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Mathematical Model of Concentration Dependent Viscosity for the Effect of RBC on the Transport of Nanoparticles

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ABSTRACT: The protensive transport of nanoparticles through blood vessels has been analysed in blood having viscosity dependent on the concentration of red blood cell. The Taylor & Aris diffusion model has been considered to model the transport of nanoparticles in the capillaries. The influence of the red blood cell on the permeability of vessel wall and pressure gradient on the protensive transport of nanoparticles and its diffusivity has been investigated. The present work concerns with the nanoparticle diffusivity in the capillaries with the effect of volume concentration of RBC, and is of significant importance in nanodrug for targeted delivery. The noteworthy outcome of the study is that red blood cells largely effect the nanoparticle dispersion due to their tumbling motion that aligns the nanoparticles along the margin of the capillaries which leads to an increase in their diffusion rate.

KEYWORDS: Nanoparticles, Diffusion, Longitudinal diffusion coefficient, Haematocrit, Non-Newtonian fluid, Interstitial fluid pressure, Rheological parameter, Concentration dependent viscosity

I. INTRODUCTION

The blood flow in our body maintains the circulatory system. Different blood vessels like arteries, veins and capillaries show fluid dynamic complexities. The cardiovascular system is responsible for the transport of solutes like nutrients, drugs and metabolic products across the body. The phenomenon of diffusion is responsible for this transportation. Capillaries are the thinnest blood vessels in the body that bring about diffusion. As the blood vessels become thinner the multiphase character of blood becomes more prominent. Red blood cells (RBCs) are the most abundant cellular constituent of blood. Red blood cells govern many characteristics of blood. The increase in the value of haematocrit or RBCs in the core region is responsible for the non-Newtonian characteristic of blood flow in capillaries.

Nanoparticles have emerged as an effective approach for the treatment of cardiovascular diseases. Nanoparticle based drug delivery therapies aim to commute drugs to the target site so as to deliver effective volumes of therapeutic drugs. Nanotechnology is an active area of research in biomedicine and therapeutics. There are broadly three parameters that effect the diffusion of nanoparticles in the blood namely- effective nanoparticle volume fraction, the range of shear rate and the viscosity of blood.

The haematocrit (volume concentration of red blood cell) for normal human blood varies between 40-45%. The relative viscosity enhances with for an increase in haematocrit and also declines for an increase in rate of shear. The RBCs serve dual roles in nanoparticle dispersion. The RBCs interact with the nanoparticle thus increasing their dispersion coefficient. Also, the RBCs trap the small nanoparticles that diffuse faster than RBC motion. The effective velocity of nanoparticles along the capillaries is affected by the concentration of RBCs.

When haematocrit is of 0% an equal scattering is predicted nanoparticles i.e. in the unavailability of red blood cell flow can be regarded as a Poiseuille's flow. The increase in haematocrit also has an effect on the velocity of nanoparticles across the whole vessels. It is predicted that this will have an influence on the movement of the particles along the

capillary wall, as it changes the Brownian force fraction and their transport to the capillary surface, because of enhanced wall shear stress.

For biomedical usage, nanoparticles are inoculated and transferred within capillaries of varying radii and length. In 1953 & 1956, the diffusive and convective contribution for an effective longitudinal diffusion is given by Taylor [1] and Aris [2]. Their theory is applicable in large time intervals or in steady state. Gill [3], Gill and Sankarsubramaniam [4] have expanded the theory of Taylor and Aris by analysing the dispersion of solute both in small- and large-time intervals. Sankarsubramaniam and Gill [5] studied the dispersion in time varying flow with a given concentration. The expression of effective longitudinal diffusion and transient effective diffusion coefficient for many non-Newtonian fluids has been given by Sharp [6].

