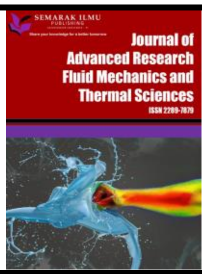
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Numerical Solution of Two-Phase Radiated Unsteady Flow Over a Horizontal Stretching Sheet with Simultaneous Effect of Electrification, Radiation and Non-Uniform Internal Heat Source/Sink

Subhrajit Kanungo[1], Tumbanath Samantara[1,*]

[1] Department of Mathematic, Centurion University of Technology and Management, Odisha, 752050 India

ARTICLE INFO

Article history:
Received 15 May 2022
Received in revised form 29 September 2022
Accepted 9 October 2022
Available online 2 November 2022

Keywords:
Boundary layer flow; tribo-electrification; radiation; non-uniform heat source/sink; stretching sheet; two-phase flow; Bvp4c

ABSTRACT

A parametric study to investigate the impact of electrification and radiation inside a thermal particulate boundary layer, where the flow is due to an unsteady stretching sheet in presence of non-uniform heat source/sink. Both the fluid as well as the particles are assumed to be gray, emitting and absorbing radiation. Again, neither the fluid is considered in electric medium nor supplied by an external electric force. But, due to the random motion of the particles i.e., the interaction between particle-particle, particle-fluid and particle-wall, a tribo-electrification occurred. As on impact, both the fluid and particles are electrified though the flow has been considered in a neutral medium. Hence, a balanced mathematical model of highly non-linear partial differential equations has been formulated for two-phase unsteady boundary layer considering the above parameters/impacts on both the phases. An appropriate similarity transformation has been employed to transfer the governing equations into ordinary differential equations and solved numerically by built in solver Bvp4c of MATLAB. An excellent agreement between the present and previous literature has been made to validate the result. Moreover, the influence of Electrification parameter, Radiation parameter, Internal heat source/sink parameter on the rate of heat transfer and other flow characteristics has been analyzed.

1.Introduction

The study of electrification, non-uniform heat source/sink, radiation and the unsteady boundary layer flow of fluid over a horizontal stretchable sheet have a tremendous application in the field of engineering and sciences. In many manufacturing plants like paper production plant, hot rolling, glass blowing, glass fiber production, food processing units and petroleum industry etc. is using phenomenon of the flow due to the horizontal stretching sheet. The stretching rate plays an important role in product development for spreading of liquid substances on a surface. Due to the vast area of application, in past three decades, many people have blended over the boundary layer flow of fluid over a stretchable surface with electrification and radiation effect and have given many

[*] *Corresponding author.*
E-mail address: tnsamantara@gmail.com

https://doi.org/10.37934/arfmts.100.3.1122

analytical and numerical solutions for several flow characteristics. The first ever exploration about the boundary layer behavior on a hard surface which is continuous, was done by Sakiadis [13] in the year 1961. For investigation, he had taken both exact and approximation method. Later his operational work was extended by Crane [3] in 1970. An experimental work on momentum and heat transfer inside a thin liquid film on an unsteady horizontal stretchable sheet was done by Chen [2]. An investigation on the similarity solution of unsteady, viscous incompressible fluid over a stretchable sheet have been obtained by Sharidan *et al.,* [17].

The study on the impact of non-uniform heat source/sink has a greater importance in most of the fluid problems. Mostly its use is seen in plastic and rubber sheet manufacture, disposal of radioactive waste products, food storage etc. So many authors have analyzed the heat transfer on non-uniform heat source/sink over a horizontal stretching surface. In an article Abel *et al.,* [18] have discussed about the heat transfer and boundary layer flow over a stretching sheet. Tsai *et al.,* [21] have also investigated on the flow and heat transfer of a quiescent fluid passed over an unsteady stretchable sheet and examined the impact of non-uniform heat source/sink on it. From their study they concluded that both the heat transfer rate and skin friction are direct proportional with unsteady parameter. Further, an analysis was performed by Ishak *et al.,* [9] on an unsteady laminar flow over a horizontal stretchable sheet. An investigation on flow and heat transfer over an unsteady stretchable sheet with slip conditions was conducted by Mukhopadhyay and Andersson [11]. In an article Hsiao [8] studied on a viscoelastic incompressible MHD flow of a second-grade fluid over a stretchable surface with effect of non-uniform heat source/sink with both electric and magnetic dispersion. Effect of laminar and boundary layer flow of a dusty fluid which passed on a stretchable surface has been discussed by Gireesha *et al.,* [5] They considered the stretching sheet as nonlinear and continue their analysis in presence of non-uniform heat source/sink. In an article Asghar and Ying [1] studied about the 3-D MHD nanofluid flow in presence of a rotating stretching sheet. They also analyzed the characteristics of boundary layer and heat transfer with other physical parameters which surrounded with the fluid flow.

Recently, Ramesh *et al.,* [12] did an analysis on the characteristics of heat transfer and MHD flow of dusty fluid which passed over a stretchable surface, being there of non-uniform heat source. A theoretical analysis on the hydromagnetic heat transfer of a dusty fluid has been carried out by Gireesha *et al.,*[6]. Tan *et al.,* [20] have investigated self-diffusion of the nano-particles in the base fluid with thermal diffusion. They gave a numerical idea about the diffusivity of nano-particle. Gireesha *et al.,* [10] have employed a work on a two-phase maxwell fluid with effect of non-linear thermal radiation and non-uniform heat source/sink. Tripathy *et al.,*[19] did a numerical study about the two-phase boundary layer flow and heat transfer over a non-uniform grid. Das *et al.,*[4] have investigated on a collective effect of chemical reaction, heat and mass transfer of an unsteady 2D laminar boundary layer flow passed over a horizontal stretchable sheet. Samantara *et al.,* [14], Samatara [15], and Mishra and Samantara [16] have studied impact of electrification of particles in flow geometry of horizontal plate, inclined stretching sheet and jet flow.

