Theoretical analysis of Casson flow of blood with hybrid magnetic nanoparticles as a drug carrier with magnetic field- Application to treatment of Cancer

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Abstract

Currently the treatment of diseases primarily depends on the delivery of medicines with the help of magnetic nanofragments in the human circulatory system. In this treatment, drug particles and magnetic nanoparticles are introduced into the bloodstream and shipped to the appropriate organs under magnetic intensity, which is normally applied locally and helps to promote the release of drugs. This approach is used in numerous medicinal processes, including as the healing of cancer, the targeted administration of drugs, the wound-healing process of wounds, reducing bleeding in the course of surgical treatment, and the magnetic attraction of blood. Therefore, the purpose of this paper is to conduct a theoretical analysis of blood flow of a Casson fluid that is carrying hematite (Fe_2O_3) and magnetite (Fe_3O_4), two different types of magnetic nanoparticles, across a planar surface. The MATLAB mathematical tool's built-in Bvp4c function was used to plot the results graphically. The fluid kinetic energy is absorbed by the magnetic field via the Lorentz force, which reduces any disruptions and prevents the flow from transitioning. Temperature fluctuations are dissipated by thermal radiation, increasing the amount of magnetic nanoparticles in the vicinity of the tumour tissue. The Casson parameter keeps the instabilities that cause the nanoparticles to precipitate in place and permits easy horizontal flow. The findings have a significant impact on medicine and potentially save costs and post-operative difficulties in patients by treating vascular and malignant diseases without necessity for surgery.

Keywords: Magneto hydrodynamics, Thermal radiation, Casson fluid, Runge-Kutta method (bvp4c), Magnetic nanoparticles

1. Introduction

A set of disorders known as cancer involve the unchecked growth and division of aberrant cells. Such cells go through modifications to achieve infinite replication, which allows them to spread to other organs and cause cancer. Due to the alarming rise in cancer incidence and anomalies in treatment, cancer is now the second leading cause of death in the world. Magnetic nanoparticles (MNPs), with sizes between 1 and 100 nm, have played a significant role in science and technology from the past twenty years. MNPs are widely used for drug delivery, enzyme immobilization, and many other interesting biotechnological applications. They possess desirable properties like high surface area, size uniformity, biocompatibility, super paramagnetism, adsorption kinetics, and a magnetic moment that can be employed for several purposes. Among them, iron oxide nanoparticles are extensively studied since they do not retain any magnetization if zero magnetic field. This particularity has led to the application of iron oxide nanoparticles (Fe_2O_3 and Fe_2O_4) for biomedical applications which are inserted in the base fluid called Ferrofluids. The NP's size ranging from 5 – 15 nm and are coated with a layer of surfactant. Ferrofluids have dual characteristics because they function simultaneously as magnetic solids and liquids. We can regulate the flow of fluid and the rate of heat transfer by applying a magnetic field across the ferrofluids. Tumour cells can be heated and killed using the MNPs. Compared to healthy cells, tumour cells are more vulnerable to temperature increases. Cancer cells are killed by collecting nanoparticles of magnetic material into tumours and emitting energy in the form of heat when subjected to external magnetic effects. MNPs chemical and physical properties are greatly influenced by their size, shape, crystal arrangement, and chemical make-up. Additionally, MNPs have unique magnetic features like high susceptibility, super paramagnetic, and low Curie temperature. The idea behind MNPs was that the anticancer medications were tied outside to the small magnetic beds before injecting them into the body. A potent external magnetic field attracts the drug-filled NPs in the tumour tissue after injection into the bloodstream. The medication burden should be greatly reduced with this technique. This avoids undesirable side effects like hair loss, nausea, and a compromised immune system linked to the regular use of chemotherapy medications. A recent and extremely interdisciplinary subject, the use of magnet-based NPs in medical applications holds considerable promise for in vitro and in vivo medicinal and diagnostic tests. More studies related to the MNPs are found in [1-8]

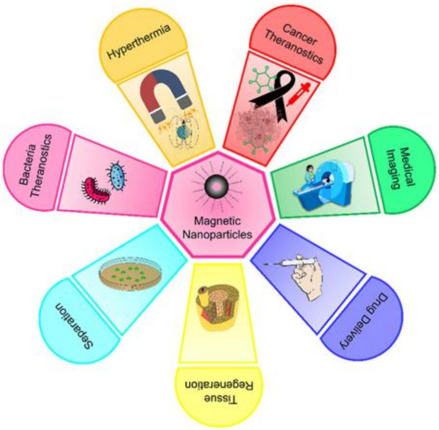

Figure 1: Applications of Magnetic Nanoparticles

These particles' ability to directly target cancer cells and mix with a wide variety of proteins and medicines is a highly crucial trait. When the nanoparticles come into contact with the cancer cell, temperatures were generated by them ranging from 40 to 45 degrees Celsius, which heat up and burn the tumour. Liquids that contain nanoparticles are generally referred to as nanofluids. Examples of nanoparticles include carbon nanotubes, metallic nanoparticles (Cu, Ag, etc.), oxides (Al2O3, Fe2O4, etc.), and others. Water, ethylene glycol, and oil are examples of base fluids. Nanofluids are not just useful in the biomedical sector. The transportation industry, nuclear reactors, micro-mechanoelectro systems, thermal exchangers, reactors with catalyst, fibre and granular insulation, and packed beds are just a few of the industries that use them. Hybrid nanofluid can be made by mixing different combinations of nano sized particles in a base liquid to improve the physical features of nanofluids. More research on the hybrid Nano liquid flow is discussed in [9-17].

