Lateral migration of solid spheroidal nanoparticles and highly deformable hydrogel nanofilaments under the influence of oscillatory flow

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Introduction

Most of the phenomena describing particles behaviour in flow in micro scale are based on the approximation of creeping flow. The microfluidic devices for focusing and sorting of biological objects are based on hydrodynamic interactions responsible for the lateral migration of selected objects suspended in liquid. Cross-flow migration effect has long research history. Early experiments presented redistribution of red blood cells in capillaries and spherical particles in a tube flow. As a solid spherical particle is obviously very coarse highly deformable blood cells approximation, as an erythrocytes models, the liquid droplets suspended in the flow was used. These studies have shown that the inertial forces which are usually neglected in microfluidics play an important role for proper interpretation of lateral migration of droplets and particles. The migration problem started to be more complex in case of elongated objects (e.g. rod-like particles, filaments, biomolecules). One of the most frequently used strategies for simplified of microscale migration effects of elongated objects is an ellipsoidal model. There are not many experimental data which would show details of the migration process for elongated nano-objects. Migration of elongated objects (like fibres) in Poiseuille flow has great importance for medicine, biology and for industry. It has important influence on such phenomenon like drug delivery and Brownian motion of biological polymers (DNA, proteins). Still it is one of the fundamental challenges of modern rheology.

Experiments were performed in a microfluidic channel with 30 mm length and rectangular cross-section (200 μm x 60 μm). In two separated experiments the commercial polystyrene spherical 1 μm particles (suspended in water), and elektrospune PNIPAAm-BIS-AAm nanofilaments [1] (suspended in water – DMF (4:1)) were used. In-house designed squeeze-tube micro-pump was used to produce sinusoidal oscillating flow within the channel. The velocity amplitude V_{max} varied from 50 μm/s to 900 μm/s, flow oscillations frequency was set around 0.1 Hz. Nanofilaments were imaged using epifluorescence microscope (Leica AM TIRF MC) equipped with 20x/0.40 NA air objective and a mercury lamp light source. The flow-induced migration of nanofilaments was recorded using a high-gain EM-CCD camera (C9100-2, Hamamatsu) with typical frame rate of 15 Hz [2].

Performed experimental investigations demonstrated presence of lateral migration of spherical and elongated tracers. Long term behavior of tracers after hundreds of flow oscillation periods was observed. It was found that despite relatively low flow Reynolds number ($Re < 0.2$) their corss-flow migration in the channel is well pronounced. Experimental data for this two type of nano-objects were compared. In most of the cases the spherical particles were observed to migrated toward the channel center while nanofilaments migration direction depends on dimension and behavior of them. In the case of hydrogel nanofilaments the experimental data are compared with hydrodynamic worm-like beads model of fibers conveyed by shear flow [3], confirming predicted fiber tumbling and lateral migration.

We report for the first time ever the use of hydrogel nanofilaments as an alternative to model flow dynamics of molecular chains.

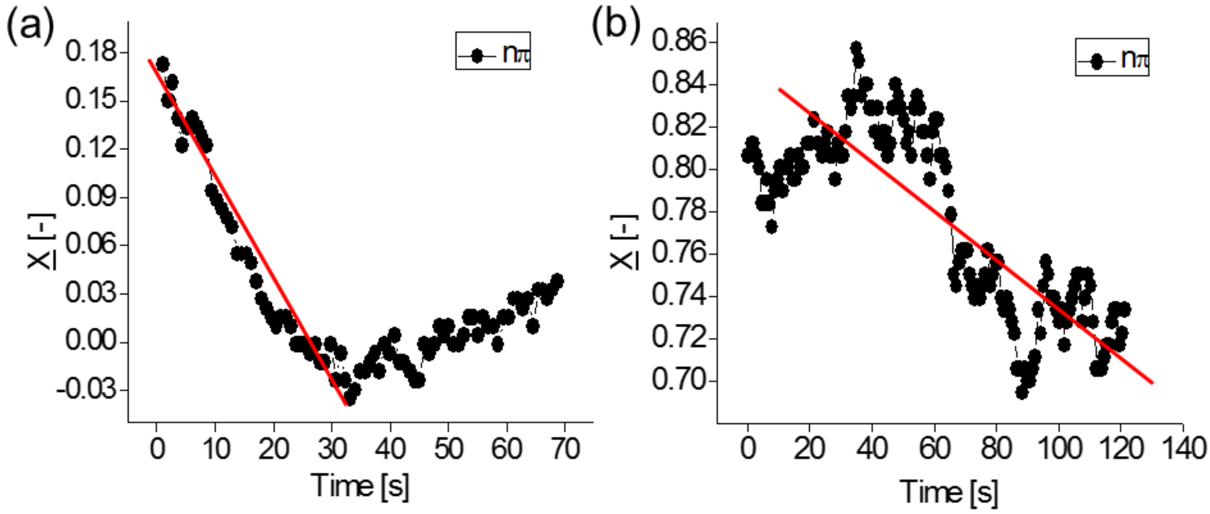

Figure 1: Lateral migration of 1 μm spherical particle in the oscillatory flow: (a) close to the microchannel centre (*V_{max} = 259 μm/s; Re = 0.063; ω = 5.9; U_r = 2.1 10^{-3}*); (b) close to microchannel wall (*V_{max} = 119 μm/s, Re = 0.046; ω = 5.9; U_r = 0.6 10^{-3}*).

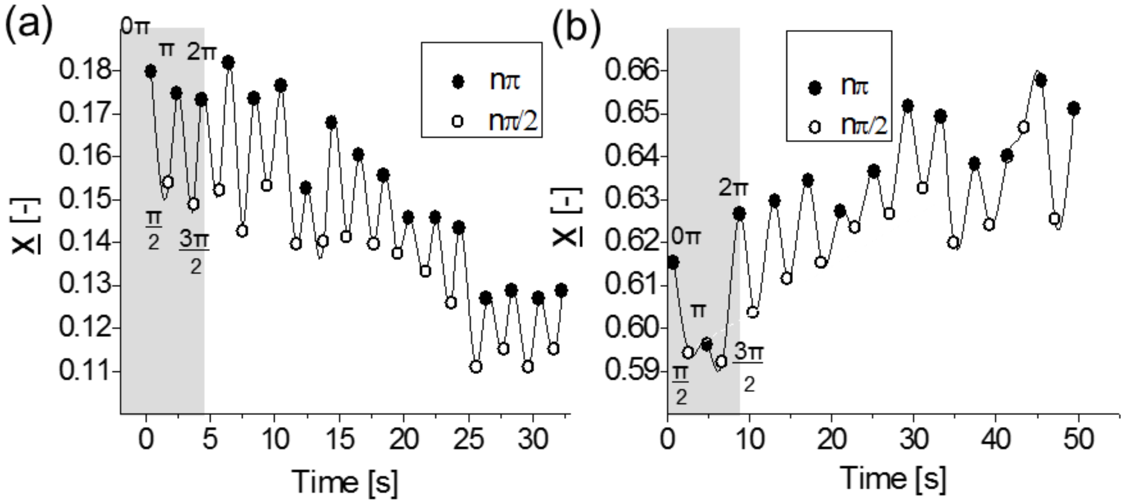

Figure 2: Lateral migration of elongated hydrogel nanofilaments in the oscillatory flow: (a) toward to the microchannel centre (*d = 105 nm; L = 41 μm; V_{max} = 250 μm/s; U_r = 0.85 10^{-3}*); (b) toward to the wall of microchannel (*d = 134 nm, L = 54 μm, V_{max} = 132 μm/s, U_r = 0.6 10^{-3}*).

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