Effects of The Rotation and A Magnetic Field on The Mixed Convection Heat Transfer Analysis for The Peristaltic Transport of Viscoplastic Fluid Through A Porous Medium in Asymmetric Channel

Hatem Nahi Mohaisen 1*, Ahmed M. Abdulhadi 2**

1Department of Mathematics ministers office, Ministry of High Education and Scientific Research, Iraq
2Department of Mathematics, College of Science, University of Baghdad, Iraq

Email: ha19652010@yahoo.com, ahm6161@yahoo.com

Abstract In this paper, we study the impact of the variable rotation, magnetic field and different variable such as the rate flow, Grashof number, Bingham number, Brinkman number, density, viscosity and … etc, on the mixed convection heat transfer analysis for the peristaltic transport of viscoplastic fluid through the porous medium, consideration small Reynolds number and long wavelength, peristaltic transport in asymmetric channel tapered horizontal channel and possess to different amplitude and phases difference. Series solutions for the axial velocity, stream function, stress at the upper and lower channels, temperature and pressure gradient. The impact of parameters discussion and illustrated graphically through the set of figures.

Keywords: peristaltic transport, heat transfer, porous medium, rotation, velocity, stream function, stress, magnetic field, viscoplastic.

1- Introduction

The transportation of fluid by a wave of contraction and expansion from a region of lower pressure to higher pressure is called peristaltic pumping. The study of peristaltic motion gained considerable interest because of its extensive use. It is an inherent property of many biological systems. In living systems, it is a distinctive pattern of smooth muscle contractions that propel the contents of the tube, as foodstuffs through esophagus and alimentary canal, urine from kidneys to bladder and other glandular ducts. The mechanism of peristaltic transport has been exploited for industrial applications like sanitary fluid transport, blood pumps in heart lung machine and transport of corrosive fluids where the contact of the fluid with the machinery parts is prohibited. Peristaltic transport of a toxic liquid is used in the nuclear industry to avoid contamination of the outside environment. The vast applications of peristalsis has been attracting the interests of researchers. There are several important research studies on the thermal analysis of MHD electro-osmotic peristaltic pumping of Casson fluid through a rotating asymmetric micro-channel [1], Peristaltic motion of Sisko fluid in an inclined asymmetric tapered channel with nonlinear radiation[2], magnetic field and rotation effects on peristaltic transport and effects of heat transfer in porosity space on the asymmetric [3-8,19], effect of an inclined magnetic field on peristaltic flow of Bingham plastic fluid in an inclined symmetric channel with slip conditions [9], effect of porous Medium and Magnetic Field, rotation and initial stress on peristaltic transport.
[10-14,16], Hall current and Joule heating effects on peristaltic flow of viscous fluid in a rotating channel with convective boundary conditions [15], mathematical analysis of heat transfer in peristaltic transport through a Rough non-uniform inclined channel [17], Mixed convective heat transfer analysis for the peristaltic transport of viscoplastic fluid: perturbation and numerical study [18,20], effect of a magnetic field on peristaltic transport of Bingham plastic fluid in a symmetric channel [21] and impact of heat and mass transfer on magneto hydrodynamic peristaltic flow having temperature-dependent properties in an inclined channel through porous media [22].

In the present paper, we investigated rotation and magnetic field effects of the mixed convection of heat transfer for the peristaltic transport in porosity space on an asymmetric channel using different value of the parameters of rotation and Hartmann number and permeability parameter and discussion the velocity, temperature, gradient pressure, variation of stress on two wall and stream function, further that study different value of Grashof, Brinkman and Bingham numbers.

