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Impact of Thermal Radiation and Heat Source on MHD Blood Flow with an Inclined Magnetic Field in Treating Tumor and Low Blood Pressure

Ekakitie Omamoke[1*], Emeka Amos[2] and Efere Jatari[3]

[1]*Department of Mathematics, Bayelsa Medical University, Bayelsa State, Nigeria.*
[2]*Department of Mathematics, Rivers State University, Port Harcourt, Nigeria.*
[3]*Department of Physics, Bayelsa Medical University, Bayelsa State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

In this paper, we will be analyzing the impact of thermal radiation and heat source on blood flow past a horizontal channel that is permeable with an applied magnetic field that is inclined at variable angles. The non-linear higher partial differential equation which is the governing equation is transformed to ordinary differential equations using non-dimensional variable to non-dimensional equations that is then solved analytically with the application of required boundary conditions for the blood flow and temperature equations which is a function of y and t. Parameters that are varied shows an effect on the blood flow and temperature profile with the presentation of results shown graphically and results clearly discussed. Observations from the research shows that when the thermal radiation increases, there will be a mixed effect in the flow of blood, increase in the magnetic field on the artery shows an increase in flow of blood while the blood flow reduces and the temperature of the blood increases when the heat source is increased. Other parameters also shows an effect on the flow of the blood.

*Corresponding author: E-mail: omamoke.ekakitie@bmu.edu.ng, ekakitieomamoke@gmail.com;

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1 Introduction

There is a rich application of MHD in the medical sciences, sciences, biomedical engineering and others as a result of its dealings with the flow of fluid that conducts electricity in a magnetic field present. Mediums that are permeable have pores which affects the flow of fluids. Application of permeability in bio fluids, tissues and organs are of a necessity in modern research. Pressure is created when the heart pumps blood for proper circulation helping to provide oxygen and required nutrients for both tissues and body organs. Tissue necrosis, bone necrosis, pain, infraction of body organs can be experienced when there is a blockage in the artery as a result of stenosis, atherosclerosis, occlusion etc. Kolin [1] did the first study on the principles of electromagnetic flow with application in measurement of flow of blood which was later extended by Korchevskii and Marochnick [2] who used MHD device in the treatment of cardiovascular disease by reducing the velocity flow. These studies further showed that MHD devices can be used in treating certain ailments.

A model on pulsatile blood flow in a bed that is homogenous and porous in the presence of an inclined magnetic field with time suction was carried out by Ogulu and Amos [3]. Muhammed Usman and Syed Tauseef Mohyud Din [4] did a study investigating fluid flow and heat transfer of blood that has Nano-particles through a vessel that is porous with the presence of a magnetic field while Asma Khalid [5] did a study on MHD blood flow whose medium is porous and has carbon Nano-tubes and thermal analysis. His research showed that when the carbon-nanotubes volume is increased, there is an increase in the velocity and the temperature. Prakash [6] did a research studying how heat source will affect MHD Blood flow through an artery that is bifurcated. His research showed that heat source and magnetic field will have a modified effect on the flow of the fluid and also increase the blood temperature. Tripathy and Kumar [7] used a mathematical model to show how blood will flow through an artery inclined with a magnetic field that is also inclined with observation that heat and mass transfer shows an effect on two phase pulsatile blood flow through a narrow stenosis artery. Neetu Srivastava [8] did a research that analyzed the flow characteristics of blood that is flowing through a tapered artery that is with mild stenosis, porous and inclined at an angle. Tzirtzilakis [9] did a mathematical model for the flow of blood in a magnetic field. Blessy Thomas and Suman [10] did a review on flow of blood in human arterial systems using models for fluid structure and blood flow and simulated the flow of blood with the view in structure and function of veins and arteries. Latha and Kumar [11] did a research that studied MHD unsteady flow of blood through a medium that is porous in a plate channel that is parallel and Vincent et al. [12] did a study of velocity profile for unsteady blood flow through a tube that is circular and inclined in the presence of a magnetic field. Tripathy and Sharma [13] did a research that studied the effect of variable viscosity on MHD inclined arterial flow of blood with chemical reaction present while Islam Eldesoky [14] did a mathematical analysis of MHD flow of blood that is unsteady through a channel plate that is parallel with heat source present. His research showed shows that when there is an increase in the heat source, the axial velocity and the temperature will increase while the normal velocity and Prandtl number decreases with an increase in the decay parameter.

