MHD VISCOS NANOFLUID FLOW WITH BASE FLUIDS’ WATER AND KEROSENE IN THE PRESENCE OF A TEMPERATURE GRADIENT DEPENDENT HEAT SINK WITH PRESCRIBED HEAT FLUX

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Abstract—MHD viscous nanofluid flow with viscous dissipation and thermal radiation in the presence of a temperature gradient dependent heat sink is analyzed. Hence, this work mainly deals nano fluids with nanoparticles Cu, Ag, Al, Al₂O₃, TiO₂ and with base fluids’ water and kerosene. Prescribed heat flux boundary condition is employed on the porous surface. Suitable similarity transformations are introduced for converting nonlinear partial differential equations into the nonlinear ordinary differential equations and then solved by analytically. The influence of various physical parameters over the velocity and temperature of nanofluids Cu-water and Cu-kerosene are examined by utilizing graphs. Skin friction coefficient and Nusselt number of various nanofluids tabulated and analyzed. It is found that skin friction coefficient and heat transfer rate of kerosene based nanofluid is higher than the water based nanofluid in the presence of considered physical effects.

Keywords—Porous surface; Nanofluid; Viscous dissipation; Thermal radiation; Heat flux.

I. INTRODUCTION

One of the major studies in fluid dynamics is MHD wherein magnetic fields give importance in the flow of electrically conducting fluid. The study of boundary layer flow of fluid in MHD has a wide range of applications in the field of industry, scientific, astrophysical, geophysical and engineering. Chaim (1993) investigated Magneto hydrodynamic boundary layer flow due to a continuous moving flat plate. Liu (2005) studied heat transfer for a hydro magnetic flow over a stretching sheet. The MHD boundary layer flow of a nanofluid with viscous dissipation and radiation is investigated by Wahiduzzaman et al. (2015). Narayana et al. (2017) analyzed MHD nanofluid flow with thermal radiation and heat source/sink past stretching sheet.

In the last two decades voluminous research has been done on the flow through porous media. The applications of a porous media are there in various fields such as hydrology, environmental pollution, insulation of building and equipment, energy storage and recovery, geothermal reservoirs, nuclear waste disposal, chemical reactor engineering and the storage of heat generating materials such as grain, coal and geophysics. Steady flows through porous media investigated by Greenkorn (1981). Flow over exponentially stretching sheet through porous media with a heat source/sink is studied by Swain et al. (2015). The latest developments in nanofluid flow and heat transfer in porous media are analyzed by Kasaeian et al. (2017).

Pandey and Kumar (2017) examined the effects of thermal radiation and viscous dissipation on nanofluid flow over a stretching cylinder in a porous medium.


So far no significant contribution has been made on MHD viscous nanofluid flow with dissipation and radiation in the presence of a temperature gradient dependent heat sink with prescribed heat flux. Hence, this work mainly deals nano fluids with nanoparticles Cu, Ag, Au, Al, Al₂O₃, TiO₂ and with base fluids’ water and kerosene. Suitable similarity transformations are introduced for converting the conservation equations of the problem then solved by analytically. The impact of different physical parameters over the velocity and temperature of nanofluid Cu-water and Cu-kerosene nanofluids is analyzed by utilizing diagrams. Skin friction coefficient and Nusselt number of various nanofluids with nanoparticles Ag, Al, Al₂O₃ and TiO₂ are analyzed with the help of tables.

II. FORMULATION OF THE PROBLEM

Analysis of Heat transfer in the MHD boundary layer flow of a Nanofluid with dissipation and radiation in the presence of a temperature gradient dependent heat sink is formulated. Two types of base fluids (water and kerosene) and 5 types of nanoparticles Copper(Cu), Silver(Ag), Aluminum(Al) Aluminum Oxide(Al₂O₃) and Titanium Oxide(TiO₂) are considered. Porous Surface with prescribed heat flux is considered as the surface.
boundary condition. Physical model of the problem is shown in Fig.1. The conservation equations of the problem with boundary conditions can be expressed as follows.

