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Effect of Charged Nanoparticles and Viscous Dissipation on the Nanofluid Flow over a Moving Plate

Subhashree Panda[1], Ashok Misra[2*], and Saroj Kumar Mishra[3]

[1,2,3] Centurion University of Technology and Management, Odisha, India
[1]littlesubhashree92@gmail.com, [2]amisra1972@gmail.com, [3]s1_mishra@yahoo.com

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Abstract

A steady state flow of water-Al2O3 nanofluid over a moving plate with viscous dissipation and charged nanoparticles have been carried out. The boundary layer equations of flow field are transferred to nonlinear ordinary differential equations using similarity variables and the respective computational results are obtained using bvp4c of MATLAB software. The numerical results of the flow parameters are depicted through figures and tables. It is observed that the impact of electrification of nanoparticles is to enhance the non-dimensional velocity profile of nanofluid as well as the dimensionless skin friction coefficient and rate of non-dimensional mass transfer, whereas to reduce both the normalized temperature profile of nanofluid and non-dimensional concentration distribution of nanoparticles as well as the rate of dimensionless heat transfer of nanofluid.

Keywords: Electrification of nanoparticles, Nanofluid, Viscous dissipation

I. INTRODUCTION

Due to the global demand, many industries are trying to develop fluids with significantly higher thermal conductivities as compared to the lower thermal conductivity of the ordinary base fluids like water, oil, and ethylene glycol etc. Choi and Eastman [1] have already worked on the enhancement of the thermal conductivity of such ordinary base fluids by adding the nano sized metal particles to this fluid.

There are various applications of the problem of nanofluid flow over a moving plate in polymer industries, metal extrusion, hot rolling industry and copper wire industry. Bachok et al. [2] have investigated the boundary layer flow of nanofluid over a moving surface in a flowing fluid. Similarly, Ishak et al. [3] and Olanrewaju et al. [4] have studied the boundary layer flow of nanofluid over a moving surface in the presence of radiation. Buongiorno [5] has studied the non-homogeneous model of nanofluid flow focusing on Brownian diffusion and thermophoresis to enhance the thermal conductivity of nanofluid. Similarly, Kuznetsov and Nield [6] have investigated the classical problem of natural convective nanofluid flow past a vertical plate just by following Buongiorno.

Soo [7] has analysed the effect of electrification of suspended particles on the dynamic of a particulate system. At low temperature, electrification of suspended particle occurs due to the particle-particle collision and particle-wall interaction and thus an effective drag force is produced on the ions which would significantly affect the heat transfer and concentration distribution in the flow of a fluid-solid system. Similarly, Pati et al. [8, 10] and Patnaik et al. [9] have shown the effect of nanoparticle electrification on the boundary layer flow of nanofluid with different flow conditions. Many literature study, Gebhart [11] has first investigated viscous dissipation in free convection flow. Mohamed et al. [12] has analyzed the effect of viscous dissipation on forced convection nanofluid flow over a moving plate. But in all the above literature, know such attention has been given to study the effect of electrification of nanoparticles on the boundary layer flow of a

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nanofluid past a moving plate with viscous dissipation.

Hence in the present study, the boundary layer flow of water - Al_2O_3 nanofluid past a moving plate with viscous dissipation and electrification of nanoparticles have been considered to especially show the effect of electrification of nanoparticles on various flow parameters of nanofluid as well as on the heat transfer of nanofluid and concentration distribution of nanoparticles.

II. MODELLING OF THE PROBLEM

A steady state two dimensional boundary layer flow of water –Al_2O_3 nanofluid over a moving plate is considered. The plate is immersed in a nanofluid of ambient temperature T_∞. Let T and T_w be the temp of nanofluid within the boundary layer and on the plate respectively. The plate velocity is given by: $U_w(x) = \varepsilon U(x)$, where U is the free stream velocity of nanofluid and ε is the plate velocity parameter. Let C be the concentration distribution of nanoparticles which is a function of x, y and t and C_w and C_∞ be the volume concentration of nanoparticles on the plate and in the free stream respectively. The flow geometry is shown in Fig. 1.

