International Archive of Applied Sciences and Technology
Int. Arch. App. Sci. Technol; Vol 7 [1] March 2016: 61-65
© 2016 Society of Education, India
[ISO9001: 2008 Certified Organization]
www.soeagra.com/iaast.html

IAAST
ONLINE ISSN 2277- 1565
PRINT ISSN 0976 - 4828

CODEN: IAASCA ORIGINAL ARTICLE

A Study on Influence of Magnetic Field on Blood

ABDULMOIZ MOHAMMED
Department of Basic Sciences, Preparatory Year, University of Hail,
P.O Box # 2440, Hail, Saudi Arabia
Email: mr.mamoiz@gmail.com

ABSTRACT

The influence of biofluid (blood) in the presence of magnetic field is presented. A comprehensive mathematical model pertaining to the influence of magnetic field on biofluid (blood) accounting both Lorentz force and magnetization force is presented. Physical properties, and magnetic susceptibilities of oxygenated state of biofluid (blood) in the presence of magnetic field is presented. The applications of magnetic field, and its interaction with the biofluid are also presented.

Keywords: *Magnetic field; Fluid dynamics; Biofluid; Blood; Newtonian; Magnetization; Susceptibility; Incompressible.*

Received 02/01/2016 **Revised 21/01/2016** **Accepted 15/02/2016**

Citation of this article

A M MOHAMMED. A Study on Influence of Magnetic Field on Blood . Int. Arch. App. Sci. Technol; Vol 7 [1] March 2016: 61-65. DOI.10.15515/iaast.0976-4828.7.1.6165

INTRODUCTION

The fluid dynamics of biological fluids in the presence of magnetic field is known as bio-magnetic fluid dynamics (BDF), which is relatively a new area in fluid mechanics. A bio-magnetic fluid is a fluid which is obtained from a living organism or creature, and its flow is influenced by the presence of magnetic field. The most characteristics bio-magnetic fluid is blood, which behaves as a magnetic fluid, due to the complex interaction of the intercellular proteins, cell membrane and hemoglobin. The magnetic property of the blood is determined by the state of oxygenation of hemoglobin (a form of iron oxides present in red blood cells) [1]. Studying the effect of magnetic field on the blood is of interest to many researchers.

Pauling and Coryell were first to account the paramagnetic susceptibility of deoxyhemoglobin, and diamagnetic susceptibility of oxyhemoglobin [2]. Later, Higashi et al. performed the experiment with strong magnetic field of strength 8T, and found that the erythrocytes orient parallel to the direction of applied magnetic field [3]. The red blood corpuscles (RBCs) and platelets were found to orient with the applied magnetic field strength of 4T and 3T respectively [4]. Haik et al. observed that one of the plasma protein known as fibrinogen is polymerized and orient with the applied magnetic field at 4T [5].

Nakona et al. demonstrated that the orientation of blood cells is due to magnetic torque, when subjected to a magnetic field. They pointed out that the torque is very small, and very large, if the magnetic field is parallel and perpendicular to heme planes in unit blood cells respectively. With this orientation, blood cells and surrounding plasma fluid will interact and, combine with magnetic force, increases the apparent viscosity of the blood [6]. Blood as a whole is considered as a non-Newtonian fluid, while the plasma solution in the blood obeys the linear Newtonian model for viscosity [7-10]. The decrease in the flow rate is due to an increase in the apparent viscosity of the blood due to magnetic field [5]. It is important to understand and quantify the biofluid dynamics, particularly flow of blood in venous or arterial branches with or without presence of magnetic field. Several investigators have described the influence of magnetic field on blood theoretically. In the present work, an attempt is made to correlate the theoretical findings with that of experimental findings.

MATHEMATICAL FORMULATION

Based on the modified form of Stokes principle, and analogy with the fluid dynamics of ferrofluids, Haik et al. proposed a mathematical model to describe the dynamics of the biofluid, in the presence of gradients of magnetic field, by including the magnetization force, and neglecting the Lorentz force. They considered the flow of the biofluid as incompressible, laminar, Newtonian and electrically poor conductor. The equations of motion for such a flow are as follows [5]:

Continuity Equation: $\nabla \quad V = 0$ (1)

Linear Momentum Equation:

$$\rho\left(\frac{DV}{Dt}\right) = \quad \nabla P + \rho F + \eta \nabla^2 V + \xi(\nabla^2 V + 2\nabla \times \omega) + \mu_o (M \quad \nabla) H \tag{2}$$

Angular Momentum Equation:

$$\rho I\left(\frac{D\omega}{Dt}\right) = \mu_o M \times H + \rho F + \eta' \nabla^2 \omega + 2\zeta(\nabla \times V \quad 2\omega) \tag{3}$$

In comparison to the Navier-Stokes equation for Newtonian fluids, equation (2) contains two additional terms which are described as:

$\xi(\nabla^2 V + 2\nabla \times \omega)$	$\mu_o (M \quad \nabla) H$
Represent the antisymmetric stress tensor. Directionally dependent of fluid particle rotation and rotation of the flow field.	Represent magnetic force due to polarization. Depends on the existence of the magnetic gradient. When magnetic gradient is absent, this force vanishes.

