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Impact of magneto hydrodynamics (MHD) on oscillatory flow behavior of Carreau fluid within a periodically varying temperature channel

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ABSTRACT

The impact of magneto hydrodynamic oscillatory flow for Carreau fluid via regularly spaced channels with variable temperatures is examined in this research for two different geometries "Couette flow and Poiseuille flow ". It is believed that the fluid is Carreau fluid, a non-Newtonian fluid. There are numerous applications for studying flow across a porous media in different fields of science and technology. Filtration of fluids is one of the applications where flow across a porous media is most prominent. The perturbation approach uses mathematics to solve the governing equations. The investigation's objective is to determine the Weissenberg number's small number solution ($We \ll 1$) It help the (MATHEMATICA-12) program produce the numerical outcomes and drawings in order to achieve unambiguous forms for the velocity field. Presenting a graphical discussion allows for the simultaneous discussion of the physical characteristics of the Darcy, Reynolds, Peclet, magnetic, and radiation parameters. With the aid of graphics, the fields pertaining to the speed and temperature are described at various values of the concernedeee parameter..

1. Introduction

Non-Newtonian fluid laminar flow studies have drawn a lot of interest since they have a broad range of uses in science and engineering technologies. Different fluids have different viscosities, which can vary depending on the rate of deformation. Additionally, some fluids have an elastic nature and are reeferred to as non-Newtonian fluids. Numerous researchers have looked at the heat and mass transport properties of non-Newtonian fluids, according to the literature that has already been published (“Nigam and Singh, 1960”) [1], (“Kavita and others, 2012”) [8]. [12] Muhammad Amin Sadiq Murad at al. studied stagnation point over a continuous moving sheet, [13] Sohail Rehman at al. Onset about isothermal flow of Carreau flow with Cattaneo-Christov heat and mass fluxes. Due to its many applications in geophysics and technology, flow across a porous media under the effect of temperature fluctuations is one of the most crucial modern issues. Practical applications of the study of sedimentary liquid flow include flow across packed beds, environmental contamination, sedimentation, and central particle filtering. (“Frigaard and Ryan, 2004”) [7] investigated the blood flow in the arteries and veins. According to Hamza and colleagues (2011) [5], Recent technological advancements have sparked interest in fluid flow research, which involve the interaction of numerous phenomena. ("Raptis and others, 1982") [3]examined the occurrence of variable viscosity in the oscillatory flow of a Jeffrey liquid in a channel under magneto hydro dynamics, and assessed heat transfer's impact. Heat transmission to magneto hydro dynamics oscillatory flow via a porous media has been researched by (Al-Khatib and Wilson, 2001) [6] in slip form. ("Khudair and Al-Khafajy, 2018") [9] examined the way Williamson fluid behaved in a channel that was inclined, examining two distinct geometries: "Couette flow" and "Poiseuille flow". Heat transfer in magneto-hydrodynamics is influenced by the oscillatory flow of Williamson fluid through a porous media channel. This phenomenon is examined using models for two distinct geometries, namely "Poiseuille flow" and "Couette flow". analyzed the magneto-hydrodynamic boundary layer slip flow across a stretching surface with temperature in a porous middle ("Attia and Kotb, 1996") [2]. An irregular channel filled

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with porous media and the impact of chemical reactions on free convection flow in magnetohydrodynamics have been discussed (Mostafa, 2009) [4]. The research considers a mathematical model of the impact of magnetohydrodynamics on the oscillatory flow of a Carreau fluid via channels of varying temperatures.

2. Preliminaries

To assess the impacts of a magnetic field and heat transfer associated with radioactivity, visualize a Carreau fluid moving through a channel with a width of 1, as seen in Fig.1. This paper hypothesised that the fluid would have little electrical conductivity and produce negligible electromagnetism. a Cartesian coordinate system in which the velocity vector is written as ((y), 0,0), where the x-axis and y are perpendicular, and v is the velocity's x component.

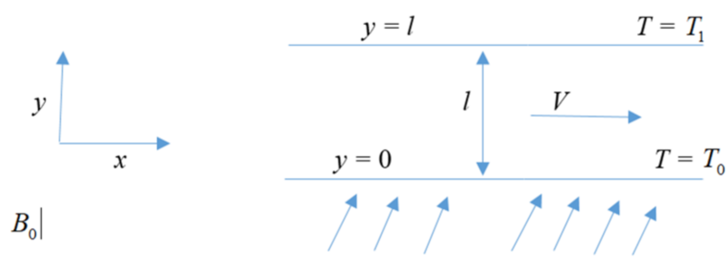

Fig.1 Graph depicting the issue

Carreau fluid's fundamental equation is (Nadeem, 2014)[10]:

$$\boldsymbol{S} = -\bar{p}\boldsymbol{I} + \tau \tag{1}$$

$$\bar{\tau} = \left[\mu_\infty + (\mu_0 - \mu_\infty)((1 + \Gamma\bar{\dot{\gamma}})^2)^{\frac{n-1}{2}}\right] A^* \tag{2}$$

If the pressure is $\bar{p}$, $\boldsymbol{I}$ denote the unit tensor, the supplemental stress tensor is $\bar{\tau}$, Γ represent the time constant, and the infinite and zero shear rate viscosity are μ_∞ and μ_0. With these definitions, $\bar{\dot{\gamma}}$ can be defined as follows::

$$\dot{\gamma} = \sqrt{\frac{1}{2}\sum_i \sum_j \dot{\gamma}_{ij}\dot{\gamma}_{ji}} = \sqrt{\frac{1}{2}\prod} \quad and \quad \prod = tr\,(A^*)^2\,,\; A^* = \nabla\bar{V} + (\nabla\bar{V})^T \tag{3}$$

