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Effects of Thermal Radiation on the Heat Transfer Characteristics of a Rotating Nanofluid Flow Passing Through an Oscillating Vertical Plate with Variable Temperature

Antony Gnana Aravind A, Ravikumar J*

Department of Mathematics, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Vadapalani 600026, India

Corresponding Author Email: ravikumj@srmist.edu.in

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ABSTRACT

This work intends to evaluate the heat transfer properties shown by an unsteady rotating nanofluid flow passing over a vertical plate that oscillates and has a temperature that changes when thermal radiation is present. It is produced exact analytical solutions for various water-based nanofluids comprising Ag, Al_2O_3 and TiO_2. The study successfully addresses temperature and velocity-related challenges and comprehensively investigates the impacts of multiple factors, including the Prandtl number, Radiation parameter, Thermal Grasshof number, and time duration, on the temperature and velocity of the plate. The results are presented in detail with graphical illustrations. The significance of this discovery may be examined by the comparable velocity distributions of Al_2O_3-water and TiO_2-water, which their almost identical densities can interpret. However, the increased density of Ag causes the Ag-water mixture to have a higher dynamic viscosity, resulting in a smaller boundary layer when compared to other particles.

1. INTRODUCTION

Nanotechnology has revolutionized the field of heat and mass transfer by nanofluids, which have the potential to greatly improve thermal management and fluid dynamics. Nanofluids are a kind of sophisticated fluids that include nanoparticles, usually between 1 and 100 nanometers in size, which are evenly distributed in a base fluid like water, oil, or ethylene glycol. Nanofluids have unique properties, including enhanced thermal conductivity, convective heat transfer coefficients, and rheological behaviour, which transcend those of traditional heat transfer fluids. Some of the most common fluids used for heat transmission include mixes of ethylene glycol, water, and oil; however, their low thermal conductivity limits their heat transmission capabilities. By employing this cooling method with these fluids, both manufacturing and operational costs can be reduced. Abu-Nada [1] has studied How the different features of nanofluids affect spontaneous flow in spaces. In a series of studies, researchers investigated various aspects of nanofluid flow and heat transfer under different conditions. In order to make these fluids more heat-conductive, researchers have explored the incorporation of nanoparticles into the liquids [2]. In a study conducted by Sheikholeslami et al. [3], in the presence of a rotating vertical plate, they examined the effect of thermal diffusion and heat generation on the flow of magnetohydrodynamic (MHD) nanofluid through a porous medium. Nanofluids are better than regular fluids in terms of conductivity, heating, and heat transfer through convection [4, 5]. Nanofluids are used in many different ways in industry and engineering, such as making chemicals, cooling solar panels and power plants, cooling transformer oil, making microelectronics, cooling cars and air conditioners, making advanced nuclear systems, delivering nanodrugs, doing microfluidics, transportation, biomedicine, solid-state lighting, and making things [6].

Recent research conducted by Bachok et al. [7] looked at the flow of a nanofluid across a boundary layer as it moved past a surface that was travelling through another fluid. Ravikumar and Vijayalakshmi [8] researched the accurate solution for a vertical plate submerged in a fluid that rotated while experiencing changes in temperature, mass diffusion, and thermal radiation. Rajesh et al. [9] investigated nanofluid flow and thermal radiation from a vertically moving cylinder. The convective flow and heat transfer behaviour of an incompressible, thick nanofluid were investigated as it passed through a semi-infinite sheet that was stretched vertically by Hamad [10] in the presence of a magnetic field. Das et al. [11] investigated heat radiation and Hall effects in magnetohydrodynamic free convective nanofluid flow using an oscillating porous flat plate in a rotating system.

Kakac and Pramuanjaroenkij [12] investigated a great aggregation of the studies done on nanofluids in a recent review publication. In their study, Dharmendar Reddy and Shankar Goud [13] conducted a thorough investigation of the influence of heat radiation on the behaviour of an unstable magnetohydrodynamic (MHD) nanofluid flow across an infinitely long vertical flat plate subjected to a temperature ramp and heat consumption. Tzou [14] provided evidence of the thermodynamic instability of nanofluids in spontaneous convection. In their study, Nithya and Vennila [15] investigated the characteristics of magnetohydrodynamic (MHD) nanoliquid flow on a stretched surface, considering the influences of thermal radiation and chemical reactions. Numerical investigation of natural convection in partially heated rectangular containers filled with nanofluids has been investigated by Oztop and Abu-Nada [16]. Geetha et al. [17] examined how heat radiation impacted an unsteady nanofluid flow that passed through a vertical plate. A study was conducted by Arulmozh et al. [18], in which they investigated the phenomena of heat and mass transfer in the presence of radiative and chemical reactive effects on the flow of magnetohydrodynamic (MHD) nanofluid over a vertical plate that moves infinitely.