However, blood exhibits high static electrical conductivity and is temperature dependent. The electrical conductivity of blood depends on the flow rate. Hence, both magnetization due to the orientation of erythrocytes with the magnetic field, and Lorentz force due to electric current generating from the moving ions in the plasma, must be taken into account. Tzirtzilakis considered a model for incompressible, laminar flow of a homogeneous Newtonian and electrically conducting biofluid [1]. In this model, along with the magnetization force, the Lorentz force was also accounted. The biofluid when subjected to equilibrium magnetization due to applied magnetic field then,

Momentum Equation:

$$\rho\left(\frac{DV}{Dt}\right) = \quad \nabla \mathrm{p} + \rho F + \mu \nabla^2 V + J \times B + \mu_o (M \quad \nabla) H \tag{4}$$

From equation (4), $\mu_o (M \quad \nabla) H$ is the magnetic force due to magnetization per unit volume. Under equilibrium magnetization, M is parallel to H, considered the magnetic field to be solenoid ($\nabla \quad B = 0$), and using $B = \mu_o H, J = \nabla \times H$ then,

$$\begin{aligned}
\mu_o (M \quad \nabla) H \quad &= \mu_o \frac{M}{H} (H \quad \nabla) H \\
&= \mu_o \frac{M}{H} \left(\frac{1}{2} \nabla (\mathrm{H} \quad \mathrm{H}) \quad \mathrm{H} \times (\nabla \times \mathrm{H})\right) \\
&= \mu_o \frac{M}{H} \frac{1}{2} \nabla \mathrm{H}^2 \quad \mu_o \frac{M}{H} (H \times J) \\
&= \mu_o M \nabla \mathrm{H} \quad \frac{M}{H} (B \times J) \\
&= \mu_o M \nabla \mathrm{H} + \frac{M}{H} (J \times B)
\end{aligned}$$

Thus, magnetization force along with the Lorentz force is,

$$= \mu_o (M \quad \nabla) H + \frac{M}{H} (J \times B) + J \times B$$

$$= \mu_o M \nabla H + \left(1 + \frac{M}{H}\right) (J \times B) \tag{5}$$

As $H \gg M$, implies $\frac{M}{H} \ll 1$. Therefore, equation (5) becomes

$$\mu_o (M \quad \nabla) H \quad = \mu_o M \nabla H + (J \times B) \tag{6}$$

The first term in equation (6) represents the component of magnetic force per unit volume, and the second term represents the Lorentz force per unit volume. $\mu_o M \nabla H$ is due to the existence of magnetic gradient, and $(J \times B)$ is due to the electrical conductivity.

Energy Equation: For non-isothermal,

$$\rho C_p \left(\frac{DT}{Dt}\right) + \mu_o T \left(\frac{\partial M}{\partial T}\right) \frac{DH}{Dt} \quad \frac{J \quad J}{\sigma} = k \nabla^2 T + \mu \Phi \tag{7}$$

where, $\Phi =$ dissipation function; $\mu_o T \left(\frac{\partial M}{\partial T}\right) \frac{DH}{Dt}$, is due the magneto-caloric effect and represents the thermal power per unit volume. The term $\frac{J \quad J}{\sigma}$ is due to magneto-hydrodynamics, and known as Joule heating.

Magnetic Field Equation:

$$\nabla \times H = J = \sigma(V \times B)$$
$$\nabla \cdot B = \nabla \cdot (H + M) = 0 \qquad (8)$$

Magnetization, M, is the property which describes the behavior of a bio-magnetic fluid when exposed to external magnetic field. In general, the magnetization, M, is characterized by the density, temperature of the biofluid, and the magnetic field intensity, H.There exist, different equations for magnetization depending on the parameters considered in the experiment. In what follows are some of the equation used to determine the magnetization:

$$M = \chi H \qquad (9)$$

Where χ is the magnetic susceptibility.