In this context, the symbol $\prod$ represents the strain's second invariant tensor. In this case, we consider the fundamental equation (2) $\Gamma\bar{\dot{\gamma}} < 1$,

and μ_∞ is equal to zero. The component of the additional stress tensor can be expressed as follows:

$$\bar{\tau} = \mu_0[1 + (\frac{n-1}{2})\Gamma^2\dot{\gamma}^2]A^* \tag{4}$$

The Boussineq approximation governs the momentum and energy equations for such a flow, are :

$$\frac{\partial\bar{u}}{\partial\bar{x}} + \frac{\partial\bar{v}}{\partial\bar{y}} = 0 \tag{5}$$

$$\rho(\frac{\partial\bar{u}}{\partial\bar{t}} + \bar{u}\frac{\partial\bar{u}}{\partial\bar{x}} + \bar{v}\frac{\partial\bar{u}}{\partial\bar{y}}) = -\frac{\partial\bar{p}}{\partial\bar{x}} + \frac{\partial\bar{\tau}_{\overline{xx}}}{\partial\bar{x}} + \frac{\partial\bar{\tau}_{\overline{xy}}}{\partial\bar{y}} + \rho g\beta(T - T_0) - \sigma B_0^2\sin^2(\zeta)\bar{u} - \frac{\mu_0}{k}\bar{u} \tag{6}$$

$$\rho(\frac{\partial\bar{v}}{\partial\bar{t}}+\bar{u}\frac{\partial\bar{v}}{\partial\bar{x}}+\bar{v}\frac{\partial\bar{v}}{\partial\bar{y}})=-\frac{\partial\bar{p}}{\partial\bar{y}}+\frac{\partial\bar{\tau}_{\overline{xy}}}{\partial\bar{x}}+\frac{\partial\bar{\tau}_{\overline{yy}}}{\partial\bar{y}}-\frac{\mu_0}{k}\bar{v} \qquad (7)$$

$$\rho\frac{\partial T}{\partial\bar{t}}=\frac{K}{C_p}\frac{\partial^2 T}{\partial\bar{y}^2}-\frac{1}{C_p}\frac{\partial q}{\partial y} \qquad (8)$$

The temperatures shown on the tunnel walls are referred to as:

$$T=T_0 \text{ at } \bar{y}=0\,, \text{ and } T=T_1 \text{at } \bar{y}=l \qquad (9)$$

Within this context, $\bar{v}$ represents the velocity along the axis, T indicates the fluid temperature, B_0 represents the strength of the magnetic flux, ρ signifies the density of the fluid, σ represents the fluid's conductivity, β symbolizes the coefficient regarding the expansion of volume resulting from changes in temperature, g denotes the acceleration caused by gravity, k represents the permeability, C_p indicates the fluid's specific heat capacity under steady pressure, K denotes the fluid's thermal , and q represents the heat flux arising from radioactivity.

It is postulated that the fluid is characterized by a low optical density and have a relatively low density in accordance with (Vinvent and others, 1968) [11], and the radioactive heat flow is defined as:

$$\frac{\partial q}{\partial y}=4b^2(T_0-T) \qquad (10)$$

(b) represents the coefficient of absorption for radiation.

The non-dimensional parameters specified in the study conducted by ("Khudair and Al-Khafajy") in 2018 [9] are as follows:

$$\left.\begin{array}{l} x=\frac{\bar{x}}{l}\,, y=\frac{\bar{y}}{l}\,, u=\frac{\bar{u}}{U}\,, \theta=\frac{T-T_0}{T_1-T_0}\,, t=\frac{\bar{t}U}{h}\,, p=\frac{\bar{p}h}{\mu V}\,, M^2=\frac{\sigma B_0^2\sin^2(\zeta)h^2}{\mu} \\ v=\frac{\bar{v}}{V}\,, We=\frac{\Gamma U}{h}, \tau_{xx}=\frac{h}{\mu_0 U}\bar{\tau}_{\overline{xx}}, \tau_{xy}=\frac{h}{\mu_0 U}\bar{\tau}_{\overline{xy}}, \dot{\gamma}=\frac{h}{U}\bar{\dot{\gamma}}, Da=\frac{k}{h^2} \\ t=\frac{\bar{t}V}{l}\,, Re=\frac{\rho hU}{\mu}\,, Pe=\frac{\rho hUc_p}{K}\,, N^2=\frac{4\eta^2h^2}{K}, Gr=\frac{\rho g\beta h^2(T_1-T_0)}{\mu U} \end{array}\right\} \qquad (11)$$

Where V is the average flow rate, Da is the Darcy parameter, Re is the Reynolds parameter, Pe is the Peclet parameter, M is the magnetic parameter, Gr is the Grashof parameter, and N is the radiation parameter.

Equation substitution of (10) and (11) into equations (5) - (9), we obtain :

$$"\frac{\partial(Uu)}{\partial(xl)}+\frac{\partial(Uv)}{\partial(yl)}=0" \qquad (12)$$

$$\rho\frac{Vl}{\mu_0}\frac{\partial v}{\partial t}=-\frac{\partial p}{\partial x}+\frac{\partial\tau_{xy}}{\partial y}+\frac{\rho g\beta(T_1-T_0)l^2}{\mu_0 V}\theta-\frac{\sigma B_0^2\sin^2(\zeta)l^2}{\mu_0}v-\frac{l^2}{k}v \qquad (13)$$

$$\frac{\rho VC_P h}{k}\;\frac{\partial(\theta(T_1-T_0)+T_0))}{\partial t}=\frac{\partial^2(\theta(T_1-T_0)+T_0))}{\partial y^2}-\frac{4h^2\eta^2(T_0-(\theta(T_1-T_0)+T_0))}{k} \qquad (14)$$

where $\tau_{xx}=\tau_{yy}=\tau_{xz}=\tau_{yz}=0$

$$\tau_{xy}=\tau_{yx}=\mu_0\left[\left(1+\left(\frac{n-1}{2}\right)(we)^2\dot{\gamma}^2\right)\right]$$

The non-dimensionalized boundary conditions for the temperature equation can be stated as:

$$\theta(0) = 0 \ , \ \theta(1) = 1 \tag{15}$$

The resulting dimensional-free equations are as follows:

$$Re\frac{\partial v}{\partial t} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial y}\left[\left(1 + \left(\frac{n-1}{2}\right)(we)^2\left(\frac{\partial v}{\partial y}\right)^2\right)\frac{\partial v}{\partial y}\right] + Gr\theta - \left(M^2 + \frac{1}{Da}\right)v \tag{16}$$

$$\rho\frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + N^2\theta \tag{17}$$

In order to find an answer to the temperature equation (17) given certain constraints (15), let

$$\theta(y,t) = \theta_f(y)e^{i\omega t} \tag{18}$$

In this given context, ω represents the oscillation frequency.