Nanofluids are often created by dispersing nanoparticles evenly across a base fluid using dispersion methods. Nanofluids possess distinct characteristics in comparison to traditional fluids, mostly due to the inclusion of nanoparticles. Several important characteristics include: Nanoparticles significantly increase the thermal conductivity of the fluid underneath, leading to improved efficiency in transferring heat. Nanofluids provide enhanced convective heat transfer coefficients in comparison to pure base fluids, hence enabling more effective heat transmission. Incorporating nanoparticles into the nanofluid may modify its viscosity, hence impacting its flow properties and pressure drop characteristics. The stability of nanofluids is of utmost importance for their long-term performance, and it is affected by a number of factors, including dispersant efficiency, nanoparticle concentration, and surface chemistry. The thermal and rheological parameters of a nanofluid are influenced by the size and distribution of nanoparticles. Generally, nanofluids with smaller and more evenly distributed particles tend to exhibit superior performance.

Examining the dynamics of a vertically oscillating plate within the framework of heat and mass transfer introduces several novel aspects and serves specific purposes in various engineering and scientific applications. Now, let's explore the meaning and uniqueness of this concept: The main objective of studying an oscillating vertical plate is to increase the rates of heat and mass transmission compared to when the plate is fixed. When a plate undergoes oscillation, it creates fluid motion near its surface, causing disturbance to the boundary layer and increasing the exchange of heat and mass between the surface and the surrounding fluid. This better transmission is helpful in places where efficient heat and mass movement is needed, like heat exchanges, cooling systems, and chemical reactions. The assumption of uniform angular velocity is often used in the examination of fluid flow around oscillating objects, such as vertically oscillating plates, in order to simplify the mathematical model and aid in solving the problem. This assumption suggests that the plate experiences simple harmonic motion with a consistent angular velocity throughout its oscillation cycle. Although this assumption may not precisely represent the temporary behavior of the flow around the plate, it may provide useful insights into the entire flow characteristics and heat transfer processes.

The authors have reached the conclusion that, to the best of their knowledge, there has not been any research that has been published on an unstable rotating nanofluid flow via an oscillating vertical plate with a varying temperature while thermal radiation is present. This research aims to investigate the impact of heat radiation on the rotational flow of a nanofluid undergoing free convection across an oscillating vertical plate characterized by a temperature gradient. Nonlinear partial differential equations are transformed into dimensionless form, the solutions are then obtained by using the Laplace transform. The purpose of this research was to investigate three distinct types of nanofluids that were based on water and included nanoparticles of silver (Ag), aluminum oxide (Al_2O_3), and titanium dioxide (TiO_2). Closed-form analytical solutions are presented for the governing equations. This research provides a thorough assessment and graphical representation of the effects of many parameters on the temperature and velocity of the plate. The experimental period's duration, the thermal radiation parameter, the Grashof number, and the Prandtl number are the parameters incorporated in this study.

2. MATHEMATICAL ANALYSIS

A study was conducted to analysis the flow of a thick liquid that cannot be compressed, including tiny particles, as it rotates over a plate that moves up and down, while the plate's temperature changes. The study also included the effects of thermal radiation. Furthermore, at T_∞, it is a fluid incompressible which flows in an unsteady manner across an infinite vertical plate. The z' axis is perpendicular to this plate's surface, whereas the x' and y' axes are normal. We glance up from the plate's fixed vertical angle for the x' axis. The fluid and plate rotate around the z'-axis with a constant angular velocity Ω'.

At the initial time t'=0, both the plate and the fluid have a temperature of T_∞. When time t'>0 passes, the plate is heated to T_W by being forced at a velocity within its own plane, defying the pull of gravity. It is also assumed that the plate experiences a q_r radiative heat flow in the normal direction. The nanofluid consists of a mixture of water and three distinct kinds of nanoparticles, namely silver (Ag), aluminum oxide (Al_2O_3), and titanium dioxide (TiO_2). Additionally, it is presumed that the ambient temperature of the nanoparticles floating in the host fluid is equivalent to the temperature of the nanofluids. Table 1 displays the thermophysical characteristics of the nanofluids.

