Soret and Dufour Effects on MHD Natural Convective Casson Fluid Flow Past an Infinite Vertical Inclined Porous Plate: Numerical Study

Allenki Divya[a,b], Siva Reddy Sheri[b], Anjan KumarSuram[a] and P Megaraju[c]

[a]*Department of Mathematics, B V Raju Institute of Technology, Narsapur, Medak-502313, Telangana, India*

[b]*Department of Mathematics, GITAM University, Hyderabad Campus, Rudram-502329, Telangana, India*

[c] *Department of Mathematics, JNTUH UCESTH, Kukatpally Hyderabad, Telangana, India*

Abstract:

In the current research, Effects of Soret and Dufour on magneto hydrodynamics natural convection a numerical study is done on the Casson fluid flow past an infinite inclined vertical porous plate.The dimensionless flow regulating equations are arithmetically determined by applying the finite element method for this study. Visual representations of the outcomes for the velocity u, temperature θ and concentration ϕ profiles against flow pertinent constraintsshow how these factors have a significant influence on the flow field and other physical interest aspects.The quantitative findings are contrasted with those that have already been published, and it is discovered that there is qualitative agreement.

Keywords: MHD, Natural Convection, Casson Fluid, FEM, Dufour and Soret effect.

NOMENCLATURE

B_0	Magnetic field strength (Tesla)
C_p	Specific heat at constant pressure ($K^{-1}m^2s^{-2}$)
C_w	Concentration at the wall (kg m^{-3})
C_∞	Free stream concentration (kg m^{-3})
C	Dimensional concentration (Kgm^{-3})
D_m	Chemical molecular diffusivity (m^2s^{-1})
Df	Dufour number
Ec	Eckert number
g	Acceleration due to gravity (ms^{-2})
Gr	Grashof number for heat transfer (thermal)
Gc	Grashof number for mass transfer (solutal)
k_1	Thermal conductivity of the MHD generator working fluid ($Wm^{-1}K^{-1}$)
k	Permeability of the porous medium (m^2)
M	Hartmann number
Pr	Prandtl number
Sc	Schmidt number
t	Time (s)
T	Temperature of the fluid (K)
T_∞	Temperature of free stream (K)

T_w	Temperature at the wall (K)
u	Velocity of the fluid (m s^{-1})
Sr	Soret number
Q	Heat absorption parameter
K	Permeability parameter
S	Heat source parameter
D	Molecular mass diffusivity (m^2 s^{-1})
K_c'	Chemical reaction constant
Kr	Chemical reaction parameter
Nu	Nusselt number
Sh	Sherwood number
C_f	Skinfriction number
Greek	
θ	Dimensionless temperature
ϕ	Dimensionless concentration
ν	Kinematic viscosity of MHD generator working fluid (m^2s^{-1})
ρ	Density of MHD generator working fluid (Kgm^{-3})
β	Coefficient of thermal expansion
β^*	Coefficient of expansion for species concentration
α	Angle of inclination
ω	Frequency of oscillations (s^{-1})
η_0	Coefficient of viscosity
Subscripts	
w	Condition at the wall
∞	Free stream conditions
p	constant pressure

Introduction:

The survey of magneto hydrodynamic flow and heat transfer in non-porous and porous media has been prompted by the impact of magnetic fields on the regulation of boundary layer flow and the interpretation of numerous systems utilizing electrically conducting fluids. Additionally, this kind of flow has drawn the attention of numerous analysts owing to its uses in various kinds of engineering issues, including plasma investigations, nuclear reactors, MHD generators and geothermal energy extraction. Numerous researchers have demonstrated their enthusiasm for MHD like Shiva Rao and Paramananda [1] contributed anunsteady MHD williamson Nano fluid flow numerical investigation past a permeable mobiling cylinder with chemical reaction and heat radiation. Sanni et al. [2] discussed a numerical examination of a non-Newtonian MHD fluids nonlinear radiative fluidity brought on by a multi-physical curved process that is nonlinearly driven and has a changing magnetic field. Doley et al. [3] studied numerical study of heat transfer between hot moving material and ambient medium using various hybrid Nano fluids under MHD radiative-convection, viscous dissipation effects, and time-fractional condition. Sangeetha et al. [4] considered impact of MHD with micro polar fluid b/w conical rough bearings rious hybrid Nano fluids. Megaraju et al. [5] investigateda transient magneto hydrodynamic (MHD) flow with the Hall effect, chemical reaction effect, and finite element method (FEM) is experienced by an exponentially accelerated isothermal vertical plate.

A temperature variance speeds up the thermo-fluidic phenomena in free convection, a buoyancy-inducedprocess of heat transfer technique. The physics of natural convection and computer analysis are heavily used in a wide range of industries, including Heat dissipation for heat-generating components, solar energy collection, Thermal exchanger configuration, metrology, building insulation, crystal growth process, nuclear industry etc. The research on this topic is done by Junhao et al. [6] studied the vertical natural convection boundary layer turbulence development. Khudhair et al. [7] analysis ofan exponential enquiry of the paraphernalia of induced vibration on free convection between a horizontal cylinder's closed-ended eccentric and concentric annular. Tsinober et al. [8] researched computational analysis of the impact of hydrodynamic dispersion on solutal natural convection. Siva Reddy Sheri et al. [9] emphasized the significance of viscous dissipation on free convection flow on a vertical plate moving rapidly and reaching higher temperatures.Siva Reddy and Anand rao [10] deliberated MHD free convection flow through a vertical sliding plate under the effects of mass and heat transfer.

Casson fluid is a shear-thinning fluid with unlimited viscosity at zero extent of shear, zero viscosity at infinite rate of shear, and an extension stress below which no flow occurs. Tomato sauce, honey, soup, orange juice, human blood and other common liquids that exhibit Casson fluid characteristics are merely a few examples. A two-fluid model of blood has been developed, with the plasma on the periphery acting as a Newtonian fluid and the core area, in which all of the erythrocytes are suspended, as a Casson fluid.Non-Newtonian fluid characteristics are difficult to evaluate because they are different from those of Newtonian fluids, many scientists, researchers, and engineers have worked together on these diverse applications, including Amin [11] et al. deliberated analytical testify of Casson fluid flow at its stagnation point across a continuously moving surface.Shuaib et al. [12] exploredvolumetric thermos-convective Casson fluid flow across an inclination extended surface that is nonlinear. Anantha Kumar et al. [13] explored impact of heat radiation that is not linear on MHD Casson fluid flow with chemical reaction across a stretched surface. Shankar goud et al. [14] studied MHD and the performs of radiation chemical reaction taking place in a Forchheimer porous medium with Casson fluid flow across an inclined non-linear surface. Osman et al. [15] considered Cattaneo's law for Casson fluids was generalised across a vertical cylinder. Swarnalathamma et al. [16] investigated the implications of Chemical reactions and radiation absorption associated on infinite vertical inclined porous plate with free convective Casson fluid flow.

A collection of methods known as finite element methods was created to effectively solve partial differential equations (PDEs). Boundary value problems are frequently used as models for the physics of phenomena found in engineering applications. Initial value problems are equations that describe the evolution over time and are composed of an ordinary differential equation (ODE) in time coupled with a boundary value problem in space. The study of equations incorporating derivatives of the unknown has caused a revaluation of the definition of derivation. Finally, let's talk about how the theory of distributions can be used to generalise the idea of a derivative. High-performance computing enabling more detailed and accurate simulations. Advances in open-source and commercial software for CFD and FEM, making these tools more accessible. Multidisciplinary applications of fluid-structure interaction, particularly in aerospace and automotive design. Growing interest in renewable energy and environmental applications, including wind energy and hydrodynamics. Research into sustainable and environmentally friendly fluid dynamics solutions. It's important to note that these fields are continually evolving, and new research is published regularly, so the state-of-the-art may have progressed since my last update. Researchers are likely to continue pushing the boundaries of computational methods, experimental techniques, and real-world applications in both fluid dynamics and FEM. Some of the authors investigated by Bountourelis et al. [17] presented a high-performance lower prosthetic limbs finite element analysis and topology optimisation. Zhengzhong Yang et al. [18]

investigated an analysis using finite elements shows the impact of various loads on the shoulder in abduction postures. Boskovic et al. [19] discussed a microwave cancer ablation finite element analysis was carried out using free software components. Siva Reddy Sheri and Anjan kumar[20] surveyed finite element analysis of the transfer of heat and mass with a vertical plate moving irregularly at a ramped temperature. Sheri Siva Reddy and Shamshuddin [21] designed On a vertical porous plate, transient MHD free convective chemically reactive micropolar fluid flow will be studied using finite element analysis, Hall current, and viscous dissipation.

