Impact of aligned Magnetohydrodynamic (MHD) Nanofuid Flow over stretching sheet

Bhawna Kaushik[1]*, Vikas Poply[2], Praneeta Verma[3]
[1,3]Department of Mathematics, Starex University, Gurugram, Haryana, India.
[2]Department of Mathematics, K.L.P. College, Rewari, Haryana, India

***Corresponding Author:**
Bhawna Kaushik
Email: bhawnakaushik66@gmail.com

Article History: Received: 10/05/2022 Revised: 16/06/2022 Accepted: 12/07/2022

Abstract

The problem of statically aligned MHD magnetic nanofluid flow past a stationary wedge is studied in this paper. The constant temperature at the surface as well as the current aligned magnetic field are considered. Official partial differential equations are transformed into ordinary differential equations using equality transformations subject to boundary conditions. The transformed equations are solved numerically by the Keller-box method. To check the validity of the present method, the numerical results for the dimensionless local skin friction coefficient and the rate of heat transfer are compared as special cases with the results from the available literature and appear to be in good agreement. The effect of relevant parameters on velocity, temperature profile, as well as wall shear stress and heat transfer rate are displayed in graphical form and discussed. It is found that the fluid velocity increases with the increase of tilt angle, magnetic parameter and thermal buoyancy parameter while decreases for increasing nanoparticle volume fraction. It is also observed that the magnetic parameter significantly affects the fluid velocity and temperature.

Keywords: Aligned MHD, Nano Fluid, Aligned magnetic field, Oblique flow, Heat Transfer, exponentially stretching surface.

DOI:10.48047/ecb/2022.11.7.23

1. Introduction:- The study of heat and mass in MHD flow over a incompressible flow on a stretching sheet has been achieved a great attention of researchers due to its importance in science. Many researchers have based their inventions on analyzing the effect of Radiation, MHD and heat transfer on a stretching sheet using numerical and analytical methods. Several authors note boundary layer flow over a shrinking sheet because of their important physical properties. Generally, shrinking sheet flow produces circling and then the flow is not free to move over a boundary surface, the resulting problem it appears that there we need an external force to help it flow smoothly. The effect of suction is suitable when the external force is limited. This happens only when the flow is in steady state[1].

Study of boundary layer flow and transfer of heat and the mass energy on the stretching surfaces reasons widely presented by many researchers for their vast range of technical applications such as the design manufacturing of electronic chips, metal and plastic sheets.[2]

The basic work on those ranges is done by crane[]. Later many investigations were carried out to study the behavior of mass transfer along linear, non-linear, variable thickness, exponential stretching surfaces etc.[2]

In recent years, there has been a developing trend in nanotechnology and nano science that reveals the synthesis and progress of specific nano materials because of their importance in the field of science and engineering. Nano materials and nanofluids are attached by many researchers because of their absorptive and thermal transport behavior in different regions. As nano fluids have high thermal conductivity, they were found to have stability to prevent rapid settling and hindrance in addition to the boundaries of heat transmission zone.[2] Magnetic field strength changes behavior of nanofluid flow.[3] Fluid flow over a porous medium also has an important role in the construction of many functions such as thermal radiators, plastic extrusion, petroleum refining, geothermal power process, water purification plant, grain storage plant, etc.[3]
Studies related to non-Newtonian fluids have generated considerable interest in recent times. It is like resulting in their many uses in industrial products. In general, such fluids cannot be explained by a single constitutional Equation. Therefore, considering the diversity of such liquids, various constitutive equations have been proposed. Non-Newtonian types of fluids are mainly distributed among integral, rate and differential types. Maxwell fluid rate type belongs to the non-viscous fluid category.[4] The nanofluids a new type of heat transfer fluid is one that contains both nanoparticles and a fluid, that is, it is a fluid mixture in which
a micrometer-sized solid particle that can be used as a heat transfer fluid since its thermal conductivity of these the fluid is more than water. Some recent inventions show how microparticles could be used to heat transfer application. The dissipation of nano-sized fusible particles in conventional heat transfer fluids is known to nanofluids. The disadvantage of using micro-sized particles (up to 10-6 m) is that they build up with the effluent. Channel causes path crash. This form of liquid has piqued the curiosity of researchers investigating liquids from all around the world. It is found in a wide range of modern technological applications that help people live better life. Nanofluids are also used in medical applications, such as the treatment of cancerous tumors. Fabrication of gold nanoparticles and miniaturized explosives to destroy tumors.[5] Boundary layer flow over a stretching sheet is important in applications such as extrusion, wire drawing, metal spinning, hot rolling etc.[6] The unsteady MHD convection over a vertically permeable sheet was numerically studied the fourth order Runge–Kutta method with shooting the technique transforms the boundary value problem into an initial value problem.[7] Effect of thermal radiation on MHD heat transfer flow of a nanofluid on a drawn surface has an important role in driven thermal engineering design tool at high temperature.[8] Hydromagnetics is the study of the interaction of conducting fluids with electromagnetic phenomena. The advantage of hydromagnetic nanofluid is that fluid flow and heat transfer can be controlled by an