Table 1. Thermophysical characteristics of water and nanoparticles [9]

Physical Properties	Water/ Base Fluid	Ag	Al_2O_3	TiO_2
$\rho\left(\frac{kg}{m^3}\right)$	997.1	10500	3970	4250
c_p	4179	235	765	686.2
$K\left(\frac{W}{mK}\right)$	0.613	429	40	8.9538
ϕ	0.0	0.05	0.15	0.2
$\beta(K^{-1})$	21×10⁻⁵	1.89×10⁻⁵	0.85×10⁻⁵	0.9×10⁻⁵

The following equations govern the unsteady flow according to the traditional Boussinesq's approximation:

$$\rho_{nf}\left(\frac{\partial u'}{\partial t'} - 2\Omega' v'\right) = g(\rho\beta)_{nf}(T - T_\infty) + \mu_{nf}\frac{\partial^2 u'}{\partial z'^2} \tag{1}$$

$$\rho_{nf}\left(\frac{\partial v'}{\partial t'} + 2\Omega' u'\right) = \mu_{nf}\frac{\partial^2 u'}{\partial z'^2} \tag{2}$$

$$(\rho C_p)_{nf}\frac{\partial T}{\partial t'} = k_{nf}\frac{\partial^2 T}{\partial z'^2} - \frac{\partial q_r}{\partial z'} \tag{3}$$

where, u represents the velocity components along the x -axis, v represents the velocity components along the y -axis, and the nanofluid's temperature is denoted by T, the nanofluid's dynamic viscosity is denoted μ_{nf}, the nanofluid's thermal expansion coefficient is denoted by β_{nf}, the nanofluid's density is denoted by ρ_{nf}, the nanofluid's thermal conductivity is denoted by k_{nf}, the acceleration due to gravity is denoted by g, the radiative heat flux is denoted by q_r and the nanofluid's heat capacitance is denoted by $(\rho c_p)_{nf}$, which are given by:

$$\mu_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}}, \rho_{nf} = (1-\phi)\rho_f + \phi\rho_s$$
$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p)_f + \phi(\rho c_p)_s \qquad (4)$$
$$(\rho\beta)_{nf} = (1-\phi)(\rho\beta)_f + \phi(\rho\beta)_s$$

where, the nanoparticle's solid volume fraction is denoted by ϕ, ρ_f the base fluid's density, ρ_s the nanoparticle's density, μ_f the base liquid's viscosity, $(\rho c_p)_f$ the base fluid's heat capacitance, and $(\rho c_p)_s$ the heat capacitance of the nanoparticle. Understand that clauses (1) and (2) refer simply to spherical nanoparticles and not to other nanoparticle shapes. The Hamilton and Crosser model gives the nanofluid's actual thermal conductivity:

$$k_{nf} = k_f \frac{[k_s + 2k_f - 2\phi(k_f - k_s)]}{[k_s + 2k_f + \phi(k_f - k_s)]} \qquad (5)$$

where, the base fluid's thermal conductivity is denoted by k_f and the nanoparticle's thermal conductivity is denoted by k_s. The subscripts $_{nf}$, $_f$ and $_s$ in Eqs. (1)-(5) represent the Nanofluid, base fluid, and nanoparticle thermophysical properties, in that order.

Beginning and boundary conditions for the proposed problem are given by:

$$u' = 0, \quad v' = 0, \ T = T_\infty \ \text{for all } z', \ t' \le 0$$
$$t' > 0: u' = u_0 \cos\omega' t', \quad v' = 0,$$
$$T = T_\infty + (T_w - T_\infty)At' \text{ at } z' = 0 \qquad (6)$$
$$u' \to 0, \ v' \to 0, \ T \to T_\infty \quad \text{as } z' \to \infty$$

where, $A = \frac{u_0^2}{v}$.