Substituting Equation (18) into Equation (17) yields:

$$\frac{\partial^2 \theta_f}{\partial y^2} + (N^2 - i\omega Pe)\theta_f = 0 \tag{19}$$

In the case of boundary conditions (15), the answer to equation (19) is

$\theta_f(y) = \csc(\varphi)\sin(\varphi)$, where $\varphi = \sqrt{N^2 - i\omega Pe}$. Therefore

$$\theta(y,t) = \csc(\varphi)\sin(\varphi)\, e^{i\omega t} \tag{20}$$

The solution for equation (16) has been computed in the subsequent sections for two different types of boundary conditions, namely "Poiseuille flow" and "Couette flow".

3. PROBLEM SOLUTION

(i) "Poiseuille flow"

Under this condition, it is assumed that the rigid flakes located at y = 0 and y = l are stationary. Hence:

$\bar{v} = 0$ at $\bar{y} = 0,$ and $\bar{v} = 0$ at $\bar{y} = l$

The boundary conditions in non-dimensional form can be expressed as:

$$v(0) = 0\ ,\ v(1) = 0 \tag{21}$$

To address the equation of momentum (16), consider the following approach:

$$-\frac{dp}{dx} = \lambda e^{i\omega t} \tag{22}$$

$$v(y,t) = v_f(y)e^{i\omega t} \tag{23}$$

Here, λ represents a constant value in the real number domain.

By inserting equations (22) and (23) into equation (16), the resulting equation is:

$$Re\frac{\partial}{\partial t}\left(v_f(y)e^{i\omega t}\right) = \lambda e^{i\omega t} + \frac{\partial}{\partial y}\left[\left(1+\left(\frac{n-1}{2}\right)(we)^2\left(\frac{\partial}{\partial y}\left(v_f(y)e^{i\omega t}\right)\right)^2\right)\frac{\partial}{\partial y}\left(v_f(y)e^{i\omega t}\right)\right]\left(v_f(y)e^{i\omega t}\right) + Gr\theta_0 - \left(M^2+\frac{1}{Da}\right)\left(v_f(y)e^{i\omega t}\right) \quad (24)$$

Since equation (24), which is non-linear, is difficult to solve precisely. As a result, waning (We) accepts a straightforward analytical solution to the boundary value problem. The equation can be resolved in this situation. Nevertheless, we employed the perturbation approach to overcome the issue and provide a modest. Accordingly, we write :

$$v_f = v_{00} + We^2 v_{02} + o(We^4) \quad (25)$$

After replacing equation (25) into equation (24) while considering the boundary conditions (21), we can equate the powers of (We), resulting in:

A - System of zero-orders (We)

$$\frac{\partial^2 v_{00}}{\partial y^2} - \left(M^2 + Rei\omega + \frac{1}{Da}\right)v_{00} = -(\lambda + Gr\theta_f) \quad (26)$$

The related boundary conditions can be described as:

$$v_{00}(0) = v_{00}(1) = 0 \quad (27)$$

B - Second -order system (We^2)

$$\frac{\partial^2 v_{01}}{\partial y^2} - \left(M^2 + Rei\omega + \frac{1}{Da}\right)v_{01} = \frac{-3(n-1)}{2}\left(\frac{\partial v_{00}}{\partial y}\right)^2\left(\frac{\partial^2 v_{00}}{\partial y^2}\right)e^{i\omega t} \quad (28)$$

The associated boundary conditions are:

$$v_{01}(0) = v_{01}(1) = 0 \quad (29)$$

In conclusion, the perturbation solutions for vf up to second order are provided as follows:

$$v_f = v_{00} + We^2 v_{02} + o(We^4)$$

Hence, the velocity of the fluid can be represented by:

$$v(y,t) = v_f(y)e^{i\omega t} \quad (30)$$

(ii) "Couette flow"

Lower flake velocity Vh is fixed, while the higher flake is in motion. The Couette flow problem's boundary conditions are:

$$v(0) = 0 \quad , \quad v(1) = V_0 \tag{31}$$

In the Poiseuille flow equation (24), we have the same definition as the governing equation. The perturbation technique was used to calculate the solution in this instance, and the findings have been explained in graphs.

4. OUTCOMES AND DISCUSSIONS

In several outcomes throughout the graphical illustrations, this part explored the impact of magneto hydrodynamics oscillatory flow for Carreau fluid through regularly spaced channels with variable temperatures for "Poiseuille flow" and "Couette flow". Figure (2-15) illustrates the numerical assessments of the analytical findings along with some of the outcomes that are visually significant.

The MATHEMATICA-12 program was utilized to derive results and visual representations. The equation of momentum was solved employing the "perturbation technique," and all the outcomes were graphically discussed.

Using equation (22), the temperature profile is depicted in Figures (2-4). Figure 2 demonstrates a decreasing profile of temperature with increasing pe. Figure 3 illustrates a decreasing profile of temperature with increasing ω. Figure 4 illustrates a rising profile of temperature with increasing N. The equation of momentum is solved utilizing the "perturbation technique," and a graphical analysis is performed to discuss all the obtained results.

Figures 5 to 15 display the velocity profiles of Poiseuille flow. Figure 5 illustrates an increasing velocity profile, V, with an increase in b. Figure 6 depicts V rising as We increases. Figure 7 demonstrates V increasing with an increase in Pe. Figure 8 indicates a decrease in V with increasing W. Figure 9 shows an increasing velocity profile, V, with an increase in G1. Figure 10 exhibits V increasing with an increase in M. Figure 11 reveals a decrease in the velocity profile, V, with an increase in Re. Figure 12 displays V decreasing with increasing Da. Figure 13 portrays an increasing velocity profile, V, with an increase in n. Figure 14 demonstrates V rising as N increases. Finally, Figure 15 illustrates an increase in the velocity profile, V, with an increase in λ.