The term thermal-diffusion aftermath refers to the mass flux produced by a heat gradient. Diffusion-thermo effect describes the energy flux brought on through concentration variances. This phenomenon was identified in 1873 by renowned Swiss Scientist L. Dufour. This influence is developed by Eckert and Drake [22]. Subhrajit Sarma and Nazibuddin ahmed [23] analysed Dufour effect on a vertical plate imbedded in a porous material with a ramped temperature. Burmasheva and prosviyakov[24] investigated influence of the Dufour effect on shear thermal diffusion flows. Shilpa [25] et al. effects of Soret and Dufour on the double-diffusive mixed convective heat and mass transport of pair stress fluid in an electrically conducting and non-conducting channel. Chandra shekar [26] et al. discussed the repercussions of Dufour and Soret on Nano fluid's bio convective flow in a porous square cavity. Siva reddy Sheri et al. [27] surveyed Finite element analysis was employed to investigate the impact of Hall current, Dufour, and Soret effects on the transient magneto hydrodynamic (MHD) flow across an inclined porous plate.

Most of the research workers assumed infinite vertical inclined porous plate and they have neglected soret and dufour number. This research looks into the possibility of using finite element analysis to analyse the properties of MHD naturally convective Casson fluid flow through an exponentially accelerating plate while taking Soret and Dufour number into account. The FEM is used to deal with the flow's governing non-dimensional PDEs as well as the accompanying initial and boundary conditions. Numerous parameters, including the $M, Gr, Gc, \Pr, Sc, Kr, K, Q, \gamma, t, S\ and\ Ec$ have graphical representations to provide numerical values for study.In the end, the results were compared to the body of literature and found to be in great agreement.

Mathematical Formulation:

It is assumed that the y-axis heldvertically along the plate and that it is located at a right angle to the x-axis. Angled from horizontal to vertical, the plate slopes. The induced magnetic domain was disregarded because there wasn't much magnetic Reynolds amount in the flow. This was initially based on the notion that the plates and the surrounding liquid would be by the uniform temperature and concentration. The buoyancy force has constant expressions when subject to fluid restrictions. The chemical reaction andvariations in radiation are covered in the article.

According to Das et al. [28] incompressible and isotropic flow behaviour of Casson fluid, the physicochemical leading equations are relating to the state are as follows:

$$\tau = \tau_0 + \mu\alpha^*$$
(1)

Equivalently,

$$\tau_{ij} = \begin{Bmatrix} 2\left(\mu_B + \dfrac{p_y}{\sqrt{2\pi}}\right)e_{ij}, \pi > \pi_c \\ 2\left(\mu_B + \dfrac{p_y}{\sqrt{2\pi_c}}\right)e_{ij}, \pi < \pi_c \end{Bmatrix}$$
(2)

Where $\tau, \tau_0, \mu \, and \, \alpha^*$ were shear stresses, shear rates, Casson yield stresses as well as dynamical viscosity; in addition to $\pi = e_{ij}e_{ij}$ and here e_{ij} existed the (i, j) th constituents of the deformation rates, π_c is the essential values of the products, π stands the fluid maintained by the non-Newtonians products, p_y fluids yield stresses as well as μ_B is the plastic vigorousviscidness of non-Newtonians fluids.

The rheological elementary equation of Casson fluids diminished to be

$$\tau_{ij} = \mu_B \left(1 + \frac{1}{\gamma}\right) 2e_{ij} \tag{3}$$

Here, $\gamma = \mu_B \frac{\sqrt{2\pi}}{p_y}$, if $\gamma \to \infty$, then both the fluids, non-Newtonian characteristics and their performance resemble those of Newtonian fluids. Following are the primary equations for unstable MHD complementary essentialwarming flows of viscous in compressible fluids across indefinitely upendedflexible plates entrenched in holey media:

$$\frac{\partial v}{\partial y} = 0 \Rightarrow v = -v_0 \tag{4}$$

$$\frac{\partial u}{\partial t} + \upsilon \frac{\partial u}{\partial y} = \left(1 + \frac{1}{\gamma}\right) \frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2}{\rho} u - \frac{v}{k} u + g\beta (T - T_\infty) \cos\alpha + g\beta^* (C_w - C_\infty) \cos\alpha \tag{5}$$

$$\frac{\partial T}{\partial t} + \upsilon \frac{\partial T}{\partial y} = k_1 \frac{\partial^2 T}{\partial y^2} + \frac{\upsilon}{C_p} \left(\frac{\partial u}{\partial y}\right)^2 + S'(T - T_\infty) + Q'(C - C_\infty) + \frac{D_m K_T}{C_s C_p} \frac{\partial^2 C}{\partial y^2} \tag{6}$$

$$\frac{\partial C}{\partial t} + \upsilon \frac{\partial C}{\partial y} = D \frac{\partial^2 C}{\partial y^2} - K_c'(C - C_\infty) + \frac{D_m K_T}{T_m} \frac{\partial^2 T}{\partial y^2} \tag{7}$$

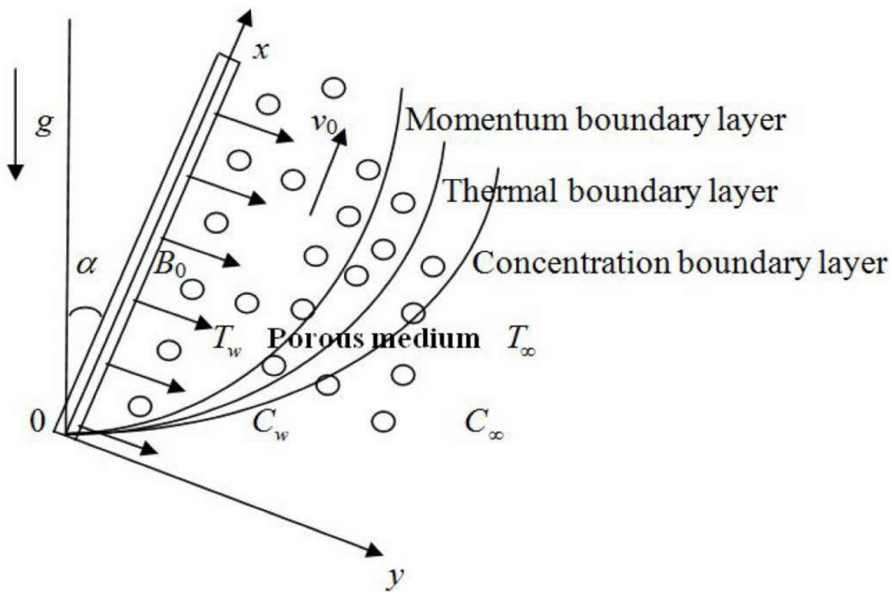

Fig 1. Physical Model

The initial conditions

$u=0, T=T_w+\in(T_w-T_\infty)e^{i\omega t}, C=C_w+\in(C_w-C_\infty)e^{i\omega t}$ at $y=0$ (8)

$u \to 0, \theta \to \theta_\infty, \phi \to \phi_\infty$ as $y \to \infty$ (9)

Consequently, the following non-dimensional variable and parameters are introduced.

$$y^*=\frac{y\upsilon_0}{v}, t^*=\frac{t\upsilon_0^2}{4v}, \omega^*=\frac{4\upsilon\omega}{\upsilon_0^2}, u^*=\frac{u}{\upsilon_0^2}, v=\frac{\eta_0}{\rho}, \theta=\frac{T-T_\infty}{T_w-T_\infty}, C=\frac{C-C_\infty}{C_w-C_\infty}, M^2=\frac{\sigma B_0^2 v}{\rho\upsilon_0^2},$$

$$K=\frac{\upsilon_0^2 k}{v^2,}\Pr=\frac{v}{k_1}, Sc=\frac{v}{D}, Gr=\frac{g\beta\upsilon(T_W-T_\infty)}{\upsilon_0^3}, Gc=\frac{g\beta^*\upsilon(C_W-C_\infty)}{\upsilon_0^3}, S=\frac{4S'v}{\upsilon_0^2}, \tag{10}$$

$$Ec=\frac{\upsilon_0^2}{C_p(T_w-T_\infty)}, Kr=\frac{Kc'v}{\upsilon_0^2}, Q=\frac{v^2Q'(C_w-C_\infty)}{u\upsilon_0^2(T_w-T_\infty)}, Du=\frac{D_mK_T(C_w-C_\infty)}{C_sC_p(T_w-T_\infty)}, Sr=\frac{D_mk_T(T_w-T_\infty)}{vT_m(C_w-C_\infty)}$$