2- Mathematical Formulation

Consider the flow incompressible magnetohydrodynamic (MHD) viscoplastic fluid in a two dimensional tapered asymmetric channel of width \((\mu g^{3365} + \mu g^{2869} \sqrt{\mu g^{2940}})\) through a porosity medium. Let us consider \(X, Y\) axes along and vertical to the flow respectively. The motion is made by sinusoidal wave sequences propagation with constant speed \((c)\) and wavelength of channel walls. See figure (1) given the schematic diagram of the asymmetric channel, while the \(T_2\) and \(T_1\) are the temperature at the upper and the lower walls respectively. The equations of walls geometry are presented by:

\[
\begin{align*}
\bar{H}_1 (\bar{X}, \bar{T}) &= a_1 + \alpha \cos \left( \frac{2 \pi X}{\lambda} - cT \right) \quad \text{Upper wall} \quad (1) \\
\bar{H}_2 (\bar{X}, \bar{T}) &= -a_2 - \beta \cos \left( \frac{2 \pi X}{\lambda} - cT + \phi \right) \quad \text{Lowe wall} \quad (2)
\end{align*}
\]

Where \(a_1\) and \(a_2\) are the width of channel, \(\alpha\) and \(\beta\) are the amplitudes wave, the wavelength is \(\lambda\), the time is \(\bar{T}\), \(\phi\) is the phase difference with range \((0 \leq \phi \leq \pi)\), in which \((\phi = 0)\) matches up to the symmetric channel with wave out of phase while \((\phi = \pi)\) matches up to the waves in phase. The following parameters \(a_1, a_2, \alpha, \beta\) and \(\phi\) satisfying the condition:

\[
\alpha^2 + \beta^2 + 2 \alpha \beta \leq (a_1 + a_2)^2
\]

3- Fundamental Equation

Figure (1) Schematic diagram of problem
The governing equation for the conservation of mass, momentum and energy equation of fluid in a symmetric channel there are three couple non-linear differential equations can be written as:

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \quad \text{(this continuity equation)}
\]

\[
\rho \frac{\partial \mathbf{v}}{\partial t} + \rho \mathbf{v} \cdot \nabla \mathbf{v} = -\nabla p + \nabla \cdot \mathbf{T} + \rho \mathbf{g}
\]  \hspace{1cm} \text{(momentum equation on x-axes)}

\[
\rho \frac{\partial E}{\partial t} + \rho \mathbf{v} \cdot \nabla E = \nabla \cdot (k \nabla T) + \frac{1}{2} \frac{d}{dt} \left( \mathbf{v} \cdot \mathbf{v} \right)
\]  \hspace{1cm} \text{(energy equation)}

From equations (9,10), the components of extra stress tensor become in laboratory frame:

\[
\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot (\rho \mathbf{v} 
abla \mathbf{v}) = \nabla \cdot (\mathbf{T} + \rho \mathbf{g}) + \nabla \cdot \mathbf{S} \quad \text{(in equation (9) the yield stress is } \tau_0, \text{ the rate of deformation tensor } \omega, \text{ } \hat{\omega} \text{ the tensor are defined:)}
\]

\[
\omega = \frac{1}{\rho} \nabla \mathbf{P} + \frac{\hat{S}}{2}
\]

\[
\hat{S} = 2 \mu \omega + 2 \tau_0 \hat{\omega}
\]

\[
\nabla \cdot \mathbf{S} = 2 \mu \partial \mathbf{v} + \nabla \cdot \left( \nabla \mathbf{v} \right)
\]

(11)

The components of extra stress tensor become in laboratory frame:

\[
\mathbf{S}_{xx} = 2 \mu \omega_{xx} + \frac{2 \tau_0}{\sqrt{\tau_0}} \omega_{xx} \cdot \mathbf{u}_{xx} \cdot \mathbf{u}_{xx} = 2 \mu \omega_{xx} + \frac{2 \tau_0}{\sqrt{\tau_0}} \omega_{xx} \cdot \mathbf{u}_{xx} \cdot \mathbf{u}_{xx}
\]

(12)