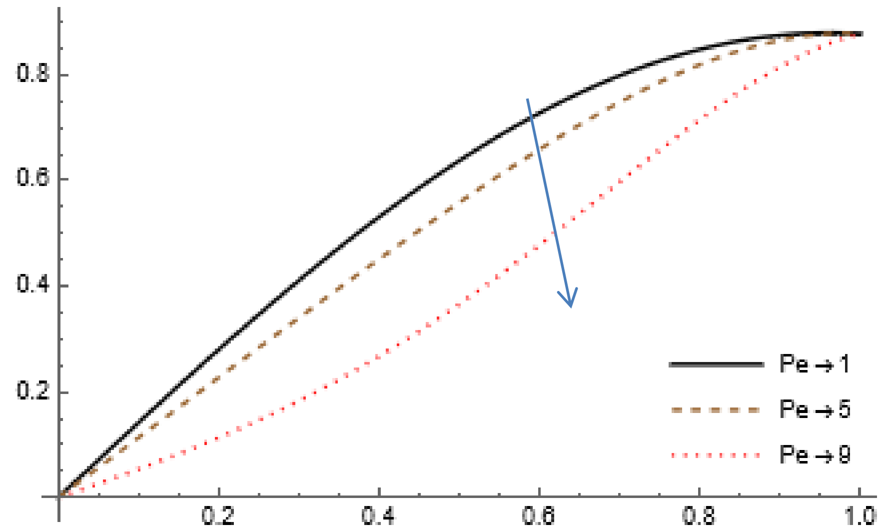

Fig 2 The impact of Pe on Temperature θ for $w = 1$, $N = 1$, $t = 0.5$.

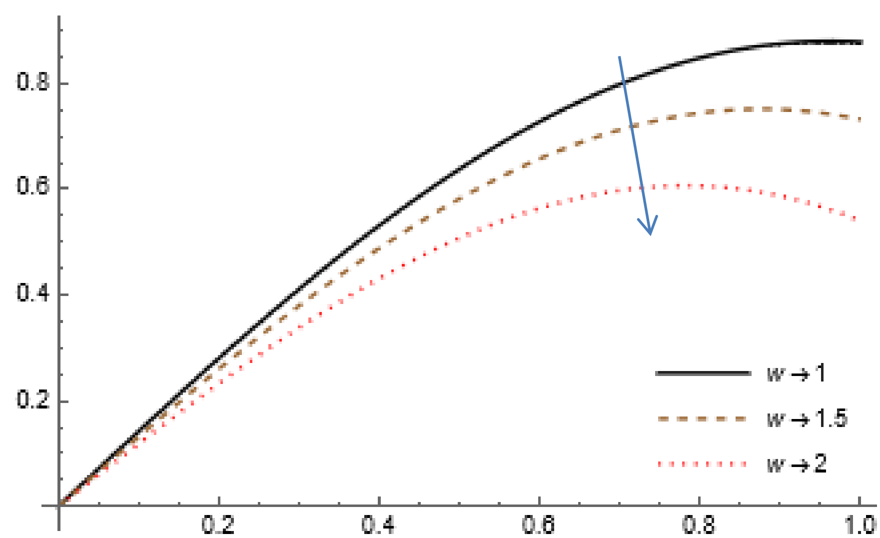

Fig 3 Influence of w on Temperature θ for $Pe = 1$, $N = 1.5$, $t = 0.5$.

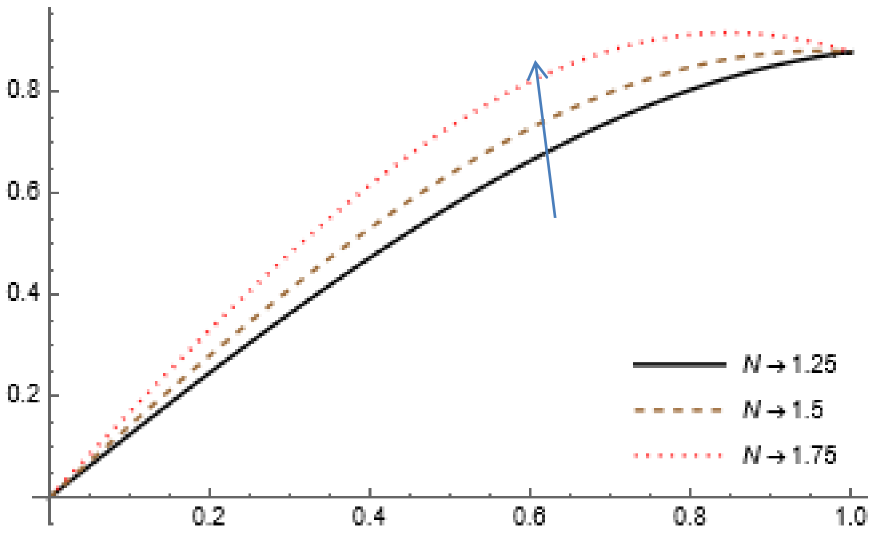

Fig 4 The impact of N on Temperature θ for $Pe = 1, w = 1, t = 0.5$.