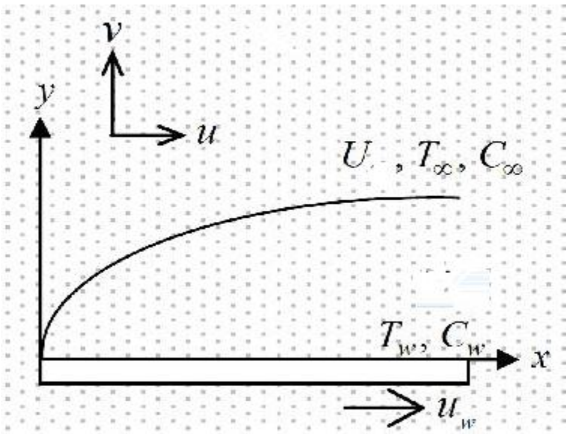

Figure. 1 Geometry of the problem

Including the phenomena of electrification of nanoparticles and viscous dissipation in the Buongiorno's model [5], the governing equations corresponding to the above physical model are given by:

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

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T}\frac{\partial^2 T}{\partial y^2}+\left(\frac{q}{m}\right)\frac{1}{F}\left(\frac{\partial(CE_X)}{\partial x}+\frac{\partial(CE_y)}{\partial y}\right) \qquad (2)$$

$$\rho_{nf}\left[u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right]=-\frac{\partial p}{\partial x}+\mu_{nf}\frac{\partial^2 u}{\partial y^2}+C\rho_s\left(\frac{q}{m}\right)E_X \qquad (3)$$

$$\frac{\partial p}{\partial y}=O(\delta) \qquad (4)$$

$$(\rho c)_{nf}\left[u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right]=k_{nf}\frac{\partial^2 T}{\partial y^2}+\rho_s c_s D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{\rho_s c_s D_T}{T}\left(\frac{\partial T}{\partial y}\right)^2+\left(\frac{q}{m}\right)\frac{C\rho_s c_s}{F}\left(E_X\frac{\partial T}{\partial x}+E_y\frac{\partial T}{\partial y}\right)+\mu_{nf}\left(\frac{\partial u}{\partial y}\right)^2 \qquad (5)$$

subjected to the boundary conditions as given below:

$$\left.\begin{array}{l} y=0, u=U_w=\varepsilon U, v=0, T=T_w, C=C_w \\ y=\infty, u=U=const, v=0, T\to T_\infty, C\to C_\infty \end{array}\right\} \qquad (6)$$

The E-field is given by the equation:

$$\frac{\partial E_x}{\partial x}+\frac{\partial E_y}{\partial y}=\frac{\rho_s}{\varepsilon_0}\frac{q}{m} \qquad (7)$$

Where, ε_0 is the permittivity.

Neglecting the change in electric field in the x-direction as discussed in Soo, the transverse electric field is given by

$$\frac{\partial E_y}{\partial y}=\frac{\rho_s}{\varepsilon_0}\frac{q}{m} \qquad (8)$$

2.1. SIMILLARITY TRANSFERMATION

Introducing the following similarity transformations

$$\eta=y\sqrt{\frac{U}{2\nu_f x}},\theta=\frac{T-T_\infty}{T_W-T_\infty},u=Uf',v=-\sqrt{\frac{\nu_f U}{2x}}\left(f-\eta f''\right),\psi=\sqrt{2\nu_f Ux}\,f(\eta),S=\frac{C-C_\infty}{C_W-C_\infty}$$

the equation (1) is satisfied and the equations (2), (3) and (5) along with the boundary conditions (6) are converted into:

$$S''+ScfS'+\frac{Nt}{Nb}\theta''-MSc\eta S'+2Sc\frac{N_F}{N_{Re}}\left(S+N_c+\eta S'\right)=0 \qquad (9)$$

$$\varphi_1 f'''+ff''+2\frac{MN_b}{N_F}Sc\varphi_2 S=0 \qquad (10)$$

$$\frac{\phi_3\phi_4}{\Pr}\theta''+f\theta'+\phi_3 N_b\theta'S'+\phi_3 Nt\left(\theta'\right)^2+\left(2\frac{N_F}{N_{Re}}-M\right)ScN_b\phi_3\left(S+N_c\right)\eta\theta'+\phi_5 Ec\left(f''\right)^2=0 \qquad (11)$$

subjected to

$$\left.\begin{array}{l} \eta=0, f(0)=0, f'(0)=\varepsilon,\theta(0)=1,S(0)=1 \\ \eta=\infty, f'(\infty)=1,\theta(\infty)=0,S(\infty)=0 \end{array}\right\} \qquad (12)$$