Numerous experimental and theoretical studies have been conducted on the fluid flow of an electrically conductive fluid when it is subjected to the magnetic field. Magnetic fields cause modifications to the dynamics of bio magnetic fluids. Magnetohydrodynamics (MHD) is the branch of fluid mechanics that studies fluid flow in the presence of a magnetic field. MHD has become extremely significant in a number of biomedical, commercial, and technical applications. For instance, the transport of medication, embryonic stem cells, and healing cells to a patient can be managed utilising magnetic fields. Additionally, magnetic fields can be used to guide magnetic nanoparticles to specific regions of the body in an effort to eradicate bacteria and cancer cells. Magnetic fields are utilised in medical settings to thin the blood and regulate blood flow during surgical procedures. The study of the magnetic and velocity fields in the existence of an electrically conducting liquid is known as magnetohydrodynamics. Analogous studies on this issue may be referred here [18-21].

In the mechanical and technological industries, thermal radiation is crucial. Solar power accumulators, nuclear reactors, rocket propulsion, heating and icing of compartments and other translucent ecological processes are some examples. Thermal radiation is defined as the emission of electromagnetic waves in all directions from a heated surface. Thermal radiations travel at the speed of light towards the absorption site. The radiation influence on blood flow is a significant area of study due to its extensive applications in the field of biomedical engineering and multiple medical treatment options. One of the most popular methods for producing thermal radiation is infrared radiation, which allows for the direct heating of the blood vessels in the body parts that are affected. Using strong radiation doses is another efficient method of killing cancer cells. Radiotherapy is the name of this process. Radiation therapy directly affects the DNA of cancer cells to kill them and a few studies were given in the references [22-27].

The treated fluids in the majority of flow applications are non-Newtonian fluids. Physics experts, engineers, and mathematicians are interested in these categories of fluid. Applications for non-Newtonian fluids can be found in biology, pharmaceuticals, and other fields. Non-Newtonian fluids are modelled mathematically using non-linear behaviour theory, which usually link up stress rates to strain rates. Casson's modelling is one of the many mathematical models that are extensively used. Applications for Casson's fluids can be found in a variety of disciplines, including geophysical fluid dynamics, biomedical and engineering, and power generation. A fluid with an elastic limit is called a casson's fluid. The fluid stops flowing and begins to act like a solid when subjected to a tension below its elastic limit. A flow in fluid is seen when tension is more than the elastic nature. As a result, Casson's fluid has null viscosity at boundless and unlimited viscosity at infinity and beyond. Blood that circulates in the arteries at greater shear rate is viewed as Newtonian fluid. Contrarily, blood in general a non-Newtonian fluid. In actuality, blood is a Casson liquid. Tomato ketchup, blood, jelly, and honey are all examples of Casson fluid. Some significant studies in non-Newtonian fluids with different aspects are cited here by the investigators [28-34].

The primary purpose of this current work is to focus on the impacts of hybrid nanofluid over stretched sheet with magnetic strength and radiation. Blood is recycled as base liquid with Fe_2O_3 and Fe_3O_4. Also the non-Newtonian Casson model is considered. The graphical results were obtained by plotting the Bvp4c built-in function in the mathematical software MATLAB. The medical operations for eliminating micro-organisms and treating cancer could greatly benefit from this study. This model can be used in a variety of therapeutic applications, such as the treatment of infections, cancer, and vascular illnesses like atherosclerosis. It can also be used to dissolve blood clots.

2. Mathematical formulation

Two-dimensional heat propagation over a MHD Casson hybrid nanofluid with thermal radiation is considered. Two types of nanoparticles (Fe_2O_3, Fe_3O_4) are engrossed in the base fluid blood. Let u and v be the velocity components along x and y directions with the sheet velocity $u_w = ax$. T_w, T_∞ are the temperatures of the sheet and the free stream. The thermophysical characteristic of blood and hybrid nanoparticles are shown in Table.1.

