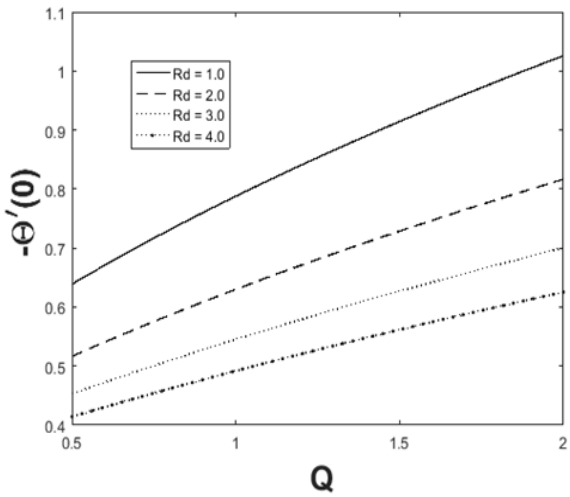

Figure 10. Outcome of *Rd* on Nusselt number.

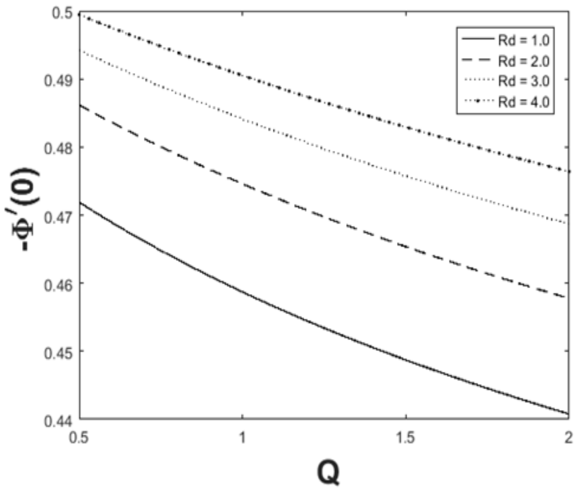

Figure 11. Outcome of *Rd* on Sherwood number.

For the importance of industrial applications, a study has been carried out to understand the local Nusselt (Nu_x), and Sherwood number (Sh_x) for various non-dimensional parameters. Both the local Nusselt (Nu_x) and Sherwood (Sh_x) numbers drop when the Rheological parameter grows, as seen in Figures 8 and 9. In Figures 10 and 11, the rate of heat transmission is shown against the radiation parameter Rd for various values of the heat production parameter. For a certain heat production parameter, the rate of heat transfer reduces as the radiation parameter improves for a given distance from the flat plate, as shown in Figure 10. It is also discovered that because shear thinning fluids have lower viscosity, heat energy may be easily transferred to nearby fluid particles, and therefore the rate of heat transfer is greater in shear thinning fluids than shear thickening fluids. The opposite pattern is noticed in the case Sherwood number as the radiation parameter improves from Figure 11.

4.0 Conclusions

For the above mathematical model, the following results are reached. (i) The velocity distribution declines as the dimensionless rheological parameter and heat production parameter rise, but temperature and concentration profiles exhibit the reverse tendency. (ii) The velocity and temperature curves grow as the radiation parameter rises, whereas the concentration curves fall as the radiation parameter rises. (iii) As the buoyancy ratio grows, so do the velocity profiles, while temperature $\theta(\eta)$, and concentration $\phi(\eta)$, profiles exhibit the opposite trend. (iv) Both the Nusselt and Sherwood values drop when the Rheological parameter improves. (v) The local Nusselt number (Nu_x) drops and the Sherwood number (Sh_x) grows as the radiation parameter improves.