considering $\frac{T_W-T_\infty}{T_\infty} << 1$

where,

$$M=\left(\frac{q}{m}\right)\frac{1}{FU}E_x, N_F=\frac{U}{Fx}, \frac{1}{N_{\mathrm{Re}}}=\left(\left(\frac{q}{m}\right)^2\frac{\rho s x^2}{U^2\varepsilon_0}\right), N_b=\frac{\tau D_B\left(C-C_\infty\right)}{\nu_f}, Nt=\frac{\tau D_T\left(T-T_\infty\right)}{\nu_f T_\infty}$$

$$\mathrm{Pr}=\frac{\nu_f}{\alpha_f}, Sc=\frac{\nu_f}{D_B}, N_C=\frac{C_\infty}{C_W-C_\infty}, \tau=\frac{\rho_s c_s}{\rho_f c_f}, \quad Ec=\frac{U^2}{c_f\left(T_w-T_\infty\right)}$$

Again using the Maxwell model [13] for thermal conductivity, the thermo physical constants $\varphi_1,\varphi_2,\varphi_3,\varphi_4,\varphi_5$ are obtained as:

$$\varphi_1=\frac{1}{\left(1-C_\infty\right)^{2.5}}\frac{1}{\left[\left(1-C_\infty\right)+C_\infty\frac{\rho_s}{\rho_f}\right]}, \varphi_2=\frac{\rho_s}{\rho_f}\frac{1}{\left[\left(1-C_\infty\right)+C_\infty\frac{\rho_s}{\rho_f}\right]},$$

$$\varphi_3=\frac{1}{\left(1-C_\infty\right)+C_\infty\tau}, \varphi_4=\frac{k_s+2k_f-2C_\infty\left(k_f-k_s\right)}{k_s+2k_f+C_\infty\left(k_f-k_s\right)}, \varphi_5=\frac{1}{\left(1-C_\infty\right)^{2.5}}$$

III. DISSICUSSION OF RESULTS

The equations 9-11 are solved using MATLAB bvp4c package. A comparative study has been carried out in Tables I and II for the validation of results. The variations of the numerical values of non-dimensional skin friction coefficient $f''(0)$, non-dimensional rate of heat transfer $-\theta'(0)$, non-dimensional rate of mass transfer $-S'(0)$ with different values of the parameters M, N_b, N_t and E_c are presented in Table III. Similarly, the variations of non-dimensional velocity profile f'(η), non-dimensional temperature profile θ(η) of water – Al_2O_3 nanofluid and dimensionless concentration distribution of nanoparticle S(η) with different values of M, N_b, N_t and E_c are depicted through the figures from 2-13.

In table I, the present numerical values of $\frac{-\theta'(0)}{\sqrt{2}}$ have been compared with that of Rosca and pop [14] and Mohamed et al. [12] for different P_r and are observed in good agreement.

Table. 1 Comparison of present values of $\frac{-\theta'(0)}{\sqrt{2}}$ with that of Rosca and pop [14] & Mohamed et al. [12] for different P_r when $\varepsilon = N_b = N_f = N_t = E_c = S_c = M = 0$.

P_r	Roşca and Pop[14]	Mohamed et al.[12]	Present analysis
0.7	0.29268	0.29268	0.292678
0.8	0.30691	0.306917	0.306919
1.0	0.33205	0.332057	0.332057
5.0	0.57668	0.576689	0.576695
10.0	0.72814	0.78141	0.728150

In Table II, the computed values of $f''(0)$, $-\theta'(0)$ and $-S'(0)$ in the present study have been compared with those values of Mohamed et al. [12] for different ε and both are observed in good agreement.

Table. 2 Comparison of present values of $f''(0)$, $-\theta'(0)$ and $-S'(0)$ with that of Mohamed et al. [12] for different ε when $N_b = N_f = N_t = E_c$=0.1, S_c =10, M = 0.0, P_r=7.0.

