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Magnetohydrodynamic Nanofluid Flows Passing through a Smart Fabric under the Influence of Magnetic Field and Radiative Flux

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ABSTRACT

The study of MHD have been widely on topics with complex problems. Just as this topic involves inductive polymers or smart fabrics for engineering in machinery or protective equipment. The smart fabrics can be involved in MHD studies become a useful material. The smart fabric is a sheet of inductive polymer that can be an influence in the MHD analysis as well as a parameter that can be considered. In this study, the MHD of nanofluid namely Iron-(III)-oxide flows past in smart fabrics under influence of magnetic field and radiative flux is studied by constructing a mathematical model and then the model solved numerically using the Keller-Box scheme. The effect of Mixed Convection and stretching parameter is considered on the model. Numerical simulations were carried out to examine the effect of the parameters, are obtained the profile of velocity and temperature increase when the magnetic and stretching parameters increases, the velocity profile and temperature decreases when the Prandtl number are increases, the profiles of velocity are decreases and temperature increases when porosity variable and volume fraction parameter's value increases, and the profile of temperature increase when the mixed convection's value and the radiation parameter increases.

1. Introduction

Various phenomena in nature both in the fields of chemistry, biology, and physics can be made by mathematical models [1]. In the analysis, the theory that needs to be used to support the proof that a mathematical equation represents the phenomenon. In the phenomenon of mass transfer or heat transfer, for example, a mathematical model of fluid flow can then be formed. In fluid flow, it is necessary to carry out a basic analysis of the model formation and its solution. Fluid flow models such as type fluid or flow on influence built through continuity equations, mass conservation equations, energy equations, and several supporting theories can form a mathematical model that represents fluid phenomena which can then be called type fluids or magnetohydrodynamics.

Magnetohydrodynamic (MHD) is studied about the relation of fluid flow and magnetic fields [2]. Magnetohydrodynamics is a magnetic field can induce an electric in a moving conductive liquid, which in turn polarizes the liquid and reciprocally changes the magnetic field itself [3-11].

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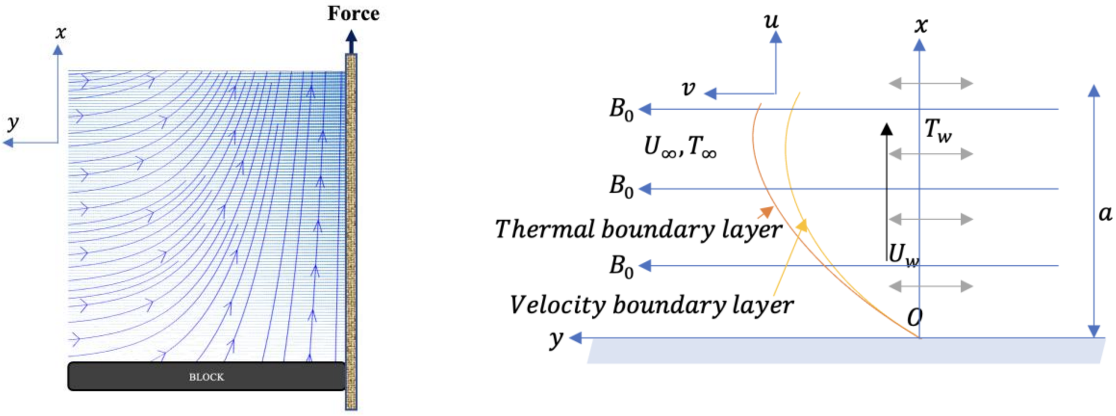
Magnetohydrodynamics is an important in generator applications with engineering and industrial applications such as magnetohydrodynamics, nuclear reactor reactors, crystallization of ship propulsion engines, manufacture of type protective polymer materials [4].

