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Effect of Radiation and Non-Uniform Heat Source/Sink on Flow over a Linear Stretching Sheet with Fluid Particle Suspension

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ABSTRACT

In this paper, the flow and heat transfer of dusty flow over a linear stretchable sheet has been analyzed. The effects of radiation and non-uniform heat source or sink have been studied. Considering the mentioned terms and conditions, the problem has been formulated. The formulation consists of systems of nonlinear PDEs which has been converted to a system of ODEs by taking suitable similarity transformations. Then the systems of ODEs have been solved by using Rungakutta method of 4th order. The computations work has been carried out by using BVP4C tool of MATLAB. The impact of flow parameters like radiation parameter, prandtl number, eckret number, fluid Particle interaction parameter β and diffusivity parameter on flow and heat transfer are investigated. The results are presented through graphs and tables. From the graphs, it is concluded that the presence of particles in fluid has some impact of different parameters in flow and heat transfer. The parameters like Eckert number, Fluid- particle interaction parameter, diffusivity parameter have remarkable effects of presence of particles.

1. Introduction

Heat transfer procedure of two-phase steady flow of a fluid and effect of non-linear radiation over a stretchable sheet has a huge impact in engineering process and many manufacturing industries. The fundamentals of steady multi-phase flow have used to design compressor which is a work or power consumption device. Many industrial applications based on stretching sheets such as the preparation of plastic sheets, making of papers, coloring of sheets etc. The quantity of heat flux over any plane determines the quality of product. Due to massive utilities, many researchers have shown their special interest for working on flow and heat transfer of fluid particle suspension over stretchable sheet with the effect of radiation and non-uniform heat source/sink. They have presented the numerical and analytical solution for different flow parameters. These research areas have great role in industries appliances. The initial investigational work on boundary layer flow over a stretchable surface was made by Sakiadis [1] in 1961. Crane [2] was first studied the boundary layer flow occurred due to a linearly stretched sheet. Subsequently, many researches extended their work

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on linearly stretching sheet by considering different physical parameters. A numerical and analytical study has been conducted on heat and mass transfer on a linear stretching sheet by Gupta *et al.,* [3]. An investigation on magneto hydrodynamic boundary layer flow and heat transfer over an exponential stretching sheet with different boundary condition has been done by Mukhopadhaya [4]. Khan *et al.,* [5] presented an analysis on MHD flow of a double stratified micro polar fluid which passed over a vertical stretching sheet. They considered the problem in presence of chemical reaction and heat source effect.

So many researchers have conducted their work on the boundary layer flow with effect of radiation and non-uniform heat source/sink on linearly stretching surface. THayat [6] introduced the effect of thermal radiation and non-uniform heat source/sink in a fluid which passed over a stretched cylinder. Krishnaiah [7] numerically analyzed the result of non-uniform heat source/sink on stagnation point flow of MHD fluid which passed on an exponential stretched sheet. Swain *et al.,* [8] have majorly contributed toward the effect of non-uniform heat source/sink on MHD flow of a nano fluid. The Impact of thermal radiation and non-uniform heat source/sink of a 2-D unsteady mixed convective flow over a stretching sheet, was studied by Gireesha *et al.,* [9] An analysis of heat transfer hypothesis of power-law for fluid with non-uniform heat source/sink within a stretched disk has been carried out by Mallick *et al.,* [10]. Tripathy*et al.,* [11] did a numerical study about the two phase boundary layer flow and heat transfer with non-uniform grid. Das *et al.,* [12] 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.,* [17,18, 22] have studied impact of electrification of particles in flow geometry of horizontal plate, inclined stretching sheet and jet flow. Kanungo *et al.,* [19] have investigated on the electrification ad radiation effect of unsteady two phase flow on a horizontal stretching sheet. Sharafatmandjoor [20] did an analysis on the effect of imposition and thermal forces of a microorganism of Nano fluid. Kotnurkar *et al.,* [21] have investigated on effect of magnetic field and surface roughness of a Peristaltic flow of a Nano fluid.

2. Modeling of the Problem

A boundary layer dusty flow over steady horizontal stretchable sheet is assumed in 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.

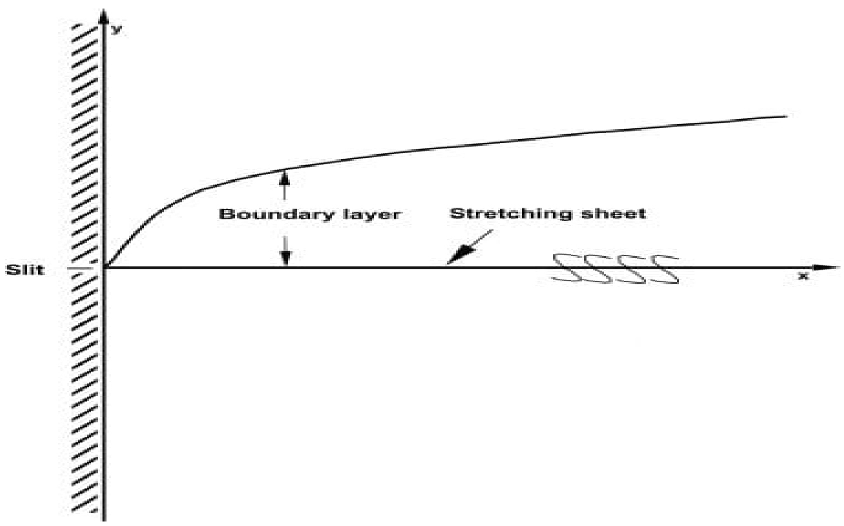

Fig. 1. Geometry of the flow problem

The prevailing equations are

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

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

$$(1-\varphi)\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=(1-\varphi)\mu\frac{\partial^2 u}{\partial y^2}-\frac{1}{\tau_p}\varphi\rho_s\left(u-u_p\right) \tag{3}$$

