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# ELECTRORHEOLOGY OF LIQUID CRYSTALS

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*The results of experimental investigation of rheological properties of a nematic liquid crystal (NLC) 5CB (4-cyano-4'-pentylbiphenyl) confined to submicron pores of polymer PET-films in the presence of AC electric field are presented. The decay flow method, elaborated previously for plane channels, was successfully adopted and applied to the LC-PET composite media, which can be considered as a number of cylindrical channels, connected in parallel schema, filled with flowing LC. It provides the calculation of the effective shear viscosity as a function of the electric field strength. The character of this function indicates on the electrically induced orientation transformation in LC inside pores due to breaking of a surface anchoring.*
***Key words:*** *liquid crystals, electrorheology, 4-cyano-4'-pentylbiphenyl.*

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# ЭЛЕКТРОРЕОЛОГИЯ ЖИДКИХ КРИСТАЛЛОВ

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*Представлены результаты экспериментального исследования реологических свойств нематического жидкого кристалла (НЖК) 5 ЦБ (пентил-цианобифенил), заключенного в субмикронные поры полимерных ПЭТ-пленок при наличии переменного электрического поля. Метод затухающего потока, разработанный ранее для плоских каналов, был успешно приспособлен и применен к ЖК – ПЭТ композитной среде, которую можно рассматривать, как набор цилиндрических каналов, соединенных по параллельной схеме и заполненных текущим ЖК. Это обеспечивает расчет эффективной сдвиговой вязкости как функции напряженности электрического поля. Характер этой функции указывает на вызванное электрическим полем ориентационное преобразование ЖК внутри пор посредством нарушения поверхностного сцепления.*
***Ключевые слова:*** *жидкие кристаллы, электрореология, пентил-цианобифенил*

**Introduction**

Liquid crystals are known as materials, which play a key role in modern display industry [1]. Nevertheless, the practical application of these materials is not restricted only by liquid crystal displays (LCD), but also includes a number of devices of photonics like switchers, polarizer controllers, filters and so on [2]. In the latter case composite LC materials can show some advantages in the comparison with the electrically controlled layers, traditionally used in LCD. The particular class of composite materials includes the porous polymer PET films, filled with liquid crystals. The ability to control optical properties of these materials using an electric field and light irradiation [3, 4] makes them promising for elaboration of new photonics [5] and microfluidic [6, 7, 8] devices. There is a well elaborated industrial technology for production of the porous polymer matrix, which provides the samples of films with open cylindrical pores of submicron and micron diameters [9]. Liquid crystal immersed into the pores undergoes the influence of strong space confinement, which can result in modification of a number of material parameters, describing LC state [10, 11, 12]. Additionally, the strong space confinement also acts on interaction of LC with the polymer surface and weak surface effects play the essential role in formation of the orientational configuration of LC inside pores. The particular type of such configuration depends on the pore's diameter and a number of bulk (like Franks' modules) and surface (like surface director and anchoring strength) parameters [13, 14]. This essentially complicates theoretical description of different physical phenomena inside the pores filled with LC and makes the direct experimental investigations of different physical properties of LC desirable.

Recently we published [15, 16] the results of experimental investigation of a decay Poiseuille flow of LC through the porous PET films filled with a liquid crystal. In this paper we describe the similar investigations, extended to the case of electric field, which can effectively modify the orientational structure and shear viscosity of LC, which is of interest for a basic science and practical applications.

**Experimental**

The construction of the experimental cell and the geometry of the experiment are shown in Fig. 1. The principle of the construction is similar to that used earlier in carrying out rheological studies of porous polymer films filled with a liquid crystal in the absence of an electric field [15, 16]. The main difference is connected with electrodes, providing the supply of an electric field to a sample of a porous film filled with a liquid crystal. In experiments we used two samples of porous polymer PET films of square $S = 2.25$ cm$^2$ and thickness $L = 23$ μm with submicron pore diameters $d = 0.6$ and $0.5$ μm with the corresponding porosity $N_0$ equal to $4 \cdot 10^7$ pcs / cm$^2$ and $8 \cdot 10^7$ pcs / cm$^2$ for two samples. PET film can be considered as a number $N = N_0 S$ of cylindrical pores of submicron diameters of a length equal to the thickness of the porous film, under the action of a hydrostatic pressure gradient, which is via the difference of levels ΔH in the open cylindrical tubes of diameter $D = 1$ mm connected by the sample of porous film.
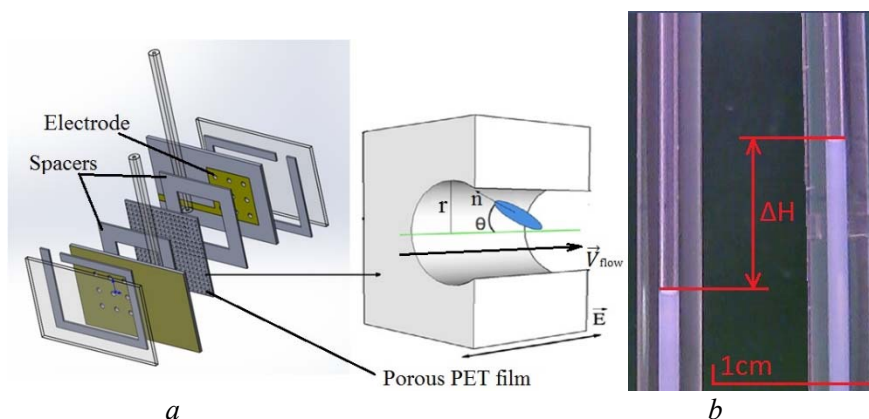


