MethodsX 4 (2017) 305–309

Contents lists available at ScienceDirect

MethodsX

journal homepage: www.elsevier.com/locate/mex

Method Article

Determination of the critical values of flow parameters characteristic of the alignment of cylindrical nano-objects in suspensions

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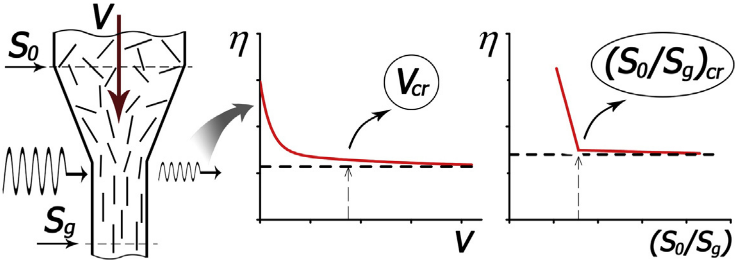
GRAPHICAL ABSTRACT



ABSTRACT

A method for determining the critical values of the flow speed and the flow constriction degree characteristic of the alignment of cylindrical nano-objects in a flowing suspension is proposed. Previously, the alignment process of cylindrical nano-objects in suspensions was investigated by using birefringence of the polarized light and the small-angle X-ray scattering. While both methods are suitable for measuring the alignment degree of cylindrical nano-objects in suspensions diluted down to low concentrations, they are restricted for the application to undiluted concentrated suspensions because of non-transparency and multiple scattering of X-rays. In addition, the use of the second method requires an expensive synchrotron equipment. We present a simple and faster

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http://dx.doi.org/10.1016/j.mex.2017.09.002

method based on the direct ultrasound attenuation measurements of longitudinal viscosity of a suspension containing cylindrical nano-objects, which decreases monotonically, approaching its asymptotic value with increase in the flow speed and the flow constriction degree. The principle and advantages of the proposed method are as follows:

- The cylindrical nano-objects align along an accelerated flow at overcritical values of the flow speed and the constriction degree.
- The critical values correspond to the state of a suspension possessing viscosity close to the asymptotic value.
- The method is applicable to undiluted concentrated suspensions, including opaque ones.

ARTICLE INFO

Keywords: Ultrasound attenuation, Longitudinal viscosity, Suspension, Cylindrical nano-objects, Alignment, Critical parameters

Article history: Received 7 November 2016; Accepted 9 September 2017; Available online 21 September 2017

Method

The given method is a realization of the well-known methodology of ultrasound attenuation spectroscopy [1] for determining the critical parameters of the flow, the flow speed V and the flow constriction degree $Z = S_0/S_g$, above which the degree of orientation of cylindrical nano-objects in a suspension along the flow is approaching its maximum value (parallel alignment). As an experimental test of forming the oriented state of cylindrical nano-objects in the suspension flow, the direct ultrasound attenuation measurements of longitudinal viscosity η were used [2].

Two other techniques allowing to control the orientation of cylindrical nano-objects in suspensions are reported in papers [3,4]. The first one is based on the effect of rotation of the plane of polarization of linearly polarized light as it travels through the suspension containing oriented cylindrical nano-objects: the higher is the degree of alignment of nano-objects, the higher is the light intensity. This method can be applied to the transparent suspensions only with the concentration of colloidal objects below 0.3–1.0 wt.% depending on the material. The second technique is based on small-angle X-ray scattering (SAXS). Similarly to the first technique, the second one can be applied to quite dilute suspensions; also because of the need to use synchrotron radiation that enables to achieve higher signal-to-noise ratio, it becomes time-consuming and expensive for users. The proposed method offers two advantages over these common techniques: i) simplicity of application due to the availability and mobility of acoustic instruments; ii) applicability to concentrated suspensions (0.3–70.0 wt.%), including opaque ones.

The theoretical background of the experiment consists in the decrease in the longitudinal viscosity of the suspension containing cylindrical nano-objects in the course of their alignment along the direction of a flow as a result of reduced interaction between the parallel layers of a suspension.

In the flow-type measurement cell of the acoustic spectrometer DT-500 (Dispersion Technology, USA), the measurements of the acoustic attenuation spectra and the longitudinal viscosity of the flowing suspension were carried out at different values of the flow speed and the flow constriction degree at the filler neck (Fig. 1). The flexible measurement cell made of silicon rubber tube has a crucified form with four branch pipes, two of which serve for connecting the closed-loop circular channel with the inner diameter D. Two other branch pipes are intended for plugging the transmitter $\boldsymbol{T}$ and the receiver $\boldsymbol{R}$ of the acoustic sensor so that the positions of their end faces coincide with the inner wall of the circular channel. The suspension under study is poured into the channel and put into motion by the peristaltic pump with the adjustable speed of the flow. The ultrasonic wave is propagating from the transmitter to the receiver through a suspension containing cylindrical nano-objects aligned preferably along the direction of the flow accelerated in the constricted channel of the measurement cell.

Due to the flexibility of the silicon rubber tube, the transmitter can move relative to the receiver during the measurements. As a result, the cross-section of the channel in the measurement zone represents a flattened circle with the width b corresponding to the gap between the transmitter and