Research Article

Scrutinization of Slip Due to Lateral Velocity on the Dynamics of Engine Oil Conveying Cupric and Alumina Nanoparticles Subject to Coriolis Force

Mubashar Arshad,1 Azad Hussain,1 Ali Hassan,1 Hanen Karamti,2 Piotr Wróblewski,3,4 Ilyas Khan,5 Mulugeta Andualem,6 and Ahmed M. Galal7,8

1Department of Mathematics, University of Gujrat, Gujrat 50700, Pakistan
2Department of Computer Sciences, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University, P.O.Box 84428, Riyadh 11671, Saudi Arabia
3Faculty of Engineering, University of Technology and Economics H. Chodkowska in Warsaw, Jutrzenki 135, 02-231, Warsaw, Poland
4Faculty of Mechatronics, Armament and Aerospace, Military University of Technology, Ul. Gen. Sylwestra Kaliskiego 2, 00-908, Warsaw, Poland
5Department of Mathematics, College of Science Al-Zulfi, Majmaah University, Al-Majmaah 11952, Saudi Arabia
6Department of Mathematics, Bonga University, Bonga, Ethiopia
7Department of Mechanical Engineering, College of Engineering in Wadi Alldawasir, Prince Sattam Bin Abdulaziz University, Riyadh, Saudi Arabia
8Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, P.O 35516, Mansoura, Egypt

Correspondence should be addressed to Mubashar Arshad; imbashrii@gmail.com

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This study is an attempt to investigate the three-dimensional flow of engine oil-based nanofluid under the impact of rotation and partial slip phenomenon over a stretchable surface. Partial slip condition is incorporated into the system at boundaries and the arising quotient of angular speed to stretching constant is regarded as rotation impression on freely moving three-dimensional flow of copper oxide-engine oil and aluminum oxide-engine oil nanofluid. The designed problem has been tackled numerically with the boundary value problem technique, this numerical mechanism requires one to transform the flow governing highly nonlinear PDEs into first-order differential equations along with associated boundary conditions. This procedure is carried out by employing a suitable similarity transformation. The investigation determines the impact of slip and rotation on primary and secondary velocity profiles, shear stress rates, and heat transfer coefficient. Minimum skin friction and Maximum Nusselt number has been observed for CuO – Engine Oil nanofluid under partial slip parameter as compared to Al2O3 – Engine Oil nanofluid. Reduced skin coefficients were achieved for both nanofluids. Moreover, the outcomes of the study have been related with already available literature and were found in good agreement.

1. Introduction

Due to enhanced thermal performance, prospective advantages, and applications in different industries such as microelectronics, microfluidics, transportation, manufacturing, medical, and so on, several researchers are focused on the field of nanotechnology in recent years. Many research centers around the globe have established research facilities dedicated to the development of nanofluids. Crane [1] was the first who inspected the rotating flow over the
stretching surface. This field of investigation was discovered to be quite fascinating and is currently being investigated under various physical limitations. Fang & Aziz [2] studied viscous flow owing to second-order slip velocity above a stretchable sheet. Hayat et al. [3] examined the 3D visco-elastic fluid flow above the stretching surface. Li et al. [4] have discussed the consequence of variable temperature transmission on Non-Newtonian fluid flow. Thakkar and Nath [5] elaborated on the unsteady rotating fluid flow above a stretchable sheet in the presence of a magnetic effect. Anantha et al. [6] discovered the magneto-hydrodynamic flow of micropolar fluid over a stretchable surface taking into account viscous dissipation with a improved heat flux model. Wang et al. [7] analyzed the viscous flow due to stretching sheets with suction and surface slip effect. Kumari and Nath [8] gave the analytical result of three-dimensional unsteady magneto-hydrodynamic boundary layer flow and heat transmission over a stretchable surface. Takhar and Nath [9] described the magnetic field impact for unsteady rotating fluid flow over an stretching sheet. Anderson et al. [10] described the heat transmission for the unsteady stretchable surface.

Choi presented the idea of enhancing the thermal conductivity of fluids by using nanoparticles. Patel et al. [11] experimentally explored the thermal conductivity improvement by using oxide nanoparticles in nanofluid. Such fluids proved to be more effective and efficient when compared to conventional fluids like water and ethylene glycol. Tawfik [12] gave an experimental review on applications and thermal conductivity improvement of nanofluids. Singh et al. [13] described the performance for carbon nanotubes-based fluids under the high temperature and high pressure. Lakshminisha et al. [14] deliberated heat and mass transmission for unsteady flow in three dimension above the continuously stretchable surface. Ali et al. [15] made finite element simulation for three-dimen sional micropolar nanofluid flow with multislip effects.