external magnetic field.[9] Nanofluids have an important role in enhancing heat transfer properties of fluids, for example, nanofluids shows high thermal conductivity rate compared to a normal fluid such as water which makes these ideal fluid as an advanced heat transfer fluid.[10] Newtonian and non-Newtonian fluid flow based on an exponentially stretched surface in recent times it has been discussed by scientists.[11] Nanofluids have improved thermo-physical properties such as melting diffusivity, stability, melting point and heat conduction characteristics compared to common base liquids water, engine oils and lubricants, polymer solutions, bio-fluids and other general fluids. In fact, the main concept of using nanoparticles is to improve the melting ability of liquid based.[12] Non-Newtonian materials are materials that do not satisfy Newton's law of viscosity. A common subclass of non-Newtonian fluids are Jeffrey fluids in which the convection derivative is with the viscoelastic non-Newtonian fluid model replaced by the time derivative which determines structures of both relaxation and retardation times. have a reasonable number of probes jeffrey has been found in the literature highlighting fluid flow.[13]Thermal conductivity increases upon addition of nanoparticles.[14] In non-Newtonian fluids, the Jeffrey fluid model is a simplest model. This is a relatively simple linear model using time derivatives instead of convergent derivatives.[15] In stretching sheet problems, the geometry of the problem is important, due to its time dependence as well as the nature of the sheet.[16] Increase in heat source or sink parameter decreases velocity profile but increases temperature profile.[17] Sheets spread to like thickness and rate of cooling is an important factor at the time of production determination of the properties of the final manufactured item.[18] The present study investigates the analysis of mass and heat transfer axisymmetric MHD nano-fluid flow over a stretching sheet in the presence of multiple slip conditions
with buoyancy effect, chemical reaction and thermal radiation. Governing fractional difference the equations of the model are converted into ordinary differential equations by means of appropriate equalities change. The ODE is then solved via the finite element method.[19] The second law of thermodynamics is used to measure irreversibility at the optimum thermal
system design. Construct entropy is a criterion for non-optimal operation of
thermal system.[20] It has been revealed the sticky dissipation effect on MHD flow exponentially drawn surface with fluid particle suspension.[21] Non-Newtonian fluids can be classified into the following three types, viz., (i) Differential type (ii) rate type and (iii) integral type. The Maxwell fluid model, the simplest subclass of rate-type fluids, describes features of rest time. Thermoplastic polymers in the vicinity of their melting temperature, fresh concrete (neglecting its aging), many metals at temperatures close to their melting points, geomaterials etc generally behave as Maxwell fluids.[22] Nanofluids are considered to be top coolants in fluid flow. The concept of fluid flow in a porous medium is quite natural. flow-through a natural flow of liquids through rocky surface, sand and dusty areas etc. is very actual conditions around us since the creation of the universe.[23] The oblique stagnation flow takes place if and only if the applied magnetic field and dividing streamlines are in the same direction.[24] Sheets with variable thickness are practically important in real life applications and are being used in metallurgical engineering, equipment structures and Patterns, nuclear reactor mechanization, and paper production.[25] There is an irregular relationship of stress and strain in shear thickened fluids and it is very Non-Newtonian fluids are difficult to analyze because of their Navier–Stokes equations and its relationship is very complex in nature.[26] No-slip boundary conditions are often used in flow problems of viscous fluids. However, there are many cases where such a condition is insufficient and slippage may occur at the boundary, when liquid particles such as emulsions, suspensions, foams and polymer solutions. Fluid behavior of the flow under slip flow

governance shows a large discrepancy from the conventional flow. Discrepancy of the shear between the velocity of the fluid at the wall and the velocity of the wall itself is proportional to tension.[27] MHD boundary layer flow and heat transfer from an exponentially stretching sheet embedded in a thermally stratified medium, and observed that the heat transfer rate on stretching sheet increases in the presence of thermal stratification whereas the fluid velocity decreases with increasing magnetic parameter.[28] It has been checked that the value of Hartmann number reduced the velocity profile.[29] The effect of slip boundary condition on heat has been studied transfer characteristics of nanofluidic flow on fixed stretching sheet convection boundary conditions using a model that takes into account dynamic effects of nanoparticles. His work showed that increasing slip factor and Biot number have a strong effect on reducing the nucellt and Sherwood No.[30] The result of a magnetic field imparted on a viscous fluid flow compressed with parallel plates and explained by perturbation method.[31] Three properties that make nanofluids promising the coolant has increased thermal conductivity enhanced heat transfer and increased critical heat flow. Two characteristics are very important for heat transfer systems have extreme stability and high thermal conductivity.[32] It has been analyzed in two-dimensional MHD nanofluid flow near a stagnation point including effects of Brownian motion and thermophoresis spreading. They found that the speed boundary layer becomes thinner with increasing values of speed magnetic parameter.[33] It has been observed that nanofluids are fundamentally characterized by the fact that Brownian agitation overcomes any settling motion due to gravity. Thus, a stable nanofluid is theoretically possible as long as particles stay small enough.[34] Nanofluid is prepared when the particles of nanometer size are suspended in basic fluids such as convection heat transfer fluid. Thermal conductivity plays an important role for heat transfer between heat transfer surfaces and medium both are therefore vast ways used to maintain thermal conductivity by introducing nano particles in liquids.[35] After extended viscosity, non-newtonian fluids are best treated by including viscoelastic terms (second grade models) which is known as the subclass classification of differential non-newtonian fluids related to the normal stress characteristic.[36] It has been analyzed that the effect of heat transfer and thermal radiation on magnetohydrodynamics nanofluid flow through a two-phase model and showed that there is a direct relation between Nusselt number, Reynolds number and radiation parameter while its inverse is relationship with other parameters.[37] It has been discussed that the introduction of nanofluid bioconveyance in a horizontal porous layer heated from below. They checked cases of nonoscillatory and oscillatory convection. The results obtained showed that the effect of microorganisms may depend on the stability of the suspension the value of the bioconductance Peclate number.[38] It was demonstrated that thermal boundary layers evolved for increasing thermophoretic parameters, but opposite phenomena were observed for Brownian parameters.[39] It has been examined that the hydromagnetic flow investigated at a traversing a surface with power-law velocity using shooting method.[40]

Due to such critical applications, boundary layer flow of an incompressible viscous fluid was considered by [41] because of the elastic surface deforming under uniformly applied magnetic field. Exact solution of boundary layer obtained with a vertical plate under the flow [42] applied by Magnetic Field. Analytical expressions were obtained in the series form flows for Sakiadis and Blasius-Sakiadis. Studied in [43] effect of heat generation or absorption and viscous dissipation in a moving wedge on the force convection flow of a viscous fluid under injection/suction. It was found that the presence of heat the source caused the high temperature. An equal solution process was presented by [44] to find out exact solutions for laminar forced convection heat transfer from both uniform-flux and isothermal wedges to fluids with any Prandtl number. Recently, the MHD caisson nanofluid flow was investigated by [45] on a wedge with Newtonian heating. They employed Keller-box method to solve the problem numerically and found high skin friction resulting from a Newtonian fluid in comparison with caisson fluid.

