SIMULATION OF MICROFLUIDIC BLOOD VISCOSITY FOR MEMS DEVICES

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ABSTRACT

Blood analyzer MEMS will require generating blood microflows. For their design it will be necessary to develop a model of blood transport in microchannels. In this work we analyze the rheological behavior of blood by varying the concentration of red blood cells. We propose modifications to the coefficients of the basic power law model of viscosity for non-Newtonian fluids, based on the general behavior of viscosity of polymeric suspensions. It is found that the modifications reproduce the qualitative variation of viscosity with concentration.

RESUMEN

Para analizar sangre en MEMS, Sistemas Micro Electro Mecánicos, requerimos generar micro fluidos de sangre. Para este diseño será necesario desarrollar un modelo de transporte de sangre en micro canales. En este trabajo analizamos el comportamiento rheológico de la sangre variando la concentración de las células de glóbulos rojos en la sangre. Proponemos modificaciones de los coeficientes del modelo básico de potencia para baja viscosidad para fluidos no Newtonianos, basados en el comportamiento general de viscosidad en una suspensión polimérica. Donde encontramos que las modificaciones reproducen la variación cualitativa de la viscosidad con la concentración.

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Para analizar sangre en MEMS, Sistemas Micro Electro Mecánicos, requerimos generar micro fluidos de sangre. Para este diseño será necesario desarrollas un modelo de transporte de sangre en micro canales. En este trabajo analizamos en comportamiento rheológico de la sangre variando la concentración de las células de glóbulos rojos en la sangre. Proponemos modificaciones de los coeficientes del modelo básico de potencia para baja viscosidad para fluidos no Newtonianos, basado en el comportamiento general de viscosidad en una suspensión polimérica. Donde encontramos que las modificaciones reproducen la variación cualitativa de la viscosidad con la concentración.

1. INTRODUCTION

Microfluidic MEMS for biomedical applications have great importance because of their commercial potential. With the development of new technologies in the fabrication of integrated circuits, it is possible to generate flows in microchannels that have reduced widths in the 3 μm-300 μm range [1].

A blood analyzer MEMS, requires taking a sample by means of generating a blood microflow through a microneedle of the microfluidic system. To develop these systems it is necessary to have a model describing the main properties of blood transport in a microchannel.

Because microfluidics is an interdisciplinary science, involving firstly, the study on the blood's physiological properties, of which we only consider that blood is roughly a suspension of red blood cells (RBCs) suspended in water with variable concentration. Secondly, we must consider the apparent viscosity behavior of blood, before constructing the numerical simulation of a non-Newtonian flow in a simple microchannel.

In this paper, we analyze the rheological [2] behavior of blood by varying the concentration of the RBCs in a modification of the basic power law model of viscosity for non-Newtonian fluids.

The constitutive relation has the form of a generalized power law with coefficients depending on the rate of shear. We propose some modifications to these coefficients based on the general behavior of viscosity of polymeric suspensions, by taking into account changes in the concentration of the RBCs .

2. MODEL OF MICROFLUIDIC BLOOD VISCOSITY

Low channel dimension modifies the main characteristics of blood flow, in particular, we don't expect any turbulence effects. Also because of the non-slip boundary conditions, for pressure driven flows, we will have a parabolic velocity profile. This kind of laminar profile introduces some restrictions on the transport processes within the channels. In fact, it can be shown that transverse transport flow will only appear by diffusion.

Another important feature of microfluidic flow consists in normal Newtonian fluids becoming non-Newtonian due to the microscopic size of the channel. In blood microflow this situation leads to obtaining some form of blunt parabolic profile, characteristic of complex rheological fluids.

Before developing any simulations of microfluidic blood flow, it's necessary to have an expression for the effective viscosity. For non-Newtonian flows some heuristic constitutive relations have been proposed in the literature [3-4], relating the stress tensor with the shear rate of deformation of blood through an apparent viscosity coefficient. The goal is to reproduce the rheological properties of blood samples, considered here as a polymeric solution with viscosity depending on the high shear rate of deformation due to the microchannel confinement.

The rheological properties of blood for microfluidic MEMS devices, can be expressed through a generalized constitutive non-Newtonian relation,

$$\tau = \eta\left(\dot{\gamma}\right)\dot{\gamma} \qquad (1)$$

where τ denotes the stress tensor, $\dot{\gamma}$ the shear rate of deformation, and $\eta(\dot{\gamma})$ is the apparent nonlinear viscosity of the fluid. At low shear rates the viscosity of blood is a constant, then as the shear rate increases, it drops down in a process known as shear thinning, until it again reaches a lower constant value. A similar behavior presents itself in the elastic coefficient of the fluid, when an oscillatory viscosimeter is used.

A very useful model is that corresponding to the so called "generalized power law", which can be expressed as:

$$\eta\left(\dot{\gamma}\right) = \lambda\dot{\gamma}^{(n-1)}\dot{\gamma} \qquad (2)$$

here

$$\lambda\left(\dot{\gamma}\right) = \mu_{\infty} + \Delta\mu\left[-\left(1+\frac{\dot{\gamma}}{a}\right)\exp\left(-\frac{b}{\dot{\gamma}}\right)\right] \qquad (3)$$

and

$$\eta\left(\dot{\gamma}\right) = \eta_{\infty} + \Delta\eta\left[-\left(1+\frac{\dot{\gamma}}{c}\right)\exp\left(-\frac{bd}{\dot{\gamma}}\right)\right] \qquad (4)$$

The experimental results for the viscosity of blood are reproduced correctly by this model with $\mu\infty$=0.035, $\Delta\mu$=0.25, $n\infty$=1.0, Δn=0.45, a=50.0, b=3.0, c=50.0, and d=4.0.

