# Modeling the Impact of Flow Parameters on Fluid Velocity and Temperature in an Electrically Conducting Fluid Past a Wedge

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***Abstract*— The main concern of the present paper is to study the impact of flow parameters on fluid velocity and temperature in an electrically conducting fluid past a wedge. MHD mixed convective heat transfer for an incompressible, laminar, and electrically conducting casson nanofluid flow past a permeable wedge investigated via a numerical method, called fourth-order accurate collocation-based solver (BVP4C). The boundary-layer governing partial differential equations (PDEs) are transformed into highly nonlinear coupled ordinary differential equations (ODEs) consisting of the momentum and energy equations using similarity solution. The velocity is found to increase with an increasing Falkner Skan exponent whereas the temperature decreases. With the rise of the Casson fluid parameter, the fluid velocity increases but the temperature is found to decrease in this case. It is found that the temperature decreases as the Prandtl number increases and thermal boundary layer thickness decreases with increasing values of the Prandtl number. A significant finding of this investigation is that flow separation can be controlled by increasing the value of the Casson fluid parameter. The results demonstrate a good agreement with previously published studies for some special cases.**

***Keywords*– Casson Fluid, Nanofluid, Fluid Flow Parameters and Electrically Conducting**

## I. INTRODUCTION

Magnetohydromagnetics (MHD) is the study of the behavior of an electrically conducting fluid as it flows in the presence of a magnetic field [1], [16]. From a technical perspective, it is crucial to investigate the flow of an electrically conducting fluid in the presence of a magnetic field. There are numerous instances where a strong magnetic field is encountered in an electrically conducting fluid. These include applications in nuclear engineering, astrophysical flows, solar power technology, electric power generation, and space vehicle re- entry, among others [12]. The following are some examples of applications in engineering and industry: MHD pumps, grain regression, electrostatic precipitation, aerodynamic heating, paper and textile dyeing, liquid crystal solidification, food preservation, petroleum industries, cooling of metallic sheets in baths, and magneto hydrodynamic generators [7], [8]. When a real fluid passes a solid barrier that is stationary, the layer of fluid that touches the boundary surface has a velocity equal to the surface. In the fluid layer that can't break away from the boundary surface, retardation takes place. Because of the additional retardation that this retarded layer causes to the adjacent fluid layers, the fluid in the immediate vicinity of the boundary surface develops a small region where the velocity of the flowing fluid rapidly increases from zero at the boundary surface to the velocity of the mainstream. The layer closest to the boundary is known as the boundary layer [4], [13].

Several factors have been studied when applying a magnetic field to control the motion of an electrically conducting fluid. These factors include the type of conducting fluid, the geometry of the flow the fluid is in, the source of the magnetic field, the fluid's degree of ionization, and the applied Magnetic field strength. The convection heat transfer method is influenced by the density, conductivity, and specific heat of the fluid. Fluid flow is impacted by viscosity. Heat transfer is widely used in many different applications, such as heat exchangers that improve heat transmission or steam pipes that try to limit it. In modern technology, heat transfer is significantly employed in areas such as energy production, nuclear reactors, and heat exchangers (which are used in power generation, air conditioning, refrigeration, and space heating) [5].

Heat transfer is the movement of thermal energy between physical systems. The rate of heat transmission depends on the system temperature and the properties of the medium. On the other hand, temperature is the result of using a thermometer to quantify hotness or coolness. Variations in temperature inside a fluid can be caused by differences in temperature between the fluid at the boundary and the ambient fluid. The absorption of thermal energy across a boundary in a thermodynamic system is another source of variance. As a result, by dissipating heat, heat transfer which defines the flow of thermal energy between physical systems depends on temperature and pressure [11].

According to [17], the three less complex processes that make up heat transmission are radiation, convection, and conduction. The laws that govern each of these heat transfer methods are different. The process of molecular heat transfer by tiny particles (atoms, molecules, ions, etc.) in a medium with a temperature gradient is known as conduction of heat. Heat is transferred through convection, which is the movement of a medium's macroscopic components, also known as molar volumes.

Convective heat transfer is the process that transfers heat when heat conduction and convection occur simultaneously.

The particular instance of this process is convective heat exchange, or heat transfer, which occurs between a moving media and its interface with a solid, liquid, or gaseous medium [10]. Heat transfer modifies the internal energy of both participating systems, in accordance with the first rule of thermodynamics. Measurable heat transfer is how the second law characterizes thermodynamics [2].

An equilibrium state is reached when all bodies are at the same temperature. The geometrical, hydrodynamic, and thermal properties of the system under examination all affect the heat transfer coefficient, which is not a constant value. When flow occurs across a surface, a velocity boundary layer forms. It is linked to shear forces that run parallel to the surface, and it causes the velocity to rise through the boundary layer from almost zero at the surface to the free stream velocity at a considerable distance from it [6], [9].

Casson fluid flow past a symmetric wedge has not yet been studied widely in literature. Therefore, this study attempts to investigate the impact of flow parameters on fluid velocity and Temperature in an electrically conducting fluid past a wedge. With the help of transformations, the governing partial differential equations corresponding to the momentum and energy equations are transformed to ordinary differential equation. Fourth-order accurate collocation-based solver (BVP4C), a numerical solution of the problem is obtained. The results are found to be in agreement with already published work. The effects of different parameters have been studied in detail with the help of their graphical representations.