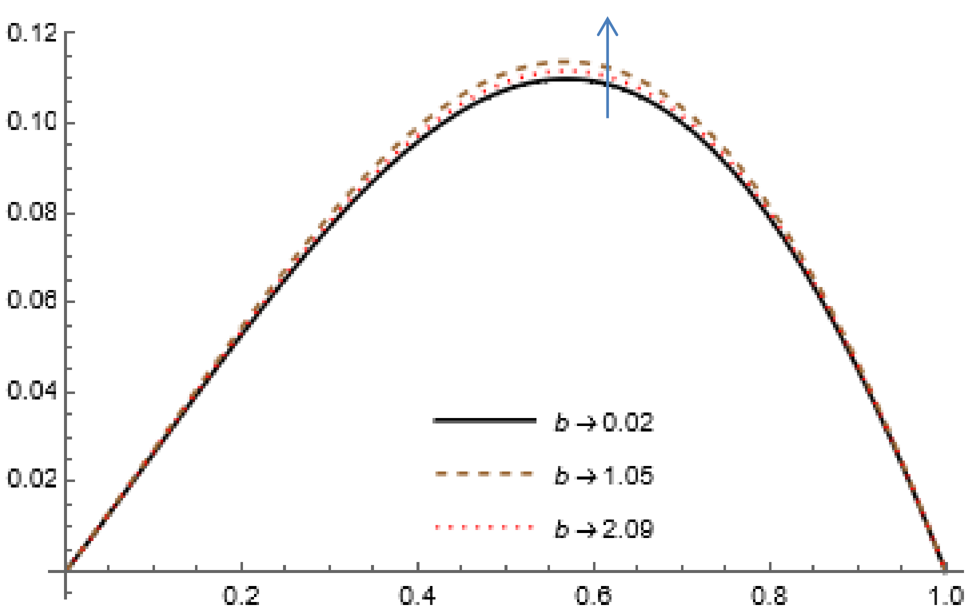

Fig 5 Profile of velocity for b with $We = 1,\ Pe = 1,\ \mathrm{w} = 1,\ G_1 = 1,\ \mathrm{M} = 1,$ $Re = 1, Da = 0.8, \mathrm{n} = 1, N = 1, \lambda = 1,\ t = 0.5, z = 0.1$ in Couette flow.

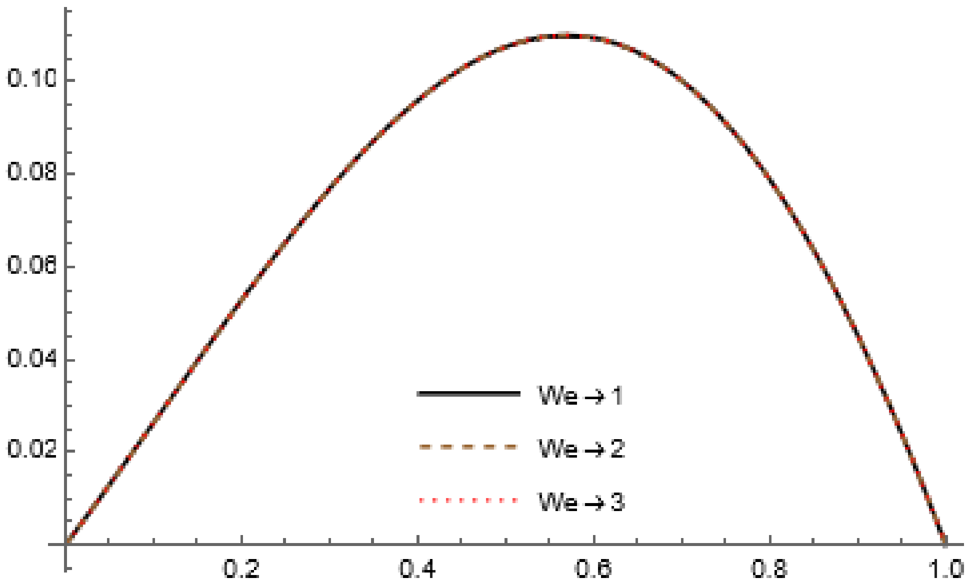

Fig 6 Velocity profile for We with $b = 0.03$, $Pe = 1$, $\mathrm{w} = 1$, $G_1 = 1$, $\mathrm{M} = 1$, $Re = 1$, $Da = 0.8$, $\mathrm{n} = 1$, $N = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

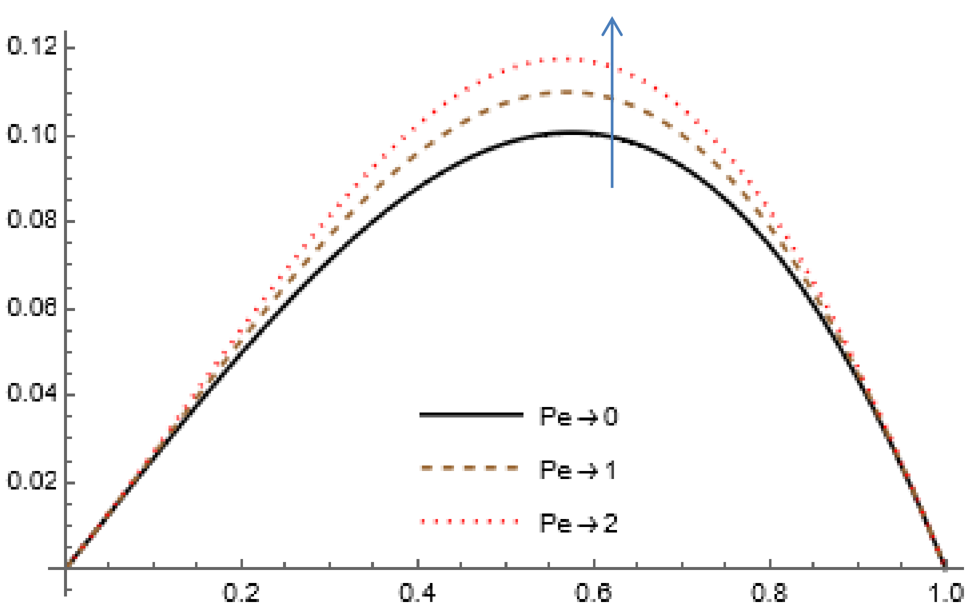

Fig 7 Velocity profile for Pe with $b = 0.03$, $We = 1$, $\mathrm{w} = 1$, $G_1 = 1$, $\mathrm{M} = 1$, $Re = 1$, $Da = 0.8$, $\mathrm{n} = 1$, $N = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

