International Journal Of Scientific & Engineering Research Volume 9, Issue 8, August -2018
ISSN 2229-5518

Free Convection Flow and Heat Transfer of a Nano Fluid over a Porous Plate in a Darcy-Forccheimer Flow

Ramonu O.J[1], Alerechi L.W[2], Akinyemi T.O[3]

Abstract - A free convection flow and heat transfer of nanofluid over a porous plate in a Darcy-Forccheimer flow has been investigated. The governing partial differential equations are transformed into a system of ordinary differential equations using similarity transformation method and solved numerically using the Runge-Kutta fourth order alongside shooting technique. The influences of solutal Grashof number *Gm*, thermal Grashof number *Gr*, Brownian motion *Nb*, Lewis number Le and Thermophoresis *Nt* on the temperature, velocity and concentration distribution are investigated and the results are illustrated graphically. The reduced local Nusselt number and the reduced local Sherwood numbers are presented and compared with existing related studies; the comparisons are in excellent agreement.

Keywords: Darcy-Forccheimer, Free Convection, Heat Transfer, Nanofluid, Porous plate, Runge-Kutta, Grashof number.

1 INTRODUCTION

Nanofluid is an enhanced type of fluid made up of a two phase mixture prepared by dispersing nanometer sized materials in conventional or base fluids. The nanometer sized materials could be nanoparticles, nanowires, nanorods, nanotubes or nanofibers while the base fluids could be water, oils, biofluids, lubricants, organic liquid (refrigerants, glycols, ethylene or polymeric solutions) and common liquids. The combination of any of the above distinct materials and a base fluid yields a Nanofluid. Materials generally used as nanoparticles include metal oxides (e.g., alumina, silica, titania), oxide ceramics (e.g. Al_2O_3, CuO), chemically stable metals (e.g. gold, copper), carbon in various forms (e.g., diamond, graphite, carbon nanotubes, fullerene), metal carbides (e.g. SiC) and functionalized nanoparticles. Nanofluids are said to possess enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared to those of base fluids like oil or water. Wei and Huaqing[1].

• *Ramonu O.J. completed his master degree program in Mechanical Engineering (Thermo-Fluid Option) in the University of Ibadan, Nigeria. He is a lecturer at Federal Polytechnic, Ilaro, Ogun State, Nigeria. +2348107297152, E-mail: yinkard4mee@gmail.com*
•*Alerechi L.W completed his master degree program in Mechanical Engineering (Thermo-Fluid Option) in the University of Ibadan, Nigeria. He is a lecturer at Ignatius Ajuru University of Education, Port Harcourt, Rivers state. Nigeria. +2348036902675, E-mail:alerechilucky@gmail.com*
• *Akinyemi T.O. completed his master degree program in Mechanical Engineering (Thermo-Fluid Option) in the University of Ibadan, Nigeria. He is a lecturer at ESEP-LE BERGER Universite, Cotonou. +2347068364389, E-mail: engrtolu@gmail.com*

Choi [2] pioneered the proposition that fluids with nano particles suspended in them can be referred to as Nanofluids and concluded that they can be the next generation heat transfer fluids because they offer exciting new possibilities that can enhance heat transfer performance compared to pure liquids. Keblinski et al. [3] and Wang and Mujumdar[4] findings reveals that nanofluids can have significantly better heat transfer characteristics than the conventional fluids but this possibility is dependent upon the type, size and concentration of nanoparticles and the nanofluids transport through a porous media.
Xuan and Li [5] examined possible reasons for the improved effective thermal conductivity of nanofluids and highlighted four reasons which are the increased surface area due to suspended nanoparticles, the interaction and collision among particles, the intensified mixing fluctuation and turbulence of the fluid, and the dispersion of nanoparticles. Xuan and Roetzel [6] carried out a research which was the first to indicate a mechanism for heat transfer in nanofluids. They were able to propose thermal dispersion as a major mechanism of heat transfer in flowing fluid, as well as enhanced nanofluid thermal conductivity. However, no evidence was presented to support their conclusions.On the other hand, Eastman et al. [7] examined that with less than1% volume fraction of CuO, the convection heat transfer rate increased by more than 15% in water. Sun and Pop [8] examined the numerical solution of steady-state free convection heat transfer behaviour of nanofluids inside a triangular enclosure saturated by a porous media and they observed that the heat transfer rate

International Journal Of Scientific & Engineering Research Volume 9, Issue 8, August -2018
ISSN 2229-5518

increases with increased nanoparticle volume concentration at a low Rayleigh number, an opposite trend was discovered for a high Rayleigh number while Khan et al. [9] studied the free convection of nanofluids along a vertical plate in a porous media. In their own study, Servati et al. [10] numerically examined the forced convective MHD flow of a nanofluid in a channel partially filled with porous media. The steady mixed convection boundary layer flow of nanofluids past a vertical flat plate embedded in porous media was investigated by Ahmad and Pop [11] while Chamkha and Ismael [12] were able to conduct a numerical study to solve the problem of differentially heated and partially layered vertical porous cavity filled with a nanofluid on free convection, this was the first time such a numerical study was carried out and they applied the Darcy-Brinkman model. Falana and Ramonu [13], studied the effects of viscous dissipation and thermal radiation on an unsteady MHD boundary layer flow due to stretching sheet and heat transfer. Xuan and Li [14] found that heat transfer by forced convection is enhanced in nanofluids and concluded that much of this enhancement has to do with the type of nanoparticles used; cinvective studies were performed by them with oxide nanoparticles with results showing a moderately enhanced conductivity and increasing viscosity at the same time. The study concluded that the real advantage is expected in metallic nanofluids, which due to its high enhancement rate, require only a small volume fraction (<1%) that will keep viscosity almost unaffected but increase the heat transfer. Seddeek [15] studied mixed convection flow in view of Darcy-Forchheimer relation.