## II. MATHEMATICAL FORMULATION

A steady two-dimensional, incompressible, laminar, free convective heat and mass transfer flow of a Casson Nanofluid past a stationary wedge with influence of induced magnetic field is studied.

### *A) Flow Configuration*

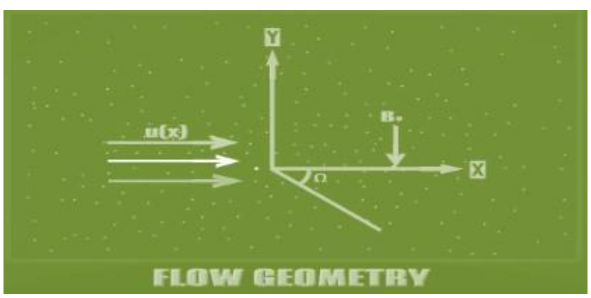


Fig. 1. Flow Configuration

At the wall of the wedge, $Uw(x) = 0$ for the stationary wedge and at time $t = 0$, the temperature of the wedge is $Tw$ with species concentration $Cw$ Instantaneously at $t > 0$, the temperature of the wedge surface and the species concentration of the wedge surface are raised to $T\infty$ and $C\infty$ respectively which are thereafter maintained constant. A strong magnetic field $B\vec{0}$ is applied in y-direction. The motion of fluid drags the induced magnetic field $\vec{b}$ along the x-xis towards the direction of fluid flow. The Lorentz force, which is created by this dragging, opposes the dragging of the magnetic field. When an electrically conducting fluid is subjected to a normal magnetic field, the Lorentz force is generated. The fluid motion is choked down by this force because it is directed against the direction of the fluid flow.

### *B) Continuity Equation*

The Casson fluid flows continuously and its mass is conserved. The flow is considered as incompressible in this study. The foundation of the continuity concept consists of two fundamental propositions which are: Since mass cannot be created or destroyed, the fluid's mass is conserved, the flow is continuous such that there are no empty spaces in between particles in contact. The fluid element's net mass rise per unit time must be equal to the fluid element's mass increase rate and mass of the fluid in element is given by: $\rho\,(dxdydz)$. The rate of increase with time is:

$$\frac{\partial}{\partial t}(\rho dxdydz) = \frac{\partial \rho}{\partial t}(dxdydz) - \frac{\partial}{\partial x}(\rho u)\frac{\partial}{\partial y}(\rho v)\frac{\partial}{\partial z}(\rho w) \;\; dxdydz \tag{1}$$

This study is dealing with a two-dimensional steady flow, such that the density is constant, and the variables are independent of time and so the equation of continuity reduces to

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

### *C) Equations of Conservation of Momentum*

This equation is derived from Newton's second law of motion, which stipulates that in the context of fluid dynamics, the rate of change of total momentum in a fluid motion must equal the sum of forces acting on the fluid. It is also known as the equation of motion or Euler's equation of motion.

$$\frac{\partial \vec{q}}{\partial t} + (\vec{q}\cdot\nabla)\vec{q} = -\frac{1}{\rho}\nabla P + \vartheta\nabla^2\vec{q} + \vec{F} \tag{3}$$

Here, $\frac{\partial \vec{q}}{\partial t}$ is the temporal acceleration

$\vec{q}\cdot\nabla)\vec{q}$ is the convective acceleration

$-\frac{1}{\rho}\nabla P$ is the pressure gradient

$\vartheta\nabla^2\vec{q}$ is the viscous drag

$\vec{F}$ is the external force due to gravitational field $\vec{F_g}$ and the electromagnetic force $\vec{F_e}$

where $\vec{F_e}$ is given by $\rho_e E + \vec{J}\vec{B}$ and $\vec{J} = \delta(\vec{E} + \vec{q}\vec{B})$ (Ohms law) for a moving electrically conducting fluid in a magnetic field $\vec{B}$

Since we are dealing with laminar two-dimensional flow with pressure gradient being zero,

$$(\vec{q}.\nabla)\vec{q} = \vartheta \nabla^2 \vec{q} + \vec{F} \tag{4}$$

$$\vec{q} = u\vec{i} + v\vec{j} \tag{5}$$

Gradient operator

$$\nabla = i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z} \tag{6}$$

$$(\vec{q}.\nabla)\vec{q} = u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} \tag{7}$$

$$\vartheta \nabla^2 \vec{q} = \vartheta(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2})(ui + v\boldsymbol{j}) \tag{8}$$

This work addresses the heat and mass transfer of a Casson nanofluid embedded in a porous medium with viscous dissipation, Brownian motion, and thermophoresis parameter effects in MHD boundary layer flow past a wedge. The Hartree pressure gradient parameter related to the wedge total angle and the Falkner-Skan power-law parameter is m and $\beta$ whose relation is: $\beta = \frac{2m}{1+m}$ and $\beta = \frac{\Omega}{\Pi}$

For the stationary wedge with wedge angle , the momentum equation is therefore written as: written as:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = U_x\frac{du}{dx} + \vartheta(1 + \frac{1}{\beta})(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}) + \vec{F} \tag{9}$$

The Lorentz forces $\vec{F}$ are produced by a strong applied magnetic field combined with an induced magnetic field.

These can be obtained using the equations of Maxwell. The flow incorporates Maxwell's electromagnetism equations since it is subjected to a strong applied magnetics field.