Gentile et al [7] analyzed the transfer of nanoparticles in blood vessels taking into account permeability and rheology. Tan et al [8] studied the influence of RBCs on nanoparticle transport and dispersion. Shaw et al [9] examined the dispersion of blood in nanoparticle governed drug delivery in a permeable vessel with very less radius. Fullstone et al [10] used agent-based approach model the transfer of nanoparticles in blood flow in capillaries. Bali et al [11] used Herschel-Bulkley fluid model in capillary to study the diffusion of nanoparticles in the permeable capillaries. Liu et al [12] analyzed the nanoparticle transfer in cellular blood flow. Tan et al [13] attached nanoparticles on the surface of RBCs and studied their effects on the nanoparticle drug delivery. Sabourain et al [14] in their review article on intra cellular uptake of nanoparticles discussed the enhancement methods for nanoparticle cellular uptake. They discussed factors like nanoparticle concentrations, viscosity and temperature influence the nanoparticle transport. Wang et al [15] modeled the optimal drug carrying nanoparticles in blood and studied their interactions with the RBCs.

This paper discusses the dispersion of nanoparticles in blood capillaries where the viscosity of blood depends on the concentration of RBCs. The study emphasizes the fundamental understanding of how the nanoparticle diffusivity is affected by the concentration of RBCs. The analytical expressions for the effective longitudinal diffusion of nanoparticles, mean fluid velocity and pressure gradient in the permeable capillary have been estimated using Taylor's theory of dispersion. This a novel mathematical approach to analyze the protensive transport of nanoparticles in the capillaries using the expression for viscosity dependency on the concentration of RBCs.

II. MATHEMATICAL FORMULATION

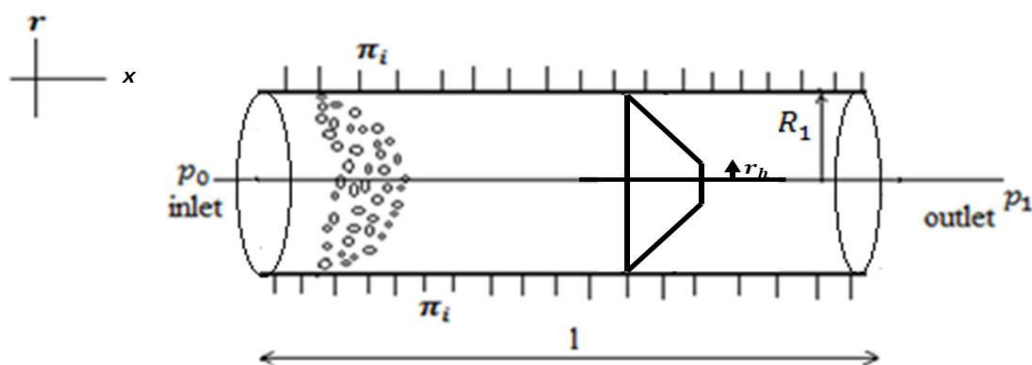


Fig. 1 Longitudinal transport of nanoparticles in blood capillary

Capillary of radius R_1 and length l is taken into consideration, where the flow of blood is characterised as the slow viscous flow in narrow capillary therefore the viscosity μ_1 of the blood is depending on the local variation of the concentration c' as given by the relation

$$\mu'_1 = \mu_0(1 + \alpha c') \quad (1)$$

where μ_0 is the viscosity of plasma and α is the parameter depending on the viscosity of plasma.

Mean fluid velocity in a concentration dependent fluid

Equation of motion for the region of suspension ($r'_h < r' < R_1$)

$$-\frac{\partial P'}{\partial x'} + \frac{1}{r'} \frac{\partial}{\partial r'} \left(\mu'_1 r' \frac{\partial u'_1}{\partial r'} \right) = 0 \quad (2)$$

The concentration c' of the suspended red blood cells is determined by one dimensional diffusion equation

$$D' \left[\frac{\partial^2 c'}{\partial r'^2} + \frac{1}{r'} \frac{\partial c'}{\partial r'} \right] + m' = 0 \quad (3)$$

where D' is the diffusion coefficient and m' is the rate of production of RBC's.

