Journal of the Nigerian Association of Mathematical Physics
***Volume 29,* (*March, 2015*), pp 477 – 490**
© J. of NAMP

An Analytic Investigation of Convective Boundary-Layer Flow of a Nanofluid Past a Stretching Sheet With Radiation

Y.M. Aiyesimi, A. Yusuf and M. Jiya

Department of Mathematics and Statistics, Federal University of Technology, PMB 65, Minna, 00176-0000 Nigeria, Niger State, Nigeria.

Abstract

The solution of laminar fluid flow which results from the stretching of a flat surface in a nanofluid has been obtained using the Adomian Decomposition Method. The model used for the nanofluid was presented in its rectangular form and incorporates both the convective effect, thermal radiative effect and the effect of Brownian motion and thermomophoresis. A similarity solution is presented which depends on both thermal and concentration Grashof number Gr_T, Gr_c***, the Prandtl number Pr, Schmidt number Sc, Radiation Ra, Lewis number Le, Brownian motion number Nb and thermophoresis number Nt. In the results presented graphically it is observed that both thermal and concentration Grashof number enhance the velocity, temperature and concentration profile of the fluid.***

Key words: Adomian Decomposition Method, Nanofluid, Nanopaticles, Thermophoresis, Boundary layer, Convection, Radiation.

1.0 Introduction

"The flow over a stretching surface is an important problem in many engineering processes with applications in industries such as extrusion, melt-spinning, the hot rolling, wire drawing, glass fiber production, manufacture of plastic and rubber sheets, cooling of a large metallic plate in a bath, which may be an electrolyte, etc. In industry, polymer sheets and filaments are manufactured by continuous extrusion of the polymer from a die to a wind up roller, which is located at a finite distance away. The thin polymer sheet constitutes a continuously moving surface with anon-uniform velocity through an ambient fluid. Takhar et al.[1]. Experiments show that the velocity of the stretching surface is approximately proportional to the distance from the orifice Vleggar[2]. Crane [3] studied the steady two-dimensional incompressible boundary layer flow of a Newtonian fluid caused by the stretching of an elastic flat sheet which moves in its own plane with a velocity varying linearly with the distance from a fixed point due to the application of a uniform stress. This problem is particularly interesting since an exact solution of the two-dimensional Navier–Stokes equations has been obtained by Crane [3]. After this pioneering work, the flow field over a stretching surface has drawn considerable attention and a good amount of literature has been generated on this problem ashmisha[4]."

"In the past few years, convective heat transfer in nanofluids has become a topic of major contemporary interest. The word "nanofluid" coined by Choi [5] describes a liquid suspension containing ultra-fine particles. Masuda et al. [6]. Experimental studies show that even with small volumetric fraction of nano particles (usually less than 5%), the thermal conductivity ofthe base liquid is enhanced by 50% with a remarkable improvement in the convective heat transfer coefficient. The literature on nanofluids has been reviewed by Trisaksri and Wongwises[7], Wang and Mujumdar [8], Eastman et al. [9], and Kakac and Pramuanjaroenkij [10], among several others. These reviews discuss in detail the work done on convective transport in nanofluids. In a recent paper, Boungiorno [11] evaluated the different theories explaining the enhanced heat transfer characteristics of nanofluids. He showed that the high heat transfer coefficients in nanofluids cannot be explained satisfactorily by thermal dispersion phenomenon or increase in turbulence intensity promoted by the presence of nanoparticles or nanoparticle rotation as suggested in the literature. He developed an analytical model for convective transport innanofluids which takes into account the Brownian diffusion and thermophoresis.

Corresponding author: Y.M. Aiyesimi, E-mail: yusuf.abdulhakeem@futminna.edu.ng, Tel.: +2347032143075, 08154993902.

The Boungiorno [11] model has recently been used by Kuznetsov and Nield [12] to study the natural convective flow of a nanofluid over a vertical plate. Their similarity analysis identified our parameters governing the transport process, namely a Lewis number Le, a buoyancy-ratio number Nr, a Brownian motion number Nb, and a thermophoresis number Nt. The same authors later extended the work to a nanofluid saturated porous medium Nield and Kuznetsov[13]". In a recent paper Khan and Pop [14] used the model of Kuznetsov and Nield [12] to study the boundary layer flow of a nanofluid past a stretching sheet with a constant surface temperature. Following the work of Khan and Pop [14], it seemed appropriate to us to introduce a thermal effect and thermal radiation to their analysis and use the Adomian Decompositon Method (ADM) to obtain the analytical solution of the model. Aiyesimi et al.[15] have previously used the Adomian Decomposition to obtain the analytical solution of hydro magnetic boundary layer micropolar fluid flow over a stretching surface embeded in a non darcian medium with variable permeability. A few examples are the papers by Aiyesimi et al. [16], Jiya and Oyubu[17], Jiya and Oyubu[18].
This work is a new development in the literature in which an analytical solution of a convective boundary-layer flow of a nanofluid past a stretching sheet is proposed using the Adomian Decomposition Method.