2. Formulation

A boundary layer unsteady dusty flow over a horizontal “permeable” stretchable sheet is assumed (Figure 1). The wall is stretched with a linear, due to the application of two-interacting opposite forces on the wall. X-axis is considered along the flow and y-axis is normal to it. Due to tribo-electrification, both the phases are influenced by electric force.

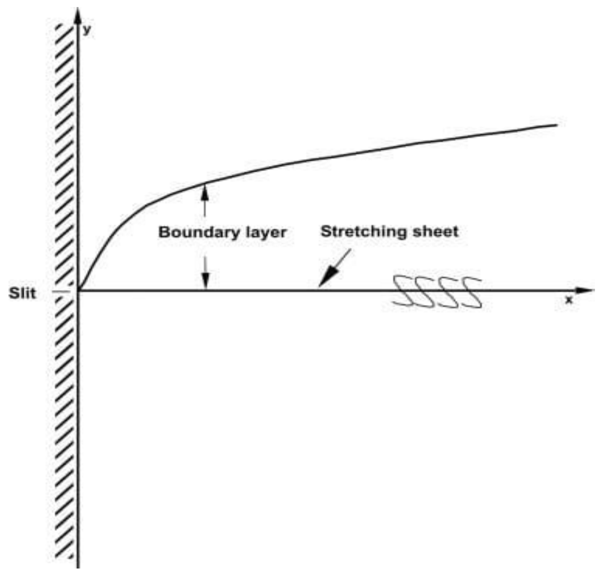


Fig. 1. Geometry of the flow problem

With the above assumption, the Governing Equations within the boundary layer of the flow field is given by

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

$$\frac{\partial \rho_p}{\partial t}+\frac{\partial}{\partial x}\left(\rho_p u_p\right)+\frac{\partial}{\partial y}\left(\rho_p v_p\right)=0 \tag{2}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-\frac{1}{1-\varphi}\frac{1}{\tau_p}\frac{\rho_p}{\rho}\left(u-u_p\right)+\frac{1}{1-\varphi}\frac{\rho_p}{\rho}\left(\frac{e}{m}\right)E \tag{3}$$

$$\frac{\partial u_p}{\partial t}+u_p\frac{\partial u_p}{\partial x}+v_p\frac{\partial u_p}{\partial y}=\nu_s\frac{\partial^2 u_p}{\partial y^2}+\frac{1}{\tau_p}\left(u-u_p\right)+\left(\frac{e}{m}\right)E \tag{4}$$

$$\frac{\partial v_p}{\partial t}+u_p\frac{\partial v_p}{\partial x}+v_p\frac{\partial v_p}{\partial y}=\nu_s\frac{\partial^2 v_p}{\partial y^2}+\frac{1}{\tau_p}\left(v-v_p\right) \tag{5}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{1}{1-\varphi}\frac{\rho_p}{\rho}\frac{c_s}{c_p}\frac{1}{\tau_T}\left(T_p-T\right)+\frac{1}{1-\varphi}\frac{1}{\tau_p}\frac{\rho_p}{\rho}\frac{1}{c_p}\left(u-u_p\right)^2+\frac{\mu}{\rho c_p}\left(\frac{\partial u}{\partial y}\right)^2+ \frac{1}{1-\varphi}\frac{\rho_p}{\rho}\frac{1}{c_p}\left(\frac{e}{m}\right)Eu_p-\frac{1}{\rho c_p}\frac{\partial q_{rf}}{\partial y}+\frac{\mathbf{1}}{\boldsymbol{\rho c_p}}q^{\prime\prime\prime} \tag{6}$$

$$\frac{\partial T_p}{\partial t}+u_p\frac{\partial T_p}{\partial x}+v_p\frac{\partial T_p}{\partial y}=\frac{k_s}{\rho_s c_s}\frac{\partial^2 T_p}{\partial y^2}-\frac{1}{\tau_T}\left(T_p-T\right)-\frac{1}{\tau_p c_s}\left(u-u_p\right)^2+\frac{\mu_s}{\rho_s c_s}\left[u_p\frac{\partial^2 u_p}{\partial y^2}+\left(\frac{\partial u_p}{\partial y}\right)^2\right]+ \frac{1}{c_s}\left(\frac{e}{m}\right)Eu_p-\frac{1}{\rho_s c_s}\frac{\partial q_{rp}}{\partial y}+\frac{\mathbf{1}}{\boldsymbol{\rho_s c_s}}q_p^{\prime\prime\prime} \tag{7}$$

With boundary conditions

$$\left.\begin{array}{l} u=U_w(x,t)=\frac{cx}{1-at}\,,v=V_w(x,t)=-\frac{v_0}{\sqrt{1-at}}\ at\ y=0 \\ \rho_p=\omega\rho, u=0\,,u_p=0\,,v_p\rightarrow v\ as\ y\rightarrow\infty \end{array}\right\} \tag{8}$$

$$T = T_w = T_\infty + T_0 \frac{cx^2}{\nu(1-at)^2} \; at \; y = 0 T \to T_\infty, T_p \to T_\infty \; as \; y \to \infty$$

ω : density ratio in main stream

Eq. (1) and Eq. (2) represent the continuity equation i.e., conservation of mass of fluid phase and particle phase respectively. Similarly, Eq. (3) and Eq. (4) represent the conservation of momentum in X-direction of fluid phase and particle phase respectively. Eq. (5) represents the conservation of momentum of particle phase in Y-direction. The conservation of momentum of fluid phase in Y-direction has been neglected. Eq. (6) and Eq. (7) represents the conservation of energy equation in fluid and particle phase respectively.