After using the following non-dimensional scheme:-

$$\mu = \frac{\mu'_1}{\mu_0} = (1 + \lambda c) \text{ where } \lambda = \alpha c_0 \quad (4)$$

$$x = \frac{x'}{R_1}; u = \frac{u'}{u_{b0}}; c = \frac{c'}{c_0}; r = \frac{r'}{R_1}; P_\varepsilon = \frac{u_{b0} R_1}{D'}; m' = \frac{M u_{b0} c_0}{R_1}; P = \frac{P'}{\rho u_{b0}^2}; \quad (5)$$

$$\frac{\partial^2 c}{\partial r^2} + \frac{1}{r} \frac{\partial c}{\partial r} = -M P_\varepsilon \quad (6)$$

And applying boundary conditions as:-

$$\left. \begin{array}{l} \frac{\partial c}{\partial r} = 0 \\ c = 0 \end{array} \right\} \begin{array}{l} r = 0 \\ r = 1 \end{array} \quad (7)$$

The concentration of RBCs is obtained as:-

$$c = \frac{M P_\varepsilon}{4} (1 - r^2) \quad (8)$$

and after solving equation (2) with boundary conditions (9), the velocity in the suspension region is given by equation (10)

$$\left. \begin{array}{l} \frac{\partial u_1}{\partial r} = 0 \\ u_1 = 0 \end{array} \right\} \begin{array}{l} r = 0 \\ r = 1 \end{array} \quad (9)$$

$$u_1 = \left(1 + \frac{\lambda M P_\varepsilon}{4}\right) \left\{ \frac{r^2}{4} + \frac{\lambda M P_\varepsilon}{4 \left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \frac{r^4}{4} \right\} \frac{\partial P}{\partial x} + B_1 \quad (10)$$

$$\text{where } B_1 = - \left(1 + \frac{\lambda M P_\varepsilon}{4}\right) \left\{ \frac{1}{2} + \frac{\lambda M P_\varepsilon}{4 \left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \frac{1}{4} \right\} \frac{\partial P}{\partial x} \quad (11)$$

velocity in the core region is given by using the condition $u_1 = u_c$ at $r = r_h$

$$u_c = - \left(1 + \frac{\lambda M P_\varepsilon}{4}\right) \left\{ \frac{(1-r_h^2)}{2} + \frac{\lambda M P_\varepsilon}{4 \left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \frac{(1-r_h^4)}{4} \right\} \frac{\partial P}{\partial x} \quad (12)$$

Volumetric flow rate is given by

$$Q = Q_1 + Q_c \quad (13)$$

$$= \int_{r_h}^1 2\pi r u_1 dr + \int_0^{r_h} 2\pi r u_c dr \quad (14)$$

Pressure in the permeable capillary

The equation for L_p hydraulic conductivity, π_i interstitial fluid pressure, p_0 inlet and p_1 outlet vascular pressures are written as:-

$$-\frac{\pi R_1^4}{8\mu} \frac{\partial^2 p}{\partial x^2} - L_p(\pi_i - p)\lambda_p = 0 \quad (17)$$

Pressure in the permeable capillary is given by the expression

$$P = A_1 e^{\left(\frac{8\mu}{\pi R_1^2 L_p \lambda_p}\right)x} - A_2 e^{-\left(\frac{8\mu}{\pi R_1^2 L_p \lambda_p}\right)x} + \frac{\pi R_1^2 L_p \lambda_p \pi_i}{8\mu} \quad (18)$$

For finding the value of A_1 and A_2 , using boundary and matching condition given in equation no. (15)

$$\left. \begin{aligned} P' &= P_0' & x' &= 0 \\ P' &= P_l' & x' &= l' \end{aligned} \right\} \quad (19)$$

where P_0' is the entering pressure i.e. the pressure when blood entering the capillary and P_l' is the pressure when blood come out from the capillary.

