Proceedings of BIO2006
2006 Summer Bioengineering Conference
June 21-25, Amelia Island Plantation, Amelia Island, Florida, USA

BIO2006-157423

SEPERATION OF RBC FROM PLASMA AND NON-NEWTONIAN VISCOSITY EFFECT USING MICRO-CHANNELS

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INTRODUCTION

Many applications in clinical diagnostics need separation of the serum and particles mainly in blood, protein or cell solutions. Centrifuge has been the primary method of separation for such applications, which is relatively time consuming and hazardous for the cells in these solutions. Micro-fluidic systems, having slug flows, can minimize cell damage during the separation, as the shear force on the bio-particles is negligible. Hence, bio-particle separation in micro-fluidics has been of great interest to researchers for many years as such systems can be used to obtain the desired separation faster. When short duration pressure pulses are applied to the sample which is plasma containing the red blood cells (RBC), RBC can be separated from the plasma by a net force, which prevents it from reaching the same velocity as that of plasma [1]. To find the critical factors of pulse, viscosity on separation of RBC, a numerical analysis, with experimental validation is conducted in this study. Due to the shear thinning effect of the non-Newtonian viscosity of the blood, it is observed that the RBC in plasma with non-Newtonian viscosity moves to the front end of the plasma column, where as with Newtonian viscosity it moves to the back end of the plasma column. Further, for a Newtonian approximation of blood viscosity, there is a denser accumulation of RBC after 30 pulses when compared to 5 pulses in the rear end of the plasma column.

NUMERICAL SIMULATIONS

A micro channel of 250×100 microns has been used for the calculations. Particle size and density of 4.1μm, 1050 kg/m^3 similar to the size and density of RBC have been used for the Newtonian calculation. Blood properties have been taken for the non-Newtonian calculation, where in Carreau model has been adopted for the non-Newtonian viscosity as shown in equation 1.

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty)\left[1 + (\lambda\dot{\gamma})^2\right]^{(n-1)/2} \quad (1)$$

where λ (=3.313) s represents time constant, n (=0.3568) is power-law index, $\dot{\gamma}$ is the local shear rate, η_0 (=0.56 poise) and η_∞ (=0.0345 poise)are zero shear viscosity and infinite shear viscosity, respectively. Volume of fluid (VOF) and discrete phase modules have been used for the fluid and particle simulations respectively. The Navier-Stoke equations are solved for the fluid motion and following equation 2 and 3 is used for the interface tracking of the fluid.

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right) + \nabla \cdot \left(\alpha_q \rho_q \vec{v}_q\right) = 0 \quad (2)$$

$$\sum_{q=1}^{n} \alpha_q = 1 \quad (3)$$

where α_q, ρ_q, v_q denotes volume fraction, density and velocity of the qth phase respectively.

Fluid velocities from the Navier-Stoke equations are solved and the values are incorporated into the discrete phase model. Using these velocities the particle Reynolds number (Re) and the net drag on the particles are calculated using equation 4, 5 and 6.

$$\frac{dV_p}{dt} = F_D\left(V - V_p\right) \quad (4)$$

$$\mathrm{Re} = \frac{\rho d_p (V - V_p)}{\mu} \qquad (5)$$

$$F_D = \frac{18 \mu C_D \mathrm{Re}}{24 \rho_p d_p^2} \qquad (6)$$

where F_D $(v-v_p)$ is the drag force per unit particle mass, Re is the relative Reynolds number. C_D, μ , v, v_p represent the coefficient of drag force, dynamic viscosity, fluid and particle velocities, respectively.

RESULTS AND DISCUSSIONS

RBC separations for both Newtonian and non-Newtonian fluids have been calculated. It has been observed that the RBC in plasma with non-Newtonian viscosity moves to the front of the plasma, where as, with Newtonian viscosity it moves to the back of the plasma. This phenomenon is caused due to the shear thinning effect of the non-Newtonian viscosity of the plasma. Figure 1 shows the particle distribution inside the micro channel after 5 & 30 pulses of 3 psi pressure for plasma with Newtonian viscosity. It can be observed that there is a denser accumulation after 30 pulses when compared to 5 pulse and the particles get accumulated in the rear end of the plasma.

From equations 4, 5 and 6, it is observed that the particle velocity is always less than the fluid velocity, which causes the particles to lag and accumulate at the back of the fluid. Figure 2 and 3 show the percentage of plasma free from RBC with number of pressure pulses for Newtonian and non-Newtonian viscosities, respectively. Figure 2 also shows the comparison between experimental and numerical results and the effect of pulse pressure and particle density on the separation of RBC in plasma. For about 15 pulses the separation of RBC, using 5 psi, is about 20% more as compared to a pulse pressure of 3 psi. After about 30 pulses the separation of particles become independent of pressure. About 40% increase in density (from 1050 kg/m^3 to 1500 kg/m^3) leads to a 15% more separation for 10 pulses of 3 psi pressure. Figure 3 shows the comparison for non-Newtonian viscosity with experimental results, a maximum of 20% separation of RBC is obtained with a pressure of 5 psi.