The radiative heat flux q_{rf} and q_{rp} in the energy equation of both the phases are approximated by Rosseland approximation and can be represented as

$$q_{rf} = -\frac{4\sigma^*}{3\,\kappa^*}\frac{\partial T^4}{\partial y} \tag{9}$$

Hence with reference to Eq. (6) and Eq. (7)

For fluid phase $\frac{\partial q_{rf}}{\partial y} = -\frac{16 T_\infty^3 \sigma^*}{3\,\kappa^*}\frac{\partial^2 T}{\partial y^2}$ (10)

Similarly, for the particle phase $\frac{\partial q_{rp}}{\partial y} = -\frac{16 T_\infty^3 \sigma^*}{3\,\kappa^*}\frac{\partial^2 T_p}{\partial y^2}$ (11)

where A^* and B^* are the parameters of the space and the temperature dependent internal heat source/sink.A^* and B^* are positive for heat source and negative for internal heat sink. q''' is the space-and temperature-dependent internal heat generation/absorption (non-uniform heat source/sink) and can be written as

$$q''' = \left(\frac{kU_\omega(x)}{x\nu}\right)\left[A^*(T_w - T_\infty)f' + B^*(T - T_\infty)\right] \tag{12}$$

$$q_p^{\iota\iota\iota} = \left(\frac{k_s U_\omega(x)}{x\nu_s}\right)\left[A^*(T_w - T_\infty)F + B^*\left(T_p - T_\infty\right)\right] \tag{13}$$

For most of the gases $\tau_p \approx \tau_T,\; k_s = k\frac{c_s}{c_p}\frac{\mu_s}{\mu} \; if \; \frac{c_s}{c_p} = \frac{2}{3P_r}$

The non-dimensional variables used to solve Eq. (1) to Eq. (7)

$$u = \frac{cx}{1-at}f'(\eta), v = -\sqrt{\frac{c\nu}{1-at}}f(\eta), \frac{\varphi\rho_s}{\rho} = \frac{\rho_p}{\rho} = \rho_r = H(\eta)$$

$$u_p = \frac{cx}{1-at}F(\eta), v_P = \sqrt{\frac{c\nu}{1-at}}G(\eta), \eta = \sqrt{\frac{c}{\nu(1-at)}}y$$

where,

$\theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty}$, $\theta_p(\eta) = \frac{T_p-T_\infty}{T_w-T_\infty}$; Where $-T_\infty = T_0 \frac{cx^2}{\nu(1-at)^2}\theta$, $T_p - T_\infty = T_0 \frac{cx^2}{\nu(1-at)^2}\theta_p$,

$P_r = \frac{\mu c_p}{k}$, $\beta = \frac{1-at}{c\tau_p}$, $\epsilon = \frac{\nu_s}{\nu}$, $\varphi = \frac{\rho_p}{\rho_s}$, $\mathrm{A} = \frac{a}{c}$, $Ec = \frac{c\nu}{C_p T_0}$, $\gamma = \frac{\rho_s}{\rho}$, $\nu = \frac{\mu}{\rho}$,

M=$\frac{E}{c^2x}\left(\frac{e}{m}\right)(1-at)^2$

Using the similarity transformation (16) to aboveEq. (1) to Eq. (7), we get the followings

$$H' = -\,[HF + HG']/\left[\frac{\eta}{2}A + G\right] \tag{14}$$

$$f''' = A\left[f''\frac{\eta}{2} + f'\right] + (f')^2 - ff'' + \frac{H\beta}{1-\varphi}(f' - F) - \frac{HM}{1-\varphi} \tag{15}$$

$$F'' = \frac{1}{\epsilon}\left[A\frac{\eta}{2}F' + F + F^2 + G\,F' - \beta(f' - F) - M\right] \tag{16}$$

$$G''(\eta) = \frac{1}{\epsilon}\left[\frac{A}{2}(\eta G' + G) + GG' + \beta(f + G)\right] \tag{17}$$

$$\theta'' = \frac{P_r}{1+R_a}\begin{bmatrix} A\left(2\theta + \frac{\eta}{2}\theta'\right) + 2f'\theta - f\theta' - \frac{1}{1-\varphi}H\frac{2}{3P_r}\beta\left(\theta_p - \theta\right) - \frac{1}{1-\varphi}H\beta E_c(f' - F)^2 \\ -E_c f''^2 - \frac{1}{1-\varphi}HME_c - \frac{1}{P_r}(A^* f' + B^*\theta) \end{bmatrix} \tag{18}$$

$$\theta_p'' = \frac{Pr}{\epsilon}\frac{2}{3}\frac{\gamma}{Ra}\begin{bmatrix} A\left(\theta_p'\frac{\eta}{2} + 2\theta_p\right) + 2F\theta_p + G\theta'_p + \beta\left(\theta_p - \theta\right) + \frac{3}{2}Pr\beta E_c(f - F)^2 \\ -\frac{3}{2}PrE_c\left(FF' + F'^2\right) - \frac{1}{Pr}\left(A^* F + B^*\theta_p\right) \end{bmatrix} \tag{19}$$

Subject to the boundary conditions

$G' = 0\,, f = 0\,, f' = 1\,, F' = 0, \theta = 1, \theta'_p = 0\ as\ \eta \to 0$

and

$f' = 0\,, F = 0, G = -f\,, H = \omega\,, \theta \to 0\,, \theta_p \to 0 as\ \eta \to \infty.$

3. Numerical Solution of the Problem

The system of Figure 14 to Figure 19 with the conditions (20) are computed by applying Runge-Kutte 4th order method with BVP4C tool of MATLAB. By considering finite value of $\eta \to \infty$ say $\eta = 15$ with a particular tolerance level of less than $o(10^{-06})$. The results are also matched with the results available in previous literature [5,7,18] as shown in Table 1. Here the values of rate of heat transfer are matched with the previous authors. So, it proves the validation of our program.