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

(1)

Equation of Momentum
\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = v_n f \frac{\partial^2 u}{\partial y^2} - \frac{\nu_n f}{\kappa_p} \frac{\partial u}{\partial y} - \frac{\sigma_n f}{\rho_n f} u
\]

(2)

Equation of Energy
\[
\frac{\partial T}{\partial x} + \frac{\partial v}{\partial y} = \frac{\nu_n f}{\kappa_p} \frac{\partial^2 T}{\partial y^2} + \frac{\mu_n f}{(\rho c_p)_n f} \left( \frac{\partial u}{\partial y} \right)^2 - \frac{1}{(\rho c_p)_n f} Q^r \frac{\partial T}{\partial y}
\]

(3)

where the term \(-Q^r \frac{\partial T}{\partial y}\) represents temperature gradient dependent heat sink and \(Q = bQ^r\) is the volumetric rate is a linear function of the temperature field (Veena et al., 2011). The Rosseland diffusivity approximation for the radiation heat flux term is \(q_r = \frac{-16\alpha^2 T^3}{3\kappa_n f}\) (Raptis et al., 2004), where \(\sigma^*\) is the Stefan Boltzmann constant and \(\kappa_n f\) is the mean absorption coefficient of the nanofluid.

\[
\alpha_n f = \frac{k_n f}{(\rho c_p)_n f}, \quad \mu_n f = \frac{\mu_n f}{\rho_n f}, \quad k_n f = (1 - \phi) k_f + \phi k_n, \quad \rho_n f = (1 - \phi) \rho_f + \phi \rho_n
\]

(4)

\[
(\rho c_p)_n f = (1 - \phi) (\rho c_p)_f + \phi (\rho c_p)_n
\]

(5)

\[
\frac{k_n f}{k_f} = \frac{k_n f + 2\phi k_f}{k_n f + 2\phi k_f} (6)
\]

(6)

which boundary conditions are
\[
\begin{align*}
&u = \alpha x, \quad v = -V_0, \quad k_f \frac{\partial T}{\partial y} = q_w = E_0 x^2 \quad \text{at} \quad y = 0 \\
&u \to 0, \quad T \to T_{\infty} \quad \text{as} \quad y \to \infty
\end{align*}
\]

(7)

(8)

where \(\alpha\) is dimensional constant and \(V_0\) is the constant suction velocity, \(E_0\) positive constant, \(B_0\) applied magnetic field, \(K_p\) permeability of the medium, \(T\) temperature of the dynamic fluid, \(T_{\infty}\) temperature away from the surface \(q_w\) rate of heat transfer (kW/m²), \(\alpha_n f\) thermal diffusivity of the nanofluid, \((c_p)_n f\) specific heat capacitance of the nanofluid (J/kg.K), \((c_p)_f\) specific heat capacitance of the base fluid (J/kg.K), \((c_p)_n\) specific heat capacitance of the nanoparticle (J/kg.K), \(k_n f\) thermal conductivity of nanofluid, \(k_f\) thermal conductivity of base fluid (W/mK), \(k_s\) thermal conductivity of nanoparticle (W/mK), \(\mu_n f\) dynamic viscosity of nanofluid (Pa.s), \(\mu_f\) dynamic viscosity of base fluid (Pa.s), \(\rho_n f\) density of the nanofluid (kg/m³), \(\rho_f\) density of the basefluid (kg/m³), \(\nu_n f\) kinematic viscosity of the nanofluid (m²/s), \(\nu_f\) kinematic viscosity of the base fluid (m²/s), \(\nu_s\) kinematic viscosity of the nanoparticle (m²/s).

Suitable similarity transformation is introducing for converting the Eqs. (1)–(3) in to the nonlinear ordinary differential equations as follows
\[
\psi = (n f)^{0.5} x f(\eta), \quad \eta = \frac{a}{n f}, \quad u = \frac{\partial \psi}{\partial y}
\]

(9)

\[
v = -\frac{\partial \psi}{\partial y}, \quad f - T_{\infty} = \frac{\rho_n f}{k_f} \sqrt{\frac{v f}{a}} q(\eta)
\]

(10)

The resulting nonlinear differential equations are given by
\[
f'''' + \phi_1 (f f'''' - f'') - \left( \frac{1}{\eta_p} + M \right) f' = 0
\]

(11)

\[
g'' + D (1 + g) f' g' - 2 D f' g = - \frac{E_0}{\phi_f} f''
\]

