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Consequence effects of inclined Lorentz force flow of hybrid nanofluid over a stretching sheet with dissimilar base fluids

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Abstract:

The primary goal of this research is to provide detailed insights into the stable and incompressible flow of a hybrid nanofluid over a stretching sheet in two dimensions. The hybrid nanofluid under consideration consists of TiO_2 and Cu nanoparticles, with (H_2O,$NaC_6H_9O_7$) as the base fluids. The study also incorporates the influence of inclined magnetic field. Formulating partial differential equations (PDEs) to represent the flow of the hybrid nanofluid over a stretching sheet in two dimensions. Converting the PDEs into ordinary differential equations (ODEs) using similarity transformations. Employing the Runge-Kutta fourth-order method as a numerical technique to solve the ODEs. Solid volume fractions of nanoparticles and the Casson parameter also have a significant impact on velocity and temperature profiles. The study shows that sodium alginate-based hybrid nanofluid is more effective than water-based hybrid nanofluid in TiO_2–Cu hybrid nanoparticles under certain conditions. The results indicate that the inclined magnetic parameter significantly influences velocity and temperature profiles. The results may need to be validated through experimentation or further computational studies to ensure their accuracy and applicability. The research may have implications for understanding and optimizing the flow characteristics of hybrid nanofluids, especially in the presence of magnetic fields.

Key words: Hybrid nanofluid, stretching sheet, Inclined Magnetic field, Incompressible

Nomenclature

B	magnetic field intensity, $kgs^{-2}a^{-1}$
C_f	skin friction coefficient
C_p	specific heat, $jkg^{-1}k^{-1}$
k	thermal conductivity, $wm^{-1}k^{-1}$
M	magnetic parameter
Nu_x	local Nusselt number
Pr	prandtl number
q_w	surface heat flux, wm^{-2}
Re	local reynolds number
F	Dimensionless fluid velocity
T	temperature of fluid
T_w	ambient thermal
T_∞	surface thermal
U	reference velocity, ms^{-1}
U_w	constant velocity,
U_∞	free stream momentum

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u	momentum factor in the x way
x , r	cylindrical directs
Greek letters	
α	angle
β	thermal expansion coefficient, k^{-1}
ϕ_1 , ϕ_2	nanoparticles of volume fraction
μ	dynamic viscosity, $kgm^{-1}s^{-1}$
υ	kinematic viscosity, m^2s^{-1}
σ	electrical conductivity, sm^{-1}
ρ	density, kgm^{-3}
τ_w	wall shear stress, nm^{-2}
Subscripts	
hnf	hybrid nanofluid
nf	nanofluid
f	fluid
s	solid

1.Introduction:

Hybrid nanofluids may find applications in energy storage and conversion systems, especially in the presence of inclined magnetic fields. The combination of magnetic effects and enhanced thermal properties could be harnessed for improving the efficiency of energy-related processes. Nanofluids are engineered colloidal suspensions of nanoparticles in a base fluid, and they have shown promise in various applications due to their improved thermal properties. This study looks into how well nanofluids can dissipate heat from electronic components, preventing overheating and extending the lifespan and overall performance of electronic devices [1]. This work has investigated natural convection heat transfer as a possible practical application. It is essential to have a thorough grasp of how the properties of base fluid, enclosure geometry, and nanoparticles interact [2]. This work investigates the difficulty of analytically solving non-Newtonian fluid problems, emphasizing the use of numerical techniques in complex scenarios and the incorporation of nanofluid properties into the analysis [3]. The Casson fluid model assumes that the relationship between the shear stress and the rate of strain is nonlinear and is given by the Casson equation. This model is used to describe non-Newtonian fluids, particularly those with a yield stress has been investigated in this research [4]. In this analysis, natural fluid motion resulting from temperature variations-induced differences in density is discussed [5]. Combining the study of MHD with the geometry of a spinning down-pointing vertical cone and the Tiwari-Das model could yield important insights into the behavior of nanofluids in these applications, which could help with the design and optimization of the various technological systems under investigation in this research [6]. The research examines heat transfer, shear stress, and velocity profiles of nanoliquids, requiring advanced mathematical modelling and simulations to understand the impact of nanoparticles and geometric variations [7]. Research on nanofluid behavior on surfaces influences heat transfer processes, with thermo-diffusion adding complexity to analysis due to temperature gradients separating components has been examined [8]. Thermal radiation involves the transfer of heat in the form of electromagnetic waves. When considering heat transfer in a fluid flow scenario, thermal radiation plays a significant role, particularly in influencing temperature profiles and energy distribution, as has been examined in this research [9]. The numerical solution examined incorporates MHD effects, highlighting the importance of considering the magnetic field's impact on fluid flow and heat transfer [10]. Researchers often conduct parametric studies to investigate the influence of various factors such as nanoparticle volume fraction, Reynolds number, and thermal boundary conditions. These studies help in identifying the optimal conditions for enhanced heat transfer [11]. The presence of internal heat generation will introduce a volumetric heat source term in the energy equation. This term is typically represented by a source term in the energy equation has been examined [12].

