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Full Length Research Paper

Solutal Stratification on MHD Water Base Nanofluid Flow over a Porous Vertical Plate

Owoyemi, A. E.[1*], Olowo, S. E.[2], Bamishaiye, O. M.[1], Dauda, H. S.[2] and Umunagbu, M. U.[1]

[1]Department of General Studies, Federal College of Agricultural Produce Technology, Kano, Nigeria.
[2]Department of Computer and Statistics, Federal College of Agricultural Produce Technology, Kano, Nigeria.
*Corresponding Author E-mail: abiodunowoyemi9@gmail.com

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ABSTRACT: This study presents a solutal stratification on Magnetohydrodynamics (MHD) water base nanofluid. The governing nonlinear partial differential equations (PDEs) are modeled and then simplified with the aid of suitable similarity transformations into ordinary differential equation (ODEs). Well known numerical algorithm Runge–Kutta–Fehlberg method of order fourth/fifth is utilized to solve the system. Concrete graphical and table analysis are carried out to investigate the behavior of different pertinent parameters on both velocity $f(\eta)$, and concentration, $\varphi(\eta)$, profile with inclusive discussion. Numerical influence of magnetic field, porous, thermophoresis, Brownian motion, Buoyancy, and suction are also discussed. Due to the mixed effect of permeability of the porous medium and the kinematic viscosity of the nanofluid, it is shown that the velocity of the nanofluid decreases and the concentration of the nanofluid increases with increase in porosity.

Keywords: Nanofluid, Nanoparticle, Solutal stratification and MHD

INTRODUCTION

The increase in the efficacy of fluid transfer (such as water, oil, ethylene glycol) has been a huge research work in science and engineering in recent years. This has led to the discovery of additive to the base fluid because from its poor heat transfer properties. There are three mechanisms in heat transfer (Keblinski et al., 2001), which are by conduction (in solid), convection (in liquid and gas) and radiation (through penetrating objects). In solutal convection, heat is being transferred via a mass movement of liquid (oil and gas).

History has it that, Stephen U. S. Choi introduced a term called nanofluid (Choi and Eastman, 1995). This nanofluid comprises a dispersal of submicronic solid particle that is referred to as nanoparticle (Khan, 2017).

The main objective of this so called nanoparticle is to diffusing the solid particle in the fluid in order to boost thermal conductivity (Hwang et al., 2006; Jiang et al., 2009; Sheikholeslami et al., 2014). This has been further investigated and proved correct by several researchers such as the works in (Hassani et al., 2015; Lee et al., 2017; Krahl et al., 2018; Zhao et al.,2018). Nanoparticles can be obtained from metals such as Al and Cu, oxides such as and single surface carbon nanotubes (SWCNTs). On the other hands, nanofluid can be described as a single stage composite of nanometer sized solid suspended particles and fibers in traditional base fluids. The frequently utilized as based fluid are; oil, ethylene glycol mixture, toluene, etc. Nanofluids attempts

many distinct assets in manufacturing employments including; fuel cell, nuclear reactors, transportation, microelectronics, and biomedicine (Wang and Mujumdar, 2008; Mohammed et al., 2017; Islam et al., 2017; Ul Haq et al., 2015).

In industrial applications, nanoparticles have been used to avoid overheat of the instrument (Wong and De Leon, 2010). Thus, nanoparticle plays an important role as the coolant substance to transfer heat, an example of such is our computer system (Islam et al., 2017). The heat sink helps to absorb and cool the heat generated in the system, thereby avoid being overheated. This is because the diameter less than 100nm and this condition will affect the properties of the liquid surface area to enhance the heat transfer compare to the micron-size particle (Anderson et al., 2013).

Various nanoparticle shapes have been utilized over the experiment (Xie et al., 2002; Murshed et al., 2005), which presented the first kind of experimental analysis. On both heat and mass transfer, solutal stratification indeed has several practical applications most especially in industrial and engineering (Ibrahim and Makinde, 2013). These applications include rubber sheet (Mahdy, 2015), annealing, rubber and plastic manufacturing (Mahdy, 2015) and solar power collector just to mention a few. The impact spread to boundary layer nanofluid flow over a porous vertical plate.

The word “magnetohydrodynamics” is derived from magneto, which mean magnetic field; hydro, which also mean water; and dynamic, which mean movement. This aspect was introduced by Hannes Alfven, where he received the Nobel prize in Physics in 1970. MHD is the study of the magnetic properties of electrically conducting fluid. Examples of such magnetofluids are plasmas, liquid metals, salt water, and electrolytes. MHD flow with two-non-dimensionless unsteady spill of a viscous, which is in between two parallel infinite plates were proposed in (Siddiqui et al., 2008). However, and having known the impact and effort that solutal is contributing in industrial and engineering, it is therefore paramount for researchers to explore more on the impacts of solutal conductivity that would be better than the traditional method. Maxwell is one of the examples of traditional theories (Sheikholeslami et al., 2016). One of the challenges of the Maxwell’s theories is that the cooling capacities are low and poor in thermal conductivity (Hatami et al., 2017), (Torsater et al., 2012; Levidow et al., 2014; Yu et al., 2008). Besides these low cooling capacities, it is observed that its behavior is insufficient when compared to the nanoparticle conductivity.