The notion nanofluid was accessed by Choi and Eastman first time in the year 1995. They discovered a mechanism through which the temperature conductivity of a conventional fluid can be improved. This process involves the distribution of nanometer-sized particles into the host base fluid, this addition of nano-particle enhances the thermal transmission \( k_{nf} > k_f \) of the formed fluid termed “nanofluid.” Recently, a new phenomenon has been discovered, known as “Hybrid nanofluids.” These nanofluids are formed when more than one nano-meter sized nanoparticle is distributed in the base fluid, as a result, an abrupt upsurge in thermal conductivity \( k_{nf} > k_{nf} \) of the formed fluid occurs. Mahanta and Shaw [16] studied the Casson fluid flow with convective boundary conditions above the stretching surface. Bagherzadeh et al. [17] gave the compet ency of hybrid nanofluids. Hussain et al. [18] have carried out a computational investigation on three-dimensional rotating nanofluid flow with the mutual effect of nonlinear radiation and magnetic force. Arshad et al. [19] have described the impact of thermophoresis and Brownian diffusion on rotating nanofluids in the presence of chemical reactions and magnetization.

Hussain et al. [20] have introduced a comsolic model for compressible time-dependent fluid flow. Hassan et al. [21] have elaborated on different hybrid nanofluids over rotating cone for enhanced heat transfer coefficient with radiative and magnetic field effect. Hussain et al. [22] have examined heat transportation in hybrid nanofluids using carbon nanotubes over a rotating cone. Hassan et al. [23] have studied composite carbon nanotube and silver nanoparticles over the spinning body for a prescribed wall temperature case. Hussain et al. [24] investigated two distinctly positioned elliptic cylinders for heat transport enrichment. Many researchers worked on nanofluids under different effects and geometry [25–28]. Oudina [29] provided convective heat transmission of titania based nanofluid in an annulus cylinder with a distinct heat source. Abbas et al. [30] described the heat and mass transfer of nanofluid over a moving rotating plate incorporating nanoparticles shape factor. Swain et al. [31] illustrated the effect of hybrid nanoparticles on the non-linear porous shrinking surface with slip boundary and chemical reaction.

Many researchers [32–36] have made their investigations according to their area of interest using different geometries and effects. Haider et al. [37] examined the rotating cone fluid flow to assess the heat and mass transfer by numerical approach. Nasirzadehroschenin et al. [38] used CNT nanofluid in a tube for a better temperature transfer rate. Arshad et al. [39] gave an analysis for heat and mass transmission with chemical reaction above an infinite stretching surface. Wang et al. [40] gave DTM-Pade and LDM approximations above inclined permeable fin for convective and radiative temperature transmission.

The objective of the current study is the numerical investigation of the heat transmission possessions and velocity of rotating nanofluid over a stretchable surface in the incidence of a partial slip. In this study physical model, i.e., the single-phase nanofluid model is utilized to deliberate the problem. Through a deep literature review, no one has described the impact of rotation and partial slip on three-dimensional engine oil-based nanofluid with CuO and Al₂O₃ over the linear stretching surface in the presence of slip. Such flows are useful in a variety of applications in up-to-date devices, e.g., cooling of electronic chips, hot rollers, plasma flow, and geothermal engineering.

This motivates one to examine the effect of incorporating conditions of partial slip and rotation on these opted specific nanofluids. Thus, to study the influence of such parameters following research questions have been designed:

(a) What is the result of increasing partial slip parameter on primary and secondary velocity profiles for both CuO – Engine Oil and Al₂O₃ – Engine Oil nanofluids with fixed volume fraction of nanoparticles and rotation value

(b) How the increment in slip parameter does effects the thermal boundary layer, skin coefficients, and heat
transfer rates of CuO–Engine Oil and Al2O3–Engine Oil nanofluids

(c) How does rotation affect the velocity and temperature constituents of CuO–Engine Oil and Al2O3–Engine Oil, and how does it affect important coefficients like skin friction and Nusselt number

(d) Do the current outcomes provide a good agreement with already published previous results

2. Formulation of the Problem

Consider incompressible engine oil-based nanofluid is flowing over a flat stretchable sheet in the region \( z \geq 0 \) which is rotating along the \( z \)–axis with fixed angular speed \( \Omega \). Alongside the \( x \)-axis, two identical and opposite forces are applied such that the surface is stretched at a speed \( U(x) \), strictly proportional to the distance from the origin at \( x = 0 \). The nanofluid is subjected to conditions of slip-flow. Figure 1 below, describes the flow configuration and coordinate system of the present problem.