Table 1
Result Validating Table

Pr	B.J Gireesha *et al.,*[5]	Gurbka *et al.,* [7]	Subhas *et al.,* [18]	Present Study
0.72	1.0885	1.0885	1.0885	1.08862
1.0	1.3333	1.3333	1.3333	1.33333
3.0	NIL	NIL	NIL	2.50972
10.0	4.7968	4.7969	4.7968	4.79687

The investigations of numerical computations have been made for the impact of different physical parameters like “unsteady parameter(A)” Electrification parameter(M), “Prandtl number(Pr)”, “Eckert number(Ec)”, “Radiation (Ra)” and Buouancy parameter (λ) are represented graphically and by tables.

4. Results Analysis

4.1 Effect of Unsteady Parameter(A)

Figure 2 to Figure 5 depicts the graphical representation of impact of unsteady parameter (A) on velocity and temperature distribution of both phases. It is observed from Figure 3, for high value of unsteady parameter, the particles move very fast and it generates an opposing force to oppose the fluid phase. Hence, the fluid velocity decreases with increasing values of unsteady parameter, as shown in Figure 2. For high value of unsteady parameter, since the fluid velocity is less and subsequently declining the fluid temperature. Accordingly, the particle temperature also enhanced for high values of A.

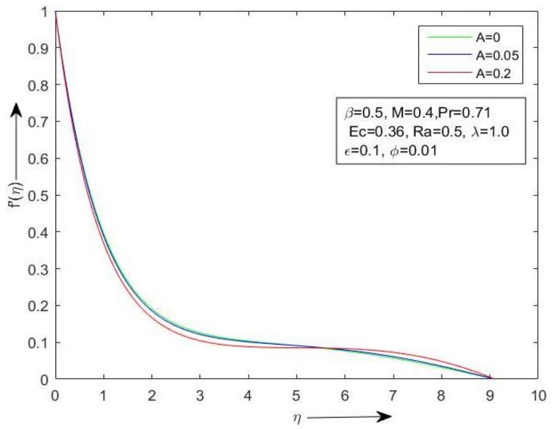


Fig. 2. Effect of unsteady Parameter (A) on fluid velocity

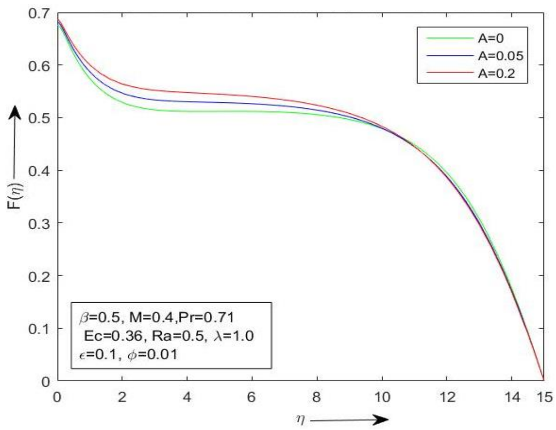


Fig. 3. Effect of unsteady Parameter (A) on particle velocity

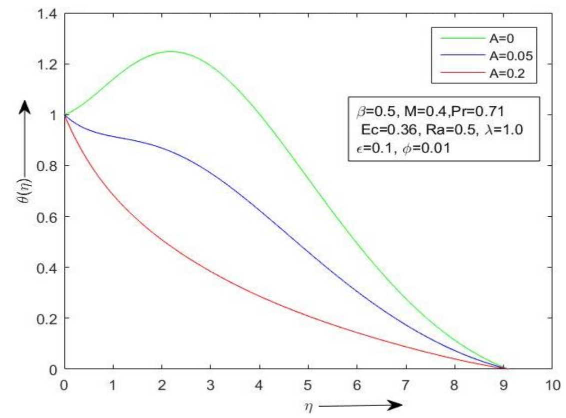


Fig. 4. Effect of unsteady Parameter (A) on fluid temperature

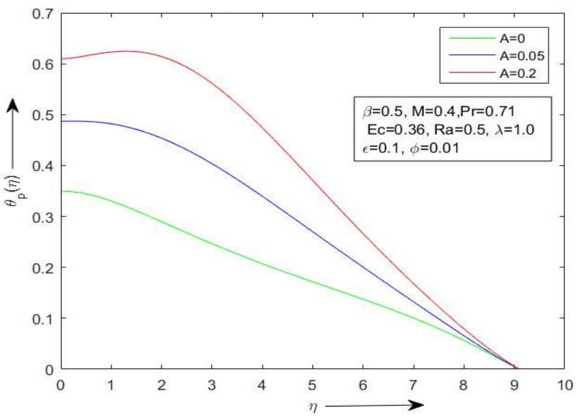


Fig. 5. Effect of unsteady Parameter (A) on particle temperature

4.2 Effect of Fluid Interaction Parameter (β)

Figure 6 to Figure 9 graphically show the variation of momentum and thermal boundary layer of both phases versus η for different values of fluid-particle interaction parameter β. The thickness of momentum boundary layer of dust phase becomes thicker when fluid-particle interaction is more. i.e., particles move faster for higher values of β and subsequently it creates an opposing force against the fluid. Hence, the fluid velocity slows down until and unless velocity of both phases reaches in equilibrium. During this time, particles dominant the fluid velocity, which leads to generate less temperature in fluid phase and the temperature of particles become more.

