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Full Length Research Article

STAGNATION POINT FLOW WITH THERMAL AND MAGNETIC FIELD OVER A STRETCHING SHEET

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ABSTRACT
The purpose of this research is to examine effects of thermal radiation and magnetic field on 2D stagnation point flow toward a stretching sheet. The governing equations are transformed into a system of nonlinear ordinary differential equations by similarities transformation method and then, solved, numerically using implicit finite difference scheme. The Velocity profile increase for higher values of stagnation point parameter, opposite occurred with magnetic field. The temperature profile is an increasing function of radiative energy.

Keywords: Thermal radiation, magnetic field, stagnation point flow, stretching sheet.

INTRODUCTION
Considering the impingement of flow on the medium forms a stagnation point around the surface (Hayat et al., 2020). The disappearance of the flow away from the medium produces another stagnation point on the trailing surface (Khan et al., 2020). Flow and heat transfer of an incompressible viscous fluid over a stretching sheet have been deliberated in numerous processes, ranging from industry: extrusion mechanized of polymers, cooling of metallic plates, the aerodynamic extrusion of plastic sheets, and others (Daniel et al., 2017a; Khashi'ie et al., 2020; Nandeppanavar et al., 2021; Daniel et al. 2017b; Nadeem et al. 2020; Daniel et al. 2019a; Ghasemi & Hatami, 2021 and Daniel et al., 2019b). MHD stagnation flow over a stretching sheet is imperative due to its applications in several engineering challenges such as rapid spray cooling and quenching in metal foundries, emergency core cooling systems, cooling of microelectronics, polymer extrusion in a melt-spinning process, glass manufacturing and purification of crude oil (Oyelakin et al., 2020; Anuar et al., 2020; Daniel, 2015; Nasir et al., 2020; Daniel and Daniel, 2015 and Lund et al., 2020). When scientific processes take place at high thermal energy, such as cooling of a metal or glass sheet, thermal radiation impacts begins to display significant role which cannot be overlook (Daniel et al., 2017c; Zainal et al., 2021 and Chaudhary et al., 2021). The problem of MHD flow and heat transfer of incompressible viscous fluids has been discussed by a number of researchers including the literatures (Maqbool 2020; Daniel et al., 2017; Hussain et al., 2020, Daniel et al., 2018; Afify et al. 2020 and Daniel 2016) among others.
In the present investigation, a novel stagnation point flow and energy conversion study for conjugate conduction–convection and radiative heat transfer problem has been performed. The magnetic field is to control and to manipulate the flow behaviour with the capacity to increase the thermal conductivity and heat transfer performance. A convection radiative heat transfer model with effect of Lorentz force using electrically conducting fluid passing over a stretching surface have been processed.

MATHEMATICAL MODEL
Consider a two-dimensional steady magnetohydrodynamic (MHD) over a linear stretching sheet. Such that the stagnation point flow is incompressible and laminar (Maqbool 2020). The velocity of the stretching sheet is denoted as $u_W(x)$, where the surface is taken at $y = 0$. The incompressible stagnation point flow of viscous fluid in the presence of an applied magnetic field $B(x)$ is taken into consideration. The fluid is electrically conducting. The stagnation point flow is due to stretching of a sheet from a slot through two equal and opposite force and thermally radiative. The magnetic field of strength $B(x)$ is applied normal to the flow field, such that the magnetic Reynolds number is selected small. The induced magnetic field is smaller to the applied magnetic field. Hence the induced magnetic field is absence for small magnetic Reynolds number. We choose the Cartesian coordinate system such that x is chosen along the stretching sheet and $the\ y$-axis denotes the normal to the stretching sheet, u and v are the velocity components of the fluid in the x and y-direction. T is the fluid temperature. The magnetic field control flow. The combined effects of thermal radiation, and magnetic field are incorporated. The stagnation point flow of the model is the composition of the continuity equation, the momentum equation, and energy equation which are formulated (Ghasemi, S. E., & Hatami, 2021):

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = u_\infty \frac{\partial u_\infty}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\sigma B^2(x)}{\rho_f}(u - u_\infty) \qquad (2)$$

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = u_\infty \frac{\partial u_\infty}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\sigma B^2(x)}{\rho_f}(u - u_\infty) \qquad (3)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) - \frac{1}{(\rho c)_f}\left(\frac{\partial q_r}{\partial y}\right) \qquad (4)$$

The boundary conditions at the sheet for the physical model are presented (Khan et al., 2020):

$$y = 0: \quad u = u_w(x) = ax, \quad v = 0, \quad T = T_w \qquad (5)$$

$$y \longrightarrow \infty: \quad u \to u_\infty(x) = bx, \quad T \longrightarrow T_\infty, \tag{6}$$