2.1. Flow Governing Equations. The flow governing the three-dimensional flow of nanofluids above the surface is derived from classical Naiver-Stokes for incompressible viscous flow. The continuity, conservation of momentum, and energy equation along with boundaries are given as follows:

\[
\begin{align*}
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} &= 0, \\
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial (\rho u v)}{\partial z} + 2\Omega v &= \frac{\mu_{nf}}{\rho_{nf}} \frac{\partial^2 v}{\partial z^2}, \\
\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} + \frac{\partial (\rho u v)}{\partial z} + 2\Omega v &= \frac{\mu_{nf}}{\rho_{nf}} \frac{\partial^2 u}{\partial z^2}, \\
\frac{\partial w}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial (\rho u v)}{\partial z} + 2\Omega v &= \frac{\mu_{nf}}{\rho_{nf}} \frac{\partial^2 w}{\partial z^2}, \\
\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} &= \frac{\alpha_{nf}}{\rho_{nf} C_{p, nf}} \frac{\partial T}{\partial z},
\end{align*}
\]

Here, \( u \) is \( x \) component, \( v \) is \( y \) component and \( w \) is \( z \) component of velocity \( \Omega \), \( \mu_{nf} \) is fluid’s dynamic viscosity, \( \rho_{nf} \) is density, \( \alpha_{nf} \) is the thermal diffusivity, \( T \) is the temperature, \( (\rho C_{p})_s \) is the volumetric heat capacity of the base fluid, \( (\rho C_{p})_f \) is the volumetric heat capacity of the solid nanoparticles. All of these are related to the \([27]\) particle volume fraction of nanoparticles \( \phi \) as follows:

\[
\begin{align*}
(p C_p)_f = (p C_p)_s (1 - \phi) + \phi (p C_p)_f, \quad \frac{k_{nf}}{\alpha_{nf}} = k_f \\
\rho_{nf} = \rho_f (1 - \phi) + \phi \rho_s, \quad \mu_{nf} = \mu_f (1 - \phi) + \phi \mu_s.
\end{align*}
\]

2.2. Transformation Methodology. The following given similarity transformation is used to transform partial differential equations into ordinary differential equation to tackle numerically at Matlab.

\[
\begin{align*}
\eta &= \sqrt[\alpha]{z}, \theta(\eta) = \frac{T - T_{\infty}}{T - T_w}, \\
\frac{1}{(1 - \phi)^{3/2}} \frac{d^{\alpha} f'}{dx^\alpha} + \left(1 + \phi \frac{\rho_s}{\rho_{nf}} - \phi \right) \left(2h_k + f'' - f' \right)^2 &= 0, \\
\frac{1}{(1 - \phi)^{3/2}} \frac{d^{\alpha} f''}{dx^\alpha} + \left(1 + \phi \frac{\rho_s}{\rho_{nf}} - \phi \right) \left(f h' - h f'' - 2 \lambda f' \right) &= 0.
\end{align*}
\]
The physical quantities of heat transfer coefficient is known as Nusselt number $Nu$ are given as follows:

$$\frac{k_{nf}}{k_f} \tau'' (\eta) + Pr \left[ 1 - \varphi + \varphi \left( \frac{\rho C_p}{\rho C_p} \right)_f \right] f' (\eta) = 0. \tag{11}$$

The boundary equations will take the following form:

$$\begin{cases} f(0) = 0, f'(0) = K f''(0) + 1, f'(\infty) = 0, \\ h(0) = h'(0) = 0, h(\infty) = 0, \theta(0) = 1, \theta(\infty) = 0. \end{cases} \tag{12}$$

In equations (9)–(11) $\lambda$ is the rotation and $Pr$ denotes the Prandtl number, respectively and defined as follows:

$$\lambda = \frac{\Omega}{a}, Pr = \frac{(\mu C_p)_f}{k_f}. \tag{13}$$

Here, $K = k_0 \sqrt{\hat{a} \nu'_f}$ is the slip parameter. If $K = 0$, then there is no slip.