By utilising non-dimensional variables, the equations underneath initial conditions we get

$$\frac{1}{4}\frac{\partial u}{\partial t}-\frac{\partial u}{\partial y}=\left(1+\frac{1}{\gamma}\right)\frac{\partial^2 u}{\partial y^2}-\left(M^2+\frac{1}{K}\right)u+Gr\cos\alpha\,\theta+Gc\cos\alpha\,\theta \tag{11}$$

$$\frac{1}{4}\frac{\partial\theta}{\partial t}-\frac{\partial\theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}+\frac{1}{4}S\theta+Q\theta+Ec\left(\frac{\partial u}{\partial y}\right)^2+Du\frac{\partial^2\phi}{\partial y^2} \tag{12}$$

$$\frac{1}{4}\frac{\partial\phi}{\partial t}-\frac{\partial\phi}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\phi}{\partial y^2}-Kr\,\phi+Sr\frac{\partial^2\theta}{\partial y^2} \tag{13}$$

The similar initial circumstances were as

$u=0, \theta=1+\in e^{i\omega t}, \phi=1+\in e^{i\omega t}$ at $y=0$ (14)

$u \to 0, \theta \to 0, \phi \to 0$ as $y \to \infty$ (15)

Method of solution:

The conventional of coupled, nonlinear, condensed, time-dependent, non-dimensional partial differential equations (11)– (13) theme of boundary conditions (14, 15) cannot be solved analytically since they are coupled and nonlinear in nature. Ordinary differential or partial differential equations as well as integral equations can be solved effectively using the finite element method. Both Newtonian and non-Newtonian issues can be solved with it. There are basic descriptions of this methodology in Bathe [29] and Reddy [30] and the abdorption form is especially common on behalf of fluid mechanics replications.

Step 1: The infinite fluid field is discretized into finite elements.

The discretization of the field involves breaking the field up into a finite number of subdomains. A finite element is referred to as each subdomain. The finite-element mesh is the term used to describe the group of elements.

Step 2: Equations derived from elements:

The following three steps are involved in the process of constructing algebraic or finite element equations from the undefined variables of a finite element analysis.

1. Construct differential equation's variational formulation.

2. Assume that a typical finite element has the shape of the approximate solution.

3. Put the approximation into the variational formulation to get the finite element equations.

Following these procedures yields a matrix eqn of the form $\left[K^e\right]\left\{u^e\right\}=\left\{F^e\right\}$, this explains how the initial equation's finite element model works.

Step 3: Coupling equations for several elements:

The inter-element continuity constraints are imposed in order to build the algebraic equations that were thusly derived, which require that the values of the nodal variables by the knots be the same for two or more components. The result is the global finite element model, a set of several algebraic equations. These rules apply to the entire stream domain.

Step 4: Establishing boundary situations:

The aforementioned combined equations are applied to the initial and boundary conditions measured in equations (14,15).

Step 5: Solving the compiled equations:

It is possible to use a direct or iterative approach to solve the obtained final matrix equation.

Numerical Validation:

The truthfulness of the algebraic scheme recycled in the present work is evaluated by direct comparison with earlier published work by Das [28]; Tables 1, 2, and 3 show comparison for the Sherwood number Sh, Nusselt number Nu and Skin friction τ with the findings obtained using an analytical technique whenever $Du=0\,\&\,Sr=0$.These outcomes show a very good agreement.

$$Nu=-\left[\frac{\partial T}{\partial y}\right]_{y=0} \qquad Sh=-\left[\frac{\partial C}{\partial y}\right]_{y=0} \qquad \tau=\left[\frac{\partial u}{\partial y}\right]_{y=0}$$

By employing the finite element method, we have obtained solutions to the non-dimensionalized velocity, concentration and temperature equations. By initially taking our numerical technique to the issue raised by Swarnalathamma et al. [16], we were able to compare our findings to those of Swarnalathamma et al. [16] without the use of the Dufour number and Soret number. This allowed us to determine the accuracy and validity of this method. Tables 1–3 compare these results and show that their conclusions are generally in excellent agreement.

Table 1 depicts the determine of the M, Gr, Gc, K, Temperature source constraint S, Heat absorption parameter Q, Eckert number Ec, Kr, Casson fluid parameter γ and time t on the Skin friction of the Infinite vertical inclined plate. It is recognised from this table there is increase in Skin friction for climbing values of M, Gr, Gc, S, Ec and Kr whereas Skin friction diminshes increasing for values of $K, Q, \gamma\, and\, t$.

Table 2 illustrates the effect of the $\Pr$, Q, temperature source constraint, Eckert number and time on the Nusselt number Nu of the infinite vertical inclined plate. It perceived from this table there is rise in Nusselt number for accelerating values of $Q, S, Ec\, and\, t$ whereas Nusselt number declinesaccumulative for value of Prandtl number.

Table 3 publicizes the impact of the Sc, Kr and t on the Sh of the infinite vertical inclined plate. It shows regarded that here is hike in Sh for accelerating the value of Schmidt number whereas Sherwood number drops amplifies for values of time and chemical reaction parameter Kr.

Table 1

Differentiation of Co-efficient of Skin friction (when $Du=0\,\&\,Sr=0$)

M	K	Gr	Gc	S	Q	Ec	Kr	γ	t	Results by Swarnalathamma et al. [16]	Current results
0.5	0.5	5	3	0.2	0.5	0.02	0.5	0.5	0.2	0.625148477854	0.625148488611
1.0	0.5	5	3	0.2	0.5	0.02	0.5	0.5	0.2	0.745885855021	0.745885945231
1.5	0.5	5	3	0.2	0.5	0.02	0.5	0.5	0.2	0.870146985660	0.870146995745
1.5	1.0	5	3	0.2	0.5	0.02	0.5	0.5	0.2	0.452145001425	0.452145001223
1.5	1.5	5	3	0.2	0.5	0.02	0.5	0.5	0.2	0.225879112354	0.225879109563
1.5	1.5	10	3	0.2	0.5	0.02	0.5	0.5	0.2	0.521404896698	0.521404895698
1.5	1.5	15	3	0.2	0.5	0.02	0.5	0.5	0.2	0.415288405211	0.415288414211
1.5	1.5	15	6	0.2	0.5	0.02	0.5	0.5	0.2	0.855254325669	0.855254326669
1.5	1.5	15	9	0.2	0.5	0.02	0.5	0.5	0.2	1.202256874559	1.202256875559
1.5	1.5	15	9	0.4	0.5	0.02	0.5	0.5	0.2	1.665484100210	1.665484112210
1.5	1.5	15	9	0.6	0.5	0.02	0.5	0.5	0.2	2.598879966369	2.598879968969
1.5	1.5	15	9	0.6	1.0	0.02	0.5	0.5	0.2	0.125547789645	0.125547798547
1.5	1.5	15	9	0.6	1.5	0.02	0.5	0.5	0.2	0.052466445285	0.052466475485
1.5	1.5	15	9	0.6	1.5	0.04	0.5	0.5	0.2	0.336980001425	0.336980012436
1.5	1.5	15	9	0.6	1.5	0.06	0.5	0.5	0.2	0.090405985699	0.090405987689
1.5	1.5	15	9	0.6	1.5	0.06	1.0	0.5	0.2	1.522468852214	1.522468864513
1.5	1.5	15	9	0.6	1.5	0.06	1.5	0.5	0.2	2.556589566325	2.556589586425
1.5	1.5	15	9	0.6	1.5	0.06	1.5	1.0	0.2	0.758895554655	0.758895555645
1.5	1.5	15	9	0.6	1.5	0.06	1.5	1.5	0.2	0.856698547260	0.856698569206
1.5	1.5	15	9	0.6	1.5	0.06	1.5	1.5	0.3	0.410558456223	0.410558656273
1.5	1.5	15	9	0.6	1.5	0.06	1.5	1.5	0.4	0.204588985447	0.204588885437

Table 2

Differentiation of co-efficient of Nusselt number Nu (when $Du = 0$ & $Sr = 0$)