When the following dimensionless quantities are introduced, they become:

$$(u,v) = \frac{(u',v')}{u_0}, \qquad t = \frac{t'(u_0)^2}{v_f}, \qquad z = \frac{z' u_0}{v_f},$$
$$Pr = \frac{\mu c_p}{k_f}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \ \Omega = \frac{\Omega' v}{u_0^2}, \qquad (7)$$
$$\omega = \frac{\omega' v}{u_0^2}, \ Gr = \frac{g v_f \beta(T_w - T_\infty)}{(u_0)^3}, R = \frac{16a^*\sigma(T_\infty)^3}{k_f}\left(\frac{v_f^2}{u_0^2}\right)$$

In the case of a gray gas that is visually thin, the local radiant is given by:

$$\frac{\partial q_r}{\partial z} = -4a^*\sigma(T_\infty^4 - T^4) \qquad (8)$$

where, T^4 is assumed to be a linear function of temperature because of the way little the temperature varies inside the flow. This is done by ignoring higher-order terms and extending T^4 in a Taylor series around T_∞, thus:

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \qquad (9)$$

When you use Eqs. (7) and (8), Eq. (3) becomes:

$$(\rho c_p)_{nf}\frac{\partial T}{\partial t'} = k_{nf}\frac{\partial^2 T}{\partial z^2} + 16a^*\sigma T_\infty^3(T_\infty - T) \qquad (10)$$

The expression $q=u+iv$, a complex velocity, $i = \sqrt{-1}$ in Eqs. (1)-(3) and (6). By using Eqs. (4), (5) and (7), Eqs. (1) and (10) leads to:

$$A_1\left(\frac{\partial q}{\partial t} + 2i\Omega\right) = A_3\frac{\partial^2 q}{\partial z^2} + A_2 Gr\theta \qquad (11)$$

$$A_4\frac{\partial\theta}{\partial t} = A_5\frac{1}{Pr}\frac{\partial^2\theta}{\partial z^2} - \frac{R}{Pr}\theta \qquad (12)$$

where, $A_1 = (1-\phi) + \phi\left(\frac{\rho_s}{\rho_f}\right)$, $A_2 = (1-\phi) + \phi\left(\frac{(\rho\beta)_s}{(\rho\beta)_f}\right)$, $A_3 = \frac{1}{(1-\phi)^{2.5}}$, $A_4 = (1-\phi) + \phi\left(\frac{(\rho c_p)_s}{(\rho c_p)_f}\right)$.

$$A_5 = k_f\frac{[k_s + 2k_f - 2\phi(k_f - k_s)]}{[k_s + 2k_f + 2\phi(k_f - k_s)]} \qquad (13)$$

where, Gr represents the thermal Grashof number, Pr represents the Prandtl number, and R represents the radiation parameter. While $R \to 0$ denotes no radiation impact, R implies a significant radiation effect.

The dimensionless beginning and boundary conditions are:

$$q = 0, \ \theta = t \quad \text{for all } z, \ t \le 0$$
$$t > 0: \ q = \cos\omega t, \ \theta = t \ \text{ at } z = 0 \qquad (14)$$
$$q \to 0 \quad \theta \to 0 \quad \text{as } z \to \infty$$

Using the conventional Laplace-transform method, both Eqs. (11) and (12) of the dimensionless governing equations may be solved by the beginning and boundary conditions (14), and the following results are obtained:

$$\theta = \frac{t}{2}\left[\exp(-2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} - \sqrt{bt}) + \exp(2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} + \sqrt{bt})\right] - \frac{\eta\sqrt{at}}{\sqrt{b}}\left[\exp(-2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} - \sqrt{bt}) - \exp(2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} + \sqrt{bt})\right]$$

