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MAGNETOHYDRODYNAMIC CASSON HYBRID NANOFLUID DYNAMICS IN CIRCULATING BLOOD CONSIDERING THERMAL RADIATION AND CHEMICAL REACTIONS

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The purpose of this work is to investigate the relevance of thermal radiation and chemical reaction in the thermal and radiative analysis of hybrid Casson nanofluid dynamics. The physical model was based on the mixture of Gold and Silver hybrid nanoparticles (HN) which are suspended in a blood past a stretchable sheet. The dynamics of fluid past a stretchable sheet is a notable analysis for thermal and momentum boundary layers. It finds applications in various technological fields and in industries. The model equations were investigated using a system of partial differential equations (PDEs). Acceptable transformation was used to convert these PDEs into total differential equations (ODEs). Later, the system of equations was solved using the Runge-Kutta algorithm along with shooting. The analysis described in this paper explained that hybrid nanoparticles have high performance in radiative and thermal processes when compared with nanofluid. The fluid's velocity was observed to be repelled by an increasing magnetic value because of the Lorentz force. A comparison with previous work showed close agreement.
Keywords: *Thermal analysis; Radiative analysis; Hybrid nanofluid; Thermal radiation; Magnetohydrodynamics*
PACS: 47.65.-d, 47.56.+r, 44.40.+a, 66.20.-d, 47.85.mb

Nomenclature

f_d=	Clear fluid	K=	thermal conductivity $(Wm^{-1}K^{-1})$
nf=	nano fluid	T_w=	gradient of temperature at the wall (K)
T=	Temperature	HN=	hybrid nanofluid
μ=	dynamic viscosity $(kgm^{-1}s^{-1})$	φ=	inclination angle
C_{fx}=	Coefficient of skin friction	T_∞=	stream temperature
c_p=	specific heat $(JKg^{-1}K^{-1})$	Q_c=	heat generation coefficient
ϕ_1=	Volume fraction of gold nanoparticle	q_r=	heat flux
u,v=	x and y-direction velocity (ms^{-1})	B_0=	magnetic strength
ϕ_2=	Volume fraction of silver nanoparticle	β_t=	Volumetric capacity for temperature
ρ=	fluid density	g=	acceleration base on gravity
σ=	electrical conductivity (sm^{-1})		

INTRODUCTION

The study of Magnetohydrodynamic (MHD) Casson hybrid nanofluids in circulating blood is a complex and interdisciplinary field that combines fluid dynamics, thermodynamics, and nanotechnology. These nanofluids, which are composed of blood as the base fluid and hybrid nanoparticles, have gained significant attention due to their potential applications in biomedical engineering, particularly in drug delivery, cancer treatment, and thermal management systems. The inclusion of thermal radiation and chemical reactions further complicates the dynamics, making it essential to understand their effects on flow, heat transfer, and mass transfer characteristics.

This comprehensive review aims to explore the current state of research on MHD Casson hybrid nanofluids in circulating blood, focusing on the effects of thermal radiation and chemical reactions. The review synthesizes findings from multiple studies to provide a detailed understanding of the physical phenomena involved and their implications for practical applications. Several parameters, including the magnetic field strength, nanoparticle volume fraction, and thermal radiation influence the flow characteristics of MHD Casson hybrid nanofluids. The Casson fluid model is particularly suitable for blood, as it accounts for its non-Newtonian behavior, which exhibits yield stress and shear-thinning properties. Recently, a lot of attention has been paid to the numerical analysis of heat transmission in hybrid nanofluids. The effective heat transmission of this type of nanofluid, along with radiative effects, has numerous applications in the pharmaceutical industry and engineering. Alqawasmi et al. [1] examined numerical simulation toward

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hybrid nanofluid movement. Based on the morphology of nanoparticles and gyrotactic microorganisms, Raza et al. [2] investigated the effect of nanolayers on the movement of tri-hybrid nanofluid. Shamshuddin et al. [3] looked at the impact of radiation on the dissipative HN flow in a revolving disk. The term "nanofluids" describes a synthesis approach that utilizes nanometallics due to nano-scale formation and thermal design. Noreen and colleagues [4] conducted a comparative study of THN by analyzing the influence of Cattaneo-Christov heat flux in conjunction with the role of radiation. The combination of CNT-Gr-Fe_3O_4 and MgO-Cu-Au hybrid nanoparticles of the kerosene oil type was investigated by Choudhary et al. [5] using a bidirectional stretching sheet. Rajamani and Reddy [6] examined MHD pulsating channel with Joule heating along with thermal radiation impacts. Nabwey et al. [7] studied heat transmission in MHD dynamics of Carreau HN past a curved surface that is exponentially stretched. In another study of Yu et al. [8], the optimisation of heat transmission with viscous nanofluid dynamics in a stretching and shrinking thin needle was discussed extensively.

