ISSN: 2141 – 3290
www.wojast.org

Supported by tetfund TERTIARY EDUCATION TRUST FUND

CASSON FLUID FLOW WITH HEAT GENERATION AND RADIATION EFFECT THROUGH A POROUS MEDIUM OF AN EXPONENTIALLY SHRINKING SHEET

EKANG, I.F.[1*], JOSHUA, E.E.[1], SENGE, I.O.[2]
[1]*Department of Mathematics, University of Uyo, Uyo, Nigeria*
[2]*Department of Mathematics, University of Benin, Benin City, Nigeria*
[*]*corresponding author: idongesitekang@uniuyo.edu.ng*

ABSTRACT

In the paper, the effects of radiation on two dimensional non-Newtonian Casson fluid flows over an exponentially shrinking sheet through a porous medium with heat generation and viscous dissipation are investigated. The governing high nonlinear partial differential equations, with the aid of similarity transformation are converted to nonlinear ordinary differential equations and then solved numerically using a shooting method with fourth order Runge-Kutta scheme. The effects of the controlling parameters on velocity and temperature profiles are illustrated graphically using MATLAB software. The result shows that the skin-friction coefficient and Nusselt number reduces with increase in the values of the radiation and suction parameter. Also, increase in the Casson and suction parameters leads to increase in the velocity distribution of the fluid and decrease in the temperature distribution of the fluid.

KEYWORDS: Casson fluid, radiation, porous medium, shrinking sheet

INTRODUCTION

The advancement of science and technology has brought about keen interest in magnetohydrodynamic (MHD) flows over a stretching surface due to its wide range of applications in our everyday life. Theoretical and experimental researches are available for study. (Crane, 1970) worked on viscous fluid flow over a linearly stretching sheet. (Gupta and Gupta, 1977) investigated stretching sheet of heat and mass transfer with suction or blowing. Many researchers over time took their research further by investigating different models of exponentially stretching sheet like (Ekang *et al.*, 2021). Non-Newtonian fluids are gaining more ground because in modern industrial and engineering processes, many fluids display non-Newtonian dynamics and behaviour. Casson fluid which acts like elastic solids (e.g. human blood, honey, jelly, tomato sauce, etc.) is one of such non- Newtonian fluids. Solving analytically using Homotopy Analysis Method (HAM), (Animasaun *et al.*, 2016) worked on Casson fluid flow with variable thermo-physical properties along an exponentially stretching sheet with suction and exponentially decaying internal heat generation. They concluded that an increase in the variable plastic dynamic viscosity parameter of Casson fluid corresponds to an increase in the velocity profile and a decrease in temperature profile. (Nadeem *et al.*, 2013) studied 3D Casson fluid flow past a porous linearly stretching sheet; their findings show that the magnetic field, Casson fluid parameter and porosity parameter reduces the velocity profiles. (Sharada and Shankar, 2015) investigated effects of soret and dufour on Casson fluid over an exponentially stretching surface. From their work it was observed that temperature increases with increasing values of the dufour number and chemical reaction parameter while the velocity profile decreases. An increase in the Soret number increases the concentration profile and the boundary layer thickness. (Mukhopadhayay *et al.*, 2013) looked into Casson fluid flow exponentially stretching permeable surface. They observed that increasing the values of the Casson parameter decreases the velocity profile and enhances the temperature profile. It was also observed that increase in the values of the suction parameter increases the skin-friction coefficient. Chemically reactive Casson fluid flow with hall current and dufour effect was studied by (Viyayaragavan and Karthikeyan, 2018). Their studies show that the velocity in the boundary layer region increases when the magnetic parameter, Schmidt number and chemical reaction parameter are increased. The temperature decreases with increase in Prandtl number and radiation parameter.

Boundary layer flow and heat transfer of Casson fluid over a porous linear stretching sheet with variable wall was handled by (Sankad and Maharudrappa, 2018). Recently, (Kumar *et al.*, 2020) studied Casson fluid flow over an exponentially curved sheet with radiation effect. They concluded that friction heating contributed to fluid temperature rising. Also, that fluid velocity is a declining function of Casson and magnetic field parameters. MHD Casson fluid flow with multiple slip effects was investigated by (Jain and Parmar, 2018).