2.0 Problem Formulation

The work considers the steady two-dimensional boundary layer flow of a nanofluid past a stretching sheet in the presence of thermal effect and Radiation with the linear velocity $u = ax$, where a is constant, x is the coordinate measured from the stretching sheet is zero. A steady uniform stress leading to equal and opposite forces is applied so that the sheet is stretched keeping the origin fixed. It is assumed that at the stretching sheet, the temperature T and the nanoparticle fraction C takes constant values T_W and C_W, respectively. The ambient values, attained as y tends to infinity, of T and C are denoted by T_∞ and C_∞, respectively. The Khan and Pop [14] model may be modified for this problem to give the continuity, momentum, energy and the nanofraction equations as follows:-

Continuity equation:,

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

Momentum equation:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\circ_f}\frac{\partial p}{\partial x}+{}^3\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+g\quad(T-T_\infty)+g\quad(C-C_\infty) \qquad (2)$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\circ_f}\frac{\partial p}{\partial y}+{}^3\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+g\quad(T-T_\infty)+g\quad(C-C_\infty) \qquad (3)$$

Energy equation:-

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\sim\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)$$
$$+{}^2\left(D_B\left(\frac{\partial C}{\partial x}\frac{\partial T}{\partial x}+\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}\right)+\frac{D_T}{T_\infty}\left(\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2\right)\right)-\frac{1}{\circ C_p}\frac{\partial q_r}{\partial y} \qquad (4)$$

Nanofraction equation:-

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)+\left(\frac{D_T}{T_\infty}\right)\left(\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial y^2}\right)-\pm(C-C_\infty) \qquad (5)$$

Subject to the boundary conditions:

$$y=0: u=ax, \qquad v=0, \qquad T=T_W, \qquad C=C_W$$
$$y\to\infty: u\to 0,\ T\to T_\infty,\ C\to C_\infty, \qquad (6)$$

Where u and v are the velocity components along the x and y axes respectively, p is the fluid pressure, $\circ_f$ is the density of the base fluid, $\sim$ is the thermal diffusivity, ^{3} is the kinematic viscousity, k^* is the thermal conductivity, C_p is the specific heat capacity at constant pressure, a is a positive constant, D_B is the Brownian diffusion coefficient, D_T is the thermopheric diffusion coefficient and ² $= \dfrac{(°c)_p}{(°c)_f}$ is the ratio between the effective heat capacity of the fluid with ° being the density, c is the volumetric volume expansion coefficient and $°_P$ is the density of the particles g is the acceleration due to gravity, is the volumetric coefficient of thermal expansion, q_r is the radiative heat flux.

Following Roseland approximation we have $q_r = -\dfrac{4\pm^*}{3¢}\dfrac{\partial T^4}{\partial y}$, where $\pm^*$ and ¢ are the Stefan-Boltzmann constant and the mean absorption coefficient respectively. The temperature differences within the fluid is assumed sufficiently small such that T^4 may be expressed as a linear function of Temperature. Expanding T^4 in Taylor's series about T_∞ and neglecting higher order terms, we get $T^4 \cong 4TT_\infty^3 - 3T_\infty^4$ (7)

therefore, $\dfrac{\partial q_r}{\partial y} = -\dfrac{16\pm^*}{3¢}\dfrac{\partial^2 T^4}{\partial y^2}$

Defining the dimensional stream function $(\cdot\ (x,y))$ in the usual way such that $u = \dfrac{\partial \cdot}{\partial y}$ and $v = -\dfrac{\partial \cdot}{\partial x}$ and using the following dimensionless variables:-

$$¦ = \left(\frac{a}{³}\right)^{1/2} y, \quad \cdot = (a³)^{1/2} x f(¦), ¯(¦) = \frac{T - T_\infty}{T_w - T_\infty}, \text{ and } ¤(¦) = \frac{C - C_\infty}{C - C_\infty} \qquad (8)$$

where ¦, $f(¦)$, $¯(¦)$, $¤(¦)$ are the dimensionless fluid distance, velocity profile, temperature profile, and nanoparticle concentration.

An order of magnitude analysis of the y direction momentum equation (normal to the sheet) using the usual boundary layer approximations we have :-

$$u > v, \frac{\partial}{\partial} > \frac{\partial}{\partial}, \frac{\partial}{\partial}, \frac{\partial}{\partial}, sho \quad tha \ \frac{\partial}{\partial} = 0$$

Substituting the expressions in (8) into (1)-(5), and (6) and neglecting the pressure gradient the equations reduces to the following local similarity solution:-

$$f''' + ff'' - f'^2 + Gr_{Tx} + Gr_{Cx} = 0 \qquad (9)$$

$$\left(1 + \frac{4Ra}{3}\right)¯'' + \Pr f¯' + \Pr N_b ¤' ¯' + \Pr N_t ¯'^2 = 0 \qquad (10)$$

$$¤'' + L_e f ¤' + \frac{N_t}{N_b}¯'' - KS_C ¤ = 0 \qquad (11)$$

with corresponding boundary conditions:

$$f(0) = 0,\ f'(0) = 1,\ ¯(0) = 1,\ ¤(0) = 0,$$

$$f'(\infty) = 0,\ ¯(\infty) = 0,\ ¤(\infty) = 0. \qquad (12)$$

in which : $Gr_{Tx} = \dfrac{g\ (T - T_\infty)}{a^2 x}$, $Gr_{Cx} = \dfrac{g\ (C - C_\infty)}{a^2 x}$, $Ra = \dfrac{4\pm^* T_\infty^3}{¢k^*}$, $P_r = \dfrac{³}{\sim}$, $L_e = \dfrac{³}{D_B}$, $N_b = \dfrac{(°c)_p D_B (C_W - C_\infty)}{(°c)_f ³}$,

$$N_t = \frac{(°c)_p D_T (T_W - T_\infty)}{(°c)_f T_\infty ³}, \qquad (13)$$

$S_c = \dfrac{³}{D_B}$, $K = \dfrac{\pm}{a}$, are the local Thermal Grashof number, local concentration Grashof number, Radiation, Prandtl number, Lewis number, Brownian motion parameter, thermophoresis parameter, Schmidt number, and the nanoparticle parameter respectively.

