Numerical Analysis of Mass Transfer in MHD Nanoparticle Based Crude Oil Flow on a Flat Plate under Various Slip Condition

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Abstract: This work analyzed of crude oil based nanofluid of $\text{Al}_2\text{O}_3$, Cu, SWCNTs (single walled carbon nanotubes) the mass transfer in two dimensional MHD of incompressible steady, viscous and electrically conducting in the presence of magnetic field over a flat plate under various slip conditions. The result was obtained using similarity transformation and the fourth-fifth order Runge Kutta Fehlberg technique with shooting method using Maple 18. The velocity profile and the nanoparticle concentration were plotted for both low and high velocity slip conditions. Various effects of parameters were tested on the rate of skin friction and mass transfer. The effect that involves the magnetic parameter $M$, buoyancy ratio $G$, Schmidt number $Sc$, velocity slip parameter and nanoparticle volume fraction were analyzed. It was found that magnetic field with Grashof number and Schmidt number parameters are dominant on momentum and concentration dimensionless parameters. Copper with velocity slip 0.1 was higher shear stress then other materials as well as, for SWCNT with velocity slip 1.0 was lower shear stress. Furthermore, copper with velocity slip 0.1 is higher of mass transfer than other materials as well as oxide aluminium is lower compared to other materials with velocity slip 1.0.

1. Introduction
Mass transfer is referred to as a process when there is a net movement of mass at one situated area to another area. This is commonly referred to as a stream, fraction, phase or component. This net movement does take place in various processes, which are; precipitation, absorption, drying, membrane, distillation, just to mention a few. The application is very relevant in science and engineering processes such as the heat transfer engineering [1], separation engineering, reaction engineering and many subject disciples in chemical engineering [2].

The study of magneto-hydrodynamic MHD flow has essential applications in physics, chemistry and engineering. MHD deals with low frequency interactions of the plasma with the magnetic field such as Alfvén wave [3]. It is basically used in space plasmas [4], magnetically confined fusion plasma [5], [6]. Industrial equipment, such as (MHD) generators, pumps, bearings and boundary layer control are affected by the interaction between the electrically conducting fluid and a magnetic field. One of the basic and important problems in this area is the hydro-magnetic behavior of boundary layers...
along fixed or moving surfaces in the presence of a transverse magnetic field. MHD boundary layers are observed in various technical systems employing liquid metal and plasma flow transverse of magnetic fields. Heat transfer is thermal energy in transit due to a spatial temperature difference, which is classified into three major mechanisms, namely thermal conduction, thermal convection and thermal radiation. Thermal conduction and thermal convection involve particle, while radiation involves electromagnetics wave.

However, thermal conduction is the heat transfer through a solid, which involves a direct microscopic exchange of kinetic energy of the particle as a result of the boundary between a bi-system [7]. Thermal convection is the heat transfer from one location to another location by the bulk motion of a fluid, which includes gas or liquid after when the fluid heated is caused to flow away from the source [8]. Energy is transferred through thermal convection by bulk, or macroscopic, the motion of the fluid, due to specific molecular motion (diffusion). On the other hand, the thermal radiation heat transfer occurs due to electromagnetic wave propagation, an example of such is the heat transfer from the sun [9]. This shows that the thermal energy can be transitioned in either solid, fluid or gas. So, thermal conductivity (i.e. rate at which heat passes through a special material) of oil, water and ethylene glycol plays a crucial role in the heat transfer, used in many industrial and engineering applications to reduce operating temperature [10].

On top of that, due to the poor thermal conductivity traditional means of transferring heat fluid used, the improvement in cooling capability have been limited [11]. The recent heat transfer bulk transfer of fluid (gas or oil) is the use of nano-sized (1-100nm) solid particle, which is an additive suspended in the base fluid. This is a new technique for the enhancement of heat transfer by adding and testing conductive solids into fluids.

Stephen Choi in 1995 was the first researcher who introduced the term of nanofluids [12]. Nanofluid is referred to a liquid which contains a dispersion of submicronic solid particles, which is called nanoparticles. The fundamental objective of the using of nanoparticles is to diffuse solid particles in the fluid to boost thermal conductivity. In real-time application, nanofluid has been proved to be boosting the heat transfer more than 50%, even when the volume ratio of the nanoparticle to the base is less than 0.3% [13]. When comparing nanofluid with other base fluids, nanofluid has an upper hand in the boosting of thermal conductivity [10], [14], [15] and [16].