Pal and Mondal [16] examined hydromagnetic Darcy-Forchheimer flow of variable viscosity liquid while Sadiq and Hayat [17] investigated Darcy-Forchheimer flow of magneto Maxwell liquid bounded by a convectively heated sheet. Effects of internal heat generation, viscous dissipation and thermal radiation on an unsteady hydromagnetic flow past a stretching surface embedded in a porous medium was examined by Odunlami and Ramonu [18], the study concluded that there is a significant increase in the thermal boundary thickness and boundary layer temperature distribution with an increase in the radiation parameter. Umavathi et al. [19] performed numerical analysis of natural convective flow of nanofluids in a vertical rectangular duct using Darcy-Forchheimer-Brinkman model. Hayat et al. [20a] provided a comparative study for Darcy-Forchheimer flow of viscoelastic nanofluids and Recently Hayat et al. [20b] also discussed Darcy-Forchheimer flow of viscoelastic fluids with Cattaneo-Christov heat flux and homogeneous-heterogeneous reactions. Ramonu and Odunlami investigated the combined influence of Brownian motion, Thermophoresis and Lewis number on boundary layer flow of a nanofluid, they concluded that increase in the Thermophoresis parameter and Brownian motion parameter increases the temperature profile.

Nanofluids can be used to improve heat transfer and energy efficiency in a variety of thermal systems. This implies its great importance as a cooling fluid in many applications such as Engine cooling, Nuclear cooling system, Cooling of electronic circuit, Refrigeration, Enhancement of heat transfer exchange, Thermal storage, Biomedical application, Cooling of microchips, In defense and space application, Transportation, Petroleum industry, Inkjet printing, Environmental remediation, Surface coating, Fuel additives and Lubricant.

2 MATHEMATICAL ANALYSIS

Here, consideration is given to a steady, laminar, incompressible and two dimensional boundary layer free convection flow and heat transfer of a nanofluid over a porous plate embedded in a porous medium. The x-axis is taking along the surface of the porous plate and the y-axis perpendicular to it. The temperature Tw and concentration Cw on the surface of the plate are kept constant, and assumed to be greater than the ambient temperature and concentration, $T\infty$ and $C\infty$, respectively.

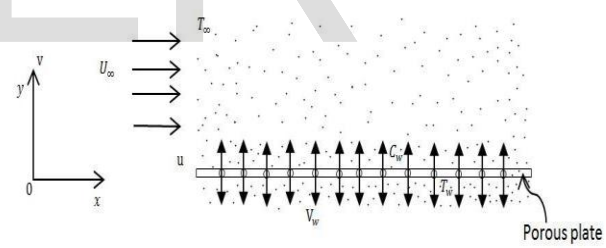

Fig. 1. Geometry of the physical model

The governing equations for the conservation of mass, momentum which is based on the Darcy-Forchheimer model, thermal energy and nanoparticle concentration are expressed as follow:

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu \frac{\partial^2 u}{\partial y^2} - \frac{\nu}{K}(u - u_\infty) - \frac{K^*}{\sqrt{K}}(u^2 - u_\infty^2) + g\beta\,(T - T_\infty) + g\beta^*\,(C - C_\infty) \qquad (2)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left[D_B \frac{\partial C}{\partial y}\left(\frac{\partial T}{\partial y}\right) + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right] \qquad (3)$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\left(\frac{\partial^2 C}{\partial y^2}\right) + \frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial y^2}\right) \qquad (4)$$

International Journal Of Scientific & Engineering Research Volume 9, Issue 8, August -2018
ISSN 2229-5518

Where u and v are the velocity components in the x and y directions respectively, $u\infty$ is the free stream velocity, μ is the viscosity, T is the temperature of the nanofluid, C is the concentration of the nanofluid, Tw is the temperature along the porous plate, Cw is the concentration along the porous plate, $T\infty$ and $C\infty$ are the ambient temperature and concentration respectively, $\upsilon=\frac{\mu}{\varrho}$ is the kinematic viscosity, Gm is the solutal Grashof number, Gr is the thermal Grashof number, $\kappa=k_0 x$ is the Darcy permeability of the porous medium, D_B is the Brownian motion coefficient, D_T is the thermophoresis coefficient, k is the thermal conductivity, $(\rho c)p$ is the heat capacitance of the nanoparticles, $(\rho c)f$ is the heat capacitance of the base fluid, $\alpha=\frac{k}{(\varrho c)f}$ is the thermal diffusivity, $\tau=\frac{(\varrho c)p}{(\varrho c)f}$ is the ratio between the heat capacitance of the nanoparticles and the heat capacitance of the base fluid.