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{10}$$

With the assumption of absence of external electric field, E=0 The total electromagnetic force Fe=JB where

$$J = \sigma(E + q \times B) \tag{11}$$

but E=0 and

$$\vec{B} = \vec{b}i + \vec{B}_0 j \tag{12}$$

$$q \times B = \begin{vmatrix} i & j & k \\ u & v & 0 \\ b & B_0 & 0 \end{vmatrix} = uB_0k - bvk \tag{13}$$

$$J \times B = \begin{vmatrix} i & j & k \\ 0 & 0 & uB_0 - bv \\ b & B_0 & 0 \end{vmatrix} = (-uB_0^2 + B_0 bv)i \tag{14}$$

The specific momentum equation governing the flow, considering electrical conductivity σ in x-direction is:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = U(\infty)\frac{du_\infty}{dx} + \vartheta(1+\frac{1}{\beta})(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}) - \frac{\sigma B_0^2(u - u_\infty)}{\rho} + \frac{\sigma E}{} \tag{15}$$

## *D) The Energy Equation*

Fluid properties at the solid- fluid interface have temperature equal to that of the interface. The temperature at the interface differs with temperature on the free stream layers hence occurrence of temperature variations within the fluid.

The Mathematical formulation of equation of conservation of thermal energy is based on the first law of thermohydrodynamics. This law states that the amount of heat added to a system dQ is equal to the change in internal energy dE plus the work done dW and is expressed as $dQ = dE + dW$.

Since the flow is incompressible and with variable conductivity k, the energy equation is given by:

$$\rho\frac{\partial h}{\partial t} + v.(h\vec{v}) = -\frac{Dp}{Dt} + \nabla.(k\nabla T) + \phi \tag{16}$$

Taking into consideration an incompressible flow and that $dh = cpdT$, this equation reduces to:

$$\rho C_p\frac{\partial T}{\partial t} + (\vec{v}.v)T = k\nabla^2 T + \phi \tag{17}$$

$\phi$ denotes the dissipation function representing the work done against viscous forces irreversibly converted into internal energy. In our case, the Brownian motion of nanoparticles and Thermophoresis effects contribute to this function such that:

$$(\vec{v}\nabla T = u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}$$

$$\nabla^2 T = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}$$

$$\Phi = \tau\, D_B \overline{\frac{\partial C \partial T}{\partial x \partial x}} + \overline{\frac{\partial c \partial T}{\partial y \partial y}} + \frac{DT}{T\infty}\overline{\frac{\partial T}{\partial x}}^2 + \overline{\frac{\partial T}{\partial y}}^2$$

$$\tau = \frac{(\rho c)_p}{(\rho c)_f} = \frac{heatcapacityofnanoparticle}{heatcapacityofthefluid}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \tau'' D_B\frac{\partial C \partial T}{\partial x \partial x} + \frac{\partial c \partial T}{\partial y \partial y} \tag{18}$$

where $\alpha = \frac{\kappa}{\rho cp}$

## *E) The Concentration Equation*

Concentration is a measure of how much of a given species dissolves in another substance per unit volume. It deals with the diffusion of nanoparticles due to temperature gradient and Brownian motion which is as a result of the vibratory energy of fluid particles which are in continuous random motion. The bombardment between nanoparticles and fluid particles constitutes the Brownian motion. This equation is derived from the principle of conservation of mass and is used when the porous medium is saturated with the fluid and obeys Darcys law. Concentration equation is given by:

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2} \qquad (19)$$

Where u and v are the components of velocity along x and y directions respectively, C is the dimensional concentration, and D is the molecular diffusivity of Nanofluid. We derive our concentration equation from the equation of mass conservation:

$$\frac{\partial C}{\partial t}+\frac{\partial q}{\partial x}=0 \qquad (20)$$

The advection-diffusion equation gives $q = UC - D\frac{\partial C}{\partial x}$ Substituting q in the mass conservation equation, we get:

$$\frac{\partial C}{\partial t}+\frac{\partial\ \ uc-D\frac{\partial C}{\partial x}}{\partial x}=0 \qquad (21)$$

$$\frac{\partial C}{\partial t}+\frac{\partial UC}{\partial x}=\frac{\partial}{\partial x}\quad D\frac{\partial C}{\partial x} \qquad (22)$$

For a two- dimensional steady flow with Brownian motion and Thermophoresis effects, the concentration equation becomes:

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\quad\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\quad\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2} \qquad (23)$$

## III. METHOD OF SOLUTION

The goal of non-dimyensionalization of the PDEs is to identify the critical parameters required for flow problem analysis. It minimizes the number of model parameters governing an incompressible fluid's flow. Each parameter represents the ratio of the forces acting on the fluid flow. The forces' relative relevance for the flow is shown by their magnitude. The results gained for a boundary experiencing a certain set of conditions can be applied to another boundary that is geometrically comparable but experiencing entirely different solutions because of non-dimensional parameters. One of the most crucial tools for mathematics in the study of fluid mechanics is dimensional analysis. It makes logic to transform the conservation equations into a non-dimensional form in order to represent various transport processes that arise in fluid dynamics problems.

Non-dimyensionalization allow for any analysis of any system, regardless of the material properties. It also simplifies the understanding of the system's controlling flow parameters during investigation, generalizes the geometry's size and shape, and provides insight into the physical problem before an experiment is conducted. The right scale selection helps to accomplish these goals. Therefore, non-dimensional variables are provided along with the boundary conditions in order to obtain the dimensionless form of the governing equations.