The applications mentioned above in the literature and discussion the main sources of inspiration for studying stable coalition were MHD magnetic nanofluid flows over a stationary/moving wedge. Similarity transform was employed to convert non-linear converting partial differential equations to non-linear ordinary differentials the equation. An implicit finite difference scheme known as the Keller-box method was employed to solve the highly nonlinear transform numerically equation [46].

2. Mathematical Formulation

Consider a stationary, aligned magnetohydrodynamic Faulkner-scan flow in two-dimension on moving or static wedge for waterbased Nanofluid with magnetic nanoparticle (Fe_3O_4). Table 1 lists the fluid's thermophysical properties and nanoparticle. The wedge total angle is Ω = λΠ, λ =$\frac{2m}{m+1}$ which refers to the wedge angle parameter. $u_e(x) = U_\infty x^m$ and $u_w(x) = U_w x^m$ represents the velocities at the free stream and wedge respectively. As shown in figure, in the direction of direction of flow, a variable magnetic field $B(x) = B_0 x^{\frac{m+1}{2}}$ is applied. The direction of the generated magnetic fields assumed to be normal to the surface as well as uniform. This also the electric field due to polarization of charges is assumed to be negligible and the magnetic Reynolds number is assumed to be small. Furthermore, it is assumed that all thermo-physical properties of fluid remains constant with the exception of a change in density body force term as well as thermal conductivity.

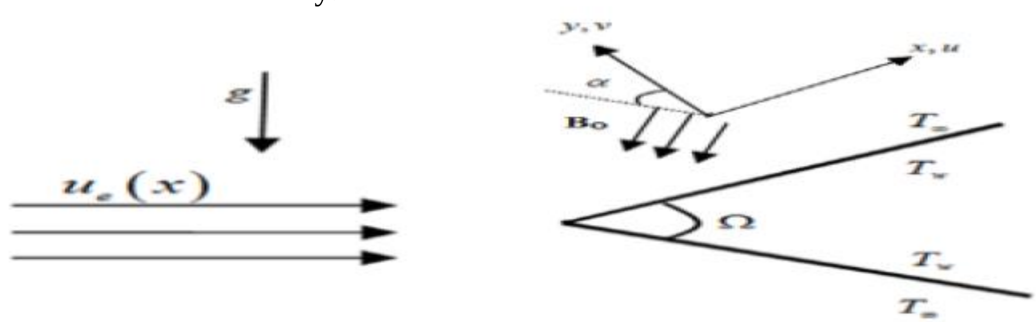

Figure: Physical flow model and coordinate system

Table: Thermophysical Properties of the base fluid and nanoparticals.[48-49]

Physical Properties	Fluid Phase(water)	Fe_3O_4
ρ(J/kgK)	997.1	5200
c_p(kg/m3)	4179	670
k(W/mk)	0.613	6
β×$10^{-5}(K^{-1})$	21	1.3

Pr	6.2	-

Based on these assumptions and the general Boussinesq approximation, governing boundary layer equation related to the conservation of mass, momentum and energy can be given as:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=u_e\frac{\partial u_e}{\partial x}+v_{nf}\frac{\partial^2 u}{\partial y^2}+\frac{\sigma B^2(x)}{\rho_{nf}}Sin^2\alpha(u_e-u)+\frac{(\alpha\beta)_{nf}}{\rho_{nf}}g(T-T_\infty)\sin\frac{\Omega}{2} \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\frac{\partial^2 T}{\partial y^2} \tag{3}$$

The Boundary conditions are:

$$u=u_w(x), v=0, T=T_w \qquad \text{at } y=0,$$

$$u=u_e(x), T\to T_\infty, \qquad \text{as } y\to\infty, \tag{4}$$

where u and v denote the velocity components along x in the y axes, respectively, T represents the nanofluid temperature boundary layer, T_∞ denotes the temperature of the ambient fluid outside boundary layer, σ denotes magnetic permeability, v_{nf} and ρ_{nf} denotes the kinematic and density viscosities of the nanofluid, nnf and α_{nf} represent thermal viscosity and diffusivity respectively which can be defined as [47]

$$v_{nf}=\frac{u_{nf}}{\rho_{nf}}, u_{nf}=\frac{u_f}{(1-\emptyset)^{2.5}},$$

$$\rho_{nf}=(1-\emptyset)\rho_f+\emptyset\rho_s,$$

$$(\rho\beta)_{nf}=(1-\emptyset)(\rho\beta)_f+\emptyset(\rho\beta)_s,$$

$$(\rho C_p)_{nf}=(1-\emptyset)(\rho C_p)_f+\emptyset(\rho C_p)_s,$$

$$\alpha_{nf}=\frac{K_{nf}}{(\rho C_p)_{nf}}, \frac{K_{nf}}{K_f}=\frac{(K_s+2K_f)-2\emptyset(K_f-K_s)}{(K_s+2K_f)+2\emptyset(K_f-K_s)} \tag{5}$$

where $\emptyset$ represents the solid volume friction of the nanofluid, u_f represents viscosities of the base fluid, ρ_s and ρ_f represent the densities of the nanoparticle and pure liquid respectively $(\rho C_p)_s$ and $(\rho C_p)_f$ denote the specific heat parameters of the nanoparticle and original liquid respectively $(\rho\beta)_s$ and $(\rho\beta)_f$ indicate volumetric expansion coefficient of the nanoparticle and the original fluid, respectively andK_s and K_f are the thermal conductivities of the nanoparticle and the original fluid respectively. Following equality variable were introduced to:

$$\Psi = \sqrt{\frac{2v_f x u_e}{m+1}} f(\eta), \qquad \eta = \sqrt{\frac{(m+1)u_e}{2xv_f}}\, y, \qquad \theta = \frac{T-T_\infty}{T_w-T_\infty} \tag{6}$$