With the associated boundary conditions:

At y = 0

$$u = 0\,; v = 0; T = T_w\,;\, C = \boldsymbol{C_w} \tag{5}$$

At $y \to \infty$

$$u \to u_\infty;\ T \to T_\infty\,;\ C \to \boldsymbol{C_\infty} \tag{6}$$

Further, we seek for a similarity solution of Equations (1) to (4) subject to the boundary conditions (5) and (6). The governing partial differential forms can be solved by converting them to ordinary differential equations; this is done by using similarity functions:

$$\Psi(x,y) = \sqrt{u_\infty v x}\, f(\eta)$$

and

$$\eta = \left({}^{y}/_{x}\right)(Re_x)^{\frac{1}{2}} = y\left(\frac{u_\infty}{vx}\right)^{\frac{1}{2}}$$

$$\theta(\eta) = \left(\frac{T - T_\infty}{T_w - T_\infty}\right) \quad \phi(\eta) = \left(\frac{C - C_\infty}{C_w - C_\infty}\right) \tag{7}$$

where the free stream function $\Psi(x,y)$ *defined by* ;

$$U = \frac{d\Psi}{dy}\ ;\ V = -\frac{d\Psi}{dx} \tag{8}$$

Applying these similarity variables on the governing partial differential equations, transformed conservation equations and boundary conditions are then obtained as follows

$$f''' + \frac{1}{2} f f'' - K_1(f' - 1) - K_2[(f')^2 - 1] + Gr_x\theta + Gm_x\phi = 0 \tag{9}$$

$$\frac{\theta''}{Pr} + Nb\phi'\theta' + Nt(\theta')^2 + \frac{1}{2} f\theta' = 0 \tag{10}$$

$$\phi'' + \frac{Nt}{Nb}\theta'' + \frac{Le}{2} f\phi' = 0 \tag{11}$$

The boundary conditions:

$$\eta = 0,\ f'(0) = 0, f(0) = 0, \theta(0) = 1, \phi(0) = 1 \tag{12}$$

At $y \longrightarrow \infty$

$$\eta \longrightarrow \infty, f'(\infty) \longrightarrow 1, \theta(\infty) \longrightarrow 0, \phi(\infty) \longrightarrow 0 \tag{13}$$

However, the quantities of physical and engineering interest are the skin friction coefficient, reduced Nusselt number and reduced Sherwood number:

Having the knowledge of the velocity field, the skin-friction at the plate is obtained in a non-dimensional form and given by

$C_f\ Re_x^{\frac{1}{2}} = f''(0)$,

Also, with the knowledge of the temperature field, the rate of heat transfer coefficient can be obtained, which is in a non-dimensional form, in terms of the Nusselt number, and given by

$Nu_x = -Re_x^{\frac{1}{2}}\theta'(0)$,

Having the knowledge of the concentration field, the rate of mass transfer coefficient can be obtained, which is in a non-dimensional form, in terms of the Sherwood number, is given by

$Sh_x = -Re_x^{\frac{1}{2}}\ \phi'(0)$.

3 NUMERICAL METHOD FOR SOLUTION

The set of coupled non-linear governing boundary layer equations together with boundary conditions are solved numerically by using Runge-Kutta fourth order technique along with shooting method. The higher order non-linear differential equations are converted into first order simultaneous linear differential equations which are further transformed into initial value problem by applying the shooting technique and the resultant initial value problem is solved by employing Runge-Kutta fourth order method.

$f = y_1,\quad f' = y_2,\quad f'' = y_3,$

$\theta = y_4,\quad \theta' = y_5, \phi = y_6, \phi' = y_7$

$f' = y_1' = y_2,$

$f'' = y_2', = y_3$

$f''' = y_3'$ and

$\theta' = y_4' = y_5, \phi' = y_6' = y_7$

International Journal Of Scientific & Engineering Research Volume 9, Issue 8, August -2018
ISSN 2229-5518

4. RESULTS AND DISCUSSION

The transformed non linear equations (9)-(11) subjected to the boundary conditions (12) and (13) was solved numerically using the Runge Kutta fourth order algorithm which is implemented in MATLAB as an m-file in the form of ode with f ″(0) and θ′(0) chosen a prior until the boundary conditions at infinity are satisfied. Resulting from the numerical calculations, the temperature profile, velocity profile and the nanoparticle concentration distribution for the fluid flow being considered are obtained with their behaviours discussed for varying governing parameters of interest which are solutal Grashof number *Gm*, thermal Grashof number *Gr*, Thermophoresis parameter N_t, Brownian motionN_b, permeability parameter K_1, Lewis number Le, and Prandtl number Pr. Table 1: shows the numerical values of reduced Nusselt number Nu and reduced Sherwood number Sh for various values of Nt and Nb to validate the present study with existing literatures by Khan and Pop [21], Makinde and Aziz [22] The comparison is found to be in excellent agreement.

