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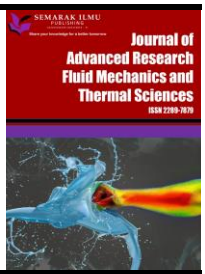

Numerical Computation of Radiative MHD Micropolar Nanofluid Flow over a Stretching Sheet with First Order Chemical Reaction and Soret Effects

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ABSTRACT

The outcomes of the current study may have broad applications in contemporary industrial technologies, including those involved in blood transportation, lubrication, rigid and random cooling particles of metallic sheets, etc. New studies have shown that the thermal conductivity of a nanofluid is triggered by Brownian motion and thermophoretic collisions. Primary research interests include the effects of chemical reaction, radiation, and the Soret effect on micropolar nanofluids along an inclined stretched sheet. Effects of thermophoresis and Brownian motion is considered and the Buongiorno's model is taken into account. To get the nonlinear ordinary differential equation from the PDEs, compatible transformations are used. Mathematica's NDSolve technique is implemented to do a numerical treatment of the dimensionless equations once they have been translated. The upsides of this strategy lie in its ability to automatically track errors and select the best algorithm. Graphical and numerical treatments of the physical quantities of interest are provided. The tabulated magnitudes of the numerical outputs compare well with those that currently exist. Graphs showing the energy transfer rate as a function of the many contributing factors. As the Brownian motion factor increases, the skin friction and the mass transfer rate upsurge and the rate at which energy may be transported climbs. As the angle of incidence increases, skin friction rises while the Nusselt number and Sherwood number fall. Velocity profile rises with the material parameter. Radiation parameter tends to rise the temperature.

1. Introduction

Over the last several decades, scientists have conducted more studies on the effects of various physical characteristics on heat transport and mass. Hydrodynamic machinery, chemical processing equipment, lubrication systems, and polymer manufacturing are just some of the numerous areas where this phenomenon may be put to use. It also aids in the preservation of food, the development and dispersal of fog, and the preservation of crops from freezing.

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The ability to control or create the varying thermophysical properties of these fluids might significantly boost a system's performance in several ways. Particularly intriguing is the possibility of increasing the coolant fluids' thermal conductivity by adding.

Nanoparticles of extremely thermally conductive materials. They are of use in the cooling systems of automobiles (where they can be used to increase the efficiency of heat transmission, hence allowing engines to run at optimum temperatures), deep drilling (where they could improve performance), micro-electronics (where they could improve performance), and fuel economy (thanks to lighter radiators, pumps, and other vehicle components) are just some of the industries that could benefit from nanofluids with enhanced heat transfer performance. Because of its low temperature and high heat transfer coefficient, nanofluids are well-suited for usage in microelectronics. Since nanofluids are more efficient heat conductors, radiators, pumps, and other vehicle parts may be made smaller and lighter without sacrificing engine performance, opening more room in large vehicles like semis and trucks. Because of the lower quantity of pumping power essential, lighter automobiles with improved fuel efficiency may be manufactured by nanofluids with higher heat transfer coefficients. From the viewpoints of thermal management and conversion, the study by Murshed *et al.,* [1] provided experimental investigation of the heat transmission capabilities of nanofluids with varying geometries via natural convection. Bhatti *et al.,* [2] explored in depth how nanoparticles of diamond (C) and silica (SiO2) behave as they float over an exponentially elastic surface while suspended in a water-based hybrid nanofluid. Efemwenkiekie *et al.*, [3] examines the effectiveness of aluminium sulphate nanofluids, magnesium sulphate nanofluids, and their hybrids in a radiator, using both distilled water (DW) and an ethylene glycol-DW combination (EG-DW). Safdar *et al.*, [4] present a theoretical and numerical model for steady MHD Maxwell nanofluid flow over the porous stretching sheet containing gyrotactic microorganisms; their model is based on the idea that the microorganisms stabilise the suspended nanoparticles via bio convection induced by the impacts of buoyancy forces. Using a minichannel heat sink with 12 rectangular minichannels of depth 1, width 1, and hydraulic diameter 22 mm, Khan *et al.*, [5] explored the hydraulic and thermal performance of a stable alumina-silica/water hybrid nanofluid.

Micropolar fluid has microscale components and internal microstructure. These fluids have micro-rotational inertia and phenomena. Micropolar fluid flow analysis is required in the production of liquid crystal solidification, bath metal plate cooling, suspension and colloidal solutions, polymer fluid extrusion, and unique lubricants. The research by Shi *et al.,* [6] refined the numerical analysis of a non-Newtonian micropolar fluid in an MHD boundary layer, caused by an exponentially curved stretching sheet. Yasmin *et al.*, [7] studied in detail mass and heat transfer in an electrically conducting non-Newtonian micropolar fluid experiencing magnetohydrodynamics (MHD) flow as a result of the curved stretching sheet. What a convective Darcy-Forchheimer flow of a Maxwell nanofluid across a linear porous stretched sheet is affected by heat and mass transfer is investigated by Jawad *et al.*, [8] also considered are several chemical reactions, heat transfer, and thermophoresis.

When it comes to developing solar energy engineering for materials like electroconductive magnetic micropolar polymers, computational and mathematical models are a crucial supplement to experimental investigations. Motivated by a desire to learn more about the intricate fluid dynamics at play in these procedures, Shamshuddin *et al.*, [9] takes a look at the non-linear steady, hydromagnetic micropolar flow, taking into account the effects of radiation and heat sinks. Jawad *et al.*, [10] conduct an investigation of the heat transfer in an electrical MHD flow of Williamson Nano Casson fluid. The fluid and the mass flow are directed towards a porous, stretched sheet. The results of nonlinear thermal radiation and chemical diffusion are also examined. Rehman *et al.*, [11] addressed the influence of buoyancy factors and radiation on the flow of magneto-hydrodynamic (MHD) micro-polar nano-fluid across a stretching/shrinking sheet.

To initiate a chemical reaction, reactants must have the lowest activation energy possible. Paper, food, ceramics, drying, dehydration, oil, and water emulsions all make use of fluid movement, chemical reaction, and activation energy. Changing the nanoparticle composition, size, and distribution affects the nanofluid's thermal radiation characteristics. Most research over the last several decades has focused on determining the thermal radiation characteristics of nanoparticles of varying radii and composition. The goal was to identify the optimal combination that would maximise the heating efficiency of nanofluids through their thermal radiation qualities. Chen *et al.,* [12] explored nanofluid thermal radiation properties, including nanoparticle aggregation, using experiment and theory.

Safdar *et al.*, [13] used a theoretical and computational method to examine the incompressible, steady, and magnetohydrodynamic flow of Buongiorno nanofluid across a stretchy surface. Arrhenius activation energy, chemical diffusion, thermal conductivity, and buoyancy forces are all discussed in this study and their effects are analysed. Additionally, the effect of gyrotactic microbe suspension in nanofluids is investigated. Flow, conduction, convection, thermal radiation, and phase change heat transfer are all discussed in the work by Xu *et al.,* [14] as they pertain to the increase of heat transfer by nanofluid thermal transport in porous metals. Rusdi *et al.,* [15] examined the influences of heat radiation and partial slip on the dynamics of nanofluid flow across an exponentially thinned sheet with the focus being on Nanoscale silver (Ag) particles in water and kerosene oil. Younes *et al.*, [16] addressed the importance of nanofluids and discussed the factors that have been shown to significantly affect their thermal behaviour and thermal conductivity. Particle size, shape, pH, surfactant, solvent type, hydrogen bonding, temperature, base fluids, and nanoparticle orientation (carbon nanotubes, graphene, and metal oxides) are all important.