In this paper, the objective is to study using a mathematical model, the treatment of strokes and pain resulting from sickle cell anemia and the treatment of low blood pressure, using magnetic field inclined at varying angles and also treatment of tumors with thermal radiation.

2 Mathematical Formulation

The medium where the blood that is flowing is incompressible fluid is said to be permeable with a viscosity that is constant. In this mathematical model, the effect of thermal radiation, heat source and magnetic field that is inclined applied to the artery with blood flowing will be considered. In the equations below, B_0 is the magnetic field, S is the heat source, K is the permeability of the porous medium, q_r' is radiative heat flux, u and v are velocities, x and y are Cartesian coordinates, α is angle of inclination of magnetic field, t is time,

θ is temperature, g is acceleration due to gravity, λ is decay value, C_p is specific heat capacity, M is magnetic parameter, Pr is Prandtl number, δ_c is electrical conductivity, ρ is density of the blood, β_T is coefficient of volume expansion for temperature, β_C is coefficient of volume expansion for concentration, R is radiation parameter and L is diameter of porous medium.

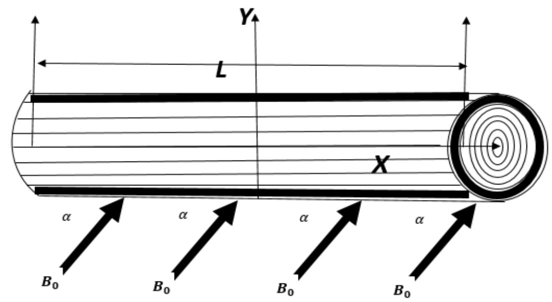

Fig. 1. Geometry of the problem

Thus the flow equations are as follows.

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

$$\frac{\partial u'}{\partial t'} + v\frac{\partial u'}{\partial y'} + \frac{1}{\rho}\frac{\partial p'}{\partial x} = v\frac{\partial^2 u'}{\partial y'} - \left[\frac{\delta_c B_0^2 \cos^2\alpha}{\rho} + \frac{v}{k}\right]u + gB_T\theta' \tag{2}$$

$$\frac{\rho C_p}{K_T}\left[\frac{\partial T'}{\partial t'}\right] + v\frac{\partial T'}{\partial y'} = \frac{\partial^2 T'}{\partial y'^2} + \frac{Q}{K_T}\theta' - \frac{\partial q_r'}{\partial y'} \tag{3}$$

The thermal radiation heat flux q using Roseland's approximation is expressed as

$$q_r' = -\frac{4\delta'}{3k'}\frac{\partial T'}{\partial y'} = -\frac{4\delta'}{3k'}\nabla T'$$

k' is Rosseland mean absorption coefficient while δ' is Stefan – Boltzmann constant. We assume the small temperature differences within the flow which is sufficiently small so that T' is a linear function of temperature

$T' = 4T_O^3 T - 3T_O'$ This implies that

$$q_r' = -\frac{16\delta' T_O^3}{3k'}\frac{\partial T}{\partial y} \tag{4}$$

An introduction of dimensionless quantities is done to write the governing equations and boundary conditions in non-dimensional form.

$$y = \frac{y'}{h}; x = \frac{x'}{h}; u = \frac{u'm}{2\rho h}; t = \frac{\mu t'}{\rho h^2}; \theta = \frac{\theta' 2\rho^2 h^3}{\mu m}; h(x,t) = (\partial p'/\partial x')/(\mu m/2\rho^2 h^3); M = \frac{\delta_c B_0^2 L^2}{\mu}; K = \frac{K_r' L^2}{v}; R = \frac{16\delta' T_0^2}{3k'k}; v = \frac{\mu}{\rho}; P_r = \frac{\mu C_p}{K_T}; H = \frac{QL^2}{K_T} \tag{5}$$