Relation, $u = \frac{\partial\Psi}{\partial y}$, $v = -\frac{\partial\Psi}{\partial x}$, define stream function Ψ (1) are satisfied uniformly, where v_f represents the kinetic speed of the fluid viscosity. The following non-linear ordinary differential equation substituting (5) and (6) into (2) and (3), we get:

$$f''' + (1-\emptyset)^{2.5}\left((1-\emptyset)+\emptyset\frac{\rho_s}{\rho_f}\right)[ff' + \lambda(1-(f')^2)] + (1-\emptyset)^{2.5} MSin^2\alpha(1-f')$$
$$+(1-\emptyset)^{2.5}\left((1-\emptyset)+\emptyset\frac{(\rho\beta)_s}{(\rho\beta)_f}\right)\lambda_r\theta\sin\frac{\Omega}{2} \tag{7}$$

$$\frac{K_{nf}}{K_f}\theta'' + Pr\left((1-\emptyset)+\emptyset\frac{(\rho C_p)_s}{(\rho C_p)_f}\right)f\theta' = 0 \tag{8}$$

Under boundary conditions in (4):

$f(\eta) = 0$, $f'(\eta) = \gamma$, $\theta(\eta)=1$ at $\eta = 0$

$$f'(\eta) = 1,\ \theta(\eta) = 0 \text{ at } \eta \to \infty \tag{9}$$

where the prime symbol signifies differentiation with respect to η . Here, Prandtl number Pr = $\frac{v_f}{\alpha_f}$, Reynold's number $Re_x = \frac{xu_e}{v_f}$ is magnetic parameter is M = $2\sigma\beta_0{}^2/\rho U_\infty(m+1)$, thermal buoyancy parameter is $\lambda_T = Gr_x/Re_x{}^2$, Grashof number is $Gr_x = 2g\beta(T-T_\infty)x^3/v_f{}^2(m+1)$ and moving wedge parameter is $\gamma = \frac{U_w}{U_e}$. For this flow and heat transfer case, the important physical parameters include local Nusselt number and local skin-friction coefficient defined as follows:

$$c_f = \frac{\tau_w}{\rho_f(u_e(x))^2}, \qquad Nu_x = \frac{xq_w}{K_f(T_w-T_\infty)} \tag{10}$$

Where

$$\tau_w = \mu_{nf}(\partial u/\partial y)_{y=0}, \quad q_w = -K_{nf}(\partial T/\partial y)_{y=0} \tag{11}$$

are given by shear stress and surface heat flux respectively. Employing new similarity variables in (6) and (7) gives:

$$c_f\left(\frac{2Re_x}{m+1}\right)^{\frac{1}{2}} = \frac{1}{(1-\emptyset)^{2.5}} f''(0),$$

$$Nu_x\left(\frac{(m+1)Re_x}{m+1}\right)^{\frac{1}{2}} = -\frac{K_{nf}}{K_f}\theta'(0).$$

3. Numerical Method

The Keller-box method was used to numerically solve in (7) and (8) subject to boundary conditions in (9) as described in the work of [50]. The following four steps are involved in obtaining the solution.

(i) Reduction in (7) and (8) to first-order system.

(ii) Employ central differences to write the difference equations.

(iii) Use Newton's method to linearize the resulting algebraic equations and note it in the matrix-vector form.

(iv) Employ the block tridiagonal elimination technique to solve the linear system.

Results and Discussion

An inherent finite difference method called the Keller box method was engaged to numerically calculate the non-linear method of in (7) and (8). This study uses the step dimension of $\Delta\eta = 0.01$. Moreover, to obtain the results for the specified boundary value problem, the MATLAB software was engaged to build up an algorithm. To observe the nature of temperature and velocity profiles for the physical problem, numerical calculations were completed for various ideals of parameters, including magnetic parameter M, aligned magnetic field α, thermal buoyancy parameter λ_T and nanoparticle volume fraction $\emptyset$. For numerical computations, some of the non dimensional values remain fixed such as α = 90^0, M = 2, $\emptyset = 0.05, \lambda = 0.2, \lambda_T = 1.5, \Omega = 60^0$. In whole analysis, these standards are treated to be common, without the different displayed values in specific tables and figures. The crate λ_T relate to pure free convection, λ_T relates to pure required convection and λ_T relates to mixed convection.

Reynold's number: The Reynolds number is the ratio of inertial forces to viscous forces. The Reynolds number is a dimensionless number used to categorize the fluids systems in which the effect of viscosity is important in controlling the velocities or the flow pattern of a fluid. The Reynolds number is used to determine whether a fluid is in laminar or turbulent flow.

Nusselt number: The ***N***usselt number is a dimensionless number. Both numbers are used to describe the ratio of the thermal energy convected to the fluid to the thermal energy conducted within the fluid. Nusselt number is equal to the dimensionless temperature gradient at the surface, and it provides a measure of the convection heat transfer occurring at the surface. The Nusselt number is named after a German engineer Wilhelm Nusselt. The conductive component is measured under the same conditions as the heat convection but with stagnant fluid. The Nusselt number is to the thermal boundary layer what the friction coefficient is to the velocity boundary layer.

Prandtl number: The Prandtl number is a dimensionless quantity that puts the viscosity of a fluid in correlation with the thermal conductivity. It therefore assesses the relation between momentum transport and thermal transport capacity of a fluid. The Prandtl number is an example of a dimensionless number that is an intrinsic property of a fluid. Fluids with small Prandtl numbers are free-flowing liquids with high thermal conductivity and are therefore a good choice for heat conducting liquids.