$$\varphi\rho_s\left(u_p\frac{\partial u_p}{\partial x}+v_p\frac{\partial u_p}{\partial y}\right)=\frac{\partial}{\partial y}\left(\varphi\mu_s\frac{\partial u_p}{\partial y}\right)+\frac{1}{\tau_p}\varphi\rho_s\left(u-u_p\right) \tag{4}$$

$$\varphi\rho_s\left(u_p\frac{\partial v_p}{\partial x}+v_p\frac{\partial v_p}{\partial y}\right)=\frac{\partial}{\partial y}\left(\varphi\mu_s\frac{\partial v_p}{\partial y}\right)+\frac{1}{\tau_p}\varphi\rho_s\left(v-v_p\right) \tag{5}$$

$$\begin{aligned}(1-\varphi)\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=&\ (1-\varphi)k\frac{\partial^2 T}{\partial y^2}+\frac{1}{\tau_T}\varphi\rho_s c_s\left(T_p-T\right)+\frac{1}{\tau_p}\varphi\rho_s\left(u-u_p\right)^2\\&+(1-\varphi)\mu\left(\frac{\partial u}{\partial y}\right)^2-(1-\varphi)\frac{\boldsymbol{\partial q_{rf}}}{\boldsymbol{\partial y}}+(1-\varphi)q'''\end{aligned} \tag{6}$$

$$\begin{aligned}\varphi\rho_s c_s\left(u_p\frac{\partial T_p}{\partial x}+v_p\frac{\partial T_p}{\partial y}\right)=&\ \frac{\partial}{\partial y}\left(\varphi k_s\frac{\partial T_p}{\partial y}\right)-\frac{1}{\tau_T}\varphi\rho_s c_s\left(T_p-T\right)-\frac{1}{\tau_p}\varphi\rho_s\left(u-u_p\right)^2\\&+\varphi\mu_s\left[u_p\frac{\partial^2 u_p}{\partial y^2}+\left(\frac{\partial u_p}{\partial y}\right)^2\right]-\varphi\frac{\partial q_{rp}}{\partial y}+\varphi {q_p}'''\end{aligned} \tag{7}$$

The radiative heat flux q_{rf} and q_{rp} in the energy equation of both the phases are approximated by Rosseland approximation. Using Rosseland approximation, the radiation heat flux q_{rf} for the fluid phase is

$$q_{rf}=-\frac{4\sigma^*}{3\,\kappa^*}\frac{\partial T^4}{\partial y} \tag{8}$$

Hence with reference to equation

$$\frac{\partial q_{rf}}{\partial y}=-\frac{16T_\infty^3\sigma^*}{3\,\kappa^*}\frac{\partial^2 T}{\partial y^2} \tag{9}$$

Similarly, for the particle phase

$$\frac{\partial q_{rp}}{\partial y}=-\frac{16T_\infty^3\sigma^*}{3\,\kappa^*}\frac{\partial^2 T_p}{\partial y^2} \tag{10}$$

Where

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

$$q_p'''=\left(\frac{k_sU_\omega(x)}{x\nu_s}\right)\left[C^*(T_w-T_\infty)F+D^*\left(T_p-T_\infty\right)\right]$$

The boundary conditions for the flow problem are given by

$$u = U_w(x), v = 0, T = T_w = T_\infty + A\left(\frac{x}{l}\right)^2 ;\text{as} y \to 0 \tag{11a}$$

$$\rho_p = \omega\rho, u = 0, u_p = 0, v_p = v, T = T_p = T_\infty; \text{ as } y \to \infty \tag{11b}$$

Where $U_w(x) = cx$, is a stretching sheet velocity, c is the initial stretching rate being a positive constant and ω is the density ratio in the main stream. $T_w$is the wall temperature and A is a positive constant,$l = \sqrt{\nu/c}$ is a characteristic length. For most of the gases $\tau_p \approx \tau_T$ if$\frac{c_s}{c_p} = \frac{2}{3Pr}$and $k_s = k\frac{c_s}{c_p}\frac{\mu_s}{\mu}$.