The goal of this research appears to be gaining a comprehensive understanding of how these factors interact and influence heat transfer over a stretching sheet. The stretching sheet represents a common scenario in boundary layer flows. As the fluid flows over a surface that is continuously stretching, it leads to changes in boundary layer thickness and flow characteristics. The choice of base fluid is crucial, as it forms the primary medium for heat transfer. Different base fluids have distinct thermophysical properties, and selecting the appropriate one can significantly impact the overall heat transfer characteristics of the nanofluid. The convective flow, driven by temperature differences within the fluid, plays a key role in heat transfer. The study examines the Lorentz force, which influences the movement of charged particles in the presence of an electromagnetic field, which is crucial in the field of magnetohydrodynamics (MHD) and can significantly affect fluid behavior and heat transfer. This type of study is valuable for applications in thermal management, materials science, and engineering systems where understanding and optimizing heat transfer processes are essential.

2.Mathematical Formulation:

Flow Description:

Steady: The flow does not vary with time.

Laminar: The fluid motion is smooth and predictable.

Stretching sheet: The surface along which the fluid is flowing is stretching.

Base Fluids:

Water (H_2O): A common fluid with well-known properties.

Sodium Alginate ($NaC_6H_9O_7$): This is a biopolymer derived from seaweed. Its properties may differ significantly from water.

Hybrid Nanoparticles:

Titanium Oxide (TiO_2): Often used in nanofluids for its stability and thermal properties.

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Copper (Cu): Known for its good thermal conductivity.

Temperature Conditions:

T_w (temperature at the wall): This is assumed to be constant at the stretching surface.

T_∞ (ambient temperature): This represents the temperature at infinity or far away from the stretching surface.

Magnetic Field:

Inclined Magnetic Field: The presence of a magnetic field, which is inclined to the stretching surface, can influence the flow and heat transfer characteristics.The physical sketch of present model is shown in Fig.1

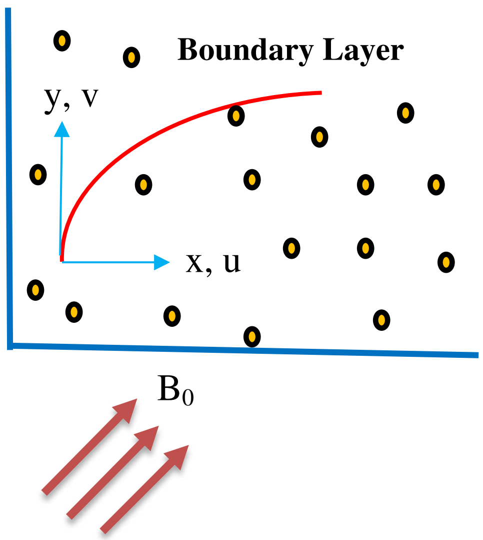

Fig.I Geometry of the problem

2.1. Problem Formulation:

Under these assumptions, the governing equations of continuity, momentum and energy in steady state can be written as

Continuity Equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0\,, \quad (1)$$

Momentum Equation:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu_{hnf}\left(1+\frac{1}{\beta}\right)\mu_{hnf}\frac{\partial^2 u}{\partial y^2}-\frac{\sigma_{hnf}}{\rho_{hnf}}B_0^2u*sin^2\alpha \quad (2)$$