For the momentum equation to have a similarity solution, the parameters Gr_{Tx} and Gr_{Cx} most be constant and not functions of x as in the equation (8). This can be met if volumetric coefficient of thermal expansion is proportional to x. We therefore assume

$$= {}_0 x \quad (14)$$

where ${}_0$ is a constant. Substituting (14) into (13) we have $Gr_T = \frac{g\ {}_0 (T - T_\infty)}{a^2}$, $Gr_C = \frac{g\ {}_0 (C - C_\infty)}{a^2}$ (15)

in which Gr_T, and Gr_C defined by (15), the solution of (9) to (11) yield the similarity solutions.

3.0 Analysis of Method

3.1 Adomian Decomposition Method

For the purpose of illustrating the method of Adomian decomposition we begin with the (deterministic) form $F(u) = g$(t) where F is a nonlinear ordinary differential operator with linear and nonlinear items. We could represent the linear term L where L is a linear operator. We write the linear term $L + R$ where we choose L as the highest-ordered derivative. Now L^{-1} is simply n-fold integration for an n^{th} order. The remainder of the linear operator is R (in case where stochastic terms are present in linear operator, we can include a stochastic operator term R). The nonlinear term is represented by N .Thus, $L + R + N = g$ and we write

$L^{-1}L = L^{-1}$ g$-L^{-1} R - L^{-1} N$ for initial value problems we conveniently define $L^{-1} = \frac{d^n}{dt^n}$ as the n- fold definite integration operator from 0 to t. For the operator $L = \frac{d^2}{dt^2}$, for example we have,

$L^{-1}L = u - u(0) - t\ '(0)$

$\therefore u = u(0) + L^{-1}$ g$- L^{-1} R - L^{-1} N$

For the same operator equation but now considering a boundary value problem, we let L^{-1} be an indefinite integral and write $u = A + B$ for the first two terms and evaluate A, B from the given condition the first three terms are identified as u_0 in the assumed decomposition

u=$\sum_{n=0}^{\infty} u_n$

Finally, assuming *Nu* is analytic, we write

Nu=$\sum_{n=0}^{\infty} A_n(u_0 \ldots u_n)$where the A_n are specially generated Adomian polynomials for the specific nonlinearity.

3.2 Implementation of Method

The nonlinear coupled differential equations (9) to (11) with boundary conditions (12) are solved using the ADM methods.

If ADM is applied on (9) to (11) and we defined $L_1 = \frac{d^3}{d¦^3}$, and $L_2 = \frac{d^2}{d¦^2}$, then

$$L_1[f] = -ff'' + f'^2 - Gr_T - Gr_C \quad (16)$$

$$L_2[¯] = \frac{-3\mathrm{P}_r}{(4Ra+3)}\left(f¯' + N_b ¤'¯' + N_t ¯'^2\right) \quad (17)$$

$$L_2[¤] = -L_e f¤' - \frac{N_t}{N_b}¯'' + KS_c ¤ \quad (18)$$

Applying inverse operator on equation (16) to (18), we have

$$L_1^{-1}L_1[f] = -L_1^{-1}[ff''] + L^{-1}{}_1[f'^2] - L_1^{-1}[Gr_T] - L_1^{-1}[Gr_C] \quad (19)$$

$$L_2^{-1}L_2[¯] = \frac{-3\mathrm{P}_r}{(3+4Ra)} L_2^{-1}[(f¯' + N_b¯'¤' + N_t¯'^2)] \quad (20)$$

$$L_2^{-1}L_2[¤] = L_2^{-1}[-L_e f¤' - \frac{N_t}{N_b}¯'' + KS_c ¤] \quad (21)$$

where $L_1^{-1} = \int\int\int(.)d¦\,d¦\,d¦$ and $L_2^{-1} = \int\int(.)d¦\,d¦$

The ADM solution is obtained by:

$$\sum_{m=0}^{\infty} f_m(\eta) = 1 - be^{-\eta} - L_1^{-1}[\sum_{m=0}^{\infty} A_m] + L_1^{-1}[\sum_{m=0}^{\infty} B_m] - L_1^{-1}[\sum_{m=0}^{\infty} Gr_T] - L_1^{-1}[\sum_{m=0}^{\infty} Gr_C] \quad (22)$$

$$\sum_{n=0}^{\infty} \theta_n(\eta) = ce^{-\eta} + \left(\frac{-3P_r}{(3+4Ra)}\right)\left(L_2^{-1}[\sum_{n=0}^{\infty} C_n] + N_b L_2^{-1}[\sum_{n=0}^{\infty} D_n] + N_t L_2^{-1}[\sum_{n=0}^{\infty} E_n]\right) \quad (23)$$

$$\sum_{n=0}^{\infty} \phi_n(\eta) = he^{-\eta} - L_e L_2^{-1}[\sum_{n=0}^{\infty} F_n] - \frac{N_t}{N_b} L_2^{-1}[\sum_{n=0}^{\infty} \theta''_n] + KS_c L_2^{-1}[\phi_n] \quad (24)$$

where

$$A_m = \sum_{v=0}^{m} f_{m-v} f''_v \quad (25)$$

$$B_n = \sum_{v=0}^{n} f'_{n-v} f'_v \quad (26)$$

$$C_n = \sum_{v=0}^{n} f_{n-v} \theta'_v \quad (27)$$

$$D_n = \sum_{v=0}^{n} \theta'_{n-v} \phi'_v \quad (28)$$

$$E_n = \sum_{v=0}^{n} \theta'_{n-v} \theta'_v \quad (29)$$

$$F_n = \sum_{v=0}^{n} f_{n-v} \phi'_v \quad (30)$$

In other to take care of problems at infinity, we therefore take functions which satisfies the boundary conditions at infinity as our initial guesses.