The dimensionless form of continuity, momentum, energy and diffusion equation in is written as

$$\frac{\partial u}{\partial y} = 0 \tag{6}$$

$$\frac{\partial u}{\partial t} + L\frac{\partial u}{\partial y} + h = \frac{\partial^2 u}{\partial y^2} - \left(M\cos^2\alpha + \frac{L^2}{K}\right)u + g\beta_T\theta \quad (7)$$

$$P_r\frac{\partial \theta}{\partial t} + P_r L\frac{\partial \theta}{\partial y} = (P_r + R)\frac{\partial^2 \theta}{\partial y^2} + S\theta \quad (8)$$

3 Solution to the Problem

The dimensionless form of the corresponding boundary conditions [6,11] are:

$$\begin{aligned} &u = e^{-\lambda^2 t}, \theta = e^{-\lambda^2 t} && at\ y = -1 \\ &u = 0, \theta = 0, && at\ y = 1 \end{aligned} \quad (9)$$

The solutions of equations (7) – (10) will become

$$u(y,t) = F(y)e^{-\lambda^2 t} \quad (10)$$

$$\theta(y,t) = G(y)e^{-\lambda^2 t} \quad (11)$$

Substitute equation (10) – (11) into equation (6) – (8)

$$\frac{\partial^2 F}{\partial y^2} - L\frac{\partial F}{\partial y} + \left(\lambda^2 - M\cos^2\alpha + \frac{L^2}{K}\right)F = -g\beta_T\theta + h \quad (12)$$

$$(P_r + R)\frac{\partial^2 G}{\partial y^2} - P_r L\frac{\partial G}{\partial y} + (S + P_r\lambda^2)G = 0 \quad (13)$$

$$\begin{aligned} &F = 1; G = 1; && at\ y = -1 \\ &F = 0; G = 0; && at\ y = 1 \end{aligned} \quad (14)$$

Substitute the solutions of equation (12) – (14) into equation (10) and (11), the velocity and temperature will become

$$u(y,t) = [b_1 e^{m_2 y} + b_2 e^{-m_2 y} - b_3 e^{-m_1 y} - b_4 e^{-m_1 y} + b_5]\, e^{-\lambda^2 t} \quad (15)$$

$$\theta(y,t) = [a_1 e^{m_1 y} + a_2 e^{-m_1 y}]e^{-\lambda^2 t} \quad (16)$$

Solutions for the volumetric Blood flow rate Q, is defined by

$$Q = \int_0^{h(x)} u(y,t)dy \quad (17)$$

U is integrated from equation (15) so that equation (17) is expressed as

$$Q = [b1f1 + b2f2 + b3f3 + b4f4 + b5f5]e^{-\lambda^2 t} \quad (18)$$

The dimensionless form of the wall shear stress is given by

$$WSS = \tau_w = \left[\frac{du}{dy}\right]_{y=h(x)} \quad (19)$$

$$\tau_w = [m2b1e^{m2h(x)} - m2b2e^{-m2h(x)} + m1b3e^{-m1h(x)} + m1b4e^{-m1h(x)}]e^{-\lambda^2 t} \quad (20)$$

4 Results and Discussion

In this session we will discuss the results for axial velocity, temperature and volumetric flow rate for the blood. Profile is shown graphically for different values of magnetic field, thermal radiation, heat source, porosity and angle of inclination.

For the graphical illustration of the blood flow profile in Fig. 4.1, it is observed that the increase in the thermal radiation resulted to the decrease in the blood flow profile. Fig. 4.2 shows that the increase in the heat source increases the blood flow profile, Fig. 4.3 shows that an increase in the permeability of the porous medium causes the decrease in the blood flow profile. In Fig. 4.4, the increase in magnetic field causes the increase in the blood flow profile. This is as a result of the Lorentz force been introduced by the magnetic field which overcomes the frictional force creating an increased flow rate.