The Eq. (1) is identically satisfied through introducing the stream function $\psi(x, y) = \sqrt{c\nu}xf(\eta)$, such that $u = \partial\psi/\partial y$ and $v = -\partial\psi/\partial x$. We further introduce the following transformations in the Eq. (2) to (7), to convert the governing equations into a set of Ordinary differential equations,

$$\left.\begin{array}{l} u = cxf'(\eta), \quad v = -\sqrt{c\nu}f(\eta), \ \eta = \sqrt{c/\nu}\, y, \\ u_p = cxF(\eta), \quad v_p = \sqrt{c\nu}G(\eta), \quad \rho_r = \rho_p/\rho = H(\eta) \\ \theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty}, \ \theta_p(\eta) = \frac{T_p-T_\infty}{T_w-T_\infty}, \end{array}\right\} \tag{12}$$

Where $T - T_\infty = A\left(\frac{x}{l}\right)^2 \theta(\eta), \ T_p - T_\infty = A\left(\frac{x}{l}\right)^2 \theta_p(\eta)$

$$H' = -\frac{(HF - HG')}{G} \tag{13}$$

$$f''' = {f'}^2 - ff'' + \frac{1}{1-\varphi}\beta H(f' - F) \tag{14}$$

$$F'' = \frac{1}{\epsilon}[F^2 + F'G - \beta(f' - F)] \tag{15}$$

$$G'' = \frac{1}{\epsilon}[GG' + \beta(f + G)] \tag{16}$$

$$\theta'' = \frac{\left[(2f'\theta - f\theta')Pr - \frac{2}{3(1-\phi)}\frac{H\beta}{}(\theta_p - \theta) - \frac{H\beta PrEc}{(1-\phi)}(f' - F)^2 - PrEcf''^2 + (A^*f' + B^*\theta)\right]}{(1 + Ra)} \tag{17}$$

$$\theta_p'' = \frac{\left[2F\theta_p + G\theta_p' + \beta(\theta_p - \theta) - \frac{3}{2}PrEc\beta(f' - F)^2 - \frac{3}{2}PrEc(FF'' + {F'}^2) - \frac{1}{Pr}(C * F + D * \theta_p)\right]}{\left(\frac{\epsilon}{Pr} + \frac{3}{2}\frac{Ra}{\gamma}\right)} \tag{18}$$

3. Numerical Computation

The coupled Eq. (13) to (18) 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 analysis of numerical solutions has been done for the effect of various physical parameters like radiation parameter (Ra), Prandlt Number (Pr), Particle interaction parameter (β), Eckert Number (Ec) etc. The results are also matched with the results available in previous literature [4, 6, 17]. Here the values of rate of heat transfer are matched with the previous authors. So, it proves the validation of our program.

In Table 1 The results are also matched with the results available in previous literature [5, 9, 13-16]. Here the values of rate of heat transfer are matched with the previous authors. Hence the validation of our program.

Table 1
Result Validating Table

Prandtl number, Pr	Ishak *et al.,* [13]	Subhas *et al.,* [14]	Giressha *et al.,* [9]	Chen [15]	Gurbka *et al.,* [16]	Mukhopadhya *et al.,* [5]	Current Study
0.72	----------	1.0885	1.0885	1.0885	1.0885	1.0885	1.0884
1.0	1.3333	1.3333	1.3333	1.3333	1.3333	1.3333	1.3333
3.0	2.5097	---------	2.5097	2.5097	----------	2.5097	2.5097
10.0	4.7969	4.7969	4.7969	4.7969	4.7969	----------	4.7969

4. Result

4.1 Effect of Prandtl Number (Pr)

Figure 2 to 5 represents the effects of Prandtl Number(Pr) on velocity and temperature profile of fluid as well as particle phase of flow geometry. From the graph it is observed that the variation of Pr has very negligible or almost no effects on velocity profile of fluid as well as particle phase. But in case of temperature profile, the effects of Pr is prominent. The effect on air and water are quite opposite and of bell shaped, where as in case of brine, the graph looks like parallel to x-axis and maintains uniform.