$$q = \frac{\exp(i\omega t)}{4}\begin{bmatrix} \exp(2\eta\sqrt{e}\sqrt{i\omega t + gt})\,erfc(\eta\sqrt{e} + \sqrt{i\omega t + gt}) \\ + \exp(-2\eta\sqrt{e}\sqrt{i\omega t + gt})\,erfc(\eta\sqrt{e} - \sqrt{i\omega t + gt}) \end{bmatrix} + \frac{\exp(-i\omega t)}{4}\begin{bmatrix} \exp(2\eta\sqrt{e}\sqrt{-i\omega t + gt})\,erfc(\eta\sqrt{e} + \sqrt{-i\omega t + gt}) \\ + \exp(-2\eta\sqrt{e}\sqrt{-i\omega t + gt})\,erfc(\eta\sqrt{e} - \sqrt{-i\omega t + gt}) \end{bmatrix}$$
$$- \frac{c}{2d^2}\begin{bmatrix} \exp(2\eta\sqrt{e}\sqrt{gt})\,erfc(\eta\sqrt{e} + \sqrt{gt}) \\ + \exp(-2\eta\sqrt{e}\sqrt{gt})\,erfc(\eta\sqrt{e} - \sqrt{gt}) \end{bmatrix} - \frac{c}{d}\begin{bmatrix} \frac{t}{2}\begin{bmatrix} \exp(2\eta\sqrt{e}\sqrt{gt})\,erfc(\eta\sqrt{e} + \sqrt{gt}) \\ + \exp(-2\eta\sqrt{e}\sqrt{gt})\,erfc(\eta\sqrt{e} - \sqrt{gt}) \end{bmatrix} \\ - \frac{\eta\sqrt{et}}{\sqrt{g}}\begin{bmatrix} \exp(-2\eta\sqrt{e}\sqrt{gt})\,erfc(\eta\sqrt{e} - \sqrt{gt}) \\ - \exp(2\eta\sqrt{e}\sqrt{gt})\,erfc(\eta\sqrt{e} + \sqrt{gt}) \end{bmatrix} \end{bmatrix} + \frac{c}{d^2}\frac{\exp(dt)}{2}\begin{bmatrix} \exp(2\eta\sqrt{e}\sqrt{(d+g)t})\,erfc(\eta\sqrt{e} + \sqrt{(d+g)t}) \\ + \exp(-2\eta\sqrt{e}\sqrt{(d+g)t})\,erfc(\eta\sqrt{e} - \sqrt{(d+g)t}) \end{bmatrix}$$
$$+ \frac{c}{2d^2}\begin{bmatrix} \exp(2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} + \sqrt{bt}) \\ + \exp(-2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} - \sqrt{bt}) \end{bmatrix} + \frac{c}{d}\begin{bmatrix} \frac{t}{2}\begin{bmatrix} \exp(2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} + \sqrt{bt}) \\ + \exp(-2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} - \sqrt{bt}) \end{bmatrix} \\ - \frac{\eta\sqrt{at}}{\sqrt{b}}\begin{bmatrix} \exp(-2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} - \sqrt{bt}) - \\ \exp(2\eta\sqrt{a}\sqrt{bt})\,erfc(\eta\sqrt{a} + \sqrt{bt}) \end{bmatrix} \end{bmatrix} - \frac{c}{d^2}\frac{\exp(dt)}{2}\begin{bmatrix} \exp\left(2\eta\sqrt{a}\sqrt{(b+d)t}\right)erfc\left(\eta\sqrt{a} + \sqrt{(b+d)t}\right) \\ + \exp\left(-2\eta\sqrt{a}\sqrt{(b+d)t}\right)erfc\left(\eta\sqrt{a} - \sqrt{(b+d)t}\right) \end{bmatrix}$$

where, $a = \frac{A_5 Pr}{A_6}$, $b = \frac{R}{A_5 Pr}$, $c = \frac{Gr A_2}{a A_3 - A_1}$, $d = \frac{g A_1 - ab A_3}{a A_3 - A_1}$, $e = \frac{A_1}{A_3}$, $g = 2i\Omega$, $\eta = \frac{z}{2\sqrt{t}}$, *erfc* is the error complimentary function.

Both the error function and the error complimentary function make use of complex parameters. The complex velocity parameter q may be simplified to its real and imaginary parts using the following formula.

$$\mathrm{erf}(x+iy) = \mathrm{erf}(x) + \frac{\exp(-x^2)}{2x\pi}[1-\cos(2xy) + i\sin(2xy)] + \frac{2\exp(-x^2)}{\pi}\sum_{n=1}^{\infty}\frac{\exp(-n^2/4)}{n^2+4x^2}[f_m(x,y) + i g_m(x,y)] + \epsilon(x,y)$$

where,
$f_m = 2x - 2x\cosh(my)\cos(2xy) + m\sinh(my)\sin(2xy)$,
$g_m = 2x\cosh(my)\sin(2xy) + m\sinh(my)\cos(2xy)$,
$|\epsilon(x,y)| \approx\approx 10^{-16}|\mathrm{erf}(x+iy)|$.

The numerical solutions are obtained by MATLAB programming and shown graphically to demonstrate the physical importance of non-dimensional parameters.