Fig. 4.5 shows that the increased angle of inclination of the magnetic field causes the blood flow profile to increase near the wall of the artery but decreases far from the wall and the blood flow profile reduced as the time increases in Fig. 4.6.

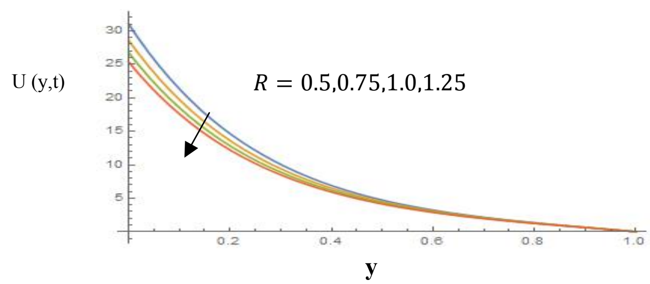

Fig. 4.1. Blood flow profile with variation of radiation R for $Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta 1 = 0.5, \beta 2 = 0.5, t = 1$

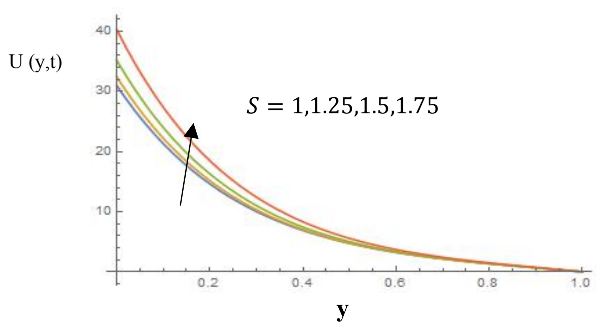

Fig. 4.2. Blood flow profile with variation of heat source S for $R = 0.5, Pr = 0.5, L = 0.5, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta 1 = 0.5, \beta 2 = 0.5, t = 1$

The graphical illustration for the blood temperature profile shows that, in Fig. 4.7, an increase in the thermal radiation causes the blood temperature profile to reduce, while in Fig. 4.8, an increase in the heat source increased the blood temperature profile. It is observed that in Fig. 4.9, the rate of blood flow increases with an increase in radiation which is minimal at the throat of the stenosis. The increase in the heat source causes the increase in the flow rate in Fig. 4.10. The rate of blood flow reduces with an increase in permeability of the stenosis in Fig. 4.11, while an increase in the magnetic field increases the rate of blood flow in Fig. 4.12. Furthermore, when the angle of inclination of the magnetic field increases the rate of flow of the blood increases in Fig. 4.13.

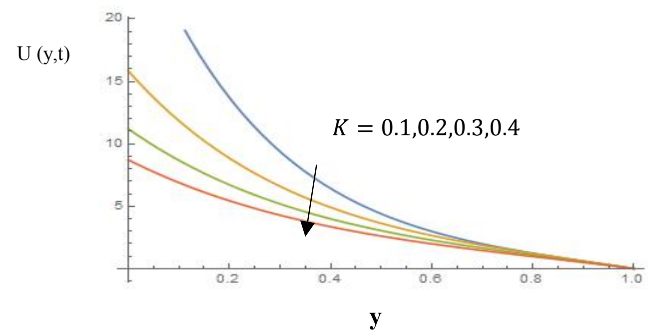

Fig. 4.3. Blood flow profile with variation of permeability of porous medium K for $R = 0.5, Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta1 = 0.5, \beta2 = 0.5, t = 1$