Pr	Q	S	Ec	t	Results by Swarnalathamma et al.[16]	Current results
0.71	0.5	0.30	0.02	0.2	0.5699872365528	0.5699872655283
3.00	0.5	0.30	0.02	0.2	0.3524897448799	0.3524897455789
7.00	0.5	0.30	0.02	0.2	0.1410841220058	0.1410841252056
7.00	1.0	0.30	0.02	0.2	0.6850413325987	0.6850413346989
7.00	1.5	0.30	0.02	0.2	0.8955746652589	0.8955746653579
7.00	1.5	0.50	0.02	0.2	0.8554781100210	0.8554781110250
7.00	1.5	0.70	0.02	0.2	1.1447800014522	1.1447800116532
7.00	1.5	0.70	0.03	0.2	1.0258814566985	1.0258814576885
7.00	1.5	0.70	0.04	0.2	1.5628881124521	1.5628881134821
7.00	1.5	0.70	0.04	0.4	2.0025477896654	2.0025477987654
7.00	1.5	0.70	0.04	0.6	3.5887497899544	3.5887497879569

Table 3

Differentiation of co-efficient of Sherwood number (when $Du = 0$ & $Sr = 0$)

Sc	Kr	t	Results by Swarnalathamma et al. [16]	Current results
0.22	0.50	0.2	0.459883001255	0.459883101355
0.30	0.50	0.2	0.565891145221	0.565891245321
0.60	0.50	0.2	0.925416456638	0.925416457658

0.60	1.00	0.2	0.592354859665	0.592354848569
0.60	1.50	0.2	0.695582411521	0.695582610531
0.60	1.50	0.4	0.459871001254	0.459871021264
0.60	1.50	0.6	0.459855221452	0.459855253467

Results and Discussions:

A geometrical investigation of the impacts of Diffusion-thermo and Thermo-diffusion on magneto hydrodynamics natural convective Casson fluid flow across an infinitely vertically inclined porous plate was conducted for the purpose of clarifying the physical problems. Investigate and graphical presentation of the influence of relevant constraints include temperature θ, velocity u and concentration ϕ. The succeeding default parameter values for finite element computations were used in the current experiment.

$$\varepsilon = 0.001, \alpha = \frac{\pi}{4}, \omega = \frac{\pi}{6}, \gamma = 1, K = 0.5, Gr = 5, Gc = 3, Ec = 0.01, M = 0.5, t = 0.2, Q = 0.5,$$
$$Kr = 1, Sr = 0.1, Du = 0.01 \, and \, S = 0.2.$$

Fig. 2 illustrates how the fluid velocity affects the Hartmann number. Here is an illustration of the connection between fluid velocity and Hartmann number. The magnetic pressure decrease that influences the velocity is delayed as the Hartmann number increases owing to a frictional force is called as a Lorentz force. The effect is a slowing of the motion. As a result, the velocity drops as M increases.

Fig. 3 shows how the fluid velocity is impacted by the Permeability parameter. Permeability is defined as the volume of a fluid with a given viscosity passing through a given cross section of a given media in a given amount of time and under a given pressure gradient. When the permeability parameter is increased, it is realized that the fluid velocity u grows as well. Liquid flow is accelerated in an increase in medium permeability since this indicates that the porous medium's resistance is decreasing.

Fig. 4 illustrated the impact of Gr on the fluid rapidity. The proportion of the buoyant to viscous force exerted on a fluid in the velocity boundary layer is represented by the Gr. It is conformed that the fluid velocity grows on enlarge the Gr. On account of the buoyancy force.

Fig. 5 shows the accomplish of Gc on the velocity. The difference between the viscous force and the species buoyancy force is known as the Gc .When the Grashof number rises, it remains seen that the velocity also rises. because of the force of buoyancy.

Fig. 6 revealed the impact of Q on the fluid velocity. The inter-particle bonds deteriorate and break owing to heat, causing a change in state. The heat required to cause a phase change in a material is greater than the heat required to raise its temperature. It is followed that the fluid velocity accelerates as raise the heat absorption parameter. The flow velocity in the boundary layer decreases as a outcome of this drop in fluid temperature.

Fig. 7 analyses about the amplification of the Ec on the fluid velocity. The Eckert number communicates the correlation between a flows boundary layer enthalpy difference and kinetic energy (K.E). The velocity will increase on growing the value of Eckert number. Caused by kinetic energy. Greater viscous dissipative temperature causes anupsurgevoguish the fluid velocity.

Fig. 8 explains the reaction of Kr on the flow velocity. Chemical bonds are created or ruptured between atoms during chemical processes. Reactants are the substances that initiate a chemical reaction, and products are the compounds that result from it. As an improvement to the Kr, the fluid velocity stay situated minimised.

Fig. 9 describes the upshot of S onto the fluid velocity. The extent speed boosts up through a climbing in S. It is examined that the velocity climbs as hike the S.

Fig. 10 publicizes the cause of the $\Pr$ taking place the fluid velocity. The thermal conductivity and viscosity of a fluid are related by a dimensionless quantity known as the $\Pr$. The association b/w momentum transmission and a fluid's ability to conduct heat is therefore assessed. This occurs when the velocity grows slower on higher values of the. Because the thermal boundary layer chunkiness within the frontier layer declines by way of the Prandtl number climbs.

Fig. 11 depicts the aftermath of the Sc on the fluid velocity. Sc is described as the relationship of mass diffusivity and momentum viscosity. This is due to fact that the dwindle the fluid velocity as build-up of the Sc .This suggests that mass diffusion generally tends to speed up fluid flow.

Fig. 12 exhibits the outgrowth of Dufour number on the velocity u. The Dufour number indicates how much the concentration gradient contributes to the flow's thermal energy flux. It is observed that the fluid velocity climbs as hike the Dufour number.

Fig. 13 reveals the stimulus of Sr on the fluid velocity. Soret number refers to a gradient of precipitation and a greater temperature differential. This implies that the accumulate the velocity as spike on the Soret number.

Fig. 14 disports the conclusion of γ on the velocity. A growing number of Casson parameters reduce yield stress and limit delivery velocity. As the Casson fluid parameter amplified significantly, the fluid started to operate like a Newtonian fluid. It has been determined that increasing the γ reduces velocity.

Fig. 15 displayed the significance of $\Pr$ on the flow temperature θ. The temperature lowers and the $\Pr$ is heard constructing. The Prandtl number is the proportion between viscous boundary layers and the thicknesses of the thermal. With an increase in the value of the fluid's temperature rises.

Fig. 16 indicates the cause of heat absorption parameter Q on the temperature. It suggests that fluid temperature drops as heat absorption rises. This may be explained by the fact that fluid temperature tends to drop as heat is absorbed, which weakens the thermal buoyancy force and outcomes in a net drop in fluid temperature θ.

Fig. 17 performs the influence of S on the temperature. According to calculations, the fluid medium's fluid temperature will rise as the temperature source parameter improves.

Fig. 18 represents the reaction of Ec on the fluid temperature θ. It is agreed upon that the increase in temperature will prolong the Ec opposite flows for buoyancy. With rising levels of Ec, the thermal boundary layer thickness falls.

Fig. 19 communicates the outcome of Du on temperature. The thermal energy flux in the fluid flow is measured through the Du, which denotes the contribution of energy gradients. It is mind to that raise the temperature on enlarge the Du.

Fig. 20 presents the conclusions of Sc on fluid concentration ϕ. It is hypothesised that lessening the focus will increase the Sc. The proportion of mass diffusivity to momentum is represented by the Sc. The comparative proficiency of momentum and mass movement by diffusion in the hydrodynamic and concentration frontier layers is consequently measured by the Sc. The concentration ϕ reduces as the Schmidt number rises.

