



## Unsteady of two-phase flow of blood with magnetic dusty particles in cylindrical region

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### Abstract

The present study is focused on the unsteady two-phase flow of blood in a cylindrical region. Blood is taken as a counter-example of Brinkman type fluid containing magnetic (dust) particles. The oscillating pressure gradient has been considered because for blood flow it is necessary to investigate in the form of a diastolic and systolic pressure. The transverse magnetic field has been applied externally to the cylindrical tube to study its impact on both fluids as well as particles. The system of derived governing equations based on Navier Stoke's, Maxwell and heat equations has been generalized using the well-known Caputo–Fabrizio (C–F) fractional derivative. The considered fractional model has been solved analytically using the joint Laplace and Hankel (L&H) transfor- mations. The effect of various physical parameters such as fractional parameter,  $Gr$ ,  $M$  and  $\alpha$  on blood and magnetic particles has been shown graphically using the Mathcad software. The fluid behaviour is thinner in fractional order as compared to the classical one.

**Keywords:** Two-phase blood flow, dusty fluid, Brinkman type model, magnetic dusty particles, heat transfer, C–F derivative

### Introduction

Biomagnetic fluid dynamic (BFD) is a new area in fluid mechanics. It focuses on the usage of the magnetic particles as drug carriers in magnetic drug targeting, cancer tumor treatment and many more [1,3]. The Biomagnetic fluid occurs in all living organisms and for its investigation, the BFD model was initially recommended by [3]. Fluids that show non-linear relation between shear stress and strain are termed as non-Newtonian fluids e.g., blood. Blood is the only biological electrically conducting fluid and its mobility is influenced by an applied magnetic field. It contains plasma and red blood cells (RBC) that are oxides of iron and have hemoglobin fragments in high concentrations [4]. Due to the oxygenated state, blood exhibits a magnetic nature [5]. The non-Newtonian behaviour of blood due to the suspension of red blood cells in plasma and human thoracic aorta is analyzed [6] and have examined the Non-Newtonian blood in a channel and attained analytical solutions for the velocity, volumetric flow rate and wavelength. In the human left ventricle (LV), the significance of the non-Newtonian blood has examined and evaluated the difference between Newtonian and non-Newtonian blood models and concluded that the non- Newtonian blood has more/less augmented wall shear stress as compared to the Newtonian blood [7]. Since blood is a biological fluid, biological heating is significant for metabolic heat generation [8]. The phenomenon in biological fluids was first discussed. Afterwards, bioheat transfer became a topic applied in the practice of biology in a wide variety of applications such as chemotherapy [9], human thermoregulation system [10] investigated the heat transfer applications in peripheral vascular disease using FHD principle through two inclined permanent magnets in a channel. An analytical study of heat propagation in biological tissues for constant and variable heat flux at the skin surface with hypothermia treatment [11] the heat transfer modelling in thermoregulatory responses in the human body [12]. The heat transfer model for the

prediction of human skin temperature using the bioheat equation [13].

The consideration of Two-phase flow is due to the presence of numerous interfaces separating two immiscible phases. The blood flow through a tiny tube at a very low shear is responsible for the two- phase flow surrounded by a cell-depleted peripheral layer. Different types of particles have been considered as the second phase in blood flow, but the most recommended and suitable particles are magnetic particles. The magnetic particles in blood have a vital role in numerous medical applications [14]. In drug delivery, a specific number of magnetic particles are used to transport the maximum number of a drug to the area of its choice. Due to the mentioned applications of magnetic particles, several researchers used the two-phase blood flow along with magnetic particles. Described a dual-phase blood flow model in thin pipes with the fundamental core of deferred erythrocytes and cell unrestricted film and found the results for the nonlinear problem numerically [15]. The thermal and mass concentration effect of the multiphase blood model in a stenosed artery has been investigated an analytical approach has been used for the results to comprehend the compartment of blood flow rate, wall shear stress and flow resistivity a reliable two-phase RBC model for the blood vessel and calculated the viscosity, phase dispersals and volume fractions using the depletion theory [16]. They have associated their results with numerical as well as experimental study and found extraordinary conclusions. They have concluded that thermal and shear stress slow down with increase in the levels of the plasma layer thickness and they are very effective for the diseased arterial treatment. the two-phase dusty fluid with heat transfer in a fluctuating plate, and found that by enhancing the number of embedded particles, the dusty fluid velocity increases. Due to multidimensional features, the non-integer order calculus is attracting the attention of scientists and researchers [17]. Fractional calculus is an important and

fruitful tool for describing many systems including memory effects. In the preceding few decades, fractional calculus is used for many purposes in various fields, such as electrochemistry, transportation of water in ground level, electromagnetism, elasticity, diffusion and in conduction of heat process worked together in the field of non-integer order calculus and presented a new expression for the non-integer order derivative with the non-singular kernel [18]. So, keeping in sight the importance of CF operators, many researchers used the CF operator in their studies such as in physics, biological mathematics, and many more.

There is no attempt found in the literature relevant to Caputo–Fabrizio fractional approach to find the closed-form solution for magnetite particles-based blood flow with thermal concentration. Hence, in the present article, the work has been generalized by taking the flow of blood as a Brinkman type fluid with magnetic particles in cylinder [20]. The governing equations for both fluid and particles are modelled and using the Caputo–Fabrizio fractional-order approach, the closed-form solutions have been obtained by using joint Laplace and Hankel transformations. The impact of different embedded parameters on blood and particles velocities have been examined through graphs.