On top of these, many researchers have carried out research activity to improve the thermal conductivity properties so that it would behave like a fluid but has thermal conductivity as a metal by adding and testing conductive solids into fluids. Nanoparticle used are usually made of metal (Al, Cu), oxides (Al₂O₃) and SWCNTs, just to mention a few. In view of this, and because of the new additive working fluid, it is very important and necessary to study the impact of heat transfer behavior and characteristics, namely thermal conductivity, heat transfer, viscosity and so on.

In this research direction, mathematicians and physicists are among the academic researchers who contribute to the knowledge of thermal conductivity. Though, research has shown that nanofluid provides higher heat transfer boosting with respect of the base fluid, but with respect to the nanofluid thermal particles, the actual number of available experimental data in the literature is still few especially on the oil-based [17].

In this project report, our focus was to investigate the effect of velocity slip condition on momentum and the mass transfer in two dimensional MHD flow of an incompressible, electrically conducting, viscous and steady flow of nanoparticles-based crude oil nanofluid in the presence of magnetic field over a flat plate.

2. Mathematical formulation

In this work, we followed the proposed mathematical formulation which, considered that the steady flow of alumina oxide-copper-SWCNTs/crude oil nanofluid in the presence of magnetic field over a flat plate was moving with an impulsive motion[15]. The physical look of the formulation is displayed in Figure 1.
The proposed governing equations:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]  

(1)

\[
u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = v_{nf} \frac{\partial^2 u}{\partial y^2} + \frac{\sigma_{nf} \beta(x)}{\rho_{nf}} (u_{\infty} - u) + g (\beta_s)_{nf} (C - C_{\infty})
\]

(2)

\[
u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} = D_{nf} \left( \frac{\partial^2 c}{\partial y^2} \right)
\]

(3)

Along with the following boundary conditions

\[
u = v_{sf} \frac{\partial u}{\partial y}; \quad v = 0, \quad C = C_w = T_{\infty} + C_w x^\lambda \quad \text{at} \quad y = 0
\]

(4)

while for the flat plate distance from the wall, we had

\[
u \rightarrow U_{\infty} ; \quad C \rightarrow C_{\infty} \quad \text{at} \quad y \rightarrow \infty
\]

(5)

where,

\[ho_{nf} = (1 - \zeta) \rho_f + \zeta \rho_s, \quad \mu_{nf} = \frac{\mu_f}{(1 - \zeta)^2 + \zeta}, \quad (\rho C_p)_{nf} = (1 - \zeta) (\rho C_p)_f + \zeta (\rho C_p)_s,
\]

\[eta_{nf} = (1 - \zeta + \zeta \frac{\beta_s}{\beta_f})
\]

where \(v_{sf} = v_0 \sqrt{\frac{\nu_{nf}}{\nu_{nf}}} \) was interpreted as the factor of the velocity slip of the plate along with the initial measure \(v_0\). \(\sigma_s, \sigma_f\)-represents the conductivity of the circuitry/electrical for the oil-based and the nanofluid, respectively \(v_0(t)\)'s was fixed to be a constant sensor apparent for the velocity at which the penetrable apparent was examined. \(\zeta\)-the nanoparticle of solid volume fraction, \(u, v\)-velocity factor on \(x\) and \(y\) is axis directions, respectively, \(C_w\)-concentration for the nanofluid near the wall, \(T_{\infty}\)-ambient temperature of nanofluid, \(C_{\infty}\)-ambient concentration of the nanofluid, \(C\)-Nano fluid concentration, \(\rho_{nf}\)-nanofluid effective density, \(\mu_{nf}\)-coefficient of nanofluid dynamic viscosity, \((\rho C_p)_{nf}\)-nanofluid heat capacitance, \((\beta_s)_{nf}\)-solutal expansion coefficient, which define as:

The local Rayleigh number and the stream function, \(\psi\) were given as below, respectively;

\[
R_e = \frac{\nu_{nf} x}{v_{nf}}; \quad u = \frac{\partial \psi}{\partial y}, \quad v = -\frac{\partial \psi}{\partial x}
\]

(6)