Shrinking sheet literatures are available for study but limited when compared with stretching sheet yet it is also important. (Bhattacharyya, 2011) worked on an exponentially shrinking sheet. They observed that the temperature and the thermal boundary layer thickness decreases with Prandtl number, radiation parameter and heat sink parameter and the heat source parameter act oppositely. Stagnation point flow and heat transfer over an exponentially shrinking sheet was investigated by (Bhattacharyya and Vajravelu, 2012). It was highlighted that dual solutions exist even when the shrinking rate is smaller than the straining rate. (Bhattachryya and Pop, 2011) considered boundary layer flow due to an exponentially shrinking vertical sheet with suction. From their analysis, it was observed that dual solutions for the flow field are obtained and the velocity at a point increase with the magnetic parameter for the first solution and decreases for the second solution.

Porous stretching surfaces have many applications in petroleum industries, crystal fiber production, manufacturing processes; MHD power generators etc.

(Nadeem *et al*., 2012) investigated a Casson fluid flow using an exponentially shrinking sheet. Casson fluid through a porous medium over a stretching/shrinking sheet was discussed by (Rao and Sreenadh, 2017). It was observed that the boundary layer thickness reduces with increase in Casson parameter values. Recently, (Senge *et al*., 2021) investigated MHD flow over an exponentially stretching sheet embedded in a thermally stratified porous medium.

The purpose of this present work is to unveil Casson fluid flow with heat generation and radiation effect through a porous medium of an exponentially shrinking sheet in the presence of viscous dissipation. The governing partial differential equations (PDEs) are converted to ordinary differential equations (ODEs) with the help of suitable similarity transformation. These obtained ODEs are solved using shooting method along with fourth order Runge-Kutta scheme. The resulting numerical values of the controlling parameters are demonstrated in graphs and discussed.

To the best of the authors' knowledge, no information is yet available for this exact research work.

METHODS

Mathematical Formulation

We consider a two-dimensional, steady, electrically conducting and incompressible viscous flow over an exponentially shrinking sheet through a porous medium in the presence of a uniform magnetic field, radiation and heat source. The induced magnetic field is neglected under the approximation of the small Reynolds number. The sheet is situated at $y = 0$, with the flow being confined in $y > 0$. Under the above assumptions, the continuity, momentum and energy equations may be written as:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \vartheta\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2}{\rho}u - \frac{\vartheta}{k^*}u \qquad (2)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{\vartheta}{C_p}\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)^2 + \frac{Q_o}{\rho C_p}(T - T_\infty) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \qquad (3)$$

where u and v are the components of velocity in x and y directions respectively, $\vartheta = \frac{\mu}{\rho}$ is the kinematic viscosity, ρ is the density, $\beta = \frac{\mu_B\sqrt{2\pi_c}}{p_y}$ is the Casson parameter, T is the temperature, $\alpha = \frac{k}{\rho C_p}$ is the thermal diffusivity, C_p is the specific heat, q_r is the radioactive heat flux, Q_o is the heat source coefficient, σ is the electrical conductivity, $B(x) = B_o e^{\frac{x}{L}}$ is the magnetic field where B_o is the constant, k^* is the permeability coefficient of porous medium.
Using approximation of Rosseland for radiation, the radiative heat flux can be written as follows:

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

where σ is the Stefan-Boltzman constant and k^* is the absorption coefficient. Using Taylor series to expand T about T^4 and neglecting higher order terms, we can write:

$$T^4 = 4T_\infty^3 T - 3T_\infty^4 \qquad (5)$$

Hence;

$$\frac{\partial q_r}{\partial y} = -\frac{16\sigma^* T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial y^2} \qquad \dots (6)$$

Therefore the energy equation (eqn. 3) can be written as follows:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{\vartheta}{C_p}\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)^2 + \frac{Q_o}{\rho C_p}(T - T_\infty) + \frac{16\sigma^* T_\infty^3}{3\rho C_p k^*}\frac{\partial^2 T}{\partial y^2} \qquad \dots (7)$$