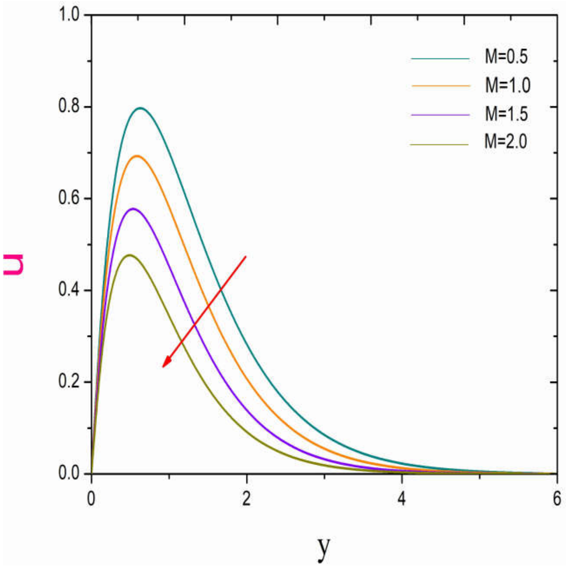

Fig 2. Impact M on u

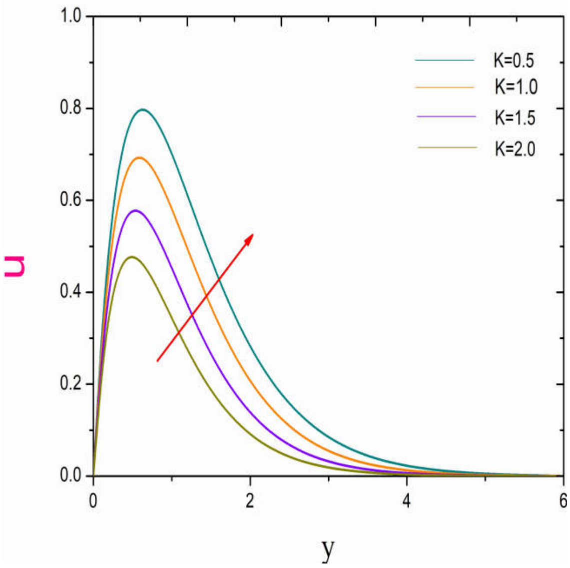

Fig 3. Impact K on u

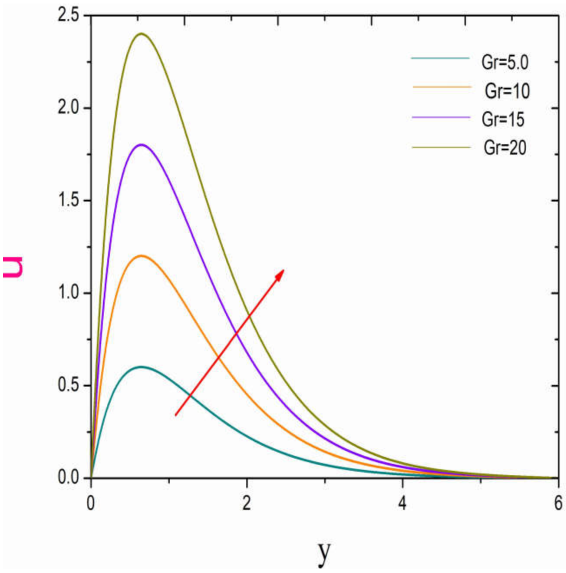

Fig 4. Impact Gr on u

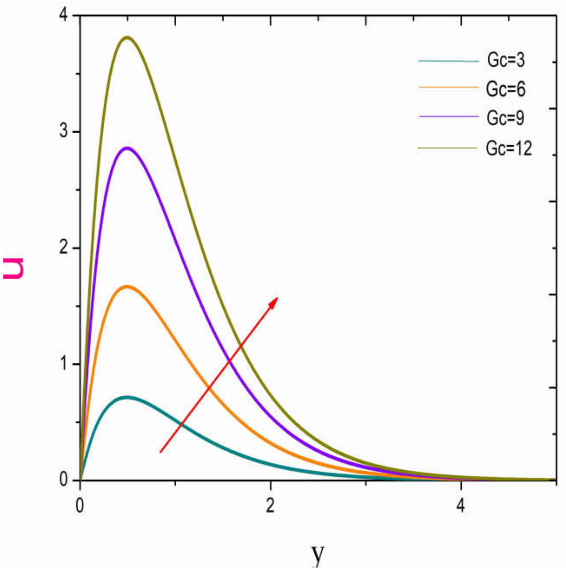

Fig 5. Impact Gc on u

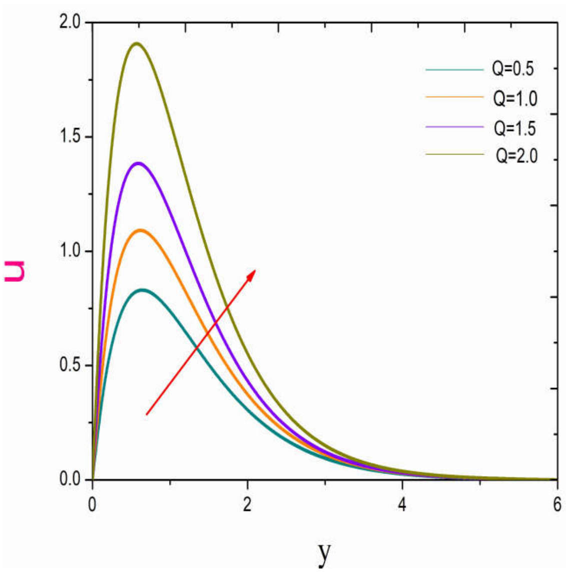

Fig 6. Impact Q on u

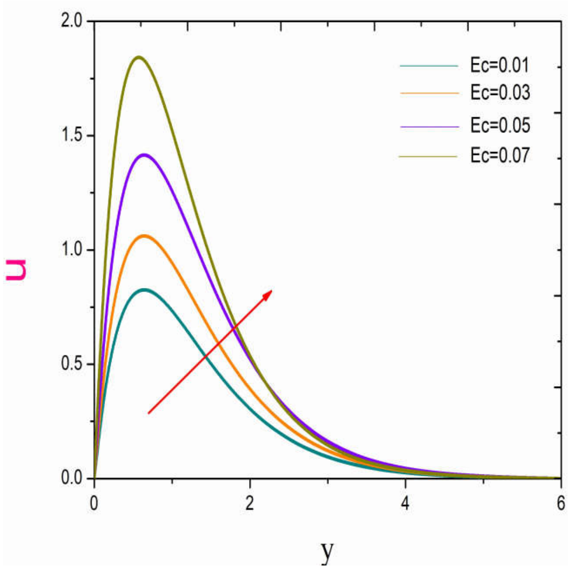

Fig 7. Impact Ec on u

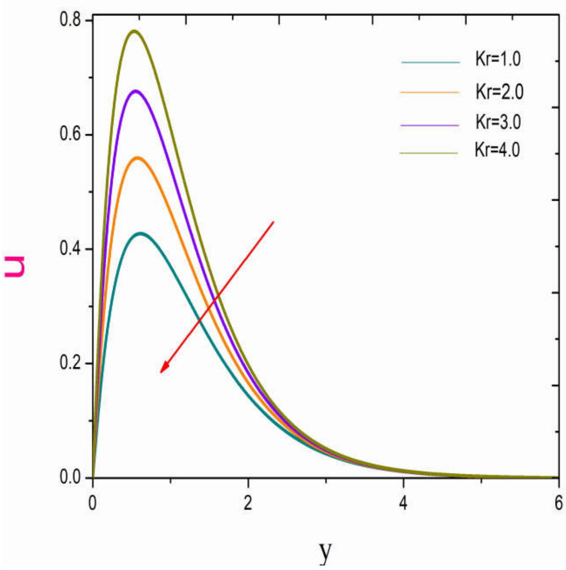

Fig 8. Impact Kr on u

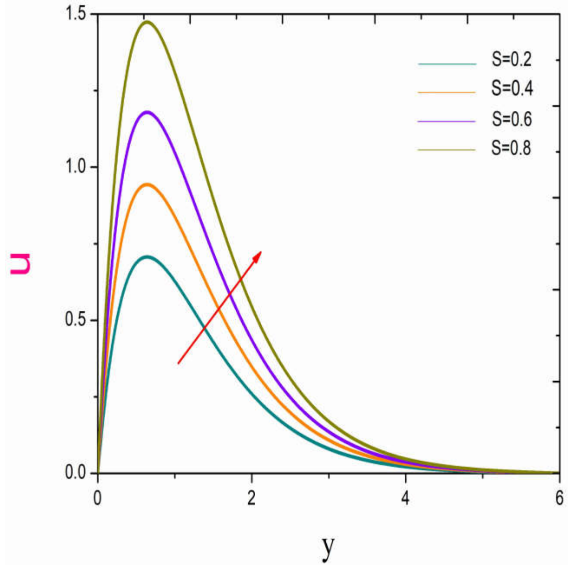

Fig 9. Impact S on u

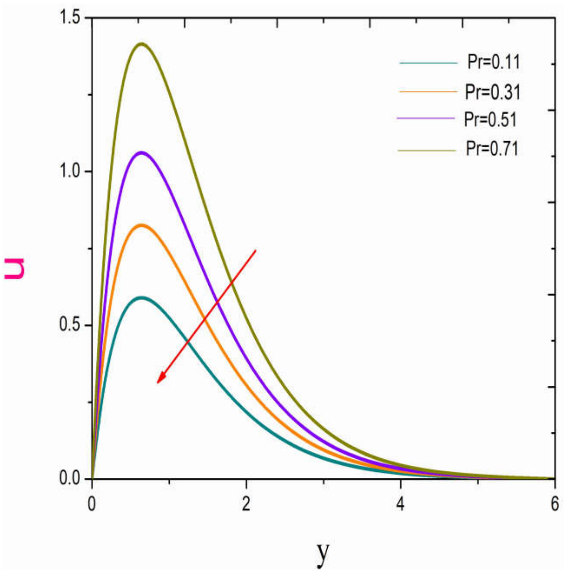

Fig 10. Impact $\Pr$ on u

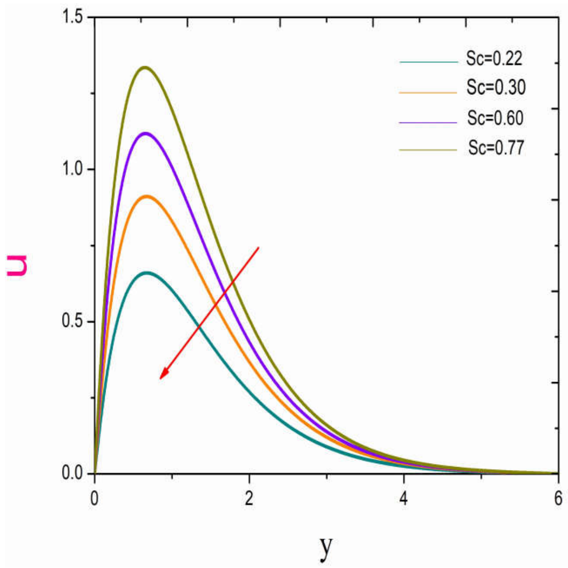

Fig 11. Impact Sc on u

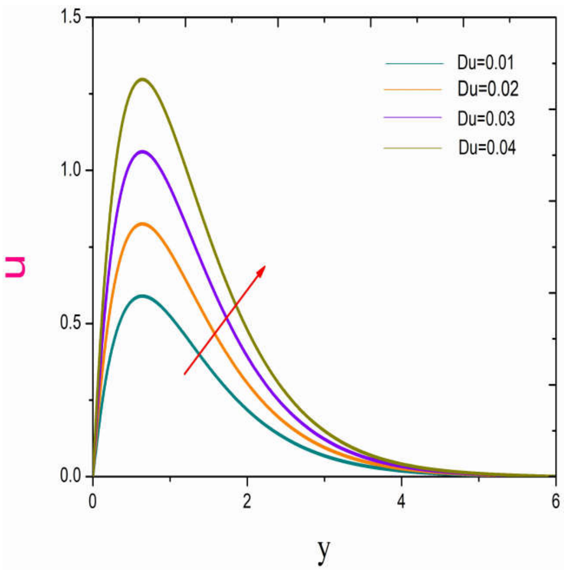

Fig 12. Impact Du on u

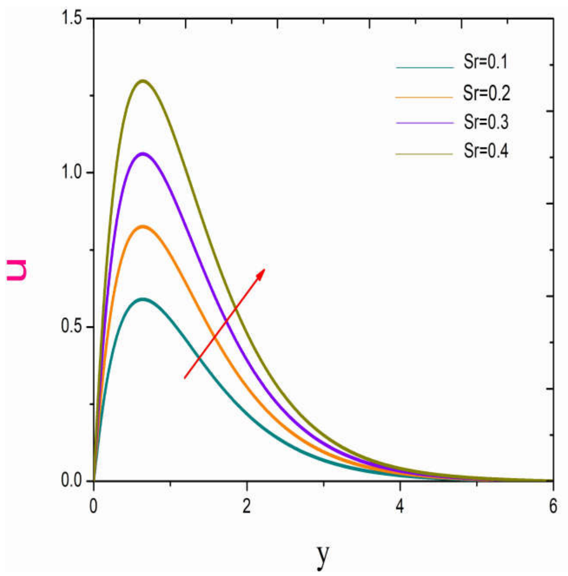

Fig 13. Impact Sr on u

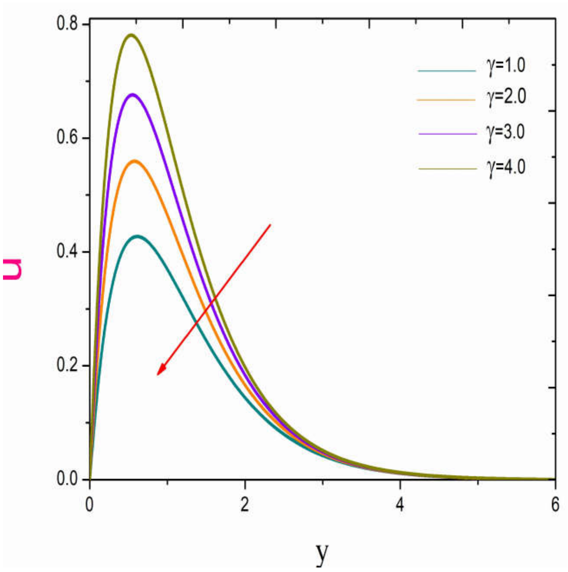

Fig 14. Impact γ on u

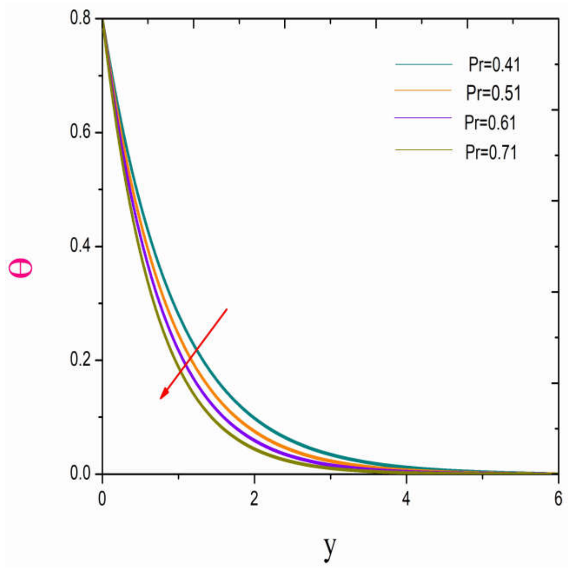

Fig 15. Impact $\Pr$ on θ

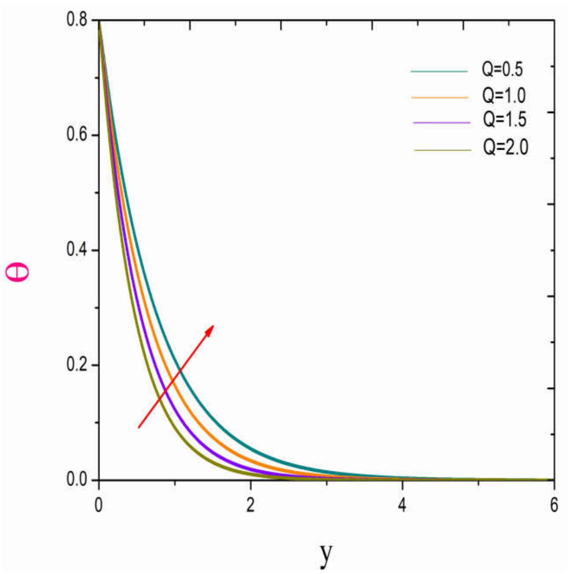

Fig 16. Impact Q on θ

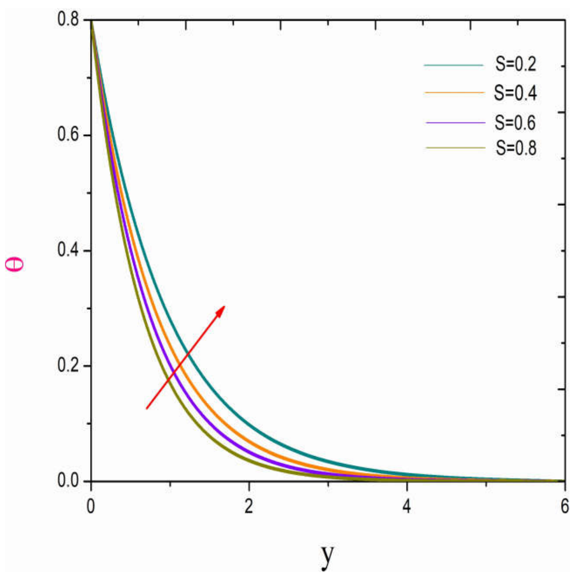