*Fig. 1. a* – Scheme of the experimental cell and the cylindrical pore of a porous PET film,
*b* – Relative levels of 5CB in cylindrical capillaries

Each cell was placed under vacuum and filled with a liquid crystal 5CB (4-cyano-4'-pentylbiphenyl (5CB, Merck)). The levels of LC in the open tubes become equal in about 20 min. Afterwards the air pressure difference of about 500 Pa were applied to create the initial difference of the levels $\Delta H_{max}$. The backward decay Poisueille flow was induced by the hydrostatic pressure gradient, proportional to the difference of the levels after turning off the air pressure difference. It is simple to show that for an isotropic Newtonian liquid the time variations of the levels difference are described by the simple exponential law:

$$\Delta H(t) = \Delta H_{max} \exp(-t/\tau), \qquad (1)$$

where the decay time is proportional to the shear viscosity η of a liquid. The same law is valid also for a liquid crystal in the case of small perturbations of the initial orientation, induced by a flow. It corresponds to the behavior of the conventionally Newtonian liquid [17] with a constant value of the shear viscosity, which depends on the orientation of LC.
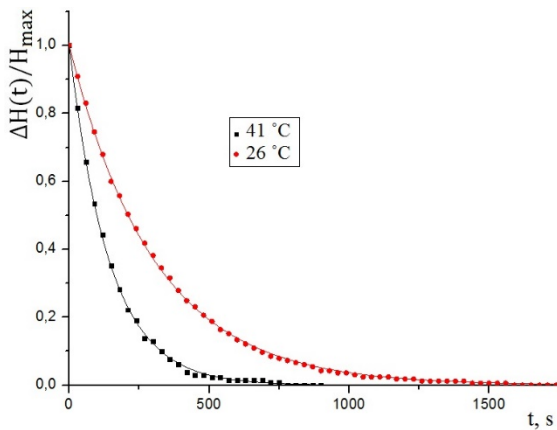


*Fig. 2.* Time dependences of relative levels of 5CB in pores ($d = 0.5$ μm) at different temperatures. Solid lines show the approximation of experimental data by the equation (1) with values of the decay time 142 and 304 s for $T = 41$ and 26 $^0$C

The basic equations describing the Poiseuille decay flow for a rectangular capillary [18] are also applicable in the case of a flow through the porous film. The final expression for the decay time $\tau_N$ can be written as [15, 16]:

$$\tau_N = [\eta/(\rho g)][(D^2 L)/(N r^4)] \qquad (2)$$

So, experimental measurements of a decay time $\tau_N$ provide determination of the shear viscosity coefficient η in accordance with the expression:

$$\eta = \frac{\tau_N \cdot \rho g r^4 N}{D^2 L} . \qquad (3)$$

In our experiments, the primary experimental information was obtained by taking and processing the digital images (the example of such image "is shown in Fig. 1, *b*). The LC cell was calibrated by performing measurements in isotropic phase of a liquid crystal, using the data of independent measurements of shear viscosity [19]. The dependences of the relative difference in the meniscus levels $\Delta H(t)$ for the isotropic and nematic phases are shown in Fig. 2. Equation (1) describes the experimental dependences well, which confirms the invariance of the orientational structure under the given experimental conditions (temperature and pressure gradient).
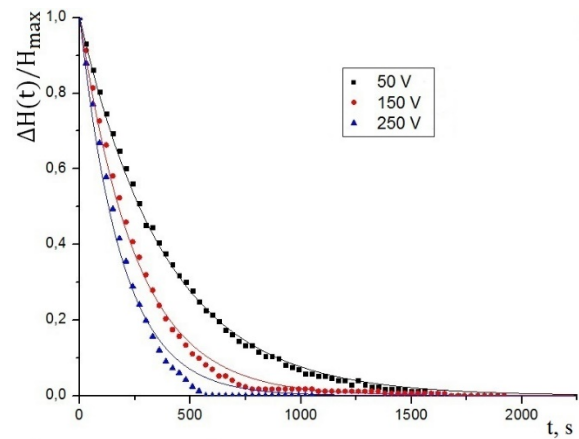


*Fig. 3.* Time dependences of relative levels' difference for films with $d = 0.5$ μm at different voltages. Solid lines show the approximation in accordance with equation (1) which results in the values of the decay time 289, 253 and 188 s at $U = 50$, 150 and 250 V

The time dependences of the difference in meniscus levels for different voltages are shown in Fig. 3. Via an approximation of these dependences by equation (1) it was established the essential decreasing of the decay time with voltage. The dependences of the effective viscosity of LC confined by pores on the electric field strength $E$ of are shown in Fig. 4.