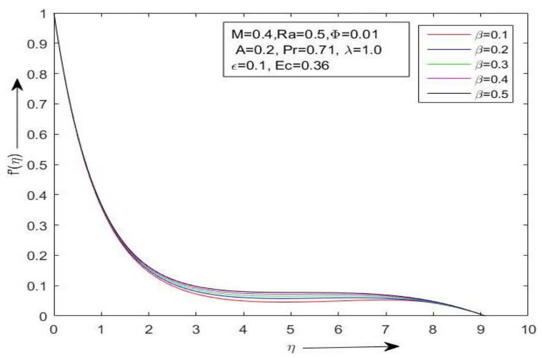


Fig. 6. Effect of particle interaction parameter (β) on fluid velocity

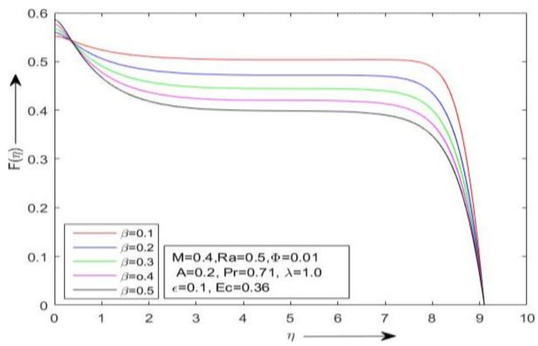


Fig. 7. Effect of particle interaction parameter (β) on particle velocity

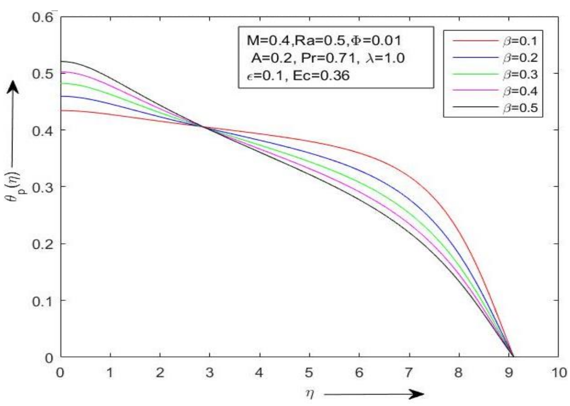


Fig. 8. Effect of particle interaction parameter (β) on particle temperature

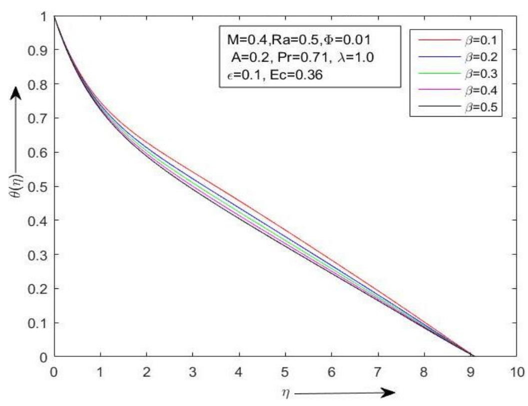


Fig. 9. Effect of particle interaction parameter (β) on fluid temperature

4.3 Effect of Prandtl Number (Pr)

Figure 10 and Figure 11 show the effect of Prandtl number (Pr) on the temperature profiles of fluid and particle phase respectively. The present study deals with the fluid like air, water and electrolyte solution whose Pr value corresponds to 0.71, 1.0 and 7.0. It is noticed from Figure 10 that, the thermal boundary layer becomes more thinner for the higher values of Pr. It is due to the thermal enhancing thermal conductivity for smaller values of Pr and therefore, heat is diffused away from the surface of the stretching sheet. As a consequence, the rate of heat transfer is less rather than water and electrolyte solution, which is observed in Table 1. The same trend is maintained in case of particle temperature also, shown in Figure 11.

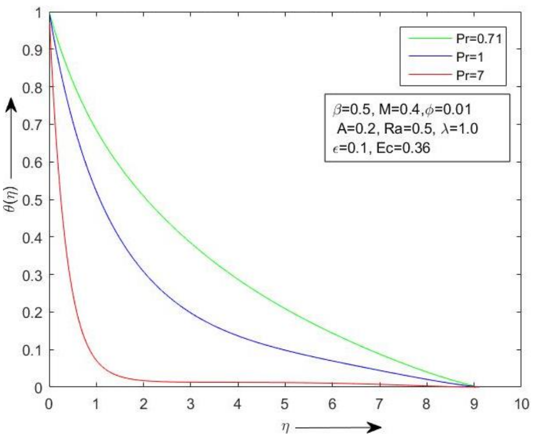


Fig. 10. Effect of Prandtl Number (Pr) on fluid temperature

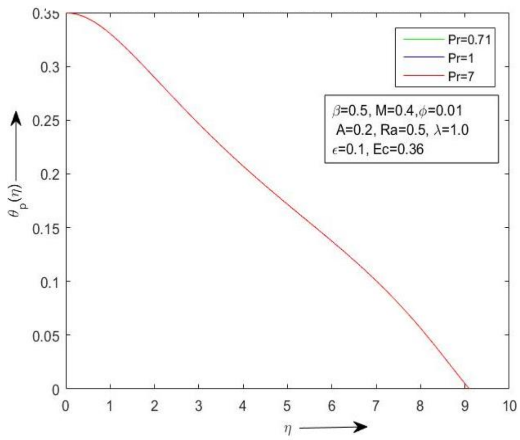


Fig. 11. Effect of Prandtl Number (Pr) on particle temperature

4.4 Effect of Eckert Number (Ec)

Figure 12 and Figure 13 show the temperature distribution for the fluid and particle phase against η for different values of Ec. By observing the graphs, As Eckert number Ec is related between fluid kinetic energy to difference of heat enthalpy and average of kinetic energy is the temperature. So, the temperature of the fluid enhanced due to the rise in value of Ec, observed from Figure 12. Since Ec is inversely connected with the boundary layer enthalpy. Hence, rise in the value of Eckert number declines the temperature between the surface and ambient fluid. It means, it declines the rate of heat transfer from surface of the sheet, which is seen in Table 1. But the particle temperature decreases for higher value of Ec, as shown in Figure 13.

