The influence of fluid - flexible particle interaction on fluid flow optical non-homogeneity in channel bifurcation

F Kh Tazyukov, E R Kutuzova and F A Garifullin
Kazan national research technological university, 68 Karl Marx street, Kazan, 68, 420015, Republic of Tatarstan, Russian Federation
E-mail: elvira.kutuzova@list.ru

Abstract. In the present paper peculiar properties of convergent fluid flow in T-junction channel is considered. There is no interaction between flexible particles in the flow. Such kind of situation is described by rheological FENE-P and Oldroyd-B models. The first one predicts viscosity anomaly, dependence of longitudinal viscosity on longitudinal strain rate and elastic properties; the last one – existence of longitudinal viscosity depending on longitudinal strain rate \( \dot{\varepsilon} \) and having a physical sense only for \( \dot{\varepsilon} \ll \frac{1}{(2\lambda)} \) and elastic properties. The model’s governing parameters are the Weissenberg number \( (We) \), the Reynolds number \( (Re) \), the ability of flexible particle to change its orientation and stretching degree \( (L^2) \) in the main flow. The bifurcation area is of great importance due to possibility of high stresses and velocities existence not only in central area, but also on the walls and near the corners. The symmetry-loss effect at creeping flows regime \( (Re \ll 1) \) is investigated. It has been showed that at certain set of \( We \) and \( L^2 \) values the symmetrical shape of fluid flow turns to asymmetrical shape.

1. Introduction
Many scientists all over the world investigate on microfluidic flows since the previous century [1], including non-Newtonian flows through T-junction channels. These fluids such as suspensions, emulsions, liquid bioassays, polymer melts and solutions play a special part in nowadays. Studying and understanding its behavior is of great importance due to its common usage: conducting chemical and medical analyses, microfluidic devices production, industrial production [2-4]. Flexible particles and fluid flow interaction is responsible for the effects emerging in channel bifurcation. The aim of the present paper is to investigate the fluid flow structure in a planar T-junction symmetrical channel with cavity.

2. Governing equations
Fluid flow may be described by the momentum equations and mass conversation:

\[
\rho \left( \frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v} \right) = -\nabla p + \nabla \cdot \vec{\tau}, \tag{1}
\]

\[
\nabla \cdot \vec{v} = 0, \tag{2}
\]

For non-Newtonian fluids the extra-stress is the sum of polymer and solvent stress contributions:

\[
\vec{\tau} = \vec{\tau}^p + \vec{\tau}^s, \tag{3}
\]
where \( \tau^S = 2\eta^s \vec{D} \).

Non-Newtonian stress contribution for the FENE-P model could be written as follows:

\[
\tau^p = \frac{\eta^p}{\lambda} \left[ \frac{\tilde{A} - \frac{1}{\sqrt{1 - (tr\tilde{A}) / (3L^2)}}}{1 - \frac{1}{\sqrt{1 - (tr\tilde{A}) / (3L^2)}}} \right] ,
\]

\[
\frac{\tilde{A}}{1 - (tr\tilde{A}) / (3L^2)} + \frac{\tau}{1 - 1/L^2}.
\]

\[
\text{We} = \frac{\lambda U}{l} , \quad \text{Re} = \frac{\rho U l}{\eta^p} , \quad \beta = \frac{\eta^s}{\eta^p} , \quad L^2 = 3 \left( \frac{Q_0}{Q_{eq}} \right)^2.
\]

3. Boundary conditions

Schematic representation of the channel with boundaries is sketched on figure 1. The length of the channels was set to 10 channel’s width for the formation of the velocity profile in the inlet flow and to establish the outlet flow.

4. Results

To get an idea about fluid - flexible particle interaction is possible by means of Re, We numbers and retardation coefficient \( \beta \) characterizing the particles concentration for Oldroyd-B model. For the fluid models such as FENE-P taking into account the stretching of flexible particles, one of the most important parameter is \( L^2 \). Combination of We
and \( L^2 \) (at fixed value retardation coefficient \( \beta = 0.1 \) and \( Re = 0.01 \)) is certainly characterizing the fluid behavior performed by the FENE-P model [5, 6].

The asymmetrical form of fluid flow is emerging in the channel bifurcation for the Oldroyd-B and FENE-P models at \( L^2 = 100 \) (fig. 2). From streamline patterns picture follows that the symmetry loss effect is observed for the Oldroyd-B model at \( We = 0.6 \) and for the FENE-P model at \( We = 0.6; L^2 = 100 \). As it might be seeing that for the set of values \( We = 0.6; L^2 = 10 \) flexible particle’s stretching is not enough for breaking symmetry behavior.

![Figure 2](image)

**Figure 2 - Viscoelastic fluid flow through a channel with cavity:**

(a) – Oldroyd-B, (b, c) – FENE-P

The distribution of shear stresses along the symmetry line of outlet channel’s part one can see on fig. 3. For the FENE-P model at values of \( We = 0.6; L^2 = 10 \) this distribution is symmetrical that corresponds to fig. 2b. For the symmetry loss cases the patterns of \( \tau_{xy} \) are similar for both models. However, the area of maximum values is more shifted from the symmetry line compared to FENE-P model’s results and the values are greater approximately for 3 times.

![Figure 3](image)

**Figure 3 – Shear stresses distribution**

From fig. 4 follows that for the first normal difference \( N1 \) the maximum change of values is observed for the fluid presented by Oldroyd-B model. This behavior caused by the ability of flexible particles to
infinitely extension. Due to the linear relation between its elongation and interaction force between the ends of flexible particles. Large elongation leads to increase of interaction force and significant change in tension state in the fluid flow.

5. Conclusions
In the present paper the numerical results for convergent viscoelastic fluid flow in branched channel have been presented. The symmetrical shape of flow turns to asymmetrical at $We=0.06$ for both models. This effect of the loss-symmetry patterns is associated with the interaction of flexible particle and the main flow. The differences of presented viscoelastic fluids lies in consideration of flexible particles behavior. For the Oldroyd-B model the particle theoretically could infinitely elongate and for the FENE-P model the elongation characterizing by the $L^p$ parameter. It means that for the same values of $We$ number the particles stretching will be different. The changing of the flow direction leads to changes in conformation of flexible particles associated with their stretching and orientation in the flow. This non-equilibrium configuration, in turn, leads to change in normal stresses that also affect on the flow patterns.

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