More work on these nanoparticles have been investigated with the connection of industrial and engineering application. Some of such investigations covers aspect including oscillatory enhancement (Zwick et al., 1997), nanoparticle effects on copper (Kim et al., 2011), stead and unsteady squeeze flow (Sheikholeslami et al., 2016) and lots more. And such have been applied to different aspect, which include chemical production (Baer et al., 2010), engineering (Macfarlane et al., 2011), power development of a power plant (Lu et al., 2012), automotive (Pal et al., 2011), beforehand nuclear systems (Wibisono et al., 2015). A convection of solutal stratified medium of nanofluid was proposed in (Varma et al., 2017) (Kumar and Shalini, 2005). The authors concluded that the application of solutal has a significant and important problem due to the fast that it has huge amount of applications. Solutal stratification has however plays a dominant role in dying industries (Ibrahim and Makinde, 2013).

Recently, a convective fluid flow in a porous medium was investigated. Result obtained in (Wong and De Leon, 2010) considered the used of nanoparticles as a good particle especially when one wants to avoid overheat. Islam et al. (2017) supported such and cited example of a computer system, where nanoparticles served as a coolant substance in heat transfers. The current work is to investigate the solutal stratification on MHD water base nanofluid flow over a porous vertical plate. This will among other things share influence of solutal stratification with variable stream condition. The impacts of governing parameters on velocity, concentration, magnetic field, porous, thermophoresis, Brownian motion, Buoyancy and suction are analyzed.

FORMULATION OF MODEL AND METHODOLOGY

A porous vertical plate that is position along the -axis, where the normal plate is also stationed along the -axis, which is a steadier connective two- dimensional nanofluid flow is proposed in (Kandasamy et al., 2018). B_0 is represents as the non-negative direction along the -axis. The ambient temperature along with the nanofluid concentration is taken into consideration, which is given as $T_\infty = T_{\infty,0} + Ax$ and $C_\infty = C_{\infty,0} + Bx$, respectively, where $T_{\infty,0}$ and $C_{\infty,0}$ is the depth of stratification. The surface of the temperature is considered to be constant rate, which is given as, T_W. C_W for the nanofluid concentration. A and B remain constant values. The proposed coordinate system and the flow structure as proposed is given in (Figure 1). The physical significant governing equations (i.e. continuity, momentum and diffusion equations), which is based on approximation of the boundary layer are given in equation (1) -(3).

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

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial y^2}\right) + \tau\left\{D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right\} \quad (2)$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} \quad (3)$$

where the boundary conditions are

$$u = 0, \quad v = -V_0, \quad T = T_W, \quad C = C_W, at\ \eta = 0$$
$$u = 0,\ T = T_\infty,\ C = C_\infty,\ and\ \eta = \infty \quad (4)$$

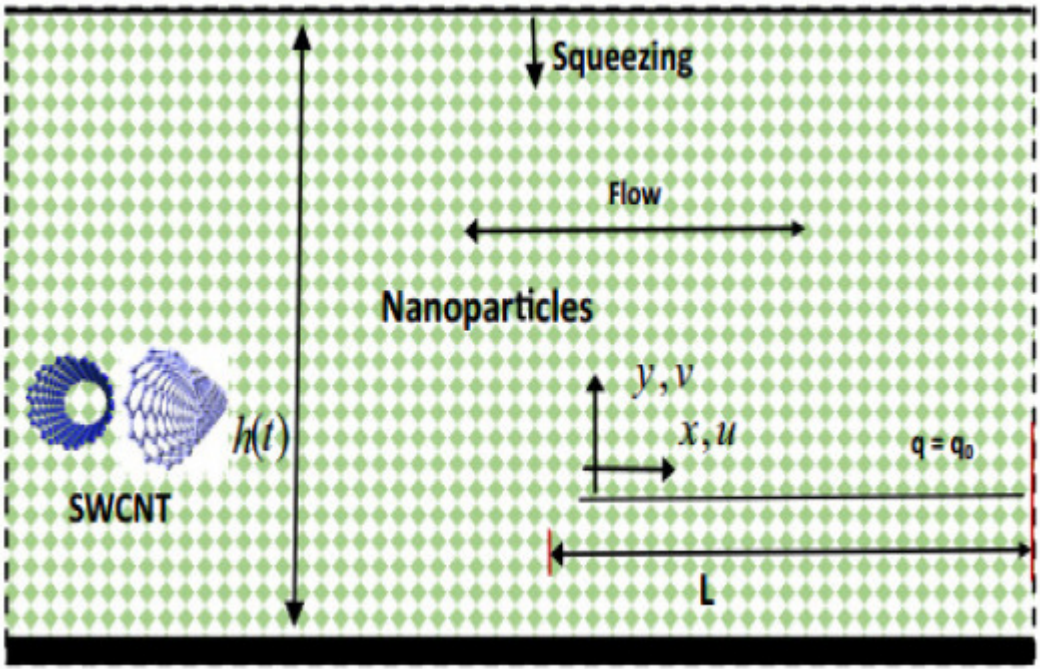

Figure 1. The system of the coordinate with flow configuration (Kandasamy et al., 2017).

We have below the local Rayleigh number along with the stream function ψ, respectively

$$Ra_x = \frac{(1+C_{\infty,0})\rho f_{\infty,0}\beta g(T-T_{\infty,0})}{v\alpha},\ u = \frac{\partial\psi}{\partial y}, v = -\frac{\partial\psi}{\partial x} \quad (5)$$

The energy as well as the equations of diffusion are transformed into the equivalent differential equation via the below similarity transformation;

$$\eta = \frac{y}{x}Ra_x^{\frac{1}{4}}, \psi = Ra_x^{\frac{1}{4}}\alpha f(\eta), \theta(\eta) = \frac{T-T_\infty}{T_W-T_{\infty,0}} - \frac{Ax}{T_W-T_{\infty,0}},\ \varphi(\eta) = \frac{C-C_\infty}{C_W-C_{\infty,0}} - \frac{Bx}{C_W-C_{\infty,0}} \quad (6)$$

where, $C_w - C_{\infty,0} = mx, T_w - T_{\infty,0} = nx, m, n$ are constants.