Energy Equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_{hnf}}{(\rho C_p)_{hnf}}\frac{\partial^2 T}{\partial y^2} \quad (3)$$

Relevant boundary circumstances are

$$u=u_w=cx, v=0, \quad T=T_w \ \ at\ y=0,$$
$$u=0, T=T_\infty \quad at \quad y\to\infty \quad (4)$$

Hybrid Nanofluid Properties
$\mu_{hnf}=\frac{\mu_f}{(1-\phi_{np1})^{2.5}(1-\phi_{np2})^{2.5}}$
$\rho_{hnf}=\{(1-\phi_{np2})[(1-\phi_{np1})\rho_f+\phi_{np1}\rho_{np1}]\}+\phi_2\rho_{np2}$
$\alpha_{hnf}=\frac{k_{hnf}}{(\rho C_p)_{hnf}}$
$(\rho C_p)_{hnf}=\{(1-\phi_{np2})[(1-\phi_{np1})(\rho C_p)_f+\phi_{np1}(\rho C_p)_{np1}]\}+\phi_{np2}(\rho C_p)_{np2}$
$(\rho\beta_T)_{hnf}=\{(1-\phi_{np2})[(1-\phi_{np1})(\rho\beta_T)_f+\phi_1(\rho\beta_T)_{np1}]\}+\phi_2(\rho\beta_T)_{np2}$
$\frac{k_{hnf}}{k_{nf}}=\frac{k_{np2}+2k_{nf}-2\phi_{np2}(k_{nf}-k_{np2})}{k_{np2}+2k_{nf}+\phi_{np2}(k_{nf}-k_{np2})}$
$\frac{k_{nf}}{k_f}=\frac{k_{np1}+2k_f-2\phi_{np1}(k_f-k_{np1})}{k_{np1}+2k_f+\phi_{np1}(k_f-k_{np1})}$
$\frac{\sigma_{hnf}}{\sigma_{nf}}=\frac{\sigma_{np2}+2\sigma_{nf}-2\phi_{np2}(\sigma_{nf}-\sigma_{np2})}{\sigma_{np2}+2\sigma_{nf}+\phi_{np2}(\sigma_{nf}-\sigma_{np2})}$
$\frac{\sigma_{nf}}{\sigma_f}=\frac{\sigma_{np1}+2\sigma_f-2\phi_{np1}(\sigma_f-\sigma_{np1})}{\sigma_{np1}+2\sigma_f+\phi_{np1}(\sigma_f-\sigma_{np1})}$

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The suitable set of variables are

$$u = cxf'(\varepsilon), \qquad v = -(cv)^{\frac{1}{2}} f(\varepsilon),$$

$$\varepsilon = \left(\frac{c}{v}\right)^{\frac{1}{2}} y\ , T - T_0 = (T_w - T_\infty)\theta(\varepsilon) \qquad (5)$$

Using above eqn. (5), eqns. (1) – (3) can be transmuted as,

$$\frac{\left(1+\frac{1}{\beta}\right)}{(1-\phi_{np1})^{2.5}(1-\phi_{np2})^{2.5}} f''' - \frac{\sigma_{hnf}}{\sigma_f} M * sin^2\alpha * F' + \left[\left(1-\phi_{np2}\right)\left[1-\phi_{np1}+\phi_{np1}\frac{\rho_{np1}}{\rho_f}\right] + \phi_{np2}\frac{\rho_{np2}}{\rho_f}\right]\left[FF''-F'^2\right] = 0 \qquad (6)$$

$$\theta'' + \frac{k_f}{k_{hnf}} Prf\theta' \left[\left(1-\phi_{np2}\right)\left[1-\phi_{np1} + \phi_{np1}\frac{(\rho C_p)_{np1}}{(\rho C_p)_f}\right] + \phi_{np2}\left(\frac{(\rho C_p)_{np2}}{(\rho C_p)_f}\right)\right] = 0 \quad (7)$$

and the related boundary restrictions are

$$F(0) = 0, \qquad F'(0) = 1, \ \ \theta(0) = 1$$
$$F'(\infty) = 0, \quad \theta(\infty) = 0 \qquad (8)$$

where,

$$M = \frac{\sigma_f B_0^2}{c\rho_f}, Pr = \frac{\nu_f}{\alpha_f}, \quad Re = \frac{xu_w}{\nu_f} \qquad (9)$$