Grashof number: Grashof number is defined as the ratio of the product of inertia force and buoyant force to the square of viscous force present in the fluid. The significance of the Grashof number is that it represents the ratio between the buoyancy force due to spatial variation in fluid density (caused by temperature differences) to the restraining force due to the viscosity of the fluid. The form of the Grashof number can be derived by considering the forces on a small element of fluid of volume.

Skin-friction coefficient: The skin friction coefficient is a dimensionless skin shear stress which is non- dimensionalized by the dynamic pressure of the free stream. The skin friction coefficient is defined at any point of a surface that is subjected to the free stream.

Table: Comparison of $f''(0)$ value for different m values when Pr = 6.2, M = 0, $\lambda_T = 0, \emptyset = 0.$

m	[21]	[22]	[23]	Present
0	0.4696	0.4696	0.4696	0.4696
1/11	0.6550	0.6550	0.6550	0.6550
1/5	0.8021	0.8021	0.8021	0.8021
1/3	0.9276	0.9276	0.9277	0.9277
½	-	-	1.0389	1.0389
1		1.2326	1.2326	1.2326

Above table gives the values' comparison for $f''(0)$ with different values of m when $\lambda = 0.$
As pragmatic from the above table, the local skin friction coefficient was seen to increase with increase in value of m. From the table the results were found to be in a fine agreement. Therefore, it can be said that the present numerical results are very accurate.
Figure 2 depicts the impact of inclined angle on velocity and temperature profile. It is clear from the figures that a rise in the aligned angle of magnetic direction improves the velocity profiles and reduce the temperature profiles. The increasing values of the aligned angle of magnetic direction results a rise in the magnetic field force in the flow region.

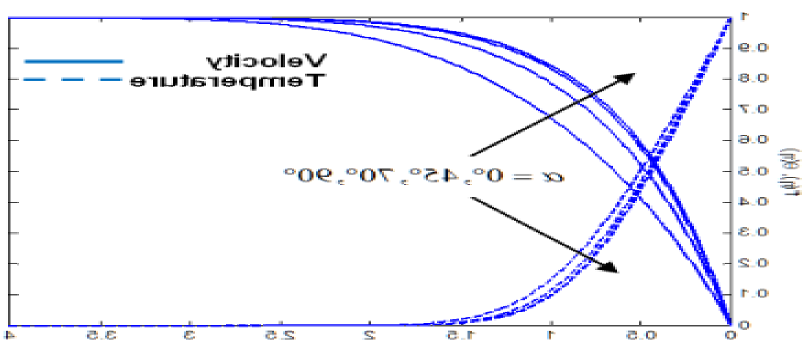

Fig. : Effect of aligned magnetic field parameters on the velocity and temperature profiles.

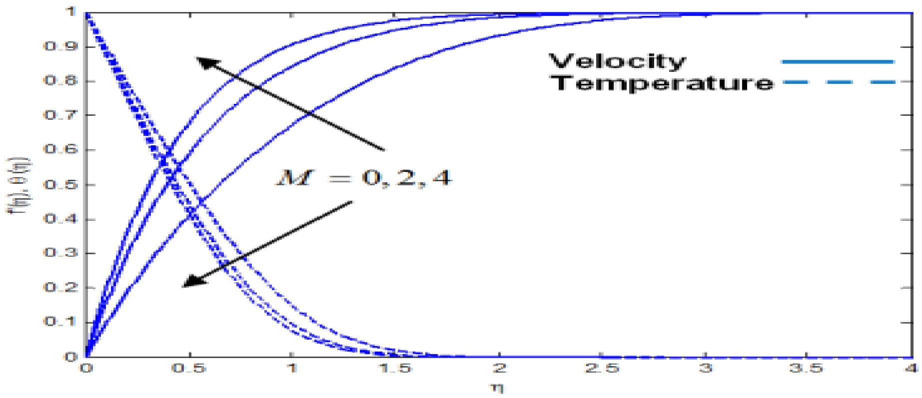

Fig. : Effect of magnetic strength parameters on the velocity and temperature profiles.
Figure**s** represent the impact of magnetic field parameter on temperature and velocity force. It is obvious that the momentum boundary layer width decreases with the increasing values of magnetic field parameter and also a turn down occurs in the thermal boundary layer. Must the restraint of Lorentz force be less, disapproval in temperature occur and results in the growth of velocity field with progressive values for magnetic field parameters.
Figure shows the effect of thermal buoyancy parameter on velocity and temperature. As λ_T rises, velocity also increases and momentum boundary layer decrease. The temperature profile and thermal boundary layer decreases with rises in λ_T.

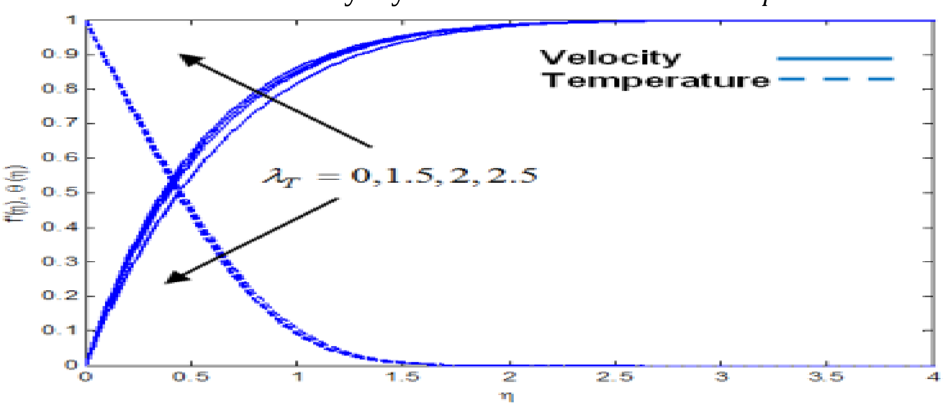

Fig. : Effect of thermal buoyancy on the velocity and temperature profiles.
Figure shows the dimensionless velocity and temperature profiles. The resistance force inside the fluid can be raise by rising nanoparticle volume fraction constraint. As a result, there is a decrease in velocity field. Rising the volume fraction parameter fallout in temperature profile escalation. The thermal conductivity of the nanofluid can be enhanced by spiraling the nanoparticle's volume fraction due to thicken of thermal boundary layer. A key parameter is the volume fraction that plays a decisive role in ornamental fluids' heat distinctiveness. In many trade processes, the nanoparticle volume fraction is adapted to organize the temperature.