Mohamed et al. [12]				Present Analysis		
ε	N_{ur}	S_{hr}	C_{fr}	N_{ur}	S_{hr}	C_{fr}
0	0.3747	1.1672	0.4696	0.37458	1.16700	0.46960
0.1	0.4705	1.3369	0.4625	0.47043	1.33674	0.46251
0.5	0.7875	1.8657	0.3288	0.78739	1.86545	0.32874
1.0	1.0717	2.3805	0	1.07170	2.38050	0
2.0	1.2994	3.3099	-1.0190	1.29904	3.30899	-1.01906

From Table III, it is found that $f''(0)$ is enhanced with the increase of the parameters M, N_b, N_t and it is reduced with the increase of parameter E_c. It is observed that $-\theta'(0)$ shows a completely decreasing trend whereas $-S'(0)$ shows a completely increasing trend with the higher values of M, N_b, N_t and E_c.

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Table. 3 Computed results of $f''(0)$, $-\theta'(0)$ and $-S'(0)$ for different values of M, Nb, Nt and Ec.

ε	E_c	φ	S_c	P_r	N_F	N_b	N_t	N_{Re}	N_c	M	$f''(0)$	$-\theta'(0)$	$-S'(0)$
0.5	0.1	0.01	1	6.2	0.1	0.1	0.1	2.0	0.1	0.0	0.31990	1.09949	-0.0594
										0.1	2.10404	0.80139	0.49057
										0.15	2.81519	0.49351	0.85612
										0.4	5.57789	- 1.56941	3.303107
0.5	0.1	0.01	1	6.2	0.1	0.05	0.1	2.0	0.1	0.1	1.56565	1.05635	-0.34020
						0.1					2.10404	0.80139	0.49057
						0.2					3.08091	0.22100	0.97599
						0.5					5.59287	- 1.63780	1.36483
0.5	0.1	0.01	1	6.2	0.1	0.1	0.05	2.0	0.1	0.1	1.90596	0.97524	0.50212
							0.1				2.10404	0.80139	0.49057
							0.2				2.41449	0.47374	0.93565
							0.5				2.82514	- 0.22122	4.53042
0.5	0.05	0.01	1	6.2	0.1	0.1	0.1	2.0	0.1	0.1	2.12777	1.08255	0.22378
	0.1										2.10404	- 0.80139	0.49057
	0.4										1.96599	- 0.72067	1.93004
	0.6										1.87773	- 1.58983	2.74728

3.1 Profiles of $f'(\eta)$, $\theta(\eta)$& $S(\eta)$ for different values of electrification parameter(M):

The effect of M on f'(η), θ(η) and S(η) are shown in Figs. 2-4. Increasing parameter M has an impact in raising the profiles of f'(η) and θ(η) and in reducing the profile of S(η). It is due to the Coulomb term $N_{p_m} q\vec{E}$ of the Lorentz force, which favors in accelerating the base fluid particles.