In natural the motion peristaltic is unsteady, we can assume steady by using transformation from laboratory frame \((\mathbf{x}, \mathbf{y})\) to wave frame \((\mathbf{X}, \mathbf{Y})\) which defined as [18]

\[
\mathbf{x} = \mathbf{x} + \mathbf{c} t, \quad \mathbf{y} = \mathbf{y} + \mathbf{c} t, \quad \mathbf{U}(\mathbf{X}, \mathbf{Y}, t) = \mathbf{U}(\mathbf{x}, \mathbf{y}, t) + \mathbf{c}, \quad \mathbf{V}(\mathbf{X}, \mathbf{Y}, t) = \mathbf{V}(\mathbf{x}, \mathbf{y}, t),
\]

(13)

\[
\mathbf{u}, \mathbf{v}, \mathbf{p} \text{ are components of velocity and pressure in frame wave respectively. Now, we transform equations (1), (2) and (4-6), (11) and (12) in wave frame with help equation (13) and normalization the result by using the following dimensionless variables:}
\]

\[
\mathbf{X} = \frac{X}{h}, \quad \mathbf{Y} = \frac{Y}{h}, \quad \mathbf{u} = \frac{U}{c}, \quad \mathbf{v} = \frac{V}{c}, \quad \mathbf{p} = \frac{P}{\mu \rho h^2}, \quad \mathbf{h}_1 = \frac{h_1}{h}, \quad \mathbf{h}_2 = \frac{h_2}{h}, \quad \mathbf{t} = \frac{t}{c}, \quad \mathbf{S} = \frac{s}{h}, \quad \mathbf{Re} = \frac{\rho c h}{\mu}, \quad \mathbf{A} = \frac{a_1}{a_2}, \quad \mathbf{B} = \frac{b_1}{b_2}, \quad \mathbf{S} = \frac{a_1 s_1}{a_2}, \quad \mathbf{M}^2 = \frac{a_1 b_1 b_2}{\mu h^2}, \quad \mathbf{GR} = \frac{g \rho c a_2 (T_1 - T_0)}{\mu c}, \quad \mathbf{B} = \frac{T - T_0}{T_1 - T_0} \quad \mathbf{K}_0 = \frac{E_0}{a_2}, \quad \mathbf{BN} = \frac{a_1 T_0}{h}, \quad \mathbf{Pr} = \frac{\mu^2 c}{h^2}, \quad \mathbf{Ec} = \frac{c^2}{\epsilon_0 T_0}, \quad \mathbf{BR} = \frac{\mathbf{Pr}}{\mathbf{Ec}}.
\]

(14)
\( \theta \) is the temperature, GR Grashof number. Substituting equation (14) with equations (1), (2) and equations (4)-(7), and if \( \psi(x, y, t) \) is stream function. The velocity components in term of stream function are:

\[
\begin{align*}
  u &= \psi + \text{\textmu}g2^935 \\
  v &= \text{-} \delta \psi + \text{\textmu}g2^935
\end{align*}
\]  
(15)

in view of the lubrication approach method and stream function equation (15) with equations (1), (2) and (4)-(7), we obtain the equations:

\[
\begin{align*}
  h_1 &= 1 + \alpha \cos[2\pi x] \\
  h_2 &= -1 - \beta \cos[2\pi x + \phi] \\
  \frac{\partial p}{\partial x} &= \frac{\partial^2}{\partial y^2} \psi + \text{\textmu}g2^935 + \text{GR} \theta - \left( M^2 + \frac{1}{k_0} \right) \psi_y + \frac{1}{k_0} \\
  \frac{\partial p}{\partial y} &= 0 \\
  \frac{\partial^2 \theta}{\partial y^2} + \text{BR} S_{yy} \psi &= 0
\end{align*}
\]  
(16)-(19)

The stress component of Bingham plastic fluid is:

\[
S_{xy} = \psi + \text{\textmu}g2^935
\]  
(20)

Substituting equation (21) in (18) and (20) and eliminated pressure between (18) and (19) by derivative with respect to \( y \) we obtain the final equation:

\[
\begin{align*}
  \frac{\partial^2}{\partial y^2} \psi_y + \frac{\partial^2}{\partial y^2} \left( \psi_y + \text{BN} \right) + \text{GR} \frac{\partial \theta}{\partial y} - \left( M^2 + \frac{1}{k_0} \right) \psi_y &= 0 \\
  \frac{\partial^2 \theta}{\partial y^2} + \text{BR} \left( \psi^2 + \text{BN} \psi \right) &= 0
\end{align*}
\]  
(21)-(22)