The rheological equation of state for an isotropic and incompressible flow of a Casson fluid is assumed to be as follows:

$$\tau_{ij} = \begin{cases} 2(\mu_B + \frac{p_y}{\sqrt{2\pi}})e_{ij}\,; & \pi > \pi_c \\ 2(\mu_B + \frac{p_y}{\sqrt{2\pi_c}})e_{ij}\,; & \pi < \pi_c \end{cases} \qquad \dots (8)$$

Here μ_β is the Casson coefficient of viscosity or plastic dynamic viscosity of the non-Newtonian fluid, π is the product of the component of deformation rate with itself (i.e. $\pi = e_{ij}e_{ji}$) where e_{ij} is the $(i,j)^{th}$ component of the deformation rate, π_c is the critical value of the product of the component of the rate of strain tensor with itself, $P_y = \frac{\mu_\beta\sqrt{2\pi}}{\beta}$ is the yield stress of the fluid, μ is the dynamic viscosity. According to (Aminasaun, 2015), in a case of Casson fluid (non-Newtonian) flow, where $\pi > \pi_c$, it is possible to say that

$$\mu = \mu_\beta + \frac{P_y}{\sqrt{2\pi}} \qquad (9)$$

Substituting the value of P_y , eqn. (9) becomes

$$\mu = \mu_\beta\left(1 + \frac{1}{\beta}\right) \qquad \dots (10)$$

The kinematic viscosity of Casson fluid is now a function depending on plastic dynamic viscosity, density and Casson parameter (β)

$$\vartheta = \frac{\mu_\beta}{\rho}\left(1 + \frac{1}{\beta}\right) \qquad (11)$$

The corresponding boundary conditions are as follows:

$$u = -u_w \quad v = V(x) \quad T = T_w \quad \text{at } y = 0$$
$$u \to 0, \quad T \to T_\infty \quad \text{as} \quad y \to \infty \qquad (12)$$

Here $u = -u_w = ae^{\frac{x}{L}}$ is the shrinking velocity with a as the shrinking constant, $T_w = T_\infty + be^{\frac{2x}{L}}$ is the temperature at the sheet, T_∞ is the free stream temperature assumed to be constant, L is the characteristics length, $V(x) = V_o e^{\frac{x}{2L}}$ is a special type of velocity at the wall where V_o is a constant, $V_o(x) < 0$ is the strength of the suction velocity and $V_o(x) > 0$ is the strength of the blowing velocity.

The continuity equation is satisfied by introducing the stream function $\psi(x, y)$ defined in its usual notation as

$$u = \frac{\partial\psi}{\partial y} \quad \text{and} \quad v = -\frac{\partial\psi}{\partial x} \tag{13}$$

Now, introduce the similarity variable η with the following similarity deformations;

$$\psi = \sqrt{2a\vartheta L}f(\eta)e^{\frac{x}{2L}},$$
$$\eta = y\sqrt{\frac{a}{2\vartheta L}}e^{\frac{x}{2L}},$$
$$T = T_\infty + be^{\frac{2x}{L}}\theta(\eta) \tag{14}$$

$$u = ae^{\frac{x}{L}}f'(\eta),$$
$$v = -\sqrt{\frac{a\vartheta}{2L}}e^{\frac{x}{2L}}[f(\eta) + \eta f'(\eta)]$$

By substituting the above equations (14) into the momentum and energy governing equations (eqn. 2 and 7), we will have the following transformation;

$$(1 + \tfrac{1}{\beta})f''' + ff'' - 2f'^2 - (M + K)f' = 0 \tag{15}$$

$$\frac{1}{P_r}\left(1 + \frac{4}{3}R\right)\theta'' - 4\theta f' + \theta' f + 2Q\theta + (1 + \tfrac{1}{\beta})Ekf''^2 = 0 \quad \ldots \tag{16}$$

Subject to the boundary conditions as follows:

$$f'(0) = -1, \quad f(0) = S \quad \theta(0) = 1 \quad at \quad \eta = 0$$
$$f'(\eta) \to 0, \quad \theta(\eta) \to 0 \quad as \quad \eta \to \infty \tag{17}$$

Here, primes denote differentiation with respect to the similarity variable η and the dimensionless parameters are as follows;

$M = \frac{2L\sigma B_0{}^2}{\rho}$ is the magnetic parameter;

$K = \frac{2\nu L}{K^*}$ is the permeability parameter;

$R = \frac{4\sigma^* T_\infty{}^3}{kk^*}$ is radiation parameter;

$Q = \frac{Q_0 L}{C_p a\rho e^{\frac{x}{L}}}$ is the heat source;

$Ek = \frac{a^2}{bC_p}$ is the Eckert number;

$S = -V_o\sqrt{\frac{2L}{a\nu}} > 0$ is suction parameter;

$P_r = \frac{\mu}{k}$ is the Prandtl number.