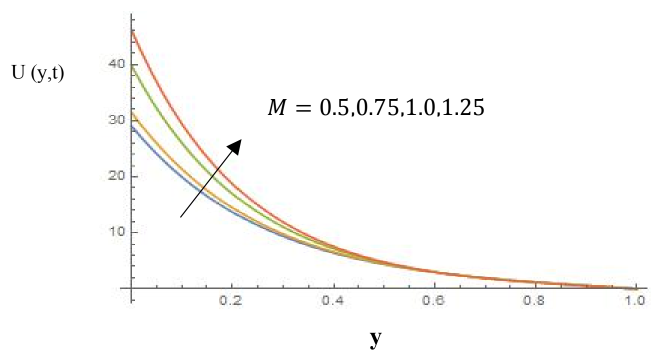

Fig. 4.4. Blood flow profile with variation of magnetic field M for $R = 0.5, Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta1 = 0.5, \beta2 = 0.5, t = 1$

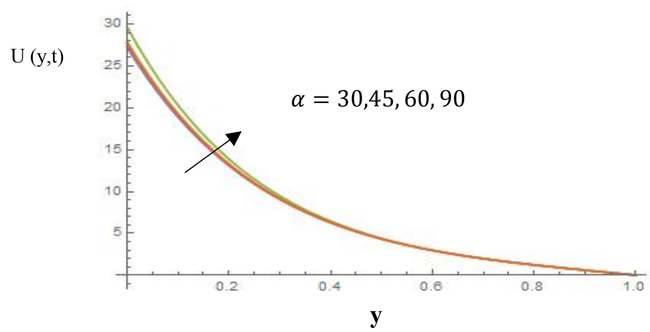

Fig. 4.5. Blood flow profile with variation of angle of inclination α for $R = 0.5, Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta1 = 0.5, \beta2 = 0.5, t = 1$

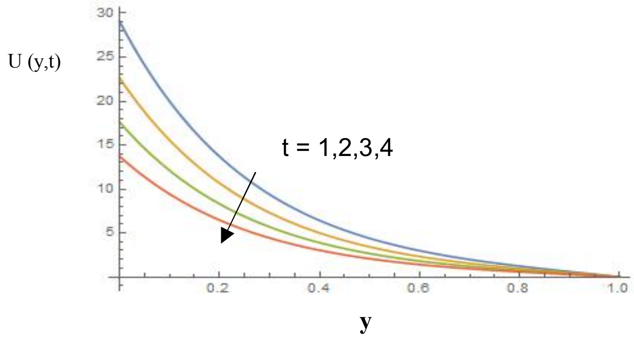

Fig. 4.6. Blood flow profile with variation of time t for $R = 0.5, Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta 1 = 0.5, \beta 2 = 0.5$

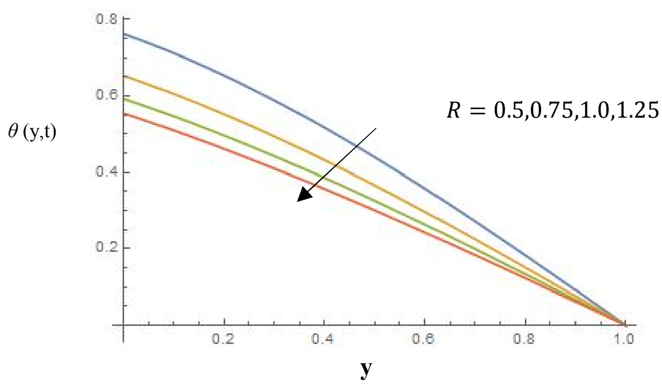

Fig. 4.7. Blood temperature profile with variation of radiation R for $Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, t = 1$

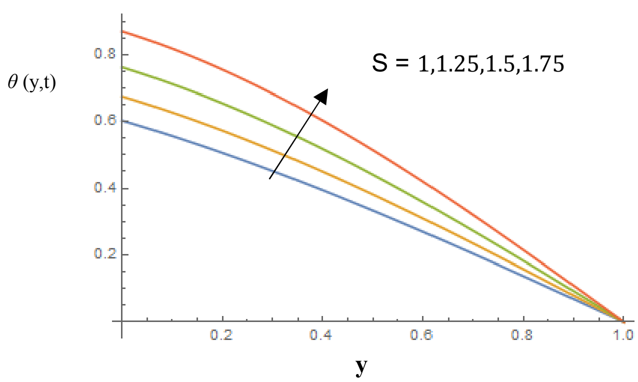

Fig. 4.8. Blood temperature profile with variation of Heat Source S for $R = 0.5, Pr = 0.5, L = 0.5, \lambda = 0.5, t = 1$