2.2. Nusselt number and Skin friction Analysis:

The dimensionless form of surface drag force C_f and heat transfer rate Nu, are

$$C_f = \frac{\tau_w}{\rho_f u_w^2}, \quad Nu = \frac{xq_w}{k_f(T_w - T_\infty)} \qquad (10)$$

$$\tau_w = \mu_{hnf}\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)_{y=0},$$

$$q_w = -k_{hnf}\left(\frac{\partial T}{\partial y}\right)_{y=0} \qquad (11)$$

$$NuRe^{\frac{-1}{2}} = -\left(\frac{k_{hnf}}{k_f}\right)\theta'(0) \qquad (12)$$

$$C_f Re^{\frac{1}{2}} = \left(1+\frac{1}{\beta}\right)\left(\frac{\mu_{hnf}}{\mu_f}\right)F''(0) \qquad (13)$$

3.Numerical Procedure:

Using the BVP4C code in MATLAB software, the resulting ordinary differential equations expressed in Eqns. (6) and (7) confined to the boundary constraints (8) have been resolved by IV[th] order Runge-Kutta form with shooting method. Using $F = y_1$, $\theta = y_4$ we create a prime step of the system in our current model as follows:

$$y_1' = y_2$$
$$y_2' = y_3$$

$$y_3' = \left(1+\frac{1}{\beta}\right)^{-1}\left((1-\phi_{np1})^{2.5}(1-\phi_{np2})^{2.5}\right)\left\{\frac{\sigma_{hnf}}{\sigma_f} M * sin^2\alpha * y_2 - \left[\left(1-\phi_{np2}\right)\left[1-\phi_{np1}+\phi_{np1}\frac{\rho_{np1}}{\rho_f}\right] + \phi_{np2}\frac{\rho_{np2}}{\rho_f}\right]\left[y_1y_3 - y_2^2\right]\right\}$$

$$y_4' = y_5$$

$$y_5' = -Pr\frac{k_f}{k_{hnf}}\left[\left(1-\phi_{np2}\right)\left[1-\phi_{np1} + \phi_{np1}\frac{(\rho C_p)_{np1}}{(\rho C_p)_f}\right] + \phi_{np2}\left(\frac{(\rho C_p)_{np2}}{(\rho C_p)_f}\right)\right][y_1y_5]$$

and

$$y_1(0) = 0, y_2(0) = 1 y_4(0) = 1$$

The initial estimates were given to $y_3(0)$ i.e., $F''(0)$ and $y_5(0)$ i.e., $\theta'(0)$. Then initial guesstimates were then conveniently modified to satisfy the boundary requirement and the convergence criterion of 10^{-6}.

4.Results and Discussions:

The objects inserted into the conundrum are shown in Figure I. The hybrid

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nanofluid flow, which consists of TiO_2 and Cu nanoparticles (water (H_2O), sodium alginate ($NaC_6H_9O_7$)) considered as base fluids, is explained in figures 2-7 with reference to physical behavior and attitude. This flow illustrates the impact of various parameters on acceleration and thermal profiles. A Newtonian fluid, whose viscosity is constant regardless of applied stress, can be likened to the behavior of a fluid with an infinitely large Casson parameter. As a result of the fluid's Newtonian behavior, the hybrid nanoparticles may still have an impact on the fluid's thermal conductivity but may not have a major effect on its momentum properties. Table 1 provided a thermophysical description of the base fluids and the nanoparticles. Table 2 provides the values of the nusselt number and surface drag force.

4.1. Movement of the momentum profile:

In Fig. 2, an inclined magnetic field applied to a fluid containing magnetic nanoparticles causes the fluid to experience a Lorentz force because the magnetic field and the nanoparticles' magnetic moment work together. In the magnetic field's direction, this force may lead to the nanoparticles aggregating and forming chains. The fluid's flow behavior may change as a result of this aggregation. An increase in the inclined magnetic field strength $(M = 1,2,3 \; and \; \alpha = 45^0)$ in the case of a hybrid nanofluid can lead to the formation of longer chains and larger aggregates among the nanoparticles. This could result in an increase in the fluid's effective viscosity and a subsequent decrease in the hybrid nanofluid velocity. Furthermore, when it comes to the base fluids in hybrid nanoparticles, non-Newtonian hybrid nanofluid outperforms Newtonian hybrid nanofluid. This implies that the density of non-Newtonian hybrid nanofluid is lower than that of Newtonian hybrid nanofluid.