Table 1: Comparisons of results for reduced Nusselt number $-\theta'(0)$ and reduced Sherwood number$-\boldsymbol{\phi}'(\mathbf{0})$ with $\boldsymbol{Le}$=$\boldsymbol{Pr}$=**10**, K_1= K_2= **0**

Nb	Nt	**Makinde andAziz [22]**		**Khan and Pop [21]**		**Present Study**	
		$-\theta'(0)$	$-\boldsymbol{\phi}'(\mathbf{0}$	$-\theta'(0)$	$-\boldsymbol{\phi}'(\mathbf{0}$	$-\theta'(0)$	$-\boldsymbol{\phi}'(\mathbf{0}$
0.1	0.1	0.9524	2.1294	0.9524	2.1294	0.9523	2.1294
0.2	0.1	0.5056	2.3819	0.5056	2.3819	0.5055	2.3819
0.3	0.1	0.2522	2.4100	0.2522	2.4100	0.2522	2.4100
0.4	0.1	0.1194	2.3997	0.1194	2.3997	0.1194	2.3997
0.5	0.1	0.0543	2.3836	0.0543	2.3836	0.0543	2.3836

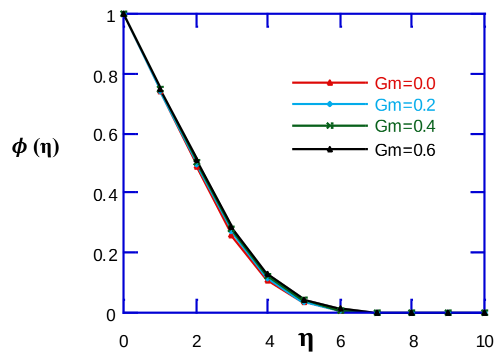

Fig.3 Concentration distribution for various values of G_m when Nt=Nb=Nt/Nb=0.1,K_1=0.1andK_2=0.1,Le=0.5,Gr=0.5,Pr= 0.7

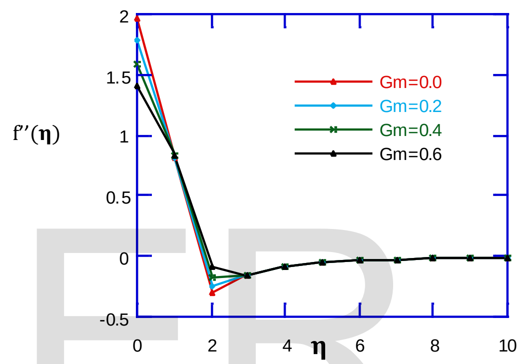

Fig.4 Skin friction for various values of G_m when Nt=Nb=Nt/Nb=0.1,K_1=0.1andK_2=0.1,Le=0.5,Gr=0.5,Pr=0.7

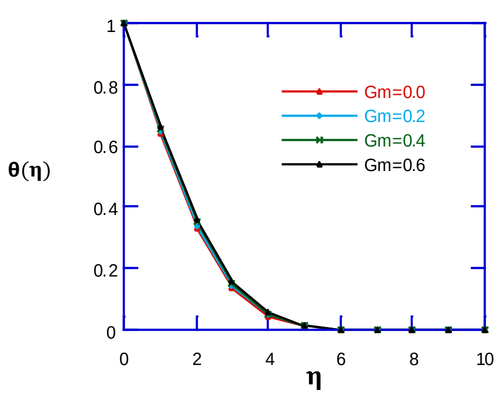

Fig. 2 Temperature Profile for various values of G_m when Nt=Nb=Nt/Nb=0.1,K_1=0.1andK_2=0.1,Le=0.5,Gr=0.5,Pr=0.7

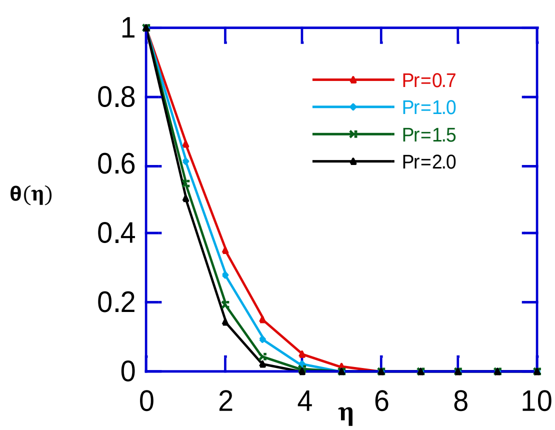

Fig. 5 Temperature Profile for various values of Pr when Nt=Nb=Nt/Nb=0.1,K_1=0.1andK_2=0.1,Le=0.5,Gr=0.5, G_m=0.5

International Journal Of Scientific & Engineering Research Volume 9, Issue 8, August -2018
ISSN 2229-5518

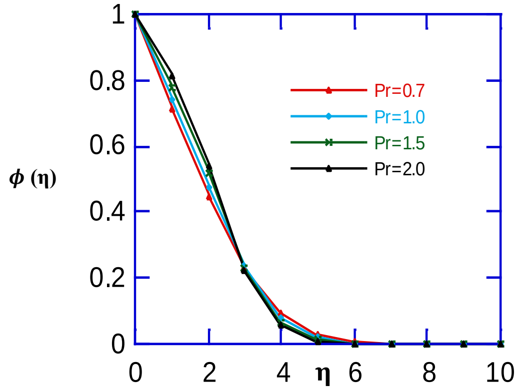

Fig.6 Concentration distribution for various values of Pr when Nt=Nb=Nt/Nb=0.1,K_1=0.1andK_2=0.1,Le=0.5,Gm=0.5, G_r=0