$$A_1 = \left(P_0 - \frac{\pi R_1^2 L_p \lambda_p \pi_i}{8\mu} \right) - \frac{\left(P_0 - \frac{\pi R_1^2 L_p \lambda_p \pi_i}{8\mu} \right) e^{\left(\frac{8\mu}{\pi R_1^2 L_p \lambda_p}\right)l} - P_l + \frac{\pi R_1^2 L_p \lambda_p \pi_i}{8\mu}}{\left(e^{\left(\frac{8\mu}{\pi R_1^2 L_p \lambda_p}\right)l} - e^{-\left(\frac{8\mu}{\pi R_1^2 L_p \lambda_p}\right)l} \right)}$$

$$A_2 = \frac{\left(P_0 - \frac{\pi R_1^2 L_p \lambda_p \pi_i}{8\eta} \right) e^{\left(\frac{8\mu}{\pi R_1^2 L_p \lambda_p} \right) l} - P_l + \frac{\pi R_1^2 L_p \lambda_p \pi_i}{8\mu}}{\left(e^{\left(\frac{8\mu}{\pi R_1^2 L_p \lambda_p} \right) l} - e^{-\left(\frac{8\mu}{\pi R_1^2 L_p \lambda_p} \right) l} \right)}$$

The mean velocity is given as

$$U = \frac{Q}{\pi R_1^2} \quad (20)$$

$$U = -2 \left(1 + \frac{\lambda M P_\varepsilon}{4} \right) \left(\frac{8\mu}{\pi R_\varepsilon^2 L_p \lambda_p} \right) \left[A_1 e^{\left(\frac{8\mu}{\pi R_\varepsilon^2 L_p \lambda_p} \right) x} - A_2 e^{-\left(\frac{8\mu}{\pi R_\varepsilon^2 L_p \lambda_p} \right) x} \right] \left[\left\{ \frac{1}{8} + \frac{\lambda M P_\varepsilon}{4 \left(1 + \frac{\lambda M P_\varepsilon}{4} \right)} \frac{1}{12} \right\} - r_h^2 \left\{ \frac{3}{4} + \frac{\lambda M P_\varepsilon}{4 \left(1 + \frac{\lambda M P_\varepsilon}{4} \right)} \frac{5}{8} \right\} - \frac{r_h^4}{8} + r_h^6 \left\{ \frac{1}{24} - \frac{\lambda M P_\varepsilon}{4 \left(1 + \frac{\lambda M P_\varepsilon}{4} \right)} \frac{1}{8} \right\} \right] \quad (21)$$

Effective longitudinal diffusion in capillary

The effective longitudinal diffusion of nanoparticles is obtained using the following diffusion equation

$$\frac{1}{r'} \frac{\partial}{\partial r'} \left(r' \frac{\partial C'}{\partial r'} \right) = \frac{\hat{u}}{D_m} \frac{\partial C'}{\partial x'} \quad (22)$$

where $\hat{u} = u(r) - U$

The non-dimensional equations in both the regions are:

$$\frac{\partial}{\partial r} \left(r \frac{\partial C_2}{\partial r} \right) = \left(\frac{u_1(r) - U}{D_m} \right) R_1 \frac{\partial C_2}{\partial x} \quad \text{for } r > r_h \quad (23)$$

$$\frac{\partial}{\partial r} \left(r \frac{\partial C_1}{\partial r} \right) = \left(\frac{u_c(r) - U}{D_m} \right) R_1 \frac{\partial C_1}{\partial x} \quad \text{for } r < r_h \quad (24)$$

Using homogeneous boundary condition:-

$$\frac{\partial C_1}{\partial r} = 0 \text{ at } r = 0 \quad \text{and} \quad (25)$$

$$C_1 = 0 \text{ at } r = 0$$

The concentration in the region $r < r_h$ is given as

$$C_1 = \left(\frac{u_c(r) - U}{D_m} \right) R_1 \frac{\partial C}{\partial x} \frac{r^2}{4} \quad (26)$$

Using the following impermeability condition at the wall and continuity condition at $r = r_h$

$$\left. \begin{aligned} \frac{\partial C_2}{\partial r} &= 0 \\ C_2 &= C_1 \end{aligned} \right\} \quad \begin{aligned} r &= 1 \\ r &= r_h \end{aligned} \quad (27)$$