Figure 3 illustrates that when the volume fraction ($\phi_1 = \phi_2$=0.04,0.06,0.08) increases, the fluid's velocity tends to decrease. The presence of nanoparticles in the nanofluid has increased its viscosity, which is the cause of this velocity decrease. A higher viscosity is brought on by the presence of nanoparticles in the nanofluid. The tendency of nanoparticles to group together in the fluid and form clusters can impede the flow of the fluid and cause its velocity to decrease. This variation in velocity could be caused by a number of things, such as variations in viscosity, surface characteristics, or the propensity of nanoparticles to group together in these particular fluids. The hybrid nanofluid based on $NaC_6H_9O_7$has a higher velocity than the hybrid nanofluid based on H_2O when these two base fluids are compared.

Figure 4 shows how the Casson model is often used to describe the rheological behavior of non-Newtonian fluids. Variations in the Casson parameter (β) values (β = 1, 2, 3), are the focus of this investigation. The velocity

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falls with an increase in β. Thus, the Casson parameter and velocity in this particular context have an inverse relationship. Here, sodium alginate is mixed with titanium dioxide (TiO2) and copper (Cu) nanoparticles. The velocity trend mentioned earlier is caused by a decrease in the fluid's yield stress. A fluid's yield stress is a measurement of the force needed to start a flow. It appears that the hybrid nanofluid's yield stress drops as the Casson parameter rises, which lowers velocity.

4.2. Movement of the Thermal profile:

Figure 5 displays the temperature profile of the inclined magnetic parameter. An inclined magnetic field with M = 1, 2, and 3 is applied to a conducting hybrid nanofluid. When an inclined magnetic field is applied, electrical currents are induced within the conducting fluid. A Lorentz force is produced by the interaction of these electrical currents with the magnetic field. The fluid heats up as a result of this Lorentz force. Joule heating is the term used to describe the heat produced when electrical currents interact with a magnetic field. The hybrid nanofluid's temperature is rising as a result of this process. In comparison to hybrid nanofluids based on $NaC_6H_9O_7$, water-based hybrid nanofluids are observed to have a significantly higher specific heat.

Figure 6 illustrates how the hybrid nanofluid's thermal conductivity rises in tandem with the concentration of TiO2 and Cu nanoparticles. This is explained by the high surface area-to-volume ratio of the nanoparticles, which, when suspended in the base fluid, form a network of connections. The fluid's heat transmission efficiency is improved by this network. The fluid's ability to transmit heat is enhanced by the nanoparticles' high surface area to volume proportion, which helps to create an interconnected network within the fluid. The higher thermal conductivity suggests that the hybrid nanofluid can transmit heat more effectively than just the base fluid can, from one place to another. When exposed to a heat source, the hybrid nanofluid's temperature rises as a result of the increased heat transfer efficiency. Compared to other base fluids containing TiO2-Cu hybrid nanoparticles, the hybrid nanofluid based on Newtonian theory has a higher density.

Figure 7 shows that the thermal profile rises in tandem with an increase in the Casson parameter (β = 1, 2, 3). This suggests that the temperature distribution in the system and the Casson parameter are correlated. The TiO2-Cu/sodium alginate hybrid nanofluids exhibit enhanced boundary layer motion as a result of elevated β values. This increased motion may be impacting the system's thermal behavior and heat transfer characteristics. The increased motion of the boundary layer in TiO2-Cu/sodium alginate hybrid nanofluids may be the cause of this increase in thermal effects.