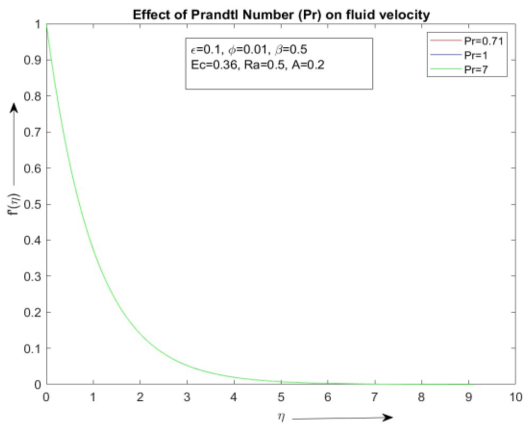

Fig. 2. Effect of Prandtl Number (Pr) on Fluid Velocity

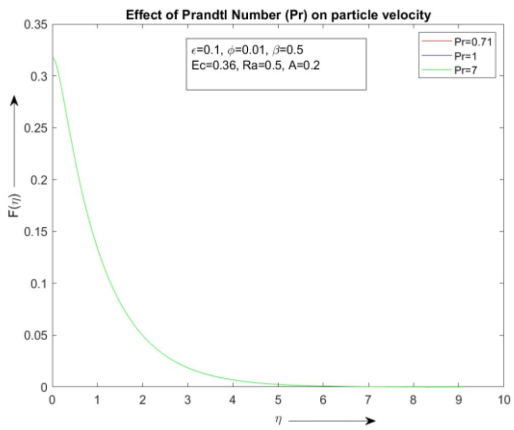

Fig. 3. Effect of Prandtl Number (Pr) on Particle Velocity

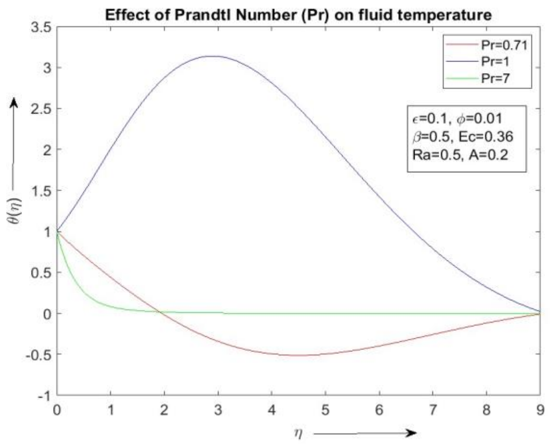

Fig. 4. Effect of Prandtl Number (Pr) on Fluid Temperature

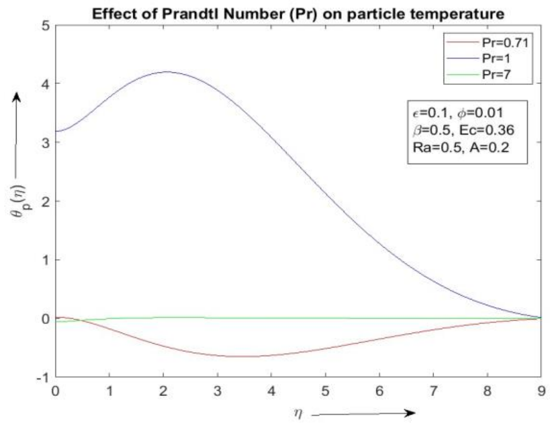

Fig. 5. Effect of Prandtl Number (Pr) on Particle Temperature

4.2 Effect of Eckert Number (Ec)

Figure 6 to 9 represents the effects of Ec on the velocity and temperature profile of the flow field. It is observed from the graph that Ec has very negligible effect on velocity profile of fluid as well as particle phase but have effect in case of thermal profile of fluid and particle phase. The effect is prominent in case of particle phase as compare to fluid phase. The temperature has inverse effect with Ec. i.e as Ec increases the temperature decreases for both the phases and vice versa.

