Influence of flexible particle presence on the flow in the channels of microfluidic devices. Results and discussing

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Abstract. At the present paper the distribution of main flow characteristics for the fluid flow in the channel of microfluidic device are considered. Numerical simulations were made by the FENE-P model. Element of microfluidic system is performed as a channel with narrowing. The simulation parameters are: Reynolds number $Re = 0.01$, Weissenberg number $We = 0.6$, retardation coefficient $\beta = 0.1$ and degree of unraveling of the flexible particle $L^2=50, 700$. Also, distribution of above mentioned characteristics are performed.

1. Introduction
Microfluidic devices are successfully implemented in many spheres of human activity. Such systems consist of a variety of channels with different shapes for consistent transformation of reagents, concentration, mixing and transfer to reaction microchambers. There are various shapes of channel that might be used in such systems. They can be T-or Y-shaped channels, or channels with narrowing. The fluids inside these devices are mostly non-Newtonian and have special properties even at small Reynolds number. During the flow through a channel with complex construction the stagnant areas may occur at these zones where particles with certain properties accumulate, and other particles freely continue to move. This effect is called a «hydrodynamic» trap.

The aim of this paper is to study a distribution of main flow characteristics at the planar channel with narrowing of 50% in the laminar flow regime.

2. Results
Numerical simulations for the viscoelastic fluids were made by the FENE-P (Finitely Extensible Nonlinear Elastic by Peterlin). It applies for diluted polymer solutions and predicts the following properties: viscosity anomaly, relaxation time and dependence of longitudinal viscosity on longitudinal deformation rate. This model considers the macromolecules as flexible dumbbells (two beads connected with the spring). It assumes that the flexible dumbbells may be stretched relative to its equilibrium length [1,2,3]. Further a flexible dumbbell will be named as flexible particle or macromolecule.

Two fluid models were used to describe a fluid behavior: a non-Newtonian and Newtonian models. Two cases of viscoelastic fluid are considered, where $L^2=50$ and $L^2=700$, the other modelling parameters ($We=0.6$, $Re=100$, $\beta=0.1$) are accepted with the same values. To get results for Newtonian fluid might be possible using the FENE-P model at $We=0.01$. It characterizes relation between elastic and viscous forces.
The streamline patterns for non-Newtonian fluid at various $L^2$ and Newtonian fluid are presented on fig.1. At first glance, all the three cases are similar and have negligible differences in sizes and shapes of stagnant area.

![Streamlines](image)

**Figure 1.** Streamlines for Newtonian fluid (a) and non-Newtonian at $L^2=50$ (b); $L^2=700$(c).

The formation of stagnant areas is primarily caused by reasons: the shape of channel and the presence of special properties of the fluid. There is a rapid velocity change near the walls from zero value to the flow rate. The velocity changes in central part of the channel are negligibly small. At the places where the walls have changes in their shapes the stagnation of the flow is occur. Geometrical sizes of such zones depend on shapes of the channel, narrowing degree and its length.

Distribution of pressure deviation and shear stresses along the symmetry line is performed on fig. 2. Pressure drop for non-Newtonian fluid at $L^2=50$ is different in comparison to other cases. Two cases are close to each other. There is an assumption that such value of macromolecules stretching $\Pi$ it does not mean that all macromolecules stretch to such values.

![Pressure and Shear Stresses](image)

**Figure 2.** Pressure distribution (a) and shear stress distribution (b) along the centerline.

Most of them remain entangled, which on the one hand leads to a decrease in viscosity compared to the Newtonian fluid, and on the other hand – entangled macromolecules make some resistance. This leads to the fact that the pressure drop for a non-Newtonian fluid at $L^2=700$ and the Newtonian fluid is approximately the same. At the same time the macromolecules length $L^2=50$ in the untangled state is not sufficient to make areas with increased resistance. Shear stresses distribution (fig. 2a) shows symmetry loss for non-Newtonian fluid at $L^2=700$. 
The principle stress difference is associated with such characteristics as first normal stress difference $N_1$ and shear stresses $\tau_{xy}$:

$$\sigma_1 - \sigma_2 = \sqrt{N_1^2 + 4\tau_{xy}^2}$$ (1)

The arising normal stresses for a Newtonian fluid are associated with a change in the shape of the flow (i.e., the channel expansion), and the shear stresses - with a velocity change. Their total contribution to the $\sigma_1 - \sigma_2$ is negligible. This explains small values of principle stress difference (fig. 3а).

Principle stress difference distribution for the Newtonian fluid has significant differences from Newtonian fluid. The peak values 10 time greater than for Newtonian case. The areas of maximum values correspond to two lines of oriented macromolecules, and these zones are asymmetric. In comparing to velocity distribution (fig. 3b), it might be seeing that the Newtonian velocities are greater than non-Newtonian. This is a reason of reduction of the sizes of stagnant areas. Lines of oriented macromolecules prevent the free penetration of fluid in the area of corner points.

![Figure 3. Principle stress differences and velocity vertical component distribution.](image-url)
At some distance (8 widths) from the channel expansion area (fig. 3c) for Newtonian fluid the narrowing influence is not significant. The distribution of the vertical velocity component in the cross section is antisymmetric. Whereas, for viscoelastic fluid, the narrowing influence is such that the resulting asymmetry in the region of contraction and at a distance of 8 widths affects the flow (fig. 3d). The emerging picture still remains symmetrical.

3. Conclusions
The considered problem is of great practical and theoretical importance. Obtained results can be used in the design of devices for the "grouping" of macromolecules in certain areas of the channel. In some cases, it is necessary to keep the particles in the measurement area for a certain time. One way to achieve that goal is to use the hydrodynamic traps in the channel of microfluidic devices. The main idea of such traps is to separate flexible particles by their properties.

The selected shape of the channel with a smooth narrowing can be used as part of a microfluidic device or lab-on-the-chip in cases where it is necessary to separate some particles from others. In addition a forming tube of oriented macromolecules and symmetry-loss effect were shown. The stability of the symmetric flow shape is influenced by both the geometric characteristics of the channel and the properties of the fluid, such as the viscosity anomaly, elastic properties and variable longitudinal viscosity. The change in the direction of fluid flow due to the presence of narrowing in the channel leads to a change in the conformation of macromolecules associated with their untangling and orientation. For microchannels in the flow of viscoelastic fluid macromolecules can be untangled in such a way that their length in the untangled state is many times greater than the size of the macromolecule in a non-equilibrium state. As a result, oriented and elongated macromolecules affect the change in normal stresses, which ones in turn affect the flow.

References
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