$$f_0(\eta) = 1 - be^{-\eta} \quad (31)$$

$$\theta_0(\eta) = ce^{-\eta} \quad (32)$$

$$\phi_0(\eta) = he^{-\eta} \quad (33)$$

For determination of other components of $f(\eta)$, $h(\eta)$ and $\theta(\eta)$, we have:

$$\sum_{m=0}^{\infty} f_{m+1}(\eta) = -L_1^{-1}[\sum_{m=0}^{\infty} A_m] + L_1^{-1}[\sum_{m=0}^{\infty} B_m] - L_1^{-1}[\sum_{m=0}^{\infty} Gr_T] - L_1^{-1}[\sum_{m=0}^{\infty} Gr_C] \quad (34)$$

$$\sum_{n=0}^{\infty} \theta_{n+1}(\eta) = \left(\frac{-3P_r}{(3+4Ra)}\right)\left(L_2^{-1}[\sum_{n=0}^{\infty} C_n] + N_b L_2^{-1}[\sum_{n=0}^{\infty} D_n] + N_t L_2^{-1}[\sum_{n=0}^{\infty} E_n]\right) \quad (35)$$

$$\sum_{n=0}^{\infty} \phi_{n+1}(\eta) = -L_e L_2^{-1}[\sum_{n=0}^{\infty} F_n] - \frac{N_t}{N_b} L_2^{-1}[\sum_{n=0}^{\infty} \theta''_n] + KS_c L_2^{-1}[\phi_n] \quad (36)$$

where b, c, and h are all constants to be determined for actual solutions.
The general solutions are:

$$f(\eta) = \sum_{m=0}^{\infty} f_m(\eta) = f_0 + f_1 + f_2 \cdots \quad (37)$$

$$\theta(\eta) = \sum_{m=0}^{\infty} \theta_m(\eta) = \theta_0 + \theta_1 + \theta_2 \cdots \quad (38)$$

$$\phi(\eta) = \sum_{m=0}^{\infty} \phi_m(\eta) = \phi_0 + \phi_1 + \phi_2 \cdots \quad (39)$$

for conveniences, we used Maple-18 to compute the integrals.

Table 1: Comparison between the previously published work with the present work for $f'(\eta)$ at $Gr_T = 0$, and $Gr_C = 0$

η	**Crane[3]**	**Khan and Pop[14]**	**Present work**
0.0	1	1	1
0.5	0.60653066	0.60653066	0.60653066
1.0	0.367879441	0.367879441	0.367879441
1.5	0.22313016	0.22313016	0.22313016
2.0	0.135335283	0.135335283	0.135335283
2.5	0.082084999	0.082084999	0.082084999
3.0	0.049787068	0.049787068	0.049787068
3.5	0.030197383	0.030197383	0.030197383
4.0	0.018315639	0.018315639	0.018315639
4.5	0.011108997	0.011108997	0.011108997
5.0	0.006737947	0.006737947	0.006737947
5.5	0.004086771	0.004086771	0.004086771
6.0	0.002478752	0.002478752	0.002478752

Table 2: Values of $-f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ with N_b, $N_t = 0.01$ and $K = 1$.

Gr_T	Gr_C	Pr	Sc	Ra	Le	$-f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0	0	10	0.01	0.01	10	1	0.918406966	0.91307301
1	0	10	0.01	0.01	10	0.980196465	0.514959356	0.355908768
10	0	10	0.01	0.01	10	0.907586914	0.265304341	0.241188888
0	0	10	0.01	0.01	10	1	0.918406966	0.91307301
0	1	10	0.01	0.01	10	0.980196465	0.514959356	0.355908768
0	10	10	0.01	0.01	10	0.907586914	0.265304341	0.241188888
0	0	0.1	0.01	0.01	10	1	0.938486161	0.685002882
0	0	1	0.01	0.01	10	1	0.88965977	0.911533062
0	0	10	0.01	0.01	10	1	0.938486161	0.91307301
0	0	10	0.01	0.01	10	1	0.918406964	0.913073011
0	0	10	10	0.01	10	1	0.918407029	0.965715561
0	0	10	100	0.01	10	1	0.918407033	0.99485203
0	0	10	0.01	0.01	10	1	0.918406966	0.913073011
0	0	10	0.01	10	10	1	0.864504429	0.798848546
0	0	10	0.01	60	10	1	0.97352682	0.646282701
0	0	10	0.01	0.01	0.01	1	0.993832011	0.997939766
0	0	10	0.01	0.01	10	1	0.918406966	0.913073011
0	0	10	0.01	0.01	200	1	0.92089133	0.918699974

4.0 Results and Discussion

The nonlinear coupled differential equations (9) to (11) with boundary conditions (12) are solved using the Adomian Decomposition Methods. In order to assess the accuracy of the present method, we have compared our solution for $f'(\eta)$ for different values of η at $Gr_T = 0$ and $Gr_c = 0$ with the previously published work as shown in Table 1. It was observed that the present method is in good agreement with the work of Crane [3] and Khan et al.[14].

