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St. Petersburg Polytechnical University Journal: Physics and Mathematics 000 (2017) 1–8
www.elsevier.com/locate/spjpm

Dielectric properties and microstructure of the disintegrated nanogel films of bacterial cellulose

Albert K. Khripunov[a], Tamara P. Stepanova[a], Albina A. Tkachenko[b], Dmitriy P. Romanov[c], Ella P. Astapenko[a], Victoria M. Kapralova[d,*]

[a] *Institute of Macromolecular Compounds RAS, St. Petersburg, Russian Federation*
[b] *St. Petersburg State University, St. Petersburg, Russian Federation*
[c] *I.V. Grebenshchikov Institute of Silicate Chemistry, St. Petersburg, Russian Federation*
[d] *Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russian Federation*

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Abstract

The concentration dependencies of dielectric permittivity and dielectric loss factor have been studied for the water suspensions of nanogel films of bacterial cellulose Gluconacetobacter xylinus (BC) disintegrated with the blade rotation rates of 15,000 and 20,000 rpm. The dipole moments of BC colloids have been evaluated using Buckingham's statistical theory of dielectric polarization modified for binary polar systems. The number of monomer units of cellobiose in the BC colloid being equal to 113, the volume and the characteristic rotation time of the colloid particles were calculated. The difference between the values of dielectric parameters for BC samples disintegrated at 15,000 and 20,000 rpm were within experimental error. The constant stoichiometry of BC colloids and the identity of orientation ordering of microfibrills in colloids to that of the BC nanogel films have been shown by dielectric and X-ray studies.

Keywords: Bacterial cellulose; Nanogel film; Aqueous suspension; Colloid; Orientation dielectric polarization.

Introduction

The interest in studying the structure and properties of nanogel films of bacterial cellulose *Gluconacetobacter Xylinus* (BC NGFs) is due to its potential applications in medicine and in the emerging industrial technologies [1–7].

The morphological structure of a native BC NGF synthesized by static cultivation is known to be complex and has not been received sufficient attention in research [8–10]. NMR spectroscopy was used to establish that BC NGFs typically have a three-dimensional ordered structure including nanosized crystallites from fragments of cellulose chains [11]. Fig. 1a shows a fragment of the cellulose structure with chain ordering due to intra- and intermolecular hydrogen bonds; Fig. 1b shows polycrystalline structures in dried BC gel films.

* Corresponding author.
E-mail addresses: xelmie@mail.macro.ru (A.K. Khripunov), t_stepanova2005@mail.ru (T.P. Stepanova), albina.tkachenko@mail.ru (A.A. Tkachenko), ichsran@isc.nw.ru (D.P. Romanov), imc@hq.macro.ru (E.P. Astapenko), kapralova2006@yandex.ru (V.M. Kapralova).

http://dx.doi.org/10.1016/j.spjpm.2017.06.002

(Peer review under responsibility of St. Petersburg Polytechnic University).

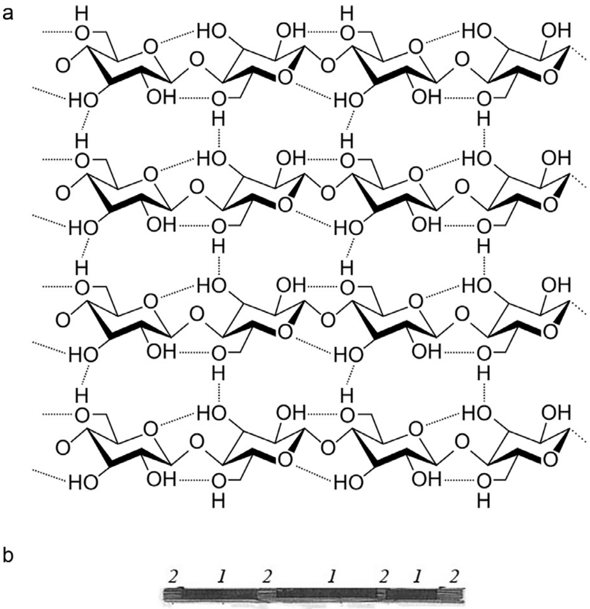

Fig. 1. Structure of bacterial cellulose *Gluconacetobacter Xylinus*: *a* is a fragment of the structure with chain ordering due to intermolecular hydrogen bonds, *b* shows crystallites (1) and amorphous regions (2) made up by cellulose macrofibrils.

