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Lateral Migration of Highly Deformable Nanofilaments Conveyed by Oscillatory Flow

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Recently, we demonstrated possibility to produce hydrogel in a form of nanofilaments, the supreme geometry for conducting targeted material delivery to regenerate aligned tissues or perform DNA transport. Hence, in the following we analyze transport properties of such objects conveyed by oscillating flow simulating typical extracellular environment. Due to nanometric size of our nanofilaments both hydrodynamic interactions and Brownian fluctuations have to be considered. The problem has analogy to exhaustive studies of DNA flow dynamics, though the coarse filaments material allows to limit problem description to purely hydrodynamic interactions, neglecting complex molecular and electrostatic interactions.

FITC-fluorescently labeled hydrogel nanofilaments were prepared by co-axial electrospinning of two immiscible polymers (PLCL polymer and NIPAAm/BIS-AAm hydrogel solution), with the former one being used to mold the hydrogel in the core-shell structure [1]. After removal of their shells, hydrogel nanofilaments suspended in water - DMF (4:1) solution were introduced into the PDMS microchannel using a syringe micro-pump. The microchannel was equipped with two additional pre-chambers used to collect nanofilaments and to introduce the selected one into the observation area. Care was taken to analyze nanofilaments solely remaining in the plane of observations. In-house designed squeeze-tube micro-pump was used to produce sinusoidal oscillating flow within the channel. The velocity amplitude Vmax varied from 100 $\mu m/s$ to 900 $\mu m/s$, 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. The mechanical properties of our nanofilaments such as persistence length (Lp) and bending stiffness were evaluated from their Brownian shape deformations. Selected for the experiment nanofilaments were characterized by flexural modulus of 2 kPa, typical radius R of about 50 nm, and contour length L of several micrometers.

Performed experimental investigations demonstrated presence of lateral migration of nanofilaments, and their complex bending dynamics, being characteristic for long biomolecules. Experimental data are compared with hydrodynamic worm-like beads model of fibers conveyed by shear flow, confirming predicted fiber tumbling and lateral migration. Our electrospun nanofilaments offer a unique capability to mimic dynamics of long flexible object conveyed by a hydrodynamic flow. At the same time, they can be successfully used to validate essential assumptions of computational models used to describe dynamics of complex suspensions.

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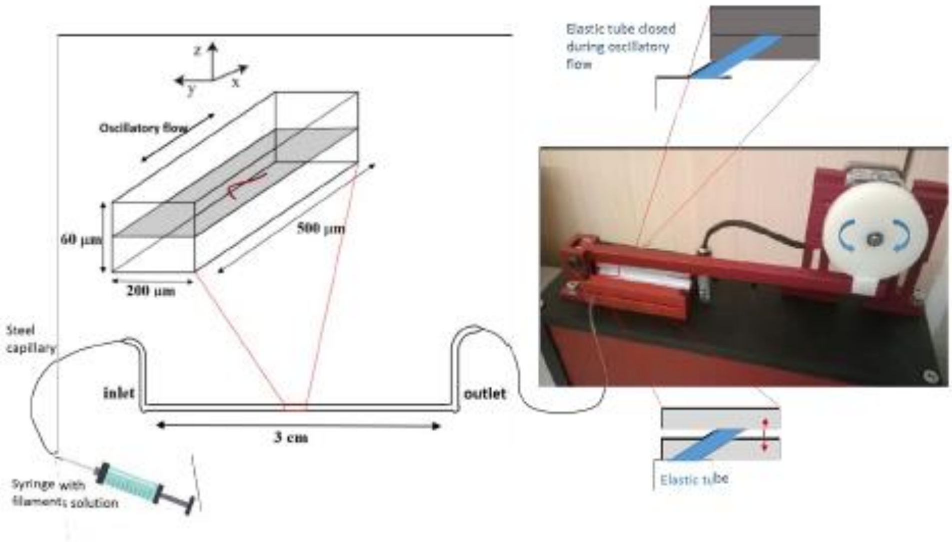

Fig. 1: Schematic of 3 mm long rectangular microchannel with nanofilament conveyed by oscillatory flow; indicated section observed under the microscope.

References

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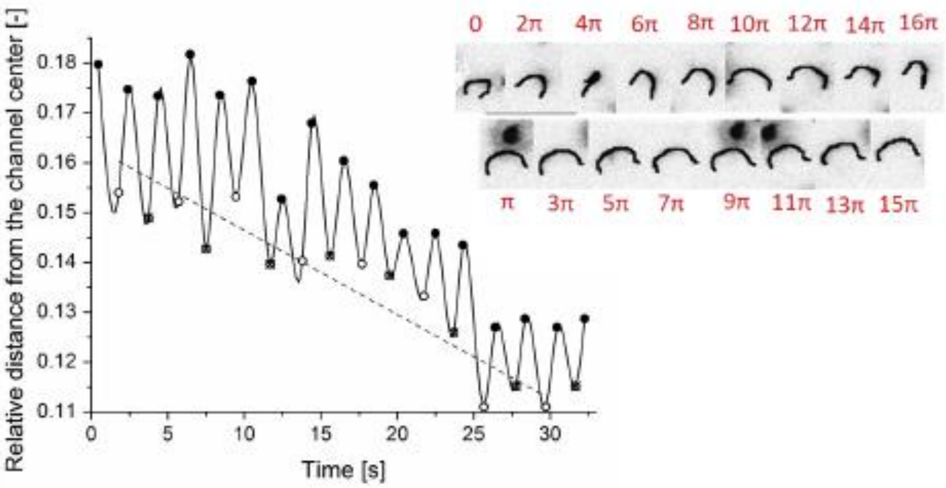

Fig. 2: Lateral migration of nanofilament into the microchannel center; insert – snapshots of filament buckling. $R = 53$ nm; $L = 41$ μm; $Lp = 2.89$ μm; $Re = 0.06$