Fluids that can be induced by electric current and are conductive are mixed fluids such as molten metal, plasma (ionized gas), and strong electrolyte fluids. Liquids such as molten metal have metal particles whose size is so small that they are commonly called nanofluids (nanofluids). Nanofluids are liquids or solutions containing nano-sized particles, which have a very small size of 1-100 nm which can also be present in basic fluids such as water [12,13]. Nano effect fluid with the aim of being able to play a role in the performance of the fluid, so that the addition of these particles can be useful as a catalyst in terms of temperature or vice versa, increasing the surface heat transfer that occurs and the heat transfer that occurs [7]. The use of liquid metals or nanofluids in the case of MHD, has been widely developed such as Ferrofluid, Lithium, Iron or Aluminum Mixtures, and so on. The media or objects studied in the fluid flow that pass through it have also been carried out by several researchers, such as solid sphere by Mardianto *et al.,* [6], Norasia *et al.,* [7], Rumite *et al.,* [9] and Mat *et al.,* [11], porous cylinder by Widodo *et al.,* [10], Ellahi *et al.,* [14] and Widodo *et al.,* [15], Sliced ball by Widodo [4] and Nursalim *et al.,* [16], porous sliced ball in Widodo *et al.,* [2], and the stretched sheet or the plate by Alizadeh-Pahlavan and Borjian-Boroujeni [17], Chaudhary and Kumar [18], Nield and Kuznetsov [19], Pantzali *et al.,* [20], and Zainal *et al.,* [21].

The focus of this research is on the stagnation point $y \approx 0$ of the boundary layer formed from a fluid flow that moves vertically from bottom to top through the surface of an inductive polymer or smart fabric, then used various concepts of the laws of physics. Then we can build continuity equations, momentum equations, and energy equations. In the method section, the Keller-box scheme of numerical method is used, which is an implicit numerical method for the mathematical model of magnetohydrodynamics in a boundary layer flowing through a vertically stretched smart fabric under the influence of a magnetic field and radiation flux. investigations for parameter variations were carried out on numerical simulations and their analysis for variations of several parameters on velocity and temperature profile.

2. Mathematical Model

Several assumptions were made, the nanofluid flowing at a constant velocity U_∞ and constant temperature T_∞ in a magnetic field space, initially not magnetized but after the surface of the conductive polymer is stretched vertically upwards with velocity in the wall is $U_w(x) = U_\infty\left(c\nu_f\right)^{\frac{1}{2}}x$, a magnetic induction event occurs, so that the fluid initially not magnetized, after passing through the magnetic field around the surface of the smart fabrics becomes magnetically charged. The focus of this research is at the stagnation point $y \approx 0$ of the boundary layer which is formed from a fluid flow that moves vertically from bottom to top through the surface of a smart fabrics, then various concepts of the laws of physics are used. From these laws, the continuity equations, momentum equations, and energy equations can be formed. To construct the model of problem, briefly the illustrate of smart fabrics are shown by Figure 1 where the smart fabrics is vertical stretched by a force.



(a) (b)

Fig. 1. Illustration of the (a) smart fabrics and (b) the coordinates systems

The form of mathematical model that represents magnetohydrodynamics phenomena. We consider the dimensional mathematical model as:

Continuity equation:

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

Momentum equation:

$$\rho_{fn}\left(\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}}+\bar{v}\frac{\partial \bar{u}}{\partial \bar{y}}\right)=\mu_{fn}\frac{\partial^2 \bar{u}}{\partial \bar{y}^2}-\left(\sigma B_0^2-\frac{\mu_{fn}}{K}\right)\bar{u}+g_{\bar{x}}\beta(\bar{T}-T_\infty). \tag{2}$$