Recently describe the blood flow of newtonian and non-newtonian fluids through blood vessels with the flexible wall [21], evaluation of viscous force effects on rotor of sequence film damper using newtonian and non-newtonian fluids [22] and study on the importance and application of non-newtonian fluids behaviour. [23]

**Materials and Methods**

The magnetic particles are equally distributed throughout the blood flow. The cylinder has been considered along the z-axis and r<sub>1</sub>-axis is chosen perpendicular to it. The direction of the motion of the blood and magnetic particles are along the z-axis. The biological thermal effect has also been considered and the radiation has been neglected. The induced magnetic field due to a very slight Reynold number has been ignored [24]. For a time, t = 0, the system is considered to be at rest with ambient temperature T<sub>∞</sub>. For t > 0 the temperature rises to T<sub>w</sub>. The force F<sub>emag</sub> is described by [25]

$$F_{emag} = -\sigma B_0^2 u(r_1, t) \vec{k}$$

where  $\vec{k}$  denotes the direction along the z-axis and  $\vec{v} = u(r_1, t) \vec{k}$  shows blood velocity. The unsteady Brinkman-type blood flow in a cylinder is specified

$$\rho c_p \frac{\partial u(r_1, t)}{\partial t} + \gamma u(r_1, t) = \frac{\partial p}{\partial z} + \mu \left( \frac{\partial^2 u(r_1, t)}{\partial r_1^2} + \frac{1}{r_1} \frac{\partial u(r_1, t)}{\partial r_1} \right) + KN (u_p(r_1, t) - u(r_1, t)) - \sigma_0 B_0^2 u(r_1, t) \pm g \beta_T (T - T_\infty) \tag{2}$$

The thermal equation is specified by.

$$\frac{\rho c_p}{K} \frac{\partial T_1(r, t)}{\partial t} + \frac{1}{r_1} \frac{\partial T_1(r_1, t)}{\partial r_1}; t > 0, r_1 \in (0, R_0),$$

By incorporating the Non-dimensional variables

$$r_1^* = \frac{r_1}{r_0}, t^* = \frac{vt}{r_0^2}, v = \frac{u_1}{u_0}, u_p = \frac{u_p}{u_0}, \theta = \frac{T_1 - T_\infty}{T_w - T_\infty}, Q^* = \frac{p_0 r_0^2}{\mu u_0}, Q^* = \frac{p_1 r_0^2}{\mu u_0},$$

then ignoring the notation, we obtain.

$$\frac{\partial v(r_1, t)}{\partial t} + \gamma_1 v(r_1, t) = (q_0 + q_1 \cos \omega t)$$

For a generalized fractional model, the newly developed CF time-fractional derivative has been used to convert the linear model to the fractional model

**Solution of the blood and particle velocities:** To obtain the solution for the blood velocity and Magnetic particles velocity, the Laplace and Hankel transforms have been applied on Eq. (15) using the corresponding transformed boundary conditions by

letting  $\lambda_{m1} = 1 + \lambda_{m0} a$ ,  $\lambda_{m2} = \frac{a_1}{\lambda_{m1}}$  and we get:

$$v_p H^{-(r_1, t)}(q) = \frac{v H^{-(r_1, t)}(q) + a_1}{\lambda_{m1}(q + \lambda_{m2})}$$

Table-1 it can be seen that by growing the fractional parameter an enhancement in (Nu) occurs for time.

**Table 1:** Time and a variation on Nusselt number

S. No	a	t	Nu
1	0.3	2	2.503
2	0.5	2	2.684
3	0.7	2	3.012
4	0.9	2	3.412
5	1	2	3.576

**Results and Discussion**

The considered work aims to study the generalized two-phase blood flow of Brinkman type fluid in a cylindrical tube. The analytical solutions have been attained for energy, velocity as well as for the magnetic particles contained in the blood. Various parameters have been discussed physically on velocities of the blood, particles and temperature. The physical model of the considered problem. shows the effect of fractional parameter on the temperature profile. It can be concluded from the figure that by using the fractional parameter, we obtained different temperature profiles by keeping the other parameters constant and this effect is called the memory effect, which is impossible in integer-order. In this graph, we obtained dual behaviour of temperature memory for different values of a and the same behaviour has been noticed as reported.

The effect of the fractional parameter a on velocity profiles. The corresponding results for regular blood and particles velocity are compared with the fractional order in a fixed time and with classical order and the fluid and particles memory has been discussed. The impact of the Magnetic parameter on blood velocity and particle velocity. From the

figures, it has been concluded that for the higher values of  $M$ , the flow of blood, as well as magnetic particles, retards. It is physically true that by increasing  $M$ , the Lorentz forces increase, which produces resistive forces due to which the flow retards. This effect is very useful in various medical fields such as Magnetic drug targeting and separation techniques by the magnetic field for the cure of different types of diseases and to maintain the normal aspects of the human body.

The impact of the Brinkman type parameter  $c_1$  on the velocities of blood and particles. It is observed that the velocity decreases with the increasing values of  $c_1$ . This is because  $c_1$  is the ratio between resistive forces and density. By increasing  $c_1$ , the opposite forces increase, which retards the fluid velocity and is directly related to the blood flow. These results are strongly in agreement.

### Conclusions

The Caputo–Fabrizio time-fractional derivative has been used. The effect of relative parameters has been shown graphically. Closed-form expressions have been obtained by using the Laplace transform and Hankel transform techniques. Based on the graphical study, it has been concluded that the velocity profile decreases in the response of an external applied magnetic field and Brinkman parameter. This phenomenon might play an important role in Magnetic wounds. Furthermore, by increasing the fractional parameter, the fluid memory becomes thicker.

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