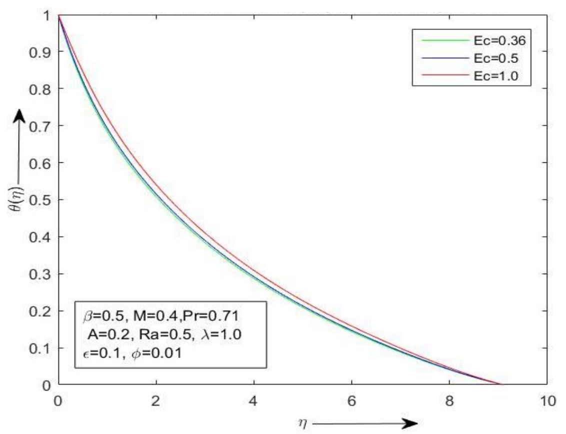


Fig. 12. Effect of Eckert number (Ec) on fluid temperature

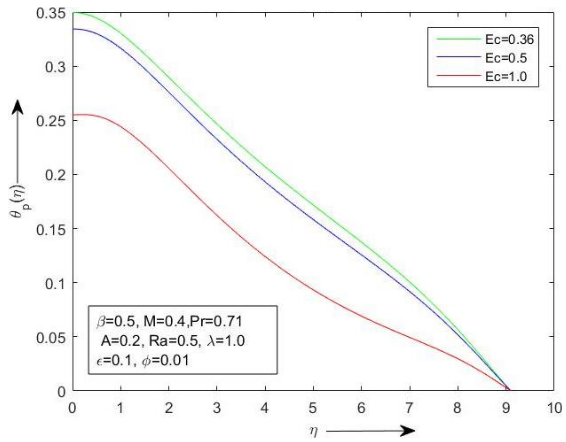


Fig. 13. Effect of Eckert number (Ec) on particle temperature

4.5 Effect of Electrification Parameter (M)

Figure 14 and Figure 15 represent the variation of flow distribution with variation of electrification parameter (M).The electrification occurs due to the interaction between particle-particle, particle-fluid and particle-surface, when the collision is more, the particles are more electrified, which accelerates the velocity of both fluid and particle. Hence, the velocity gradient decreases for high intensity of electrification, shown in Table1. Figure 16 and Figure 17 represent the temperature distribution of both phases inside the boundary layer controlled by Electrification parameter M. The temperature distribution for both phases inside the boundary layer gradually decreases for random collision between fluid-particle-wall is more i.e., when the particles are much electrified. The temperature declines gradually in case fluid whereas declines rapidly in case of particle, as observed from the figures. It shows that, the temperature transfer more from boundary layer to surface of the plate as a result the temperature gradient rises with decrease electrification parameter, observed from Table1.