(12)

\[
f' (\eta) = 1, f(\eta) = S, g' (\eta) = -1 \quad \text{at} \quad \eta = 0
\]

(13)

\[
f' (\eta) = 0, g(\eta) = 0 \quad \text{as} \quad \eta \to \infty
\]

(14)

\[
\phi_1 = (1 - \phi)^{2.5} \left( 1 - \phi + \phi \frac{\rho_n f}{\rho_f} \right), \quad \phi_2 = (1 - \phi) + \phi \frac{\rho_n f}{\rho_f}
\]

(15)

\[
D = w \phi_3, k_n f, \frac{\rho_n f}{\rho_f}, \frac{\Phi_3}{3} = (1 - \phi) \left( 1 - \phi + \phi \frac{\rho_n f}{\rho_f} \right)
\]

(16)

where \(\Phi_3 = \frac{3}{16} \frac{\rho f}{\rho_n f} \frac{R_d}{4 a (\rho f)^2} \) (suction parameter), \(N = \frac{w}{\rho f} \frac{R_d}{4 a (\rho f)^2} \) (magnetic parameter).

\[\text{III. SOLUTION OF THE PROBLEM}\]

Confluent hyper geometric function is used for finding analytic solution of the energy equation. The exact solution of the momentum equation with the boundary conditions (8) is obtained by
\[
f(\eta) = S + \frac{1 - e^{-E \eta}}{E}, \quad f'(\eta) = e^{-E \eta}
\]

(17)

\[
\text{where}
\]

\[
E = \frac{1}{2} \left( s + \sqrt{s^2 + 4(1 - \phi)^{1.5} \left( 1 - \phi + \phi \frac{\rho_n f}{\rho_f} + R_1^2 + M \right) \right)
\]

(18)

In order to solve the energy Eq. (7) new variables \(\xi\) is defined respectively as follows
\[
\xi = \frac{s E^{\frac{1}{2}}}{D (1 + \eta)}
\]

(19)

The Eq. (7) can be written by using the Eq. (10) as
\[
\xi = \frac{d g}{d \xi} + \left[ (1 - K_1) - \xi \frac{d g}{d \xi} \right] + S_1 g = -\frac{E_0 \xi^{1.5}}{\xi^{1.5} + \phi_3}, \quad g(\xi) = \frac{-z}{\xi^{1.5} + \phi_3}
\]

(20)

\[
R_1 = \frac{\rho_n f}{\rho_f}, \quad R_2 = \frac{\kappa_n f}{\kappa_f}, \quad R_3 = \frac{\mu_n f}{\mu_f}
\]

(21)

Using the Eq. (12), the solution of Eq. (11) is
\[
g(\xi) = \frac{E_0 \xi^{1.5}}{D (1 + \eta) \Phi_3} - \left[ \eta^{1.5} \left( \frac{\xi^{1.5} + \phi_3}{\eta^{1.5} + \phi_3} \right) \right]
\]

(22)

\[
\text{where}
\]

\[
\xi = \left[ \frac{E_0 \xi^{1.5}}{D (1 + \eta)} \right] \left( \frac{\xi^{1.5} + \phi_3}{\eta^{1.5} + \phi_3} \right)
\]

(23)

\[
\text{IV. RESULTS AND DISCUSSIONS}
\]

From the solution of the governing equations, it can be noticed that with increasing \(R_1\), \(R_2\), \(R_3\), \(\phi_1\), \(\phi_2\), \(\phi_3\), and \(M\) the solution of Eqs. (1)–(3) becomes stable.
The Eq. (13) can also be expressed as
\[ g(\eta) = -\frac{E_0D(1+Q)e^{-2\eta}}{S_1(S_1-K_1)\phi_t} + \frac{K_1\varepsilon_{Kr}[K_1-S_1K_1+1-K_2e^{-2\eta}]e^{-\eta}}{[K_1\varepsilon_{Kr}[K_1-S_1K_1+1-K_2e^{-2\eta}]e^{-\eta}]} \]
where
\[ K_1 = \frac{D(1+Q)}{E^2}[E^2 - R_p^{-1}], S_1 = \frac{2}{(1+Q)}, K_2 = \frac{D(1+Q)}{E^2}. \]