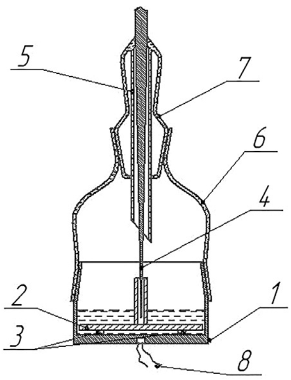

Fig. 2. Measuring cell: cylindrical tank (‘earth’) *1*, electrode *2*, glass beads *3*, platinum needle *4*, sealed glass tube *5*, bottle cap *6*, glass stopper *7*, thermocouple *8*.

BC NGF retains water at a ratio of approximately 1:100, which is an important property for use in medical supplies.

Disintegrated BC NGF proved to be the most effective for solving certain problems in medicine and technology, necessitating the study of its macroscopic properties [12–14]. The dielectric method is a useful tool in correlating the molecular structure and the macroscopic properties of polar systems [15]. For example, the studies involving static dielectric polarization of dilute aqueous solutions of modified cellulose (polymethylcellulose) have revealed that its macromolecules tend to associate, so as a result, the solution is transformed to gel under certain thermodynamic conditions [16].

The goal of this study was to investigate the specifics of dielectric behavior of disintegrated BC NGF with an initial spatial gel structure formed by a bacterium in the process of synthesis.

Experimental procedure

Biosynthesis of BC NGF was described earlier in Ref. [17]. After removal of bacteria by the conventional method of boiling in a 1% NaOH solution and thorough washing with distilled water, the obtained BC gel film was dried to constant weight. The dry BC film was dissolved in purified cadoxene (cadmium ethylenediamine complex) to obtain a molecularly dispersed solution, so that the molecular weight of the BC could then be determined by viscometry. The value of the molecular weight obtained by this method amounted to $3.89 \cdot 10^5$ Da

The BC gel film was disintegrated with the addition of distilled water in a blender (JTC, Omniblend 1, model TM-767) at two blade rotation rates: $1.5 \cdot 10^4$ and $2.0 \cdot 10^4$ rpm; the procedure was carried out in three stages lasting 5 minutes each (15 minutes overall), with 30-minute breaks to cool the colloidal suspension to room temperature.

The initial BC concentration in the resulting colloidal suspension (BC CS), determined by evaporation to constant weight, was $w_2 = 0.305$ g/g. The subsequent samples of aqueous BC CS with lower BC concentrations were obtained by adding distilled water to the initial colloidal suspension. The initial BC CS and its aqueous solutions were a gel system with non-settling colloids.

The dielectric permittivity ε of BC CS was measured in the range of BC concentrations $0.016 \le w_2 \le 0.305$ g/g in a dielectric measuring cell (Fig. 2), a bottle whose cylindrical tank (“ground”) *1* and disc-shaped potential electrode *2* were made of titanium. Glass beads *3*, determining the distance between the electrodes, were mounted on the lower surface of the potential electrode. The bottle’s cap *6*, fitted to the tank, was made of pyrex glass. Glass stopper *7* with sealed glass tube *5* and platinum needle *4* that was part of the upper electrode was connected to the upper part of the cap by means of a ground-glass joint, centering the electrode in the cell. Thermocouple *8* was inserted into the bottom of the tank.

Please cite this article as: A.K. Khripunov et al., Dielectric properties and microstructure of the disintegrated nanogel films of bacterial cellulose, St. Petersburg Polytechnical University Journal: Physics and Mathematics (2017), http://dx.doi.org/10.1016/j.spjpm.2017.06.002