The boundary conditions and dimensionless volume flow rate in wave frame are [24]

\[
\begin{align*}
  \psi &= \text{\textmu}g2^89\omega \text{\textmu}g2^2√\omega, \quad \mu_2 \mu_3 \mu_4 \mu_5 \mu_6 \mu_7 \\
  \theta &= \text{-} 1, \quad \theta = 0, \quad \text{at} \ y = h_1, \\
  \psi &= \text{\textmu}g2^89\omega \text{\textmu}g2^2√\omega, \quad \mu_2 \mu_3 \mu_4 \mu_5 \mu_6 \mu_7 \\
  \theta &= \text{-} 1, \quad \theta = 0, \quad \text{at} \ y = -h_2, \\
  F &= \int_{-h_2}^{h_1} \frac{\partial \psi}{\partial y} dy = \psi(h_1) - \psi(-h_2) = q - 2
\end{align*}
\]  
(23)-(26)

Where \( q \) & \( F \) are dimensionless mean flow rates in the fixed and wave frames respectively. The \( \Delta P_\lambda \) is the pressure rise per wavelength defined as

\[
\Delta P_\lambda = \int_0^1 \frac{dp}{dx} dx
\]  
(27)

4- Method of the solution

We dependent the perturbation method for the analytical solution of the equations, using the this expressions:

\[
\begin{align*}
  \psi &= \sum_{i=0}^{\mu} \psi_i(GR)^i + \text{BN} \sum_{i=0}^{\mu} \psi_{11}(GR)^i + O(BN^2) \\
  \theta &= \sum_{i=0}^{\mu} \theta_i(GR)^i + \text{BN} \sum_{i=0}^{\mu} \theta_{11}(GR)^i + O(BN^2)
\end{align*}
\]  
(28)-(29)

4.1- Zeroth Order System
\[ \frac{\partial^4}{\partial y^4} \psi_{00} + k \frac{\partial^2}{\partial y^2} \psi_{00} - A^2 \frac{\partial^2}{\partial y^2} \psi_{00} = 0 \]  
\[ (30) \]

\[ \frac{\partial^2}{\partial y^2} \theta_{00} + BR(\psi_{00})^2 = 0 \]  
\[ (31) \]

For example of the zeroth order:
\[ \psi_{00} = e^{-\frac{\sqrt{\tau}}{2\sqrt{\nu}}(\alpha^2 - \beta^2) t_{12}} + t_{3} + y \cdot t_{4} ; \theta_{00} = -\frac{1}{2} BR(\frac{\psi_{00}^2}{2(A-k)}) + e^{-\frac{2\sqrt{\tau}}{A-k} t_{12}} + 2t_{12}y^2 \]  
where \((t_{1}-t_{6})\) are integral constant.

The boundary condition are \(\psi_{00}(h_1) = q/2, \psi_{00}(h_2) = -q/2, \psi_{00y}(h_1) = -1, \psi_{00y}(h_2) = -1, \theta_{00}(h_1) = 0, \theta_{00}(h_2) = 0, \)

4.2- First Order System

\[ \frac{\partial^4}{\partial y^4} \psi_{01} + k \frac{\partial^2}{\partial y^2} \psi_{01} - A^2 \frac{\partial^2}{\partial y^2} \psi_{01} + \frac{\partial}{\partial y} \theta_{00} = 0 \]  
\[ (32) \]

\[ \frac{\partial^2}{\partial y^2} \theta_{01} + 2BR(\frac{\partial^2}{\partial y^2} \psi_{00})(\frac{\partial^2}{\partial y^2} \psi_{01}) = 0 \]  
\[ (33) \]