Through the use of similarity transformation, the coupled nonlinear partial differential equations governing the Casson Nanofluid past the wedge in the presence of an induced magnetic field are subsequently reduced to a coupled nonlinear ordinary differential equation.

This numerical method provides more accurate approximations and is efficient for both initial and boundary values, making it suitable for index-2 and higher Differential-Algebraic systems of Equations (DAEs). It is also adaptable and easy to apply to a range of situations.

Through the use of the MATLAB function bvp4c, a fourth-order accurate collocation-based solver provides a numerical solution of the resulting boundary value problem. The effects of relevant physical entities on the temperature, velocity, and induced magnetic fields of the nanofluid are graphically presented, while the rates of mass transfer, heat transfer, and local skin friction are tabulated.

## IV. NUMERICAL SIMULATIONS

Through the use of the MATLAB function bvp4c, a fourth-order accurate collocation-based solver provides a numerical solution of the resulting boundary value problem. The effects of relevant physical entities on the temperature, velocity, and induced magnetic fields of the nanofluid are graphically presented.

## V. EFFECTS OF PARAMETER VARIATION ON VELOCITY, TEMPERATURE, CONCENTRATION AND MAGNETIC INDUCTION PROFILES

### *A) Nanofluid velocity for different values of Casson parameter*

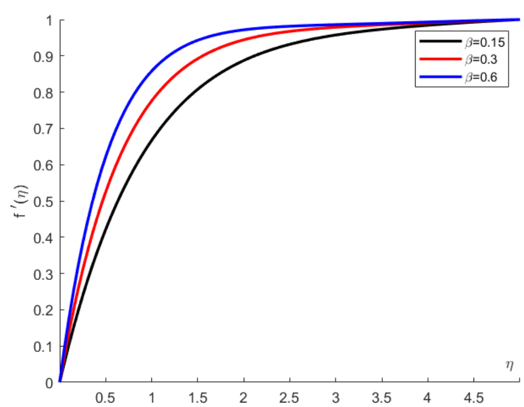


Fig. 2. Nanofluid velocity for different values of Casson parameter

The effect of increasing values of the Casson parameter is seen to suppress the velocity field and the thickness of boundary layer reduces. This is due to the fact that the Lorentz force has the property to slow down the motion of the conducting fluid in the boundary layer. From the momentum equation, with increment in the value of Casson Nanofluid parameter, the momentum equation tends to the momentum equation of a Newtonian fluid. Nanofluid velocity therefore increases as the effective viscous drag force decreases with the increase in Casson Nanofluid parameter. The Nanofluid velocity tends to reach the free stream velocity earlier for greater value.

### *B) Nanofluid velocity for different values of Biot number*

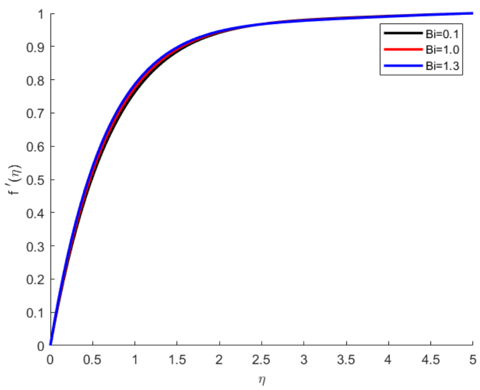


Fig. 3. Nanofluid velocity for different values of Bi

The velocity profile of nanofluid flow across the wedge is notably impacted by the Biot number, which lowers the velocity distribution. Increases in the Biot number, a measurement of the proportion of conductive to convective heat transfer, are associated with this velocity drop. The greater thickness of the thermal boundary layer and the improved temperature distribution brought about by the higher Biot number are responsible for this velocity decrease.

### *C) Nanofluid velocity for different values of Lewis Number*

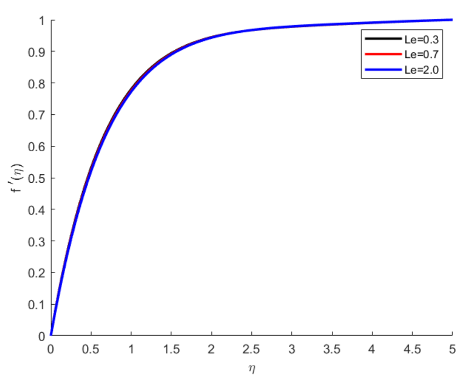


Fig. 4. Nanofluid velocity for different values of Le

The nanofluid's velocity is not directly impacted by the Lewis number. Heat and mass transfer are studied using the dimensionless Lewis number, which describes the ratio of mass diffusivity to thermal diffusivity. It has no direct effect on the nanofluid's velocity profile.

### *D) Nanofluid velocity for different values of Magnetic Parameter*

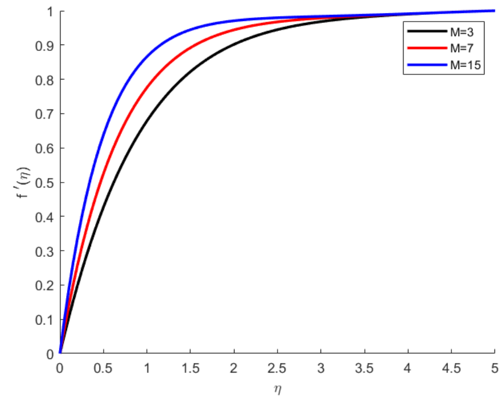


Fig. 5. Nanofluid velocity for different values of Magnetic Parameter

The Lorentz force exerted by the transverse magnetic field impedes the velocity field, causing the Nanofluid velocity to decrease as the magnetic parameter ($M$) increases.