Pr = - Prandtl number

Le = - Lewis number

$Nr = \frac{(\rho p_\infty + \rho f_{\infty,0})(C_W - C_{\infty,0})}{\rho f_\infty \beta (T_W - T_{\infty,0})(1-C_\infty}$ - nanofluid buoyancy ratio,

$Nb = \frac{(\rho c)_p D_B (C_W - C_\infty}{(\rho c)_p \alpha}$ - nanofluid buoyancy ratio,

$Nt = \frac{(\rho c)_p D_T (T_W - T_\infty}{(\rho c)_p \alpha T_{\infty,0}}$ - Brownian motion parameter,

$\varepsilon_1 = \frac{4Ax}{(T_W - T_{\infty,0})}$ = - solutal stratification parameter,

$\varepsilon_2 = \frac{4Bx}{(C_W - C_{\infty,0})}$ = - solutal stratification parameter,

$\lambda = \frac{L'}{KRa}$ - porous parameter,

$M = \frac{\sigma_0 B_0^2}{\mu Ra_x^{\frac{1}{4}}}$ - magnetic parameter,

However, the quantities parameters are;

$C_f = \frac{\tau}{\rho_f}$ - skin friction coefficient,

$Nu_x = \frac{q_W x}{k_f(T_W -$ - local Nusselt number,

where and are defined as;

$$C_f(Re_e)^{\frac{1}{2}} = \frac{f^{II}(0)}{(1-\ )^{2.5}}, \frac{Nu_x}{Re_e^{\frac{1}{2}}} = -\frac{K_{nf}}{K_f}\theta^I$$

Re_e = - The local Reynolds number.

Due to limited spaces, we skip some work here, but however, after much algebraic works, we solved simultaneously, using 2-dimensional boundary layer for the fundamental fluid dynamics. The flow of the system is steady in this study.

Along the x-axis and y-axis, we considered u and v respectively as the velocity components, while P and ρ are the pressure and density, respectively. The system of the equation is partially differential equations (PDEs)

which are converted into the ODEs via similarity transformation.

We consider that

$$u = hf'p, \tag{7}$$

$$\frac{\partial u}{\partial x} = -\frac{3}{4}\alpha\frac{Rax^{\frac{1}{2}}}{x}\eta f'' - \frac{1}{2}\alpha\frac{Rax^{1/2}}{x^2}f', \tag{8}$$

$$v = \frac{Rax^{\frac{1}{4}}}{x}\alpha\left[\frac{3\eta}{4}f' - \frac{1}{4}f\right]. \tag{9}$$

It then follows that

$$\frac{\partial u}{\partial y} = hp^2 \tag{10}$$

and

$$\frac{\partial^2 u}{\partial y^2} = hp^3. \tag{11}$$

As earlier mentioned several algebraic works are skips here because of space. Therefore, the questions are given respectively in equations (12) – (13) which in the form of PDEs that is reduced from ODEs using similarity transformation as;

$$f''' + \frac{3}{4Pr}\left(ff'' - (f')^2\right) + \theta - N_r\varphi - f'(\lambda + M) = 0 \tag{12}$$

$$\varphi'' - Lef\,\varphi' + \frac{1}{4}Lef\,\varphi' - Lef'\frac{\varepsilon_2}{4} + \frac{\alpha f'\theta''}{Nb} = 0 \tag{13}$$

$$\begin{aligned} &u = 0, v = -V_0, T = T_w, C = C_w at \eta = 0, \\ &u = 0, T = T_\infty, C = C_\infty, and \eta = \infty. \end{aligned} \tag{14}$$

RESULTS AND DISCUSSION

The numerical simulation is illustrated and discussed in this section. The result was analyzed with certain nanofluid flows. The Runge Kutta Fehnerg technique of order fourth/fifth was used along with the shooting method. The software used in the analysis was Maple 18. The shooting technique was introduced by Runge Kutta in the nineteen century and has been recently studied by many researchers (Kandasamy et al., 2016; Khan et al., 2014; Singh and Kumar, 2015). We set the parameter to use. The analysis reports the parameters' effects on the solutal stratification on MHD water based nanofluid over a porous vertical plate water, $P(kg/m^3) = 997.1$. In order to validate our result, (Figure 2) displayed the result of comparison of the magnetic effects profile for velocity$f(\eta)$, and concentration $\varphi(\eta)$. The obtained results are correlated and found to be in agreement with those obtained in (Kandasamy et al., 2018).