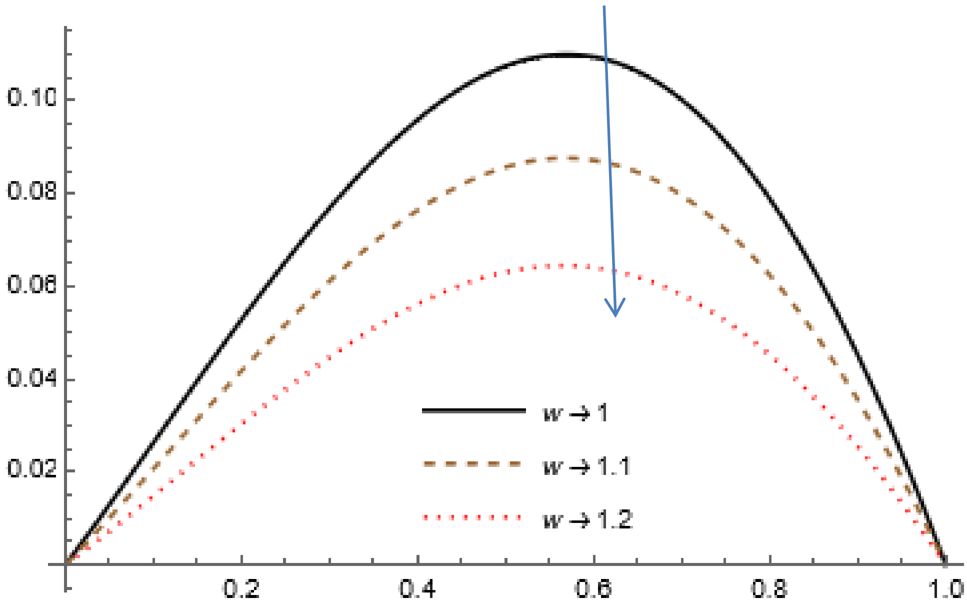

Fig 8 Profile of velocity for w with $b = 0.03$, $We = 1$, $Pe = 1$, $G_1 = 1$, $\mathrm{M} = 1$, $Re = 1$, $Da = 0.8$, $\mathrm{n} = 1$, $N = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

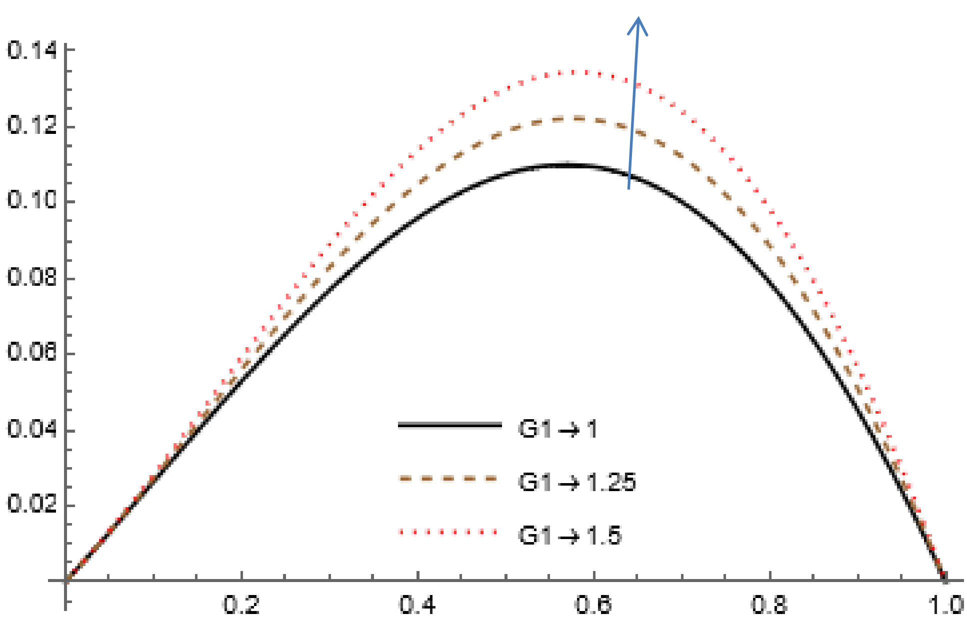

Fig 9 Velocity profile for G_1 with $b = 0.03$, $We = 1$, $Pe = 1$, $\mathrm{w} = 1$, $\mathrm{M} = 1$, $Re = 1$, $Da = 0.8$, $\mathrm{n} = 1$, $N = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

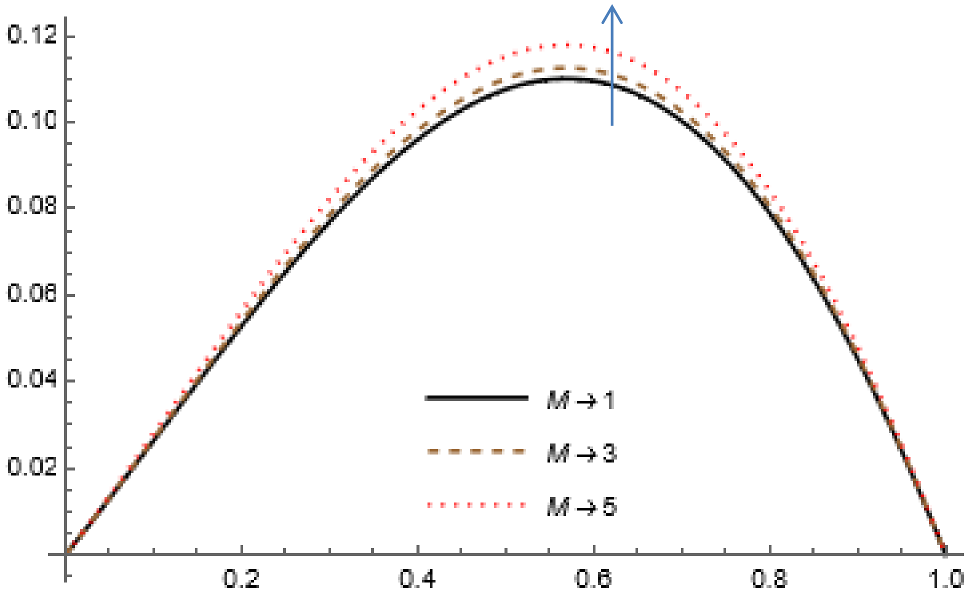

Fig 10 Profile of velocity for M with $b = 0.03$, $We = 1$, $Pe = 1$, w = 1, $G_1 = 1$, $Re = 1$, $Da = 0.8$, n = 1, $N = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