Here $u_w(x)$ is the velocity of the sheet surface. Where u and v represent the velocity components along the x and y-axis respectively. α, $\mu, v, \sigma, \rho\ \rho_f$, and ρ_p stand for the thermal diffusivity, the dynamics viscosity, the kinematic viscosity, the Steffan-Boltzmann constant, the density, the fluid density, and particles density respectively.
The radiative heat flux q_r via Rosseland approximation (Daniel et al., 2018) can be written as $q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}$. We assumed less temperature gradient within the viscous fluid flow in such a way that T^4 can be expressed as a linear function of temperature. By expanding T^4 using Taylor's series approach about a free stream temperature T_∞ is presented by (Daniel et al., 2017c):

$$T^4 = T_\infty^4 + 4T_\infty^3(T - T_\infty) + 6T_\infty^2(T - T_\infty)^2 + \cdots \tag{7}$$

Neglecting higher order terms, equation (7) resulted to an approximated:

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{8}$$

Hence equation (4) can be rewritten as (Daniel et al., 2019b):

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \frac{16\sigma^* T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial y^2} \tag{9}$$

The stream function can be defined as (Daniel et al., 2019a):

$$u = \frac{\partial \psi}{\partial y}, \qquad v = -\frac{\partial \psi}{\partial x} \tag{10}$$

The dimensionless variables are taken as:

$$u = axf'(\eta), \qquad \theta = \frac{T - T_\infty}{T_w - T_\infty}, \tag{11}$$

Substituting equations (10) & (11) into equation (1) the continuity equation is identically satisfied. After evaluating the order of magnitude analysis on y-direction momentum equation (3) which is normal to the sheet and boundary layer approximations in equations (3)-(4) and (9) define as (Daniel et al., 2017a):

$$u \gg v$$

$$\frac{\partial u}{\partial y} \gg \frac{\partial u}{\partial x}, \frac{\partial v}{\partial x}, \frac{\partial v}{\partial y} \tag{12}$$

The resultant equations of momentum, and energy in dimensionless form become:

$$f''' + ff'' - f'^2 + \lambda^2 + M(\lambda - f') = 0 \tag{13}$$

$$\left(1 + \frac{4}{3}Rd\right)\theta'' + Prf\theta' = 0 \tag{14}$$

The boundary conditions are given by

$$f = 0, \quad f' = 1, \quad \theta = 1, \quad \text{at} \quad \eta = 0 \tag{15}$$

$$f' = \lambda, \quad \theta = 0, \quad \text{as} \quad \eta \longrightarrow \infty \tag{16}$$

Here f and θ are the dimensionless velocity and temperature, respectively. Where prime represents differentiation with respect to η. $Pr = v/\alpha$ is the Prandtl number, $M = \sigma B_0^2/a\rho_f$ is the magnetic field parameter, $Rd = 4\sigma^* T_\infty^3/k^* k_1$ is the radiation parameter, and $\lambda = b/a$ denotes the ratio of the rates of free stream velocity to the velocity of the stretching sheet respectively.

RESULTS AND DISCUSSION

Fig.1 depicts that velocity profile outcomes in the increasing function of stagnation point parameter λ, when $\lambda < 1$. As such the stretching velocity $u_w(x)$ is much smaller in contrast to free stream velocity $u_\infty(x)$. It is worthy of noted that there is no formation of boundary layer, as it progresses, when $\lambda = 1$, reason is that both fluid and medium are moving with similar velocity. From Fig 2, it is observed that the velocity profile is a decreasing function of magnetic field M. This rise in parameter leads to increase in Lorentz force. This kind of force is a resistive force, consequently, weakening the velocity profile. In addition, it is witnessed that the effect of magnetic parameter is weaker in the plate compared to the surface. The strength of radiation parameter Rd on temperature profile is examined in Fig 3. It demonstrates that an upsurge in the parameter enhances the temperature distribution. Actually, more heat is transferred to the fluid as results of higher values of radiative parameter. Besides, it is observed that radiative impacts are resilient on the surface compared to the plate.

