g-Jitter Induced Natural Convection Nanofluid Flow with Mass Transfer in The Stagnation Point Region of a Three Dimensional Body

Mohamad Hidayad Ahmad Kamal\textsuperscript{1}, Noraihan Afiqah Rawi\textsuperscript{2}, Anati Ali\textsuperscript{1} and Sharidan Shafie\textsuperscript{1}

\textsuperscript{1}Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, Johor Bharu, Johor, Malaysia
\textsuperscript{2}Universiti Kuala Lumpur Malaysia, Institute Technology of Industrial Technology, Johor Bharu, Johor, Malaysia

Email: sharidan@utm.my

Abstract. The laminar flow near a stagnation point at the boundary layer is studied numerically in this paper. Viscous nanofluid with copper nanoparticles is considered in microgravity environment. The problem is described in terms of mathematical formulation and the nanofluid studies is focusing on the volume fraction of the nanoparticles. After going through Boundary Layer and Boussinesq approximations, the dimensional governing equation is then transformed into dimensionless governing equation by using semi-similar transformation technique together with its initial and boundary conditions. In a way to solve the coupled dimensionless equations, implicit finite difference method known as Keller-box method is used in studying the transportation phenomena in terms of physical quantities of interest which are skin frictions that describe the flow behaviour, Nusselt number represent the heat transfer coefficient and Sherwood number that refer to concentration distribution. It is found that stagnation point parameter which is curvature ratio, provide a different type of nanofluid flow cases. On the other hand, with the presence of g jitter which correspond to the microgravity environment, the parameter frequency of oscillation effects the convergence of the problem which the convergence occurs more frequently with bigger frequency. The enhancement of thermal conductivity is found by comparing the result of conventional fluid with nanofluid.

1. Introduction
The implementation of convective transportation involving momentum, heat and mass phenomena is hugely applied on engineering and applied sciences. In particular, the physical process involving engineering applications such as nanotechnology for turbine, electronic cooling emerging technology in sustainable energy, food processing equipment and heat pipes proving highly implementation of heat and mass transfer in the system. In order to get a smooth process and optimum result of productions, fundamental research on the boundary layer flow are compulsory in which massively done by [1-4]. As a part of sub discipline in fluid dynamic, studies on boundary layer flow provide an importance knowledge to the scientist in producing a better result such as on stagnation point flow. Stagnation point flow implies on many applications such as electronic fan cooling device, nuclear cooling system during emergency showdown and exposed solar receiver to wind current because of the fact that this small point may serve as a starting solution for the solution over entire body [5-6].
Studies on stagnation point flow analyzed by the physical law Navier Stokes equation was conducted by several researchers in [7-9] either in two dimensional or three dimensional cases. Heimenz [10]; first reporting two dimensional stagnation flow numerically using Navier-Stokes equation followed by [11-12]. Even though stagnation point holds an importance property which is having the higher local pressure [13], an exact solution is rare due to analytical difficulties correspond to non-linear boundary value problems [5]. Mahapatra and Gupta [14]; studied steady two dimensional stagnation point flow towards a stretching plane with a velocity proportional to the distance from the stagnation point. The problem is then extended in [15] by additional effect which is magnetohydrodynamic (MHD) purposely to study a steady two-dimensional stagnation-point flow of an incompressible viscous electrically conducting fluid over a flat deformable sheet. Implementing the non-Newtonian fluid on the problem, Beard and Walters [16]; studied two dimensional near a stagnation point flow with the effect of Prandtl boundary layer theory in elasto-viscous liquid.

\( g \)-Jitter effect is a natural phenomenon with regards of inertia effect occurs under microgravity environment which will affect the research output in outer space. The case for boundary layer flow research near a stagnation point region with \( g \)-jitter effect, was studies by Rees and Pop [17] on fluctuating gravitational field for a symmetric two dimensional cases to analyze shear stress and rate of heat transfer of the flow. The problem is then extended by [18] with the additional effect of porous medium under microgravity environment. After some years, Shafie \textit{et al.} [19]; implies the same environment condition on the different type of fluid by studying the effect of \( g \)-jitter in two dimensional micropolar fluid. In 2007, a numerical solution is provided by Shafie \textit{et al.} [20] by analyzing a three dimensional case of stagnation point region with the effect of \( g \)-jitter and the physical quantities of principal interest have been stressed out during the research.