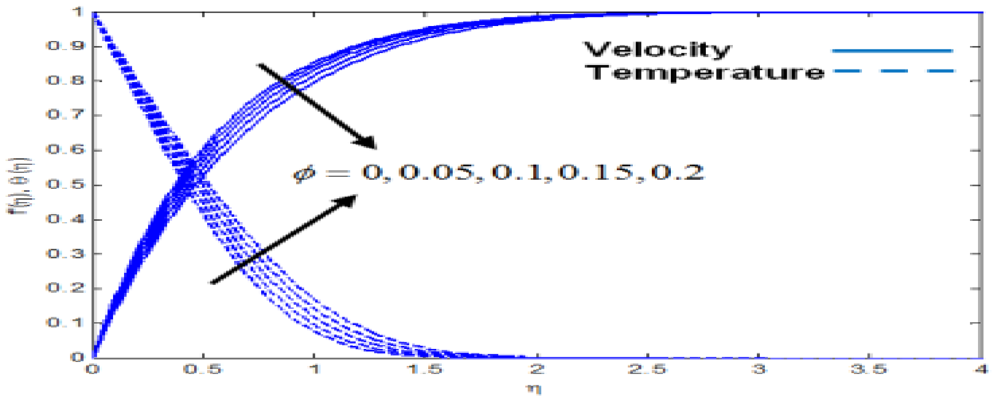

Fig. : Effect of volume fraction of nanoparticles on the velocity and temperature profiles.
Table presents the deviation happening in skin friction coefficient and Nusselt number for diverse α, M, ∅ and λ_T ethics valid to diverse hold movements. It could be obviously seen that all parameters, α, M, ∅, λ_T had an enhance outcome on the resistance aspect coefficients. The uppermost value could be seen for the case when M was modified. An improvement was seen in the heat transport rates with modifing values of λ_T, α, M and ∅ . The highest worth could be seen for the case when ∅ was diverse.

Table : Deviation in skin friction and Nusselt number coefficient for diverse values of ∅, λ_T, α, M.

α	M	∅	λ_T	Skin Friction	Nusselt Number
0^0	2	0.05	1.5	1.143526	1.129088
45^0				1.592587	1.230751
70^0				1.858815	1.279309
90^0				1.932249	1.291548
90^0	0	0.05	1.5	1.143526	1.129088
	2			1.932249	1.291548
	4			2.467423	1.369058
90^0	2	0	1.5	1.791521	1.223356
		0.05		1.932249	1.291548
		0.10.2		2.090146	1.359083
		0.15		2.268591	1.426010

		0.2		2.471866	1.492338
90^0	2	0.05	0	1.699821	1.254008
			1.5	1.932249	1.291548
			2.0	2.007934	1.303332
			2.5	2.082806	1.314791

Conclusion

1.The increase of α, M and λ_T was observed with the increase of fluid flow.
2. The increase of ∅ was observed with decrease of fluid velocity.
3. Increase of dimensionless temperature was observed with the increase of ∅.
4. Decrease of dimensionless temperature was observed with the increase of α, M and λ_T.
5. Increased in λ_T, M, α and ∅ was leads to augmented local skin friction coefficient.
6. The increase of λ_T, M, α and ∅ leads to progression and improvement of rate of heat transfer.

Acknowledgement
No authors have conflict of interest.

References:

1. Sulochana, C., Samrat, S. P., & Sandeep, N. (2016). Thermal radiation effect on MHD nanofluid flow over a stretching sheet. In *International Journal of Engineering Research in Africa* (Vol. 23, pp. 89-102). Trans Tech Publications Ltd.
2. Babu, K. S., Parandhama, A., & Vijaya, R. B. (2021). Non-linear MHD convective flow of Carreau nanofluid over an exponentially stretching surface with activation energy and viscous dissipation. *SN Applied Sciences*, *3*(3), 382.
3. Mishra, A., & Kumar, M. (2020). Thermal performance of MHD nanofluid flow over a stretching sheet due to viscous dissipation, Joule heating and thermal radiation. *International Journal of Applied and Computational Mathematics*, *6*(4), 123.
4. Farooq, U., Lu, D., Munir, S., Ramzan, M., Suleman, M., & Hussain, S. (2019). MHD flow of Maxwell fluid with nanomaterials due to an exponentially stretching surface. *Scientific reports*, *9*(1), 7312.
5. Hussain, S., Rasheed, K., Ali, A., Vrinceanu, N., Alshehri, A., & Shah, Z. (2022). A sensitivity analysis of MHD nanofluid flow across an exponentially stretched surface with non-uniform heat flux by response surface methodology. *Scientific Reports*, *12*(1), 18523.