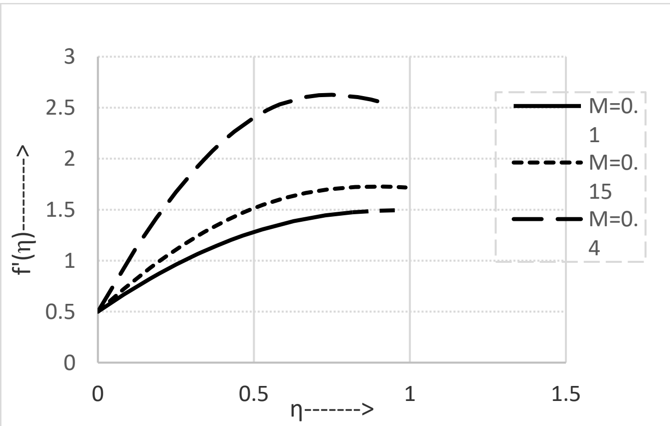

Figure. 2 Variation of $f'(\eta)$ with M

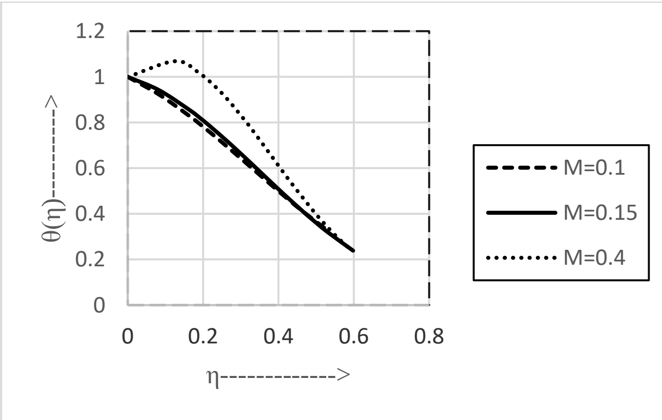

Figure. 3 Variation of $\theta(\eta)$ with *M*

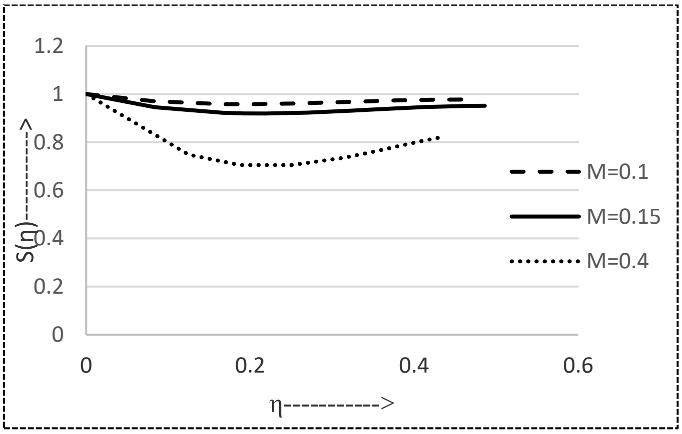

Figure. 4 Variation of *S(η)* with *M*

3.2 Profiles of f'(η), θ(η)& S(η) for different values of diffusion parameter(Nb):

In Figs. 5-7, the effect of N_b on f'(η), θ(η) and S(η) have been depicted**.** The profiles of f'(η), θ(η) show an increasing trend, whereas S(η) shows an opposite trend with the higher values of N_b.