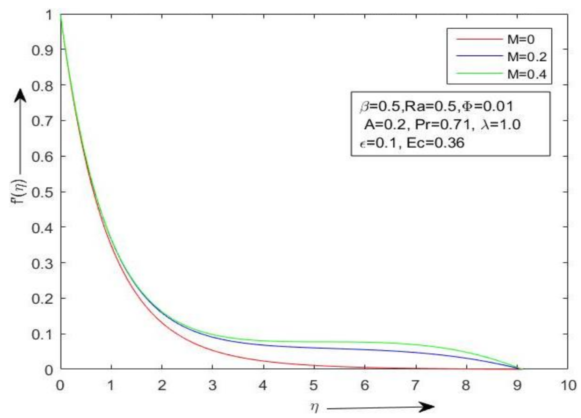


Fig. 14. Effect of electrification parameter (M) on fluid velocity

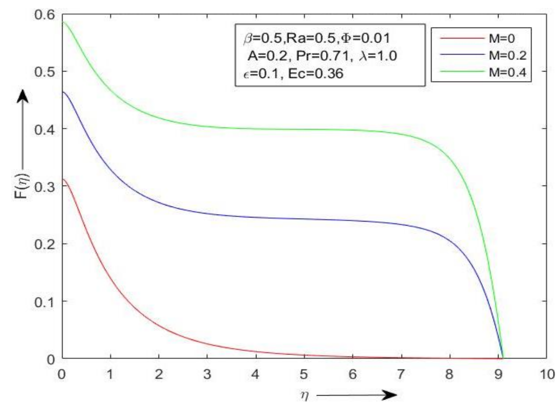


Fig. 15. Effect of electrification parameter (M) on particle velocity

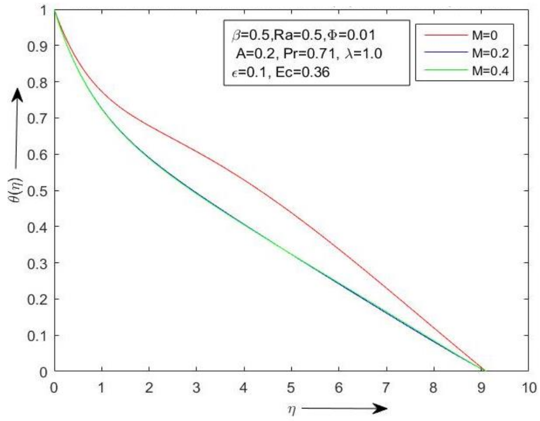


Fig. 16. Effect of electrification parameter (M) on fluid temperature

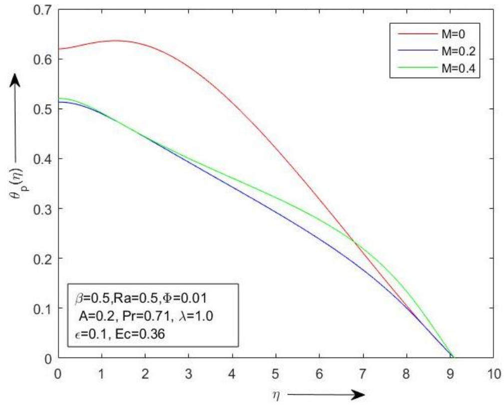


Fig. 17. Effect of electrification parameter (M) on particle temperature

4.6 Effect of Radiation Parameter (Ra)

The impact of radiation parameter (Ra) on the temperature profiles are presented through the Figure 18 and Figure 19. In all most all past literatures, the radiation is considered for fluid phase only. Since, the fluid is coupled with the particles in the flow field, both the fluid as well as particulate phase are influenced by the radiation and the particle also plays a major role in the temperature distribution. Hence, the consideration of radiation may not be neglected for the particulate phase, which is observed from Figure 19 in this present study. Figure 18 shows the impact of Ra in fluid temperature distribution. It is observed that, the non-dimensional fluid temperature rises uniformly with the intensity of radiation and increases significantly the thickness of thermal boundary layer. Table 2 shows the nature of skin friction and Nusselt number (Nu) with variation of radiation. The surface of the stretching sheet generates and radiates more temperature when the intensity of radiation is low, so that the fluid temperature increases, which is observed in Figure 19.Thus, the radiation should be minimum in order to cool the surface. The reverse trend is maintained for particle temperature.

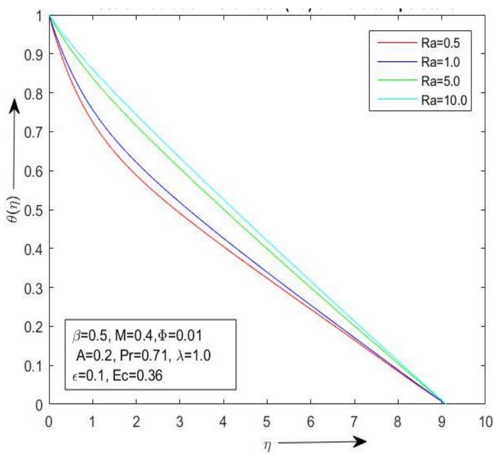


Fig. 18. Effect of radiation parameter (Ra) on fluid temperature

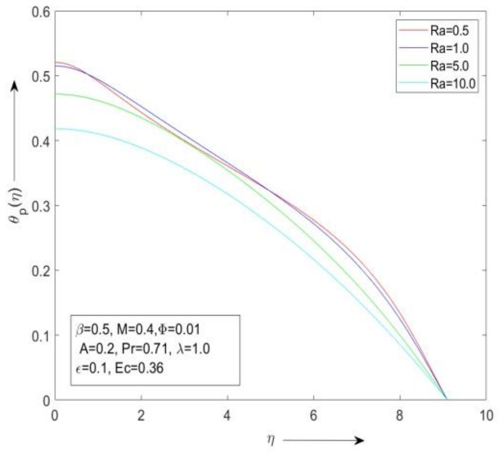


Fig. 19. Effect of radiation parameter (Ra) on particle temperature

Table 2
Effect of Prandtl number, Eckert number, Radiation parameter, angle of inclination of the sheet and Electrification parameter on skin friction and Nusselt number

Pr	Ec	Ra	M	$f''(0)$	$-\theta'(0)$
0.71	0.36	0.5	0.4	1.37148	1.05906
1.0				1.37148	1.14693
7.0				1.37148	2.52055
0.71	0.36	0.5	0.4	1.37148	1.05906
	0.5			1.37148	1.01926
	1.0			1.37148	0.87709
0.71	0.36	0.5	0.4	1.37148	1.05906
		1.0		1.37148	1.04489
		5.0		1.37148	1.01531
		10.0		1.37148	1.00839
0.71	0.36	0.5	0.4	1.37148	1.05906
			0.0	1.39382	1.05985
			0.2	1.38025	1.05957

5. Conclusion

From above graphs and result discussions, it is concluded that the presence of particles in fluid has greater impacts on flow and heat transfer profiles.

i. The presence of particles in fluid collides with each other and with the wall, thus generates electric force that helps in accelerating body force which acts in the direction of electric field. It results in reducing the skin friction on the surface of stretching sheet. The velocity gradient decreases for high intensity of electrification.
ii. It significantly enhances the temperature and it occurs more heat transfer on the surface of the stretching surface.
iii. More study can be done as an extension work by considering variation of viscosity, following power law or exponential law.