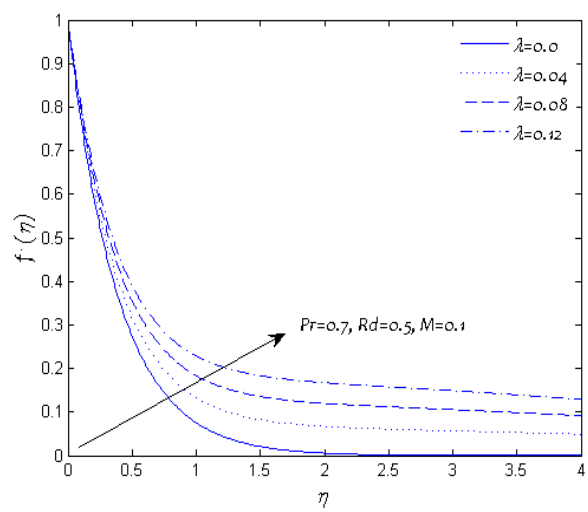

Fig.1 Effect of λ on the velocity profile $f'(\eta)$

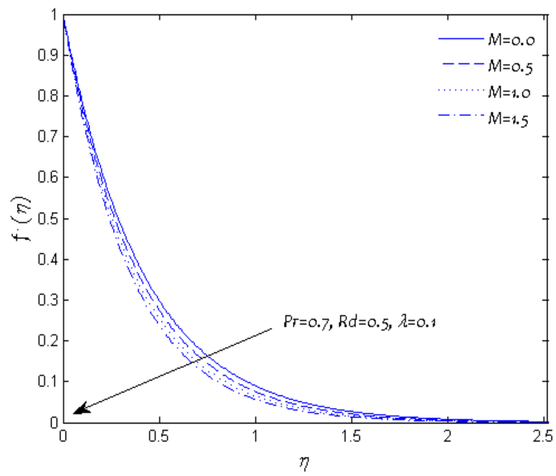

Fig.2 Effect of M on the velocity profile $f'(\eta)$

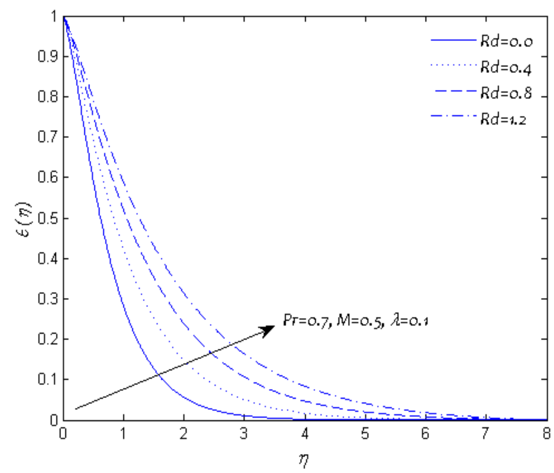

Fig.3 Effect of M on the velocity profile $\theta(\eta)$

Conclusions

We have considered the effect of radiative flow of stagnation point using MHD fluid over a stretching sheet. A numerical solution is used to examine the steady state of two-dimension stagnation point flow and heat transfer due to linear stretching sheet in an electrical conducting fluid. The impacts of different pertinent parameters on the heat transfer characteristics were scrutinized. The Velocity field increase along η for higher values in the ratio of the rates of free stream velocity to the velocity of the stretching sheet, whereas, contrary happened with magnetic field strength. The temperature profile is an increasing function of radiative heat along the stretching sheet surface.

REFERENCES

Afify, A. A., & Elgazery, N. S. (2020). Impacts of Newtonian heating, variable fluid properties and Cattaneo–Christov model on MHD stagnation point flow of Walters' B fluid induced by stretching surface. *International Journal of Modern Physics C*, *31*(09), 2050125.

Anuar, N. S., Bachok, N., & Pop, I. (2020). Cu-Al2O3/Water Hybrid Nanofluid Stagnation Point Flow Past MHD Stretching/Shrinking Sheet in Presence of Homogeneous-Heterogeneous and Convective Boundary Conditions. *Mathematics*, *8*(8), 1237.

Chaudhary, S., Singh, A., & Kanika, K. M. (2021). Mathematical analysis of MHD stagnation point flow of Cu-blood nanofluid past an exponential stretchable surface. *International Journal for Computational Methods in Engineering Science and Mechanics*, 1-11.

Daniel Y. S., Aziz Z. A., Ismail Z., and Salah F., "Entropy Analysis of Unsteady Magnetohydrodynamic Nanofluid over Stretching Sheet with Electric Field," *International Journal for Multiscale Computational Engineering,* vol. 15, no. 6, 2017a.

Daniel Y. S., Aziz Z. A., Ismail Z., and Salah F., "Entropy analysis in electrical magnetohydrodynamic (MHD) flow of nanofluid with effects of thermal radiation, viscous dissipation, and chemical reaction," *Theoretical and Applied Mechanics Letters,* vol. 7, no. 4, pp. 235-242, 2017b.

Daniel Y. S., Aziz Z. A., Ismail Z., Bahar A., and Salah F., "Slip role for unsteady MHD mixed convection of nanofluid over stretching sheet with thermal radiation and electric field," *Indian Journal of Physics,* pp. 1-13, 2019a.

Daniel Y. S., Aziz Z. A., Ismail Z., Bahar A., and Salah F., "Stratified electromagnetohydrodynamic flow of nanofluid supporting convective role," *Korean Journal of Chemical Engineering,* vol. 36, no. 7, pp. 1021-1032, 2019b.

Daniel Y. S., "Steady MHD laminar flows and heat transfer adjacent to porous stretching sheets using HAM," *American journal of heat and mass transfer,* vol. 2, no. 3, pp. 146-159, 2015.