Thermal radiation is electromagnetic energy transfer. High-temperature variance ambient fluid and boundary surface thermal radiation is considerable. Radiative influences matter in engineering and physics. High-temperature and space technology activities need radiation heat transfer effects on flows. Polymer manufacturers use radiation to monitor heat transfer, which alters product quality. Radiation affects missiles, aeroplanes, gas turbines, solar radiation, space vehicles, liquid metal fluids, MHD accelerators, and nuclear power plants. The fractal distributive features of nanoparticle aggregation are used by Ali *et al.*, [17] to create an efficient nanofluid thermal conductivity model which is a function of fractal size and concentration. Considering the thermal radiation, Newtonian heating, and chemical reaction, Aleem *et al.,* [18] presents unstable MHD nanofluid flow across an infinite vertically accelerating plate in porous media. Titanium dioxide, aluminium oxide, copper oxide, silver, and copper are the five nanoparticles often found in water, which serves as a standard base fluid. The influence of Newtonian heating on the unstable MHD free convective flow of a radiating and chemically reacting Casson hybrid nanofluid via an infinitely oscillating vertical porous plate has been examined by Krishna *et al.,* [19]. In magnetohydrodynamics, Jawad *et al.*, [20] studied a vertical stretching surface in a micropolar fluid flow at a stagnation point. Non-zero mass flow led to an investigation of thermal radiation and thermal conductivity.

Dawar *et al.*, [21] discussed micropolar nanofluid flow with electrical accompaniment across an expanding sheet under secondary slippage circumstances and calculated chemical reaction and the movement of nanofluids in two dimensions. Ramzan *et al.,* [22] describes how a binary chemical reaction with an Arrhenius activation energy is affected by nonlinear thermal radiation and dual stratification in the flow analysis. The effects of thermal radiation, heat absorption/production, buoyancy effects, and entropy generation on the magnetohydrodynamic mixed convection of a second-grade nanofluid flow across a porous media are considered by Khan *et al.*, [23]. The melting heat and mass transport features on the stagnation point flow of Powell-Eyring nanofluid across a stretchy surface were studied by Majeed *et al.,* [24] due to the widespread relevance of melting in processes such as permafrost melting, magma solidification, and the thawing of frozen soils. Khan *et al.,* [25] discussed the flow of a Maxwell liquid undergoing chemical reactions towards a stretched sheet of varying thickness, near its stagnation point.

Thermophoretic processes and Brownian motion are two of the most prominent concepts for the irrational improvement in thermal conductivity. This concept is gaining popularity since it allows us to effectively investigate new possibilities presented by the wonders of modern technology. Thermo-diffusion or the Soret effect transports molecules in a multi-component mixture driven by temperature differential. The Soret and Dufour effects are crucial in flow regimes with considerable density variations. Ahmad *et al.,* [26] investigated the time-dependent viscous fluid flow caused by a flexible spinning disc. Joule heating helps with temperature equation, and the disc is magnetised vertically. Bouslimi *et al*., [27] addresses MHD mixed convection nanofluid flow under nonlinear heating from an expanding surface, nanofluid heat transfer under magnetic field and boundary conditions. The primary goal of Imran *et al.,* [28] research was to investigate the combined effects of thermal radiation and microbial bioconvection on Brownian motion and thermophoresis diffusion in non-Newtonian Williamson fluid flow across an exponentially stretched sheet. With Brownian motion and thermophoresis effects, Sardar *et al.,* [29] looks at the local non-similar solutions of MHD Carreau nano-fluid flow over a wedge. Heat and mass transfer in a mixed convection flow are additionally impacted by diffusion-thermo (Dufour) and thermal-diffusion (Soret) effects. The wedge shape is kept in place by a constant proportion of nanoparticles and temperature. Entropy optimisation in MHD convection flow of viscous liquid around a spinning cone is the major goal of Khan *et al.,* [30], Energy equation considers Joule heating, thermal radiation, and dissipation considering Dufour and Soret's significant actions. Multi-factor thermo-diffusion transports particles. Soret–Dufour effects, heat radiation, and binary chemical reaction on stationary incompressible Darcy–Forchheimer flow of nanofluid under Buongiorno's model with Brownian motion and thermophoresis was explored by Rasool *et al.,* [31]. Majeed *et al.*, [32] numerically investigated detailed twofold stratification influence using a radiative mixed convective nanofluid across a cylinder.

Sabu *et al.*, [33] theoretically and quantitatively explored MHD convective ferro-nanofluid flow along an inclined channel with porous material, including Hall current, heat source, and Soret effects. Chu *et al*., [34] created a mathematical model to study the two-dimensional magnetohydrodynamic boundary layer flow of second-grade non-Newtonian nanofluid towards a permeable and stretchy Riga plate surface. Cattaneo-Christov double diffusions (CCDD) model is presented to study thermal and solutal relaxation. Variable thermal conductivity and mass diffusivity are considered.

Four novel aspects served as the basis for our current effort. The primary goal of this study was to simulate and analyse the two-dimensional radiative MHD flow of a micropolar nanofluid. The second objective is to examine the dynamics of this flow over an inclined surface. The third step is to examine characteristics of the chemical reaction, Soret effect, Brownian motion, and thermophoresis. As a fourth goal, we intend to use the NDSolve method to generate numerical solutions for the velocity, temperature, and concentration fields. Also, graphical analyses of the skin friction coefficient and the local Nusselt and Sherwood numbers have been performed. To our knowledge, the problem is new and no such articles reported yet in the literature.

2. Mathematical Formulation

A steady, two-dimensional boundary layer flow of micropolar nanofluid over a permeable inclined linear stretching plate with an angle Ω is considered. The primary objective of this study is to investigate the effects of radiation, chemical reaction and Soret on MHD flow in a micropolar nanofluid. In this analysis, we assume that there is a magnetic field of strength B_0 perpendicular to the inclined surface with a constant intensity, and we disregard any induced magnetic field. In this case, the flow is produced as a result of the stretching of the slanted sheet at a stretching rate $'a'$. Additionally, Ω is the angle made relative to the vertical axis of the sheet during stretching process. Thermophoretic effects and Brownian motion are taken into account. Furthermore, graphs are used to illustrate the effects of suction or injection on the rates of heat and species exchange.