3. RESULTS AND DISCUSSION

Extensive numerical computations are done for various values of the thermophysical parameters, which are shown in graphs, to offer an in-depth understanding of the physical nature of the issue. We investigate three distinct forms of nanofluids based on silver, titanium oxide, and aluminum oxide nanoparticles. The volume of nanoparticles was revised to be in the range $0 \leq \phi \leq 0.2$. The normal fluid is represented by the case $\phi = 0$. That is, nanoscale properties are abolished.

The primary velocity profiles for different types of nanoparticles (Ag, Al_2O_3 and TiO_2) and constant solid volume fraction $\phi = 0.1, Gr = 5, Pr = 6.2, R = 5, \omega t = \frac{\pi}{4}, \Omega = 0.5$ and t=0.2 are plotted in Figure 1. This observation may be attributed to the similar velocity distributions of Al_2O_3-water and TiO_2-water, which can be explained by their near densities. However, the high density of Ag results in a greater dynamic viscosity of Ag-water, leading to a thinner boundary layer compared to the other particles.

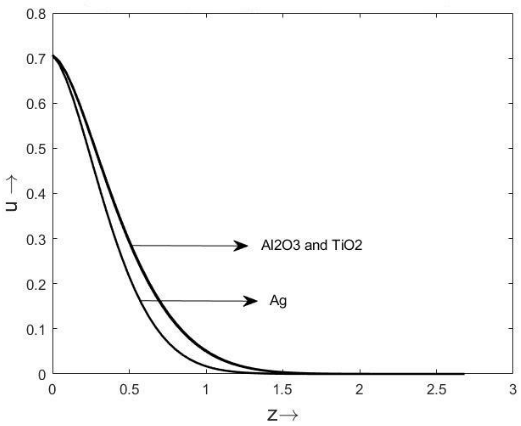

Figure 1. Primary velocity profile for different Nanofluids

The secondary velocity profiles for several kinds of nanoparticles, namely silver (Ag), aluminum oxide (Al_2O_3), and titanium dioxide (TiO_2), are examined. The solid volume fraction (ϕ) is held constant at $0.1, Gr = 5, Pr = 6.2, R = 5, \omega t = \frac{\pi}{4}, \Omega = 0.5$ and *t*=0.2. These parameters are used to generate a graph, as seen in Figure 2. It explains that the comparing of these three nanoparticles, Al_2O_3-water and TiO_2-water have low velocity and Ag-water has high velocity.

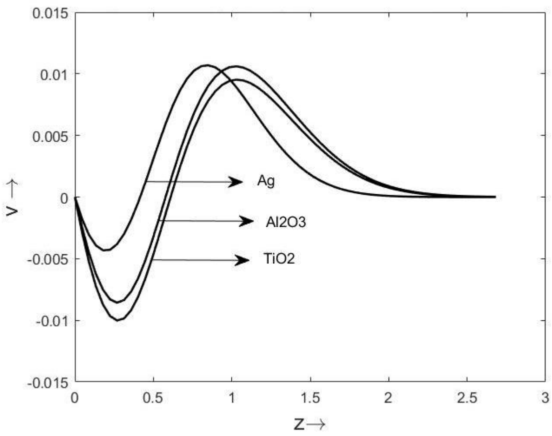

Figure 2. Secondary velocity profile for different Nanofluids

The primary and secondary velocity profiles of TiO_2-water with different values of phase angle, radiation parameter and rotation parameter are depicted in the graph which is shown in Figures 3-8 when *Pr*=6.2, *Gr*=5, ϕ=0.1 and *t*=0.2 is kept at constant.

Figure 3 illustrates that the primary velocity (*u*) exhibits an increase when the phase angle ωt decreases.

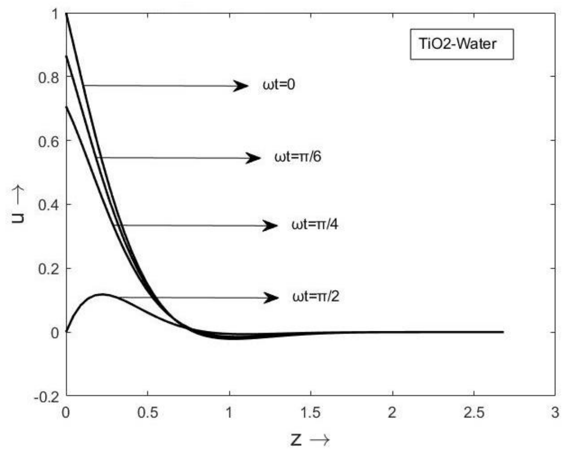

Figure 3. Primary velocity profile for different phase angle (ωt)