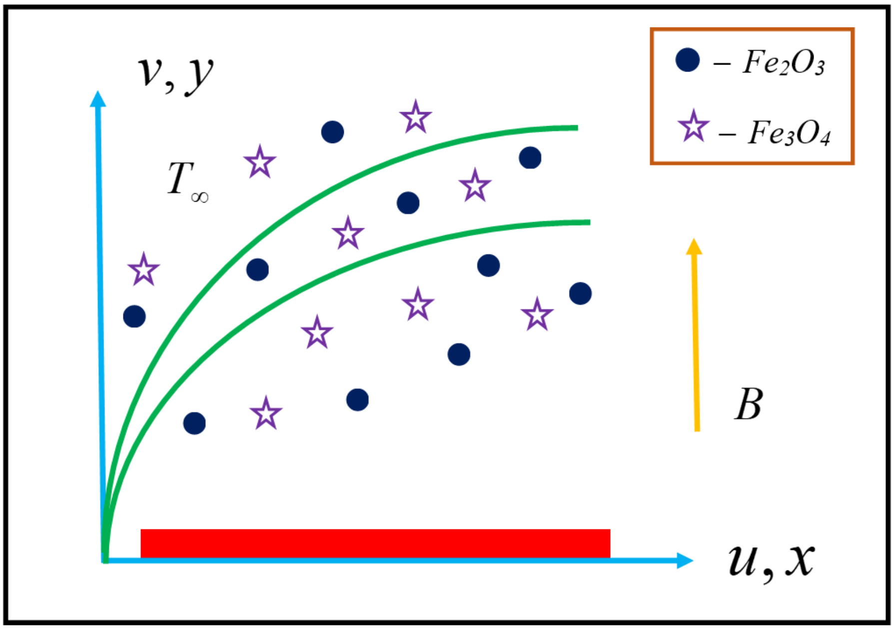

Figure 2: Geometry of the problem.

The governing flow equations are constructed as:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\left(1+\frac{1}{\beta}\right)\frac{\mu_{hnf}}{\rho_{hnf}}\left(\frac{\partial^2 u}{\partial y^2}\right)+\frac{\sigma_{hnf}}{\rho_{hnf}}\left(B^2 u\right), \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_{hnf}}{\left(\rho c_p\right)_{hnf}}\left(\frac{\partial^2 T}{\partial y^2}\right)-\frac{1}{\left(\rho c_p\right)_{hnf}}\left(\frac{\partial q_r}{\partial y}\right)+\frac{\sigma_{hnf}B^2}{\left(\rho c_p\right)_{hnf}}u^2. \tag{3}$$

By Rosseland approach, we have

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

With σ^* as Stefan–Boltzmann coefficient and k^* is the mean absorption constant. With Taylor's expansion of T^4 about T_∞ and neglecting higher order terms, we get

$$T^4=4T_\infty{}^3T-3T_\infty{}^4. \tag{5}$$

Putting Eq. (5) in Eq. (3), we get

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_{hnf}}{\left(\rho c_p\right)_{hnf}}\left(\frac{\partial^2 T}{\partial y^2}\right)-\frac{1}{\left(\rho c_p\right)_{hnf}}\frac{16T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial y^2}+\frac{\sigma_{hnf}B^2}{\left(\rho c_p\right)_{hnf}}u^2. \tag{6}$$

The corresponding boundary conditions are:

$$\begin{aligned}&u=u_w\left(x\right)=ax,\, v=0,\, k_{hnf}\frac{\partial T}{\partial y}=h_f\left(T_f-T\right), && at\ y=0\\ &u\rightarrow 0, T\rightarrow T_\infty && as\ y\rightarrow\infty.\end{aligned} \tag{7}$$

The following suitable self-similarity transformations are defined as:

$$u=axf'\left(\eta\right), v=-\sqrt{a\upsilon_f}\,f\left(\eta\right), \theta\left(\eta\right)=\frac{T-T_\infty}{T_f-T_\infty}, \eta=y\sqrt{\frac{a}{\upsilon_f}}. \tag{8}$$

Mathematical models of thermophysical properties of hybrid nanofluid

$$K_1=\frac{\mu_{hnf}}{\mu_f}, K_2=\frac{\rho_{hnf}}{\rho_f}, K_3=\frac{(\rho c_p)_{hnf}}{(\rho c_p)_f}, K_4=\frac{k_{hnf}}{k_f}, K_5=\frac{\sigma_{hnf}}{\sigma_f}.$$