For example of First order
\[ \psi_{01} = \frac{BR(\frac{\psi_{00}}{2(A-k)} + 16(A-k)t_{6}y^2 - 4BR(\frac{\psi_{00}}{2(A-k)}t_{12}y^2 + 12e^{-\frac{\sqrt{\tau}}{2\sqrt{\nu}}(A-k)t_{12}} + t_{9} + y \cdot t_{10})}{2(A-k)^2} \]

\[ \theta_{01} = \frac{1}{3(A-k)^2} BR(\frac{\psi_{00}}{2(A-k)}t_{12} + 3e^{-\sqrt{\tau}}(\frac{\sqrt{\tau}}{25BRt_{12} + 6\sqrt{\nu}t_{12} + 25BRt_{12} + 6\sqrt{\nu}t_{12}} - 12BRt_{12}y) - e^{-\frac{\sqrt{\tau}}{2\sqrt{\nu}}(A-k)t_{12}} + 12BRt_{12}y) + t_{11} + y \cdot t_{12} \]

Where \((t_{7}-t_{12})\) integral constant, the boundary condition \(\psi_{01}(h_1) = 0, \psi_{01}(h_2) = 0, \theta_{01}(h_1) = 0, \theta_{01}(h_2) = 0, \psi_{01y}(h_2) = 0, \theta_{01y}(h_2) = 0, \)

5- Result and Discussion

In this problem we study and discuss the behavior for velocity, gradient pressure, temperature, stress on upper and lower walls and the stream function using different parameters.

5.1- Velocity Behavior

Using different parameters to show distribution of the velocity. The change of the velocity for different values of \(a, b, k_1, M, GR, \phi, \Omega, \alpha_1, BR, \mu, p\) are shown in figure (2) from (A) to the (L) notes that the profile of velocity is parabolic and increasing at the center of channel mostly. The effect of \(q\) on the velocity for decreasing value leads to increasing of velocity near the channel walls and are merge with other at the center, as well as in the case change value of \(M\), either in the case \(GR, BR, k_1 \) and \(\Omega\) are merge at center and near the channel walls if there is values increasing. The density and viscosity the velocity not effect, when
decreasing value of $\mu g^2\omega^9$ leads to increasing velocity from lower part of channel and merge at the center line to upper part, either in the case of $\mu g^2\omega^8\tau^2\omega$ its conversely. When increasing value of $\phi$ leads to increasing velocity from lower part of channel and merge at the center line to upper part, and $\mu g^2\omega^8\phi$ when decreasing leads to increasing of the velocity.

5.2- Gradient Pressure Behavior

The effect of different parameters $\alpha$, $\beta$, $k_1$, $M$, $GR$, $BN$, $\phi$, $q$, $\Omega$, $a_1$, $BR$, $\mu$ and $\rho$ on gradient pressure is clearly in figure (3) from (A) to the (L) notes that the increasing values of $GR$, $BR$, $\alpha$, $\beta$, $a_1$ and $\Omega$ lead to increasing of the gradient pressure and most of cases the high value at the center of channel, either of cases $\phi$, $q$, $M$ and $k_1$ the decreasing value of these parameters leads to increasing the gradient pressure while the parameters $BN$, $\mu$ and $\rho$ not effect for every different value.

5.3- Temperature Distribution

The heat transfer phenomenon is appear clearly in figure (4) from (A) to the (L), the effect of parameters $\alpha$, $\beta$, $k_1$, $M$, $BN$, $\phi$, $q$, $\Omega$, $a_1$, $BR$, $\mu$ and $\rho$ are discuss, when increasing values of $\alpha$, $\beta$, $BR$ and $\Omega$ leads to increasing of the temperature while increasing values of $M$, $\phi$ and $a_1$ leads that decreasing value of temperature, either to the change of values of $BN$ is different from the lower and upper walls while merge at the center, as well as $k_1$ are merge from the lower part passed the center to the upper part, choose an appropriate value of parameter $q$ generates the highest temperature value, the change values of $\mu$ and $\rho$ not different temperature for choosing different values. Generally the value of temperature is highest at the center of channel.