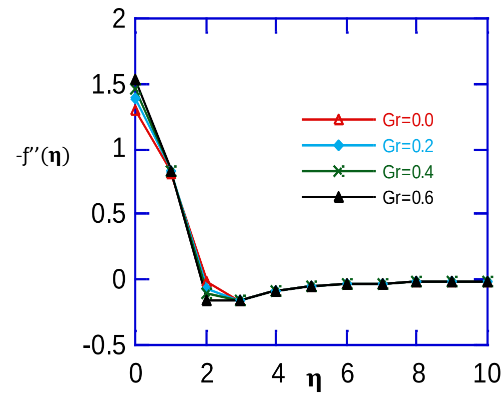

Fig.9 Skin friction for various values of G_r when Nt=Nb=Nt/Nb=0.1,K_1=0.1andK_2=0.1,Le=0.5,Gm=0.5,Pr=0.7

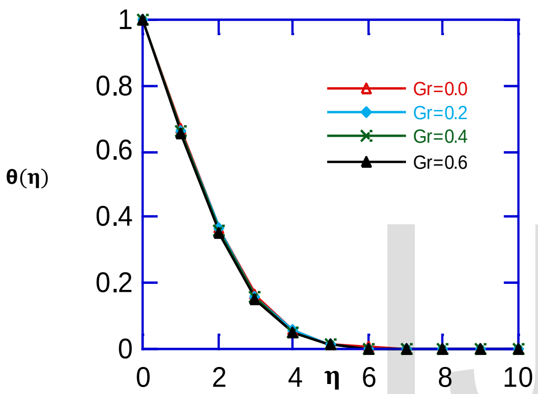

Fig.7 Temperature Profile for various values of G_r when Nt=Nb=Nt/Nb=0.1,K_1=0.1andK_2=0.1,Le=0.5,Gm=0.5,Pr=0.7

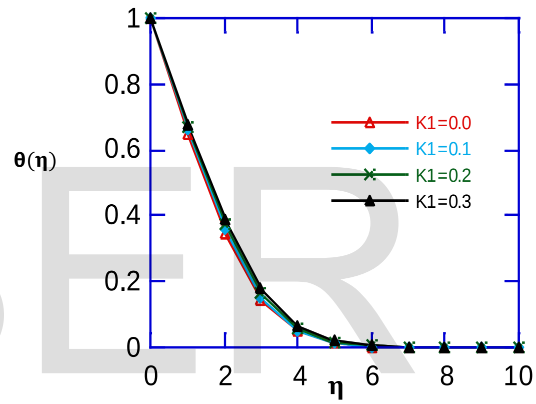

Fig.10 Temperature Profile for various values of K_1 when Nt=Nb=Nt/Nb=0.1, G_r =0.5andK_2=0.1,Le=0.5, G_m=0.5,Pr=0.7

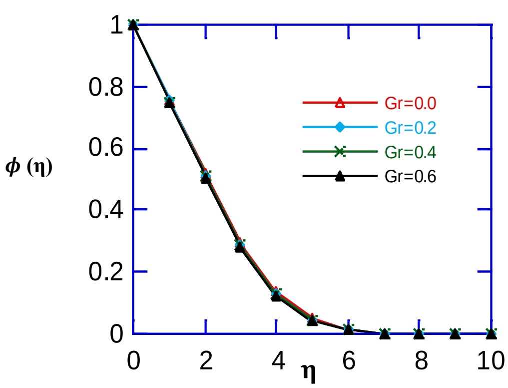

Fig.8 Concentration distribution for various values of G_r when Nt=Nb=Nt/Nb=0.1,K_1=0.1andK_2=0.1,Le=0.5,Gm=0.5,Pr=0.7

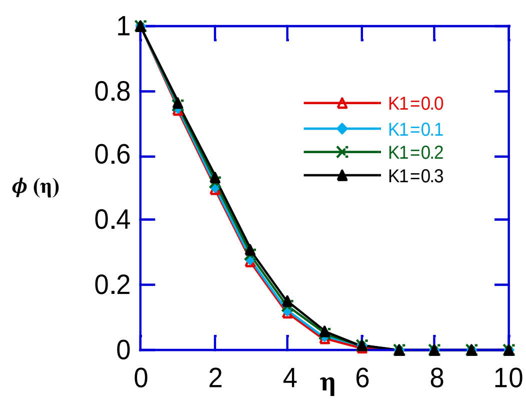

Fig.11 Concentration distribution for various values of K_1 whenNt=Nb=Nt/Nb=0.1, G_r=0.5andK_2=0.1,Le=0.5, G_m =0.5,Pr=0.7

International Journal Of Scientific & Engineering Research Volume 9, Issue 8, August -2018
ISSN 2229-5518