$$\left.\begin{aligned}
&K_1=\frac{1}{\left(1-\phi_1\right)^{2.5}\left(1-\phi_2\right)^{2.5}},\\
&K_2=\left\{\left(1-\phi_2\right)\left[\left(1-\phi_1\right)+\phi_1\left(\frac{\rho_{s_1}}{\rho_f}\right)\right]+\phi_2\frac{\rho_{s_2}}{\rho_f}\right\},\\
&K_3=\left(1-\phi_2\right)\left[\left(1-\phi_1\right)+\phi_1\left(\frac{(\rho c_p)_{s_1}}{(\rho c_p)_f}\right)\right]+\phi_2\frac{(\rho c_p)_{s_2}}{(\rho c_p)_f},\\
&K_4=\frac{k_{s_1}+2k_{bf}-2\phi_2(k_{bf}-k_{s_2})}{k_{s_2}+2k_{bf}+\phi_2(k_{bf}-k_{s_2})}\times\frac{k_{s_1}+2k_f-2\phi_1(k_f-k_{s_1})}{k_{s_1}+2k_f+\phi_1(k_f-k_{s_1})},\\
&K_5=\frac{\sigma_{s_2}+2\sigma_{nf}-2\phi_2(\sigma_{nf}-\sigma_{s_2})}{\sigma_{s_2}+2\sigma_{nf}+\phi_2(\sigma_{nf}-\sigma_{s_2})}\times\frac{\sigma_{s_1}+2\sigma_f-2\phi_1(\sigma_f-\sigma_{s_1})}{\sigma_{s_1}+2\sigma_f+\phi_1(\sigma_f-\sigma_{s_1})}.
\end{aligned}\right\} \tag{9}$$

In order to create the following dimensionless ODEs, Eqs. (2) and (6) are transformed using the ideal technique indicated in Eq (8).

$$\frac{K_1}{K_2}\left(1+\frac{1}{\beta}\right)f'''+K_2\left(ff''-\left(f'\right)^2\right)-\frac{K_5}{K_2}Mf'=0, \tag{10}$$

$$\theta''\left(K_4+\frac{4}{3}Rd\right)+K_3Prf\theta'+\frac{K_5}{K_3}MEc\left(f'\right)^2=0. \tag{11}$$

The boundaries of the change are described as:

$$\begin{aligned}&f\left(0\right)=0,\ f'\left(0\right)=1, K_4\theta'\left(0\right)=-Bi\left(1-\theta\left(0\right)\right)\\&f'\left(\infty\right)=0,\theta'\left(\infty\right)=0.\end{aligned} \tag{12}$$

Note that $M=\frac{\sigma_f B^2}{\rho_f a}$ is the magnetic field parameter, $Pr=\frac{\mu_f\left(c_p\right)_f}{k_f}$ is the Prandtl number, $Rd=\frac{4\sigma^* T_\infty^3}{k^* k_f}$ is the Radiation parameter, $Bi=\frac{h_f}{k_f}\sqrt{\frac{\upsilon_f}{a}}$ is the Biot number, β is the Casson fluid parameter, $Ec=\frac{a^2x^2}{c_p\left(T_f-T_\infty\right)}$ is the Eckert number.

The non-dimensional skin-friction constant, and Nusselt numbers are expressed as

$$C_f=\frac{\tau_w}{\rho_f u_w^2} \tag{13}$$

Where shear stress τ_w is $\tau_w=\mu_{hnf}\left.\frac{\partial u}{\partial y}\right|_{y=0}$

$$Nu = \frac{xq_w}{k_f\left(T_w - T_\infty\right)} \tag{14}$$

Where heat flux q_w is $q_w = -k_{hnf}\left.\frac{\partial T}{\partial y}\right|_{y=0}$

The Non-dimensional form of Eqs. (13–14) converts are

$$Re_r^{1/2} C_f = K_1 f''(0), \tag{15}$$

$$Re_r^{-1/2} Nu_r = -K_4 \theta'(0). \tag{16}$$

Where Re_r is the local Reynolds number.

Table 1. The thermophysical characteristic of blood and hybrid nanoparticles.

Property	Blood	Fe_2O_3	Fe_3O_4
$Density\ \rho\left(kgm^{-3}\right)$	1050	5180	5200
$Specific\ heat\ C_p\left(Jkg^{-1}K^{-1}\right)$	3617	670	670
$Heat\ conductivity\ k_f\left(Wm^{-1}K^{-1}\right)$	0.52	9.7	6
$Electrical\ conductivity\ \sigma\left(\Omega m\right)^{-1}$	0.8	25000	740000
Pr	21	-	-

3. Numerical method

The non-dimensional system of Eqs. (10-11), as well as the boundary conditions (12). First, we converted the basic equations into first-order ODEs for this scheme.

$$f = \Delta_1,\ f' = \Delta_2,\ f'' = \Delta_3, \theta = \Delta_4, \theta' = \Delta_5. \tag{17}$$

$$f''' = -\frac{1}{\frac{K_1}{K_2}\left(1+\frac{1}{\beta}\right)}\left(K_2\left(\Delta_1\Delta_3 - \left(\Delta_2\right)^2\right) - \frac{K_5}{K_2} M\Delta_2\right), \tag{18}$$

$$\theta'' = -\frac{1}{\left(K_4 + \frac{4}{3}Rd\right)}\left(K_3 Pr \Delta_1\Delta_5 + \frac{K_5}{K_3} MEc\left(\Delta_2\right)^2\right). \tag{19}$$

The boundaries of the change are described as:

$$\begin{aligned} &\Delta_1(0) = 0, \Delta_2(0) = 1, K_4\Delta_5(0) = -Bi\left(1 - \Delta_4(0)\right) \\ &\Delta_1(\infty) = 0, \Delta_5(\infty) = 0. \end{aligned} \tag{20}$$

Table 2. Comparison table for various Prandtl numbers of the current study.