The Lorentz force in momentum equation is expressed by $J\,\mathrm{X}B$ where:

J , B indicates the current density, total magnetic field
$B = B_0 + b$, Applied magnetic field is B_0, Induced magnetic field is b
$J = \sigma\left(E + VXB\right)$ (Ohm's law), electrical conductivity is σ, polarisation charge effect is E =0
$J = \sigma\left(VXB\right)$,
$J\,\mathrm{X}B = \sigma\left(VXB\right)\mathrm{X}B = \sigma\left\{\left(V.B\right)B - \left(B.B\right)V\right\}$; $B = \sigma B_0^2 u$.

The governing equations are:

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \left(\frac{\mu_f + K_1^*}{\rho_f}\right)\frac{\partial^2 u}{\partial y^2} - \left(\frac{K_1^*}{\rho_f}\right)\frac{\partial N^*}{\partial y} + g\left[\beta_t\left(T - T_\infty\right) - \beta_c\left(C - C_\infty\right)\right]\cos\Omega - \left(\frac{\sigma B^2{}_0}{\rho_f}\right)u, \tag{2}$$

$$u\frac{\partial N^*}{\partial x} + v\frac{\partial N^*}{\partial y} = \left(\frac{\gamma^*}{\left(j^*\rho\right)_f}\right)\frac{\partial^2 N^*}{\partial y^2} - \left(\frac{K_1^*}{\left(j^*\rho\right)_f}\right)\left(2N^* + \left(\frac{\partial u}{\partial y}\right)\right) \tag{3}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left(D_B\frac{\partial T}{\partial y}\frac{\partial C}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) - \frac{1}{\left(\rho C_p\right)_f}\frac{\partial q_r}{\partial y} \tag{4}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} + \frac{D_T K_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} - Kr\left(C_\infty - C\right). \tag{5}$$

Rosseland approximation is given by

$$q_r = \frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{6}$$

By Taylor's expansion we can express T^4 as

$$T^4 \cong \left(4T_\infty^{\ 3}T - 3T_\infty^{\ 4}\right) \tag{7}$$

Eq. (4) on using Eq. (6) and Eq. (7)

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \left(\alpha + \frac{16\sigma^* T_\infty^{\ 3}}{3k^*\left(\rho C_p\right)_f}\right)\frac{\partial^2 T}{\partial y^2} + \tau\left(D_B\frac{\partial T}{\partial y}\frac{\partial C}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) \tag{8}$$

Boundary conditions are

$$\left.\begin{aligned} &u = u_w\left(x\right) = ax, v = V_w, T = T_{w,} N^* = -m_0\frac{\partial u}{\partial y}, C = C_w \quad \text{at } y = 0,\\ &u \to u_\infty = 0, v \to 0, N^* \to 0, T \to T_\infty, C \to C_\infty \quad \text{at } y \to \infty. \end{aligned}\right\} \tag{9}$$

For the study at hand, the stream function $\psi = \psi\left(x, y\right)$ has the form

$$u = \frac{\partial \psi}{\partial y}, v = -\frac{\partial \psi}{\partial x} \tag{10}$$

The definition of the similarity transformations is as

$$\begin{aligned} &u = axf\left(\eta\right), v = -\sqrt{av}\, f\left(\eta\right), \eta = y\sqrt{\frac{a}{v}}, N^* = ax^m\sqrt{\frac{a\left(m+1\right)x^{m-1}}{2v}}h\left(x\right),\\ &\theta\left(\eta\right) = \frac{T - T_\infty}{T_w - T_\infty}, \phi\left(\eta\right) = \frac{C - C_\infty}{C_w - C_\infty}. \end{aligned} \tag{11}$$

Eq. (2) to Eq. (5) in its transformed form, obtained by applying Eq. (8), is

$$\left.\begin{aligned} &\left(1+K\right)f''' + ff'' - f'^2 + Kh' + \left(Gr_x\theta + Gc_x\phi\right)\cos\Omega - Mf' = 0,\\ &\left(1+\frac{K}{2}\right)h'' + fh' - hf' - K\left(2h + f''\right) = 0,\\ &\frac{1}{\Pr}\left(1+\left(\frac{4}{3}\right)R\right)\theta'' + f\theta' + Nb\phi'\theta' + Nt\theta'^2 = 0,\\ &\phi'' + Lef\phi' + SrLe\theta'' - LeC_r\phi = 0. \end{aligned}\right\} \tag{12}$$

Where

$$\left.\begin{array}{l} M=\left(\dfrac{\sigma B^{2}{}_{0}}{a\rho}\right), Le=\dfrac{\nu}{D_B}, \Pr=\dfrac{\nu}{\alpha}, Nb=\dfrac{\tau D_B\left(C_w-C_\infty\right)}{\nu},\ Nt=\dfrac{\tau D_t\left(T_w-T_\infty\right)}{\nu T_\infty}, \\ Gr_x=\dfrac{g\beta_t\left(T_w-T_\infty\right)x^{-1}}{a^2},\ Gc_x=\dfrac{g\beta_c\left(C_w-C_\infty\right)x^{-1}}{a^2},\ \mathrm{Re}_x=\dfrac{u_w x}{\nu},\ Sr=\dfrac{D_T K_T\left(T_w-T_\infty\right)}{\nu T_\infty\left(C_w-C_\infty\right)}, \\ C_r=\dfrac{Kr}{a}. \end{array}\right\} \tag{13}$$

Given that the coefficients of thermal expansion (β_t) and concentration expansion (β_c) are proportional to x^1 in the case where local Grashof number and local modified Grashof number must be free from the influence of x, we presume that (see references [35-38])

$$\beta_t = nx^1,\ \beta_c = n_1 x^1 \tag{14}$$

Where n, n_1 are the constants, Gr_x and Gc_x become

$$Gr=\frac{gn\left(T_w-T_\infty\right)}{a^2},\ Gc=\frac{gn_1\left(C_w-C_\infty\right)}{a^2}\ . \tag{15}$$

Conditions at those Boundaries are

$$\left.\begin{array}{l} f\left(\eta\right)=S,\ f'\left(\eta\right)=1,\ h\left(\eta\right)=0,\ \theta\left(\eta\right)=1, \phi\left(\eta\right)=1 \text{ at } \eta=0, \\ f'\left(\eta\right)\to 0, h\left(\eta\right)\to 0, \theta\left(\eta\right)\to 0,\ \phi\left(\eta\right)\to 0\ as\ \eta\to\infty. \end{array}\right\} \tag{16}$$

The reduced Sherwood number, reduced Nusselt number, and skin friction coefficient are related quantities that may be expressed separately as

$$-\theta'\left(0\right)=\frac{Nu_x}{\left(1+\left(4/3\right)R\right)\sqrt{\mathrm{Re}_x}},\ -\phi'\left(0\right)=\frac{Sh_x}{\sqrt{\mathrm{Re}_x}},\ C_{fx}=C_f\sqrt{\mathrm{Re}_x}=f''\left(0\right)$$

3. Methodology for Solution

In this work, we examine the boundary layer flow of micropolar nanofluids over an inclined stretched surface in the context of magnetic field and thermal radiation. The effects of Soret and chemical reactions are studied. This research makes use of Buongiorno's model for calculating the thermal efficiency of a fluid flow in the existence of Brownian motion and thermophoresis. The above common nonlinear differential equations are numerically solved in this study using Mathematica's NDSolve command. This approach is unconditionally stable and converges. The maximum step size 0.01 is used in the current numerical computations to get the numerical solution with six orders of local accuracy for the approach as a criterion of convergence. For evidence of the numerical scheme's preciseness, the latest results of $-\theta'\left(0\right)$ and $-\phi'\left(0\right)$ are assessed against Khan and Pop [38] and Rafique *et al.*, [39] outcomes in Table 1.