However, the momentum and energy equations can be transformed into the corresponding differential equation by using the similarity transformation below;
\[ \eta = \frac{\nu}{x} \sqrt{\frac{v_{nf}^3}{v}} \]  
\[ \psi = \frac{u_{nf}^2 f'f}{\sigma} \]  
with initial/boundary conditions:

\[ f(0) = 0, \quad f'(0) = \gamma f(0)'' \quad \text{and} \quad \chi(0) = 1 \quad \text{at} \quad \eta = 0 \]  
\[ f' (\eta) \to 1 \quad \text{and} \quad \phi (\eta) \to 0 \quad \text{at} \quad \eta \to \infty \]  

where, \( g \) - gravitational acceleration, \( G_c \) - solutal Grashof number, \( Sc = \frac{v_f}{D_n} \) - Schmidt number and \( \gamma = \frac{u_{nf}V_0}{v_{nf}} \) is velocity slip condition with initial value \( V_0 \) where \( E1 = (1 - \zeta)^2 \left( 1 - \zeta + \frac{\beta_s}{\rho_f} \right) \). \( E = (1 - \zeta)^{3.5} \left( 1 - \zeta + \frac{\beta_s}{\rho_f} \right), B = (1 - \zeta + \frac{\beta_s}{\rho_f}) \), \( A = (1 - \zeta + \frac{\beta_s}{\rho_f}) \), \( M = \frac{\alpha B^2 \nu}{u_{nf} \rho_f} \) is magnetic field parameter, \( G = \frac{G_c}{(R_e)^2} = \frac{v_{nf}^3}{x^2 u_{nf}^2} \) is Buoyancy ratio parameter.

3. Numerical technique

The similarity transformation was applied to regenerate the partial differential equation (2) and (3) to ordinary differential equation (8) and (9). Throughout our simulation, Runge-Kutta method, alongside the method of shooting were applied to acquire the numerical solutions of the report. The solved governing equations, namely the momentum equation and concentration equation, were transformed at this section from its third-order to the first-order and the second-order to the first-order, respectively. The momentum equation (8) from the third-order to the first-order is transformed as giving in Equation (11) below;

\[ f(\eta) = f(\eta), f'(\eta) = u(\eta), f''(\eta) = u'(\eta) = v(\eta), f'''(\eta) = v''(\eta) = v'(\eta) \]  

Maple 18 was used as the software platform along with the boundary condition in Equation (10) coupled with Equation (8), the first-order differential question was calculated. We transformed the concentration of Equation (9) from the second-order to the first-order as given in Equation (12) below;

\[ \phi(\eta) = \chi(\eta), \phi'(\eta) = w(\eta), \phi''(\eta) = w'(\eta) \]  

Similarly, by using, Maple 18 with the boundary conditions in Equation (10) coupled with Equation (9), the first-order differential question was calculated. The thermo-physical properties of the crude oil and nanoparticles used for the simulation is displayed in Table 1.

| Nanoparticles     | \( \rho(\text{kg/m}^3) \) | \( c_p \) (J/kgk) | \( k(\text{W/mk}) \) | \( \sigma(\Omega^{-1} \text{m}^{-1}) \) |
|-------------------|-----------------|-----------------|-----------------|-----------------|
| Crude Oil         | 870             | 1988            | 120             | 0.9             |
| Copper (Cu)       | 8933            | 385             | 401             | 50.6            |
| Alumina Al\(_2\)O_3 | 3970            | 765             | 40              | 16.7            |
| SWCNTs            | 2600            | 42.5            | 6600            | 1.26            |

In order to further validate the present results, a comparison of the present numerical, Table 2 displays the result of comparison of the Schmidt number and solutal Grashof number, with the rate of skin friction and the rate of mass transfer where \( \gamma = 0.1, M = 0.5, Re = 1 \). The result was in an excellent agreement with [15].
In view of previous reference paper [15] which, focus on the solutal Grashof number define the ratio of the buoyancy parameter to the viscous force. Also examine the relation between the Schmidt with the mass diffusivity of nanofluid by increase the nanoparticle volume fraction. In our work, the article examines the relation between the effects of velocity slip condition in MHD electrical conductivity in the presence of nanoparticle volume fraction of three solid nanoparticle and crude oil as a base fluid using Tiwari-Das model for nanofluid. On the other hand investigates the effect of magnetic field, Schmidt number and solutal Grashof number parameters on the mass transfer and shear stress.