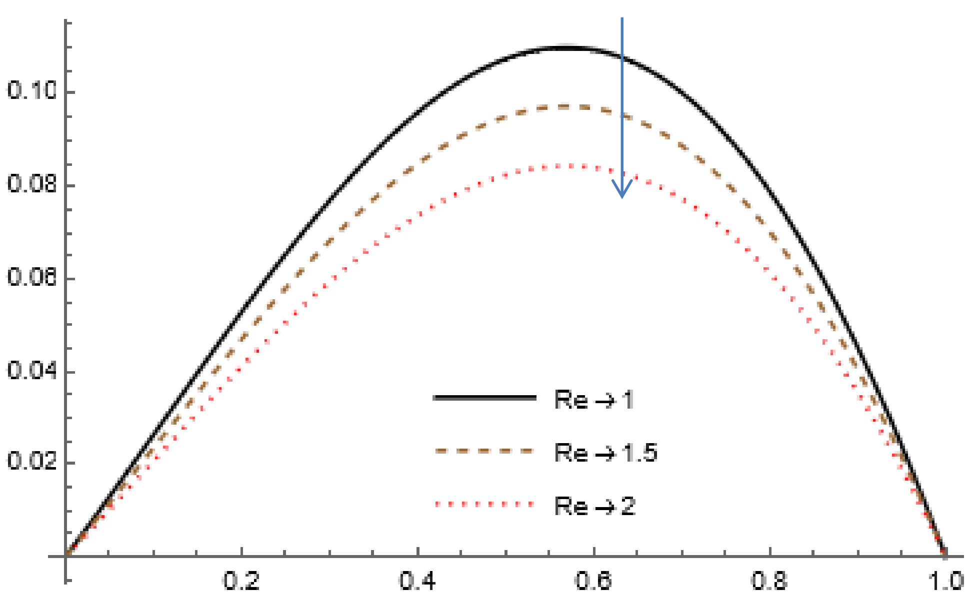

Fig 11 Velocity profile for Re with $b = 0.03$, $We = 1$, $Pe = 1$, w = 1, $G_1 = 1$, M = 1, $Da = 0.8$, n = 1, $N = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

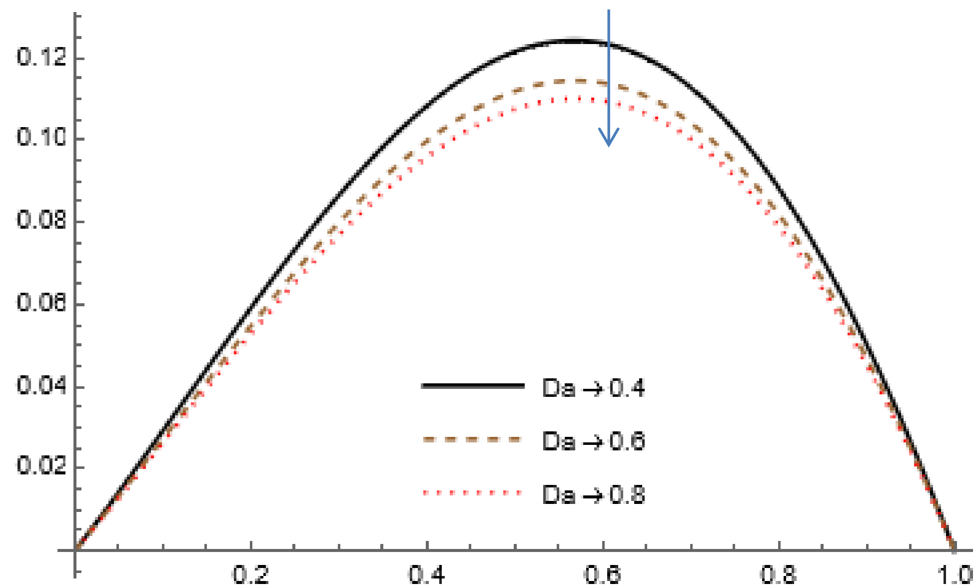

Fig 12 Velocity profile for Da with $b = 0.03$, $We = 1$, $Pe = 1$, w = 1, $G_1 = 1$, M = 1, $Re = 1$, n = 1, $N = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

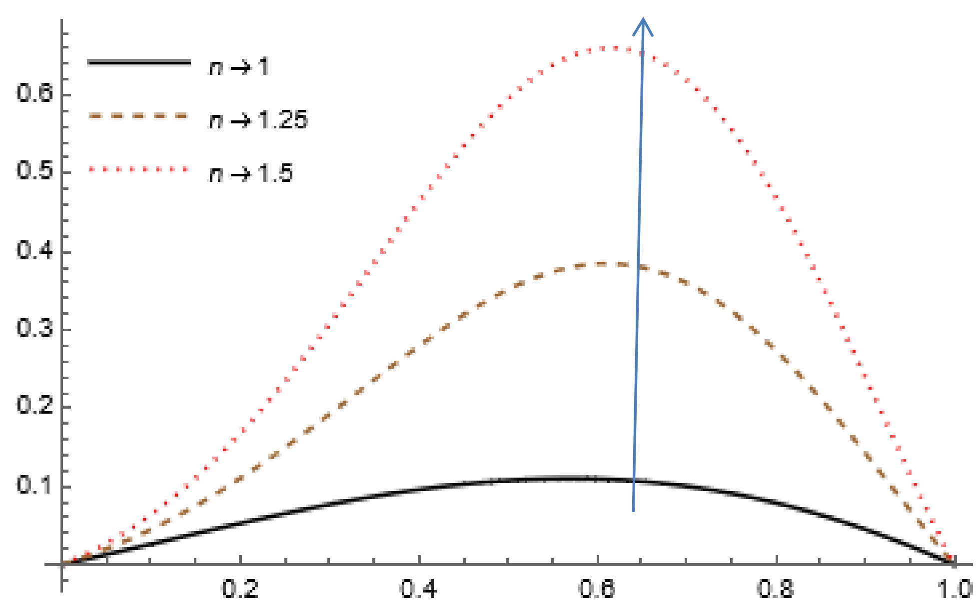

Fig 13 Profile of velocity for n with $b = 0.03$, $We = 1$, $Pe = 1$, w = 1, $G_1 = 1$, M = 1, $Re = 1$, $Da = 0.8$, $N = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