Energy equation:

$$\rho c_p\left(\bar{u}\frac{\partial \bar{T}}{\partial \bar{x}}+\bar{v}\frac{\partial \bar{T}}{\partial \bar{y}}\right)=k\left(\frac{\partial^2 \bar{T}}{\partial \bar{x}^2}+\frac{\partial^2 \bar{T}}{\partial \bar{y}^2}\right)+\frac{16\sigma^* T_\infty^3}{3k^*}\left(\frac{\partial^2 \bar{T}}{\partial \bar{x}^2}+\frac{\partial^2 \bar{T}}{\partial \bar{y}^2}\right) \tag{3}$$

where the boundary condition in dimensional

$\bar{u}=0, \bar{v}=0, \bar{T}=T_w$, for $\bar{x}=0$

$\bar{u}=U_\infty, \bar{v}\to 0, \bar{T}\to T_\infty$, for $\bar{x}\to\infty$.

The previous mathematical form is dimensional equation, so we have to transform the form to dimensionless equation with non-dimensional parameter [4]. The parameters non-dimensional is:

$x=\frac{\bar{x}}{a}, y=\frac{Re^{\frac{1}{2}}\bar{y}}{a}, u=\frac{\bar{u}}{U_\infty}, v=\frac{Re^{\frac{1}{2}}\bar{v}}{U_\infty}, Re=\frac{U_\infty a}{\nu_{fn}}, \nu_{fn}=\frac{\mu_{fn}}{\rho_{fn}}, g=\frac{g_{\bar{x}}}{cU_\infty}$, dan $\theta=\frac{\bar{T}-T_\infty}{T_w-T_\infty}$

the momentum equation is

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu_{fn}\zeta^*\frac{\partial^2 u}{\partial x^2}-(M-\phi)\,u+\omega^*\theta \tag{4}$$

then the Energy Equation is

$$u\frac{\partial\theta}{\partial x}+v\frac{\partial\theta}{\partial y}=\frac{\zeta^*}{Pr}\varrho\left(\kappa+\frac{4}{3}Rn\right)\left(\frac{\partial^2\theta}{\partial x^2}+Re\frac{\partial^2\theta}{\partial y^2}\right) \tag{5}$$

with magnetic parameter $M=\frac{a\sigma B_0^2}{U_\infty\rho_{fn}}$, porosity parameter $\phi=\frac{a\mu_{fn}}{U_\infty\rho_{fn}K}$, Prandtl number $Pr=\frac{\nu_{fn}(\rho C_p)_f}{k_f}$, density ratio $\varrho=\frac{(\rho C_p)_f}{(\rho C_p)_{fn}}$, thermal conductivity $\kappa=\frac{k_{fn}}{k_f}$, and radiation parameter $Rn=\frac{4\sigma^*T_\infty^3}{k^*k_f}$ and constant $\zeta^*=\frac{1}{aU_\infty}$, $\omega^*=\frac{gca\beta(T_w-T_\infty)}{U_\infty\rho_{fn}}$

where the boundary condition in non-dimensional equation

$u=0$, $T=T_w$, for $x=0$

$u=U_\infty \qquad T\to T_\infty$, for $x\to\infty$

The non-dimensional from Eq. (4) and Eq. (5) then these equations are converted into a similarity equation using the stream function. This is because the non-linear system of partial differential equations to be transformed into a non-linear system of ordinary differential equations [3,22]. Then it is easier to solve numerically by similarity equation

$$\psi=U_\infty\left(c\nu_f\right)^{\frac{1}{2}}ayf(\eta)\,, \qquad \eta=\left(\frac{c}{\nu_f}\right)^{\frac{1}{2}}ax, \qquad u=\frac{\partial\psi}{\partial y}, \qquad v=-\frac{\partial\psi}{\partial x}$$

With the mixed convection parameter $\gamma=\frac{Gr}{Re^2}$, $\lambda=\frac{\gamma}{ca^2\nu_f\left(\frac{c}{\nu_f}\right)^{\frac{1}{2}}}$, Parameter $\vartheta=\frac{1}{U_\infty c^2a}$, and constant $\zeta=\frac{\zeta^*}{U_\infty ca}=\frac{1}{{U_\infty}^2ca^2}$ to momentum equation will be

$$ff'=\frac{\nu_{nf}}{\nu_f}\zeta f''-(M-\phi)\vartheta f+\lambda\theta \tag{6}$$

and the energy equation is

$$f\theta'-\lambda\frac{1}{Pr}\varrho\left(\kappa+\frac{4}{3}Rn\right)\theta''=0 \tag{7}$$