Table 1 shows the various values of magnetic field deposition. It shows the solutal stratification parameter at $\varepsilon_1 = 0.01$ and $\varepsilon_2 = 0.09$. When magnetic field, *M,* is increasing, velocity is reducing. Concentration $\varphi(\eta)$ increase when the magnetic increase. Figure 3 displays the effect of solutal stratification on velocity $f(\eta)$, and concentration $\varphi(\eta)$, with magnetic parameter, M. The velocity$f(\eta)$, increase with decrease in the magnetic strength in the presence of solutal stratification, which is fixed at $\varepsilon_1 = 0.01$ and $\varepsilon_2 = 0.9$. The concentration, $\varphi(\eta)$, increase slightly with increase in the parameter of magnetic power for the solutal stratification. Tables 2 display the reaction of porous λ on solutal stratification along with the effect in the velocity and concentration. It is obtaining that an increase in porous parameters increase leads to velocity decrease and concentration increase at when solutal stratification is at both $\varepsilon 1 = 0.01$ and $\varepsilon 1 = 0.9$. The reaction of velocity $f(\eta)$ and concentration $\varphi(\eta)$ circulation in the presence of solutal stratification, $\varepsilon 1 = 0.01, 0.09$ are displayed in (Figure 4). The velocity, $f(\eta)$, increase with decrease in the porous strength. For the concentration, $\varphi(\eta)$, slightly increase with increase in solutal porous power for solutal stratification. Due to the mixed effect of permeability of the porous medium and the kinematic viscosity of the nanofluid, it is shown that the velocity of the nanofluid decreases and the concentration of the nanofluid increases with increase in porosity. Table 3 also displays the reaction of Buoyancy, Nr on solutal stratification on the velocity and concentration. The solutal stratification shows more significant effect on Buoyancy, Nr. It is therefore obtaining that as the value of the Buoyancy, Nr increase, the velocity,$f(\eta)$, reduced and concentration $\varphi(\eta)$, increase with increase in the buoyancy ratio because of the combined effect of nanoparticle mass density. The solutal stratification at $\varepsilon_1 = 0.01$ shows higher effect on the Buoyancy ratio than when the solutal stratification is fixed at $\varepsilon_2 = 0.9$. Figure 5 shows that the velocity, $f(\eta)$, decrease with increase in the Buoyancy. The effect of buoyancy in the presence of electric field $\varepsilon_1 = 0.01$ for the velocity is higher than the $\varepsilon_2 = 0.9$. The concentration $\varphi(\eta)$ shows no influence except for $\varepsilon_1 = 0.01$ the is stronger than $\varepsilon_2 = 0.9$. Table 4 displays the reaction of Brownian motionNb. The reaction indicated that the increase in Brownian motion effect the decrease in both velocity and concentration. In Figure 6, the velocity$f(\eta)$, increase as a result of the increase in the Brownian motion of the nanofluid. Concentration$\varphi(\eta)$ of the nanofluid, Nb reduce with an increase in the Brownian motion. Boundary of the solutal stratification of MHD nanofluid in presence of $\varepsilon_2 = 0.09$ is lower than the$\varepsilon_1 = 0.1$. Tables 5 displays the reaction of suction,S, on solutal stratification.

The reaction indicated that an increase in suction parameter ($s > 0$). It indicates a first rise in the velocity and concentration at when $S = 0.0, 0.5$ and later reduce

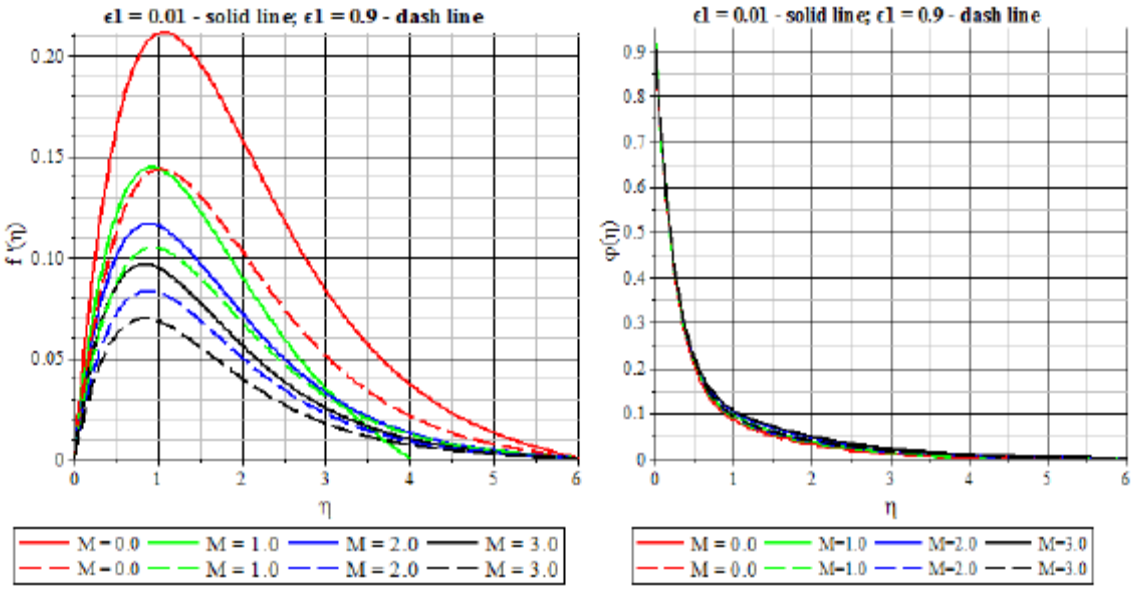

Figure 2. Comparison of magnetic strength on velocity $f(\eta)$, and concentration $\varphi(\eta)$, of the nanofluid with Figure 6 in (Kandasamy et al., 2018).

Table 1. The effect of solutal stratification with the impact of Magnetic Field, *M*.

M	$f(\eta)$	$\varphi(\eta)$	Solutal
0.0	0.46734	-3.38963	
1.0	0.36715	-3.36469	$\epsilon_1 = 0.01$
2.0	0.32548	-3.31057	
3.0	0.29029	-3. 29290	
0.0	0.32005	-3. 35741	
1.0	0.26090	-3. 33313	$\epsilon_2 = 0.9$
2.0	0.22537	-3. 31969	
3.0	0.20090	-3.31098	

Table 2. The effect of solutal stratification with the impact of porous, λ.