The physical quantities of interest are the local skin friction coefficient and Nusselt number which represent shear stress and the rate of heat transfer, which are given by
\[ c_f = -\frac{1}{(1-\phi^2)}f''(0), Nu = \frac{k_w}{k_f} \frac{1}{g(0)} \]
\[ \eta = \frac{E_0D(1+Q)}{S_1(S_1-K_1)\phi_t} + \frac{K_2\varepsilon_{Kr}[K_1-S_1K_1+1-K_2e^{-2\eta}]e^{-\eta}}{[K_1\varepsilon_{Kr}[K_1-S_1K_1+1-K_2e^{-2\eta}]e^{-\eta}]} \]

IV. RESULTS AND DISCUSSION
To exhibit the physical significance of the present study, the influence of pertinent physical parameters such as suction parameter \( S \), magnetic parameter \( M \), nanoparticle volume fraction \( \phi \), heat sink parameter \( Q \), Eckert number \( E_r \), radiation parameter \( R_d \) of Cu-water and Cu-Kerosene nanofluids is taken into consideration and the outcomes are indicated graphically. Skin friction coefficient and Nusselt number in various nanofluids are also calculated. Physical properties of the base fluids and nanoparticles are exhibited in Table 1.

As a validation of the accuracy of the present results, comparison study is made through the Table 2. The results of \(-f''(0)\) is observed to be a great concurrence with the previously reported work in a few special cases.

Figures 2 to 4 illustrate the effect of \( S, M \) and \( \phi \) on the velocity profile of the Cu-water and Cu-kerosene nanofluids. It is depicted that the velocity decreases as \( S \) and \( M \) increase, and increases as \( \phi \) increase respectively. This is due to the fact that suction reduces the thickness of the momentum boundary layer, strengthening the magnetic field cause to induce the opposite force of the flow, which slow down the motion of the flow and presence of solid nanoparticles that thickening of the momentum boundary layer. Figure 5 depicts the effect of \( S \) on the temperature profile. It is recognized that the increased value of the \( S \) corresponds to decrease the temperature within the fluid. Due to the suction fluid particles move towards the surface, which reduce the thickness of the thermal boundary layer. Figure 6 displays the influence of the \( \phi \) on temperature profile. In both the cases of Cu-water and Cu-kerosene nanofluid, it is noticed that the influence of the \( \phi \) is to increase the temperature.

Table 1. Thermo physical properties of water and nanoparticles (Domkundwar and Domdunwar, 2004)

<table>
<thead>
<tr>
<th></th>
<th>Density ( \rho ) (kg/m(^3))</th>
<th>Specific heat ( C_p ) (J/kg K)</th>
<th>Thermal conduc- ( K ) (W/m K)</th>
<th>Prandtl Number ( \nu )</th>
<th>Heat Transfer Parameter ( \phi )</th>
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<tbody>
<tr>
<td>Water</td>
<td>997.1</td>
<td>4179</td>
<td>0.613</td>
<td>6.2</td>
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<tr>
<td>Kerosene</td>
<td>783</td>
<td>2090</td>
<td>0.145</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>8933</td>
<td>385</td>
<td>401</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>10500</td>
<td>235</td>
<td>429</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>2710</td>
<td>913</td>
<td>201</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Al(_\text{O}_2)</td>
<td>3970</td>
<td>765</td>
<td>40</td>
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<tr>
<td>Ti(_\text{O}_2)</td>
<td>4250</td>
<td>686.2</td>
<td>8.9538</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Velocity profile for various \( S \).

Fig. 3. Velocity profile for various \( M \).

Fig. 4. Velocity profile for various \( \phi \).
The effect of $M$ and $\phi$ on skin friction coefficient of both Cu-water and Cu-kerosene nanofluids is exhibited in Figs. 10 and 11. It is shown that the skin friction coefficient increases when improved values of $M$ and $\phi$ in both fluids. Skin friction coefficient physically refers to the ratio between local shear stress to characteristic dynamics pressure. Shear/yield stress increases with the increasing value of $M$ and $\phi$. However, the magnitude of the skin friction coefficient of Cu-kerosene is higher than Cu-water nanofluid.