5.0 References

1. Mehta KN, Narasimha Rao K. Buoyancy induced flow of non-Newtonian fluids over a non- isothermal horizontal plate embedded in a porous medium. Int J Eng Sci. 1994; 32:521-5. https://doi.org/10.1016/0020-7225(94)90138-4
2. Masahiko I, Akira N. Numerical modeling of non-Newtonian fluid flow in a porous medium using a three-dimensional periodic array. J Flu Eng. 1998; 120:131-45. https://doi.org/10.1115/1.2819636
3. El-Hakiem MA, El-Amin MF. Mass transfer effects on the non-Newtonian fluids past a vertical plate embedded in a porous medium with non-uniform surface heat flux. H M Trans. 2001; 37:293-7. https://doi.org/10.1007/s002310000145
4. Nabil ED, Mahmoud Gabr, Abd-Elhafez E, Sameh Z. The motion of a non-Newtonian nanofluid over a semi-infinite moving vertical plate through porous medium with heat and mass transfer. Ther Scies. 2020; 24:1311-21. https://doi.org/10.2298/TSCI180604021E
5. Idowu AS, Falodun BO. Variable thermal conductivity and viscosity effects on non-Newtonian fluids flow

through a vertical porous plate under Soret-Dufour influence. Math Comp Simul. 2020; 177:358-84. https://doi.org/10.1016/j.matcom.2020.05.001
6. Laurent T, Alex H. Effective Rheology of Bi-viscous non-Newtonian fluids in porous media. Front Phys. 2020; 7:225. https://doi.org/10.3389/fphy.2019.00225
7. Wei TW, Mehrdad M. Recent advances in mechanics of non-Newtonian fluids. Fluids. 2020; 5:10. https://doi.org/10.3390/fluids5010010
8. Schowalter WR. The application of boundary-layer theory to power-law pseudo plastic fluids: similar solutions. AICHE Jour. 1960; 6:24-8. https://doi.org/10.1002/aic.690060105
9. Chen HT, Chen CK. Free convection of non-Newtonian fluids along a vertical plate embedded in a porous medium. ASME J He Trans. 1988; 110(1):257–60. https://doi.org/10.1115/1.3250462
10. Nakayama A, Koyama H. Buoyancy induced flow of non-Newtonian fluids over a non-isothermal body of arbitrary shape in a fluid-saturated porous medium. App Sci Res. 1991; 48:55–70. https://doi.org/10.1007/BF01998665
11. Mehta KN, Narasimha Rao K. Buoyancy-induced flow of non-Newtonian fluids in aporous medium pasta vertical flat plate with non-uniform surface heat flux. Int J Engg Sci. 1994; 32:297-302. https://doi.org/10.1016/0020-7225(94)90009-4
12. Jumah RY, Mujumdar AS. Natural convection heat and mass transfer from a vertical plate with variable wall temperature and concentration to power law fluids with yield stress in a porous medium. Chem Engg Comm. 2001; 185:165-82. https://doi.org/10.1080/00986440108912861
13. Lakshmi Narayana PA, Murthy PVSN, Postelnicu A. Soret and Dufour effects on free convection of a non-Newtonian power-law fluids with yield stress from a vertical flat plate in saturated porous media. J Por Med. 2009; 12:967-81. https://doi.org/10.1615/JPorMedia.v12.i10.40
14. Kim GB, Hyun JM. Buoyant convection of power-law fluid in an enclosure filled with heat-generating porous media. Num Heat Trans, Part A: App. 2004; 45:569-82. https://doi.org/10.1080/10407780490277572
15. Chamkha AJ, Al-Mudhaf AF, Pop I. Effect of heat generation or absorption on thermophoretic free convection boundary layer from a vertical flat plate embedded in a porous medium. Int Comm He Ma Trans. 2006; 33(9):1096–102. https://doi.org/10.1016/j.icheatmasstransfer.2006.04.009
16. Cheng CY. Natural convection heat and mass transfer of non-Newtonian power law fluids with yield stress in porous media from a vertical plate with variable wall heat and mass fluxes. Int Comm He Ma Trans. 2006; 33(9):1156-64. https://doi.org/10.1016/j.icheatmasstransfer.2006.06.006
17. Patil PM, Kulkarni PS. Effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. Int J Ther Sci. 2008; 47(8):1043-54. https://doi.org/10.1016/j.ijthermalsci.2007.07.013
18. Chen CH. Effects of magnetic field and suction/injection on convection heat transfer of non- Newtonian power-law fluids past a power-law stretched sheet with surface heat flux. Int J Ther Sci. 2008; 47(7):954-61. https://doi.org/10.1016/j.ijthermalsci.2007.06.003
19. Subhas Abel M, Datti PS, Mahesha N. Flow and heat transfer in a power-law fluid over a stretching sheet with variable thermal conductivity and non-uniform heat source. Int J He Ma Trans. 2009; 52(11):2902-13. https://doi.org/10.1016/j.ijheatmasstransfer.2008.08.042
20. Suresh Babu R, Rushi Kumar B, Dinesh PA. Combined effects of internal heat generation and viscous dissipation for double diffusive with Forchheimer fluid model. ECI Dig Arc, USA; 2016.
21. Cheng C. Double-diffusive natural convection along a vertical wavy truncated cone in non-Newtonian fluid saturated porous media with thermal and mass stratification. Int Comm He Ma Trans. 2008; 35:985–90. https://doi.org/10.1016/j.icheatmasstransfer.2008.04.007
22. Salem AM. Coupled heat and mass transfer in Darcy-Forchheimer mixed convection from a vertical flat plate embedded in a fluid-saturated porous medium under the effects of radiation and viscous dissipation. Int J He Ma Trans. 2009; 14:57-71.
23. Prabhu KKS, Kandasamy R, Perisamy K. Chemical reaction, heat and mass transfer on MHD flow over a vertical stretching surface with heat source and thermal stratification effects. Int J He Ma Trans. 2005; 48:4557-61. https://doi.org/10.1016/j.ijheatmasstransfer.2005.05.006
24. Ibrahim FS, Elaiw AM, Bakr AA. Effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. Nonli Sci Numer Simul. 2008; 13:1056–66. https://doi.org/10.1016/j.cnsns.2006.09.007
25. Chen CH. Magneto-Hydrodynamic mixed convection of a power-law fluid past a stretching surface in the presence of thermal radiation and internal heat generation/