In temperature dependence studies of biofluids, samples are subjected to magnetization below Curie temperature T_c, then the magnetization is given as

$$M = K(T_c - T) \qquad (10)$$

Where, K is pyrometric coefficient.

Another, equation for magnetization below Curie temperature T_c is

$$M = M_1 \left(\frac{T_c - T}{T_1}\right)^{\beta} \qquad (11)$$

Where, β is component for spontaneous magnetization, and values of β, M_1 and T_1 depends on the material.

An equation involving magnetic intensity, H, and temperature T is given as,

$$M = K^{'}H(T_c - T) \qquad (12)$$

where, K' is a constant of proportionality.

Equations (11) and (12) provides good approximations, experimentally. But, the magnetization process of red blood cells (RBCs) found by Higashi et al. is found to be more accurate, i.e., equation (13). Higashi et al. described the variation of magnetization of RBCs behaves similar to the function known as Langevin function which is given as,

$$M = mN\left[Cot\left(\frac{\mu_o mH}{kT}\right) - \frac{kT}{\mu_o mH}\right] \qquad (13)$$

where, m is the particle magnetization, N is the number of particles per unit volume and k is Boltzmann's constant.

When the magnetization of fluid flow is not temperature dependent, then equation (9) constitutes very good approximations, especially for the biofluid (blood).

RESULTS

Table 1 shows the data on physical properties of biofluid (blood). The calculated values of density, viscosity, electrical conductivity, velocity and flow rate are presented. These values were found in agreement with the literature. Table 2 shows the data on magnetic susceptibility measured experimentally by the author. The magnetic susceptibility of different states of blood oxygenated hemoglobin (oxyHb), oxygenated methemoglobin (metHb) and distilled water are presented. In addition, magnetic susceptibility of venous blood and arterial blood found by Haik et al. [12], and oxyHb found by Shalygin et al. [11] were also reported. The magnetic susceptibility values found experimentally by the author found to be in agreement with the literature, which is evident for the diamagnetic susceptibility of oxygenated state of blood.

Table 1: Data on average values of the physical properties of biofluid (blood)

Property	**Range**	**Unit**
Density	1.035-1.050	$g\ cm^{-3}$
Viscosity	0.042-0.055	P
Electrical Conductivity	0.7-0.9	$S\ m^{-1}$
Velocity	12.4 -19.2	$cm\ s^{-1}$
Flow Rate	0.096-0.151	$cm^3\ s^{-1}$

Table 2: A comparison of Magnetic Susceptibility of distilled water and biofluid (blood)

Parameter	Symbol	Sample/State	Value	Unit	Source
Magnetic Susceptibility	χ	Distilled Water	0.94×10^{-8}	$cm^3 g^{-1}$	Author [8,9]
		OxyHb	0.35×10^{-8} to 0.59×10^{-8}	$cm^3 g^{-1}$	Author [8,9]
		OxyHb	0.31×10^{-8} to 0.65×10^{-8}	$cgs\ unit$	Shalygin et al. [11]
		metHb	0.43×10^{-8} to 0.63×10^{-8}	$cm^3 g^{-1}$	Author [8,10]
		Venous blood	3.5×10^{-6}	$cgs\ unit$	Haik et al. [12]
		Arterial blood	0.66×10^{-8}	$cgs\ unit$	Haik et al. [12]

DISCUSSION AND CONCLUSIONS

Blood constitutes one of the basic substances of the human body, and has a strong nourishing effect on the body. When a biofluid (blood) is subjected to magnetic field, the blood particles flowing transverse to the field, get deflected in opposite direction, because of the induced Lorentz force. This generates electromagnetic induction in the fluid that reduce the flow rate, and flatten the velocity profile, while stretching it more in the direction of applied field. These effects heightened when magnetic field strength increases; however, but the induced magnetic field remains significant.

This magnetic field effects on biofluid (blood) may be employed for optimization of targeted drug delivery. For instance, in spite of availability of efficient drugs, in cancer therapy, it is difficult to deliver and concentrate the drug in affected areas precisely. Failure to provide localized targeting, results in an increase of toxic effect on nearby organs and tissues. To accomplish precise targeting of magnetic drug delivery, a drug is bound to magnetic compound and then injected in to the blood stream. The targeted area are subjected to an external magnetic field (1 to 1.5 T), whereby directing the biofluid magnetic compound to the site of drug delivery.