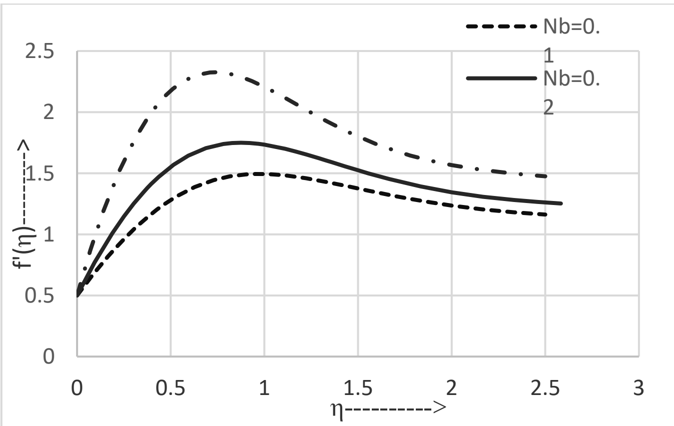

Figure. 5 Variation of $f'(\eta)$ with N_b

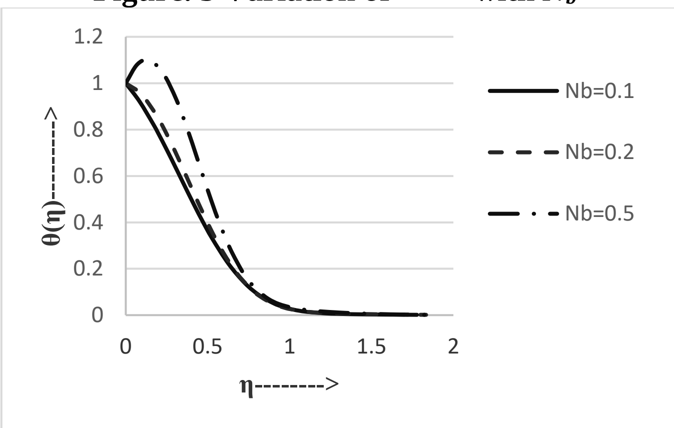

Figure. 6 Variation of $\theta(\eta)$ with N_b

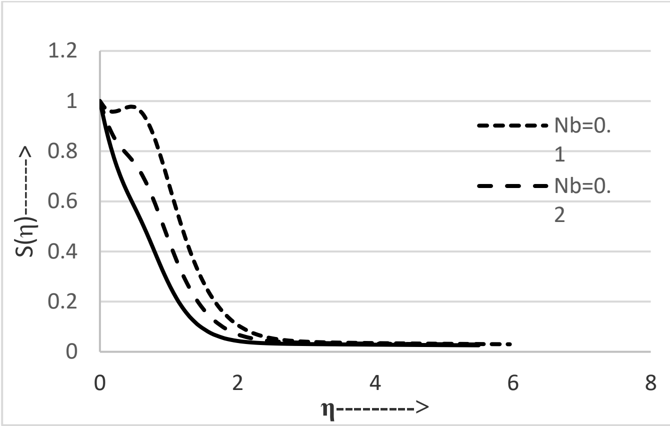

Figure. 7 Variation of *S(η)* with N_b

3.3 Profiles of f'(η), θ(η)& S(η) for different values of Thermophorotic parameter (Nt):

The effect of N_t on f'(η), θ(η) and S(η) are shown in Figs. 8-10. It is concluded that f'(η), θ(η) and S(η) are completely showing an increasing trend with increasing values of N_t.

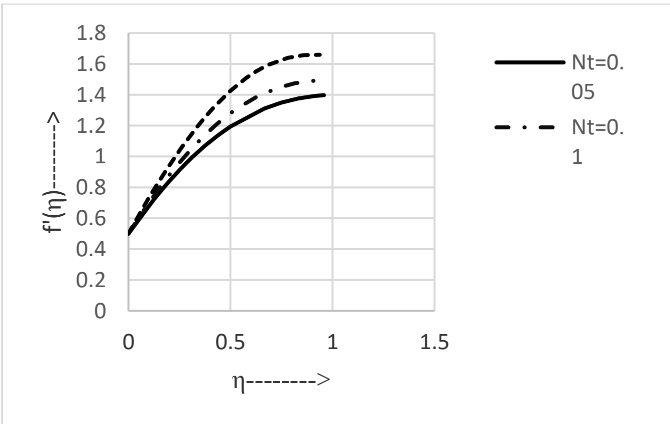

Figure. 8 Variation of $f'(\eta)$ with N_t

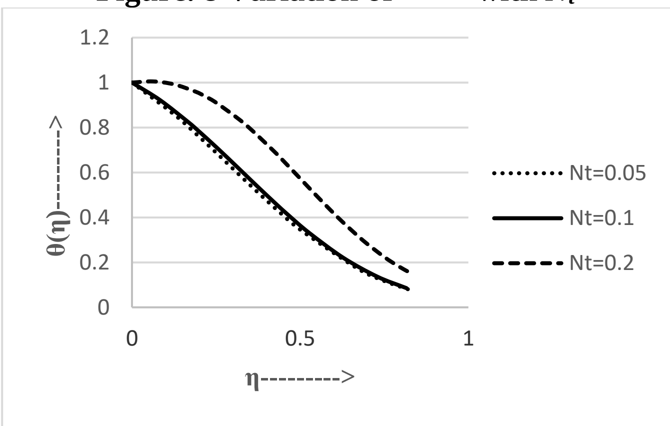

Figure. 9 Variation of $\theta(\eta)$ with N_t

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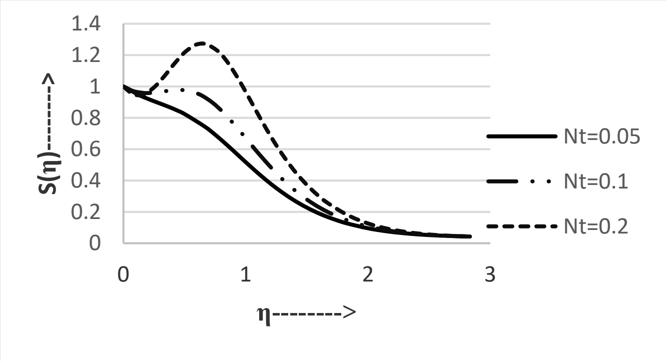

Figure. 10 Variation of *S(η)* with N_t

3.4 Profiles of f'(η), θ(η)& S(η) with different values of Eckert number (Ec):

Figs 11-13 show the effect of Ec on f'(η), θ(η) and S(η). Higher values of Ec cause in raising θ(η) but showing a reverse trend in case of f'(η) and S(η).