5.4- Stress profile

The influence values of the parameters $\alpha$, $\beta$, $k_1$, $M$, $BN$, $\phi$, $q$, $\Omega$, $a_1$, $BR$, $\mu$ and $\rho$ on the upper wall appearing in figure (5) from (A) to the (L), notes the increasing values of $BN$, $GR$, $BR$, $\alpha$, $\beta$, $k_1$, $\Omega$ and $a_1$ leads to increasing value of stress at this wall, while decreasing stress in cases of $q$, $M$, $\phi$, either in cases of $\mu$ and $\rho$ not effect stress when change values of this parameters. Either case of the lower wall clearly in figure (6) from (A) to the (L), the behavior conversely of the upper wall. Generally the value of stress is highest before arrived the center of the channel for both the lower and upper wall.

5.5- trapping phenomenon

Trapping is an important phenomenon in peristaltic transport. The shape of streamlines is similar to the shape of a waves movement through channel walls. A phenomenon in which these streamlines divided and surround a bolus which traveling as a whole under specific condition. Streamlines conduct for different parameters $\alpha$, $\beta$, $k_1$, $M$, $GR$, $\phi$, $q$, $\Omega$, $a_1$ and $BR$ is clear in figure (7) from (A) to the (D1). When increasing $\alpha$ we observed that the boluses dissolve and turn into zigzag waves, increasing value of $GR$, we notes that the bolus get bigger and then disappear and turn into winding waves. When the $BR$, $\beta$, $\phi$, $\Omega$, $a_1$, $M$, $k_1$ values are increasing, the wave expands and the number of boluses decreasing, while increasing $q$ value no bolus appeared, and dilation occurs.

6. Conclusion

In this reseach, we studied the effect of the rotation and magnetic field on mixed convection heat transfer analysis peristaltic flow of the viscoplastic through the tapered horizontal asymmetric channel through the porous medium. The channel asymmetric is produced by choosing the peristaltic waves have different amplitude and phases, low Renolds number and along wavelength. We adopt the perturbation method to
obtain the expression of the axial velocity, stream function, stress, temperature and pressure gradient. A parametric analysis is performed through various graphs.

A- notes that the profile of velocity is parabolic and increasing at the center of channel mostly.

B- In case of trapping When increasing α we observed that the boluses dissolve and turn into zigzag waves, increasing value of GR, we notes that the bolus get bigger and then disappear and turn into winding waves. When the BR, β, ϕ, Ω, aμg, M and k1 values are increasing, the wave expands and the number of boluses decreasing, while increasing q value no bolus appeared, and dilation occurs.

C- The stress distribution notes the increasing values of BN, GR, BR, α, β, k1, Ω and a1 leads to increasing value of stress at this wall, while decreasing stress in cases of q, M, ϕ, either in cases of μ and ρ not effect stress when change values of this parameters. Either case of the lower wall clearly the behavior conversely of the upper wall. Generally the value of stress is highest before arrived the center of the channel for both the lower and upper wall.

D- Temperature profile, Generally the value of temperature is highest at the center of channel.

E- In case of the pressure gradient notes that the increasing values of GR, BR, α, β, a1 and Ω lead to increasing of the gradient pressure and most of cases the high value at the center of channel, either of cases ϕ, q, M and k1 the decreasing value of these parameters leads to increasing the gradient pressure.

F- The density and viscosity are not changed because the fluid incompressible.

