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Highly deformable nanofilaments in flow

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Experimental analysis of hydrogel nanofilaments conveyed by flow is conducted to help in understanding physical phenomena responsible for transport properties and shape deformations of long bio-objects, like DNA or proteins. Investigated hydrogel nanofilaments exhibit typical for macromolecules behavior, like spontaneous conformational changes and cross-flow migration. Results of the experiments indicate critical role of thermal fluctuations behavior of single filaments.

1. Introduction

Predicting behavior of long, deformable objects carried by the flowing fluid is needed for a full understanding of the physics of macromolecular suspensions. Such knowledge is important in a variety of biological processes responsible for transport, aggregation and structure formation at the cellular level [1]. Most hydrodynamic models are based on classical complex systems of interconnected identical spherical particles (*worm-like chain*) or *dumbbell models* that describe the two particles configurations of two ends of the polymer which form the filament connected by short springs. Other molecular models are focused on experimental studies of the dynamics of DNA molecules or another bio-objects like actin filaments. However, their experimental validation is doubtful, as the mechanical properties of their components are unknown *a priori*, hence they have to be estimated or matched to very inaccurate molecular scale observations. Here, we propose *synthetic experimental model* of molecular chain, i.e., long, highly flexible nanofilaments exhibiting Brownian deformability, and still large enough to be directly observed and analyzed using optical methods.

2. Experiment

We have developed a coaxial electrospinning technique for producing highly deformable filaments [1]. They are elongated objects characterized by typical diameter of 100 nm and contour length ranging from one micrometer to millimeters. A microfluidic system for observation and analysis the dynamics of the hydrogel nanofilaments movement was made using PDMS polymer. The experiment was performed in a 500 μm long and 60 μm deep channel. The movement of nanofilaments was recorded using high-gain EM-CCD camera. The experiment is based on observation of the behavior of hydrogel nanofilament under the influence of a pulsating motion generated by the syringe pump. The instantaneous velocity profile in the channel is measured by particle tracking technique (PTV) using small amount of fluorescent tracers. For each of the analyzed filaments the stiffness was determined by calculating the Young's modulus. For this purpose we analyzed their Brownian mobility, and we have applied the cosine correlation method in order to evaluate their persistence length [1].

3. Results

Analysis of the monofilament dynamics confirms that their mechanical properties are resemble that of long biomolecules (Tab. 1). Our study shows that mobility of our filaments strongly depends on their length. Longer filaments exhibit high bending flexibility. For short pieces (10–20 µm) translational and rotational diffusion coefficients could be evaluated from Brownian motion. We can observe similar effects in pulsating flow. Short filaments move along the channel and rotate while long filaments have a tendency to coil and form knots. This effect remains prevalent for objects conveyed by Poiseuille flow (Fig. 1).

Table 1. Typical experimental parameters: mean flow velocity (*Vm*), contour length (*L*), radius (*R*), persistence length (*Lp*), and Young modulus (*E*) of the analyzed filament. Flow Reynolds number (*Re*) is based on the channel width (200 µm)

No.	*Vm* [µm/s]	*L* [µm]	*R* [nm]	*Re*	*Lp* [µm]	*E* [kPa]
1	59.02	71.91	0.081	1.51E-02	17.62	2.17
2	77.78	72.87	0.081	1.98E-02	12.38	1.53
3	39.65	34.49	0.045	1.01E-02	3.44	4.45
4	68.87	54.31	0.045	1.76E-02	7.51	9.72
5	250.43	75.58	0.045	6.39E-02	9.56	12.37
6	199.64	82.90	0.081	5.09E-02	14.34	1.77

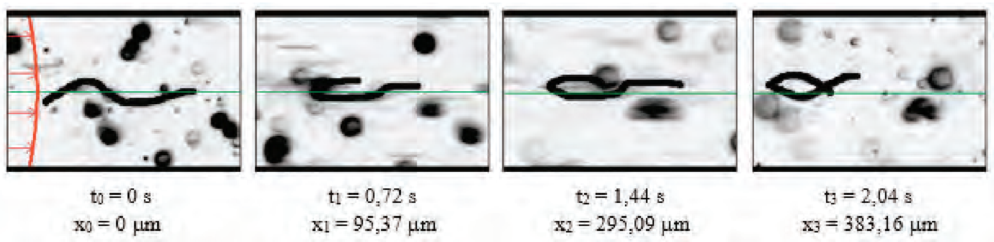

Figure 1. Sequence of images for a single flexible nanofilament conveyed by Poiseuille flow (no. 6 in Table 1), green line is a center of the channel, *t* – time stamp, *x* – distance traveled from the channel entry (picture frame moves with the object), image height 77 µm

One of the more interesting phenomena observed during the experiments is the cross-flow migration of filaments into the center of channel.

Highly deformable hydrogel nanofilaments have demonstrated the possibility to be used to study the hydrodynamic interactions for such long objects. The study of the flow characteristics in presence of highly deformable nano-objects is of fundamental importance for the understanding and prediction of the rheological properties of biological fluid environment (cytoplasm, plasma). This data can be a base to create biocompatible nano-objects that can become tools for the regeneration of biological tissues, e.g., neural tissue.

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References

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