The concentration in the suspension region is given by

$$\begin{aligned} C_2 &= \left[(u_c(r) - U) + \left(1 + \frac{\lambda M P_e}{4} \right) \left\{ \left(\frac{r_h^2 - r^2}{16} - \frac{(r_h^6 - r^6)}{144} \right) \right. \right. \\ &\quad \left. \left. + \frac{\lambda M P_e}{4 \left(1 + \frac{\lambda M P_e}{4} \right)} \left\{ \frac{(r_h^2 - r^2)}{16} - \frac{(r_h^6 - r^6)}{144} \right\} + \frac{U}{4} (r_h^2 - r^2) \right\} + \frac{1}{D_m} \frac{\partial c}{\partial x} + B_2 \log \left(\frac{r}{r_h} \right) \right] \end{aligned} \quad (28)$$

$$\text{where } B_2 = \left[\left(1 + \frac{\lambda M P_e}{4} \right) \left\{ \frac{1}{8} + \frac{\lambda M P_e}{48 \left(1 + \frac{\lambda M P_e}{4} \right)} \right\} - \frac{U}{2} \right] \frac{1}{D_m} \frac{\partial c}{\partial x}$$

The Flux of the Solute

$$J = \frac{1}{\pi R_1^2} \left[\int_0^{r_h} \left(\hat{u}_c C - D_m \frac{\partial c}{\partial x} \right) 2\pi r dr + \int_{r_h}^1 \left(\hat{u}_1 C - D_m \frac{\partial c}{\partial x} \right) 2\pi r dr \right] \quad (29)$$

The effective diffusion coefficient is stated as:-

$$D_{eff} = -J / \frac{\partial c}{\partial x} \quad (30)$$

$$\frac{D_{eff}}{D_m} = \left[1 + \frac{1}{48} \left(\frac{U \times R_1}{D_m} \right)^2 F(\xi_c) \right] \quad (31) \quad \frac{D_{eff}}{D_m} = \left[1 + \frac{1}{48} P_e^2 F(\xi_c) \right] \quad (32) \text{ where}$$

$$\begin{aligned} F(\xi_c) &= \left[\frac{128 R_1^7}{\{A(\xi_c)\}^2} \left\{ \left(\frac{1}{R_1^{12}} - \frac{\xi_c^4}{R_1^8} \right) \frac{G_1}{4} + \left(\frac{1}{R_1^{12}} - \frac{\xi_c^6}{R_1^6} \right) \frac{G_2}{6} + \left(\frac{1}{R_1^{12}} - \frac{\xi_c^8}{R_1^4} \right) \frac{G_3}{8} \right. \right. \\ &\quad \left. \left. + \left(\frac{1}{R_1^{12}} - \frac{\xi_c^{10}}{R_1^2} \right) \frac{G_4}{10} \right. \right. \end{aligned}$$

$$\left. \left(\frac{1}{R_1^{12}} - \xi_c^{12} \right) \frac{G_5}{12} + \left(-\frac{1}{4 R_1^2} - \frac{\xi_c^2}{2 R_1^{10}} \left(\log r_h - \frac{1}{2} \right) \right) G_6 + \left(-\frac{1}{16 R_1^8} \left(\log r_h - \frac{1}{16} \right) G_7 \right. \right.$$

$$\left. \left(-\frac{1}{36 R_1^{12}} - \frac{\xi_c^6}{2 R_1^6} \left(\log r_h - \frac{1}{36} \right) \right) G_8 - \left(\frac{1}{R_1^{12}} - \frac{\xi_c^2}{R_1^{10}} \right) \frac{G_9}{2} \right\} + \frac{8 \xi_c^4}{R_1^2}$$