Nanofluid is known for its purpose in enhancing the conventional fluids by adding small amount of nanoparticles with higher thermal conductivity. There is some fundamental research on boundary layer flow involving \( g \)-jitter effect with nanofluid such in [21-23]. Uddin \textit{et al.} [24]; present a two dimensional numerical solution for laminar flow involving constant thermal and mass boundary conditions with \( g \)-jitter effect. On the same year, Bhaduria in and Kiran [25]; done a weak non-linear analysis of double diffusive convection in an electrically conducting viscoelastic fluid layer heated from below. Later, Rawi \textit{et al.} [26]; focused their studies on the geometry of the boundary layer flow past an incline stretching sheet of mixed convection nanofluid flow under microgravity environment. After a year, Rawi \textit{et al.} [27]; compared different types of nanoparticles while studying unsteady mixed convection flow of Jeffrey fluid past an inclined stretching sheet induced by \( g \)-jitter.

Motivated from the previous research, the present research will investigate the behavior of boundary layer flow near a three dimensional stagnation point region induced by \( g \)-jitter in nanofluid. The problem will be solved numerically using implicit finite different method which then analyzed with respect of physical quantities of principal interest.

2. Mathematical Formulation

An incompressible viscous fluid near a three dimensional stagnation-point boundary layer flow is studied numerically with the effect of \( g \)-jitter focusing on the flow behavior, heat and mass transfer. A small amount of copper nanoparticle is added to the conventional fluid which is water in a way to enhance the thermal conductivity. Initially at \( t = 0 \), the fluid assumed moved with constant velocity with constant wall temperature \( T_w \) and mass diffusion distribution \( C_w \). After a while \( t > 0 \), the temperature of the body raised to a constant wall temperature \( T_w \), and constant concentration \( C_w \).

The problem is illustrated in a three dimensional stationary orthogonal Cartesian coordinate \((x, y, z)\) such that \( x \) – and \( y \) –coordinates are measured along with the surface while \( z \) –coordinate is measured normal to the surface of the body. The origin locates a nodal point \( N \), which is one of a point the near a stagnation point region. Since microgravity environment is taken into account, gravitational field considered in this problem is written as,

\[
g'(t^*) = g_0[1 + \epsilon \cos(\pi \omega t^*)]
\]
where $g_0, \varepsilon$ and $\omega$ are mean gravitational acceleration, amplitude of modulation and frequency of oscillation depend on time $t^\star$. From the principal of physical law, governing equation of boundary layer of nanofluid under Boundary Layer and Boussinesq approximations are presented as,

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$  \hspace{1cm} (1)$$

$$\rho_{nf} \left( \frac{\partial u}{\partial t^\star} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right)$$

$$= \frac{\partial^2 u}{\partial z^2} + g^\star(t^\star)(\rho\beta)_{nf}ax(T - T_\infty) + g^\star(t^\star)\rho_{nf}\beta_cax(C - C_\infty)$$  \hspace{1cm} (2)$$

$$\rho_{nf} \left( \frac{\partial v}{\partial t^\star} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right)$$

$$= \frac{\partial^2 v}{\partial z^2} + g^\star(t^\star)(\rho\beta)_{nf}by(T - T_\infty) + g^\star(t^\star)\rho_{nf}\beta_by(C - C_\infty)$$  \hspace{1cm} (3)$$

$$\frac{\partial T}{\partial t^\star} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} = \alpha_{nf} \frac{\partial^2 T}{\partial z^2}$$  \hspace{1cm} (4)$$

$$\frac{\partial C}{\partial t^\star} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} + w \frac{\partial C}{\partial z} = D_{nf} \frac{\partial^2 C}{\partial z^2}$$  \hspace{1cm} (5)$$