Table 1
Contrast of $-\theta'(0)$ and $-\phi'(0)$ for different values of Nb and Nt with $\Pr = Le = 10,\ \Omega = 90^{o}$ and in the absence of remaining parameters

Nb	Nt	Rafique *et al.,* [39]		Khan and Pop [38]		Current Outcomes	
		$-\theta'(0)$	$-\phi'(0)$	$-\theta'(0)$	$-\phi'(0)$	$-\theta'(0)$	$-\phi'(0)$
0.1	0.1	0.9524	2.1294	0.9524	2.1294	0.952363	2.129288
0.2	0.2	0.3654	2.5152	0.3654	2.5152	0.365358	2.515103
0.3	0.3	0.1355	2.6088	0.1355	2.6088	0.135517	2.608694
0.4	0.4	0.0495	2.6038	0.0495	2.6038	0.049467	2.603719
0.5	0.5	0.0179	2.5731	0.0179	2.5731	0.017924	2.572978

4. Results and Discussion

Applications where increased heat transfer is desired, such as in the cooling of electronic devices and solar collectors, can benefit from the use of magnetic field nanoparticles in the flow zone, as demonstrated in this work. The Soret effect increases the mass transfer rate, which is important in several processes, including the separation of mixtures and desalination. MHD micropolar nanofluid over a stretching sheet with chemical reaction and Soret effects has a wide range of potential uses beyond the aforementioned areas of study and practice, including biomedical engineering, environmental engineering, etc. In this study most of the figures become available by running through a set of values for a specific parameter, others remain fixed at a single value during the whole simulation such as:

$$K = 1.0, S = 0.5, M = Nb = Gr = Nt = 0.1,\ R = Sr = 1.0, C_r = 0.5, Gc = 1.1, Le = 5.0, \Omega = 45^{o},$$
$$\Pr = 6.5.$$

The power of magnetism M is a resistive quantity that opposes flow, causing the velocity to decrease. An electromagnetic force known as the Lorentz force is induced by applying a magnetic field to a conducting fluid (e.g., liquid metals, electrolytes) with a certain velocity profile. This force is exerted in a direction that is perpendicular to both the fluid's velocity and the magnetic field. Therefore, the fluid is subjected to extra forces, which might change its velocity distribution. As seen in Figure 1, the Lorentz force exerted by a magnetic field M slows the velocity profile when it encounters obstacles in its route.

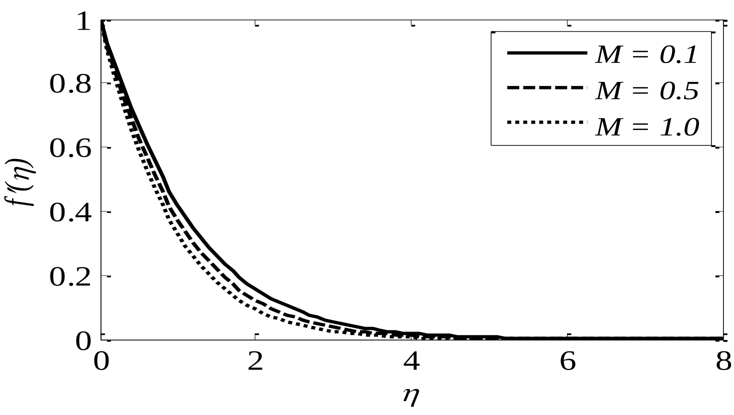

Fig. 1. Velocity profile for several values of M

The case of the angular velocity versus various quantities of M in Figure 2 displays the same outcome. However, contrasting results have been witnessed for temperature and concentration in physical phenomena. The temperature profile of the micropolar nanofluid on the slanted surface may be influenced by the magnetic parameter (M). Joule heating may be introduced into a conducting nanofluid by applying a magnetic field, which causes induced electric currents to flow through the fluid. Additionally, the thermal conductivity of magnetic nanoparticles may be raised to improve heat transmission. Alterations in the temperature distribution along the slanted surface may result from interactions between the magnetic field, the microstructural rotations, and the thermal conductivity of the nanoparticles. Magnetophoretic effects caused by the magnetic field cause the nanoparticles to move towards or away from areas of greater magnetic field intensity.

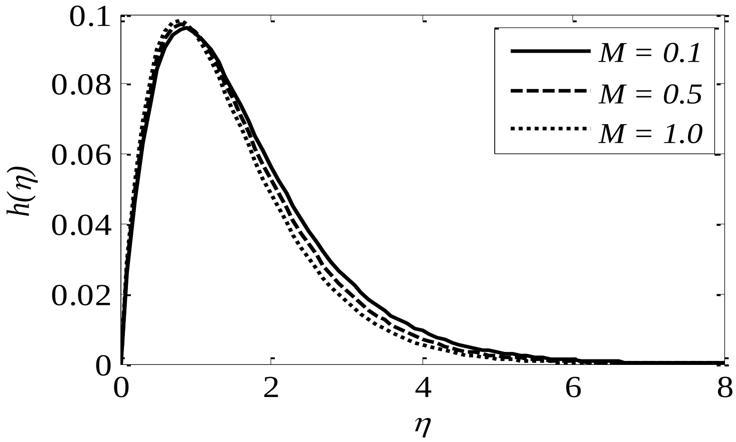

Fig. 2. Angular velocity for several values of M

Nanoparticle concentration might vary throughout the fluid layer and the inclined surface as a consequence of this movement. The implications of both temperature and concentration can be mitigated by raising M which is depicted in Figure 3 and 4.