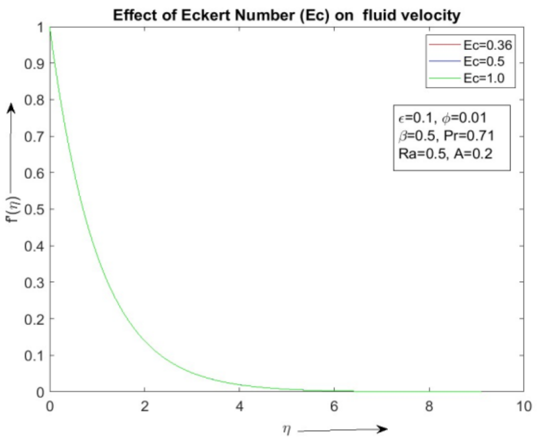

Fig. 6. Effect of Eckert Number (Ec) on Fluid Velocity

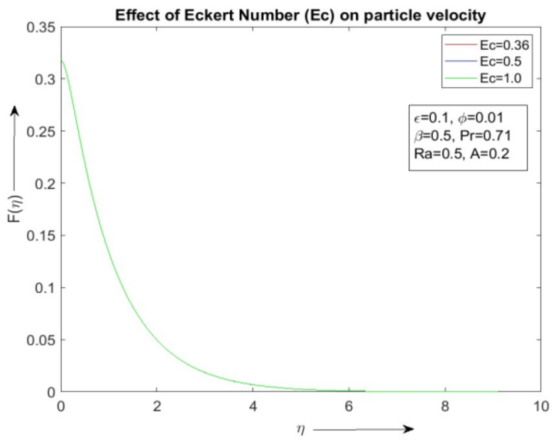

Fig. 7. Effect of Eckert Number (Ec) on Particle Velocity

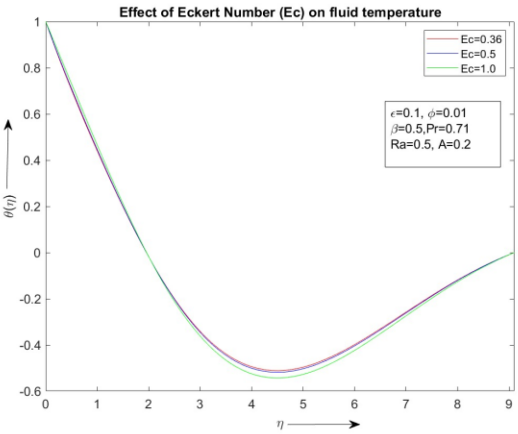

Fig. 8. Effect of Eckert Number (Ec) on Fluid Temperature

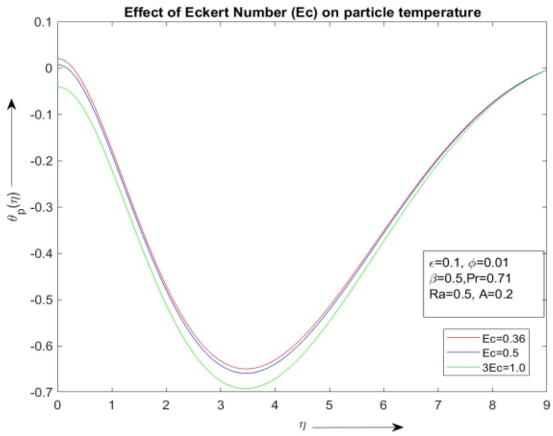

Fig. 9. Effect of Eckert Number (Ec) on Particle Temperature

4.3 Effect of Fluid Particle Interaction Parameter (β)

Figure 10 to 13 represents the effects of β on the velocity and temperature profile of the flow field. From the figure it is observed that the interaction parameter β has least impact on velocity and heat transfer of fluid phase but has remarkable effect on particle phase. From the graph it is concluded that velocity and temperature rises with increase of interaction parameter β.

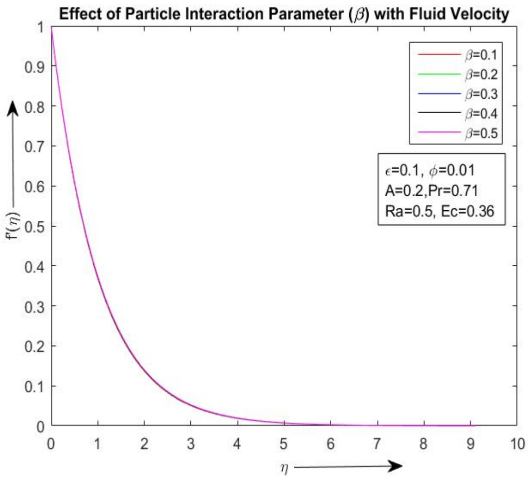

Fig. 10. Effect of Particle Interaction Parameter (β) on Fluid Velocity

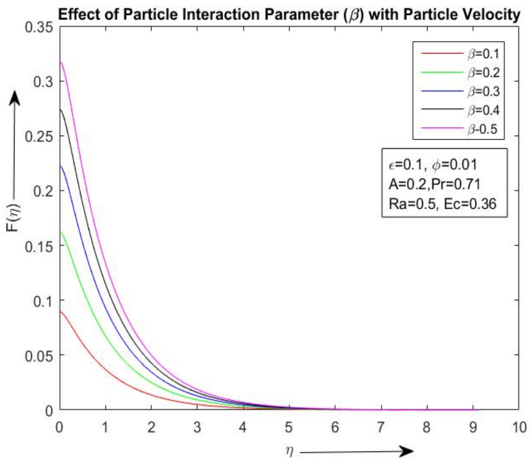

Fig. 11. Effect of Particle Interaction Parameter (β) on Particle Velocity

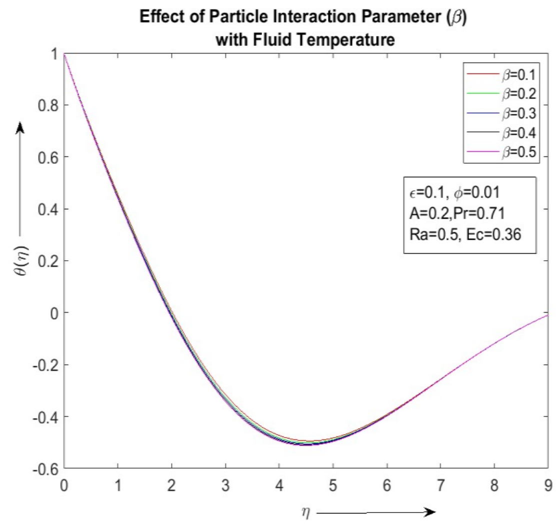

Fig. 12. Effect of Particle Interaction Parameter (β) on Fluid Temperature

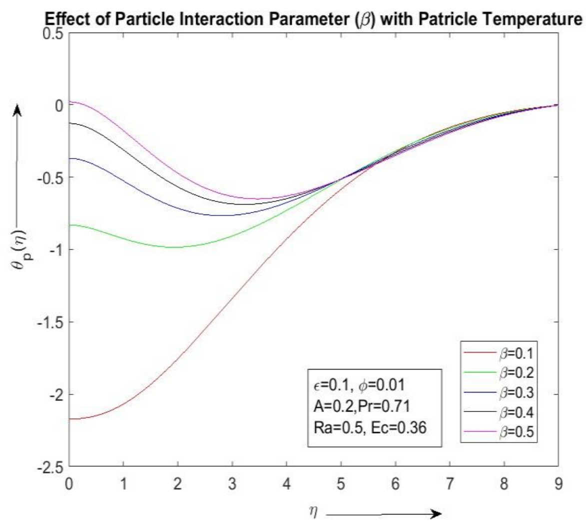

Fig. 13. Effect of Particle Interaction Parameter (β) on Particle Temperature

4.4 Effect of Diffusion Parameter (ϵ)

Figure 14 to 17 represents the effects of diffusivity parameter ∈ on the velocity and temperature profile of the flow field. From the graph it is concluded that impact of diffusivity parameter ∈ in velocity and heat transfer of fluid phase has negligible effect but has remarkable effect on particle phase. It is observed that the velocity as well as temperature of particle phase rises with increase of diffusivity parameter ∈.