Fig 17. Impact S on θ

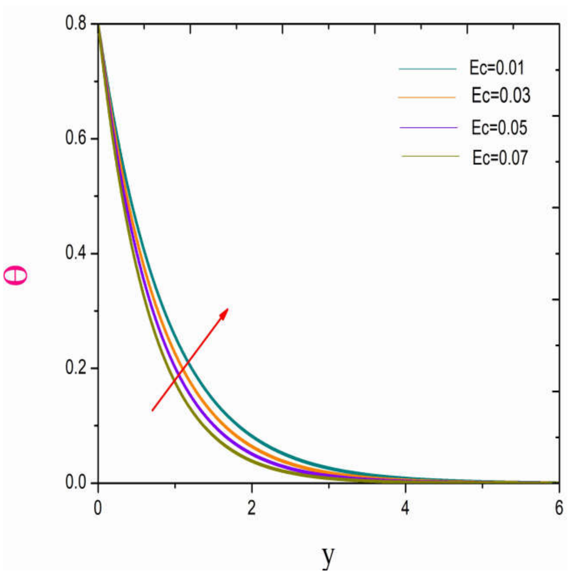

Fig 18. Impact Ec on θ

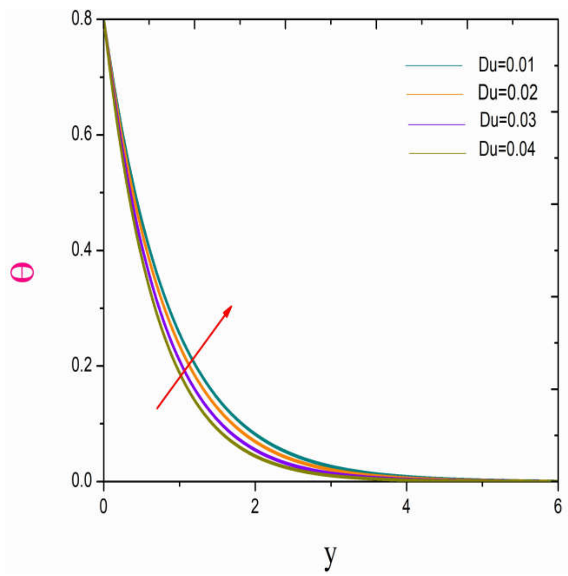

Fig 19. Impact Du on θ

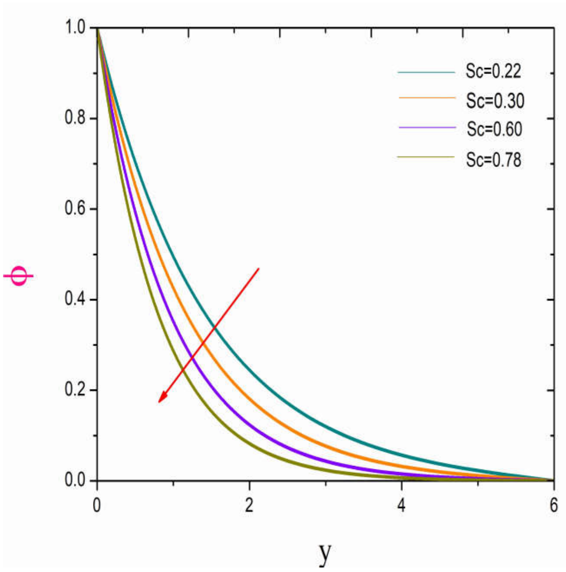

Fig 20. Impact Sc on ϕ

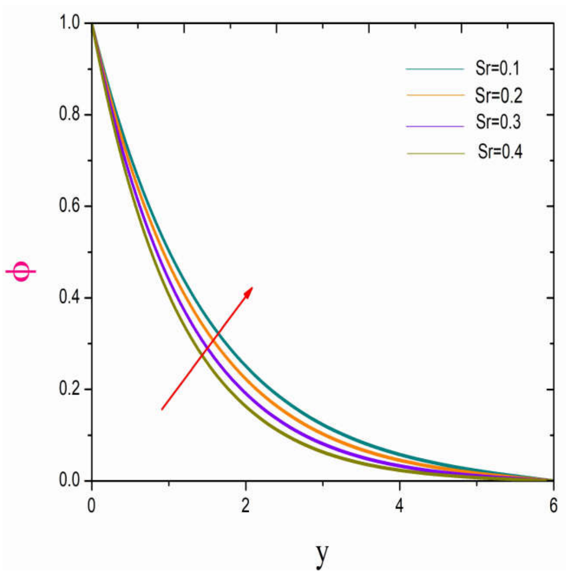

Fig 22. Impact Sr on ϕ

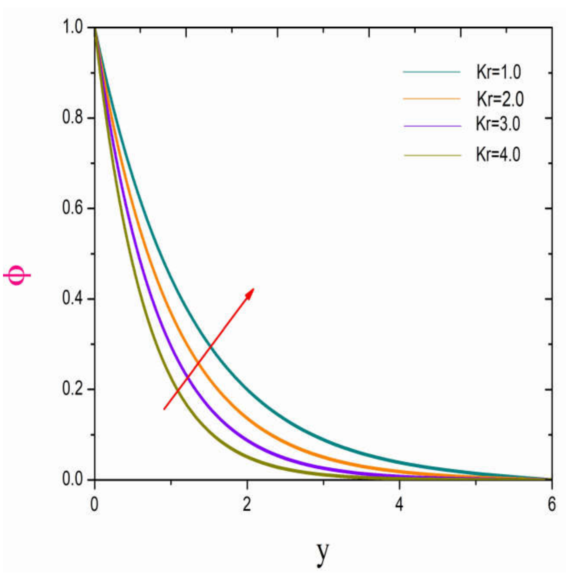

Fig 21. Impact Kr on ϕ

Fig. 21 appears the accomplishes of Kr on concentration. Because the solute concentration ϕ is slowed down by the Kr, there is a corresponding drop in fluid velocity as a result of a weaker mass buoyancy force. The concentration is amplified as the Kr is increased, and this is agreed upon.

Fig. 22 reports the executes of Soret number on fluid concentration. A rise in the Soret effect indicates a upswing in molar mass diffusivity, as stated by the explanation of Sr. The concentration grows as the mass diffusivity of the molecules rises. It is done to increase seniority and concentration.

Conclusions:

The detailed investigation of Soret Dufour effects on magneto hydrodynamics natural convection Casson fluid flow past verticalinclined infinite porous plate. The consequence of leadingrelevantparameters such as $M, Gr, Gc, K, Q, Ec, Kr, \Pr, S, Sc, Sr$ *and* Du are calculated and demonstrated with the aid of graphs.It is found that the effects of the velocity raise with the developing values of Gr, Gc, Q, Eckert number Ec, Heat source parameter, Dufour number Du and Sr and decreasing the parameters of Casson fluid parameter γ, Hartmann number M, K, Kr, $\Pr$, Sc.The temperature θ growths with the aggregate values of Q, S, Ec and Du and decreasing the values of $\Pr$. The ϕ increases by the climbing the values of Kr, Sr and decreasing the value of the Sc.The S and absorption parameter are increasing the Nu is decreasing and the $\Pr$ is increasing all of which cause the Nusselt number to increase. Agrowth in Sc and substance reacting constraint leads to an expansion of the Sherwood number Sh. Validating present results with the prior results, current results are more accurate and precise.