The physical quantity of interest is the wall skin friction coefficient C_f and Nusselt number Nu_x defined respectively as follows:

$$C_f = \frac{\tau_w}{\rho U_w{}^2}\ ; \qquad Nu_x = \frac{xq_w}{k(T_w - T_\infty)} \quad \ldots \tag{18}$$

where τ_w is the shear stress along the exponentially shrinking sheet and q_w is heat flux from the sheet and are defined as follows:

$$\tau_w = (\mu_\beta + \frac{P_y}{\sqrt{2\pi_c}})(\frac{\partial u}{\partial y})_{y=0}; q_w = -k(\frac{\partial T}{\partial y}))_{y=0} \tag{19}$$

Therefore, we get the wall skin friction coefficient and the local Nusselt number as described by (Zaib *et al.*, 2016) as follows:

$$\left(1 + \frac{1}{\beta}\right)f''(0) = \sqrt{\frac{2L}{x}}\, C_f\sqrt{Re_x} \tag{20}$$

$$-\theta'(0) = \sqrt{\frac{2L}{x}}\frac{Nu_x}{\sqrt{Re_x}} \tag{21}$$

Here the local Reynolds number is given as:

$$Re_x = \frac{xu_w}{\nu}$$

Method of Solution

We solve the dimensionless governing equations (15) and (16) subject to the corresponding boundary conditions (17) numerically using the shooting method along with fourth order Runge-Kutta technique. First, we define new variables for the equations as follows:

$$f_1 = \eta\ , f_2 = f\ , f_3 = f',\ f_4 = f''\ ,\ f_5 = \theta,\ f_6 = \theta' \tag{22}$$

The governing dimensionless coupled higher order nonlinear differential equations (15) and (16) as well as the boundary conditions (17) are transformed to a system of first order differential equations.

$$f_1{}' = 1$$
$$f_2{}' = f' = f_3$$
$$f_3{}' = f'' = f_4$$
$$f_4{}' = f''' = [2f'^2 - ff'' + (M + K)f']/(1 + \tfrac{1}{\beta}) \tag{23}$$
$$f_5{}' = \theta' = f_6$$
$$f_6{}'\theta'' = P_r\,[4\theta f' - \theta' f - 2Q\theta - \left(1 + \frac{1}{\beta}\right)Ekf''^2]\Big/\left(1 + \frac{4}{3}R\right)$$

Here, primes denote differentiation with respect to η and the boundary conditions are as follows;

$$f_3(0) = -1, \quad f_2(0) = S \quad f_5(0)\ 1 \quad at \quad f_1 = 0$$
$$f_3(\eta) \to 0, \quad f_5(\eta) \to 0 \quad as \quad f_1 \to \infty \tag{24}$$

$$f_4(0) = \varepsilon_1$$
$$f_6(0) = \varepsilon_2$$

Using the shooting method, the missing values, ε_1 and ε_2 are required but no such values are given after the boundary conditions when non-dimensioned. Suitable guessed values are chosen and the integration is carried out. The calculated values for f' and θ at $\eta_\infty = 10$ are compared with the boundary conditions. The better estimation for ε_1 and ε_2 are obtained, IVP are solved by using the fourth order Runge-Kutta technique with step size h = 0.2. The above procedure is repeated until result up to desired degree of accuracy 0.00001 is obtained. From the numerical computation, ε_1 is proportional to the skin-friction coefficient $f''(0)$ and ε_2 is proportional to Nusselt number $-\theta'(0)$. The results obtained are presented in tables and MATLAB was used to plot the graphs and the main features are analyzed and discussed.