2.3. Quantities of Engineering Importance. The skin frictions $(C_{f_x}, C_{f_y})$ along the $x -$ axis, $y -$ axis, respectively, and heat transfer coefficient is known as Nusselt number $Nu$ are major quantities of physical and engineering importance. Here, $q_w$ is the heat flux, $\tau_{xz}$ and $\tau_{yz}$ are shear stresses. These rate of heat flux and shear stresses are given as follows:

$$\begin{cases} C_{f_x} = \frac{\tau_{xz}}{\rho(ax)^{5/2}} \\ C_{f_y} = \frac{\tau_{yz}}{\rho(ax)^{5/2}} \\ Nu = \frac{xq_w}{k_f(T - T_{\infty})} \end{cases} \tag{14}$$

Here, $\tau_{xz}$ and $\tau_{yz}$ are shear stress and $q_w$ is heat flux. These quantities are defined as follows:

$$\begin{cases} \tau_{xz} = \mu_f \left( \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right)_{z=0}, \\ \tau_{yz} = \mu_f \left( \frac{\partial v}{\partial z} + \frac{\partial u}{\partial y} \right)_{z=0}, \\ q_w = -k_{nf} \left( \frac{\partial T}{\partial z} \right)_{z=0}. \end{cases} \tag{15}$$

Now, the dimensionless form of these relations is obtained by utilizing the similarity transforms from equations (8) and (15) in equation (14). The dimensionless form of skin frictions and Nusselt from number is defined as follows:

$$\begin{cases} (Re_x)^{1/2} C_{f_x} = \frac{f''(0)}{(1 - \varphi)^{5/2}}, \\ (Re_y)^{1/2} C_{f_y} = \frac{h'(0)}{(1 - \varphi)^{5/2}}, \\ (Re_s)^{-1/2} Nu = \frac{-k_{nf} \theta'(0)}{k_f}. \end{cases} \tag{16}$$

Here, local Reynolds number is $Re_x = (ax)_c / \nu_f$, Skin friction $1 / (1 - \varphi)^{5/2} f''(0)$ and heat flux $-k_{nf} / k_f \theta'(0)$ are calculated for both nanofluid with the different significance of rotation constraint $\lambda$, and slip constraint $K$.

3. Numerical Scheme

A number of numerical techniques has been employed by numerous researchers to study different problems. In this present analysis, we have adopted the boundary value problem technique in Matlab. The highly nonlinear differential equations are first converted into first-order differential equations by defining the new set of variables. These first-order differential equations are tackled in Matlab. The assumed set of new variables is given as follows:

$$\begin{cases} f = y(1), f' = y(2), f'' = y(3), f''' = y'(3), \\ h = y(4), h' = y(5), h'' = y'(5), \\ \theta = y(6), \theta' = y(7), \theta'' = y'(7). \end{cases} \tag{17}$$

Now, the obtained first-order differential equations are as follows:
Table 1: Comparison of primary and secondary velocity profile with works for \( \varphi = K = 0 \).

| \( \lambda \) | Present | Wang [41] | Present | Wang [41] | Present | Wang [41] | Current results |
|-------------|--------|-----------|--------|-----------|--------|-----------|----------------|
| 0           | 0      | 1         | 0      | 1         | 0      | 1         | 0              |
| 0.5         | 1.138  | 0.512     | 1.138  | 0.512     | 1.138  | 0.512     | 0.5123         |
| 1           | 1.325  | 0.837     | 1.325  | 0.837     | 1.325  | 0.837     | 0.8375         |
| 2.0         | 1.652  | 1.287     | 1.652  | 1.287     | 1.653  | 1.287     | 1.2876         |

Table 2: Comparison of temperature profile with works for \( \varphi = K = 0 \).