Pr	**Ramzan et al.[35]**	**Present results**
0.7	0.4539	0.4531
2.0	0.9113	0.9124
7.0	1.8964	1.8960
20	3.3539	3.3528
21	–	4.1657

4. Results and discussion

The numerical approximations were found by employing the built-in function of bvp4c in MATLAB by fixing the parameters as $M = 0.5, \Pr = 21, R = 0.7, Bi = 0.2, Ec = 0.1,$ $\mathrm{Re} = 0.02, \phi_1 = 0.01,$ and $\phi_2 = 0.02.$ Figures 3 and 4 exhibits the influence of magnetic and casson parameters on the velocity profiles for Fe_2O_3-Fe_3O_4/ blood hybrid nanofluids. The impact of M, on the velocity trend is shown in Figure 3. It is shown that the fluid's velocity reduces as M grows. These results show that a resistive strength plays a significant role in directing and slowing fluid flow. A magnetic strength has a strong relation with the resistive field, which is familiar as the Lorentz force. Figure 4 shows the effect of the Casson parameter on the velocity profile. As the Casson parameter is increased, the velocity upsurges.

The effect of the magnetic parameter (M) on the temperature profile is depicted in Figure 5. Thermal energy strengthens the Lorentz force by motivating hybrid nanofluids to dissipate sub kinetic energy. In fact, as the magnetic factor increases, the size of the boundary layer's velocity profiles falls, leading to a raise in boundary layer temperature.

Figure 6 depicts the effect of various radiation parameter (R) values on the temperature of hybrid nanofluid. This figure shows that the radiation parameter (R) has a significant impact on the temperature profile. Thermal radiation has a positive physical effect on the medium's thermal diffusibility, which increases the temperature profile. Physically, higher temperature and a thicker thermal boundary layer are correlated with increased thermal radiation parameters.

The temperature for various amounts of $\Pr$ is revealed in Figure 7. It is clear that as $\Pr$ increases, the temperature parameter decreases. The boundary layer of thermal energy is thicker and the rate of heat transmission decreases for smaller $\Pr$. Typically, $\Pr$ is employed in heat transfer-related applications to determine the width of the thermal and also the momentum border layers.

Figure 8 describes the plot of temperature counter to the Eckert number *Ec.* The production of thermal energy increases with the existence of Ec in nanofluid, becoming more intense, improving temperature distributions, and therefore increasing thermal layer thickness. This is because frictional heating causes an increase in heat energy in the flow, which the viscosity of nanofluids stores and converts into internal energy when heated.

Figures 9 and 10 depict the temperature profile behaviour for different values of nanoparticle volume fractions ϕ_1 (Fe_2O_3) and ϕ_2 (Fe_3O_4). It is clear from these results that increasing the nanoparticle volume fractions improves temperature profiles. This is because the thermal conductivity of nanofluid increases as more solid particles are suspended in the base fluid, increasing heat transfer. The width of the thermal border layer upsurges as the temperature profiles thicken. However, as the values of ϕ_1 and ϕ_2 increase from 0.01 to 0.06, the thermal boundary layer thickens. This is owing to the fact that iron has higher heat conductivity than conventionally based fluids resulting in increasing the fluid temperature.

The skin friction coefficient C_f is studied in figure. 11 against M and β. It is seen that the skin friction C_f decreases verses expanding values of M with respect to β. The deviation of M and Rd on rate of heat transfer is plotted in figure 12. Additionally, the Nusselt number increases in relation to the Radiation variables Rd as the Magnetic parameter M is improved.

The effect of skin friction coefficient with magnetic field on volume fraction of nanoparticles (ϕ_1 (Ferric oxide), ϕ_2 (Iron oxide)) is disclosed in figs.13 and 15. The skin friction coefficient increases for ϕ_1 and a decrement is noticed with ϕ_2. Figs. 14 and 16 discloses the relation between the Nusselt number and volume fraction of nanoparticles (ϕ_1 (Ferric oxide), ϕ_2 (Iron oxide)). It is observed that by increasing the amount of Ferric oxide (Fe_2o_3) nanoparticles in the base fluid with the presence of magnetic field, the rate of heat transfer is significantly boosted and a contrary for the Iron oxide. Fig. 17(a-b) exhibits the streamlined pattern for $M = 0.5$ and $M = 1.0$.