The Lorentz force is experienced by a nanofluid flowing in a magnetic field as a result of the interaction between the charged particles (ions) in the fluid and the magnetic field. The velocity field is impeded by this force because it operates perpendicular to the direction of the fluid flow and the magnetic field.

The Lorentz force increases with increasing magnetic parameter (M), a sign of a stronger magnetic field, which results in an increased hindrance to the velocity field. As a result, whenever the magnetic parameter increases, the Nanofluid's velocity decreases.

The study of Nanofluid dynamics under magnetic fields needs to consider this phenomenon since it frequently occurs in Magneto hydrodynamic (MHD) systems.

### *E) Nanofluid velocity for different values of Local Reynolds number*

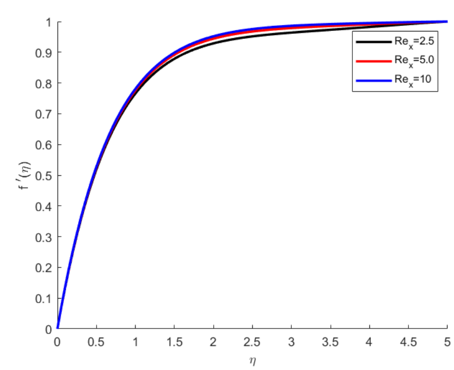


Fig. 6. Nanofluid velocity for different values of Local Reynolds Number

It is here observed that the velocity profile of the Casson Nanofluid flowing past the wedge appeared to be less impacted by the local Reynolds number (Rex).

Yield stress is included in Casson fluid models, meaning that the fluid only flows when a specific stress threshold is reached. The addition of nanoparticles can drastically change the rheological behavior when nanofluids are involved. The velocity profile is more affected by the presence of nanoparticles in the Casson fluid than by the

Reynolds number. Particle aggregation, interactions between nanoparticles and fluids, or modifications in effective viscosity brought on by nanoparticle dispersion could all be the cause of this.

### *F) Nanofluid velocity for different values of Magnetic Prandtl number*

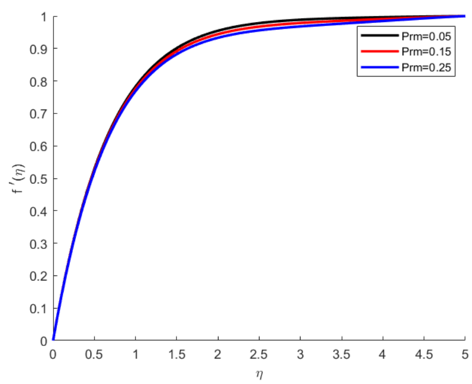


Fig. 7. Nanofluid velocity for different values of Prm

The Magnetic Prandtl number is a dimensionless quantity that represents the ratio of the magnetic field's effect on the fluid's momentum diffusivity to its thermal diffusivity. For smaller Prm values, the magnetic field's influence on the fluid flow is weak compared to viscous forces. Therefore, the velocity profile of the Casson nanofluid exhibits minimal changes compared to the case without a magnetic field. As Prm increases, the magnetic field becomes more influential relative to viscous forces. This leads to alterations in the velocity profile. At higher Prm values, the magnetic forces become dominant, significantly increases the flow velocity of the Casson nanofluid.

### *G) Nanofluid velocity for different values of Brownian motion Parameter*

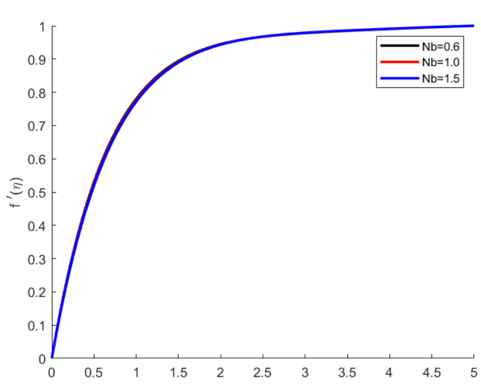


Fig. 8. Nanofluid velocity for different values of Parameter for Brownian motion

At low values of the Brownian motion parameter, the nanoparticles move randomly in the fluid in a limited way. As a result, Brownian motion has little effect on the velocity profile of the Casson nanofluid; instead, the velocity profile may resemble the base Casson fluid in which there are no nanoparticles, and any variations are mainly caused by the nanoparticles.

The random motion of nanoparticles intensifies with an increase in the Brownian motion parameter. The fluid's rheological characteristics may be impacted by the higher dispersion of nanoparticles brought about by this increased velocity. There are certain variations in the Casson nanofluid velocity profile compared to the basic Casson fluid case, especially in the vicinity of solid borders where Brownian motion might affect the creation of boundary layers and the aggregation of nanoparticles. High values of the Brownian motion parameter cause the nanoparticles to move randomly and disperse widely throughout the fluid. The Casson nanofluid's effective viscosity and other rheological characteristics are changed by this improved dispersion. The Casson nanofluid's velocity profile tends to differ significantly from the base Casson fluid's due to enhanced mixing and potential boundary layer changes.