| \( \lambda \) | Present | Wang [41] | Present | Wang [41] | Present | Wang [41] |
|-------------|--------|-----------|--------|-----------|--------|-----------|
| 0.7         | 0.45624| 0.455     | 0.39051| 0.390     | 0.25514| 0.242     |
| 2.0         | 0.91194| 0.911     | 0.85325| 0.853     | 0.63848| 0.638     |
| 7.0         | 1.89792| 1.894     | 1.85637| 1.850     | 1.66866| 1.664     |

\[
y' (1) = y (2), \quad y' (2) = y (3), \\
y' (3) = -(1 - \varphi) \frac{3}{2} \left(1 + \varphi \frac{\rho_s}{\rho_{bf}} - \phi\right) \ast \left(y (1) \ast y (3) - y (2) \ast 2 \ast y (4) \ast (\lambda)\right), \\
y' (4) = y (5), \quad y' (5) = -(1 - \varphi) \frac{3}{2} \left(1 + \varphi \frac{\rho_s}{\rho_{bf}} - \phi\right) \ast \left(y (1) \ast y (5) - y (4) \ast y (2) - 2 \ast y (2) \ast (\lambda)\right), \\
y' (6) = y (7), \quad y' (7) = \frac{k_f}{k_{nf}} \ast \left[-pr \ast (1 - \varphi)^{2.5} \left(1 + \varphi \frac{\rho_s}{\rho_{bf}} - \phi\right) \ast y (1) \ast y (7)\right].
\]

Similarly, the boundary conditions take the form:

\[
y (1) = 0, \quad y (2) = K \ast y (3) + 1, \quad y (4) = y (5) \ast K, \quad y (6) = 1 \text{ at } \eta = 0, \quad y (2) = 0, \quad y (4) = 0, \quad y (6) = 0 \text{ at } \eta \rightarrow 0
\]

4. Analysis of Results and Discussion

The following two sections contain the analysis and discussion of obtained results for this study.

4.1. Analysis of Results. The accuracy of the present numerical results is supported by Tables 1 and 2. In the absence of slip and rotation, our results for skin friction and Nusselt number are in good accord with the literature.

4.2. Discussion of Results. This section discusses the influence of physical factors such as rotation \( \lambda \) and slip parameter \( K \) on temperature and velocity profiles for \( Al_2O_3 \) and \( CuO \)-Engine oil nanofluids. Graphical data are obtained and analyzed in depth to estimate their true influence on velocity and temperature patterns. The figures are plotted for this purpose.

The influence of the slip parameter \( K \) and the rotation \( \lambda \) on the velocity profile \( f' (\eta) \) for both \( CuO \) and \( Al_2O_3 \)-Engine oil nanofluid is depicted in Figures 2(a) and 2(b), respectively. By increasing the slip constraint \( K \), a smooth rise in the boundary layer thickness for velocity profile \( f' (\eta) \) but overall velocity decays for both \( CuO \) and \( Al_2O_3 \)-Engine oil nanofluids is observed and seen in Figure 2(a). It is because, in the presence of slip, the velocity of the fluid near the sheet does not stay same to the surface stretching rate. As a result, raising the slip parameter \( K \) increases slip velocity. It, therefore, slows the fluid’s velocity since the stretching surface is only partially drawn in this situation due to the presence of the slip factor. In addition, the slip
parameter rises, while the thickness of the boundary layer decreases. However, it is interesting to note that the addition of CuO nanoparticles causes a decrease in the velocity $f'(\eta)$, whereas $Al_2O_3$ nanoparticles have the opposite effect (see Figure 2(a)). This is due to the fact that $Al_2O_3$ nanoparticles have a lower density as compared to CuO nanoparticles. As a result, their inclusion in the base fluid results in less friction. As can be seen in Figure 2(b), increasing the rotation lowers the velocity profile $f'(\eta)$, for both nanofluid. This occurs owing to the existence of slip velocity, which governs the fluid’s motion as its rotation increases. Furthermore, when compared to CuO -Engine nanofluid, the wideness of the momentum boundary layer for $Al_2O_3$ -Engine nanofluid has been seen to grow sharply.

The effect of slip parameter $K$ and rotation $\lambda$ on secondary velocity $h(\eta)$ is accessible in Figures 3(a) and 3(b), respectively for both CuO and $Al_2O_3$ -Engine oil nanofluids. In Figures 3(a) it is clear that the velocity $h(\eta)$ declines when slip parameter $K$ rises near the wall. It is worth noting that as the partial slip increases the abrupt expansion in
momentum boundary thickness was observed for the type of nanofluid. This further slows down the motion of a freely moving nanofluid. Figure 3(b) presents a decline in vertical velocity $h(\eta)$ with a rise in rotation constraint $\lambda$. This particular behavior is eminent to be the same for both $\text{Al}_2\text{O}_3$ and $\text{CuO}$-Engine oil nanofluids. The associated momentum boundary of both examined nanofluids dramatically takes a sudden cusp, and the wideness of the frontier layer has increased.