For the several parameters, we use approximation of kinematic viscosity ratio, the density and the ratio of thermal conductivity for χ is volume fraction parameter [4]

$$\rho_{fn}=(1-\chi)\rho_f+\chi\rho_s$$

$$\mu_{fn}=\frac{\mu_f}{(1-\chi)^{2.5}}$$

$$\left(\rho C_p\right)_{fn}=(1-\chi)\left(\rho C_p\right)_f+\chi\left(\rho C_p\right)_s$$

$$\frac{k_{fn}}{k_f}=\frac{(k_s+k_f)-2\chi(k_f-k_s)}{(k_s+2k_f)+\chi(k_f-k_s)}$$

$$\frac{\nu_{nf}}{\nu_f}=\frac{1}{(1-\chi)^{2.5}\left((1-\chi)+\chi\left(\frac{\rho_s}{\rho_f}\right)\right)}$$

for the boundary condition for similarity equation

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

$$f'(\eta)=0, \qquad \theta(\eta)=0, \eta\to\infty$$

3. Method

To understand and solve this problem, a mathematical model was constructed. This mathematical model is built using the principles of conservation of mass, momentum, energy, and Maxwell's equations. From these Maxwell's principles and equations, the dimensional governing equations for continuity, momentum, and energy of nanofluids are obtained. These dimensional governing equations are then transformed into dimensionless governing equations using the appropriate dimensionless variables [10]. Furthermore, the stream function is introduced to express a function that represents the flow velocity and fluid temperature [2]. Then, similarity variables are used to reduce the non-dimensional governing equations into a system of non-linear differential equations. The system of non-linear differential equations is then solved numerically using the Keller-Box implicit numerical scheme [23]. From this numerical solution/simulation, the effect of radiation, mixed convection, porosity, strain, Prandtl number and magnetic field is analyzed on changes in flow velocity and fluid temperature on the surface of the smart fabric.

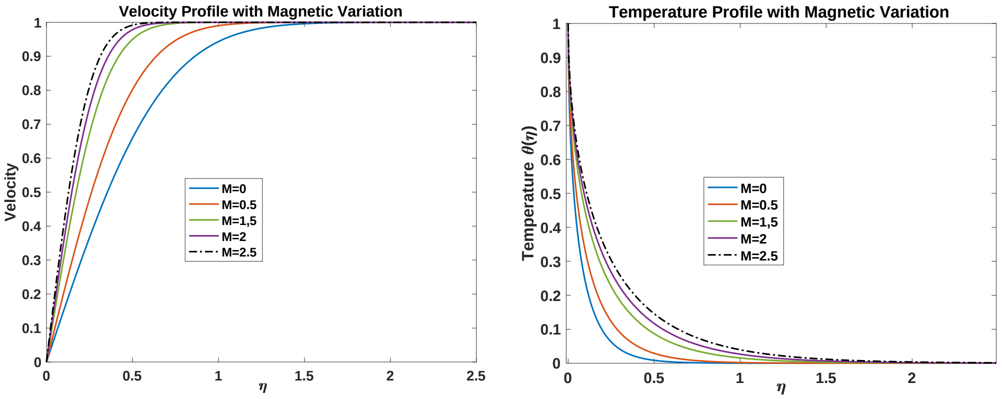
4. Results and Discussion

Before simulation the thermophysical properties of water and iron-(III)-oxide (Fe_2O_3) are given in Table 1. In the analysis, the similarity equation has been solved and the results are shown in this section. The several parameters also considered by different value and these results have been made at fixed values every parameter except for parameter that variety.