$$\left[\left(1 + \frac{\lambda M P_e}{4} \right) \left\{ \left(\frac{1}{R_1^4} - \frac{\xi_c^2}{R_1^2} \right) \frac{1}{2} + \frac{\lambda M P_e}{4 \left(1 + \frac{\lambda M P_e}{4} \right)} \left(\frac{1}{R_1^4} - \xi_c^4 \right) \frac{1}{4} \right\} - \frac{1}{R_1^2} \right]$$

$$G_1 = \left[\left\{ \frac{\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)^2}{16} \left(1 + \frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} + \frac{1}{4} \left(\frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right)^2 \right) + \frac{U}{4} \left(1 + \frac{\lambda M P_\varepsilon}{4} \right) \left(1 + \frac{19}{4} \frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right) + U \left\{ \frac{R_1}{D_m} + \frac{B_2}{2} \left(1 + \frac{\lambda M P_\varepsilon}{4} \right) \right\} \right];$$

$$G_2 = \left[\left\{ -\frac{\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)^2}{32} \left(3 + \frac{5}{4} \frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right) + \frac{1}{32} \left(1 + \frac{\lambda M P_\varepsilon}{4} \right) \frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right\} \frac{R_1}{D_m} \right] + \frac{B_2}{2} \left(1 + \frac{\lambda M P_\varepsilon}{4} \right) \frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)};$$

$$G_3 = \left[\left\{ \frac{\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)^2}{16} \left(\frac{1}{4} - \frac{5\lambda M P_\varepsilon}{36\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} - \frac{5}{72} \left(\frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right)^2 \right) - \frac{5U \left(1 + \frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right)}{288\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right\} \frac{R_1}{D_m} \right];$$

$$G_4 = \frac{17}{288} \frac{R_1}{D_m} \left[\left(1 + \frac{\lambda M P_\varepsilon}{4} \right)^2 \frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right];$$

$$G_5 = \frac{1}{576} \frac{R_1}{D_m} \left[\left(1 + \frac{\lambda M P_\varepsilon}{4} \right)^2 \left(\frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \right)^2 \right];$$

$$G_6 = \left[-\frac{\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)}{2} - \frac{\frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \left(1 + \frac{\lambda M P_\varepsilon}{4} \right)}{4} - U \right] B_2 ;$$

$$G_7 = \frac{\left(1 + \frac{\lambda M P_\varepsilon}{4} \right) B_2}{2};$$

$$G_8 = \frac{B_2}{4} \left(1 + \frac{\lambda M P_\varepsilon}{4} \right) \frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)};$$

$$G_9 = \left[-\frac{\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)}{2} - \frac{\frac{\lambda M P_\varepsilon}{4\left(1 + \frac{\lambda M P_\varepsilon}{4}\right)} \left(1 + \frac{\lambda M P_\varepsilon}{4} \right)}{4} - U \right] B_3;$$

$$B_3 = \left[\left(1 + \frac{\lambda M P_\varepsilon}{4} \right) \left\{ \frac{1}{16} + \frac{\left(1 + \frac{\lambda M P_\varepsilon}{4} \right)}{42} - U \right\} \right] \frac{\partial c}{\partial x}$$

III. RESULTS AND DISCUSSIONS

There are two terms involve in the expression of effective longitudinal diffusion D_{eff} . The first one is D_m and the other term defining convection $P_{e_0}^2$. This convective term is dependent on Π permeability, Ω pressure distribution and ξ_c blood rheology. The effective diffusivity decreases due to the permeability of the vessel. Sharp also derived the same result that as ξ_c increases D_{eff} decreases.

The effective longitudinal transport has an influence of ξ_c shown in figure 2 and 3 along permeable vessels ($\Pi = 2, 4, \Omega = -2$). It is shown through graphs that the vessel permeability reduces D_{eff}/D_m and D_{eff}/D_m decreases as ξ_c increases. It is also shown that the portion of the capillary where the effective diffusion and diffusion coefficient becomes wider as rheological parameter and permeability increases. Results are similar to those obtained by Gentile [7].

The effect of Ω is also depicted through graphs. Figure shows that as Ω decreases the pressure coming from venule decreases or outlet pressure declines that causes a greater pressure difference between the vessel ends and simultaneously decreasing the velocity. This causes a decrease in diffusivity.