5. Conclusions

In this study, a numerical investigation of Casson hybrid nanofluid Fe_2O_3 -Fe_3O_4/Blood towards a stretching sheet under the nose of thermal radiation and magnetic field was discovered. The graphical results were obtained by plotting the Bvp4c built-in function in the mathematical software MATLAB. The impact of M, Rd, Pr, Ec and nanoparticle volume fraction on the skin friction, rate of heat transfer, velocity and temperature profiles has been investigated in this study. The findings are as follows: By virtue of an increase, M reduces the skin friction coefficient, velocity, and Nusselt number for Fe_2O_3-Fe_3O_4/blood, while temperature increases; the heat transfer rate of hybrid nanofluid Fe_2O_3-Fe_3O_4/blood is more than those of Fe_2O_3/blood; the temperature is also increasing by increasing Rd. As Ec increase, so does the thermal.

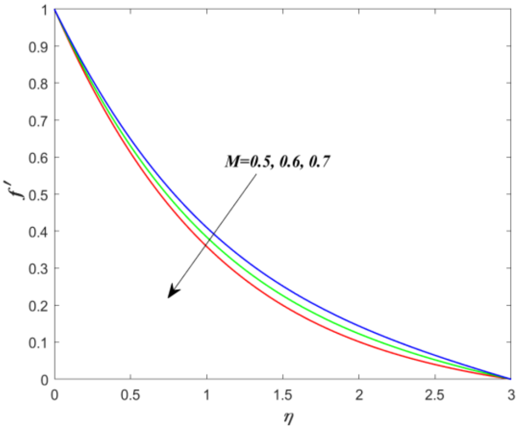

Figure 3: Variation due to M on $f'(\eta)$.

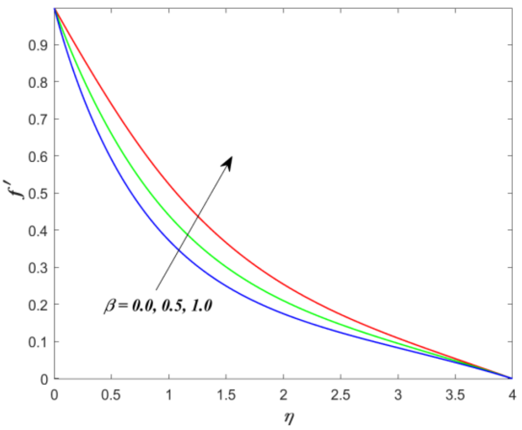

Figure 4: Variation due to β on $f'(\eta)$.

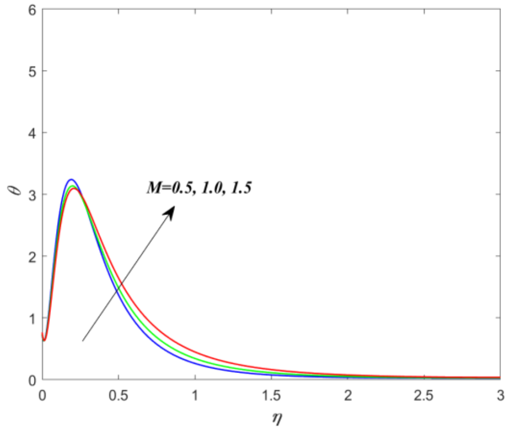

Figure 5: Variation due to M on $\theta(\eta)$.

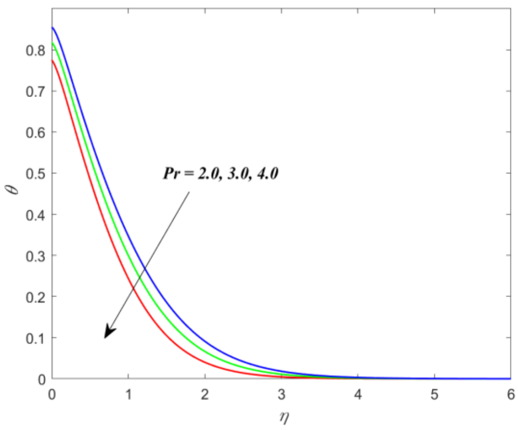

Figure 7: Variation due to Pr on $\theta(\eta)$.

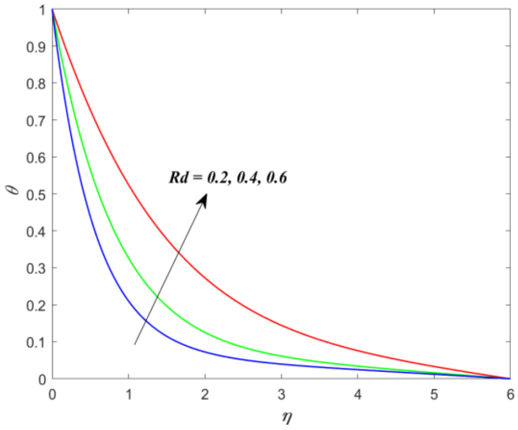

Figure 6: Variation due to Rd on $\theta(\eta)$.