λ	$f(\eta)$	$\varphi(\eta)$	Solutal
0.0	0. 44847	-3.39976	
0.5	0. 40175	-3.37942	$\epsilon_1 = 0.01$
1.0	0. 36715	-3.36469	
3.0	0. 05164	-3.57448	
0.0	0 31014	-3.37398	
0.5	0. 27843	-3.36425	$\epsilon_2 = 0.9$
1.0	0. 25465	-3.35716	
3.0	0.19720	-3.34100	

when $S = 1.0$. Figure 7 indicate effects of solutal stratification ($\epsilon = 0.01, 0.09$) on velocity $f(\eta)$, and concentration $\varphi(\eta)$, with Suction parameter, S. The velocity $f(\eta)$, fluctuate with increase in the suction strength. The concentration $\varphi(\eta)$ of heat transfer rate for all nanofluids decrease with increase in suction parameter *S*. For the heat transfer with low the electric field and increased of magnetic field, it will decrease but increased with high solutal stratification. This implies that the suction is dominated on the transfer of heat. Table 6 displays the reaction of thermophoresis, *Nt*. The reaction indicates an increase in thermophores led to an increase in the velocity and concentration. The solutal stratification parameter layer shows more significant effect on the

Table 3. The effect of solutal stratification with the impact of Buoyancy, Nr. ..

Nr	$f(\eta)$	$\varphi(\eta)$	Solutal
0.0	0.48577	-3.35674	
0.3	0.42098	-3.34578	$\epsilon_1 = 0.01$
0.6	0.35565	-3.33451	
0.9	0.32936	-3.59215	
0.0	0.36732	-3.34726	
0.3	0.30360	-3.33884	$\epsilon_2 = 0.9$
0.6	0.23948	-3.33025	
0.9	0.17497	-3.32150	

Table 4. The effect of solutal stratification with the impact of Brownian motion, Nb

Nr	$f(\eta)$	$\varphi(\eta)$	Solutal
0.1	0.25733	-1.18305	
0.3	0.34408	-3.00914	$\epsilon_1 = 0.01$
0.5	0.30091	-3.36469	
0.9	0.42384	-3.70088	
0.1	0.16381	-1.48239	
0.3	0.23536	-3.04475	$\epsilon_2 = 0.9$
0.5	0.25465	-3.35716	
0.9	0.27438	-3.55408	

Table 5. The effect of solutal stratification with the impact of suction, S.

S	$f(\eta)$	$\varphi(\eta)$	Solutal
0.0	0. 36013	-0.66318	
0.5	0. 38163	-1.92811	$\epsilon_1 = 0.01$
1.0	0. 36715	-3.36469	
2.0	0. 31272	-6.38937	
0.0	0. 20994	-1. 52969	
0.5	0. 25366	-1.84713	$\epsilon_2 = 0.9$
1.0	0. 22368	-0.75396	
2.0	0. 22303	-6.50455	

Table 6. The effect of solutal stratification with the impact of thermophoresis, Nt., .

Nt	$f(\eta)$	$\varphi(\eta)$	Solutal
0.0	0. 37360	-3.68200	
0.2	0. 37448	-3.51883	$\epsilon_1 = 0.01$
0.5	0. 37749	-3.33830	
0.8	0. 41573	-3.58333	
0.0	0. 26417	-3.65162	
0.2	0. 26241	-3.50751	$\epsilon_2 = 0.9$
0.5	0. 26090	-3.33313	
0.8	0. 26090	-3.33313	

thermophores solutal stratification parameter. The circulation in the presence of solutal stratification $\epsilon_1, \epsilon_2 = 0.01, 0.9$ is presented in Figure 8. The velocity, $f(\eta)$, slightly increase with increase in the thermophore's strength. The concentration $\varphi(\eta)$ of heat transfer rate for all nanofluids increase with an increase in the thermophores parameter. The profile also displays the rate of heat transfers MHD nanofluid.