α= 0.4, BN= 2.0, k1=0.2, M=5.0, GR=0.2, β=0.3, ϕ=Pi/4, q=1.6, Ω=0.2, a1=1.0, BR=0.4, μ = 2.0, ρ = 0.9.
Figure (2) Represented Velocity With Different Parameters
\( \alpha = 0.4, \, B_1 = 2.0, \, k_1 = 0.2, \, M = 5.0, \, \Gamma = 0.2, \, \beta = 0.3, \, \phi = \pi/4, \, q = 1.6, \, \Omega = 0.2, \, a_1 = 1.0, \, B_R = 0.4, \, \mu = 2.0, \, \rho = 0.9. \)
\( \alpha = 0.4, \quad BN = 2.0, \quad k1 = 0.2, \quad M = 5.0, \quad GR = 0.2, \quad \beta = 0.3, \quad \phi = \pi/4, \quad q = 1.6, \quad \Omega = 0.2, \quad a1 = 1.0, \quad BR = 0.4, \mu = 2.0, \quad \rho = 0.9. \)
Figure (4) Represented Temperature With Different Parameters
\[ \alpha = 0.4, B_{\text{N}} = 2.0, k_1 = 0.2, M = 5.0, GR = 0.2, \beta = 0.3, \phi = \pi/4, q = 1.6, \Omega = 0.2, \]
\[ a_1 = 1.0, BR = 0.4, \mu = 2.0, \rho = 0.9. \]

The stress when \( y \to a_1 + \alpha \cos(2 \pi x) \)
stress when \( y \to -a_1 - \beta \cdot \cos(2 \cdot \pi \cdot x + \phi) \)
Figure (6) Represented Stress Over to Lower Channel With Different Parameters

$\text{GR} = 0.2$, $\text{BR} = 0.4$, $\text{M} = 5.0$, $k_1 = 0.2$, $\alpha = 0.4$, $\beta = 0.3$, $\phi = \pi/4$, $q = 1.6$, $\mu = 2.0$, $\Omega = 0.2$, $a_1 = 1.0$, $\rho = 0.9$
Figure (7) Represented Stream Function With Different Parameters

Reference

[1] Kattamreddy Venugopal Reddy, Oluwole Daniel Makinde & Machireddy Ganeswara Reddy,(2018), Thermal analysis of MHD electro-osmotic peristaltic pumping of Casson fluid through a rotating asymmetric micro-channel, Indian Journal of Physics volume 92, pages1439–1448.
[2] Tasawar Hayat, Javaria Akram, Hina Zahir & Ahmed Alsaedi, (2019), Peristaltic motion of Sisko fluid in an inclined asymmetric tapered channel with nonlinear radiation, *Journal of Thermal Analysis and Calorimetry* volume 138, pages545–558.

[3] A. Abd-Alla, S. M. Abo-Dahab, (2015), Magnetic field and rotation effects on peristaltic transport of a Jeffrey fluid in an asymmetric channel, *Journal of Magnetism and Magnetic Materials*, Volume 374, pp.680-689.

[4] M. Kothandapani, J. Prakash, V. Pushparag, (2015), Effects of heat transfer, Magnetic field and space porosity on peristaltic flow of an a Newtonian fluid in a tapered channel, *Applied Mechanics and Materials*, Vols 813-814, pp 679-684.

[5] T. Hayat, H. Zahir, Anum Tanveer, A. Alsaedi, (2016), Numerical study for MHD peristaltic flow in a rotating frame, *Computers in Biology and Medicine*, Volume 79, Pages 215-221.

[6] A.M. Abd-Alla, S.M. Abo-Dahab, Abdullah Alsharif, (2017), Peristaltic transport of a Jeffrey fluid under the effect of gravity field and rotation in an asymmetric channel with magnetic field, *Multidiscipline Modeling in Materials and Structures*, Vol. 13 No. 4, pp. 522-538.

[7] M. Veera Krishna, (2020), Hall and ion slip impacts on unsteady MHD free convective rotating flow of Jeffreys fluid with ramped wall temperature, *International Communications in Heat and Mass Transfer*, Volume 119, December 2020.

[8] A.M. Abd-Alla, S.M. Abo-Dahab, M. Elsagheer, (2017) "Influence of magnetic field and heat and mass transfer on the peristaltic flow through a porous rotating medium with compliant walls", *Multidiscipline Modeling in Materials and Structures*, Vol. 13 Issue: 4, pp.648-663.