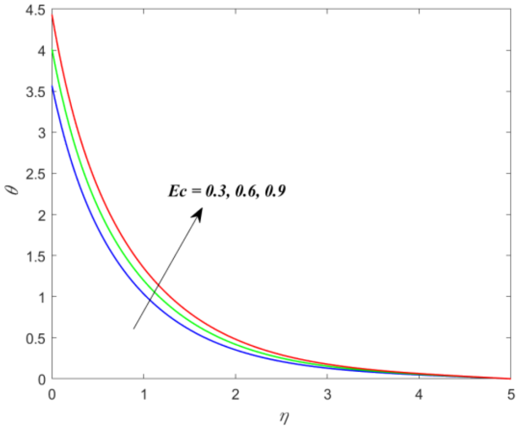

Figure 8: Variation due to Ec on $\theta(\eta)$.

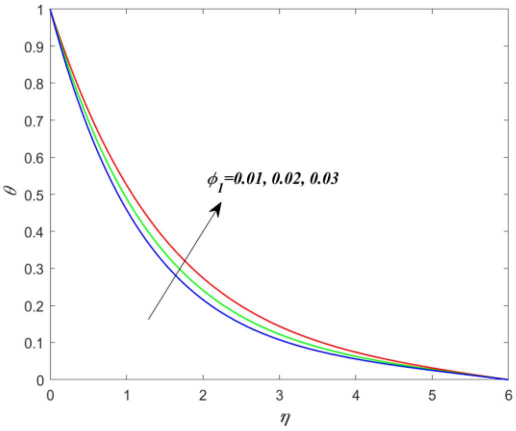

Figure 9: Variation due to ϕ_1 on $\theta(\eta)$.

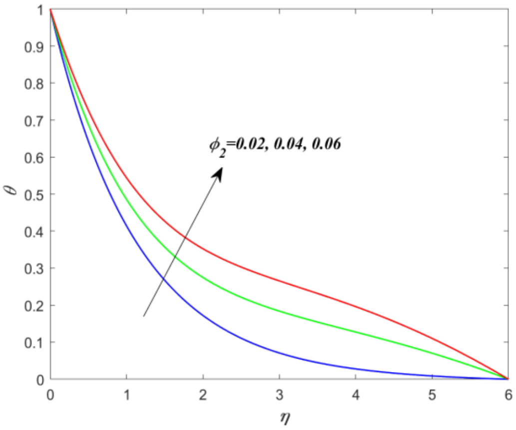

Figure 10: Variation due to ϕ_2 on $\theta(\eta)$.

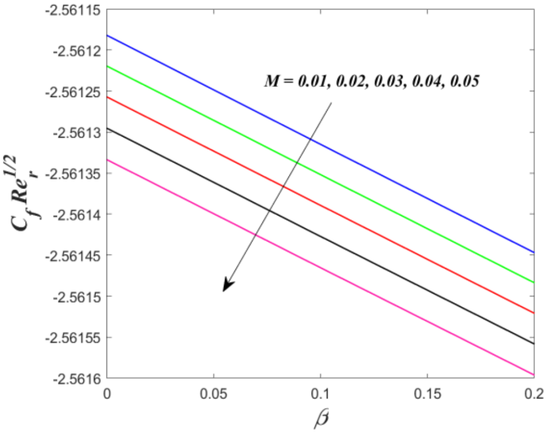

Figure 11: Influence of M and β on $C_f\,(Re_r)^{1/2}$.

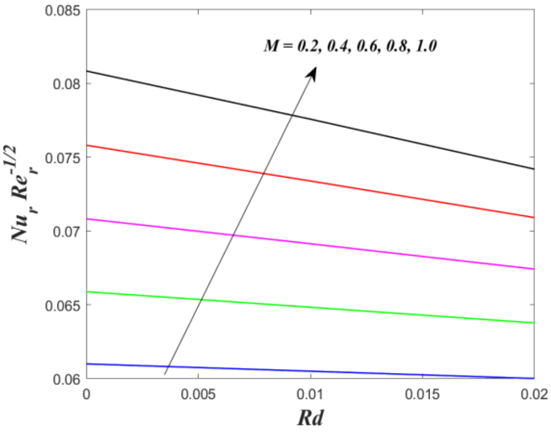

Figure 12: Influence of M and Rd on $Nu_r\,(Re_r)^{-1/2}$.