RESULTS AND DISCUSSION

The effects of the dimensionless governing parameters namely: Casson parameter (β), Magnetic parameter (M), Thermal radiation parameter (R), Prandtl number (P_r), Heat source (Q), Suction parameter (S), Permeable parameter (K) and Eckert parameter (Ek) on the velocity and temperature distribution profiles are analyzed numerically using the method mentioned in the previous section. Numerical values were plotted into graphs using MATLAB varying the fluid parameters with basic at $R = 1.0$, $M = 1.0$, $P_r = 2.0$, $S = 2.5$, $K = 1.0$, $Ek = 1.0$, $\beta = 1.0$, and $Q = 1.0$.

Figures 1 and ***2*** depict the effect of the Casson parameter on velocity and temperature distribution of the fluid. It is observed that as the values of the Casson parameter increase, the velocity increases, while the reverse is the case for the temperature distribution.

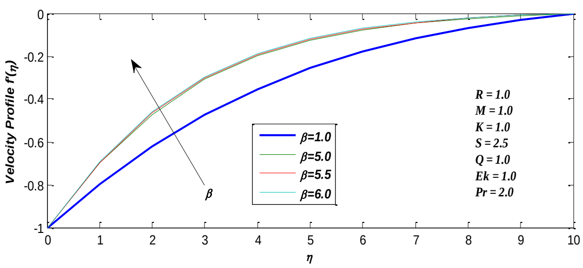

Figure 1: Effect of Casson Parameter (β) on Velocity profile

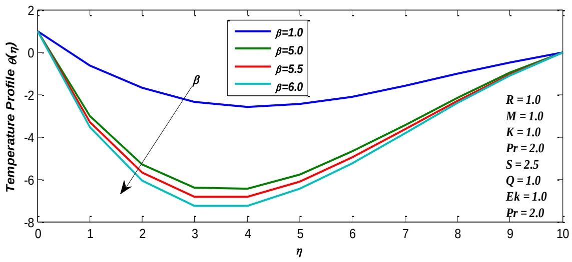

Figure 2: Effect of Casson Parameter (β) on Temperature profile.

Figures 3 and 4 show how the velocity and the temperature profiles are affected by the magnetic parameter. It can be seen that an increase in the values of the magnetic parameter leads to an increase in the velocity distribution of the fluid while in the temperature profile, there is a decrease in the temperature distribution of the fluid.

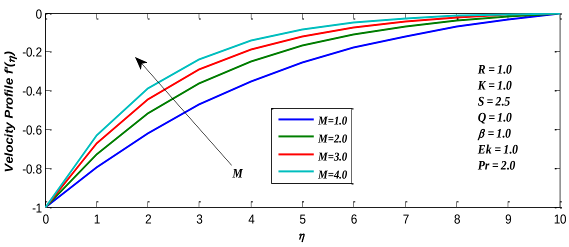

Figure 3: Effect of Magnetic Parameter (M) on Velocity profile

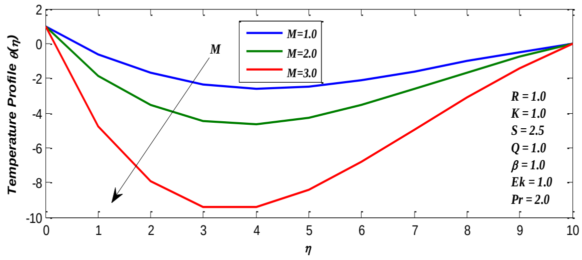

Figure 4: Effect of Magnetic Parameter (M) on Temperature profile

Figures 5 and 6 depict the effect of the suction parameter on velocity and temperature profiles. Increase in the values of the suction parameter leads to increase in the velocity distribution and decrease in the temperature distribution of the fluid.