Table 2. shows the Adomian decomposition values for the skin friction ($-f''(¦)$) , reduced Nusselt number (−¯ '(¦)) and the reduced Shawood number (−¤ '(¦)).

Figures 1 to 6 show the effect of thermal Grashof number (Gr_T) and concentration Grashof number (Gr_c) on the velocity profile, temperature and concentration profile. It is observed that the thermal Grashof number and concentration Grashof number enhances the fluid velocity, temperature, and concentration profile. This leads to increase in the boundary layers as shown in the graph.

Figures 7 to 8 display the effect of prandtl number (*Pr*) on the temperature profile and the concentration profile. The thermal boundary thickness decreases for both temperature and concentration profile as the Prandtl number increases. The reason is that smaller values of Prandtl number are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of Prandtl number. Hence there is a reduction in temperature with increase in the Prandtl number.

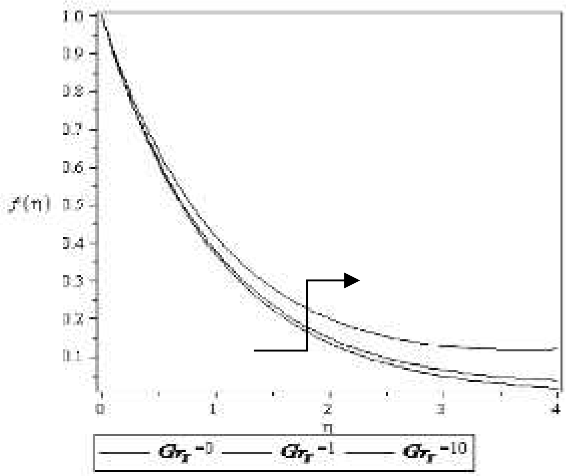

Fig 1: Effect of Gr_T on velocity profile

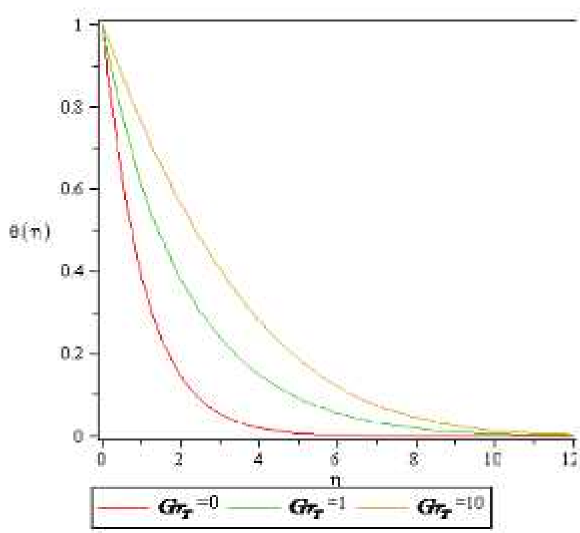

Fig 2: effect of Gr_T on temperature profile

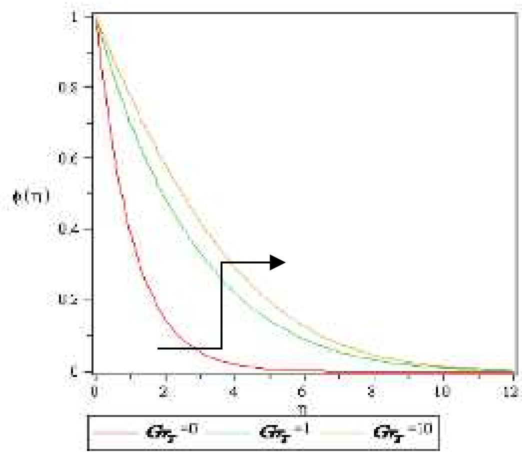

Fig 3: effect of Gr_T on concentration profile

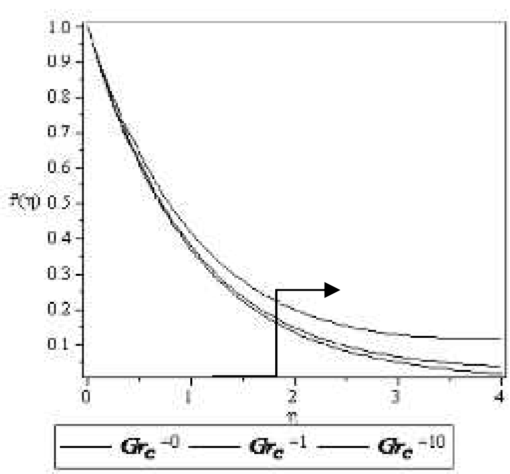

Fig 4: effect of Gr_C on velocity profile

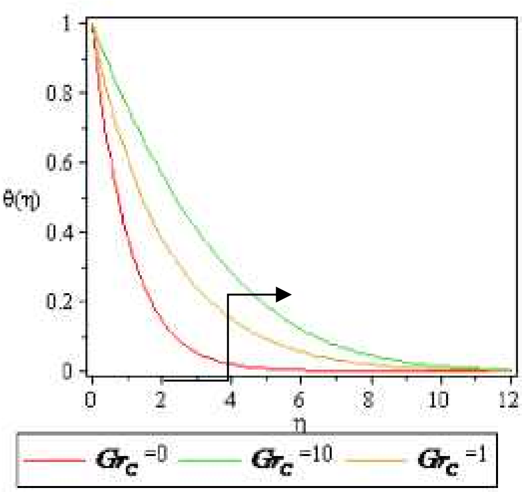

Fig 5: effect of Gr_C on temperature profile

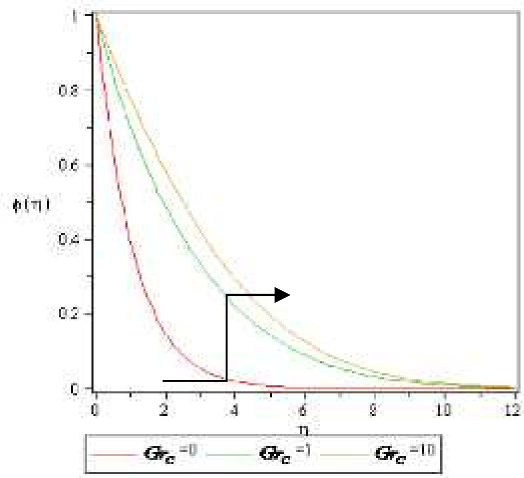

Fig 6: effect of Gr_C on concentration profile

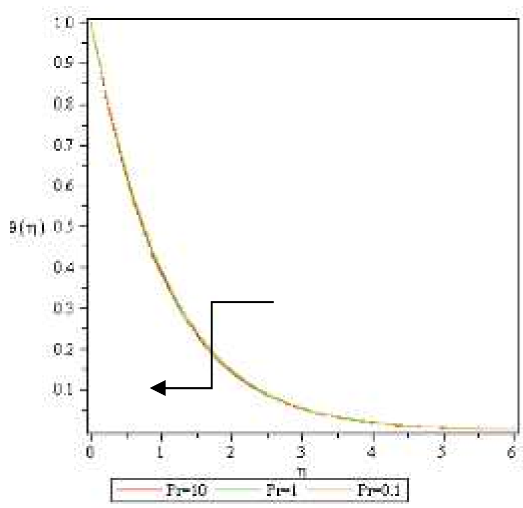

Fig 7: effect of $\Pr$ on temperature profile

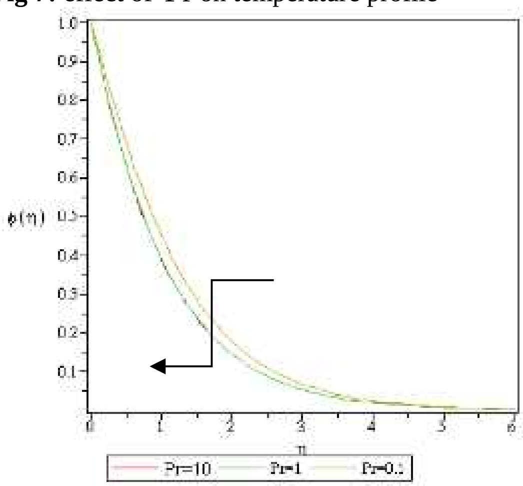

Fig 8: effect of $\Pr$ on concentration profile

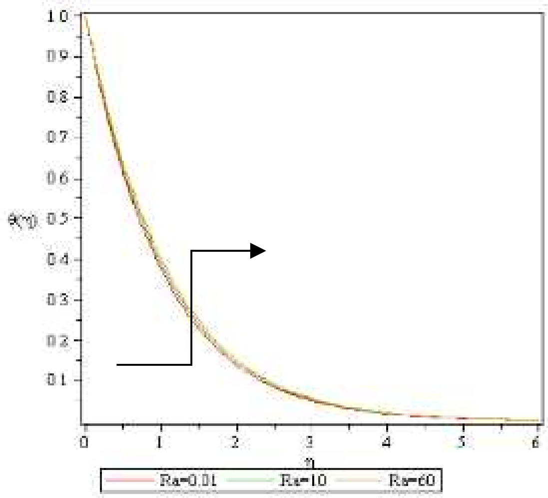

Fig 9: effect of Ra on temperature profile

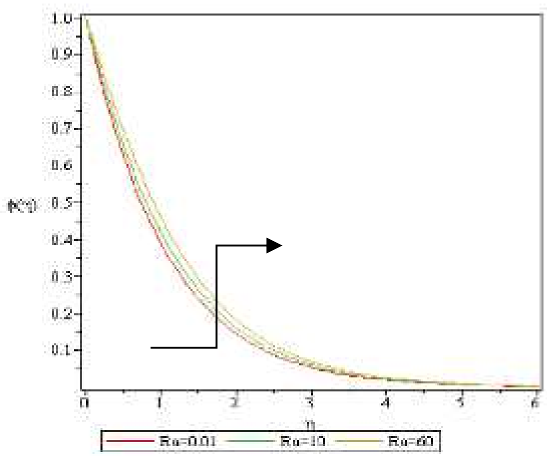

Fig 10: effect of Ra on concentration profile