Table 2. Comparison of Schmidt number and solutal Grashof number parameters of \( f''(0) \) and \( \chi'(0) \) with table 3 P. Singh and M. Kumar where \( \gamma = 0.1, M = 0.5, Re = 1 \) [15].

| \( Sc \) | \( G_c \) | P. Singh and M. Kumar \( f''(0) \) | P. Singh and M. Kumar \( \chi'(0) \) | Present work \( f''(0) \) | Present work \( \chi'(0) \) |
|---|---|---|---|---|---|
| 0.1 | 0.1 | 0.8305 | -0.1591 | 0.8304 | -0.1596 |
| 0.3 | 0.1 | 0.8146 | -0.2541 | 0.8145 | -0.2544 |
| 0.5 | 0.1 | 0.8068 | -0.3131 | 0.8067 | -0.3136 |
| 0.7 | 0.1 | 0.8015 | -0.3588 | 0.8016 | -0.3589 |
| 1.0 | 0.1 | 0.7962 | -0.4127 | 0.7962 | -0.4133 |
| 0.5 | 0.2 | 0.8879 | -0.3211 | 0.8881 | -0.3212 |
| 0.5 | 1.0 | 1.1216 | -0.3408 | 1.1214 | -0.3412 |
| 1.0 | 0.7 | 1.2701 | -0.3525 | 1.2696 | -0.3529 |
| 1.0 | 1.0 | 1.4831 | -0.3685 | 1.4833 | -0.3686 |

4. Setting and analyzing of parameter

Several values of the parameter were numerically executed along with the boundary conditions in the equations. Here, shooting method was used to solve equations (8) and (9), along with the boundary condition (10). The method was introduced by Runge Kutta in around 1900 and has seen to have been used by different authors [18] and [19]. Magnetic field \( M \), Buoyancy ratio \( G \), Schmidt number \( Sc \), velocity slip parameter \( \gamma \) and nanoparticle volume fraction are the effects of the parameters investigated and reported in this work. The parameters were investigated with the velocity slip parameter, \( \gamma = 0.1 \), and with the velocity slip parameter, \( \gamma = 1.0 \). Figure 2 (a), Figure 2 (b), Figure 2 (c), Figure 2 (d) show the effect of magnetic field \( M \) on velocity profile with various slip conditions. Figure 2 (a) indicates an increase in the velocity with the increased magnetic field. That is for the high and low impact of velocity slip conditions. In Figure 2 (a) and Figure 2 (b) show that the profile of single-walled carbon nanotube is the lowest velocity compared to other materials with increased magnetic field.

Figure 2 (b) examines the high velocity slip parameter which led to an increase in the velocity profile especially with \( M=0.0 \), but still, the profile of the velocity for SWCNT was lower compared to other materials.

Figure 2 (c) investigates the nanoparticle concentration with an increase of the magnetic field which was high for SWCNT with \( M=0.0 \) and low for aluminium with \( M=1.0 \), this happened with the low velocity slip condition. Figure 2 (d) indicates an increase of the magnetic field which led to the decrease in the nanoparticle concentration with low and high velocity slip conditions.
Figure 2 (a). show the magnetic field parameter $M$ on the velocity profiles with velocity slip condition ($\gamma = 0.1, Sc = 0.72, c = 0.1, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01$)

Figure 2 (b). show the magnetic field parameter $M$, on the velocity profiles with velocity slip condition ($\gamma = 1.0, Sc = 0.72, Gc = 0.1, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01$)

Figure 2 (c). show the magnetic field parameter $M$, on the concentration profiles with velocity slip condition ($\gamma = 0.1, Sc = 0.72, c = 0.1, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01$)

Figure 2 (d). show the magnetic field parameter $M$, on the concentration profiles with velocity slip condition ($\gamma = 1.0, Sc = 0.72, c = 0.1, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01$)
Figure 3 (a), Figure 3 (b), Figure 3 (c), Figure 3 (d) examine the effect of the Schmidt number parameter on the velocity profile with various slip conditions. Figure 3 (a) shows the increase of the Schmidt number with low velocity slip condition which leads to the decrease of the velocity contribution, especially for SWCNT.

Figure 3 (b) with high velocity slip condition, the velocity profile decreases with the increase of the Schmidt number and the diffusivity of boundary layer thickness is big. The velocity profile for copper-crude oil was higher than other materials and for SWCNT was very low compared to copper and aluminium. This was because an increase in the momentum compared to the mass diffusion in the Schmidt number had caused a drag of the nanofluid flow. Figure 3 (c) and Figure 3 (d) examine the reduction of the nanoparticle concentration profile with the increase of the Schmidt number.