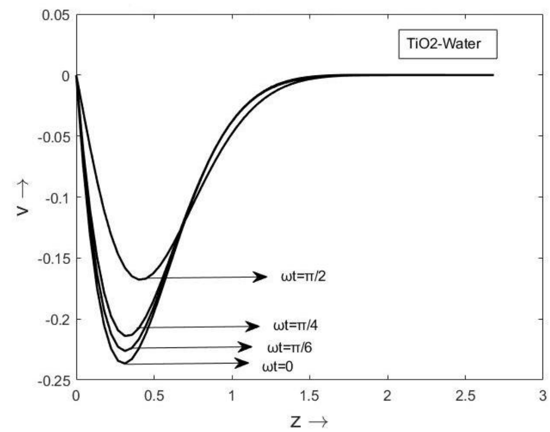

Figure 4. Secondary velocity profile for different phase angle (ωt)

According to Figure 4, the secondary velocity (v) exhibits a rise as the phase angle ωt rises.

Figure 5 illustrates a positive correlation between the primary velocity (u) and the radiation parameter R, indicating that an increase in R leads to an increase in primary velocity (u).

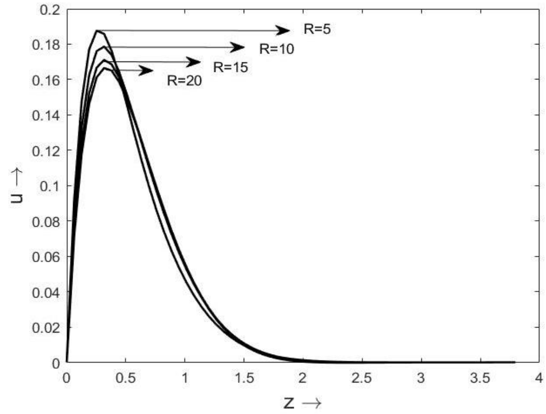

Figure 5. Primary velocity profile for different radiation parameter (R)

Figure 6 illustrates that the secondary velocity (v) exhibits a rise when the radiation parameter R decreases.

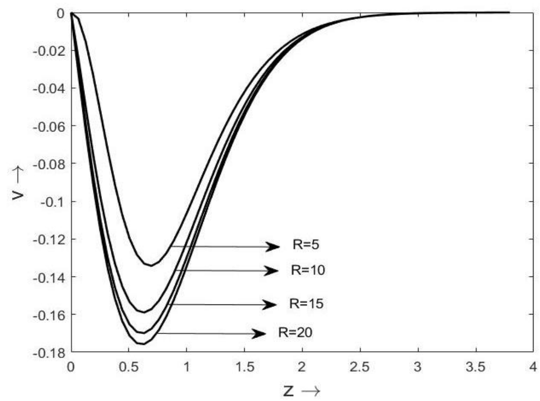

Figure 6. Secondary velocity profile for different radiation parameter (R)

Figure 7 indicates that the primary velocity (u) increases as the rotation parameter (Ω) increases.

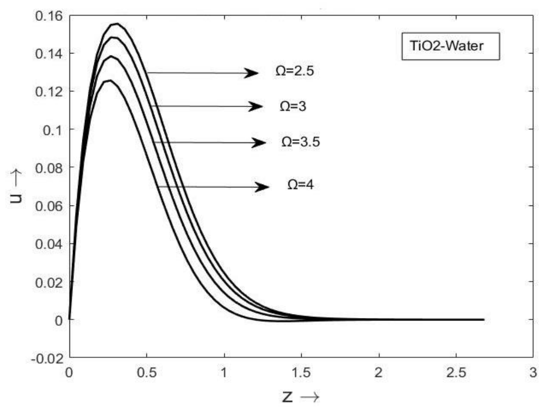

Figure 7. Primary velocity profile for different rotation parameter (Ω)

According to Figure 8, the secondary velocity (v) increases as the rotation parameter (Ω) decreases.