subject to

$$t^\star < 0 : u = v = w = 0, T = T_\infty, C = C_\infty \text{ for any } x, y \text{ and } z$$

$$t^\star \geq 0 : u = v = w = 0, T = T_\infty, C = C_\infty \text{ on } z = 0, x \geq 0, y \geq 0$$

$$u = v = w = 0, T = T_\infty, C = C_\infty \text{ as } z \rightarrow \infty, x \geq 0, y \geq 0$$  \hspace{1cm} (6)$$

where velocity component presented as $u, v, w$ along the direction of $x, y, z$ axes, $T$ is temperature of the fluid and $C$ is concentration of the fluid. Here $\rho_{nf}, \mu_{nf}, \beta_{nf}, \alpha_{nf}$ and $D_{nf}$ are density, dynamic viscosity, thermal expansion, thermal diffusivity and mass diffusivity of the nanofluid. On the other hand $\beta_c$ is a coefficient for concentration expansion. As for stagnation point effect, $a$ and $b$ are principal curvatures at the nodal point measured at the plane $x = 0$ and $y = 0$. Both values for parameter $a$ and $b$ are assumed to be positive since the problem only cover for nodal point and holding the properties without loss the generality $|a| \geq |b|$ and $a > 0$. There exist parameter curvature ratio $c$, such that $c = b/a$ with value range 0 to 1.

The nanofluid properties defined for viscous Newtonian fluid derived from Maxwell equation stated in [11] are given as

$$\mu_{nf} = \frac{\mu_f}{(1 - \phi)^{2\frac{\varepsilon^2}{5}}},$$

$$\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}},$$

$$D_{nf} = D_f \left( \frac{1 - \phi}{1 + \frac{\phi}{2}} \right),$$

$$\rho_{nf} = (1 - \phi)\rho_f + \phi\rho_s,$$

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$$\alpha_{nf} = \left( 1 - \phi \right)\alpha_f + \phi\alpha_s,$$

$$\alpha_{nf} = \left( 1 - \phi \right)\alpha_f + \phi\alpha_s,$$

$$k_{nf} = \frac{(k_s + 2k_f) - 2\phi(k_f - k_s)}{k_s + 2k_f - 2\phi(k_f - k_s)},$$

$$k_{nf} = \frac{(k_s + 2k_f) - 2\phi(k_f - k_s)}{k_s + 2k_f - 2\phi(k_f - k_s)},$$

where $\phi$ is nanoparticle volume friction which followed from Tiwari and Das nanofluid model [28]. Here $k$ is thermal conductivity while subscripts $f$ and $s$ represent fluid and solid characteristics carried by the nanofluid as shown in table 1 [11].
The semi-similar transformation technique is applied on equations (1) – (5) together with the initial and boundary conditions (6) in a way to reduce the complexity. The appropriate semi similar transformation (7) is as follows,

\[
\begin{align*}
\tau &= \Omega t, \ \eta = Gr^{1/4}az, \ t = va^{2}Gr^{1/2}t', \\
u &= va^{2}xGr^{1/2}f'(t, \eta), \ \ \nu = va^{2}Gr^{1/2}h'(t, \eta), \ w = -vaGr^{1/4}(f + h), \\
\theta(t, \eta) &= (T - T_\infty)/(T_w - T_\infty), \ \Phi(t, \eta) = (C - C_\infty)/(C_w - C_\infty), \ \Omega = \omega/va^{2}Gr^{1/2} \\
Gr &= \frac{g_0\beta(T_w - T_\infty)}{a^3\nu^2}, \ Gm = \frac{g_0\beta_c(T_w - T_\infty)}{a^3\nu^2}
\end{align*}
\]

where \(v\) is kinematic viscosity of water while \(Gr\) and \(Gm\) are thermal and mass Grashof number. The prime at the function \(f\) and \(h\) indicated the partial differential equation with respect to \(\eta\). Here \(\theta\), \(\Phi\) and \(\Omega\) are the dimensionless variable for temperature, concentration and frequency of oscillation. The partial differential equations on the equations (1) – (5) will become a dimensionless equation such that