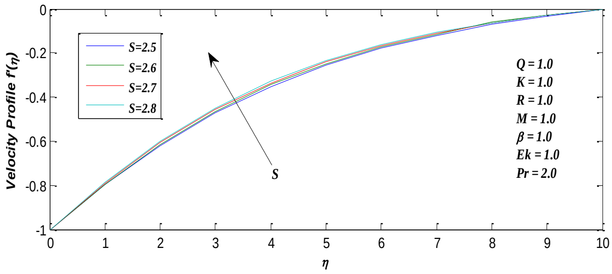

Figure 5: Effect of Suction Parameter (S) on Velocity profile

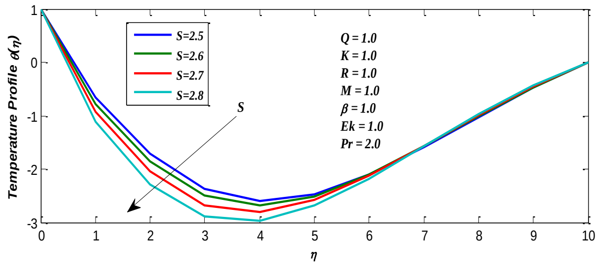

Figure 6: Effect of Suction Parameter (S) on Temperature profile

Figures 7 and 8 show the effect of the permeable parameter on velocity and temperature profiles. As the value of the permeable parameter is increased, the fluid has more spaces to flow, hence the increase in the velocity distribution of the fluid in the presence of suction. While the temperature distribution of the fluid decreases with an increase in the value of the permeable parameter.

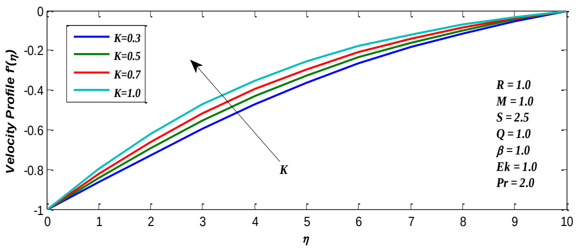

Figure 7: Effect of Permeability Parameter (K) on Velocity profile

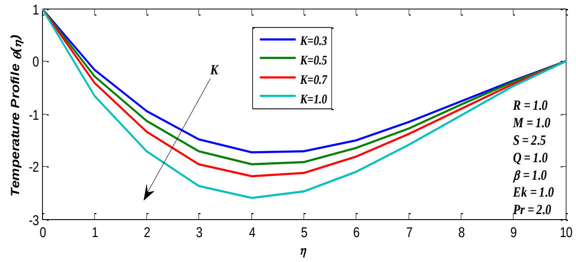

Figure 8: Effect of Permeability Parameter (K) on Temperature profile

Figure 9 highlights the effect of the heat source parameter on temperature profile. Increase in the value of the heat source parameter leads to increase in the temperature distribution of the fluid.

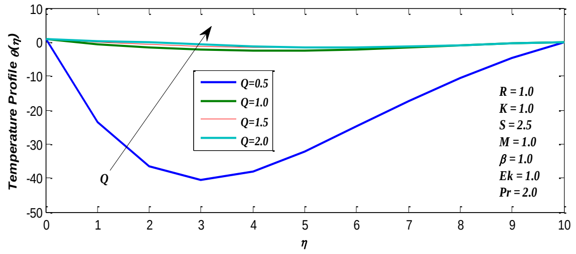

Figure 9: Effect of Heat Source Parameter (Q) on Temperature profile

Figure 10 depicts how the temperature profile is affected by the radiation parameter. The temperature distribution of the fluid decreases as the values of the radiation parameter increases.

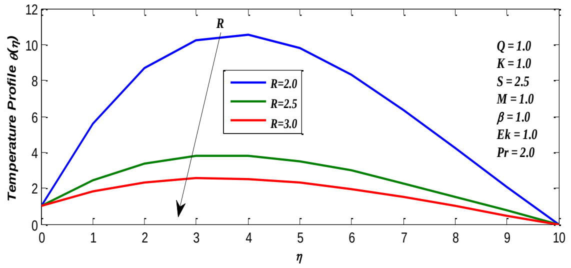

Figure 10: Effect of Radiation Parameter (R) on Temperature profile

Figure 11 illustrates how the Eckert parameter affects the temperature profile. From the graph, increase in the Eckert parameter leads to decrease of the temperature distribution of the fluid.