Table 1
Thermo-physical properties of water and iron-(III)-oxide (Fe_2O_3) [24-26]

	Water	Fe_2O_3
Density (kg/m^3)	997.1	5260
Thermal Conductivity (W/mK)	0.613	0.58
Specific Heat (j/kgK)	4179	103.9
$\beta \times 10^5$ (K^{-1})	21	1.25
Electrical conductivity (σ)	0.05	2700

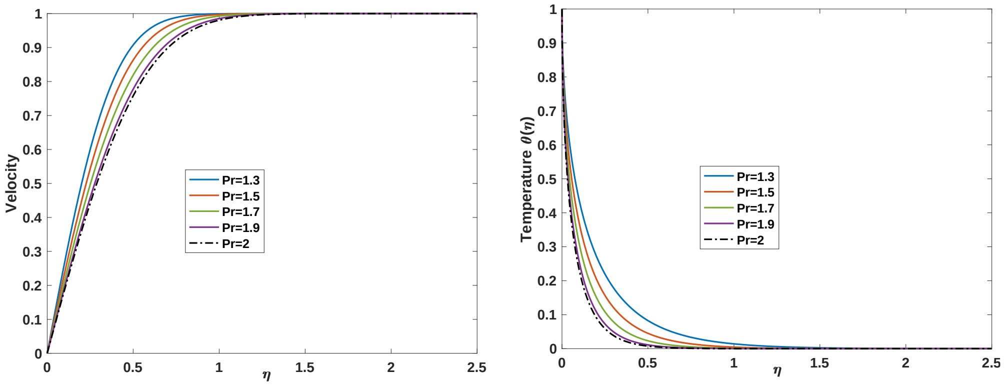
For variation of magnetic parameters $M=0$, $M=0.5$, $M=1.5$, $M=2.5$, and $M=2$, it can be seen in Figure 2 that with increasing magnetic parameter value, the velocity profile are increases and the temperature value profile also increases. This situation occurs because as the magnetic field parameter increases, the magnetic field in the area increases as a result, the greater the magnetic parameter is cause greater the attractiveness of the smart fabrics to the fluid. For the temperature profile is caused by the influence of particle friction, namely the occurrence of nanoparticle collisions so that the fluid temperature increases with increasing magnetic parameter.



(a) (b)

Fig. 2. Graph of velocity profile (a) and Temperature (b) for the Magnetic parameter is variety

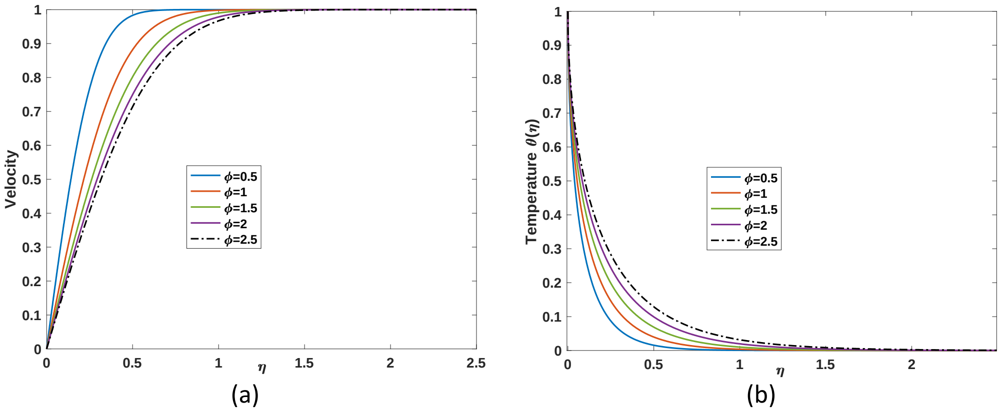
For variation of Prandtl Number $Pr = 1.3$, $Pr = 1.5$, $Pr = 1.7$, $Pr = 1.9$, and $Pr = 2$, it can be seen in Figure 3 that with increasing Prandtl Number value, the velocity profile are decreases and the temperature value profile also decreases, because the Prandtl number is inversely proportional to the thermal diffusivity parameter and directly proportional to the kinematic viscosity. Therefore, the greater the Prandtl number, the greater the value of the kinematic viscosity of the fluid so that the viscosity of the fluid increases. This means that the greater the Prandtl number, the velocity and temperature profile is decreases.