In our consideration the blood viscosity is depend upon the concentration of RBC. Therefore, as nanoparticles are inoculated in the blood, they scatter along the capillary. The nanoparticles mingle with blood cells because of the tripping and stumbling movement of RBC. This causes an increase in the volume fraction of RBC, which raises the nanoparticle concentration along the boundary of the capillary hence causing a relatively greater diffusion.

The rise in concentration of nanoparticle enhances the number of delivered nanoparticles, simultaneously unaffected their efficiency as shown by Podduturi [16]. As the concentration of nanoparticle increases the interparticle distance lessens that perturbs movement of red blood cell. This decreases the motion of nanoparticle towards the vessels and decreases the diffusion nanoparticles.

The distribution of nanoparticles is not consistent, with greater number of particles around the capillary wall. Such brimming of nanoparticles around wall is because of the hydrodynamic interactions and red blood cell volumetric exclusion effect. The nanoparticle density is higher near the capillary wall which causes a higher coherence of the nanoparticles. The binding rate of nanoparticles with red blood cell is two times higher than the without red blood cell.

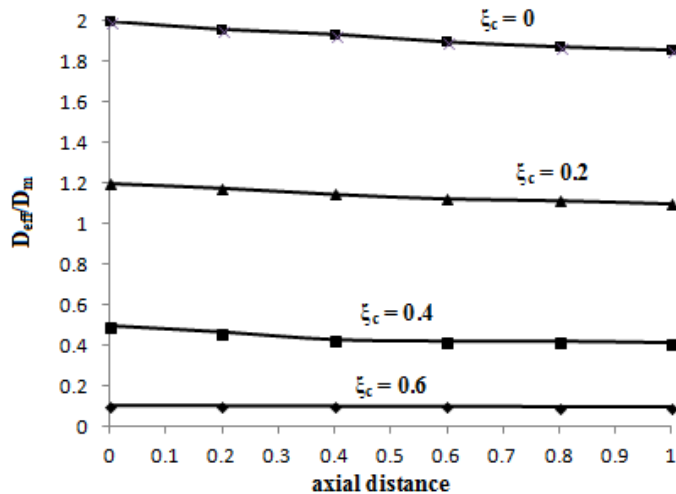


Fig.2 Variation of D_{eff}/D_m versus axial distance for distinct values of rheological parameter ξ_c for ($\Pi = 2$, $\Omega = -2$)

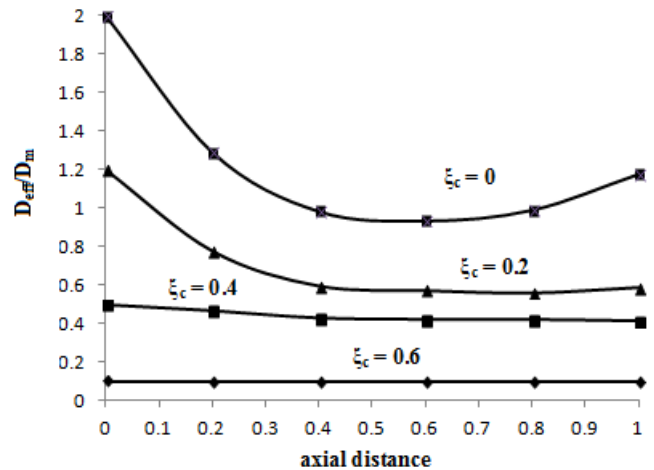


Fig. 3 Variation of D_{eff}/D_m versus axial distance for distinct values of rheological parameter ξ_c for ($\Pi = 4$, $\Omega = -2$)