Roughly, blood samples can be considered as a polymeric suspension with two characteristic viscosities: that of the solvent (water), and that of the polymeric material composed of RBCs. For describing blood microflows it is important to take into account the RBC concentration on the effective blood viscosity. In general it is an increasing function of the RBC concentration.

To take this into account in the "generalized power law" model, we propose incorporating a set of simple modifications like including a power concentration of the fractional (relative) viscosity in the term where RBCs have a dominant contribution. Also, we must take into account that increasing the weight fraction of RBCs reduces the corresponding weight fraction of water. Under such circumstances we have the following model changes

$$\lambda\left(\dot{\gamma}\right) = \mu_{\infty}(1-\omega) + \Delta\mu\omega\left(\frac{\Delta\mu}{\mu_{\infty}}\right)^{\omega}\left[-\left(1+\frac{\dot{\gamma}}{a}\right)\exp\left(-\frac{b}{\dot{\gamma}}\right)\right] \qquad (5)$$

here ω is the proportion of blood cells.

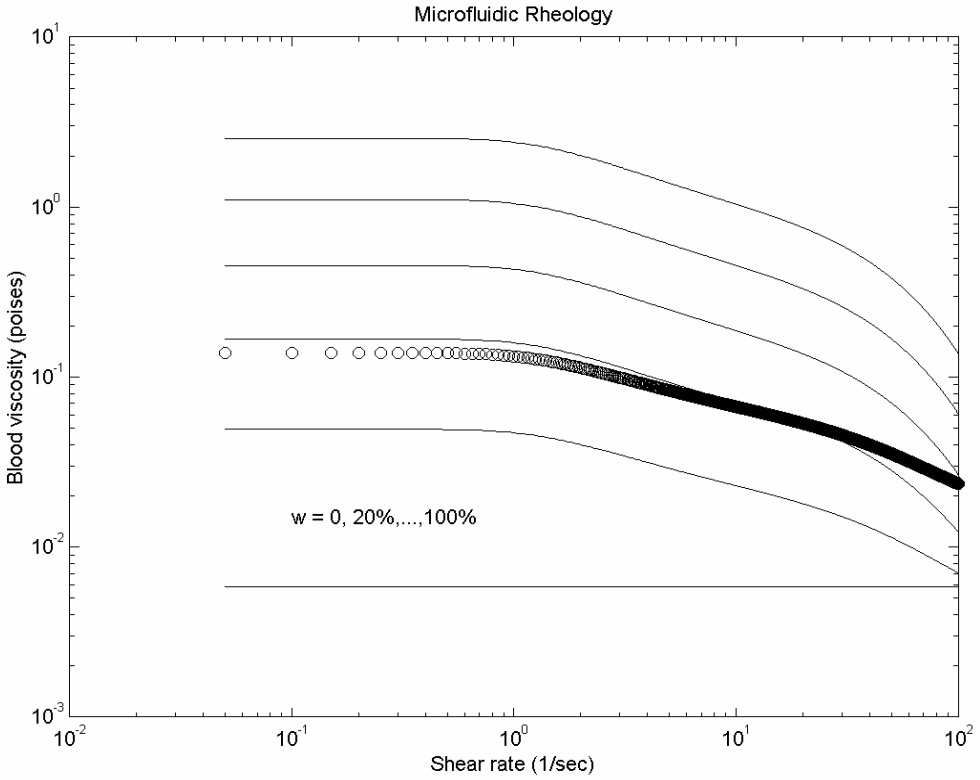

Fig. 1. Variation of viscosity with concentration of RBC's.

The results of such changes in the model are represented in Fig. 1, where we can appreciate a correct qualitative behavior of viscosity on concentration changes. In fact, our results are close to those of the original model for w=40%, which are represented by circles.

Another remark related to the RBC concentration consists in that below 8%, blood nearly behaves as a Newtonian fluid. This situation is approximately reproduced by our model, observing that the curves are rising with an increase of RBC concentration; this corresponds to the expected behavior.

Experimental measurements of viscosity down to the microrange have demonstrated some unexpected characteristics at high shear rates. It has been found that the behavior of the human blood, at different gap sizes, not only exhibits the usual shear thinning characteristic, but also the complete curve decreases with the gap size even at high shear rates. This could be considered for future study.

3. CONCLUDING REMARKS

We are mainly interested in obtaining some of the basic rhheological characteristics of microfluidic blood flow for medical MEMS applications. The analysis has been based on some macroscopic general models for the constitutive relations of non-Newtonian polymeric fluids. The conventional non-Newtonian fluid power law has been modified, under some general arguments for polymeric solution viscosities, allowing us to reproduce the variations of blood viscosity for several RBC concentrations. The results show good agreement with those for numerical analysis of rheological properties of blood in normal concentrations.

4. REFERENCES

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