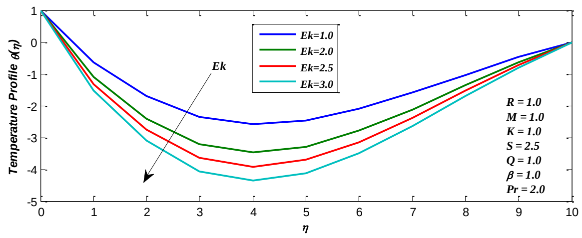

Figure 11: Effect of Eckert Parameter (Ek) on Temperature profile

Table 1: The numerical values of $f''(0)$ and $-\theta'(0)$ for different values of M and S

M	S	$f''(0)$	$-\theta'(0)$
1	2.5	0.1269	1.7875
2	2.5	0.0671	2.7867
3	2.5	0.0378	5.1429
4	2.5	0.0220	17.5599
1	2.6	0.1207	1.6769
1	2.7	0.1147	1.5854
1	2.8	0.1090	1.5143

Table 1 represents values of skin-friction coefficient and Nusselt number for various values of: Magnetic parameter (M) and suction parameter (S). The values of the other non dimensionless parameters are kept constant at the basic level. Table 1 shows that increase in the values of the magnetic parameter leads to decrease in skin-friction coefficient and increase in the Nusselt number. While increase in the suction parameter leads to decrease in skin-friction coefficient and the Nusselt number.

CONCLUSION

Two dimensional electrically conducting MHD flow was discussed in this research work. Similarity transformations were used for the conversion of nonlinear partial differential equations to nonlinear ordinary differential equations. Numerical solutions were carried out using shooting methods along with fourth order Runge-Kutta technique and graphical results for velocity and temperature profiles were obtained. The effects of various controlling parameters on the flow and heat transfer were observed from the graphs. The skin- friction coefficient, Nusselt number and the temperature distribution of the fluid are seen to reduce with enhancement in the values of the radiation parameter (R) and suction parameter (S). Momentum boundary layer thickness and the skin-friction coefficient increases while the Nusselt number decreases with increasing values of the magnetic parameter (M). The velocity and temperature distribution of the fluid increases and decreases respectively as the values of the Casson parameter (β) and suction parameter (S) increases.

Nomenclature

x	Distance along the surface
y	Distance perpendicular to the surface
u	Velocity along x-direction
v	Velocity along y-direction
g	Acceleration due to gravity
L	Reference length
T	Fluid Temperature
T_w	Surface Temperature
T_∞	Ambient Temperature
Q	Heat source parameter
Q_o	Heat generation/absorption coefficient
C_f	Skin-friction coefficient
Nu_x	Nusselt number
K	Permeable parameter
K^*	Permeability of the porous medium
B_0	Strength of the magnetic field

B	Magnetic field
q_w	Heat flux
q_r	Radiative heat flux
τ_w	Shear stress
P_r	Prandtl number
Re_x	Reynold number
c_p	Specific heat capacity
R	Radiation parameter
S	Suction parameter
Ek	Eckert parameter
M	Magnetic parameter
k	Coefficient of thermal conductivity

Greek Symbols

β	Coefficient of thermal expansion
ϑ	Kinematic viscosity
σ	Electrical conductivity
ρ	Density
η	Similarity variable
ψ	Stream function
θ	Non-dimensional temperature
μ	Dynamic viscosity
α	Thermal diffusivity

Subscript

w	Property at the surface
∞	Property at ambient

REFERENCES

Animasaun, I. L. (2015). "Casson fluid flow with variable viscosity and thermal conductivity along exponentially stretching sheet embedded in a thermally stratified medium with exponentially heat generation", *Journal of Heat and Mass Transfer Research*, 2(2)), 63-78.

Animasaun, I. L., Adebile, E. A. and Fagbade, A. I. (2016). "Casson fluid flow with variable thermo-physical property along exponentially stretching sheet with suction and exponentially decaying internal heat generation using the homotopy analysis method". *Journal of the Nigerian Mathematical Society*, 35(1), 1-17.

Bhattacharyya, K. (2011). "Effects of radiation and heat source/sink on unsteady MHD boundary layer flow and heat transfer over a shrinking sheet with suction/injection," *Frontiers of Chemical Engineering in China*, vol. 5, no. 3, pp. 376-384.