Thermal radiation plays a significant role in the mechanisms that help bodies adjust their temperature to exchange energy. The analysis of thermal radiation on a moving fluid is explained by the variation of the material's internal energy. In thermal engineering and sectors where temperatures are extremely high, thermal radiation is important. A hybrid nanofluid's rotational dynamics were studied by Asghar et al. [9] in relation to the importance of heat radiation. Recently, Ramzan et al. [10] examined the thermal and theoretical study of hybrid nanofluid dynamics beyond a number of geometries that are not isothermal and non-isosolutal mechanisms. By looking at the internal heat generation, the function of HN in a dovetail fin's thermal process was investigated by Goud et al. [11]. Alrihieli and colleagues [12] investigated convective heating and radiative MHD nanofluid dynamics. Jayanthi and Niranjan [13] studied the effects of activation energy, joule heating, and viscous dissipation on the dynamics of nanofluids brought on by MHD in a vertical surface. Yaseen et al. [14] used two parallel plates to investigate how heat generation and thermal radiation affect the dynamics of hybrid and mono-hybrid nanofluids. Guedri and colleagues [15] examined the thermal dynamics of a radiative hybrid nanofluid across a nonlinear stretchy sheet. The mechanisms of Soret-Dufour and thermal radiation in unstable chemically reactive fluid dynamics were examined by Alao et al. [16]. The convective heat transfer in nanofluid flow via a stretching sheet was investigated by Manjunath et al. [17].

The flow of magnetohydrodynamics finds numerous uses in industries like heat exchangers, micro-electronics, and the modelling of combustion. In recent times, nanotechnology has been explained as the approach for thermal augmentation. Alsagri et al. [18] elucidated MHD simulation of nanofluid dynamics by utilizing viscous dissipation. Fatunmbi et al. [19] recently examined MHD micropolar nanofluid dynamics past an upright elongating sheet with temperature-dependent viscosity. Waqas et al [20] clarified the importance of MHD dynamics in a hybrid fluid type past a circulating disk. Eid et al. [21]. investigated the viscous nanofluid dynamics of micropolar magnetic on penetrable inclined surfaces. The machine learning method of Casson for hybrid nanofluid flow over a heat-stretched surface was recently investigated by Ramasekhar et al. [22]. Nayak et al. [23] investigated the function of dissipative viscous and radiation in a decreasing surface in MHD 3D dynamics and heat transfer analysis of nanofluid. Asjad et al. [24] investigated the bioconvection dynamics of the MHD viscous nanofluid. In their discussion of the importance of MHD, Idowu and Falodun [25] varied thermal conductivity and viscosity when two non-Newtonian fluids moved at the same time. Exponentially vertical surfaces with chemical reactions were used by Biswas et al. [26] to mimic Prandtl-nanofluid dynamics. Sitamahalakshmi and colleagues [27] investigated the impact of heat-mass transit on MHD Casson blood dynamics in a stretching permeable channel. A finite element description of paraffin wax nanoparticles and sand was investigated by Nagapayani et al. [28]. Gladys and Reddy [29] discussed the dynamics of non-Newtonian nanoparticles. Al-zabaidi et al. [30] studied flowing fluids past an inclined vicinity when there is significant of entropy generation, Lorentz force, and ohmic heating.

Many studies in the literature have considered the dynamics of nanofluids by ignoring the hybrid nanofluids. To our best knowledge, studies on hybrid nanofluids do not consider the thermal and radiative analysis through Casson fluid. The current research examined the thermal and radiative analysis of MHD Casson fluid with hybrid nanoparticles with viscous dissipation and magnetic field. Analysis of this nature has not been considered in the literature as far as we are concerned. This study finds application in engineering and many scientific domains. This model plays a significant role in the biomedical industry. This intricate computational framework intricately weaves MHD and thermal radiation scenarios through the dance of blood circulation, proving invaluable in medical interventions such as radiofrequency ablation, MRI (magnetic resonance imaging), and cancer chemotherapy. Within the Results and Discussion section, visual representations illuminate various crucial physical parameters. The application of gold and silver in the biomedical field with regard to blood demonstrates a variety of nanotechnological developments, from antimicrobial coatings and implanted devices to particular drug delivery and diagnostic equipment. Consequently, scholars are confident that the latest findings are distinctive and poised to significantly impact both engineering and medical fields, potentially igniting inspiration in future researchers.