A distinction in temperature profile $\theta(\eta)$ against the slip $K$ for $\text{CuO}$ and $\text{Al}_2\text{O}_3$-Engine oil nanofluid is shown in Figure 4(a). It is fascinating to note that with an increment in slip $K$ the temperature profile $\theta(\eta)$ drops dramatically. This shows that as the slip velocity of extending surface increases the temperature profile decreases as a result the associated temperature frontier layer for both explored nanofluids has contracted. It can be determined from Figure 4(a) that the temperature constituent $\theta(\eta)$ considerably decays with an increase in slip constraint $K$. The impact of rotation is observed on the temperature profile for both nanofluids in Figure 4(b). It was observed with increment in rotation parameter the temperature profile for both nanofluids has
decreased abruptly. It is also worth noting that a severe contraction in the thermal boundary layer of free-moving nanofluid has been observed (See Figure 4(b)).

To check the distinctions on the skin friction constant and Nusselt number, the following tables are obtained. Table 3 characterizes the thermo physical characteristics of base liquid and nanoparticles. In Table 4, it can be demonstrated that for the fixed rotation parameter $\lambda$, the skin friction $1/(1 - \varphi)^{5/2} f''(0)$ decays and heat flux $(-knf/kf)\vartheta'(0)$ grows with a rise of $\varphi$, for both nano-liquid. This is owing to the addition of solid nanoparticles in the host liquid. While nanoparticles have better temperature transmission compared to host liquid, so the temperature transference speed increases. Especially, conforming values of skin friction and heat flux are different for CuO and Al$_2$O$_3$ Engine oil which specifies the significance of types of nanoparticles. In addition, for fixed $\varphi$, increasing slip $K$ decays the skin friction and. This

Figure 4: (a) The impact of slip $K$ on temperature profile $\theta(\eta)$. (b) The impact of rotation $\lambda$ on temperature profile $\theta(\eta)$.
is owing to a rise in slip clues to the reduction of friction and ultimately rises in temperature transmission at the wall. We observed that skin resistance of $\text{Al}_2\text{O}_3$ - Engine oil is always higher than $\text{CuO}$ - Engine oil. On the other side, $\text{CuO}$ is corroborated to be extra accomplished of fast conduction of temperature. Table 5 shows the effect of rotation on skin friction and heat transfer for both nanofluids. We discovered that amassed the rotation causes skin friction and heat transfer to rise. Both $\text{CuO}$ and $\text{Al}_2\text{O}_3$ - Engine oil nanofluid exhibit comparable characteristics. It is because a larger resistance at the surface arises from a higher spin for fixed slip K.

Figures 5(a), 5(b), and 5(c) show the graphical representation of numerical outcomes. It is clear if Figure 5(a) that skin friction along $x$ axis increases by increasing the rotation parameter and higher skin friction is observed for $\text{CuO}$ - Engine oil. Figure 5(b) shows the influence of
Figure 5: Continued.
rotation on skin friction along the $y$–axis. The skin friction decays when rotation increases. It is worth noting behavior in Figure 5(c) that the Nusselt number increases as the rotation increases.

5. Conclusions

The impact of rotation and slip conditions is investigated on the rotating 3D flow of different nanofluids above a linearly stretching surface. The boundary value problem technique is employed in this study in Matlab and the convergence criterion of the problem is set up to $10^{-6}$. The influence of rotation and partial slip parameters are analyzed. The main outcomes of the study are as follows:

1. Velocity profiles increase for rise in slip and decrease for rise in rotation parameter
2. The effect of particle volume fraction on temperature profile is observed to be less evident in $\text{Al}_2\text{O}_3$-Engine oil nanofluid and more prominent in $\text{CuO}$-Engine oil nanofluid
3. For both nanofluids, increasing the velocity slip parameter $K$ causes the increase in heat flow and skin friction to decrease
4. A lower rate of heat transfer and a greater rate of skin friction are both associated with a higher rate of rotational motion
5. Temperature profile increases rapidly in case of an increase in slip parameter while it increases slightly in case of a rise in rotation parameter
6. Compared to $\text{Al}_2\text{O}_3$ nanoparticles, $\text{CuO}$ nanoparticles were demonstrated to be superior heat transporters

Data Availability

All the data generated or analysed during this study are included in this published article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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