Daniel Y. S. and Daniel S. K., "Effects of buoyancy and thermal radiation on MHD flow over a stretching porous sheet using homotopy analysis method," *Alexandria Engineering Journal,* vol. 54, no. 3, pp. 705-712, 2015.

Daniel Y. S., Aziz Z. A., Ismail Z., and Salah F., "Effects of thermal radiation, viscous and Joule heating on electrical MHD nanofluid with double stratification," *Chinese Journal of Physics,* vol. 55, no. 3, pp. 630-651, 2017c.

Daniel Y. S., Aziz Z. A., Ismail Z., and Salah F., "Double stratification effects on unsteady electrical MHD mixed convection flow of nanofluid with viscous dissipation and Joule heating," *Journal of applied research and technology,* vol. 15, no. 5, pp. 464-476, 2017d.

Daniel Y. S., Aziz Z. A., Ismail Z., and Salah F., "Slip Effects on Electrical Unsteady MHD Natural Convection Flow of Nanofluid over a Permeable Shrinking Sheet with Thermal Radiation," *Engineering Letters,* vol. 26, no. 1, 2018.

Daniel Y. S., "Laminar convective boundary layer slip flow over a flat plate using homotopy analysis method," *Journal of The Institution of Engineers (India): Series E,* vol. 97, no. 2, pp. 115-121, 2016.

Ghasemi, S. E., & Hatami, M. (2021). Solar radiation effects on MHD stagnation point flow and heat transfer of a nanofluid over a stretching sheet. *Case Studies in Thermal Engineering*, *25*, 100898.

Hayat, T., Khan, S. A., Khan, M. I., Momani, S., & Alsaedi, A. (2020). Cattaneo-Christov (CC) heat flux model for nanomaterial stagnation point flow of Oldroyd-B fluid. *Computer methods and programs in biomedicine*, *187*, 105247.

Hussain, A., Afzal, S., Rizwana, R., & Malik, M. Y. (2020). MHD stagnation point flow of a Casson fluid with variable viscosity flowing past an extending/shrinking sheet with slip effects. *Physica A: Statistical Mechanics and Its Applications*, *553*, 124080.

Khan, M. I., Nigar, M., Hayat, T., & Alsaedi, A. (2020). On the numerical simulation of stagnation point flow of non-Newtonian fluid (Carreau fluid) with Cattaneo-Christov heat flux. *Computer methods and programs in biomedicine*, *187*, 105221.

Khashi'ie, N. S., Arifin, N. M., Rashidi, M. M., Hafidzuddin, E. H., & Wahi, N. (2020). Magnetohydrodynamics (MHD) stagnation point flow past a shrinking/stretching surface with double stratification effect in a porous medium. *Journal of Thermal Analysis and Calorimetry*, *139*(6), 3635-3648.

Lund, L. A., Omar, Z., Khan, I., Baleanu, D., & Nisar, K. S. (2020). Dual similarity solutions of MHD stagnation point flow of Casson fluid with effect of thermal radiation and viscous dissipation: stability analysis. *Scientific Reports*, *10*(1), 1-13.

Maqbool, R., Ijaz Khan, M., Qayyum, S., & Hayat, T. (2020). Numerical modeling and MHD stagnation point flow of ferrofluid (non-Newtonian) with Ohmic heating and viscous dissipation. *International Journal of Modern Physics B*, *34*(28), 2050265.

Nandeppanavar, M. M., Kemparaju, M. C., & Raveendra, N. (2021). Melting Heat transfer of MHD stagnation point flow of non-Newtonian fluid due to elastic sheet. *International Journal of Ambient Energy*, (just-accepted), 1-22.

Nasir, S., Shah, Z., Alrabaiah, H., Islam, S., & Khan, S. N. (2020). MHD stagnation point flow of hybrid nanofluid over a permeable cylinder with homogeneous and heterogenous reaction. *Physica Scripta*, *96*(3), 035201.

Nadeem, S., Israr-ur-Rehman, M., Saleem, S., & Bonyah, E. (2020). Dual solutions in MHD stagnation point flow of nanofluid induced by porous stretching/shrinking sheet with anisotropic slip. *AIP Advances*, *10*(6), 065207.

Oyelakin, I. S., Lalramneihmawii, P. C., Mondal, S., & Sibanda, P. (2020). Analysis of double-diffusion convection on three-dimensional MHD stagnation point flow of a tangent hyperbolic Casson nanofluid. *International Journal of Ambient Energy*, 1-12.

Zainal, N. A., Nazar, R., Naganthran, K., & Pop, I. (2021). Unsteady MHD stagnation point flow induced by exponentially permeable stretching/shrinking sheet of hybrid nanofluid. *Engineering Science and Technology, an International Journal*.