### *H) Nanofluid velocity for different values of Thermophoresis Parameter*

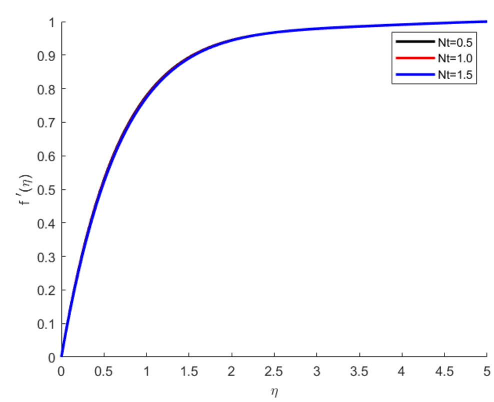


Fig. 9. Nanofluid velocity for different values of Thermophoresis Parameter

The Thermophoresis Parameter (Nt) represents the thermophoretic motion of nanoparticles in a fluid. The thermophoretic motion of nanoparticles is comparatively poor when the thermophoresis parameter is low. As a result, thermophoresis has little effect on the Casson nanofluid's velocity profile.

The Casson fluid's rheological characteristics and flow conditions may be the main determinants of the velocity profile; any variations may be attributed to the presence of nanoparticles rather than thermophoresis.

The thermophoretic mobility of nanoparticles in response to temperature gradients intensifies as the thermophoresis parameter rises. The fluid's effective viscosity and other rheological characteristics may be impacted by the non- uniform distribution of nanoparticles brought on by this increased thermophoretic mobility.

There is a possibility that the velocity profile of the Casson nanofluid will differ from that of the base Casson fluid, especially in areas where thermophoresis effects are strong and there are large temperature gradients.

At higher values of the thermophoresis parameter, the thermophoretic motion of nanoparticles is strong, leading to significant non-equilibrium distribution of nanoparticles in the fluid. This non-equilibrium distribution can cause substantial changes in the effective viscosity and thermal conductivity of the Casson nanofluid. The velocity profile of the Casson nanofluid may deviate substantially from that of the base Casson fluid, with pronounced effects in regions with strong temperature gradients.

### *I) Nanofluid Temperature for different values of Casson parameter*

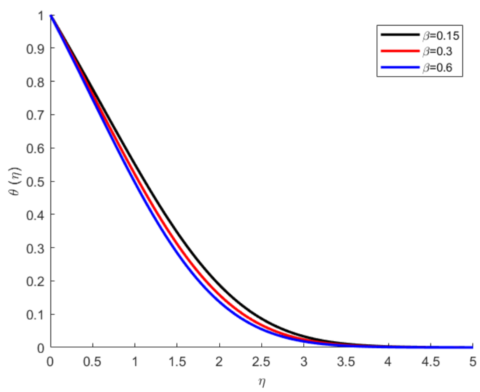


Fig. 10. Nanofluid temperature for different values of Casson Parameter

The Casson parameter significantly influences the flow of the non-Newtonian fluid. Increasing the Casson parameter values results in an anti-symmetrical temperature distribution near the walls of the wedge. The fluid's velocity profile, as shown by the Casson parameter, has an impact on the convective heat transfer coefficient. The rate of heat transfer within a fluid and between a fluid and its surroundings can be changed by variations in flow velocity.

Fluid rheological characteristics like viscosity are also influenced by the Casson parameter. Viscosity changes may have an impact on the fluid's ability to conduct heat. The modifications in flow dynamics and convective heat transfer, however, might overshadow these impacts.

In Casson nanofluids, the dispersion and aggregation of nanoparticles within the fluid may be indirectly influenced by the Casson parameter. The effective thermal conductivity and heat transfer characteristics of the nanofluid can be impacted by modifications in the distribution of nanoparticles.

Although the Casson parameter directly affects the flow behavior of Casson nanofluids, it largely has an indirect effect on the fluid's temperature through its impacts on rheological properties, flow characteristics, and convective heat transfer. It's critical to comprehend these indirect effects in order to maximize heat transfer efficiency in Casson nanofluid applications.

### *J) Nanofluid temperature for different values of Biot number*

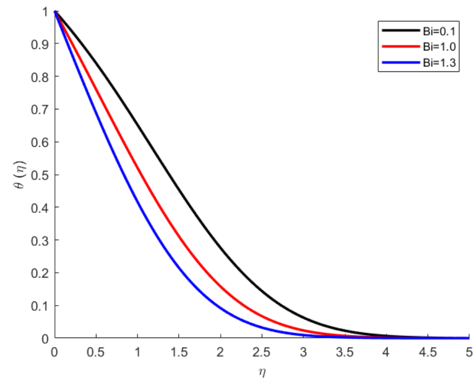


Fig. 11. Nanofluid Temperature for different values of Bi

The Biot number is defined as the ratio of the thermal resistance inside the solid (conduction) to the thermal resistance at the fluid-solid interface (convection).

The Biot number has a significant effect on the temperature of the nanofluid. The temperature distribution is enhanced, and the thickness of the boundary layer rises as the Biot number increases. The results reveal that higher Biot numbers result in increased temperature profiles.