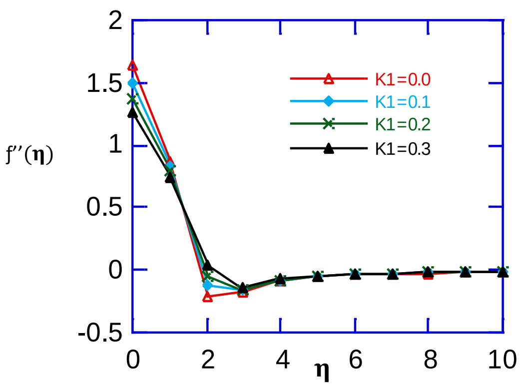

Fig.12 Skin friction for various values of K_1 when Nt=Nb=Nt/Nb=0.1, G_r =0.5andK_2=0.1,Le=0.5, G_m=0.5,Pr=0.7

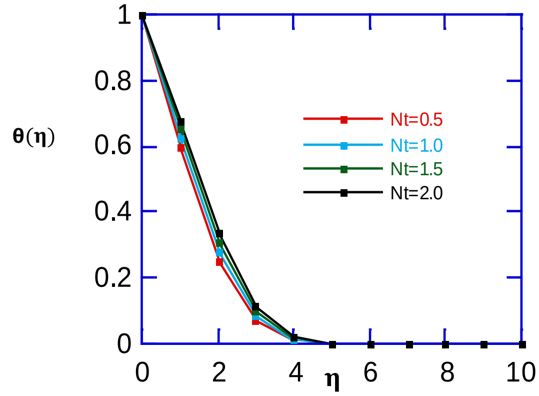

Fig.15 Temperature profile for various values of N_t when Nb=Nt/Nb=0.1, G_r =0.5,$K_1 = 0.1$, K_2=0.1,Le=0.5, G_m=0.5,Pr=0.7

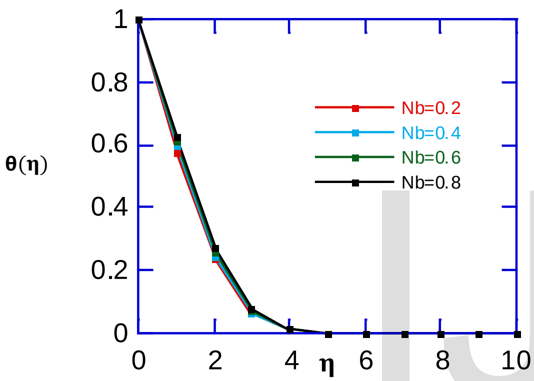

Fig.13 Temperature profile for various values of N_b when Nt=Nt/Nb=0.1, G_r =0.5,$K_1 = 0.1$, K_2=0.1,Le=0.5, G_m=0.5,Pr=0.7

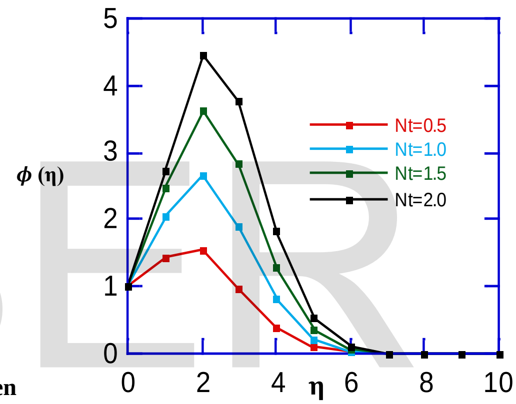

Fig.16 Concentration distribution for various values of N_t when Nb=Nt/Nb=0.1, G_r =0.5,$K_1 = 0.1$, K_2=0.1,Le=0.5, G_m=0.5,Pr=0.7

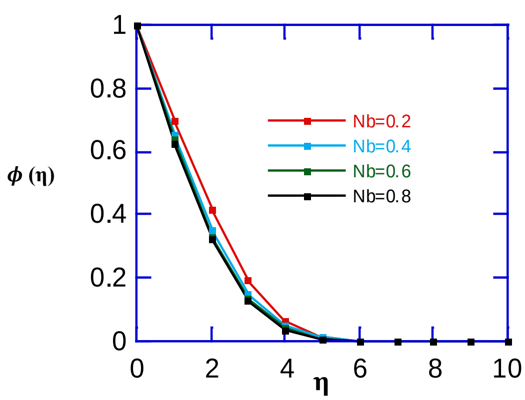

Fig.14 Concentration distribution for various values of N_b when Nt=Nt/Nb=0.1, G_r =0.5,$K_1 = 0.1$, K_2=0.1,Le=0.5, G_m=0.5,Pr=0.7

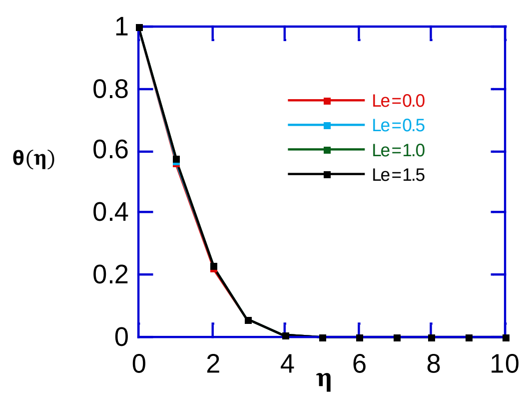

Fig.17 Temperature profile for various values of Le when Nb= N_t =Nt/Nb=0.1, G_r =0.5,$K_1 = 0.1$, K_2=0.1, G_m=0.5,Pr=0.7