Figure 4 (a), Figure 4 (b), Figure 4 (c) and Figure 4 (d) investigate the various values of solutal Grashof number on velocity and nanoparticle concentration contribution. Figure 4 (a) and Figure 4 (b) show the increase of solutal Grashof number which defines the ratio of the species buoyancy force to the viscous force, leads to the increase in the velocity profile and high velocity slip condition. Figure 4 (c) and Figure 4 (d) exhibit the nanoparticle concentration that decreases the profile since solutal Grashof number parameter increases. Since the momentum is low and the velocity is high due to the decrease in the nanoparticle concentration with high and low slip condition.
Figure 3(c). show the Schmidt number parameter $S_c$, on the concentration profiles with the velocity slip condition ($\gamma = 0.1, M = 0.5, c = 0.1, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01$).

Figure 3(d). show the Schmidt number parameter $S_c$, on the concentration profiles with the velocity slip condition ($\gamma = 1.0, M = 0.5, c = 0.1, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01$).

Figure 4(a). show the solutal Grashof number parameter $G_c$, on the velocity profiles with velocity slip condition. ($\gamma = 0.1, Sc = 0.72, M = 0.5, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01$).

Figure 4(b). show the solutal Grashof number parameter $G_c$, on the velocity profiles with velocity slip condition. ($\gamma = 1.0, Sc = 0.72, M = 0.5, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01$).
Figure 4 (c) shows the solutal Grashof number parameter Gc, on the concentration profiles with velocity slip condition. (\gamma = 0.1, \text{Sc} = 0.72, M = 0.5, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01)

Figure 4 (d) shows the solutal Grashof number parameter Gc, on the concentration profiles with velocity slip condition. (\gamma = 1.0, \text{Sc} = 0.72, M = 0.5, Y - Cu = 0.05, Y - Al2O3 = 0.15, Y - SWCNT = 0.01)

Figure 5 (a), Figure 5 (b), Figure 5 (c) and Figure 5 (d) shows the effect of nanoparticle volume fraction parameter \(Y\), on velocity and nanoparticle concentration profile with various values of velocity slip parameter. Figure 5 (a), and Figure 5 (b) indicates increase of velocity profile with increase of nanoparticle volume fraction \(Y\) parameter that is happened for copper and oxide aluminium but not for single walled carbon nanotubes SWCNTs. The interesting of nanoparticle volume fraction \(Y\) since, Tiwari-Das Model focus on density and viscosity in Boundary layer. Therefore we see different behaviour effect from parameter on physical parameter such as volume fraction in SWCNT.

Consequently Figure 5 (a), and Figure 5 (b) shows the velocity profile decrease in SWCNT in opposite to other materials. Figure 5 (c) and Figure 5 (d) investigates the effect of nanoparticle volume fraction \(Y\), parameter on concentration profile which increase of nanoparticle volume fractions led to decrease of mass transfer for various velocity slip parameter, due to increased viscosity and nanoparticle adhesion to the wall when increased nanoparticle volume fraction.

Figure 6 (a) and Figure 6 (b) show the effect of nanoparticle volume fraction \(Y\), on the shear stress \(f''(0)\) with different values of velocity slip condition. Figure 6 (a) shows the increase of the shear stress up to \(\eta = 1.0\) and then decreases, similarly for Figure 6 (b) that shows the increase of the shear stress up to \(\eta = 0.534\) and then decreases, asymptotically as the solutal Grashof number that increases the nanoparticle concentration gradient \(\chi'(0)\).

Figure 7 (a) and Figure 7 (b) show the effect of Schmidt number on the nanoparticle concentration gradient (the rate of mass transfer) on various values of velocity slip condition. Schmidt number is used to characterize the fluid flow in which there are simultaneous momentum and mass diffusion process. It is physically related to the thickness of the hydrodynamic layer and mass transfer boundary layer. Figure 7 (a) observes that the effect of Schmidt number on the concentration gradient decreases with an increase in the Schmidt number, and the concentration gradient decreases up to \(\eta = 2.415\) as the value of the Schmidt number increases with low velocity slip condition. Figure 7 (b) shows the decrease of the nanoparticle concentration profile up to \(\eta = 2.146\) and then increases for the high velocity slip condition.
Figure 5 (a). show the effect of nanoparticle volume fraction parameter, on velocity dimensionless with velocity slip condition ($\gamma = 0.1$, $Sc = 0.72$, $c = 0.1$, $M = 0.5$)