### *K) Nanofluid temperature for different values of Magnetic Parameter*

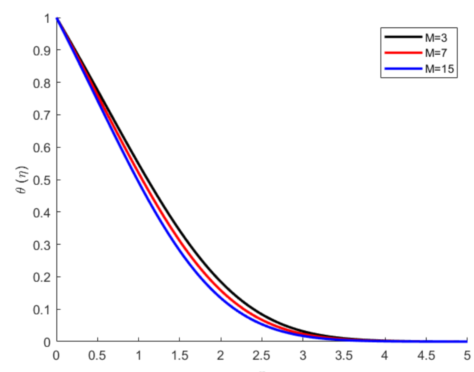


Fig. 12. Nanofluid Temperature for different values of Magnetic Parameter

Increasing the magnetic parameter enhances the temperature profile of nanofluids. This is caused by the transverse magnetic field's opposing Lorentz force, that works against both the fluid's flow direction and the magnetic field. This force has the ability to create turbulence and fluid motion, which improves heat transmission.

The disruption of the thermal boundary layer caused by the motion of fluid particles by the Lorentz force allows for increased heat transfer between the fluid and its surroundings. Furthermore, the Lorentz force-induced motion can enhance the fluid's nanoparticle mixing, which enhances thermal conductivity further.

Its therefore found that the temperature profile of nanofluids can be greatly improved by the opposing Lorentz force produced by the transverse magnetic field, which could make them advantageous in various heat transfer applications.

### *L) Nanofluid Temperature for different values of Lewis Number*

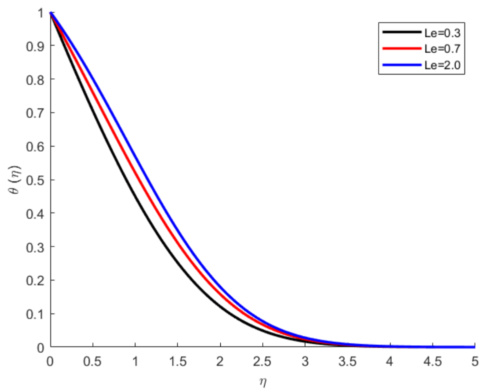


Fig. 13. Nanofluid temperature for different values of Le

The mass diffusivity of a fluid and its thermal diffusivity are related by the dimensionless Lewis number; which is the ratio of the thermal diffusivity to the mass diffusivity. The Prandtl number ($Pr$) and the Schmidt number ($Sc$) are used to express the Lewis number. $Le = \frac{Sc}{pr}$

The Schmidt number depends on both temperature and pressure, while the Prandtl number is dependent on temperature alone. Consequently, via these intermediary parameters, the Lewis number is indirectly related to both temperature and pressure.

Increased diffusion of heat relative to mass diffusion is indicated by a greater Lewis number, and vice versa.

For wedge flow, which is a type of boundary layer flow, the temperature distribution along the surface of the wedge is affected by the thermal properties of the nanofluid. A higher Lewis number typically results in a thinner thermal boundary layer near the wedge surface, indicating faster thermal diffusion.

The overall thermal conductivity and heat transfer properties of the nanofluid are influenced by the Lewis number, which also has an impact on how the nanoparticles spread and diffuse within the fluid.

Lewis numbers are taken into account by researchers and engineers when examining heat transfer in wedge flow situations involving nanofluids. Depending on the required thickness of the thermal boundary layer and the rate of temperature change along the wedge surface, modifying the composition of the nanofluid or its thermal characteristics may be able to optimize heat transfer efficiency.

### *M) Nanofluid temperature for different values of Local Reynolds number*

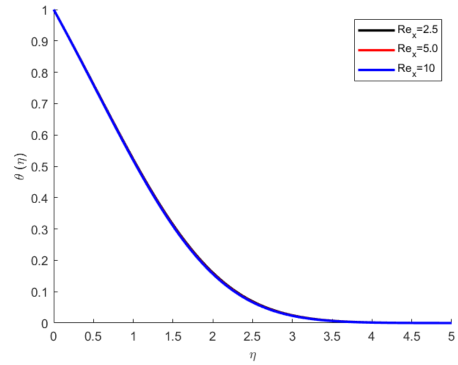


Fig. 14. Nanofluid temperature for different values of Local Reynolds Number

The wedge's surface temperature gradually rises to the free stream temperature, as seen by the temperature distribution. The thermal boundary layer close to the wedge's surface thickens with increasing Reynolds numbers. More mixing and heat transfer within the fluid are encouraged by eddies, which results in a more even temperature distribution over the wedge's surface. When compared to laminar flow, the temperature gradients near the surface are less noticeable because turbulent mixing transfers heat through the fluid more quickly.

This research looked into laminar flow of Casson nanofluid past a wedge.

### *N) Nanofluid temperature for different values of Magnetic Prandtl number*

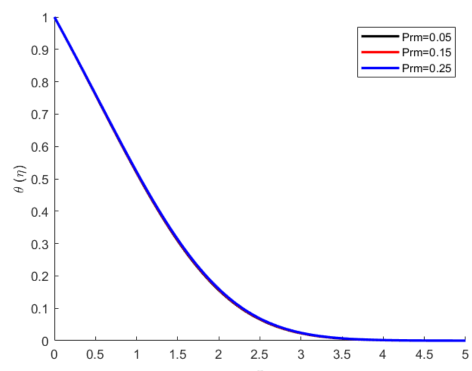


Fig. 15. Nanofluid temperature for different values of Prm

The ratio of thermal diffusivity to magnetic diffusivity in magnetohydrodynamics (MHD) is expressed by the dimensionless Magnetic Prandtl number.