\[
\begin{align*}
C_1f''' + C_2(f + h)f'' - C_2f'^2 + C_3[1 + \varepsilon \cos(\pi \tau)]\theta + \frac{Gm}{Gr}C_2[1 + \varepsilon \cos(\pi \tau)]\Phi = C_2\Omega \frac{\partial f'}{\partial \tau} \\
C_1h''' + C_2(f + h)h'' - C_2h'^2 + C_3c[1 + \varepsilon \cos(\pi \tau)]\theta + \frac{Gm}{Gr}C_2c[1 + \varepsilon \cos(\pi \tau)]\Phi = C_2\Omega \frac{\partial h'}{\partial \tau}
\end{align*}
\]

\[
\begin{align*}
\frac{1}{Pr \ C_5} \theta'' + (f + h)\theta' &= \frac{\partial \theta}{\partial \tau} \\
\frac{1}{Sc \ C_6} \phi'' + (f + h)\phi' &= \frac{\partial \phi}{\partial \tau}
\end{align*}
\]

Here \(Pr\) and \(Sc\) are Prandtl and Schmidt numbers where

\[
\begin{align*}
C_1 &= \frac{1}{(1 - \phi)^{2.5}}, \ C_2 = \left(1 - \phi + \frac{\phi \rho_s}{\rho_f}\right), \\
C_3 &= \left(1 - \phi + \frac{\phi (\rho \beta_s)}{(\rho \beta_f)}\right), \ C_4 = \frac{(k_s + 2k_f) - 2\phi (k_f - k_s)}{(k_s + 2k_f) + \phi (k_f - k_s)}, \\
C_5 &= \left(1 - \phi + \frac{\phi (\rho C_p_s)}{(\rho C_p_f)}\right), \ C_6 = \left(1 - \frac{\phi}{1 + \phi}\right)
\end{align*}
\]

Subject to dimensionless boundary conditions

\[
\begin{align*}
f'(\tau, 0) &= f'(\tau, 0) = 0 \\
h'(\tau, 0) &= h'(\tau, 0) = 0 \\
\theta(\tau, 0) &= \Phi(\tau, 0) = 1
\end{align*}
\]
\[ f' \to 0 \quad h' \to 0 \quad \theta \to 0 \quad \Phi \to 0 \quad \text{as} \quad \eta \to \infty \]

In the analysis, the paper studies the physical quantities of principal interest and the dimensional equations for skin frictions, Nusset number and Sherwood number which are presented as

\[
C_{fx} = \mu_{nf} \left( \frac{\partial u}{\partial z} \right)_{z=0}/\left( \rho_f v^2 a^3 x \right)
\]

\[
C_{fy} = \mu_{nf} \left( \frac{\partial v}{\partial z} \right)_{z=0}/\left( \rho_f v^2 a^3 y \right)
\]

\[
Nu = -a^{-1} k_{nf} \left( \frac{\partial T}{\partial z} \right)_{z=0}/k_f (T_w - T_\infty)
\]

\[
Sh = -a^{-1} D_{nf} \left( \frac{\partial C}{\partial z} \right)_{z=0}/D_f (C_w - C_\infty)
\]

and by using the same semi similar transformation, the dimensionless equations coefficients of physical quantities of principal interest are

\[
\frac{C_{fx}}{Gr^{3/4}} = f''(r,0)/(1 - \phi)^{2.5}
\]

\[
\frac{C_{fy}}{Gr^{3/4}} = h''(r,0)/(1 - \phi)^{2.5}
\]

\[
\frac{Nu}{Gr^{1/4}} = -\left( \frac{k_{nf}}{k_f} \right) \theta'(r,0)
\]

\[
\frac{Sh}{Gr^{1/4}} = -\left( \frac{1 - \phi}{1 + \phi} \right) \Phi'(r,0)
\]

### 3. Result and Discussion

The system of non-dimensional partial differential equation (7)-(10) together with boundary condition (11) are analysed numerically using implicit finite difference scheme known as Keller box method. Several procedures are taken to solve the problem using Keller box method such as reducing the system to first order system, discretise the problem using central difference, linearize the system using Newton method and finally using block tridiagonal method to solve the system.