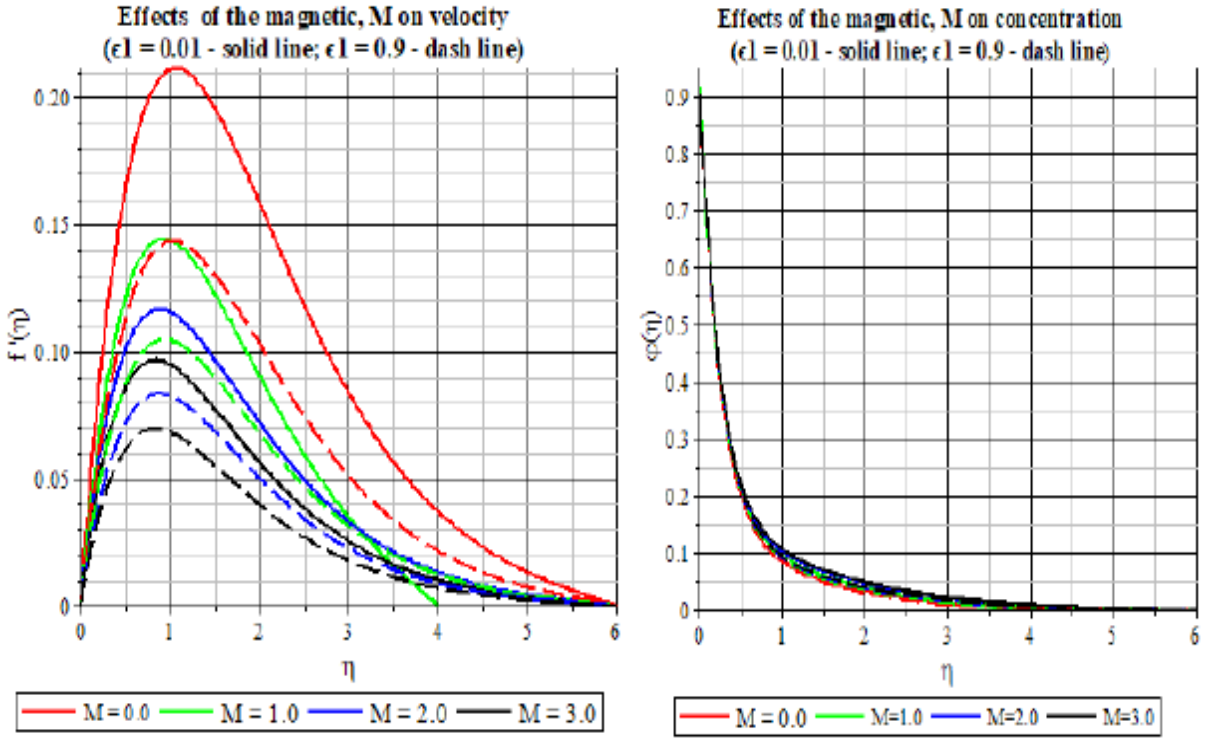

Figure 3. Solutal stratification on v velocity $f(\eta)$, and concentration $\varphi(\eta)$, of the nanofluid with Magnetic parameter M.

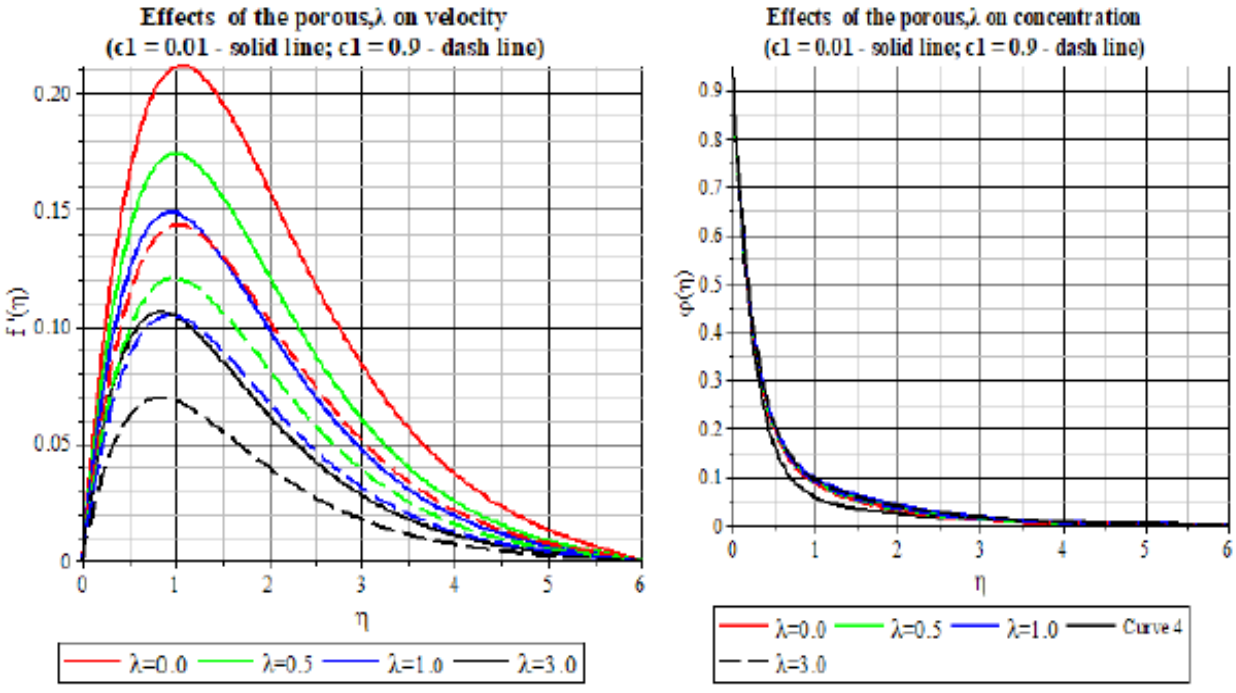

Figure 4. Effect of solutal stratification on velocity $f(\eta)$, and concentration $\varphi(\eta)$, of the nanofluid with porous, λ.

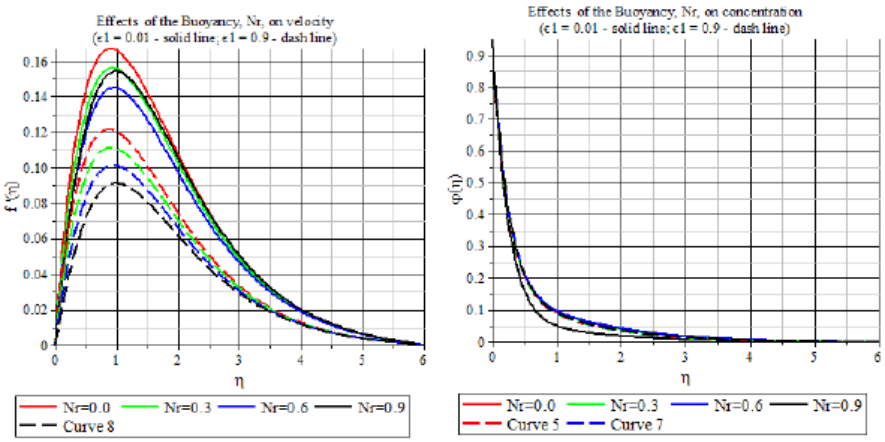

Figure 5. Effect of solutal stratification on velocity $f(\eta)$, and concentration $\varphi(\eta)$ of the nanofluid, with Buoyancy, Nr.