6. Mansur, S., Ishak, A., & Pop, I. (2015). The magnetohydrodynamic stagnation point flow of a nanofluid over a stretching/shrinking sheet with suction. *PLoS one*, *10*(3), e0117733.
7. Barik, A. K., Mishra, S. K., Mishra, S. R., & Pattnaik, P. K. (2020). Multiple slip effects on MHD nanofluid flow over an inclined, radiative, and chemically reacting stretching sheet by means of FDM. *Heat Transfer—Asian Research*, *49*(1), 477-501.
8. Narayana, P. V., Akshit, S. M., Ghori, J. P., & Venkateswarlu, B. (2017). Thermal radiation effects on an unsteady MHD nanofluid flow over a stretching sheet with non-uniform heat source/sink. *Journal of Nanofluids*, *6*(5), 899-907.
9. Govindaraju, M., Saranya, S., Hakeem, A. A., Jayaprakash, R., & Ganga, B. (2015). Analysis of slip MHD nanofluid flow on entropy generation in a stretching sheet. *Procedia Engineering*, *127*, 501-507.
10. Haroun, N. A., Mondal, S., & Sibanda, P. (2017). Effects of thermal radiation on mixed convection in a MHD nanofluid flow over a stretching sheet using a spectral relaxation method. *International Journal of Mathematical and Computational Sciences*, *11*(2), 52-61.
11. Anwar, M. I., Firdous, H., Zubaidi, A. A., Abbas, N., & Nadeem, S. (2022). Computational analysis of induced magnetohydrodynamic non-Newtonian nanofluid flow over nonlinear stretching sheet. *Progress in Reaction Kinetics and Mechanism*, *47*, 14686783211072712.
12. Tarakaramu, N., & Narayan, P. S. (2017, November). Unsteady MHD nanofluid flow over a stretching sheet with chemical reaction. In *IOP Conference Series: Materials Science and Engineering* (Vol. 263, No. 6, p. 062030). IOP Publishing.
13. Khan, M., Shahid, A., Malik, M. Y., & Salahuddin, T. (2018). Thermal and concentration diffusion in Jeffery nanofluid flow over an inclined stretching sheet: A generalized Fourier's and Fick's perspective. *Journal of Molecular Liquids*, *251*, 7-14.
14. Ali, B., Nie, Y., Khan, S. A., Sadiq, M. T., & Tariq, M. (2019). Finite element simulation of multiple slip effects on MHD unsteady maxwell nanofluid flow over a permeable stretching sheet with radiation and thermo-diffusion in the presence of chemical reaction. *Processes*, *7*(9), 628.
15. Babu, D. H., Ajmath, K. A., Venkateswarlu, B., & Narayana, P. V. (2019). Thermal radiation and heat source effects on MHD non-Newtonian nanofluid flow over a stretching sheet. *Journal of Nanofluids*, *8*(5), 1085-1092.
16. Ullah, A., Shah, Z., Kumam, P., Ayaz, M., Islam, S., & Jameel, M. (2019). Viscoelastic MHD nanofluid thin film flow over an unsteady vertical stretching sheet with entropy generation. *Processes*, *7*(5), 262.
17. Reddy, J. R., Sugunamma, V., Sandeep, N., & Kumar, K. A. (2016). Influence of non uniform heat source/sink on MHD nano fluid flow past a slendering stretching sheet with slip effects. *The Global Journal of Pure and Applied Mathematics (GJPAM)*, *12*(1), 247-254.

18. Rawat, S. K., Pandey, A. K., & Kumar, M. (2018). Effects of chemical reaction and slip in the boundary layer of MHD nanofluid flow through a semi-infinite stretching sheet with thermophoresis and Brownian motion: the lie group analysis. *Nanoscience and Technology: An International Journal*, *9*(1).
19. Khan, S. A., Nie, Y., & Ali, B. (2019). Multiple slip effects on magnetohydrodynamic axisymmetric buoyant nanofluid flow above a stretching sheet with radiation and chemical reaction. *Symmetry*, *11*(9), 1171.
20. Sibanda, P., Almakki, M., Mburu, Z., & Mondal, H. (2022). Entropy Optimization in MHD Nanofluid Flow over an Exponential Stretching Sheet. *Applied Sciences*, *12*(21), 10809.
21. Sandeep, N., & Kumar, J. (2016). Heat and mass transfer in nanofluid flow over an inclined stretching sheet with volume fraction of dust and nanoparticles. *Journal of Applied Fluid Mechanics*, *9*(5), 2205-2215.
22. Sravanthi, C. S., & Gorla, R. S. R. (2018). Effects of heat source/sink and chemical reaction on MHD Maxwell nanofluid flow over a convectively heated exponentially stretching sheet using homotopy analysis method. *International Journal of Applied Mechanics and Engineering*, *23*(1).
23. Rasool, G., Shafiq, A., Hussain, S., Zaydan, M., Wakif, A., Chamkha, A. J., & Bhutta, M. S. (2022). Significance of Rosseland's radiative process on reactive Maxwell nanofluid flows over an isothermally heated stretching sheet in the presence of Darcy–Forchheimer and Lorentz forces: Towards a new perspective on Buongiorno's model. *Micromachines*, *13*(3), 368.
24. Awan, A. U., Abid, S., & Abbas, N. (2020). Theoretical study of unsteady oblique stagnation point based Jeffrey nanofluid flow over an oscillatory stretching sheet. *Advances in Mechanical Engineering*, *12*(11), 1687814020971881.
25. Ali, A., Khan, H. S., Saleem, S., & Hussan, M. (2022). EMHD Nanofluid Flow with Radiation and Variable Heat Flux Effects along a Slandering Stretching Sheet. *Nanomaterials*, *12*(21), 3872.
26. Venkata Ramudu, A. C., Anantha Kumar, K., Sugunamma, V., & Sandeep, N. (2020). Heat and mass transfer in MHD Casson nanofluid flow past a stretching sheet with thermophoresis and Brownian motion. *Heat Transfer*, *49*(8), 5020-5037.
27. Kumar, G. V., Varma, S. V. K., & Kumar, R. V. M. S. S. K. (2019). Unsteady three-dimensional MHD nanofluid flow over a stretching sheet with variable wall thickness and slip effects. *International Journal of Applied Mechanics and Engineering*, *24*(3), 709-724.
28. Ahmad, R., & Khan, W. A. (2015). Unsteady heat and mass transfer magnetohydrodynamic (MHD) nanofluid flow over a stretching sheet with heat source–sink using quasi-linearization technique. *Canadian Journal of Physics*, *93*(12), 1477-1485.