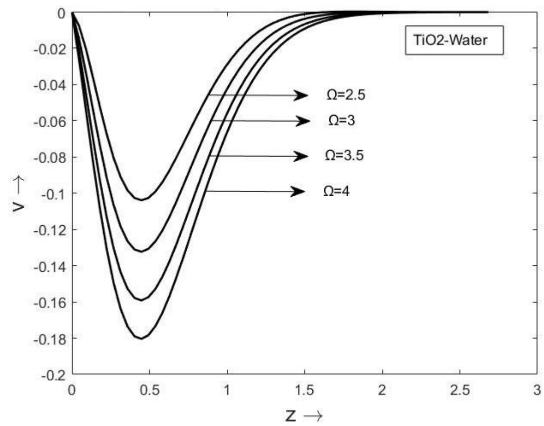

Figure 8. Secondary velocity profile for different rotation parameter (Ω)

Figure 9 displays the temperature profiles corresponding to various radiation parameter values, specifically when Pr=6.2, t=0.8, and ϕ=0.1, for the TiO_2- Water system. It is discovered that the temperature of TiO_2- Water nanofluid rises as R increases.

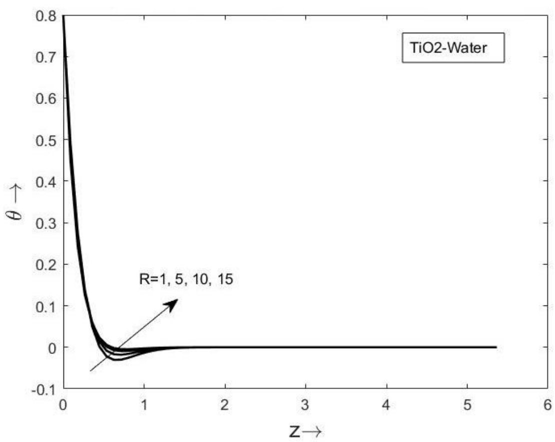

Figure 9. Temperature profile for different radiation parameter (R)

Figure 10 demonstrates that the temperature of TiO_2 - Water nanofluid decreases as time t increases.

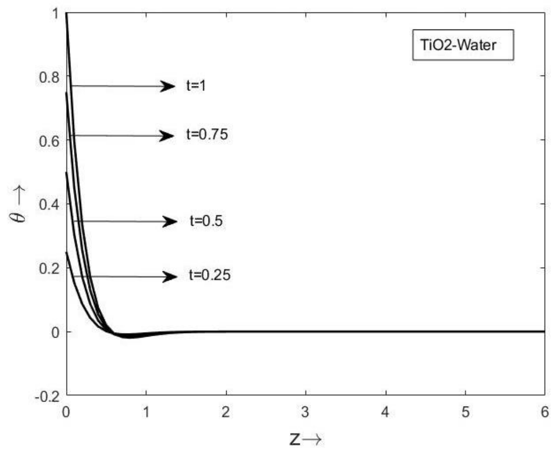

Figure 10. Temperature profile for different time (t)

This paper focuses on exploring the behavior and properties of an oscillating vertical plate with a rotating nanofluid. We compared our results with Das and Jana [19] and Arulmozhi et al. [18], who have previously published works on the same topic. We examined the relationship between fluid flow and heat transfer in a system where both the plate and the fluid are in motion. These rotation parameters probably relate to certain variables or factors associated with the rotation of the nanofluid or the oscillating plate, such as angular velocity, rotational speed, or frequency [20].

4. CONCLUSIONS

The goal of this study is to identify the unstable rotating nanofluid flow via a vertical plate that oscillates and has a variable temperature while exposed to thermal radiation. The formula for plate velocity is derived in closed form by applying the Laplace transform to three different types of nanofluids. The impacts of numerous factors on velocity are graphically displayed, and the most relevant observations are summarised as follows:

- As the phase angle (ωt) diminishes, the primary velocity (u) increases.
- As the phase angle (ωt) increases, the secondary velocity (v) increases
- As the radiation parameter (R) increases, the primary velocity (u) increases.
- As the radiation parameter (R) decreases, the secondary velocity (v) increases.
- As the rotation parameter (Ω) increases the primary velocity (u) increases.
- With a decreasing value of the rotation parameter (Ω), the secondary velocity (v) increases.

To further investigate the effects of rotation and oscillation on radiative heat transfer within different types of nanoparticles like CuO, ZnO, MnOor Fe_2O_3 and base fluids like oil or ethylene glycol and how variations in nanoparticle concentration, size, and shape affect radiative heat transfer efficiency and overall heat transfer performance.

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