MATHEMATICAL ANALYSIS

A steady, incompressible, laminar flow of hybrid nanofluids, which contains gold and silver nanoparticles, was considered as shown in Figure 1. This nanoparticles based were taken into account along with base fluid blood incorporated. Mass and thermal radiative analysis over a moving surface with its velocity to be $u_w = ax$ and free stream temperature, and concentration T_∞, C_∞ was considered. A transverse magnetic field B_0 was impose in a perpendicular direction. The heat transmission analysis was elucidated with the viscous dissipation and heat generation along with chemical reaction on the hybrid nanofluids. Figure 1 shows the physical configuration. Priyadharshini et al. [22] state that the equations that apply become valid when the boundary layer is approximated.

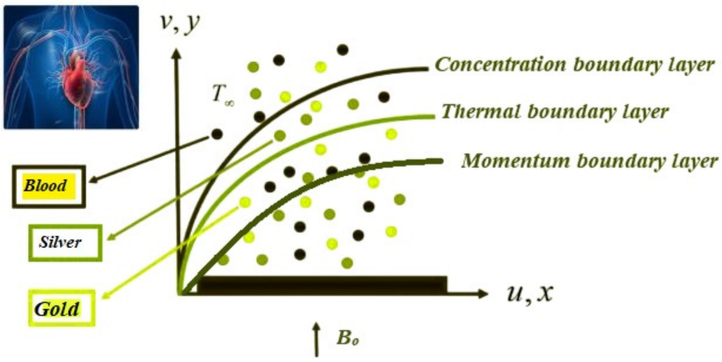

Figure 1. Physical model of the Problem

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\mu_{hnf}}{\rho_{hnf}}(1+\frac{1}{\beta})\frac{\partial^2 u}{\partial y^2} - \frac{\sigma_{hnf}}{\rho_{hnf}}B_0^2 u - \frac{\mu_{hnf}}{K^*(c_p)_{hnf}}u \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k_{hnf}}{(\rho c_p)_{hnf}}\frac{\partial^2 T}{\partial y^2} + \frac{Q_0}{(\rho c_p)_{hnf}}(T - T_\infty) - \frac{1}{(\rho c_p)_{hnf}}\frac{\partial q_r}{\partial y} - \frac{\sigma_{hnf}}{(\rho c_p)_{hnf}}B_0^2 u \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} - \mathrm{Kr}(C - C_\infty) \tag{4}$$

subject to the boundary conditions:

$$\left.\begin{array}{c} u = \mathrm{ax}, v = 0, \mathrm{T} = T_W, \mathrm{C} = C_W \; at \; y = 0 \\ u \longrightarrow 0, T \longrightarrow T_\infty, C \longrightarrow C_\infty \; as \; y \longrightarrow \infty \end{array}\right\} \tag{5}$$

The Rosseland diffusion approximation, which was employed by Reddy et al. [23], is utilized to describe the radiative heat flux that the flow faced.

$$q_r = -\frac{4\sigma_S}{3ke}\frac{\partial T^4}{\partial y} \tag{6}$$

With the use of Rosseland approximation, an optically thin fluid has been taken into consideration in the study's thermal and radiative analyses. Assume that the flow's temperature differential is negligible, so that equation (6) is linearized by simplifying T^4 by utilizing Taylor's series in T_∞ and avoiding the higher order to obtain:

$$T^4 = 4T_\infty^3 T - 3T_\infty^4 \tag{7}$$

The energy equation becomes:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k_{hnf}}{(\rho c_p)_{hnf}}\frac{\partial^2 T}{\partial y^2} + \frac{Q_0}{(\rho c_p)_{hnf}}(T - T_\infty) + \frac{16\sigma_S T_\infty^3}{3ke(\rho c_p)_{hnf}}\frac{\partial^2 T}{\partial y^2} + \frac{\mu_{hnf}}{(\rho c_p)_{hnf}}B_0^2 u \tag{8}$$

The following are the definitions of the similarity variables used in this paper:

$$u = axf'(\eta), v = -(av)^{\frac{1}{2}}f(\eta), \theta = \frac{T - T_\infty}{T_W - T_\infty}, \phi = \frac{C - C_\infty}{C_W - C_\infty}, \eta = \left(\frac{a}{\nu}\right)^{\frac{1}{2}} y \tag{9}$$