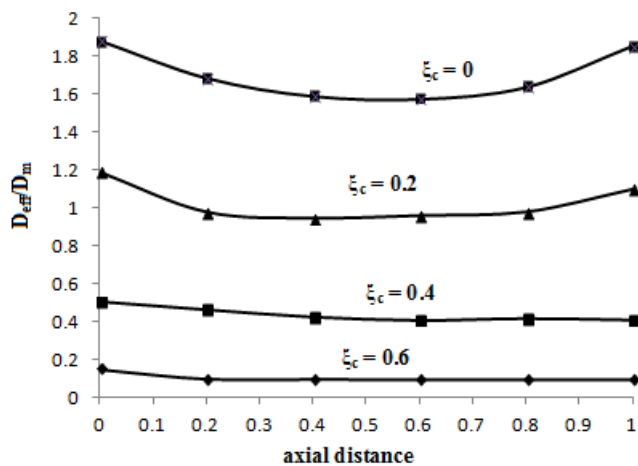


Fig. 5 Variation of D_{eff}/D_m versus axial distance for distinct values of rheological parameter ξ_c for ($\Pi = 2$, $\Omega = -8$)

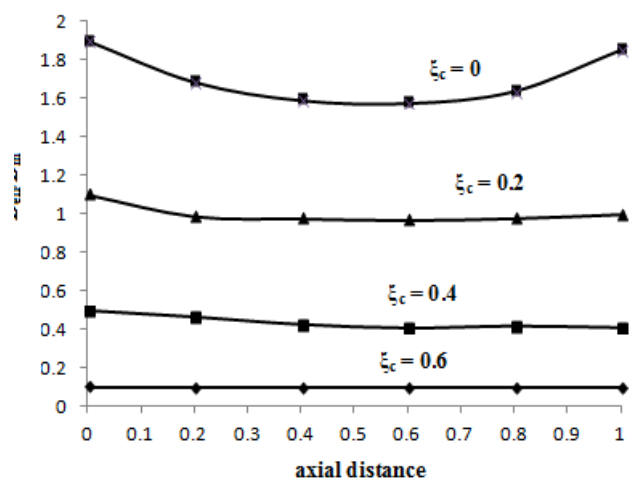


Fig. 4 Variation of D_{eff}/D_m versus axial distance for distinct values of rheological parameter ξ_c for ($\Pi = 2$, $\Omega = -4$)

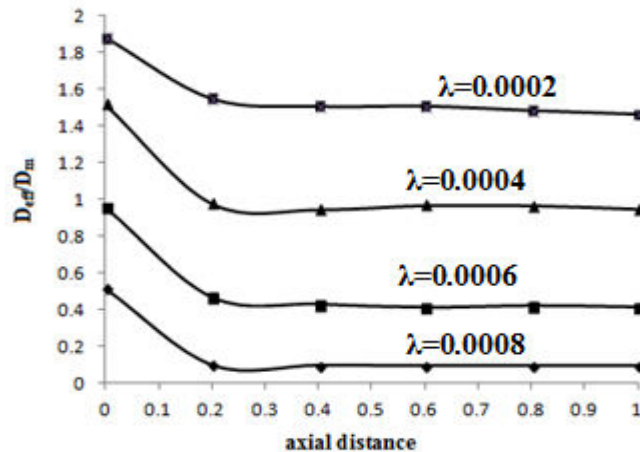


Fig. 6 Variation of D_{eff}/D_m versus axial distance for distinct values of RBC volume fraction for ($\Pi = 2$, $\Omega = -2$)

IV. CONCLUSIONS

Through this model we have tried to determine the parameters that govern the nanoparticle delivery and understand their significance. In this mathematical analysis, the influence of red blood cells (RBC) is examined by emulating the delivery of nanoparticles in the blood vessel. We have considered the viscosity depending upon the concentration of RBC. Red blood motion also affects the spreading of nanoparticle concentration. Nanoparticles inter-commute with blood cells by the stumbling movement of RBC which enhances RBC volume fraction. Nano-drug carriers locate stenosed vessel walls and transport it so it dissolves or cures deposition of cholesterol or other substances. The nano-carriers might look for early stages of stenosis and destroy tumours. For further study this model can be suitably developed and used in the treatment of different cardiovascular diseases.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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