(a) (b)

Fig. 3. Graph of velocity profile (a) and Temperature (b) for the Prandtl Number is variety

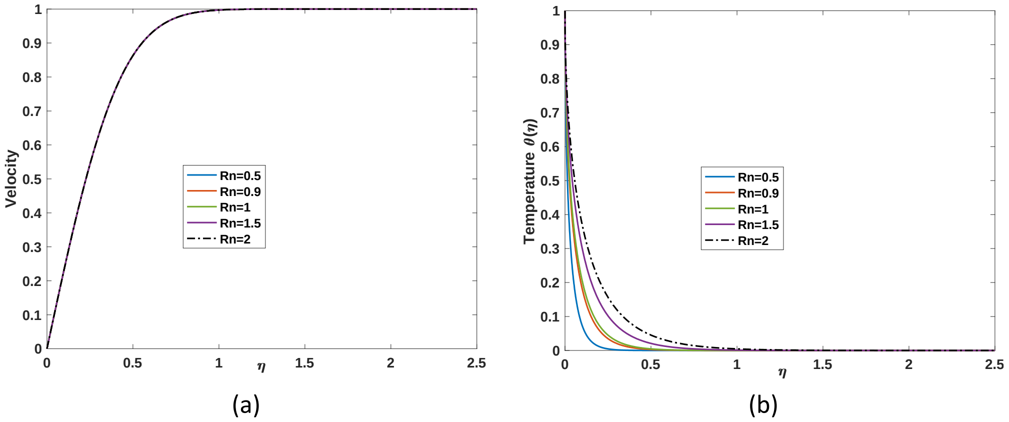
For variation of Porosity parameters $\phi = 0.5$, $\phi = 1$, $\phi = 1.5$, $\phi = 2$, and $\phi = 2.5$, it can be seen in Figure 4 that with increasing porosity parameter value, the velocity profile are increases and the temperature value profile also increases. This situation occurs because the porosity parameter is directly proportional to the dynamic viscosity of the nanofluid and inversely proportional to the density of the nanofluid. Then according to the Darcy model that was previously introduced, the porosity parameter is related to the permeability value or to the relationship between permeability and velocity, namely the greater the permeability value, the lower the velocity value. on the temperature profile due to the increased level of viscosity resulting in increased friction.



(a) (b)

Fig. 4. Graph of velocity profile (a) and Temperature (b) for the Porosity parameter is variety