Employing the equation (9) above on the governing equations to obtain:

$$\frac{\mu_{hnf}}{\mu_f}(1+\frac{1}{\beta})f''' + \frac{\rho_{hnf}}{\rho_f}(ff'' - (f')^2) - \frac{\sigma_{hnf}}{\sigma_f}Mf' - \frac{\mu_{hnf}}{K(c_p)_f}f' = 0 \tag{10}$$

$$\frac{k_{hnf}(\rho c_p)_f}{k_f(\rho c_p)_{hnf}}\left(\frac{1+R}{Pr}\right)\theta'' + \frac{(\rho c_p)_f}{(\rho c_p)_{hnf}}Q\theta + \frac{(\rho c_p)_f}{(\rho c_p)_{hnf}}Ec(f'')^2 - f\theta' = 0 \tag{11}$$

$$\phi'' + Scf\phi' - ScKr\phi = 0 \tag{12}$$

The transform boundary conditions are:

$$f(0) = 0, f'(0) = 1, \theta(0) = 1, \phi(0) = 1, f'(\infty) = 0, \theta(\infty) = 0, \theta(\infty) = 0 \tag{13}$$

where;

$M = \frac{\sigma_f B_0^2}{a\rho_f}, K = \frac{(c_p)_f aK^*}{(c_p)_{hnf}}, R = \frac{16\sigma_s T_\infty^3}{3KeK}, Pr = \frac{\nu_f}{\alpha_f}, Q = \frac{Q_0}{(\rho c_p)_f a}, Ec = \frac{B_0^2 (ax)^2}{(c_p)_f (T_w - T_\infty)}, Sc = \frac{\nu}{D_B}$, are the Schmidt number, Eckert number, Prandtl number, heat generation a parameter, permeability parameter, magnetic parameter, and thermal radiation parameter.

The quantities of engineering interest for momentum and thermal boundary layer are described as follows:

$$C_{f_x} = \frac{(\mu)_{hnf}}{\mu_f a x^2}\left(\frac{\partial u}{\partial y}\right)_{y=0}, and\ Nu_x = -\frac{x k_{hnf}}{k_f (T_w - T_\infty)}\left(\frac{\partial T}{\partial y}\right)_{y=0}, Sh = D\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

Skin friction, Nusselt number, and Sherwood number are obtained by applying the similarity variables as follows:

$$C_{f_x} = \frac{(\mu)_{hnf}}{\mu_f}\frac{f''(0)}{\sqrt{Re_x}}, Nu_x = \frac{x k_{hnf}}{k_f}\theta'(0)\sqrt{Re_x}, Sh_x = \varphi'(0)$$

METHODOLOGY

Using the Runge-Kutta and shooting procedures, the nonlinear problems controlling ODEs in equations (10)–(12) subject to (13), were solved. Solving the BVP for even an extremely finite interval would be impractical, and it is not possible on an infinite interval. We will apply an infinite boundary condition in this study at a finite point $\eta\ at\ \infty = 10$. Care has been made to shoot in steps, improve shoots in stages, and avoid round off error by computing numerical values in order to integrate $f''(0), and\ \theta'(0)$, which is an initial value problem. The collection of nonlinear equations is first transformed into first order ODEs in order to apply this technique:

$$f = y_1, \frac{df}{d\eta} = \frac{dy_1}{d\eta} = y_2, \frac{d^2 f}{d\eta^2} = \frac{d}{\eta}\left(\frac{dy_1}{d\eta}\right) = \frac{dy_2}{d\eta} = y_3, \frac{d^3 f}{d\eta^3} = \frac{d}{\eta}\left(\frac{dy_2}{d\eta}\right) = \frac{dy_3}{d\eta} \tag{14}$$

$$\theta = y_4, \frac{d\theta}{d\eta} = \frac{dy_4}{d\eta} = y_5, \frac{d^2\theta}{d\eta^2} = \frac{d}{\eta}\left(\frac{dy_4}{d\eta}\right) = \frac{dy_5}{d\eta} \tag{15}$$

$$\phi = y_6, \frac{d\phi}{d\eta} = \frac{dy_6}{d\eta} = y_7, \frac{d^2\phi}{d\eta^2} = \frac{d}{\eta}\left(\frac{dy_6}{d\eta}\right) = \frac{dy_7}{d\eta} \tag{16}$$