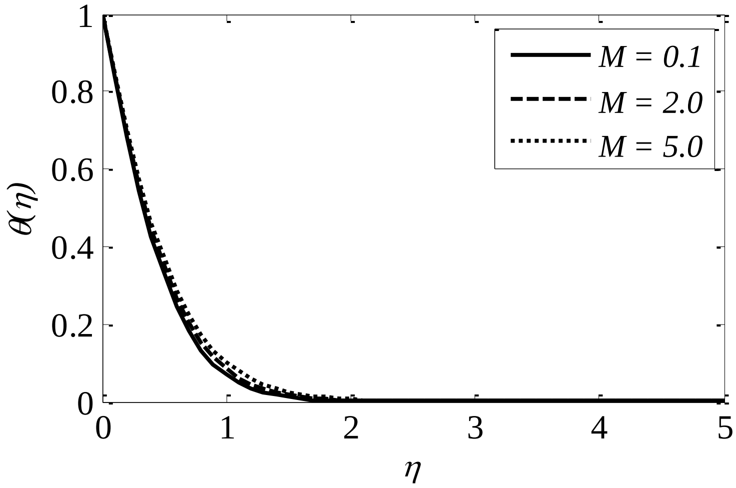

Fig. 3. Temperature profile for several values of M

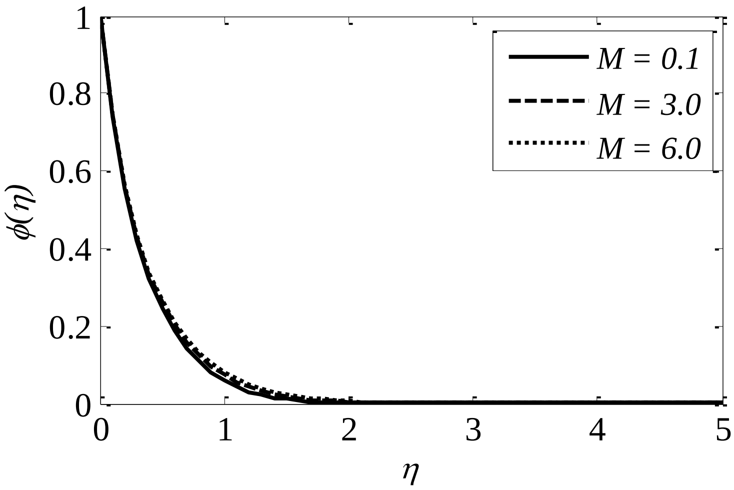

Fig. 4. Concentration profile for several values of M

In Figure 5, we recognise that when the material factor K boosts the velocity profile escalates. Developing factor K cuts down viscosity and elevates velocity physically. Instead, as K grows larger, the angular velocity climbs as shown in Figure 6.

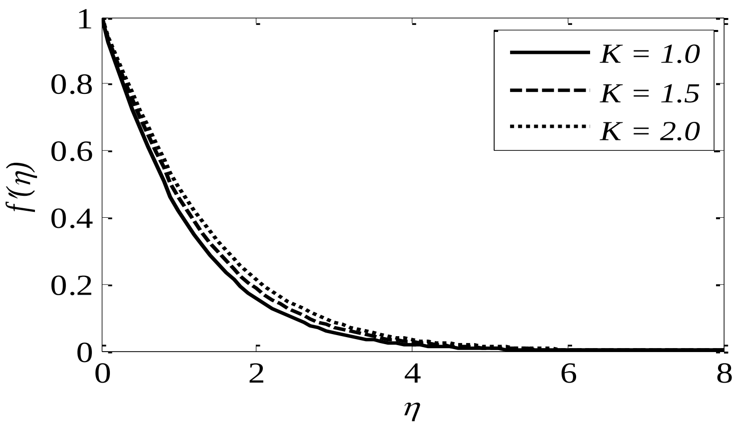

Fig. 5. Velocity profile for several values of K

The velocity profile of a micropolar-type nanofluid is highly dependent on the material component. Compared to traditional Newtonian fluids, the flow patterns may be drastically different when microstructural rotations are present due to the introduction of extra degrees of freedom in the fluid motion. The microstructural viscosity and the connection between the velocity and micro-rotation fields are both influenced by the material component. In contrast, decreased microstructural viscosity would increase the effect of micro-rotations, leading to behaviour more like to that of a classical Newtonian fluid.

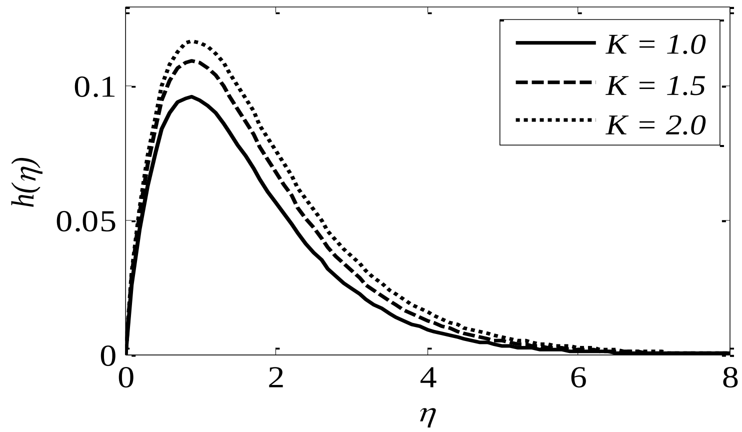

Fig. 6. Angular velocity for several values of K

The impact of the thermal Grashof number Gr on velocity is seen in Figure 7. The velocity exactly improves when the number Gr is raised. This is because buoyancy influences the fluid particles as a result of gravitational force, which increases the fluid's velocity.

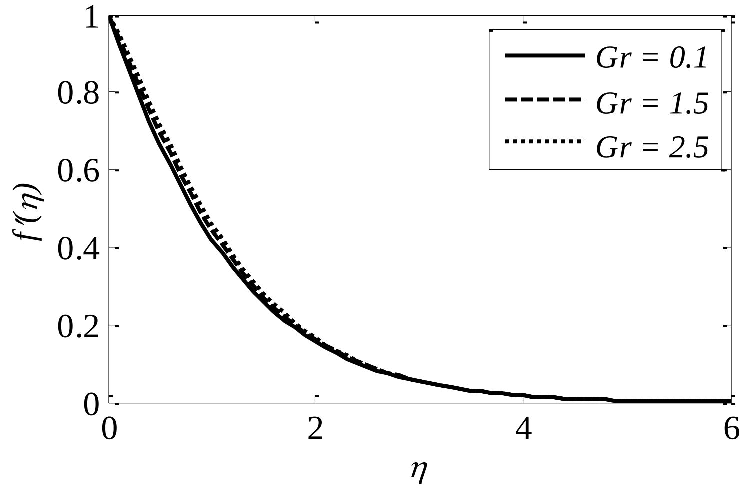

Fig. 7. Velocity profile for several values of Gr

The velocity profile is enhanced by raising the solutal buoyancy factor Gc, which is visible in Figure 8. In a physical sense, the buoyancy parameter Gc reduces the viscous forces that cause the velocity to increase.

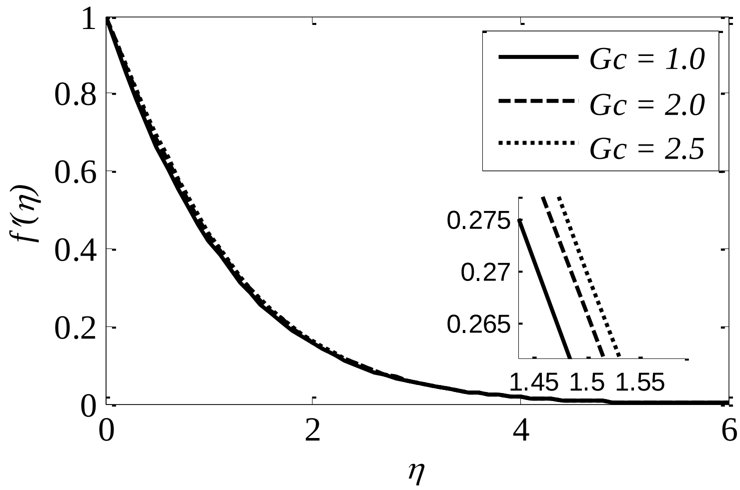

Fig. 8. Velocity profile for several values of Gc

Figure 9, clarifies and illustrates the impact of the inclination parameter Ω on the velocity outline. Looking at the figure makes it obvious that the velocity outline gets smaller as the values of γ increase. The circumstances also suggest that the gravitational force acting on flow will be at its strongest when $\Omega = 0^o$. The sheet will be vertical at this time, explaining why. On the other hand, if $\Omega = 90^o$, the sheet will be horizontal, which will cause the bouncing forces to be less powerful, originating a falling off in the velocity profile.