absorption. Int J Nonlin Mech. 2009; 44:596-603. https://doi.org/10.1016/j.ijnonlinmec.2009.02.004

26. Mohammed Ibrahim S. Chemical reaction and radiation effects on MHD free convection flow along a stretching surface with viscous dissipation and heat generation. Advances in Appl Sci Res. 2013; 4:371-82.
27. Lavanya B, Leela Ratnam A. Dufour and Soret effects on steady MHD free convective flow past a vertical porous plate embedded in a porous medium with chemical reaction, radiation heat generation and viscous dissipation. Advs Appli Sci Res. 2014; 5:127-42.
28. Swamy Reddy G, Ravi Kiran G, Archana Reddy R. Radiation impacts on free convection circulation of a Power-Law fluid past vertical plate filled along with Darcy porous medium. Int J Engig Adv Tech. 2019; 8(6):4582-5. https://doi.org/10.35940/ijeat.F8886.088619
29. Castaneda PP. Anisotropic Oldroyd-type models for non-colloidal suspensions of viscoelastic particles in Newtonian and yield-stress fluids via homogenization. J Non-New Flu Mech. 2021; 295:104625. https://doi.org/10.1016/j.jnnfm.2021.104625
30. Suresh Babu R, Ramesh NL, Sravan Kumar T. Effects of chemical reaction, Soret and Lorentz force on Casson fluid flow past an exponentially accelerated vertical plate: A Comprehensive Analysis. Heat Transfer. 2021; 51(2):2237-57. https://doi.org/10.1002/htj.22398
31. Saleem S, Mohamed Abd El-Aziz. Entropy generation and convective heat transfer of radiated non-Newtonian power-law fluid past an exponentially moving surface under slip effects. The Euro Phy J Plu. 2019; 134(4):184. https://doi.org/10.1140/epjp/i2019-12656-4
32. Falana A, Babatope OP. Velocity slip effect on MHD Power-law fluid over a moving surface with heat generation, viscous dissipation and thermal radiation. J Engg Res Rep. 2021; 20(10):103-12. https://doi.org/10.9734/jerr/2021/v20i1017394