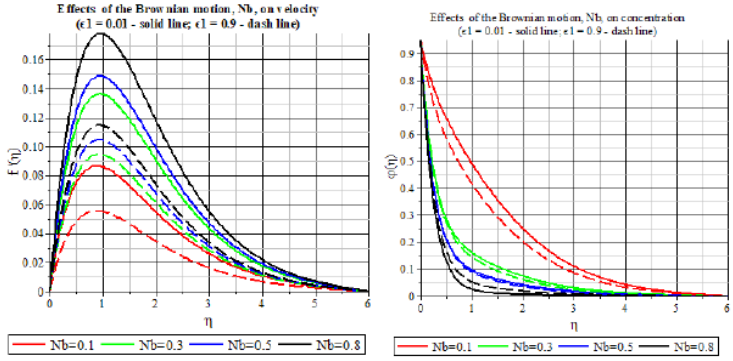

Figure 6. Effect of solutal stratification on velocity $f(\eta)$, and concentration $\varphi(\eta)$, of the nanofluid with Brownian motion, Nb.

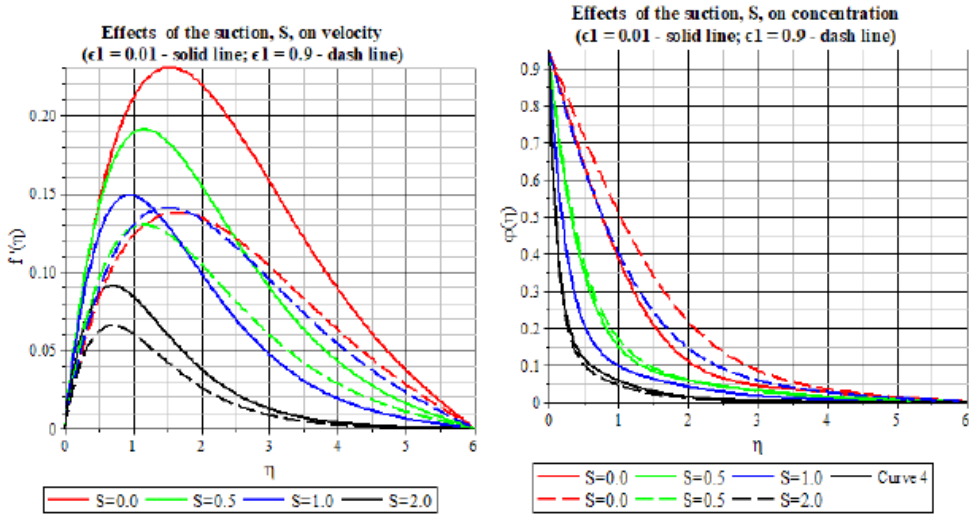

Figure 7. Effect of solutal stratification on velocity $f(\eta)$, and concentration $\varphi(\eta)$, of the nanofluid with Suction parameter, S.

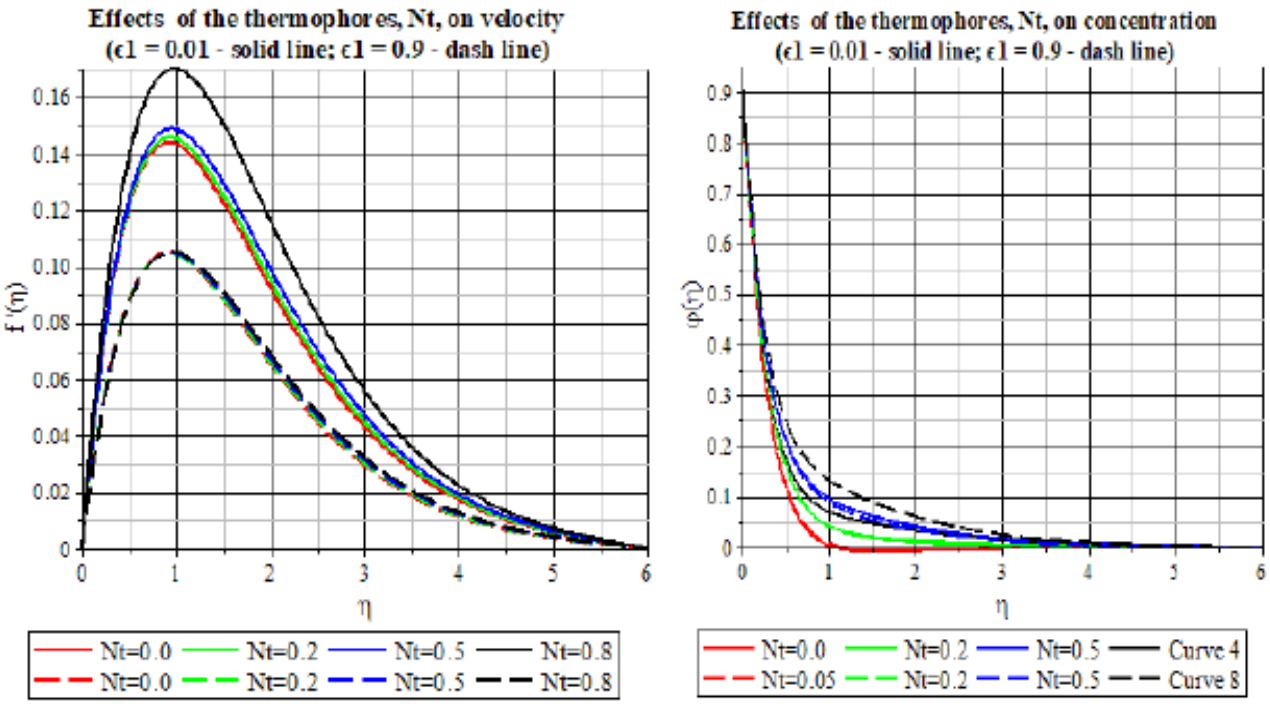

Figure 8. Effect of solutal stratification on velocity $f(\eta)$, and concentration $\varphi(\eta)$, of the nanofluid with thermophores parameter, Nt.