[9] F. A. Adnan, A. M. Abdulhadi, (2019), Effect of an inclined magnetic field on peristaltic flow of Bingham plastic fluid in an inclined symmetric channel with slip conditions, *Iraqi Journal of Science*, Vol. 60, No.7, pp: 1551-1574.

[10] S. R. Mahmoud, N. A. S. Afifi and H. M. Al-Isede, (2011), Effect of Porous Medium and Magnetic Field on Peristaltic Transport of a Jeffrey Fluid, *Int. Journal of Math. Analysis*, Vol. 5, no. 21, pp 1025 – 1034.

[11] A.M. Abd-Alla, G.A. Yahya, S.R. Mahmoud, H.S. Alosaimi, (2012), Effect of the rotation, magnetic field and initial stress on peristaltic motion of micropolar fluid, *Mechanica* vol.47, pp 1455–1465.

[12] Tamara Sh. Ahmed, (2018), Effect of Inclined Magnetic Field on Peristaltic Flow of Carreau Fluid through Porous Medium in an Inclined Tapered Asymmetric Channel, *Al-Mustansiriyah Journal of Science*, Volume 29, Issue 3.

[13] M. R. Salman, A M. Abdulhadi, (2018), Effects of MHD on Peristalsis Transport and Heat Transfer with Variables Viscosity in Porous Medium, *International Journal of Science and Research (IJSR)*, Volume 7 Issue 2.

[14] A. M. Abdulhadi, Aya H. Al-Hadad, (2016), Effects of rotation and MHD on the Nonlinear Peristaltic Flow of a Jeffrey Fluid in an Asymmetric Channel through a Porous Medium, *Iraqi Journal of Science*, Vol. 57, No.1A, pp: 223-240.

[15] Hayat, T. Zahir, H. Alsaedi, A. Ahmad, B., (2017), Hall current and Joule heating effects on peristaltic flow of viscous fluid in a rotating channel with convective boundary conditions, *Results in Physics*.

[16] T Sh Alshareef, (2020), Impress of rotation and an inclined MHD on waveform motion of the non-Newtonian fluid through porous canal, *Journal of Physics: Conference Series*, 1591 (2020), IOP Publishing.

[17] R. Shukla, A. Medhavi, S. S. Bhatt, and R. Kumar, (2020), Mathematical Analysis of Heat Transfer in Peristaltic Transport through a Rough Non-uniform Inclined Channel, *Hindawi Mathematical Problems in Engineering*, Volume 2020.

[18] Zaheer Asghar, Nasir Ali, (2019). Mixed convective heat transfer analysis for the peristaltic transport of viscoplastic fluid: perturbation and numerical study, AIP Advances 9, 095001 (2019); doi: 10.1063/1.5118846.

[19] A. Tanveer, M.Y. Malik, (2021), Slip and porosity effects on peristalsis of MHD Ree-Eyring nanofluid incurved geometry, *Ain Shams Engineering Journal* 12 (2021) 955–968.
[20] M.A. Murad and A.M. Abdulhadi, (2020). Influence of MHD on mixed convective heat and mass transfer analysis for the peristaltic transport of viscoplastic fluid with porous medium in tapered channel, Journal of Al-Qadisiyah for Computer Science and Mathematics, Vol.12(4), pp 79-90.

[21] F. A. Adnan, A. M. Abdulhadi, (2019), EFFECT OF A MAGNETIC FIELD ON PERISTALTIC TRANSPORT OF BINGHAM PLASTIC FLUID IN A SYMMETRIC CHANNEL, Sci. Int. (Lahore), 31 (1), pp 29-40.

[22] R. S. Kareem and A.M. Abdulhadi, 2020. Impact of Heat and Mass Transfer on Magneto Hydrodynamic Peristaltic Flow Having Temperature-dependent Properties in an Inclined Channel Through Porous Media, Iraqi Journal of Science, 2020, Vol. 61, No. 4, pp: 854-869.

[23] Y. Wang, Acta Mechanica 186, 187 (2006).

[24] N. Ali, T. Hayat, and Y. Wang, International Journal Numer. Method Fluid 64, 992 (2009).