From figure 2, it is observed that the pressure and the number of pulses have to be optimized in order to obtain a desired separation. Hence, separation of particles in fluids with Newtonian viscosity is faster and better when compared to non-Newtonian viscosity.

As many bio-fluids are non-Newtonian in the nature, further experiments and calculations are needed to quantify the separation mechanism for bio-fluids having non-Newtonian viscosity properties.

REFERENCE

[1] A. Jain et al, 7th International Conference on miniaturized Chemicaland Biochemical Analysis systems, October 5-9, 2003, Squaw Valley, California, USA.

[2] Jungyoup Han et al, 9th International Conference on miniaturized Chemical and Biochemical Analysis systems, October 5-9, 2005, Florida,USA

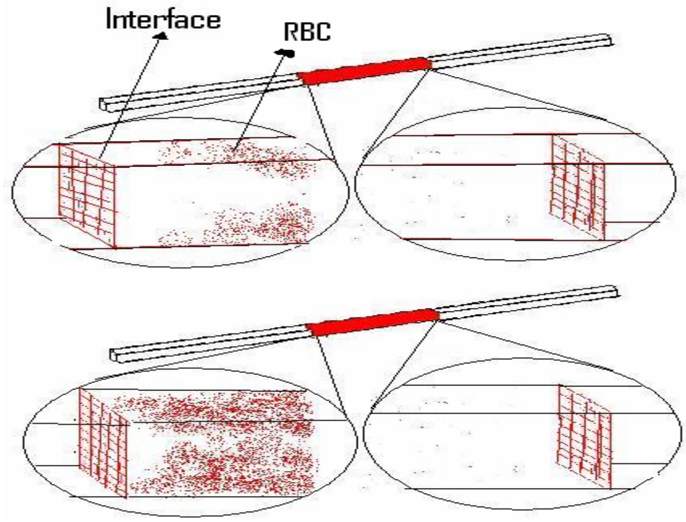

Fig. 1. RBC distribution inside the micro-channel after 5 & 30 pulses respectively using a 3 psi pressure for plasma with Newtonian viscosity

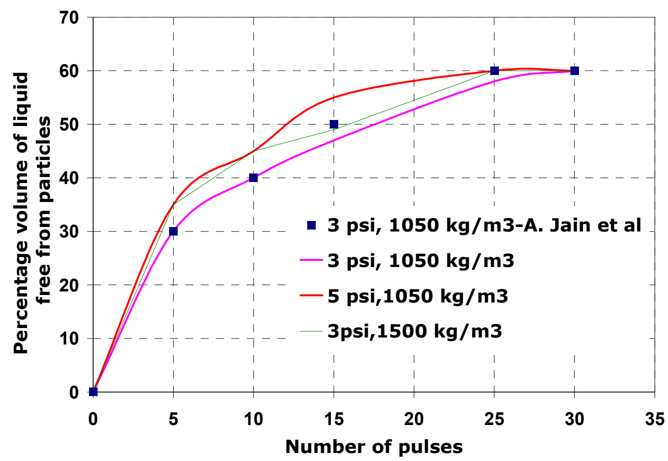

Fig. 2. Percentage plasma free from RBC with Newtonian viscosity

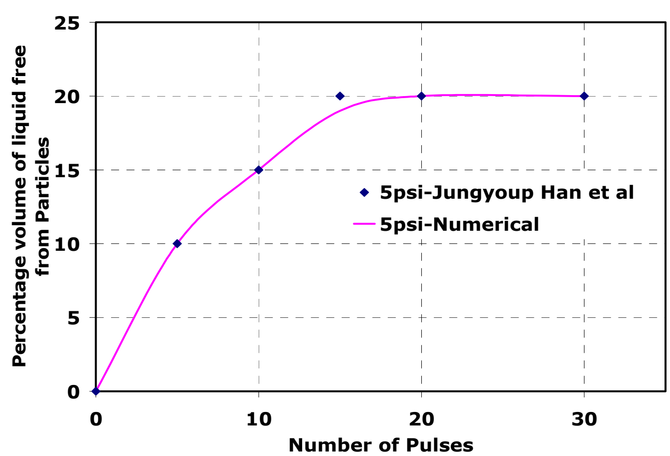

Fig. 3. Percentage plasma free from RBC with non-Newtonian viscosity