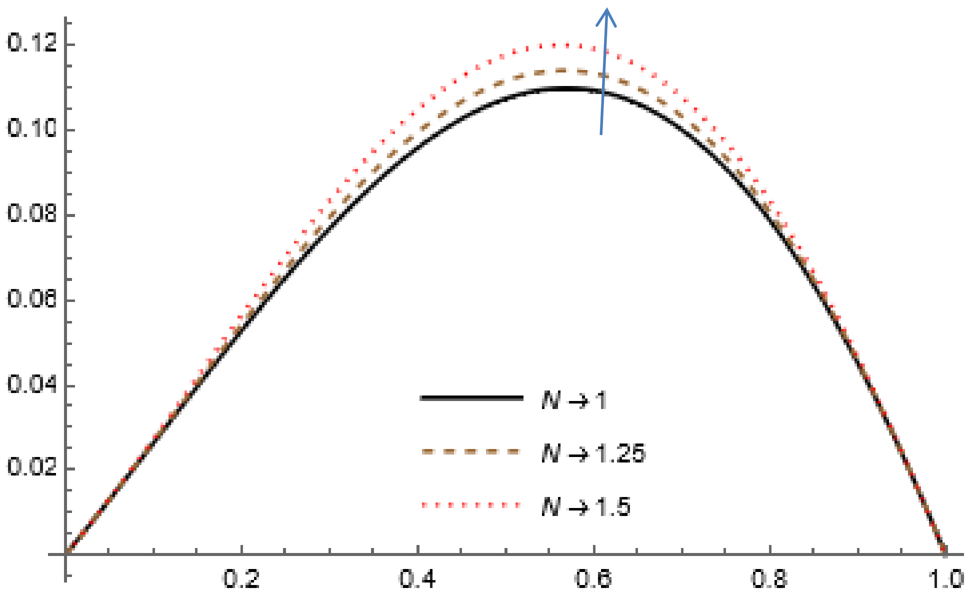

Fig 14 Profile of velocity for N with $b = 0.03$, $We = 1$, $Pe = 1$, $\mathrm{w} = 1$, $G_1 = 1$, $\mathrm{M} = 1$, $Re = 1$, $Da = 0.8$, $\mathrm{n} = 1$, $\lambda = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

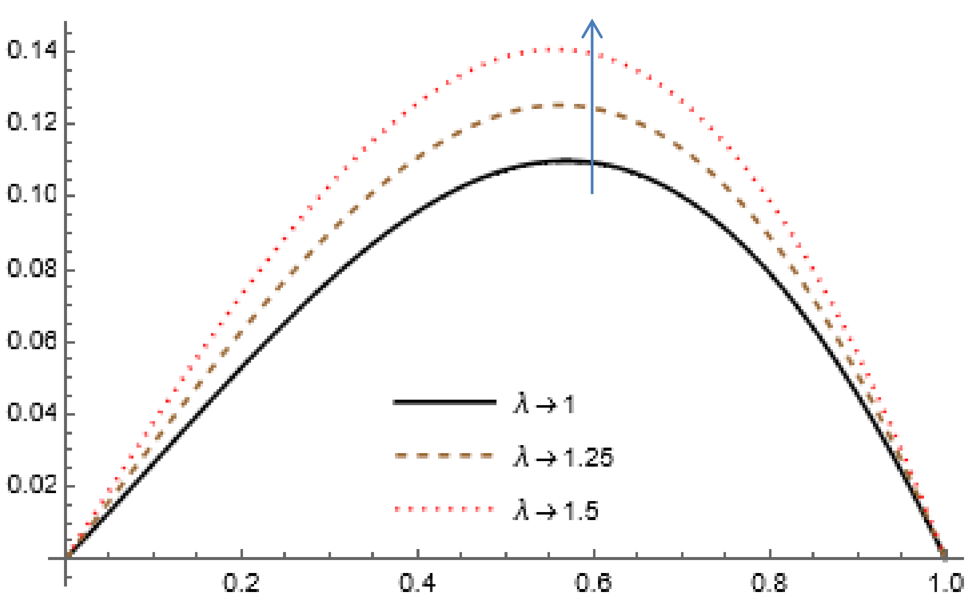

Fig 15 Profile of velocity for λ with $b = 0.03$, $We = 1$, $Pe = 1$, $\mathrm{w} = 1$, $G_1 = 1$, $\mathrm{M} = 1$, $Re = 1$, $Da = 0.8$, $\mathrm{n} = 1$, $N = 1$, $t = 0.5$, $z = 0.1$ in Couette flow.

5. Conclusions

We discussion the influence of magnetohydrodynamics oscillatory flow for Carreau fluid through regularly channel with varying temperature. We found the velocity and temperature are analytically.

We used different values to finding the results of pertinent parameters namely for the velocity and temperature (Re, , N,Da , Gr, λ, M, ω, We). The key point are:

- We show that by the increases W and Pe the temperature decreases θ and the temperature θ increasing by the increasing N.
- The velocity profiles increases by the increasing b,We, Pe ,G1,M,n, N, and λ for both the Poiseuille and Couette flow.
- The velocity profiles decreases by the increasing ω,Re and Da for both the Poiseuille and Couette flow.

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