References:

1. Shiva Rao and Paramananda Deka, “A Numerical study on unsteady MHD Williamson Nano fluid flow past a permeable moving cylinder in the presence of thermal radiation and chemical reaction”, J., Biointerface Research in Applied Chemistry., Vol. 13, Issue no. 5, pp. 1-19, 2023, DOI: 10.33263/BRIAC135.436.
2. K.M. Sanni, A.D. Adeshola and T.O. Aliu, “Numerical investigation of nonlinear radiative flux of non-newtonian MHD fluid induced by nonlinear driven multi-physical curved mechanism with variable magnetic field”, J., Nigerian Society of Physical Sciences., Vol. 5, Issue no. 3, pp. 1-11, 2023, DOI:10.46481/jnsps.2023.1435.
3. S. Doley, V. K. Alagarsamy, A. J. Chamkha, J. Lawrence and A. Jacob, “Numerical study of heat transfer between hot moving material and ambient medium using various hybrid Nano fluids under MHD radiative-convection, viscous dissipation effects, and time-fractional condition”, J., Numerical Heat Transfer, Part B: Fundamentals., Vol. 84, Issue no. 1, pp. 24-49, DOI: 10.1080/10407790.2023.2175745.
4. Sangeetha Sekar, Sujatha Elamparithi, Sivakami Lakshmi Nathan and Lakshmi Priya Saravanathan, “Effect of MHD with Micropolar Fluid Between Conical Rough Bearings”, J., Heat and Technology., Vol. 40, Issue No. 5, pp. 1210-1216, 2022, DOI: 10.18280/ijht.400512.
5. P Megaraju, Siva Reddy Sheri and Raja Shekar, “Transient MHD flows through an exponentially accelerated isothermal vertical plate with Hall effect and chemical reaction effect: FEM”, J., Partial Differential Equations in Applied Mathematics., Vol.4, pp. 100047, 2021, DOI: 10.1016/j.padiff.2021.100047.
6. Junhao Ke, N. Williamson, S.W. Armfield and A. Komiya, “the turbulence development of a vertical natural convection boundary layer”, J., Fluid Mech., Vol. 964, pp. 1-29, 2023, DOI:10.1017/jfm.2023.382.
7. B. K. Khudhair, A. M. Saleh and A. L. Ekaid, “An exponential study of forced vibration on natural convection between closed ended concentric and eccentric annular of horizontal cylinder”, J., DIAGNOSTYKA., Vol. 24, Issue no. 2, pp. 1-13, 2023, DOI: 10.29354/diag/165931.

8. A. V. Tsinober, U. Shavit and R. Rosenzweig, “Numerical investigation of the influence of hydrodynamic disperdion on Solutal natural convection”, J., Water Resource Research., Vol. 59, Issue no. 5, pp. 1-13, 2023, DOI: 10.1029/2023WR034475.
9. Siva Reddy Sheri, Ch. Vijaya Bhaskar and S. Anjan Kumar, “Effect of viscous dissipation on natural convection flow past an impulsively moving vertical plate with ramped temperature”, J., AIP Conference., Vol. 2246, Issue no.1, pp. 020007, 2020, DOI: 10.1063/5.0014628.
10. Siva Reddy Sheri and J Anand Rao, “Heat and mass transfer effect on MHD natural convection flow past a moving vertical plate”, J., Physics: conference series., Vol. 662, Issue no. 1, pp. 012013, 2015, DOI: 10.1088/1742-6596/662/1/012013.
11. Muhammad Amin Murad, Faraidun Hamasalh and Hajar F. Ismael, “Numerical study of stagnation point flow of Casson fluid over a continuous moving surface”, J., Frontiers in Heat and Mass Transfer., Vol. 20, Issue No. 1, pp. 1-8, 2023, DOI: 10.5098/hmt.20.7.
12. Muhammad Shuaib, Muhammad Anas,Hijab ur Rehman, Arshad Khan, Ilyas Khan and Sayed M. Eldin, “Volumetric thermos-convective Casson fluid flow over a nonlinear inclined extended surface”, J., Scientific Reports, Vol. 13, Issue No. 6324, pp. 1-18, 2023, DOI: 10.1038/s41598-023-33259-z.
13. K. Anantha Kumar, A.C. Venkata Ramudu, V. Sugunamma and N. Sandeep, “Effects of non-linear thermal radiation on MHD Casson fluid flow past a stretching surface with chemical reaction” J., International Journal of Ambient Energy., Vol. 43, Issue. 1, pp. 1-8, 2022, DOI: 10.1080/01430750.2022.2097947.
14. Shankar Goud Bejawada, Yanala Dharmendar Reddy,Wasim Jamshed, Kottakkaran Soopy Nisar, Abdulaziz N. Alharbi, Ridha Chouikh, “Radiation effect on MHD Casson fluid flow over an inclined non-linear surface with chemical reaction in a Forchheimer porous medium, J., Alexandria Engg., Vol. 61, Issue. 10, pp. 8207-8220, 2022, DOI:10.1016/j.aej.2022.01.043.
15. Husna Izzati Osman, Dennis Ling Ling Chuan Ching, Nur Fatihah Mod Omar, Dumitru Vieru and Zulkhibri Ismail, “Generalized cattaneo’s law over a vertical cylinder on Casson fluids”, J., CFD Letters., Vol. 14, Issue No. 12, pp. 38-51, 2022, DOI: 10.37934/cfdl.14.12.3851.
16. B.V. Swarnalathamma, D. M. Praveen Babu and M. Veera Krishna, “Combined impacts of Radiation absorption and Chemically reacting on MHD Free Convective Casson fluid flow past an infinite vertical inclined porous plate”, J., Computational Mathematics and Data Science., Vol. 5, pp. 2772-4158, 2022, DOI: 10.1016/j.jcmds.2022.100069.
17. T. E. Bountourelis, N. Kladovasilakis, K. Tsongas, P. Kyratsis and D. Tzetzis, “finite element analysis and topology optimization of a high-performance lower prosthetic limb”, J., Modern manufacturing technologies., Vol. XV, pp. 148-152, 2023, DOI: 10.54684/ijmmt.2023.15.1.148.
18. Z. Yang, Guangming Xu, Jiyong Yang and Zhifei Li, “Effect of different loads on the shoulder in abduction postures: a finite element analysis”, J., Scientific Reports., Vol. 13, Issue no.1, pp. 1-10, 2023, DOI:10.1038/s41598-023-36049-9.
19. N. Boskovic, Maria. R. R and Branislav. R, “Finite element analysis of microwave tumor ablation based on open source software components”, J., Mathematics., Vol. 11, pp. 1-23, 2023, DOI: 10.3390/math11122654.
20. Siva Reddy Sheri and S. Anjan Kumar, “Finite element analysis of heat and mass transfer past an impulsively moving vertical plate with ramped temperature”, J., Applied Science and Engineering., Vol. 19, No. 4, pp. 385-392, 2016, DOI: 10.6180/jase.2016.19.4.01.
21. SivaReddy Sheri and MD Shamshuddin, “Finite element analysis on transient magnetohydrodynamic (MHD) free convective chemically reacting micropolar fluid flow past a vertical porous plate with hall current and viscous dissipation”, J., Propulsion and Power Research., Vol. 7, Issue no. 4, pp. 353-365, 2018, DOI: 10.1016/j.jppr.2018.11.003.
22. Eckert, E. R. G. & Drake, R. M. Analysis of Heat and Mass Transfer (McGraw-Hill Book Co., 1972).
23. Subhrajit Sarma and Nazibuddin Ahmed, “Dufour effect on unsteady MHD flow past a vertical plate embedded in porous medium with ramped temperature”, J., nature portfolio., vol. 12, pp. 1-32, 2022, DOI: 10.1038/s41598-022-15603-x.

24. Natalya V. Burmasheva and Evgeniy yu. Prosviryakov, "Influence of the Dufour effect on shear thermal diffusion flows", J., dynamics., Vol. 2, Issue no. 4, pp. 367-379, 2022, DOI: 10.3390/dynamics2040021.
25. B. Shoilpa, V. Leela, B. C. Prasannakumara and Pulla Nagabhushana, "Soret and Dufour effects on MHD double diffusive mixed convective heat and mass transfer of couple stress fluid in a channel formed by electrically conducting and non-conducting walls", J., Waves in random and complex media., 2022, DOI: 10.1080/17455030.2022.2119491.
26. B. Chandra shekar, A. Ramesh, N. Kishan, MD. Rashad, "Impact of Soret and Dufour on bio convective flow of nanofluid in porous square cavity", J., Heat transfer., Vol. 50, Issue no. 5, pp. 5123-5147, 2021, DOI: 10.1002/htj.22118.
27. Siva Reddy Sheri, P. Megaraju and MN. Rajashekar, "Impact of Hall current, Dufour and Soret on transient MHD flow past an inclined porous plate: Finite element method", J., Materials Today: Proceedings., Vol. 59, pp. 1009-1021, 2022, DOI: 10.1016/j.matpr.2022.02.279.
28. Das R, Mahato R, Nandkeolyar R. Newtonian heating effect on unsteady hydro-magnetic Casson fluid flow past a flat plate with heat and mass transfer. Alex Eng J 2015;54(4):871–9.
29. Bathe, *K. J., Finite Element Procedures: Prentice Hall,* New Jersey, 1996.
30. Reddy, *J. N., An Introduction to the Finite Element Method*, 3rd Edition, McGraw-Hill Book Company, New York, 2006.