29. Sandeep, N., Sathish Kumar, M., & Rushi Kumar, B. (2017). Free convective heat transfer of MHD dissipative Carreau nanofluid flow over a stretching sheet. *Frontiers in Heat and Mass Transfer (FHMT), 8*.
30. Mondal, S., Oyelakin, I. S., & Sibanda, P. (2017). Unsteady MHD three-dimensional Casson nanofluid flow over a porous linear stretching sheet with slip condition. *Frontiers in heat and mass transfer (FHMT), 8*.
31. Ali, B., Yu, X., Sadiq, M. T., Rehman, A. U., & Ali, L. (2020). A finite element simulation of the active and passive controls of the MHD effect on an axisymmetric nanofluid flow with thermo-diffusion over a radially stretched sheet. *Processes*, *8*(2), 207.
32. Khan, N. S., Gul, T., Islam, S., Khan, A., & Shah, Z. (2017). Brownian motion and thermophoresis effects on MHD mixed convective thin film second-grade nanofluid flow with Hall effect and heat transfer past a stretching sheet. *Journal of Nanofluids*, *6*(5), 812-829.
33. Nandkeolyar, R., Mahatha, B. K., Mahato, G. K., & Sibanda, P. (2018). Effect of chemical reaction and heat absorption on MHD nanoliquid flow past a stretching sheet in the presence of a transverse magnetic field. *Magnetochemistry*, *4*(1), 18.
34. Madhu, M., & Kishan, N. (2015). Finite element analysis of MHD viscoelastic nanofluid flow over a stretching sheet with radiation. *Procedia Engineering*, *127*, 432-439.
35. Mohanty, B., Jena, S., & Pattnaik, P. K. (2019). MHD nanofluid flow over stretching/shrinking surface in presence of heat radiation using numerical method. *International Journal on Emerging Technologies*, *10*(2), 119-125.
36. Rasool, G., Shafiq, A., Alqarni, M. S., Wakif, A., Khan, I., & Bhutta, M. S. (2021). Numerical scrutinization of Darcy-Forchheimer relation in convective magnetohydrodynamic nanofluid flow bounded by nonlinear stretching surface in the perspective of heat and mass transfer. *Micromachines*, *12*(4), 374.
37. Shahid, A., Zhou, Z., Bhatti, M. M., & Tripathi, D. (2018). Magnetohydrodynamics nanofluid flow containing gyrotactic microorganisms propagating over a stretching surface by successive Taylor series linearization method. *Microgravity Science and Technology*, *30*, 445-455.
38. Khidir, A., & Sibanda, P. (2014). Effect of temperature-dependent viscosity on MHD mixed convective flow from an exponentially stretching surface in porous media with cross-diffusion. *Special Topics & Reviews in Porous Media: An International Journal*, *5*(2).
39. Al-Mamun, A., Arifuzzaman, S. M., Reza-E-Rabbi, S., Biswas, P., & Khan, M. S. (2019). Computational modelling on MHD radiative Sisko nanofluids flow through a nonlinearly stretching sheet. *International Journal of Heat and Technology*, *37*(1), 285-295.

40. Mabood, F., Khan, W. A., & Ismail, A. M. (2015). MHD boundary layer flow and heat transfer of nanofluids over a nonlinear stretching sheet: a numerical study. *Journal of Magnetism and Magnetic Materials*, *374*, 569-576.

41. Pavlov, K. B. (1974). Magnetohydrodynamic flow of an incompressible viscous fluid caused by deformation of a plane surface. *Magnitnaya Gidrodinamika*, *4*(1), 146-147.
42. A Pantokratoras. Some Exact Solutions of Boundary Layer Flows along a Vertical Plate with Buoyancy Forces Combined with Lo-rentz Forces under Uniform Suction, *Mathematical Problems in Engineering*, (2008).
43. Ahmad, Rashid and Waqar Ahmed Khan. Effect of viscous dissipa-tion and internal heat generation/absorption on heat transfer flow over a moving wedge with convective boundary condition, Heat *Transfer—Asian Research*, 42,7, (2013),589-602.
44. HT Lin and LK Lin. Similarity solutions for laminar forced convec-tion heat transfer from wedges to fluids of any Prandtl number, *In-ternational Journal of Heat and Mass Transfer*, 30, 6, (1987), 1111-1118.
45. Ahmad, Kartini, Zahir Hanouf, and Anuar Ishak. MHD Casson nanofluid flow past a wedge with Newtonian heating, *European Physical Journal Plus*, 132, 2, (2017), 87.
46. Ahmad, Kartini, Zahir Hanouf, and Anuar Ishak. MHD Casson nanofluid flow past a wedge with Newtonian heating, *European Physical Journal Plus*, 132, 2, (2017), 87.
47. F Oztop and Eiyad Abu-Nada. Numerical study of natural convec-tion in partially heated rectangular enclosures filled with nanoflu-ids, *International Journal of Heat and Fluid Flow,* 29, 5, (2008), 1326-1336.
48. Mojumder, Satyajit et al. Effect of magnetic field on natural con-vection in a C-shaped cavity filled with ferrofluid, *Procedia Engi-neering,* 105, (2015), 96-104.
49. [20] M Sheikholeslami, DD Ganji, & Mohammad Mehdi Rashidi. Fer-rofluid flow and heat transfer in a semi annulus enclosure in the presence of magnetic source considering thermal radiation, *Journal of the Taiwan Institute of Chemical Engineers,* 47, (2015), 6-17.
50. T Cebeci & P Bradshaw, *Physical and Computational Aspects of Convective Heat Transfer*, 1st ed., Springer Verlag, (1984).