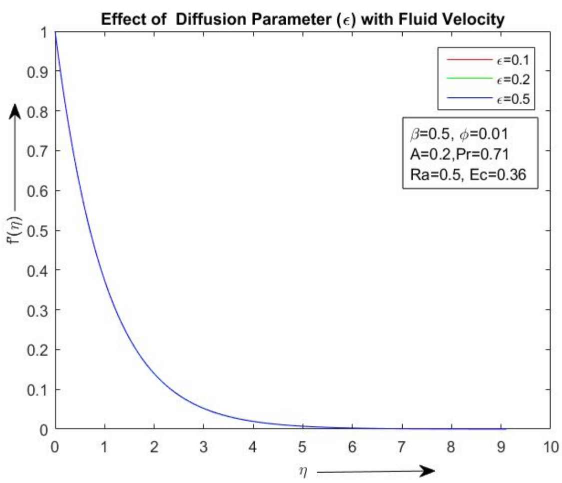

Fig. 14. Effect of Diffusion Parameter (ϵ) on Fluid Velocity

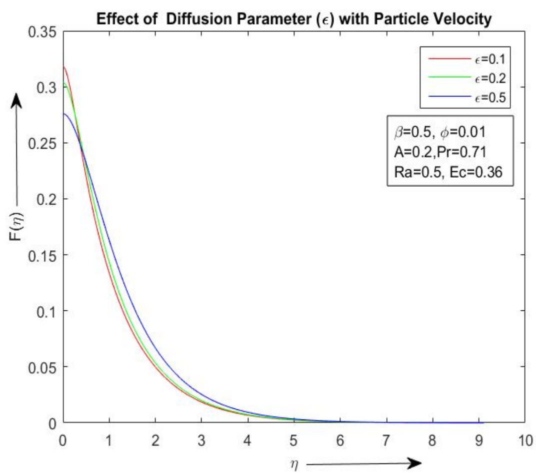

Fig. 15. Effect Diffusion Parameter (ϵ) on Particle Velocity

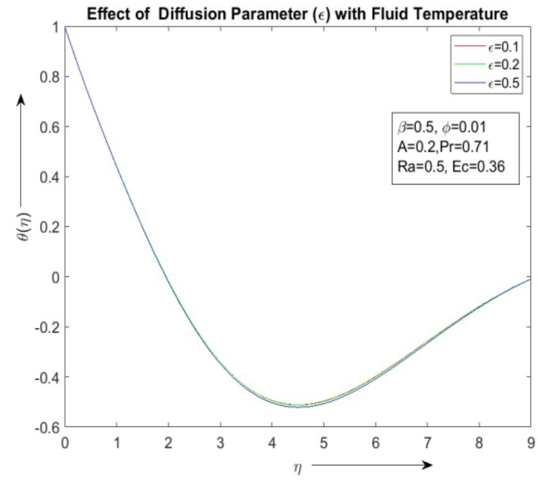

Fig. 16. Effect of Diffusion Parameter (ϵ) on Fluid Temperature

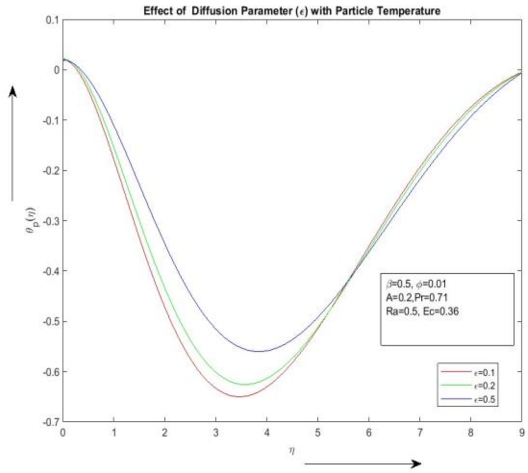

Fig. 17. Effect of Diffusion Parameter (ϵ) on Particle Temperature

4.5 Effect of Radiation Parameter (Ra)

The impact of radiation parameter (Ra) on the velocity and temperature profiles are presented through the Figure 18 to 21. 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. From the graph it is concluded that impact of Ra on velocity profile of fluid as well as particle phase has almost no effect or have negligible effect. Fig. 20 and 21 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.