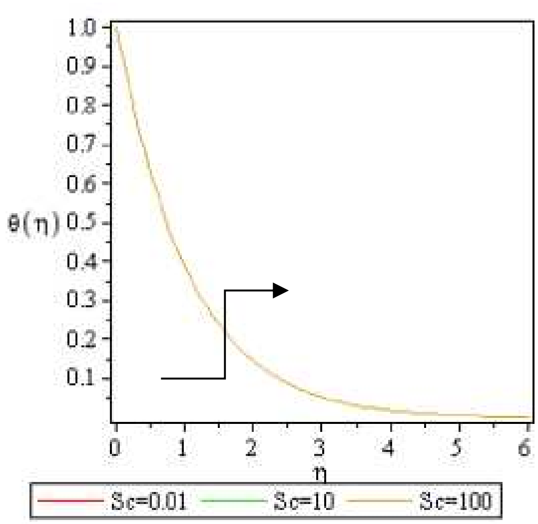

Fig 11: effect of Sc on temperature profile

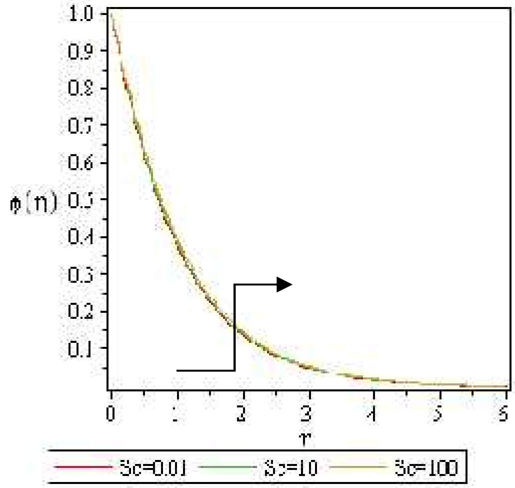

Fig 12: effect of Sc on concentration profile

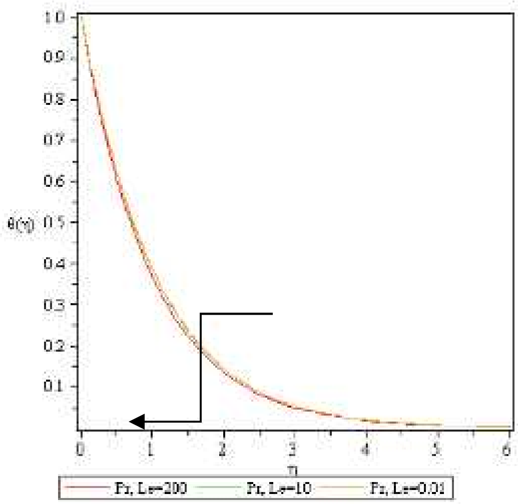

Fig 13: effect of $\Pr, Le$ on Temperature profile

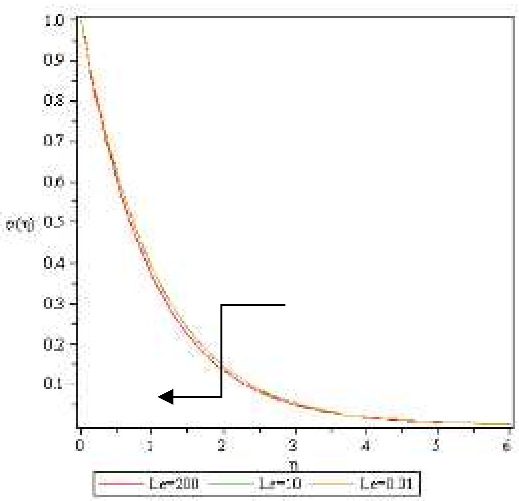

Fig 14: effect of Le on concentration profile

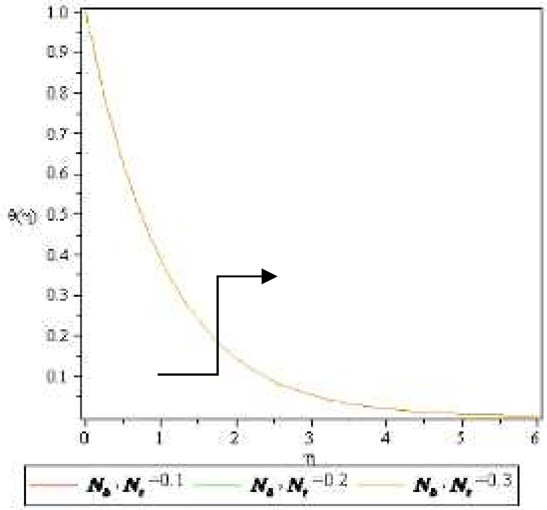

Fig 15: effect of N_b, N_t on temperature profile

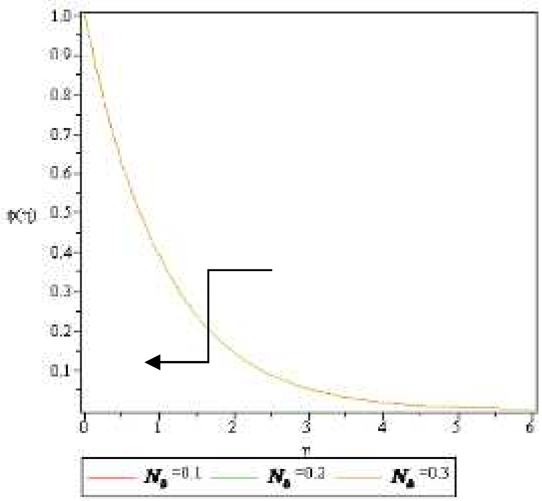

Fig 16: effect of N_b on concentration profile

Figures 9 to 10 show that the fluid temperature and concentration respectively attains their maximum value at the moving plate surface and decreases monotonically to free stream zero value away from the plate satisfying the boundary conditions. It is observe that increase in radiation (Ra) causes both the temperature and concentration profiles to increase.