Substituting equations (14), (15) and (16) into the transformed equations to obtain:

$$\frac{\mu_{hnf}}{\mu_f}\frac{dy_3}{d\eta} + \frac{\rho_{hnf}}{\rho_f}(y_1 y_3 - (y_2)^2) - \frac{\sigma_{hnf}}{\sigma_f} M y_2 - \frac{\mu_{hnf}}{Ko(c_p)_f} y_2 = 0 \tag{17}$$

$$\frac{k_{hnf}(\rho c_p)_f}{k_f(\rho c_p)_{hnf}}\left(\frac{1+R}{Pr}\right)\frac{dy_5}{d\eta} + \frac{(\rho c_p)_f}{(\rho c_p)_{hnf}} Q y_4 + \frac{(\rho c_p)_f}{(\rho c_p)_{hnf}} Ec (y_3)^2 - y_1 y_5 = 0 \tag{18}$$

$$\frac{dy_7}{d\eta} + Scy_1 y_7 - ScKr y_6 = 0 \tag{19}$$

$$f(0) = 0, f'(0) = 1, \theta(0) = 1, f'(\infty) = 0, \theta(\infty) = 0, \phi(0) = 1, \phi(\infty) = 0 \tag{20}$$

Simplifying equations (16) and (17) to obtain:

$$\frac{dy_3}{d\eta} = \frac{\frac{\rho_{hnf}}{\rho_f}(y_1 y_3 - (y_2)^2) - \frac{\sigma_{hnf}}{\sigma_f} M y_2 - \frac{\mu_{hnf}}{Ko(c_p)_f} y_2}{\frac{\mu_{hnf}}{\mu_f}} \tag{22}$$

$$\frac{dy_5}{d\eta} = \frac{\frac{(\rho c_p)_f}{(\rho c_p)_{hnf}} Q y_4 + \frac{(\rho c_p)_f}{(\rho c_p)_{hnf}} Ec (y_3)^2 - y_1 y_5}{\frac{k_{hnf}(\rho c_p)_f}{k_f(\rho c_p)_{hnf}}\left(\frac{1+R}{Pr}\right)} \tag{23}$$

$$\frac{dy_7}{d\eta} = ScKr y_6 - Scy_1 y_7 \tag{24}$$

Subject to conditions:

$$y_1(0) = 0, y_2(0) = 1, y_4(0) = 1, y_6(0) = 1, y_2(\infty) = 0,\ y_4(\infty) = 0, y_6(\infty) = 0 \tag{21}$$

The outcomes are gotten by interchanging the scale factor up to a desired value by implementing an approximate solution. To obtain the solution, a guess for the initial assumptions are properly considered and the boundary thickness of the layer are taken into account.

RESULTS AND DISCUSSION

The paper have discussed the thermal and radiative analysis of HN dynamicss with impact of viscous dissipative and magnetic field. To explain the physical influence of pertinent dynamics parameters on velocity and temperature, hybrid numerical scheme called Runge-Kutta techniques along with the novel shooting method was utilized on the equations. The control parameters have been chosen as: Q=0.2; Pr=21; Ec=0.04; M=0.2; Kr=0.1; Sc=0.22; K=0.2; R=0.5; Kr=0.2; The Prandtl number was chosen to be 21 based on the type of hybrid nanofluid considered in this study, while other parameters values are chosen based on experimental computations.

Figure 2 shows how the magnetic field affects fluid velocity when $\phi_1 = 0.02, \phi_2 = 0.01$. The effect of magnetic in Figure 2 was plotted with nanocomposite particles Gold and Silver with base fluid blood. The depth of the boundary layer was shown to decrease with an increasing magnetic parameter value. The Lorentz force appears in the equation of momentum and gives all tendency of bringing down the motion of the tri-nanocomposite particles. This force is created due to the impose of magnetism field to the heat transmission analysis. Figure 3 illustrates how Eckert affects the fluid's temperature. The temperature profile is observed to increase with an increasing Eckert number value.