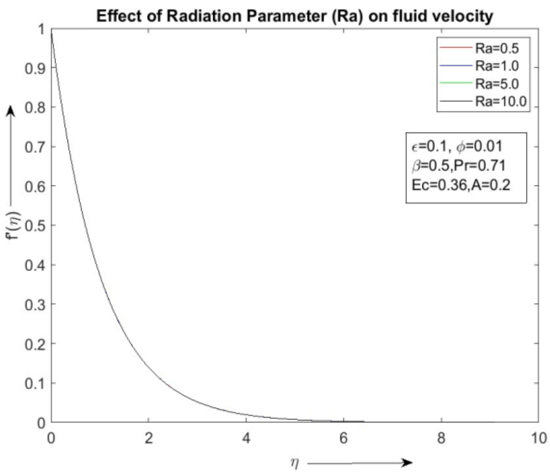

Fig. 18. Effect of Radiation Parameter (Ra) on Fluid Velocity

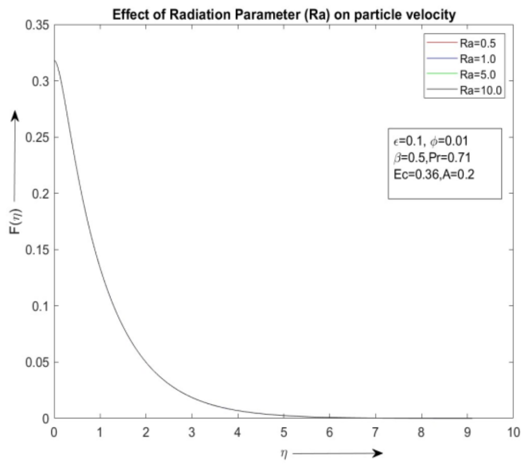

Fig. 19. Effect Radiation Parameter (Ra) on Particle Velocity

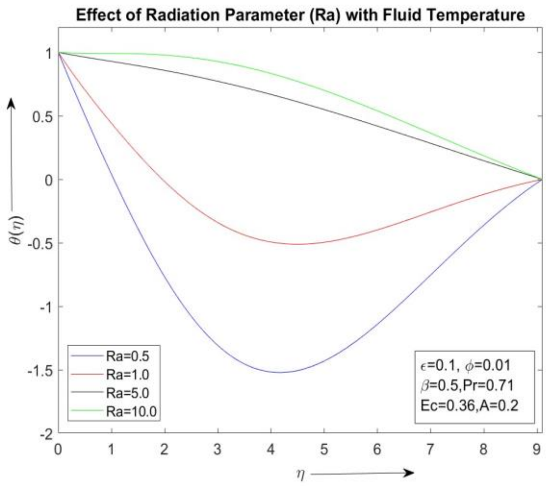

Fig. 20. Effect of Radiation Parameter (Ra) on Fluid Temperature

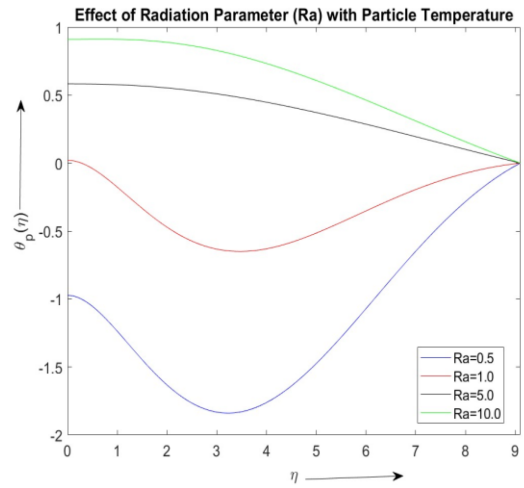

Fig. 21. Effect of Radiation Parameter (Ra) on Particle Temperature

4.6 Skin Friction and Nusselt Number

Due to accelerating flow field, the temperature of both the phases rapidly increases along the surface. i.e. the fluid-particle interaction is more for accelerated fluid and causes the stronger friction, which significantly enhances the temperature and it occurs more heat transfer on the surface of the stretching surface, shown in Table 2.

Table 2
Effect of “Prandtl number”, “Eckret number”, on skin friction and Nusselt number.

Pr	Ec	$f''(0)$	$-\theta'(0)$
0.71	0.36	-0.70052	0.95802
1.0	--	-0.73621	1.15040
7.0	--	-0.90060	3.26596
0.71	0.36	-0.70052	0.95802
	0.5	-0.69711	0.94442
	1.0	-0.68557	0.89775
0.71	0.36	-0.56578	0.98516
		-0.62664	0.97332
		-0.70052	0.95802
		-0.80015	0.93548
		-1.06634	0.85917
0.71	0.36	-0.71345	0.95527
		-0.70052	0.95802
		-0.69862	0.95891

5. Conclusion

The combined effect of radiation and source/sink within the viscous boundary layer over a linear stretching sheet with fluid particle suspension has been investigated numerically. The Runge-kutta 4th order method is used to solve the ODEs which are obtained by using the similarity transformation in governing boundary layer equations. The numerical results are obtained with the help of wellknown BVP4C code of Matlab which are found to be in good agreement with the previous reported cases. The major findings of this study are summarized below.

a) The effect of Prandtl number is major in case of thermal boundary layer rather than the momentum B.L. The thickness of the thermal boundary layer is more in case of water (Pr=1) in comparison to air (Pr=0.71) and electrolyte solution (Pr=7). The rate of heat transfer is less in electrolyte solution than that of air and water. The same trend is maintained in case of particle phase temperature.
b) The thermal boundary layer became thinner for both fluid and particle phase for high value of Ec. The less amount of heat energy stored when the frictional is less.
c) The momentum in thermal boundary layer of particle phase are majorly effected by fluid particle interaction parameter. The presence of particle cool down the temp which is of particle interest.
d) The temperature of both the phases enhanced for increasing value of radiation.