Figure 5 (b). show the effect of nanoparticle volume fraction parameter, on velocity dimensionless with velocity condition ($\gamma = 1.0$, $Sc = 0.72$, $c = 0.1$, $M = 0.5$)

Figure 5 (c). show the effect of nanoparticle volume fraction parameter, on concentration dimensionless with velocity slip condition ($\gamma = 0.1$, $Sc = 0.72$, $c = 0.1$, $M = 0.5$)

Figure 5 (d). show the effect of nanoparticle volume fraction parameter, on concentration dimensionless with velocity slip condition ($\gamma = 1.0$, $Sc = 0.72$, $c = 0.1$, $M = 0.5$)
Figure 6 (a). show the effect of nanoparticle volume fraction parameter, on the shear stress with velocity slip condition $\gamma=0.1, Sc = 0.72, c = 0.1, M = 0.5$

Figure 6 (b). show the effect of nanoparticle volume fraction parameter, on the shear stress with velocity slip condition $\gamma=1.0, Sc = 0.72, c = 0.1, M = 0.5$

Figure 7 (a). show the effect of the Schmidt number parameter $Sc$, on the concentration gradient profile with velocity slip condition ($\gamma = 0.1M = 0.5, c = 0.1, Y_Cu = 0.05, Y_{Al2O3} = 0.15, Y_{SWCNT} = 0.01$)

Figure 7 (b). show the effect of the Schmidt number parameter $Sc$, on the concentration gradient profile with velocity slip condition ($\gamma=1.0, M = 0.5, c = 0.1, Y_Cu = 0.05, Y_{Al2O3} = 0.15, Y_{SWCNT} = 0.01$)
Figure 8. The effect of nanoparticle volume fraction $\Upsilon$, on shear stress for various velocity slip parameter.

Figure 8 investigates the effect of nanoparticle volume fraction on shear stress $f''(0)$ for each material with the base fluid in various velocity slip. Figure 8 shows increase of nanoparticle volume fraction led to increase of shear stress especially with velocity slip equal 0.1. On the other hand, for copper with velocity slip 0.1 was higher shear stress than other materials as well as, for SWCNT with velocity slip 1.0 was lower shear stress.

Figure 9 investigates concentration gradient or the rate of mass transfer when increase of nanoparticle volume fraction. Figure 9 shows that for copper with velocity slip 0.1 is higher of mass transfer than other materials as well as oxide aluminium is lower compared to other materials with velocity slip 1.0.
Figure 9. The effect of nanoparticle volume fraction $\text{Y}$ on the rate of mass transfer for various velocity slip parameter.

5. Conclusion
The analysis of mass transfer in two-dimensional (MHD) flow of nanoparticles-based crude oil has been investigated, both theoretically and numerically. The project's three objectives have been achieved, where the association of velocity and nanoparticle concentration with shearing stress and the rate of mass transfer among the nanofluids over a flat plate under slip condition were presented in terms of figures and tables.

The results obtained when compared were excellent. The analysis displayed various figures for each equation, which were the velocity profile and the concentration. The figures were made and illustrated for both low velocity slip condition and high velocity slip condition. Various effects of parameters were tested. The effects that involved in the magnetic parameter, nanoparticle volume fraction $\text{Y}$, $\text{G}$, Schmidt, $\text{Sc}$, were analyzed at each section.

Different variable of the parameters was chosen as manipulated and other parameters as the constant variable, we were able to get a lot of results and reaction, which include;

- For magnetic field parameter with low and high velocity slip condition. It observed that increase the velocity profile on magnetic field and decrease the nanoparticle concentration.
- For Schmidt number parameter with low and high velocity slip condition. The velocity and nanoparticle concentration parameters were decreased. The effect of Schmidt number parameter on the rate of mass transfer was decreased and then increased.
- For Grashof number with low and high velocity slip conditions, the velocity profile was increased and decreased for nanoparticle concentration.
Nanomaterials analysis: in this work nanoparticle such as copper Cu, oxide aluminum Al2O3 and single walled carbon nanotube SWCNT with base fluid such as crude oil examine the rate of mass transfer and viscosity using Tiwari-Das model depending on physical properties such as density, thermal conductivity and specific heat under two dimensional MHD slip flow. copper with velocity slip 0.1 was higher shear stress then other materials as well as, for SWCNT with velocity slip 1.0 was lower shear stress. Furthermore, copper with velocity slip 0.1 is higher of mass transfer than other materials as well as oxide aluminium is lower compared to other materials with velocity slip 1.0.

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