International Journal Of Scientific & Engineering Research Volume 9, Issue 8, August -2018
ISSN 2229-5518

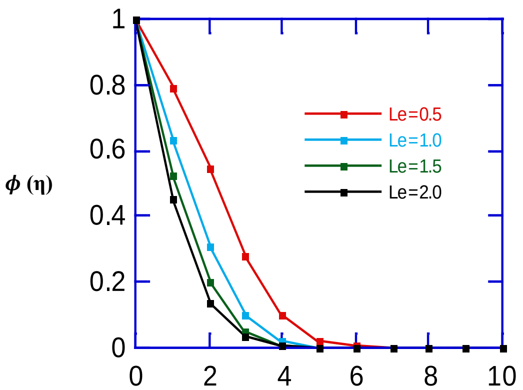

Fig.18 Concentration distribution for various values of when Le Nb= N_t =Nt/Nb=0.1, G_r =0.5,$K_1 = 0.1$, K_2=0.1, G_m=0.5,Pr=0.7

Fig.2 indicates that an increase in solutal Grashof number *Gm* result to an increase in the temperature profile while fig.3 also illustrates that increasing solutal Grashof number *Gm*, increases the concentration distribution. It is observed in Fig.4 that the skin friction increases with solutal Grashof number *Gm*. Fig.5 shows the influence of the Prandtl number Pr on the nanofluid temperature distribution. It indicates that the temperature distribution decreases with an increase in Prandtl number Pr; since a large Prandtl number, implies a small thermal diffusivity which in turn reduces the thermal boundary layer thickness while fig.6 illustrates an increase in the concentration distribution as Prandtl number Pr increases.

Likewise, the effects of thermal Grashof number *Gr* on the temperature profile, concentration distribution and skin friction are illustrated in fig.7 to fig.9 respectively; it is observed that increasing the thermal Grashof number *Gr* increases the temperature profile, concentration distribution and skin friction.

It observed in fig.10 that as the permeability parameter K_1 increases, the temperature profile decreases while fig.11 also indicates that increasing permeability parameter K_1 decreases the nanofluid concentration distribution. Fig.12 illustrates the influence of permeability parameter K_1 on skin friction; it is observed that the skin friction increases with increasing permeability parameterK_1.

It is illustrated in fig.13 that as the Brownian motion parameter N_b increases, the temperature gradient magnitude at the wall decreases. This implies that an increase in Brownian motion parameter N_b increases the temperature profile while fig.14 illustrates a decrease in the concentration distribution as Brownian motion parameter N_b increases.

Fig.15 indicates that increasing the Thermophoresis parameter N_t result to an increase in the boundary layer thickness and in turn increases the temperature profile while fig.16 also illustrate an increase in the concentration boundary layer thickness with an increase in Thermophoresis parameter N_t.

Fig.17 shows that increasing the Lewis number Le results in a small decrease in the temperature profile while fig.18 also indicates a decrease in concentration distribution as the Lewis number Le increases, which is as a result of a smaller molecular diffusivity as the Lewis number Le increase and in turn decreases the concentration distribution.

5. CONCLUSION

This study has numerically analyzed free convection flow and heat transfer of a nanofluid over a porous plate in a Darcy-Forchheimer flow. Applying the similarity transformation method, the governing partial differential equations are transformed into non-linear ordinary differential equations and the resulting equation is solved using Runge-Kutta fourth order method alongside shooting method. The effects of the governing parameters on the flow have been investigated. The following conclusions are drawn from the analysis:

1. It is observed that increasing the thermal Grashof number *Gr* and the solutal Grashof number *Gm* increase the temperature profile, concentration distribution and the skin friction.
2. The result indicates that as the permeability parameter K_1 increases, the temperature profile decreases while the skin friction increases
3. The temperature profile increases with the Brownian motion parameter N_b and the Thermophoresis parameter
4. Increase in Brownian motion parameter N_b decreases the concentration distribution and increases with the Thermophoresis parameter

REFERENCES

[1] Wei Yu andHuaqing Xie: "A Review on Nanofluids: Preparation, StabilityMechanismsand Applications", Hindawi Publishing Corporation, Journal of Nanomaterials Volume Article ID 435873, doi:10.1155/2012/435873, 2012.

[2] Choi, S. U. S:"Enhancing thermal conductivity offluids with nanoparticles; Developments andApplications of Non-Newtonian Flows", FED-Vol.231/MD-Vol. 66, 99–105 1995.

[3] Keblinski, P.; Eastman, J.; Cahill, D: Nanofluids for thermal transport. Mater. Today Vol. 8, 36–44. 2005.