Bhattacharyya, K. and Pop, I. (2011). "MHD boundary layer flow due to an exponentially shrinking sheet," *Magnetohydrodynamics*, vol. 47, no. 4, pp. 337-344.

Bhattacharyya, K. and Vajravelu, K. (2012). "Stagnation-Point flow and heat transfer over an exponentially shrinking sheet." *Communications in Nonlinear science and numerical simulation*, 17, 2728-2734.

Crane, L. J. (1970). "Flow past a stretching sheet," *Zeitschrift Fur Angewandte Mathematic and Physik*, vol. 21, no. 4, pp. 645-647.

Ekang, I. F., Joshua, E. E., Senge, I. O. and Nwachukwu, O. O. (2021). "MHD heat and mass flow of Nano-fluid over a non-linear permeable stretching sheet", *Journal of Mathematics and Computer Science*, 11(5), pp. 5196-5212. https//doi.org/10.28919/jmcs/5781. ISSN: 1927-5307.

Gupta, P. S. and Gupta, A. S. (1977). "Heat and mass transfer on a stretching sheet with suction or blowing," *The Canadian Journal of Chemical Engineering*, vol. 55, no 6, pp. 744-746.

Jain, S. and Parmar, A. (2018). "Multiple slip effects on inclined MHD Casson fluid flow over a permeable stretching surface and a melting surface" *International Journal of Heat and Technology*, Vol. 36 (2), pp. 585-594.

Kumar, A., Sugunamma, V. and Sandeep, N. (2020). "Effect of thermal radiation on MHD Casson fluid flow over an exponentially stretching curved sheet." *Journal of Thermal Analysis and Calorimetry*, vol. 140(5), pp. 2377.

Mukhopadhyay, S., Vajravelu, K. and Gorder, R. A. Van (2013). "Casson fluid flow and heat transfer at an exponentially stretching permeable surface", *Journal of Applied Mechanics*, 80 (5)

Nadeem, S., Haq, R. UI, Akbar, N. S., and Khan, Z. H., (2013). "MHD three-dimensional Casson fluid flow past a porous linearly stretching sheet", *Alexandria Engineering Journal*, Vol. 52, pp.577-582.

Nadeem, S., Haq, U.I., Lee, C. (2012). "MHD flow of a casson fluid over an exponentially shrinking sheet", Sci. Iran., (19), 1550-1553. https://doi.org/10.1016/j.scient.2012.10.021.

Rao, M. E. and Sreenadh, S. (2017). "MHD Boundary layer flow of Casson fluid over a stretching/shrinking sheet through porous medium", *Chemical and Process Engineering Research*, Vol. 47.

Sankad, G. C. and Maharudrappa, I. (2018). "Boundary layer flow and heat transfer of Casson fluid over a porous linear stretching sheet with variable wall temperature and radiation", *Numerical Heat Transfer and Fluid flow*, pp. 167-176. DOI: 10.1007/978-981-13-1903-7_20.

Senge, I. O., Oghre, E. O. and Ekang, I. F. (2021). **"**Influence Of Radiation on Magneto-Hydrodynamics Flow Over An Exponentially Stretching Sheet Embedded In A Thermally Stratified Porous Medium In The Presence Of Heat Source" *Earthline Journal of Mathematical Sciences* ISSN (Online): 2581-8147 Volume 5(2), Pages 345-363. https://doi.org/10.34198/ejms.5221.345363

Sharada, K. and Shankar, B., (2015) "MHD mixed convection flow of a Casson fluid over an exponentially stretching surface with the effects of soret, dufour, thermal radiation and chemical reaction", *World Journal of Mechanics*, Vol 5(09), 165.

Vijayaragavan, R. and Karthikeyan, S. (2018) "Hall current effect on chemically reacting MHD Casson fluid flow with dufour effect and thermal radiation", *Asian Journal of Applied science and Technology*, Vol. 2, pp. 228-245.

Zaib, A., Bhattacharyya, K., Uddin, Md. and Shafie, S. (2016). "Dual solution of non-Newtonian Casson fluid flow and heat transfer over an exponentially permeable shrinking sheet with viscous dissipation", *Modelling and simulation in Engineering*, Article ID 6968371, pp. 1-8.