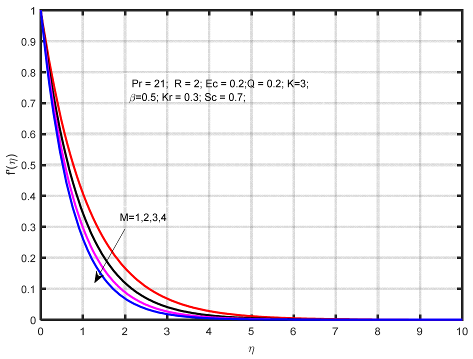

Figure 2. Significance of magnetism parameter in velocity distribution

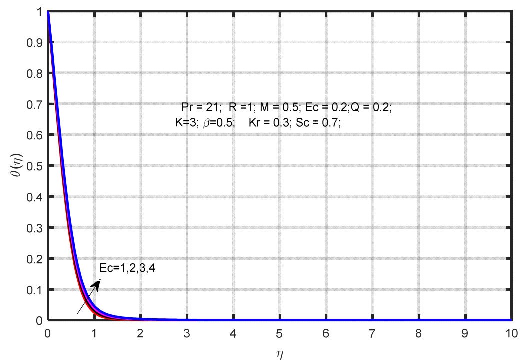

Figure 3. Eckert number significance in relation to temperature dispersion

The dissipative viscous term (Eckert number) transforms the kinetic into internal energy based on work done in anticipating viscous liquid stresses. This result indicates that increasing the Eckert value raises the temperatures and depth of the entire boundary layer. The boundary layer's enthalpy and the kinetic energy of the flow of nanofluids are represented by the Eckert number. Figure 4 showed how the fluid's temperature is affected by the heat generating parameter (Q). The result in Figure 4 indicates that the fluid temperature increased as Q increased. This implies that, the heat generated reduces the thermal process within the boundary layer. Hence, the nanocomposite fluid enhances the temperature of fluid by generating heat more than a nanocomposite. Hence, the thermal and radiative analysis enriched the fluid temperature when heat generation parameter ascended.

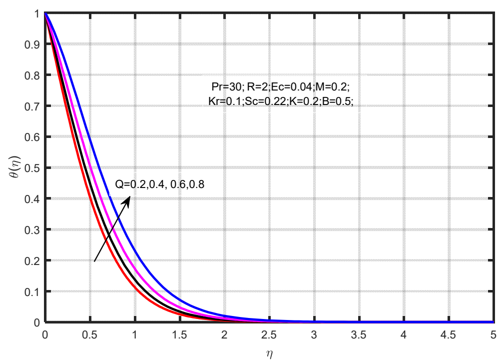

Figure 4. Significance of heat generation on the temperature distribution

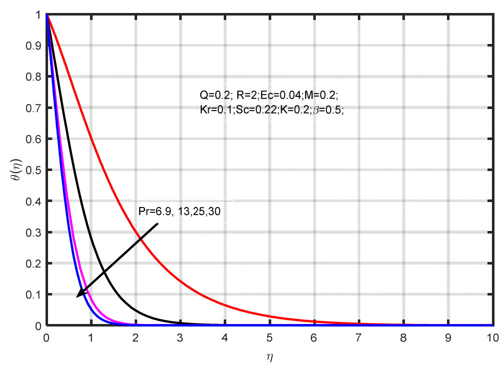

Figure 5. Prandtl number significance in relation to temperature dispersion

The effect of Prandtl number (Pr) on fluid temperature is depicted in Figure 5. It was found that the temperature distribution descended with an increasing value of Pr. This indicates that the thermal boundary layer's thickness decreased.

This paper's thermal, radiative, and heat transfer analyses are governed by the dimensionless Prandtl number. The momentum to thermal diffusion ratio is denoted by Pr. Because the nanocomposite nanoparticles have better thermal conductivities, the temperature is dropping. The corresponding thickening of the thermal and momentum layer boundaries is implied by the current analysis, which is displayed in Figure 5.

The impact of thermal radiation (R) on the temperature distribution is depicted in Figure 6. As R rises, the temperature profiles rise as well. The current research demonstrates how the temperature and depth of the thermal boundary layer are changed by the absorption of thermal radiation within the layer. Therefore, the thermal radiation improves the boundary layer's thermal and radiative analysis. Figure 7 shows how β affects the velocity profile. It claims that the velocity outline shrank as the β parameter increased. The improved Casson parameter's ability to limit the liquid's velocity by reducing the stress brought on by yield is crucial to achieving this objective.