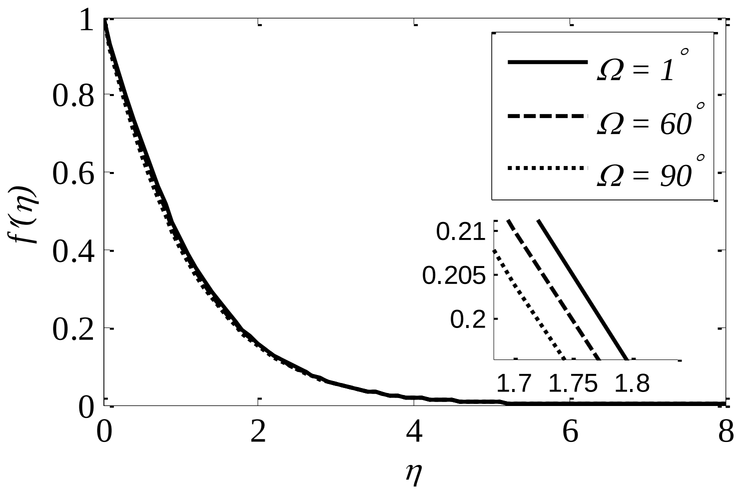

Fig. 9. Velocity profile for several values of Ω

Figure 10 exhibits the changes in the velocity distribution experienced when varying the suction parameter S. The velocity pattern appears to be lowering with boosting S, which is consistent with the generalisation that suction sustains the expansion of the boundary layer and inevitably minimises the development of the highest points in the velocity outline.

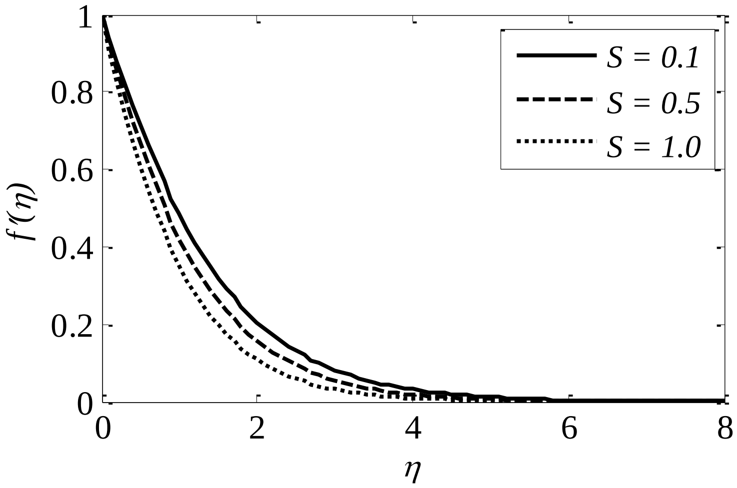

Fig. 10. Velocity profile for several values of S

The temperature distribution is shown to be controlled by the Prandtl number $\Pr$, as seen in Figure 11. The thermal boundary layer's thickness and the fluid's temperature profile both declines as $\Pr$ improves, as the thermal diffusivity is lowered while the momentum diffusivity is raised.

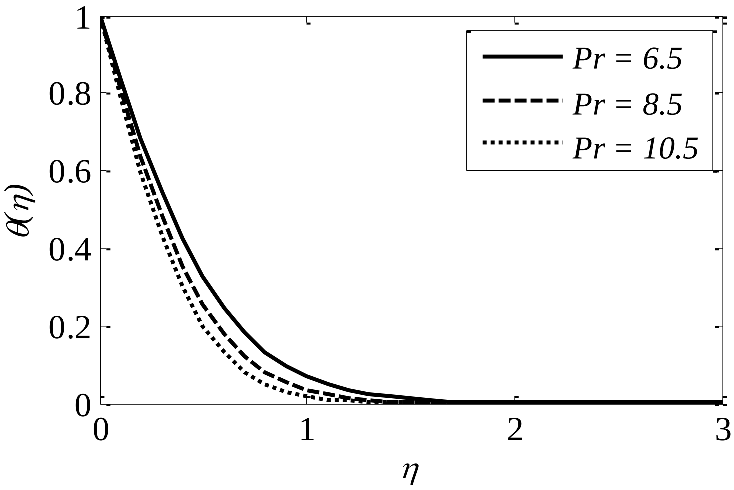

Fig. 11. Temperature profile for several values of $\Pr$

The temperature increases as the radiation parameter R does, as seen in Figure 12. A faster growth in fluid temperature comes from increases in surface heat transfer based on by greater radiation consumption.

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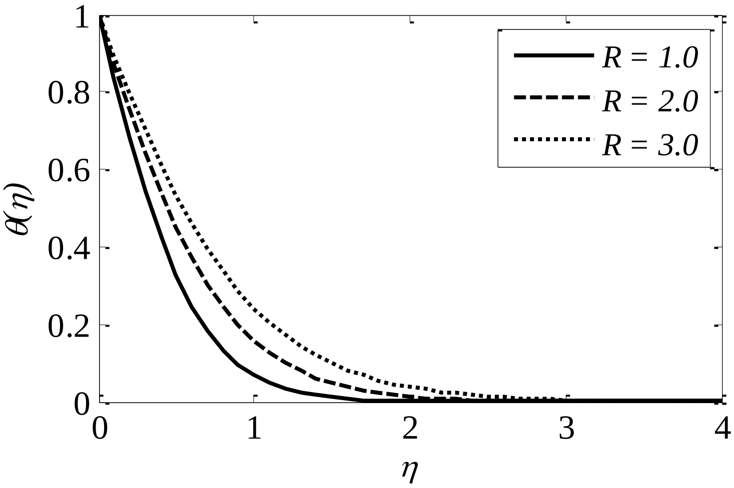

Fig. 12. Temperature profile for several values of R

Figure 13 and 14 show how the Brownian motion factor Nb modifies temperature and concentration curves. The wider range of Nb boosts nanoparticle kinetic energy, allowing more particles to transition beyond the surface, resulting in higher temperatures but lessening concentration.