Conclusion

This paper presented a solutal stratification on MHD water base nanofluid. The governing nonlinear PDEs were modeled and then simplified with the aid of suitable similarity transformations into ODEs. Well known numerical algorithm Runge–Kutta–Fehlberg method of order fourth/fifth was utilized to solve the system. Concrete graphical and table analysis was also carried out to investigate the behavior of different pertinent parameters on both velocity, $f(\eta)$, and concentration, $\varphi(\eta)$, profile with inclusive discussion. Numerical influence of magnetic field, porous, thermophoresis, Brownian motion, Buoyancy and suction are also discussed. Due to the mixed effect of permeability of the porous medium and the kinematic viscosity of the nanofluid, it is shown that the velocity of the nanofluid decreases and the concentration of the nanofluid increases with increase in porosity. Therefore, the solutal stratification of the nanofluid alongside of high strength of magnetic field is applicable to transport mechanism. This application, however include the use of conservation of the principle law of diffusion energy with the Fick and thermodynamic of diffusion. This application has however attracted various interests in thermal application, such as heating of water, application of air-conditioning, active and passive solar heating, cooling capacities (Kandasamy et al., 2018).

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Nomenclature

B_0	Flux density for the magnetic $kgs^{-2}A^1$,		**Greek symbols and subscripts**
A, B	Non-negative constant s^{-1}	α	Thermal diffusivity m^2s^{-1},
C	Volume fraction of the nanoparticle K,	β	Thermal expansion coefficient
C_w	Volume fraction of the wall nanoparticle K,	K^{-1}	Density of the base fluid, kgm^{-3},
C_∞	Volume fraction far away from the wall nanoparticle K,	ρ	Heat capacitance of the nanofluid Jkm^2K^{-1},
$C_{\infty,0}$	Volume fraction due to stratification of the nanoparticle K,	ρc_p	Electrical conductivity $\Omega^{-1}m^{-1}$,
c_p	Specific heat at constant pressure $Jkg^{-1}K^{-1}$,	σ	Dynamic viscosity of the base fluid $kgm1m^{-1}s^{-1}$,
D_B	Specific diffusivity m^2s^{-1},	μ	Thermal stratification parameter, $\frac{4Ax}{T_\infty - T_{\infty,0}} = \frac{4A}{m}\left(\frac{s^{-1}}{s^{-1}}\right)$
D_T	Thermophoresis diffusion coefficient, m^2s^{-1},	ϵ_1	Solutal stratification parameter, $\frac{4Bx}{C_\infty - C_{\infty,0}} = \frac{4B}{m}\left(\frac{s^{-1}}{s^{-1}}\right)$
K	Permeability of the porous medium m^2,	v	Dynamic viscosity, m^2s^{-1}
k	Thermal conductivity of the base fluid $kgms^2K^{-1}$,	λ	Porous parameter, $\frac{vL}{ku_w}\left(\frac{m^2s^{-1}m}{m\,m^2s^{-1}}\right)$
Le	Lewis number, $\frac{v}{D_B}\left(\frac{m^2s^{-1}}{m^2s^{-1}}\right)$	Ω	Resistance $kgm2s^{-3}A^{-2}$,
M	Magnetic parameter, $\frac{\sigma B_0^2 L^2}{\mu R a_x^{\frac{1}{2}}}\left(\frac{a^{-1}m^1(kgs^2A^1)^{-2}m^2}{kgm^{-1}s^1}\right)$	Ψ	Dimensionless stream function
Nb	Brownian motion parameter $\frac{(\rho c)_p D_B (C_\infty - C_{\infty,0})}{(\rho c)_f \alpha}\left(\frac{Jm^{-3}k^{-1}m^2s^{-1}}{kgm^{-3}k^{-1}kk}\right)$	η	Similarity variable
Nr	Buoyancy ratio, $\frac{(\rho_p - \rho_{f\infty})(C_\infty - C_{\infty,0})}{\rho_{f\infty}\beta(T_\infty - T_{\infty,0})(1 - C_{\infty,0})}\left(\frac{kgm^{-3}k}{kgm^{-3}k^{-1}kk}\right)$	f	Dimensionless stream function
Nt	Thermophoresis parameter, $\frac{(\rho c)_p D_T (T_\infty - T_{\infty,0})}{(\rho c)_f \alpha T_{\infty,0}}\left(\frac{Jm^{-3}k^{-1}m^2s^{-1}k}{Jm^{-3}k^{-1}m^2s^{-1}k}\right)$	θ, φ	Dimensionless stream function
Pr	Prandtl number $\frac{v}{\alpha} = \left(\frac{m^2s^{-1}}{m^2s^{-1}}\right)$	γ	Volume fraction
T	Temperature of the fluid K,		
T_w	Temperature of the wall K,		
T_∞	The temperature of the fluid far away from the wall K,		
$T_{\infty,0}$	The temperature of the fluid due to stratification K,		
$x; y$	Stream wise coordinate and cross-stream coordinate m,		
$u; v$	Velocity components in x and y direction ms^{-1},		
V_0	Velocity of suction/injection ms^{-1},		