When the magnetic Prandtl numbers are relatively low, the magnetic diffusivity is much lower than thermal diffusivity, temperature gradients are influenced more by thermal diffusivity than by magnetic effects. Lower $Pr_m$ values imply that thermal effects dominate. Therefore, there is no significant impact of the Magnetic Prandtl number on the temperature of the Casson nanofluid flowing past the wedge.

### *O) Nanofluid temperature for different values of Brownian motion Parameter*

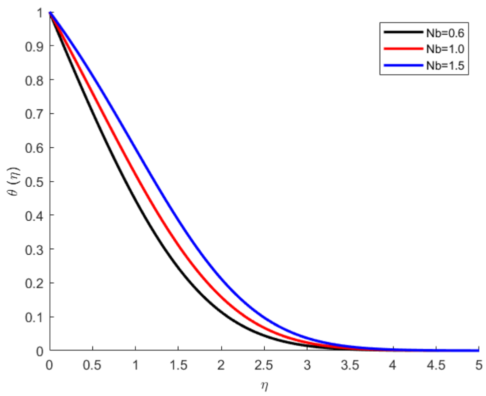


Fig. 6. Nanofluid temperature for different values of Parameter for Brownian motion

The Brownian motion parameter has an impact on the temperature distribution of the nanofluid. It is evident that the temperature distribution increased with increasing Brownian motion parameter.

The thermal boundary layer close to the wedge surface tends to be thinner because of increased Brownian motion and higher thermal conductivity of nanofluids. This is due to the fact that heat moves from the solid surface into the fluid more effectively, which lowers the temperature differential close to the surface.

### *P) Nanofluid temperature for different values of Thermophoresis Parameter*

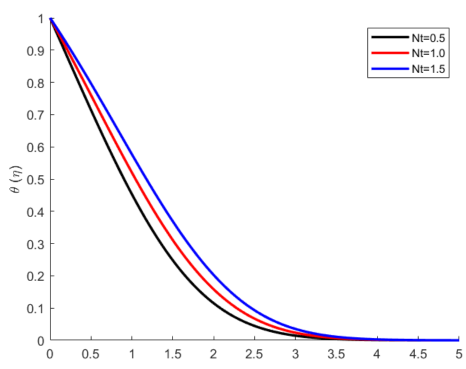


Fig. 17. Nanofluid temperature for different values of Thermophoresis Parameter

The thermophoresis parameter has an effect on the distribution of heat in the nanofluid. As the thermophoresis parameter is increased, the temperature distribution is greater. Its demonstrated that greater thermophoresis parameter values result in higher temperature values all through the regime. A non-uniform distribution of nanoparticles is the result of the nanoparticles moving in a different direction of the temperature gradient due to the thermophoretic forces generated by greater Nt values. This uneven dispersion raises the nanofluid's temperature.

## VI. CONCLUSION

When nanoparticles are added to the problem's base fluid, the flow pattern is drastically changed. The hydromagnetic field gets stronger, which amplifies the induced magnetic field and temperature distributions. This can be attributed to the distinct characteristics of the nanoparticles, which engage in magnetic field interaction to impact fluid

The previously described data analysis validates that the subsequent outcome is attained when the magnetic Prandtl's number fluctuates, and the previously mentioned parameters are maintained constant as recommended.

While the momentum boundary layer thickens with increasing magnetic induction, the energy boundary layer thickens with the development of the induced magnetic field. With magnetic induction, the concentration of nanoparticles rose.

The magnetic Prandtl number ($P\,r_m$)in MHD Casson nanofluid flows determines the significance of viscosity versus

magnetic diffusivity in structuring the induced magnetic field and its spatial distribution within the fluid, which has a substantial impact on the magnetic induction profile. In order to allow for rising values of the Biot number and Thermophoresis parameter, the concentration and temperature fields have expanded. This indicates that the high distribution of nanoparticles is caused mostly by Thermophoresis, a technique in which particles migrate in response to a temperature gradient. The Thermophoresis parameter and Biot number are important factors to take into account when evaluating the degree of Thermophoresis and how it impacts the distribution of nanoparticles. The energy boundary layer thickens with the development of the induced magnetic field, while the momentum boundary layer thickens with increasing magnetic induction. The concentration of the nanoparticles increased with magnetic induction. The rate of heat transfer is increased when the induced magnetic field parameter increases. The problem's base fluid's flow pattern is significantly altered when nanoparticles are added. The temperature distributions and induced magnetic field are amplified as a result of the hydromagnetic field becoming stronger. This is explained by the unique properties of the nanoparticles, which interact with fluid through magnetic field interaction. It is evident that when the induced magnetic field is taken into account, shielding the internal walls of channels and nozzles is essential to preventing a hot conducting fluid from getting into contact with those walls. This is especially significant when it comes to magnetic nozzles, which are used in space propulsion to accelerate and direct a plasma jet into vacuum.

The applied magnetic field in a magnetic nozzle is essential for controlling the plasma jet. The plasma experiences electric currents from the magnetic field, which provide an opposing force that pulls the plasma downstream. An understanding of how the thermophoresis parameter affects the Casson nanofluid flow behavior is crucial for heat-transfer applications such energy conversion devices based on nanofluids, thermal insulation, and cooling systems. Quantifying these effects and directing the design and development of nanofluid-based systems for heat transfer applications can be accomplished with the use of computational simulations and experimental research.

## ACKNOWLEDGEMENTS

We thank the administrative staff of the Department of Physical Sciences of Chuka University for their hospitality and assistance with matters related to our research work.

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