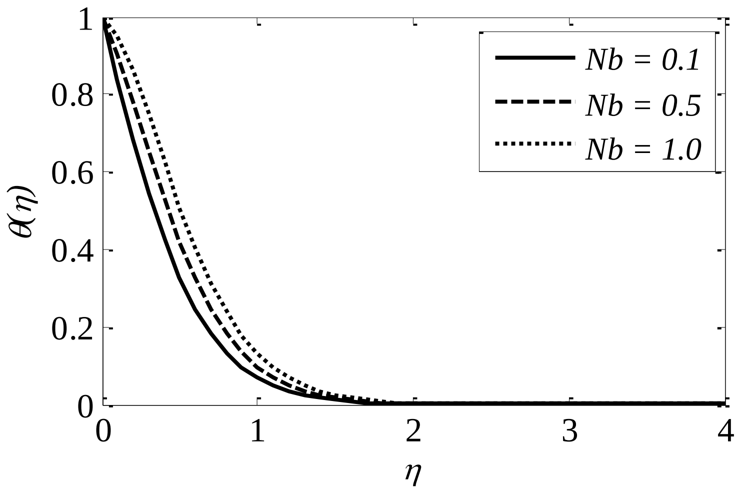

Fig. 13. Temperature profile for several values of Nb

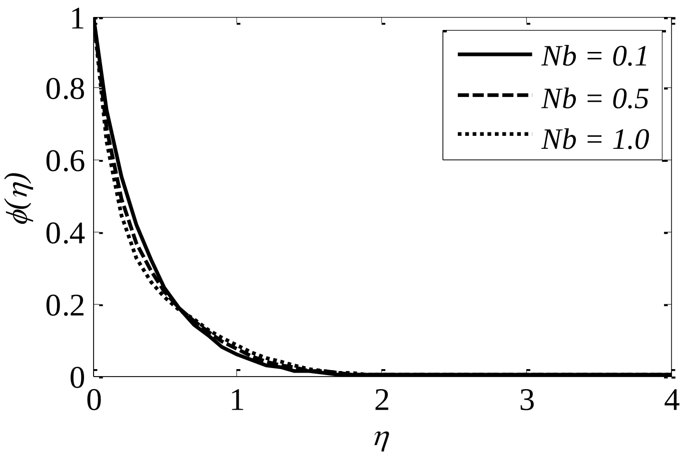

Fig. 14. Concentration profile for several values of Nb

Thermophoresis factor Nt modifies temperature and concentration patterns in Figure 15 and 16. The thermophoresis force drives nanoparticles from hot to cold, evolving the temperature profile. Also Nt alters concentration profile similarly.

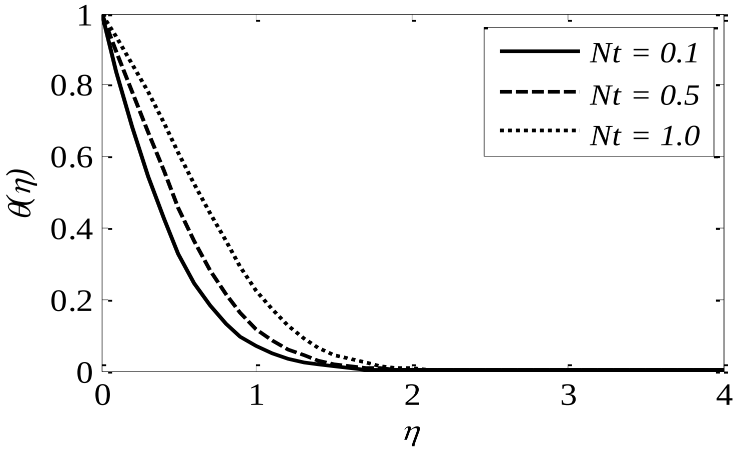

Fig. 15. Temperature profile for several values of Nt

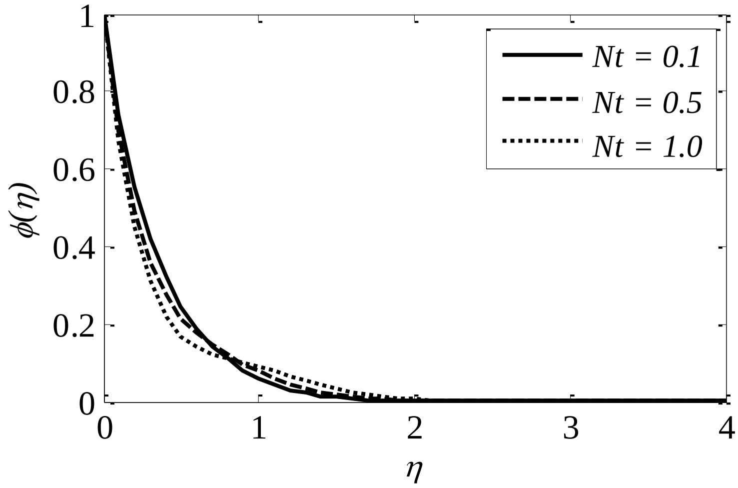

Fig. 16. Concentration profile for several values of Nt

As can be observed in Figure 17, the boundary layer viscosity reduces as the Lewis number goes up, which is related to a reduction in the concentration field.

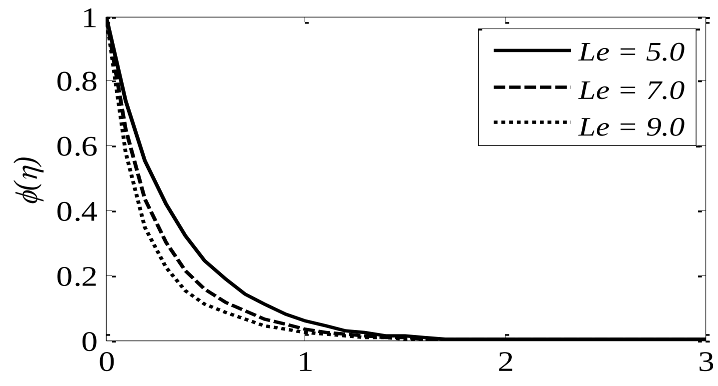

Fig. 17. Concentration profile for several values of Le

In Figure 18, we look into how the parameter C_r in a chemical process alters the concentration of nanoparticles. As the repercussions of a chemical reaction grows the concentration profile diminishes. When a chemical reaction takes place, the rate of intermolecular mass transfer rises, resulting in a volume reduction of the nanoparticles.

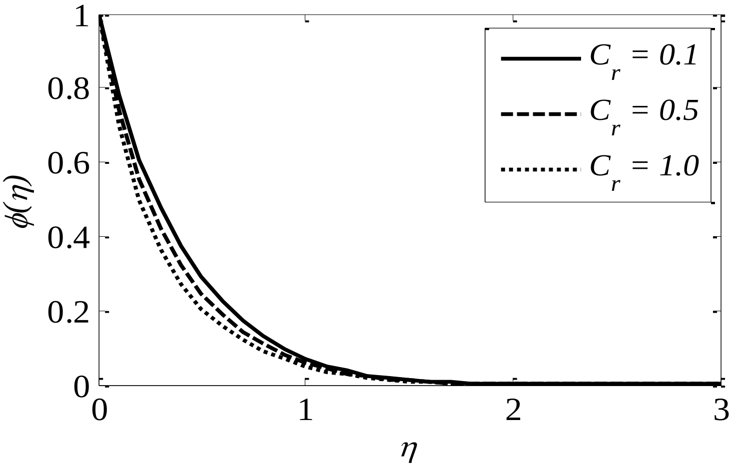

Fig. 18. Concentration profile for several values of C_r

Figure 19 reveals how the Soret number Sr alters the concentration profile. As the Sr climbs, it gets evident that temperature gradients play an important role in the diffusion of species, leading to an increase in concentration.