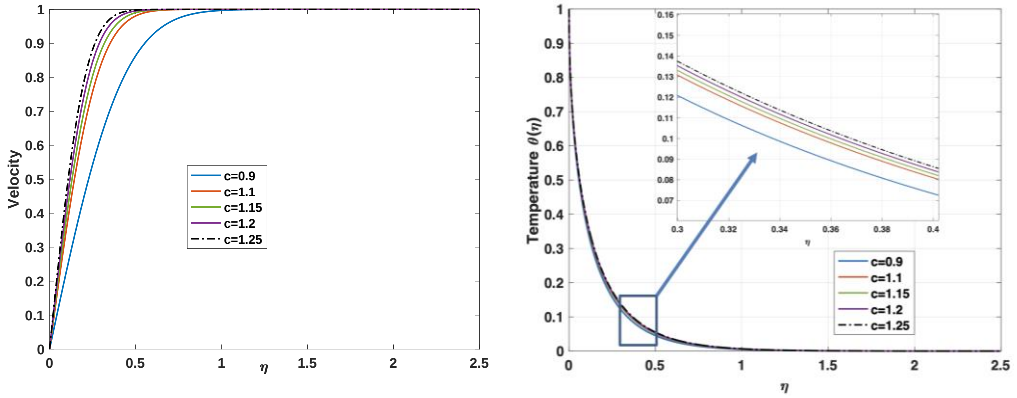
For variation of radiation parameters $Rn = 0.5$, $Rn = 0.9$, $Rn = 1$, $Rn = 1.5$, and $Rn = 2$, it can be seen in Figure 5 that with increasing radiation parameter value, the velocity profile is not change and the temperature value profile also increases. The radiative parameter is the dominant level relation of the heat source, if the radiative parameter is large, the heat source is more dominant by the influence of radiation and vice versa if the radiation parameter is small, the heat source is more dominant than the conductivity of the medium. The conductivity property is not directly related to the viscosity level of the fluid, but it does not mean that it affects the friction level and fluid velocity because the radiation parameter only gives the level of dominance of the heat source so that it directly affects the temperature value.



(a) (b)

Fig. 5. Graph of temperature for the Radiation parameter is variety

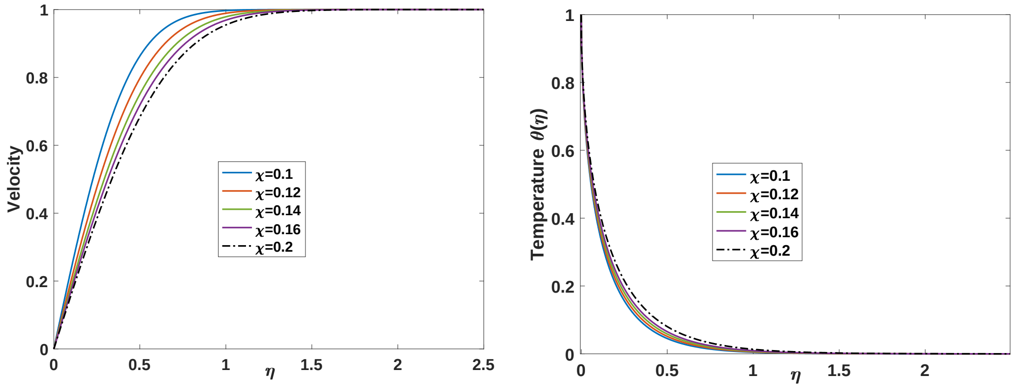
For variation of Stretching parameters $c = 0.9$, $c = 1.1$, $c = 1.15$, $c = 1.2$, and $c = 1.25$, it can be seen in Figure 6 that with increasing Stretching parameter value, the velocity profile are increases and the temperature value profile also increases. This situation occurs because the stretching properties of the fabric sheet cause the velocity value at the boundary layer to increase due to the strain properties which are directly proportional to the velocity of the fabric sheet. The strain properties are also identical to the porosity properties so that the simulation results also have the same effect on the velocity and temperature profiles. So that the graph of the relationship between the strain parameter with the velocity and temperature profile is a straight comparison with the properties of the porosity parameter.



(a) (b)

Fig. 6. Graph of velocity profile (a) and Temperature (b) for the Stretching Parameter is variety