Figures 11 to 12 display the effect of Schmidt number (Sc), and it is observe that, it has no significant effect on the temperature profile but enhances the concentration profile.

Figures 13 to 14 present the effect of Lewis number (Le) on both the temperature and the concentration profiles respectively. It is observe that increase in Lewis number causes the both the temperature and concentration profiles to reduce.

Figures 15 to 16 show the Brownian motion (N_b) causes both temperature and concentration profiles to increase insignificantly.

5.0 Conclusion

The solution to the problem of laminar fluid flow resulting from the stretching of a flat surface in a nanofluid with thermal convection and radiatiuon has been obtained using the Adomian Decomposition Method for the first time. The model used for the nanofluidwas presented in its rectangular coordinate system and incorporates the effect of Brownian motion, and thermophoresis parameter.A similarity solution was presented which depends on the Prandtl number P_r, Lewis number Le, Brownian motion N_b, thermophoresis number N_t, and Schimidt number Sc, and Grashof numbers $(Gr_{t,} Gr_c)$.

It was found thatsmaller values of Prandtl number are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of Prandtl number. Hence there is a reduction in temperature with increase in the Prandtl number.

6.0 References

[1] Takhar, H.S., Chamkha, A.J.,Nath,G. Unsteady three-dimensional MHDboundary-layer flow due to the impulsive motion of a stretching surface,Acta Mech. 146: 59–71 (2001).

[2] Vleggaar,J. Laminar boundary layer behaviour on continuous acceleratingsurface, Chem. Eng. Sci. 32 :1517–1525 (1977).

[3] Crane, L.J.Flow past a stretching plate, J. Appl. Math. Phys. (ZAMP) 21 645–647 (1970).

[4] Lakshmisha, K.N.,Venkateswaran,S., Nath, G.Three-dimensional unsteady flowwith heat and mass transfer over a continuous stretching surface, ASME J. Heat. 123, 124-139 (1998).

[5] Choi,S.U.S. Enhancing thermal conductivity of fluids with nanoparticles, in: Developments and Applications of Non-Newtonian Flows, FED-vol. 231/MDvol.66, 1995, pp. 99-105 (1999).

[6] Masuda, H., Ebata, A., Teramea, K., Hishinuma,N. Altering the thermalconductivity and viscosity of liquid by dispersing ultra-fine particles, NetsuBussei 4 (4) 227-233(1993).

[7] Trisaksri, V., Wongwises, S. Critical review of heat transfer characteristics ofnanofluids, Renew. Sust. Energ. Rev. 11:512-523 (2007).

[8] Wang, X. Q., Mujumdar, A.S. Heat transfer characteristics of nanofluids:a review, Int. J. Therm. Sci. 46 :1-19 (2007).

[9] Eastman, J.A., Phillpot, S.R., Choi,S.U.S., Keblinski, P.Thermal transport innanofluids, Annu. Rev. Mater. Res. 34, 219-246(2004).

[10] Kakac, S., Pramaumjaroenkij, A. Review of convective heat transfer enhancementwith nanofluids, Int. J. Heat Mass Transf. 52, 3187-3196 (2009).

[11] Buongiorno, J. Convective transport in nanofluids, J. Heat Transfer 128, 240-250(2006).

[12] Kuznetsov, A.V., Nield,D.A. (2010). Natural convective boundary-layer flow ofa nanofluid past a vertical plate, Int. J. Therm. Sci. 49, 243-247 (2010).

[13] Nield, D.A., Kuznetsov, A.V. The Chenge Minkowycz problem for natural convective boundary-layer flow in a porous medium saturated by a nanofluid, Int. J. Heat Mass Transf. 52, 5792-5795 (2009).

[14] Khan, W.A., Pop, I.(2010). Boundary-layer flow of a nanofluid past a stretching sheet, Int. J. Heat Mass Transf. 53, 2477-2483 (2010).

[15] Aiyesimi**,** Y.M.**,** Yusuf, A., Jiya, M.A Hydromagnetic Boundary Layer Fluid Micropolar over a Stretching Surface in a Non- Darcian Medium with Permeability, *Universal Journal of Applied Mathematics*, Vol. 1 No. 2 pg 136-141, DOI: 10.13189/ujam.2013.010216,(2013).

[16] Aiyesimi**,** Y.M.**,** Yusuf, A., Jiya, M.A Convective Flow of a Micropolar Fluid Past a Stretched Permeable Surface with Radiation, *Journal of Nigerian Association of Mathematical Physics*, Vol. 25. No. 1, pg. 109-116(2013).

[17] Jiya, M., and Oyubu, J. Adomian Decomposition Method for the Solution of Boundary Layer Convective Heat Transfer over a Flat Plate, *International Journal of Applied Science and Technology* Vol. 2 No. 8 pg 54-62.(2012)

[18] Jiya, M., and Oyubu, J. "Adomian Decomposition Method for the Solution of Boundary Layer Convective Heat Transfer with Low Pressure Gradient over a Flat Plate", *IOSR Journal of Mathematics (IOSR-JM) Vol. 4, No 1, pg 34-42, DOI:***10.9790/5728-0413442,** (2012)