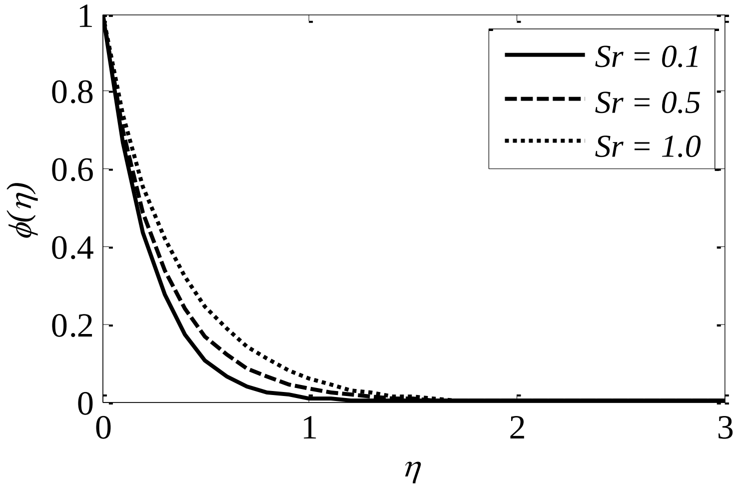

Fig. 19. Concentration profile for several values of Sr

For greater Brownian motion and inclination, exhibited in Figure 20, the rate of skin friction gets better.

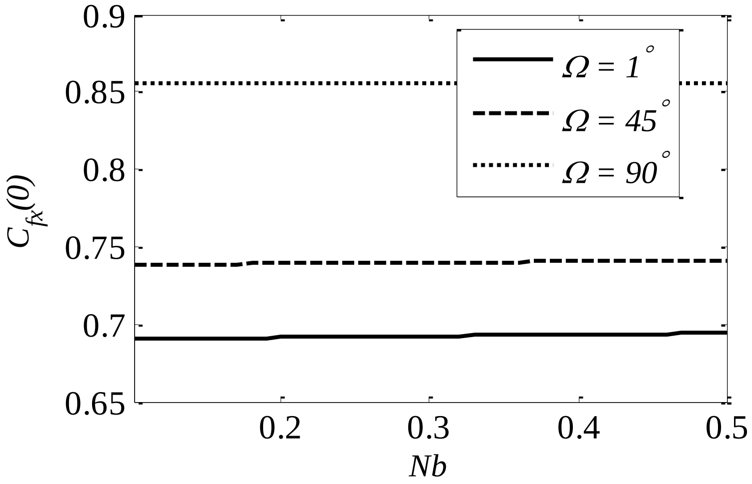

Fig. 20. Variations of skin friction with Nb for different values of Ω

The movement of dimensionless heat and mass exchange rates at the wall, coupled with skin friction, is looked at in Figure 21 and 22 in relation to the parameters Nb and Ω. The outcomes of the Brownian motion factor on various inclination parameters are seen in Figure 21.

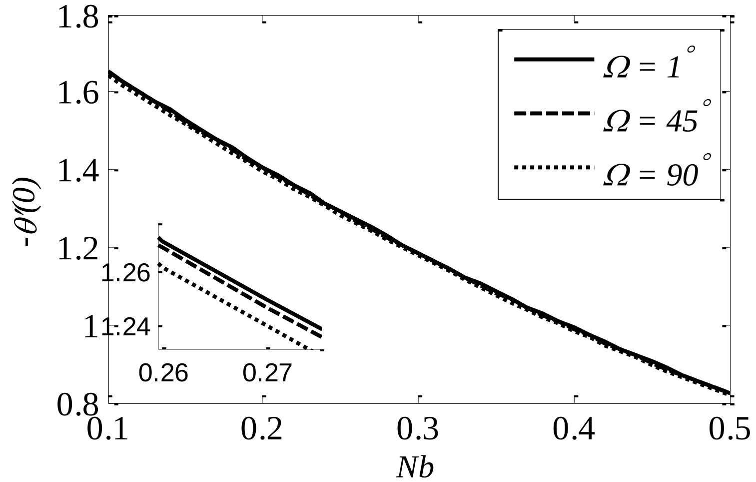

Fig. 21. Variations of reduced Nusselt number with Nb for different values of Ω

It is evident that the Brownian motion factor and inclination factor have an inverse relationship with the heat exchange rate. The rate of heat transmission diminishes as inclination and the Brownian motion component are spiked. Figure 22 demonstrates that the Brownian motion factor has positive impact and inclination parameter have negative impact on the mass exchange rate.

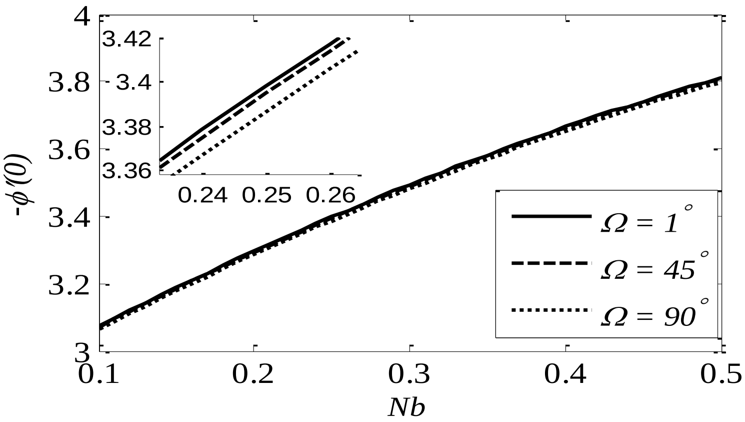

Fig. 22. Variations of reduced Sherwood number with Nb for different values of Ω

5. Conclusions

Numerical simulations of the flow of a micropolar-type nanofluid down an inclined surface are shown here. NDSolve is able to retrieve similarity findings for velocities, temperatures, and concentrations. These outcomes have an extensive connection with the prior investigation. Below are some of the most significant insights regarding the findings from this study:

i. With an increase in Brownian motion, particles move more erratically, which causes energy rate to decline while skin friction and mass rate increase.
ii. Thermal radiation boosts temperature field.
iii. As the amplitude of the Soret effect climbs, the concentration profile improves.
iv. As the amplitude of the chemical reaction effect increases, the concentration profile diminishes.
v. The concentration profile drops when the boundary layer viscosity falls in relation to Lewis number.
vi. Heat and mass transfer rates drop with angle of inclination.

6. Scope and Future Work

The results obtained in this study will be used to analyse the heat and mass transport phenomena in many non-Newtonian nanofluid fluid flow industrial applications. This work can be extended in future with some other geometries and physical conditions.

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