References

[1] 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
[2] Crane, Lawrence J. "Flow past a stretching plate." *Zeitschriftfür angewandte Mathematik und Physik ZAMP* 21, no. 4 (1970): 645-647. https://doi.org/10.1007/BF01587695
[3] Gupta, P. S., and A. S. Gupta. "Heat and mass transfer on a stretching sheet with suction or blowing." *The Canadian journal of chemical engineering* 55, no. 6 (1977): 744-746. https://doi.org/10.1002/cjce.5450550619
[4] 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
[5] Khan, AnsabAzam, KhairyZaimi, SuliadiFirdausSufahani, and Mohammad Ferdows. "MHD flow and heat transfer of double stratified micropolar fluid over a vertical permeable shrinking/stretching sheet with chemical reaction and heat source." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 21, no. 1 (2020): 1-14. https://doi.org/10.37934/araset.21.1.114
[6] Hayat, T., SadiaAsad, and A. Alsaedi. "Non-uniform heat source/sink and thermal radiation effects on the stretched flow of cylinder in a thermally stratified medium." *Journal of Applied Fluid Mechanics* 10, no. 3 (2017): 915-924. https://doi.org/10.18869/acadpub.jafm.73.240.24008
[7] Krishnaiah, Madasi, Punnam Rajendar, T. VijayaLaxmi, and M. Chenna Krishna Reddy. "Influence of non-uniform heat source/sink on stagnation point flow of a MHD Cassonnanofluid flow over an exponentially stretching surface." *Glob J Pure Appl Math* 13 (2017): 7009-7033.
[8] Swain, Kharabela, Sampada Kumar Parida, and GourangaCharan Dash. "Effects of non-uniform heat source/sink and viscous dissipation on MHD boundary layer flow of Williamson nanofluid through porous medium." In *Defect and Diffusion Forum*, vol. 389, pp. 110-127. Trans Tech Publications Ltd, 2018. https://doi.org/10.4028/www.scientific.net/DDF.389.110
[9] Gireesha, B. J., A. J. Chamkha, S. Manjunatha, and C. S. Bagewadi. "Mixed convective flow of a dusty fluid over a vertical stretching sheet with non-uniform heat source/sink and radiation." *International Journal of Numerical Methods for Heat & Fluid Flow* (2013). https://doi.org/10.1108/09615531311323764
[10] Lin, Ping, and AbuzarGhaffari. "Steady flow and heat transfer of the power-law fluid between two stretchable rotating disks with non-uniform heat source/sink." *Journal of Thermal Analysis and Calorimetry* 146, no. 4 (2021): 1735-1749. http://doi.org/10.1007/s10973-020-10142-x
[11] Tripathy, Pradeep Kumar, Tumbanath Samantara, Jayaprakash Mishra, and Sujata Panda. "Mixed convective radiative heat transfer in a particle-laden boundary layer fluid over an exponentially stretching permeable surface." In *AIP Conference Proceedings*, vol. 2435, no. 1, p. 020030. AIP Publishing LLC, 2022. https://doi.org/10.1063/5.0083840
[12] Das T.K, Mishra A. K. and Senapati N. "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.
[13] Ishak, Anuar, RoslindaNazar, and I. Pop. "Hydromagnetic flow and heat transfer adjacent to a stretching vertical sheet." *Heat and Mass Transfer* 44, no. 8 (2008): 921-927. https://doi.org/10.1007/s00231-007-0322-z

[14] Abel, M. Subhas, and N. Mahesha. "Heat transfer in MHD viscoelastic fluid flow over a stretching sheet with variable thermal conductivity, non-uniform heat source and radiation." *Applied Mathematical Modelling* 32, no. 10 (2008): 1965-1983. https://doi.org/10.1016/j.apm.2007.06.038

[15] Chen, C-H. "Laminar mixed convection adjacent to vertical, continuously stretching sheets." *Heat and Mass transfer* 33, no. 5 (1998): 471-476. https://doi.org/10.1007/s002310050217

[16] 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

[17] Samantara, Tumbanath. "Velocity profile of fluid particle suspension over a horizontal plate with electrification of particles"*International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 11, p. 1119-1122. https://doi.org/10.35940/ijitee.J1220.0981119

[18] 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

[19] Kanungo, Subhrajit, and Tumbanath Samantara. "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." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 100, no. 3 (2022): 11-22. https://doi.org/10.37934/arfmts.100.3.1122

[20] Sharafatmandjoor, Shervin. "Effect of Imposition of viscous and thermal forces on Dynamical Features of Swimming of a Microorganism in nanofluids." *Journal of Advanced Research in Micro and Nano Engineering* 8, no. 1 (2022): 1-8.

[21] Kotnurkar, Asha, and Namrata Kallolikar. "Effect of Surface Roughness and Induced Magnetic Field on Electro-Osmosis Peristaltic Flow of Eyring Powell Nanofluid in a Tapered Asymmetric Channel." *Journal of Advanced Research in Numerical Heat Transfer* 10, no. 1 (2022): 20-37.

[22] Samantara, T. N., S. K. Mishra, and T. C. Panda. "Flow and heat transfer in a laminar two-phase plane wall jet." *Int. J. Eng. Trends Technol* 4, no. 8 (2013): 3434-3447.