Velocity Profile:

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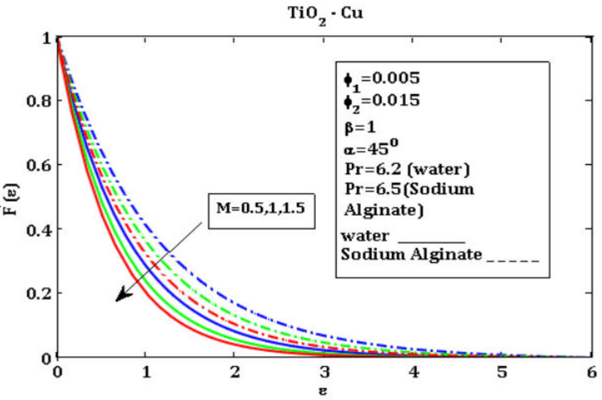

Fig.2.The impacts of $M = 0.5,1,1.5$ **on momentum**

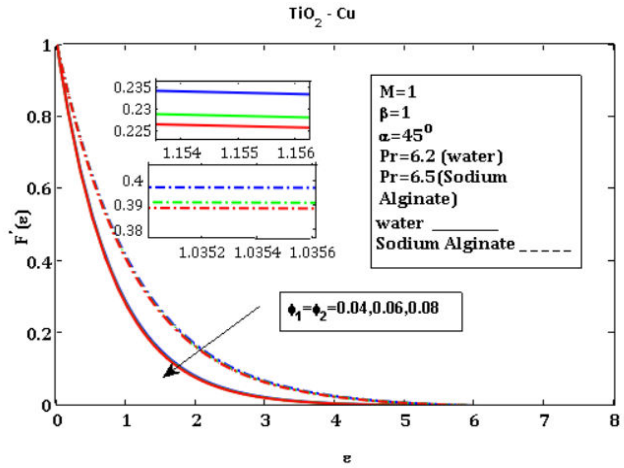

Fig.3.The impacts of $(\phi_1 = \phi_2 = 0.04,0.06,0.08)$ $momentum$

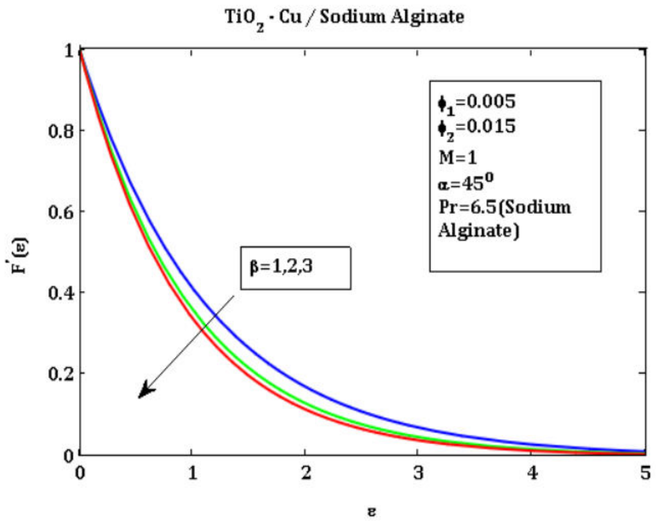

Fig.4.The impacts of $\beta = 1,2,3$ **on momentum.**

Thermal profile:

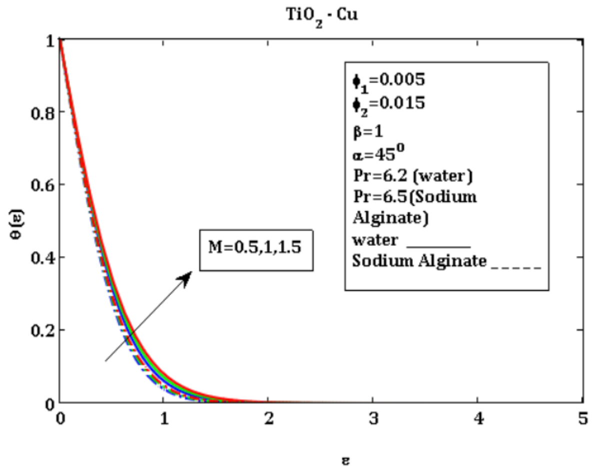

Fig.5.The impacts of $(M = 0.5,1,1.5)$ **on Thermal**

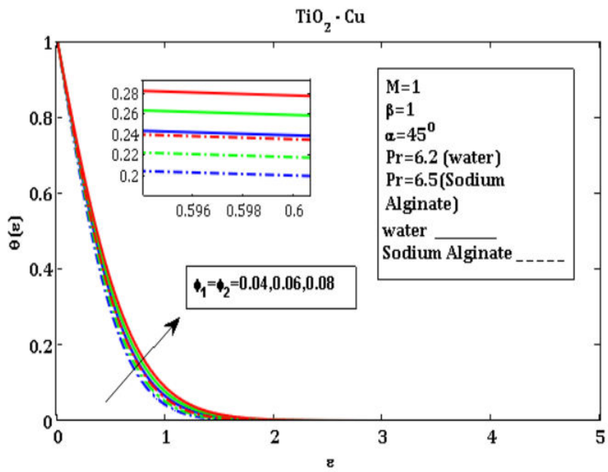

Fig.6.The impacts of $(\phi_1 = \phi_2 = 0.04,0.06,0.08)$ **on Thermal.**

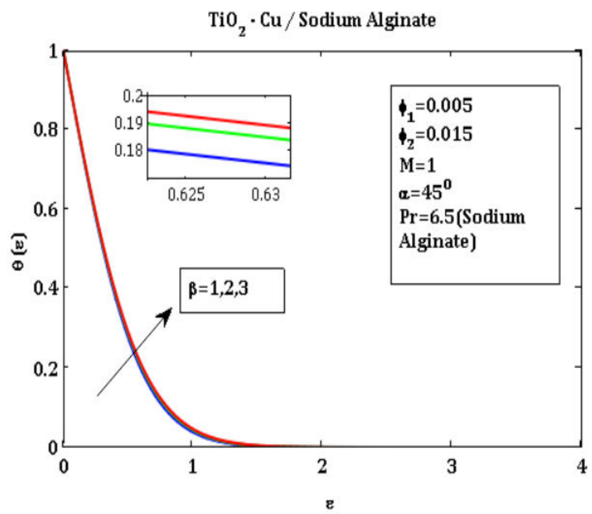

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Fig.7.The impacts of $\beta = 1,2,3$ on Thermal.

Table 1: Thermophysical characterstics of the base fluids and the nanoparticles [3],[5],[6]

Base fluid and nanoparticle	C_p/(J/(kg.K))	ρ/(kg/m^3)	k/(W/(m.K))	β/10^{-5}(1/K)	σ(s m^{-1})
H_2O	4179	997	0.613	21	0.05
$NaC_6H_9O_7$	4175	989	0.6376	99	2.6x10^{-4}
TiO_2	686.2	4250	8.954	0.9	2.38x10^6
Cu	385	8933	400	1.67	5.96x10^7

Table 2: The values of C_f coefficient and Nu for M, β with surface temperature is listed below

M	β	$C_f Re^{\frac{1}{2}}$ TiO₂ - Cu H_2O	$C_f Re^{\frac{1}{2}}$ TiO₂ - Cu $NaC_6H_9O_7$	$NuRe^{\frac{-1}{2}}$ TiO₂ - Cu H_2O	$NuRe^{\frac{-1}{2}}$ TiO₂ - Cu $NaC_6H_9O_7$
0.5	1	-1.3354	-1.8945	1.8512	1.9803
1		-1.5263	-2.1465	1.6900	1.8542
1.5		-1.6972	-2.2963	1.6742	1.7877
0.5	1	-	-1.8901	-	1.8456
	2	-	-1.7633	-	1.8321
	3	-	-1.5464	-	1.8570

Conclusion:

Studying the consequences of the inclined Lorentz force flow of a hybrid nanofluid over a stretching sheet with dissimilar base fluids involves examining several intricate aspects. Here are some potential consequences and implications of this scenario:

Thermal Conductivity: Hybrid nanofluids, consisting of nanoparticles dispersed in base fluids, often exhibit higher thermal conductivity. The Lorentz force-driven flow can further enhance this property, affecting heat transfer rates.

Temperature Distribution: Understanding how the inclined Lorentz force impacts the temperature distribution across the stretching sheet is crucial. It can lead to improved heat transfer or cooling effects, depending on the flow and material properties.

Interfacial Effects: Investigating the interfacial interactions between nanoparticles

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and base fluids under the influence of the Lorentz force is crucial for stability assessment and understanding potential changes in material properties.

This type of research is valuable for applications in various fields, including magnetohydrodynamics, thermal engineering, and materials science.

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