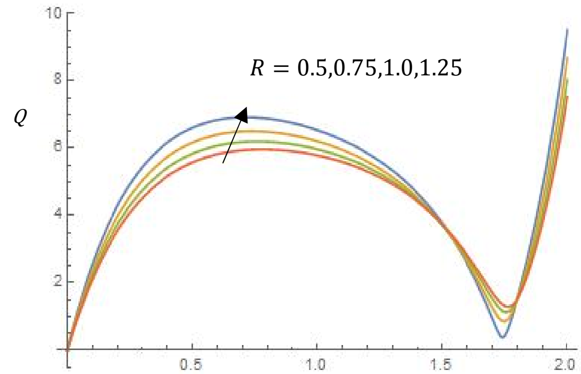

Fig. 4.9. Volumetric blood flow rate profile with variation of radiation R for $Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta1 = 0.5, \beta2 = 0.5, t = 1$

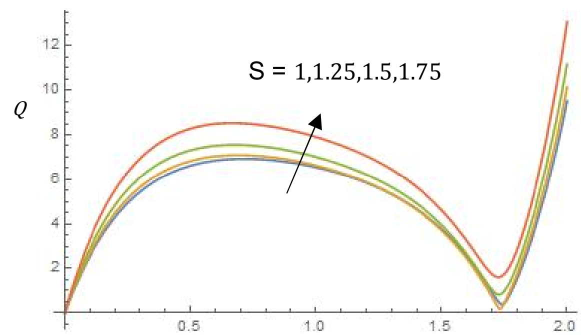

Fig. 4.10. Volumetric flow rate blood profile with variation of heat source S for $R = 0.5, Pr = 0.5, L = 0.5, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta1 = 0.5, \beta2 = 0.5, t = 1$

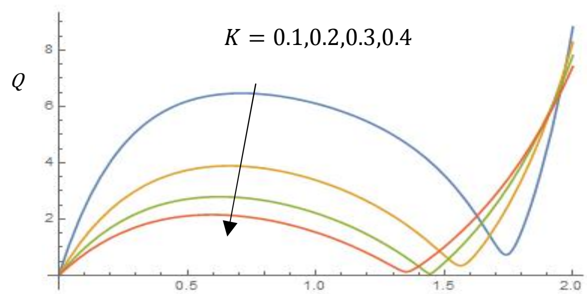

Fig. 4.11. Volumetric blood flow rate profile with variation of permeability K for $R = 0.5, Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta1 = 0.5, \beta2 = 0.5, t = 1$

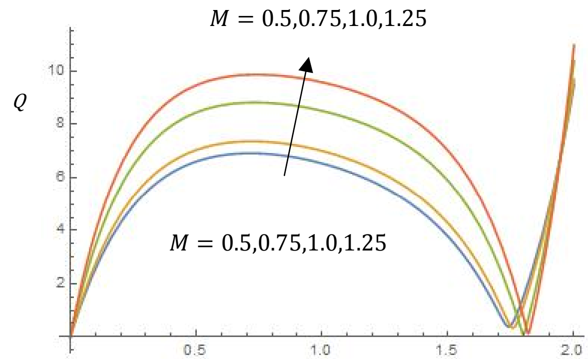

Fig. 4.12. Volumetric blood flow rate profile with variation of magnetic field M for $R = 0.5, Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta 1 = 0.5, \beta 2 = 0.5, t = 1$