The influence of various parameters $M$ and $\phi$ on the Nusselt number is portrayed in Figs. 12 and 13. In both the cases Cu-water and Cu-kerosene nanofluids, it is identified that the Nusselt number increases with increasing values of $\phi$ and decreases with increasing value of $M$. This is due to the fact that the rate of heat transfer rate is enhanced while increasing values of $\phi$ along with $R_p$ and reduced with the increase of $M$ along with $\phi$. It is also viewed that the Nusselt number of Cu-kerosene is significantly higher than that of Cu-water nanofluid.

Fig. 5. Temperature profile for various $S$.

Fig. 6. Temperature profile for various $\phi$.

Fig. 7. Temperature profile for various $Q$.

Fig. 8. Temperature profile for various $R_p$.

Fig. 9. Temperature profile for various $E_c$.

Fig. 10. Skin friction coefficient for various $M$.

Fig. 11. Skin friction coefficient for various $\phi$. 

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with base fluids water and kerosene for various values of nanofluid with nanoparticles Ag, Al,

Table 2. Comparison of skin friction coefficient \( f(\cdot) \) with the previously reported works \((S=0, R_{p}=0)\)

<table>
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<tr>
<th></th>
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<tbody>
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Table 3. Skin friction coefficient of various nanofluids.

**WATER BASED NANOFLUID**

<table>
<thead>
<tr>
<th>( \phi )</th>
<th>Cu–Water</th>
<th>Ag–Water</th>
<th>Al2O3–Water</th>
<th>TiO2–Water</th>
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**TITANIUM OXIDE**

<table>
<thead>
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<th>( \phi )</th>
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<th>Ag–Water</th>
<th>Al2O3–Water</th>
<th>TiO2–Water</th>
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</thead>
<tbody>
<tr>
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<td>2.48507</td>
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</table>

Table 4. Nusselt numbers of various nanofluids.

**WATER BASED BASED NANOFLUID**

<table>
<thead>
<tr>
<th>( \phi )</th>
<th>Cu–Water</th>
<th>Ag–Water</th>
<th>Al2O3–Water</th>
<th>TiO2–Water</th>
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<td>1.81089</td>
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<td>1.57701</td>
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<td>1.81089</td>
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</table>

Table 3 displays the skin friction coefficient of the nanofluid with nanoparticles Ag, Al, Al2O3, and TiO2 and with base fluids water and kerosene for various values of \( \phi, M, S \) and \( R_{p} \). It is noticed that, an increase in the values of \( \phi, M \) and \( S \) enhances the skin friction coefficient of all the above said nanofluids but the effect of \( R_{p} \) on it is decreased. It is also pointed out that the skin friction coefficient of nanofluid with base fluid kerosene is relatively higher than that of nanofluids with base fluid water.

The influence of the parameters \( \phi, M, S \) and \( R_{p} \) on the
Nusselt number of the nanofluid with nanoparticles Ag, Al, Al₂O₃, and TiO₂ and with base fluids water and kerosene are shown through the Table 4. From the table it is clear that the Nusselt number increases with the increasing the values of φ and R₀ and decreases while increasing values M and S. It is also identified that the Nusselt number of nanofluid with base fluid kerosene is significantly higher than that of nanofluids with base fluid water.

V. CONCLUSIONS
The flow of MHD viscous nanofluid with nanoparticles Cu, Ag, Al, Al₂O₃, and TiO₂ and with base fluids’ water and kerosene are analyzed. Heat transfer with viscous dissipation, thermal radiation in the presence of a temperature dependent heat sink subject to prescribed heat flux has been carried out through this paper. The present study summarized as follows

1) An increase in the value of the nanoparticle volume fraction caused in an enhancement of the fluid velocity, but the increasing values of magnetic parameter and suction parameter declined the velocity.
2) The fluid temperature increases while increasing values of the nanoparticle volume fraction and Eckert number and decreases with the increasing values of suction parameter, heat sink parameter and radiation parameter.

The skin friction coefficient and Nusselt number of the nanofluid with nanoparticles Cu, Ag, Al, Al₂O₃ and TiO₂ and with base fluids’ water and kerosene for various values of the nanoparticle volume fraction, suction parameter, magnetic parameter and permeability parameter are analyzed.

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