As follows from this figure, the shear viscosity decreases with increasing of $E$. At strong electric field this parameter approaches to the value of the minimal Miesowicz viscosity ($\eta_2 = 0.0204$ Pa·s) for 5CB at a given temperature [19], which corresponds to the director orientation along the flow direction. This confirms the possibility of the effective control of the liquid crystal orientation structure of inside pores by

using an electric field. At the same time, the value of the effective shear viscosity is practically independent on $E$ at relatively weak electric field ($E < 1$ V/μm), which means that the initial orientational structure of the LC, stabilized by the internal surfaces of pores, has remained unchanged. In our experiments we did not use any preliminary treatment of porous film, so it is difficult to select the corresponding orientational structure among various configurations of the LCD director, shown in the inset of Fig. 4.
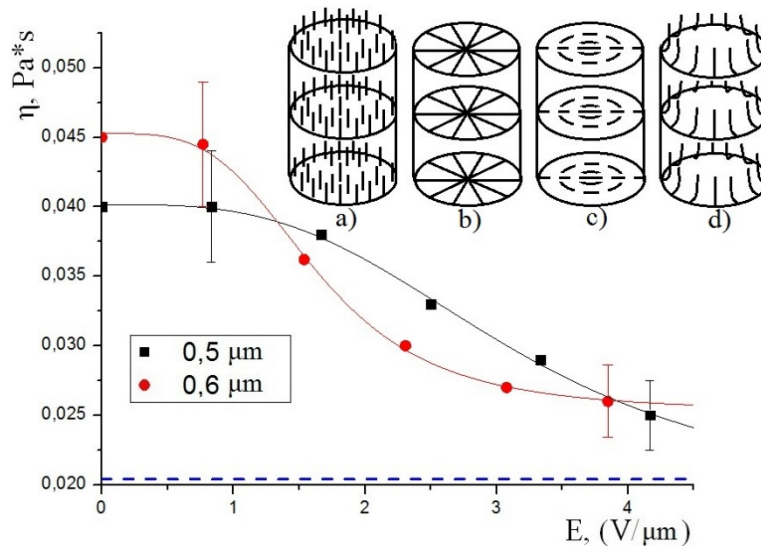


*Fig. 4.* Dependences of the effective viscosity of 5CB in pores of the PET film on strength of the applied electric field at $d = 0.5$ and 0.6 μm. The dashed line shows the minimum effective viscosity of NLC 5CB at 26 ⁰C; the possible orientational configurations of LC are shown in the inset

The experimental values of the shear viscosity obtained for LC 5CB in the absence of an electric field ($\eta_{eff} = 0.045$ and 0.04 Pa·s $d = 0.6$ and 0.5 μm (Fig. 4, *b*) are in the range of limiting changes in shear viscosities from $\eta_2 = 0.0204$ Pa·s to $\eta_1 = 0.1052$ Pa·s [19]. The previously made theoretical estimates [15, 16] show, that values of $\eta_{eff}$ mentioned above can be obtained in the framework of the escaped radial configuration (Fig. 4, *d*) taking into account weak anchoring effects, which result in increasing of the polar angle on the boundary liquid crystal – polymer with decreasing of *d*. Some difference between two values of the shear viscosity, presented above is in accordance with this conclusion. It is worthwhile to notice, that the quasi threshold values of electric field strength show the tendency to increasing with decreasing of *d*. Such behavior and typical values of the threshold field (about 0.7…1.5 V/μm) correspond to the results of a computer modelling of the electrically induced breaking of surface anchoring between nematic mixture E7 and polymer porous matrix [20] which results in the homogeneous axial configuration, shown in Fig. 4, *a*. It makes possible to assign the field induced changes of the shear viscosity to the structural transition due to surface anchoring breaking.

**Conclusion**

We performed the first experiments on influence of AC electric field on the dynamics of a decay flow of a nematic liquid crystal (5 CB) through the polymer porous PET film. It was established, that application of strong electric field, oriented normally to the film, results in the essential reduction of the decay time. The dependence of the effective shear viscosity on the electric field strength were obtained from the experimental results. At relatively low values of electric field strength (less, than 1 V/μm) this dependence is rather weak, which indicates on the approximately unchanged orientation structure of LC inside pores, formed by surfaces. The sharp decreasing of the effective shear viscosity at strong fields with a tendency to reach the minimal value of the shear viscosity coefficient can be assigned to the breaking of surface anchoring, which results in the homogeneous axial configuration. It demonstrates a possibility of usage of the decay flow method for an investigation of viscous property and orientational transformations of LC at strong confinement realized in the porous polymer matrix.

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