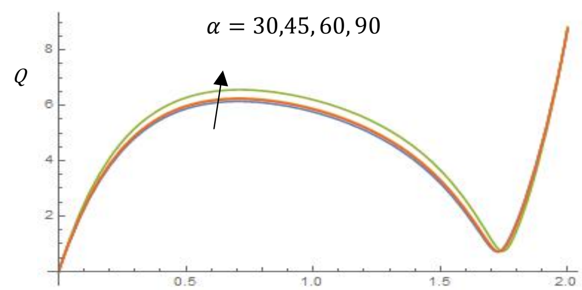

Fig. 4.13. Volumetric blood flow rate profile with variation of angle of inclination α for $R = 0.5, Pr = 0.5, L = 0.5, S = 1, \lambda = 0.5, Sc = 1, Kr = 0.8, K = 0.1, M = 0.5, \alpha = 10, h = 0.5, g = 9.81, \beta 1 = 0.5, \beta 2 = 0.5, t = 1$

5 Conclusion

The Impact of thermal radiation and heat source on unsteady MHD blood flow through an artery with an inclined magnetic field is studied while the effects of other parameters are also summarized,

- An increase in the Magnetic field causes both the blood flow and the volumetric blood flow rate through the artery to increase. This process can treat Low blood pressure by increasing the blood pressure to become normal. Sickle cell patients can also be treated by improve blood flow and oxygen in hemoglobin is maintained as a result of the increased blood flow when there is an increase in magnetic field. This can reduce strokes, swellings and pains when affected areas are exposed to the magnetic field at different angles of inclination.
- Increase in thermal radiation will decrease the blood flow while the volumetric blood flow rate increases. This is as a result of the blood vessels becoming narrow (Lesion) causing a reduction in the blood flow through the vessels. Treatment of tumor can also be done using this approach. An increased thermal radiation causes a reduction of temperature of the blood which can shrinks tumor growth in the area of exposure.
- The increase in heat source increases the flow of blood, increases the volumetric blood flow rate and also increases the blood temperature. This might result to convulsion or sometimes death.
- Increase in permeability reduces both the blood flow and volumetric blood flow rate while an increase in the angle of inclination of the magnetic field increases the blood flow near the wall of the artery but reduces it far from the wall.

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Competing Interests

Authors have declared that no competing interests exist.

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Appendix

$a_1 = \frac{e^{m1}}{1-e^{4m1}}$; $a_2 = \frac{e^{3m1}}{e^{4m1}-1}$;

$b_1 = \frac{-b_5+b_4e^{-m1}+b_3e^{m1}-b_2e^{-m2}}{e^{m2}}$;

$b_2 = \frac{b_3[e^{(m1-2m2)}-e^{m1}]-b_4[e^{-(m1+m2)}-e^{-m1}]-b_5[e^{-2m2}-1]}{e^{-3m2}+e^{-m2}}$

$b_3 = \frac{-g\beta_T(e^{m1})}{(1-e^{4m1})(m_1^2+Lm_1-\sigma)}$;

$b_4 = \frac{g\beta_T(e^{3m1})}{(e^{4m1}-1)(m_1^2-Lm_1-\sigma)}$;

$\sigma^2 = \lambda^2 - M\cos^2\alpha + \frac{L^2}{K}$; $b_5 = \frac{h}{\sigma^2}$;

$m_1 = \frac{1}{2(Pr+R)}\left(PrL \pm \sqrt{Pr^2L^2 - 4(Pr+R)(S+Pr\lambda^2)}\right)$;

$m_2 = L \pm \sqrt{L^2 - 4\sigma^2}$; $\mathrm{f1} = \frac{e^{m2h(x)}-1}{\mathrm{m2}}$;

$\mathrm{f2} = \frac{1-e^{-m2h(x)}}{\mathrm{m2}}$; ; $\mathrm{f3} = \frac{e^{m1h(x)}-1}{\mathrm{m1}}$;

$\mathrm{f4} = \frac{e^{-m1h(x)}-1}{\mathrm{m1}}$;

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