International Journal Of Scientific & Engineering Research Volume 9, Issue 8, August -2018
ISSN 2229-5518
[4] Wang, X.Q and Mujumdar, A.S: Heat transfer characteristics of nanofluids: A review. Int. J. Therm. Sci. 46, 1–19. 2007

[5] Xuan, Y and Li, Q: "Heat transfer enhancement ofnanofluids". International Journal ofHeat andFluid Transfer, 21; 58–64, 2000

[6] Xuan, Y., and Roetzel, W., Conceptions for Heat Transfer Correlationof Nano-fluids, *International Journal of* Heat and MassTransfer, vol. 43, pp. 3701–3707, 2000.

[7] Eastman, J. A., Choi, S. U. S., Li, S., Soyez, G., Thompson, L. J.and DiMelfi, R. J., Novel Thermal Properties of NanostructuredMaterials, *Journal of Metastable Nanocrystalline Materials*, vol.2, pp. 629–637, 1998.

[8] Sun, Q. and Pop, I. Free convection in a triangle cavity filled with a porous medium saturated with Nanofluidswith flush mounted heater on the wall. Int. J. Therm. Sci., Vol.50, 2141–2153. 2011

[9] Khan, W and Aziz, A. Double-diffusive natural convective boundary layer flow in a porous medium saturatedwith a nanofluid over a vertical plate: Prescribed surface heat, solute and nanoparticle fluxes. Int. J.Therm. Sci. 50, 2154–2160. 2011.

[10] Servati, V.; Javaherdeh, K. and Ashorynejad, H.R: Magnetic field effects on force convection flow of a nanofluidin a channel partially filled with porous media using lattice boltzmann method. Adv. Powder Technol. 25, 666–675, 2014.

[11] Ahmad, S. and Pop, I. Mixed convection boundary layer flow from a vertical flat plate embedded in a porousmedium filled with nanofluids. Int. Commun. Heat Mass Transf. 37, 987–991, 2010

[12] Chamkha, A. J. and Ismael, M. A. Natural convection in differentially heated partially porous layered cavities filled with a nanofluid.Numer.Heat Transfer *A* **65**, 1089–1113,2014.

[13] Falana A. and Ramonu O.J, Unsteady MHD Boundary Layer Flow and Heat Transfer due to Stretching Sheet in the Presence of Thermal Radiation and Viscous Dissipation. J.Nig.Ass.Math.phys. *Vol.* 38. pp 89-98, 2016

[14] Xuan, Y., and Li, Q., Investigation on Convective Heat Transferand FlowFeatures of Nanofluids, Transactions of ASME, Journalof Heat Transfer, vol. 125, no. 1, pp. 151–155, 2003.

[15] Seddeek MA. Influence of viscous dissipation and thermophoresis on Darcy-Forchheimer mixed convectionin a fluid saturated porous media. J Colloid Interface Sci. 293: 137-142. https://doi.org/10.1016/j.jcis.2005.06.039 PMID: 16112126, 2012.

[16] Pal D and Mondal H. "Hydromagnetic convective diffusion of species in Darcy-Forchheimer porous mediumwith non-uniform heat source/sink and variable viscosity". Int Commun, Heat Mass Transfer. 39:913-917, 2012.

[17] Sadiq MA, Hayat T. Darcy-Forchheimer flow of magneto Maxwell liquid bounded by convectively heated sheet. Results Phys. 6: 884-890, 2016.

[18] Odunlami S.A. and Ramonu O.J. Effects of Internal Heat Generation and Thermal Radiation on Unsteady Hydromagnetic Flow past a Stretching Surface Embedded in a Porous Medium with Viscous Dissipation. FUW Trends in Sci. and Tech. Journal, Vol. 2 No. 2 pp. 755-760, 2017.

[19] Umavathi J.C, Ojjela O and Vajravelu K..,"Numerical analysis of natural convective flow and heat transfer ofnanofluids in a vertical rectangular duct using Darcy-Forchheimer-Brinkman model". Int. J. Thermal Sci. 111: 511-524, 2017.

[20a]Hayat T, Haider F, Muhammad T, Alsaedi A: Darcy-Forchheimer flow with Cattaneo-Christov heat fluxand homogeneous-heterogeneous reactions. Plos One. 12: e0174938. https://doi.org/10.1371/journal.pone.0174938 PMID: 28380014, 2017.

[20b]Hayat T, Haider F, Muhammad T, Alsaedi A. On Darcy-Forchheimer flow of viscoelastic nanofluids: Acomparative study. J Mol Liq. 233: 278-287, 2017.

[21] Khan W A and Pop I, "boundary layer flow of nanofluid over a stretching sheet," International journal of Heat and mass transfer, vol. 53, no. 11-12, pp. 2477-2483, 2010.

[22] Makinde O D and Aziz A, "Boundary layer flow of a nanofluid past a stretching sheet with a convective boundary condition," International Journal of Thermal Sciences, vol. 50, pp. 1326-1332, July 2011.

[23] Falana A., Alao A.A. and Oladejo O.J. Effect of Mass and Partial Slip on Boundary Layer Flow of a Nanofluid over a Porous Plate Embedded in a Porous Medium. IOSR Journal of Mechanical and Civil Engineering. 13, 42-49, 2016.