Uniform grid for both \( \tau \) and \( \eta \) are used where \( \Delta \tau = 0.1 \) and \( \Delta \eta = 0.04 \) and the solution is consider converged when the maximum absolute change between iteration is less than \( 10^{-10} \). The results were analysed in term of physical quantities of principal interest such that skin friction to analyse the flow, Nusset number to analyse the heat transfer coefficient and Sherwood number for the concentration distribution. Values for Prandtl number and Schmidt number for water and water vapour are choose as \( Pr = 6.2 \) and \( Sc = 0.68 \) [29] in these studies. The graphical results presented are marked as (a), (b), (c) and (d) such that (a) and (b) are represent the skin frictions in their directions, (c) is for the Nusset number while Sherwood number is on (d).
Figure 1. Effect of $\epsilon$ on skin friction, Nusset number and Sherwood number when $c = 0$, $\phi = 0.05$ and $\Omega = 0.2$.

Figure 2. Effect of $\epsilon$ on skin friction, Nusset number and Sherwood number when $c = 0.5$, $\phi = 0.05$ and $\Omega = 0.2$. 
Figure 3. Effect of $\varepsilon$ on skin friction, Nusset number and Sherwood number when $c = 1.0$, $\phi = 0.05$ and $\Omega = 0.2$.

Figure 4. Effect of $\varepsilon$ and $\Omega$ on skin friction, Nusset number and Sherwood number when $c = 0.5$, and $\phi = 0.05$. 
Figure 5. Effect of $\phi$ on skin friction, Nusset number and Sherwood number when $c = 0.5$, $\epsilon = 0.5$ and $\Omega = 0.2$.

Figure 1-4 show the effect of $\epsilon$ which is one of parameter influenced by g-jitter effect on the skin frictions, Nusset number and Sherwood number as time increase. All the physical quantities of principal interest consider in this problem produce an increasing and decreasing results as parameter $\epsilon$ increase. The fluctuating behaviour shows the existence of singularity solution on the flow which indicate that the flow is passing through at least one critical point.

On the other hand, stagnation point parameter presented by curvature ratio in figure 1-3 were analysed graphically. From the analysis, it is found that values chosen for the curvature ratio will produce a special case flow of stagnation point. In figure 1 (b), it is found that there are no changes at all for the skin friction on $y-$direction as parameter $\epsilon$ is increase. Value $c = 0$ indicate a cylinder surface and plane stagnation case flow is found produced at a stagnation point region. By choosing other value as in figure 3 which is when $c = 1$, another type of special stagnation case flow is produced which is known as axisymmetric stagnation case flow. Axisymmetric case flow is produce when the flow hit a spherical surface.

Frequency of oscillation $\Omega$, is another parameter that represent the presence of g-jitter effect on the flow as studies in figure 4. Two different values of $\Omega$ are studied to show difference classes presented from each of the values. From the analysis, it is found that there are significant different between larger and smaller $\Omega$ on each of the physical quantities of principal interest but expressively on Nusset number and Sherwood number. The larger value of $\Omega$ will decrease the peak values on each of the skin friction, Nusset number and Sherwood number which indicate it will converge faster than smaller value of $\Omega$.

As for studying the effect of nanofluid, nanoparticle volume friction parameter $\phi$, is analysed and presented in figure 5. The increases of nanoparticles volume friction are found increase the values of skin frictions and Nusset number but decrease with the value of Sherwood number. It is proven that by adding small amount of nanoparticles on the conventional fluid, it may increase the thermal conductivity of the fluid. On the other hand, the small particles added on the fluid may increase the frictional force on the surface of the boundary layer which contribute the increases of skin frictions values for both directions.
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