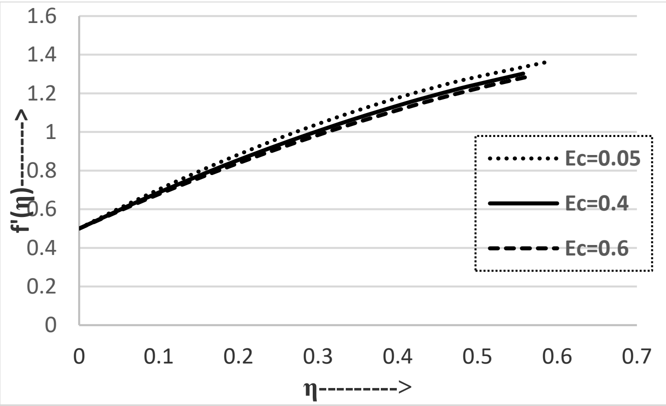

Figure. 11 Variation of $f'(\eta)$ with E_c

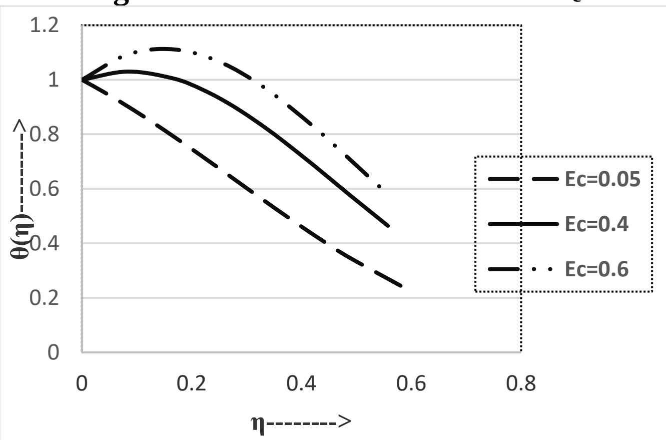

Figure. 12 Variation of $\theta(\eta)$ with E_c

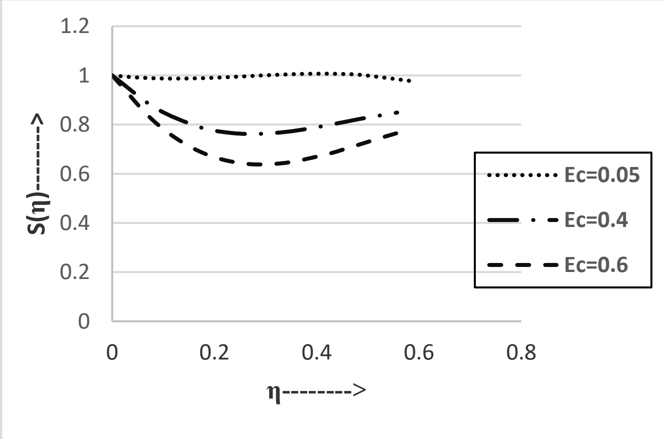

Figure. 13 Variation of *S (η)* with E_c

IV. CONCLUSION

The present study deals with the effect of charged nanoparticles on the nanofluid flow over a moving plant with viscous dissipation. The effect of various dimensional-less parameters like Diffusion parameter (N_b), electrification parameter (M), Thermophorotic parameter (N_t), Eckert no (Ec) on non-dimension velocity profile, normalized temperature profile of water- Al_2O_3 nanofluid, dimensionless concentration distribution of nanoparticles, non-dimensional skin friction coefficient, non-dimensional heat transfer of nanofluid and non-dimensional concentration distribution of nanoparticles have been analyzed through graphs and tables. The highlighted results are summarized below:

1) The higher electrification parameter M has an effect to enhance the non-dimensional velocity and non-dimensional temperature of nanofluid whereas to reduce non-dimensional concentration distribution of nanoparticles.
2) The non-dimensional velocity and non-dimensional temperature shows an increasing trend, whereas the non-dimensional concentration distribution of nanoparticles show a decreasing trend with the increasing of N_b.
3) The increasing N_t has an effect to increase non-dimensional velocity, non-dimensional temperature of nanofluid as well as the non-dimensional concentration distribution of nanoparticles.
4) Eckert number (E_c) plays an important role to increase the non -dimensional temperature and to the decrease the non-dimensional velocity of nanofluid and the non-

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dimensional concentration distribution of nanoparticles.

5) The non-dimensional skin friction coefficient is enhanced with the increase of M, N_b, N_t and it is reduced with the increase of parameter E_c. again the non-dimensional heat transfer of nanofluid shows a completely decreasing trend whereas non-dimensional concentration distribution of nanoparticles shows a completely increasing trend with the higher values of M, N_b, N_t and E_c.

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