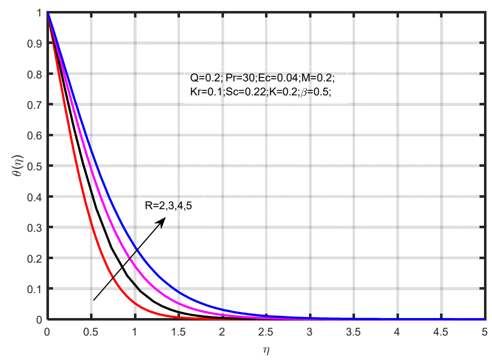

Figure 6. Thermal radiation's importance in relation to the temperature distribution

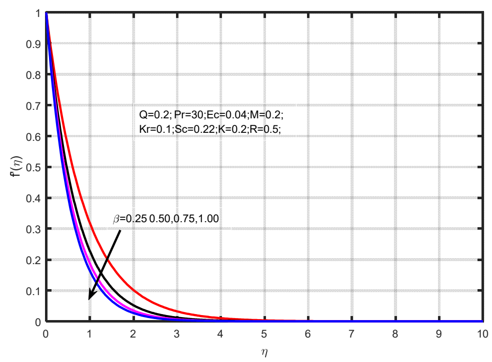

Figure 7. Effect of Casson fluid parameter on the velocity profiles

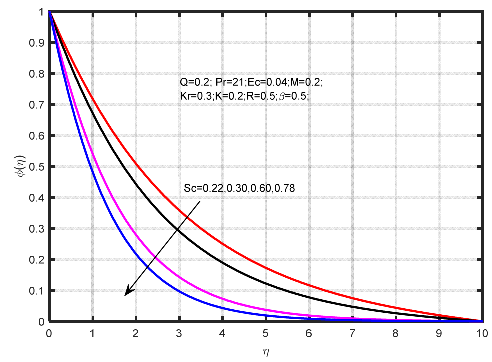

Figure 8. Schmidt number's impact on concentration profiles

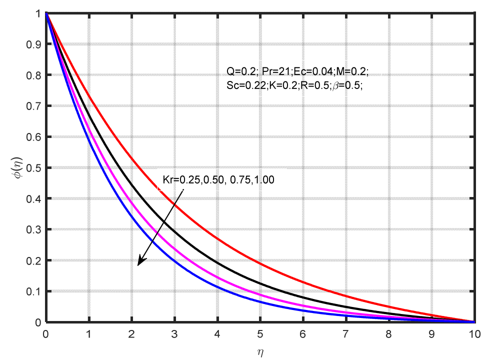

Figure 9. Chemical reactions' effects on concentration profiles

Figure 8 provides a clear illustration of how the Schmidt number affects the topography of concentration. It becomes evident that as the Schmidt number escalates, a notable reduction in the concentration field occurs. This phenomenon arises because the diffusion of solutes in fluids is inherently tied to the diffusion coefficient. Consequently, the observed decline in the concentration field correlates with a diminishing diffusion coefficient. Thus, a remarkable plunge in the concentration field in relation to the Schmidt number is clearly noted. As the parameter governing chemical reactions intensifies, the concentration profile diminishes, as illustrated in Figure 9, showcasing the significant impact of the chemical reaction parameter. Furthermore, the temperature profile follows a reversible trajectory.

Tables 1, 2, and 3 represents the fundamental thermal and comparative properties relevant to the hybrid nanofluid analysis. Table 1 lists the standard thermophysical properties of blood (as the base fluid) and nanoparticles such as gold (S1) and silver (S2), including density, specific heat, thermal conductivity, and dynamic viscosity. Table 2 outlines the mathematical formulation used to evaluate the effective thermophysical properties of the hybrid nanofluid, incorporating parameters such as density, viscosity, specific heat, thermal and electrical conductivities. Table 3 provides a comparison of the present numerical results with those reported by Manjunatha et al. [17] for various Prandtl number (Pr) values, showing excellent agreement and thereby validating the accuracy of the current computational model.

Table 1. Thermal Properties(Standard Values)

Property	Symbol	Blood (Base fluid)	Gold (S_1)	Silver (S_2)
Density (kg/m^3)	ρ	1060	19300	10500
Specific Heat (J/Kg)	Cp	3617	129	235
Thermal Conductivity (W/m)	k	0.52	318	429
Dynamic viscosity(Pa)	μ	3.5 ×10^{-3}	--	---

Table 2. Formulation of the effective thermophysical model of a hybrid nanofluid in mathematics:

Thermal property	Hybrid Nanofluids
Density	$\frac{\rho_{hnf}}{\rho_f}=(1-\phi_2)\left[1-\phi_1-\phi_1\left(\frac{\rho_{s1}}{\rho_f}\right)+\phi_2\left(\frac{\rho_{s2}}{\rho_f}\right)\right]$
Dynamic viscosity	$\frac{\mu_{hnf}}{\mu_f}=(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}$
Specific heat	$\frac{(\rho C_p)_{hnf}}{(\rho C_p)_f}=(1-\phi_2)\left[1-\phi_1-\phi_1\left(\frac{(\rho C_p)_{s1}}{\rho_f}\right)+\phi_2\left(\frac{(\rho C_p)_{s2}}{\rho_f}\right)\right]$
Thermal conductivity	$\frac{k_{hnf}}{k_f}=\frac{k_{s2}+2k_{hnf}-2\phi_2(k_{hnf}-k_{s2})}{k_{s2}+2k_{hnf}+2\phi_2(k_{hnf}-k_{s2})},\frac{k_{s1}+2k_{hnf}-2\phi_1(k_{hnf}-k_{s1})}{k_{s1}+2k_{hnf}+2\phi_1(k_{hnf}-k_{s1})}$
Electrical conductivity	$\frac{\sigma_{hnf}}{\sigma_f}=\frac{3\left[\left[\frac{\phi_1\sigma_1+\phi_2\sigma_2}{\sigma_f}\right]-(\phi_1+\phi_2)\right]}{2+\left[\frac{\phi_1\sigma_1+\phi_2\sigma_2}{\sigma_f(\phi_1+\phi_2)}\right]-\left[\left[\frac{\phi_1\sigma_1+\phi_2\sigma_2}{\sigma_f}\right]-(\phi_1+\phi_2)\right]}$

Table 3. Comparison results for $(-\boldsymbol{\theta}'(\mathbf{0}))$ for different values of Pr

Pr	Manjunatha et al. [17]	Present work
2.0	0.9113	0.9113
7.0	1.8954	1.8953
20	3.3539	3.3538

CONCLUSIONS

The thermal and radiation analysis of two-phase nanoparticles $(Gold + Silver)$ suspended in blood base fluid has been solved numerically. The dynamics of suspended nanoparticles in blood were considered past a flexible sheet in the presence of a magnetic field, dissipative viscous and thermal radiation, along with chemical reaction. The main conclusions drawn from this investigation are:

- As the magnetic parameter increases, the heat and momentum profiles decrease. This is because an electrically conducting fluid moves more slowly when the Lorentz force is created. (ii) The speed and temperature distribution rose as the heat-generating parameter was increased. This demonstrates that greater heat is generated and that the volume percentage of nanoparticles is significantly enhanced;
- A higher Prandtl number results in a decrease in the thickness of the thermal and momentum boundary layers;
- The outcomes show that hybrid nanoparticles show a very high thermal and radiative performance compared to dual-phase nanoparticles.
- It was observed that increasing the Eckert number improved the temperature and velocity profiles.
- The concentration decreases as the chemical reaction and Schmidt number increase.

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МАГНІТОГІДРОДИНАМІЧНА ДИНАМІКА ГІБРИДНОЇ НАНОРІДИНИ КАССОНА В ЦИРКУЛЮЮЧІЙ КРОВІ З УРАХУВАННЯМ ТЕПЛОВОГО ВИПРОМІНЮВАННЯ ТА ХІМІЧНИХ РЕАКЦІЙ

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Метою цієї роботи є дослідження актуальності теплового випромінювання та хімічної реакції в тепловому та радіаційному аналізі динаміки гібридної нанорідини Кассона. Фізична модель базувалася на суміші гібридних наночастинок золота та срібла (HN), які суспендовані в крові повз розтяжний лист. Динаміка рідини повз розтяжний лист є визначним аналізом для теплових та імпульсних граничних шарів. Він знаходить застосування в різних технологічних галузях та промисловості. Модельні рівняння досліджувалися за допомогою системи диференціальних рівнянь з частковими похідними (PDEs). Для перетворення цих PDEs у повні диференціальні рівняння (ODEs) було використано прийнятне перетворення. Пізніше систему рівнянь було розв'язано за допомогою алгоритму Рунге-Кутти разом зі стрільбою. Аналіз, описаний у цій статті, пояснює, що гібридні наночастинки мають високу продуктивність у радіаційних та теплових процесах порівняно з нанорідиною. Спостерігалося, що швидкість рідини відштовхується зростаючим магнітним значенням через силу Лоренца. Порівняння з попередньою роботою показало близьку відповідність.

Ключові слова: *термічний аналіз; радіаційний аналіз; гібридна нанорідина; теплове випромінювання; магнітогідродинаміка*