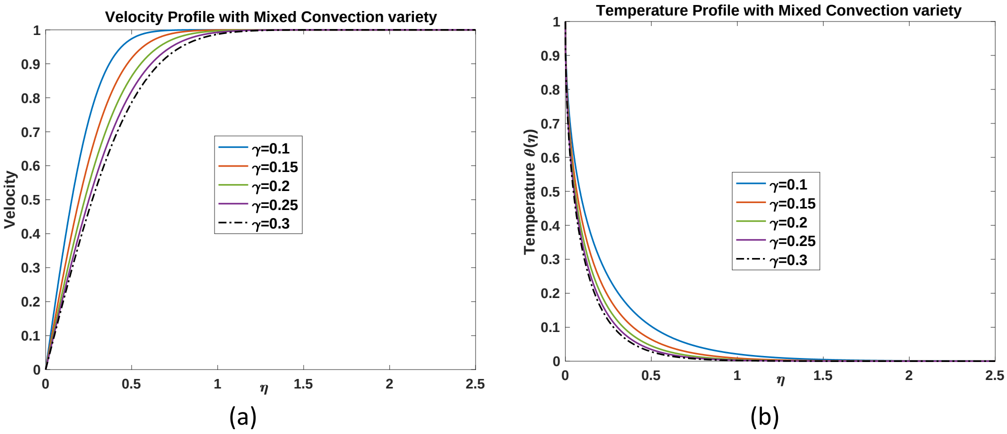
For variation of volume fraction parameters $\chi = 0.1, \chi = 0.12, \chi = 1.14, \chi = 0.16$, and $\chi = 0.2$, it can be seen in Figure 7 that with increasing volume fraction parameter value, the velocity profile are increases and the temperature value profile also increases, because the volume fraction is related to the nature of the mixture of nanofluids and base fluids. These properties affect the viscosity of nanofluids so that if the viscosity of the fluid is greater, the friction level on the cloth sheet will be greater, resulting in a decrease in the velocity value and the frictional properties also result in an increase in energy or an increase in temperature for the volume fraction parameter value which also increases.



(a) (b)

Fig. 7. Graph of velocity profile (a) and Temperature (b) for the Volume Fraction Parameter is variety

For variation of mixed convection parameters $\gamma = 0.1, \gamma = 0.15, \gamma = 0.2, \gamma = 0.25$, and $\gamma = 0.3$, by the Figure 8 is show that with increasing mixed convection parameter value, the velocity profile are increases and the temperature value profile also increases. This situation occurs because as the location of the heat source is close to stagnation point so the density is decreases and velocity increases. For the temperature profile increases is caused by the Grashof Number increases in λ parameter and it causes the viscosity decreases and the temperature profile increases.



(a) (b)

Fig. 8. Graph of velocity profile (a) and temperature (b) for the mixed convection parameter is variety

5. Conclusion

Nano fluid iron-(iii)-oxide water-based flow in presence of magnetic field and radiation for stretched smart fabrics is investigated. Keller-Box scheme is used to solve the governing equations for several parameters effect and MHD are considered. From the results of numerical simulations using several variations of parameters magnetic (M), Prandtl number (Pr), porosity parameter (ϕ), radiation parameter (Rn), and stretching parameters (c) on velocity and temperature profile, is: (1) The effect of the magnetic parameter (M) on the velocity and temperature profile is that with the increase the magnetic parameter (M), the velocity profile increases and the temperature profile also increases. (2) The effect of variations Prandtl number (Pr) on the velocity and temperature profile is by increasing the value of the prandtl number (Pr), the velocity profile u decreases and the temperature profile also decreases. (3) The effect of the porosity parameter (ϕ) on the velocity and temperature profile is by increasing the porosity parameter (ϕ), the velocity profile decreases and the temperature profile increases. (4) The radiation parameter (Rn) on the temperature profile is that the increasing value of the radiation parameter (Rn), the temperature profile increases. (5) The effect of the stretching parameter (c) on the velocity and temperature profile is that with the increase the stretching parameter (c), the velocity profile is increases and the temperature profile also increases. (6) The effect of the volume fraction parameter (χ) on the velocity and temperature profile is that with the increase in the volume fraction parameter (χ), the velocity profile is decreases and the temperature profile increases. (7) The effect of variations mixed convection parameter (γ) on the velocity and temperature profile is by increasing the value of the mixed convection parameter (γ), the velocity profile increases and the temperature profile also increases.

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