Besides this, this magnetic effects on blood may be employed in providing insight to the effects of magnetic resonance imaging (MRI) scanners. It is reported that when patients exposed to magnetic field (1 to 4 T) in MRI scanning, resulted in significant increase in blood viscosity, along with some side effects such as nausea, sleepiness, vertigo.

It is observed that an imposed magnetic field influences the electrocardiogram (ECG) of the human cardiac rhythm, indicating the significance of the induced voltages. The electrical conductivity of blood depends on its velocity, and found to increase significantly. This is due to reorientation of erythrocytes influenced by the viscous forces.

Thus, the viscosity of the biofluid under the presence of magnetic field is found to increase significantly. The electrical conductivity which is dependent on flow rate increases marginally by the imposed magnetic field. The magnetic susceptibility of oxygenated state of biofluid (blood) is found to be diamagnetic. Therefore, blood as a biofluid helps in understanding possible health effects of magnetic fields.

REFERENCES

1. E.E. TZirtzilakis, A mathematical model for blood flow in magnetic field, Physics of Fluids, Vol. 17 (2005), 077103, pp. 1-15.
2. L. Pauling and C. D. Coryell, The magnetic properties and structure of the hemochromogens and related substances, Proc. Natl. Acad. Sci. USA., Vol. 22 (1936), pp. 159-163.
3. T. Higashi, A. Yamagishi, T. Takeuchi, N. Kawaguich, S. Sagawa, S. Onishi, M. Date, Orientation of erythrocytes in a strong magnetic field, Blood, Vol. 82, No. 4 (1993), pp. 1328-1334.
4. A. Yamagishi, Biological systems in high magnetic field, J. Magn. Magn. Mater., Vol. 90 (1990), pp. 43-46.
5. Y. Haik, V. Pai, C.J. Chen, Apparent viscosity of human blood in high static magnetic field, j. Magn. Magn. Mater., Vol. 225 (2001), pp. 180-186.
6. N. Nakona, J. Ostuka, A. Tasaki, Biochem. Biophys. Acta, Vol. 278 (1972), pp. 355.
7. Basharath Ali, M. Ibraheem Altaf & Adeel Ahmad, An introduction to Human blood, J. Pure & Appl. Phys., Vol. 19, No. 2 (2007), pp. 149.
8. Abdul Moiz Mohammed, "Studies on Magnetic properties of Human Blood and its constituents" (2008), A dissertation submitted in partial fulfillment of the requirement for the Master of Philosophy (M. Phil.) in Physics, Anna Malai University, India

9. Mohammed Abdul Moiz & Adeel Ahmad, Magnetic susceptibility of normal human blood, J. Pure & Appl. Phys., Vol. 21, No. 3 (2011), pp. 395-399.
10. Abdul Moiz Mohammed & Adeel Ahmad, Magnetic properties of Methemoglobin, Intl. J. Sci. Environ. Tech., Vol. 4, No. 6 (2015), pp. 1661 – 1665.
11. A. N. Shalygin, S. B. Norina, E. I. Kondorsky, Behavior of erythrocytes in high gradient magnetic field, J. Magn. Magn. Mater., Vol. 31 (1983), pp. 555-556.
12. Y. Haik, V. Pai, C.J. Chen, Biomagnetic fluid dynamics at interfaces, Cambridge University Press, Cambridge, 1999, pp. 439-452.
13. E. Korchevskii, L. Marochnik, Magnetohydrodynamics version of movement of blood, Biophysics, Vol. 10, No. 2, (1965), pp.411-414.

Appendix I

Nomenclature:

V	$= (u, v, w)$	Velocity Field
∇	$= \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right)$	Along x, y, z direction in three dimensional system
$\frac{D}{Dt}$	$= \frac{\partial}{\partial t} + V\,\nabla$	Stokes Tensor
μ_o	$= 4\pi \times 10^{-7} Hm^{-1}$	Magnetic Permeability of Vacuum
Θ	Dissipation Function	
p	Pressure (Pa)	
C_p	Specific heat at constant pressure	
ρ	Fluid density $(g\, m^{-3})$	
F	Force per unit volume $(dyne\ cm^{-3})$	
μ	Dynamic viscosity (P)	
K	Coefficient of thermal conductivity of the fluid	
χ	Magnetic Susceptibility (.)	
M	Magnetization $(A\, m^{-1})$	
H	Magnetic field intensity $(A\, m^{-1})$	
B	Magnetic induction (T)	
σ	Electrical conductivity of the fluid $(S\, m^{-1})$	
J	Density of the electric current $(A\, m^{-2})$	
T	Temperature (K)	
k	Boltzmann constant $(J\, K^{-1})$	