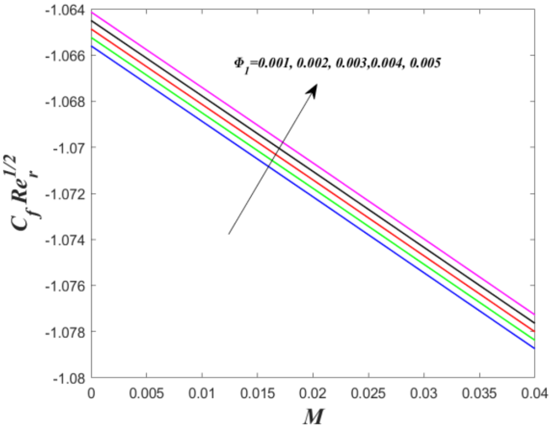

Figure 13: Influence of M and ϕ_1 on $C_f\,(Re_r)^{1/2}$

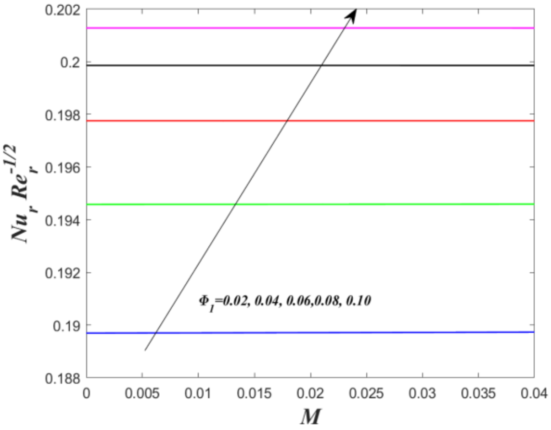

Figure 14: Influence of M and ϕ_1 on $Nu_r\,(Re_r)^{-1/2}$

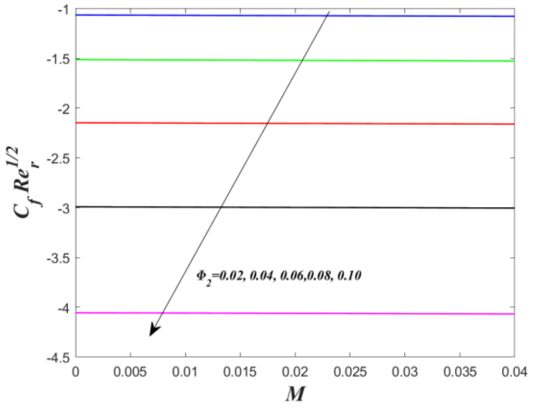

Figure 15: Influence of M and ϕ_2 on $C_f\ (Re_r)^{1/2}$

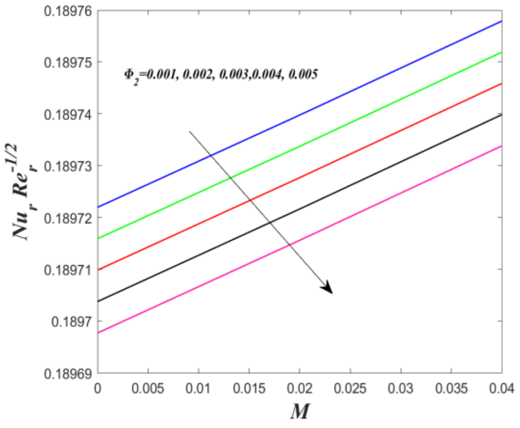

Figure 16: Influence of M and ϕ_2 on $Nu_r\ (Re_r)^{-1/2}$

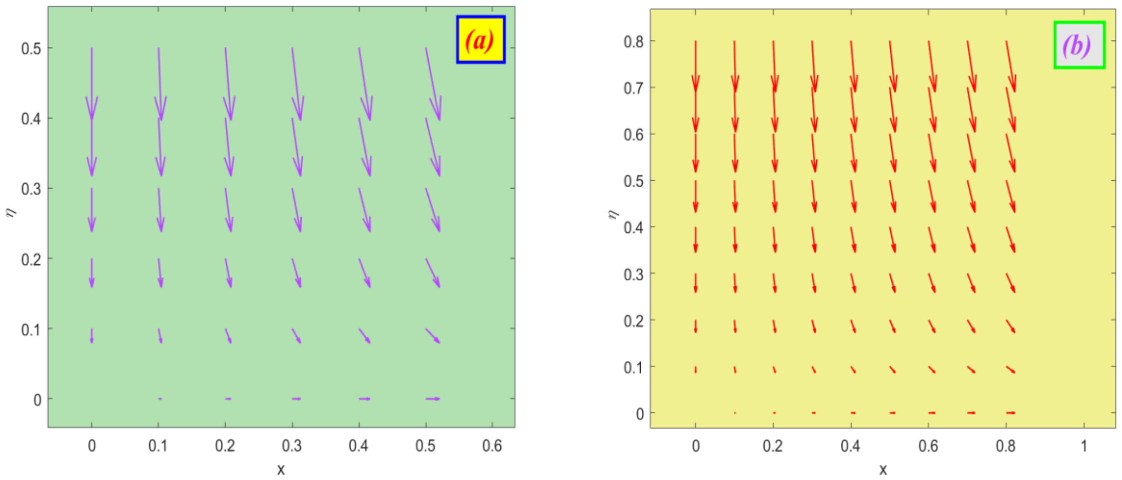

Figure 17: Streamline pattern for various values of $(a)\,M=0.5$ and $(b)\,M=1.0$.

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