Reference

[1] Asghar, Adnan, and Teh Yuan Ying. "Three dimensional MHD hybrid nanofluid Flow with rotating stretching/shrinking sheet and Joule heating." *CFD Letters* 13, no. 8 (2021): 1-19. https://doi.org/10.37934/cfdl.13.8.119
[2] Chen, Chien-Hsin. "Heat transfer in a power-law fluid film over a unsteady stretching sheet." *Heat and Mass Transfer* 39, no. 8 (2003): 791-796.https://doi.org/10.1007/s00231-002-0363-2
[3] Crane, Lawrence J. "Flow past a stretching plate." *Zeitschrift für angewandte Mathematik und Physik ZAMP* 21, no. 4 (1970): 645-647.https://doi.org/10.1007/BF01587695
[4] Das, T. K., A. K. Mishra, and N. Senapati. "The combined effect of chemical reaction, heat and mass transfer on an unsteady mhd free convective flow embedded in a porous medium with heat generation/absorption." *International Journal of Mathematical Archive* 8, no. 6 (2017): 112-124.
[5] Gireesha, J. Bijjanal, Govinakovi S. Roopa, and Channabasappa S. Bagewadi. "Boundary Layer Flow of an Unsteady Dusty Fluid and Heat Transfer Over a Stretching Sheet with Non-Uniform Heat Source/Sink." *Engineering* 3, no. 7 (2011): 726-735. https://doi.org/10.4236/eng.2011.37087
[6] Gireesha, B. J., B. Mahanthesh, Rama Subba Reddy Gorla, and P. T. Manjunatha. "Thermal radiation and Hall effects on boundary layer flow past a non-isothermal stretching surface embedded in porous medium with non-uniform heat source/sink and fluid-particle suspension." *Heat and Mass Transfer* 52, no. 4 (2016): 897-911.https://doi.org/10.1007/s00231-015-1606-3
[7] Grubka, L. J., and K. M. Bobba. "Heat transfer characteristics of a continuous stretching surface with variable temperature." *Journal of Heat Transfer* 107, no. 1 (1985): 248-250.https://doi.org/10.1115/1.3247387

[8] Hsiao, Kai-Long. "Viscoelastic fluid over a stretching sheet with electromagnetic effects and nonuniform heat source/sink." *Mathematical Problems in Engineering* 2010 (2010).https://doi.org/10.1155/2010/740943

[9] Ishak, Anuar, Roslinda Nazar, and Ioan Pop. "Heat transfer over an unsteady stretching permeable surface with prescribed wall temperature." *Nonlinear Analysis: Real World Applications* 10, no. 5 (2009): 2909-2913.https://doi.org/10.1016/j.nonrwa.2008.09.010

[10] Gireesha, B. J., B. Mahanthesh, Rama Subba Reddy Gorla, and K. L. Krupalakshmi. "Mixed convection two-phase flow of Maxwell fluid under the influence of non-linear thermal radiation, non-uniform heat source/sink and fluid-particle suspension." *Ain Shams Engineering Journal* 9, no. 4 (2018): 735-746.https://doi.org/10.1016/j.asej.2016.04.020

[11] Mukhopadhyay, Swati, and Helge I. Andersson. "Effects of slip and heat transfer analysis of flow over an unsteady stretching surface." *Heat and Mass Transfer* 45, no. 11 (2009): 1447-1452.https://doi.org/10.1007/s00231-009-0516-7

[12] Ramesh, G. K., B. J. Gireesha, and C. S. Bagewadi. "Heat transfer in MHD dusty boundary layer flow over an inclined stretching sheet with non-uniform heat source/sink." *Advances in Mathematical Physics* 2012 (2012).https://doi.org/10.1155/2012/657805

[13] Sakiadis, Byron C. "Boundary-layer behavior on continuous solid surfaces: I. Boundary-layer equations for two-dimensional and axisymmetric flow." *AIChE Journal* 7, no. 1 (1961): 26-28.https://doi.org/10.1002/aic.690070108

[14] Samantara, Tumnanath, S. K. Mishra, and T. C. Panda. "Numerical Modeling of Two Phase Jet Flow and Heat Transfer with Charged Suspended Particulate Matter (SPM)." *Modelling, Measurement and Control B* 86, no.4 (2017): 885-906. https://doi.org/10.18280/mmc_b.860405

[15] Samantara, Tumbanath. "Velocity Profile of Fluid Particle Suspension over a Horizontal Plate with Electrification of Particles." *International Journal of Innovative Technology and Exploring Engineering* 8, no. 11 (2019): 1119-1122.https://doi.org/10.35940/ijitee.J1220.0981119

[16] Mishra, Jayaprakash, and Tumbanath Samantara. "Study of Unsteady Two Phase Flow over An Inclined Permeable Stretching Sheet with Effects of Electrification and Radiation." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 97, no. 2 (2022): 26-38. https://doi.org/10.37934/arfmts.97.2.2638

[17] Sharidan, S., M. Mahmood, and I. Pop. "Similarity solutions for the unsteady boundary layer flow and heat transfer due to a stretching sheet." *Applied Mechanics and Engineering* 11, no. 3 (2006): 647-654.

[18] Abel, M. Subhas, P. G. Siddheshwar, and Mahantesh M. Nandeppanavar. "Heat transfer in a viscoelastic boundary layer flow over a stretching sheet with viscous dissipation and non-uniform heat source." *International Journal of Heat and Mass Transfer* 50, no. 5-6 (2007): 960-966.https://doi.org/10.1016/j.ijheatmasstransfer.2006.08.010

[19] Tripathy, P. K., A. Misra, S. K. Mishra, and J. Prakash. "Two phase boundary layer flow and heat transfer using non-uniform grid." *Elixir Applied Mathematics* 76 (2014): 28367-28380.

[20] Tan, Jian Hong, Toru Yamada, Yutaka Asako, Lit Ken Tan, and Nor Azwadi Che Sidik. "Study of Self Diffusion of Nanoparticle Using Dissipative Particle Dynamics." *Journal of Advanced Research in Numerical Heat Transfer* 10, no. 1 (2022): 1-7.

[21] Tsai, R., K. H. Huang, and J. S. Huang. "Flow and heat transfer over an unsteady stretching surface with non-uniform heat source." *International Communications in Heat and Mass Transfer* 35, no. 10 (2008): 1340-1343.https://doi.org/10.1016/j.icheatmasstransfer.2008.07.001