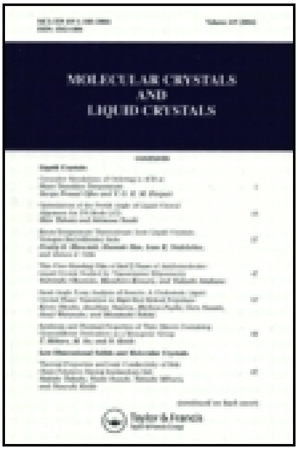

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

NEMATIC LIQUID CRYSTALS UNDER DECAY POUSEUILLE FLOW: NEW POSSIBILITIES FOR MEASUREMENT OF SHEAR VISCOSITY

Sergey V. Pasechnik [a], Valentin A. Tsvetkov [a], Alexandra V. Torchinskaya [a] & Denis O. Karandashov [a]

[a] Moscow State Academy of Instrument Engineering and Infomatics Stromynka, 20,107846, Moscow, Russia

Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2001, Vol. 366, pp. 165-171
Reprints available directly from the publisher
Photocopying permitted by license only

Nematic Liquid Crystals under Decay Pouseuille Flow: New Possibilities for Measurement of Shear Viscosity

SERGEY V. PASECHNIK, VALENTIN A. TSVETKOV, ALEXANDRA V. TORCHINSKAYA and DENIS O. KARANDASHOV

Moscow State Academy of Instrument Engineering and Infornatics Stromynka 20,107846 Moscow, Russia

The results of the optical investigation of a decay shear flow of a nematic liquid crystal are presented. The flow was produced by the varying hydrostatic pressure difference applied to the rectangular capillary. In the described experiment a quasi-stationary director motion took place. It allowed to control a pressure difference due to a measurement of an intensity of light, passing through the cell. The proposed procedure can be used to determine the shear viscosity of nematic liquid crystals.

Keywords: Pouseuille flow; electric field; shear viscosity

INTRODUCTION

The investigations of hydrodynamic flows of liquid crystals are known to be the most traditional way to obtain a complete set of dissipative parameters of anisotropic liquids. Usually they are carried out using a Poiseuille flow in a rectangular capillary induced by a constant pressure difference (Δp) [1]. In this case one can calculate a shear viscosity (η_i) of liquid crystal be measuring a volume of a liquid (ΔQ) passing through a capillary in a time Δt:

$$\frac{\Delta Q}{\Delta t} = \frac{h^3 \times a}{12 \times \eta_i \times L} \times \Delta p \qquad (1)$$

where h – the thickness of the liquid crystal layer, a and L – the width and the length of the capillary (fig.1). As nematic liquid crystals show a non-newtonian behaviour due to a connection between a director ($\vec{n}$) and a flow velocity gradient ($\partial V_X / \partial Z$) a correct determination of shear viscosities can be done only at fixed orientation (created by an intensive flow or by external magnetic fields). In the last case some errors in values of calculated viscosities can be originated by an influence of boundary layers with a non-uniform orientation. These errors are maximal when the maximal principal viscosity η_2 ($\vec{n} \perp \vec{V}$, $\vec{n} \| \mathrm{grad}\, \vec{V}$) is measured [2]. This reason may explain the contradictions between viscosity data, obtained by different authors. The results can be significantly improved by a surface treatment which creates homeotropic boundary orientation, the same as field induced orientation.

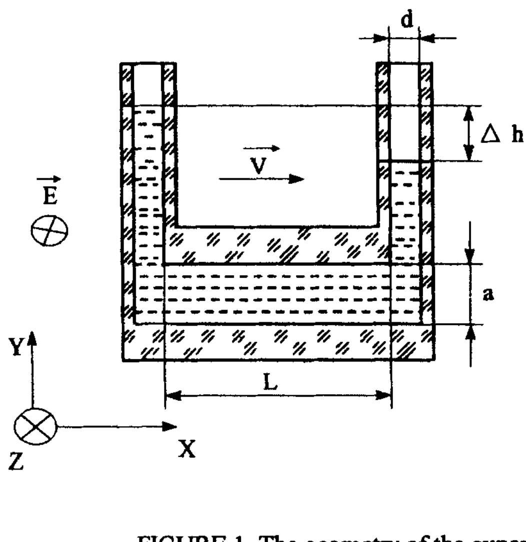

FIGURE 1 The geometry of the experiment

In this paper we describe the first results of an investigation of a decay shear flow which demonstrate new opportunities for measuring shear viscosities. The main idea of the experiment is to use the changes of an optical response of a liquid crystal layer to register an externally slow motion of nematic liquid crystal, which is induced by varying hydrostatic pressure. The geometry of the experiment is shown in figure1. The rectangular capillary (L×a×h=2,5*8*0,1 mm) and connected tubes (the inside diameter d is equal to 5 mm) are filled with nematic liquid crystal mixture LC – 654 with a positive anisotropy of permittivity ($\Delta\varepsilon$ = 10,7). At the begining of the experiment the difference of levels $\Delta h_m \approx 3 \div 6$ mm in tubes was produced by applying a constant air pressure difference $\Delta p_i \approx 300$ Pa. The electric voltage (u~ 15V, f=50Hz was applied to stabilize the initially homeotropic structure of liquid crystal layer and to avoid possible instabilities). Then the pressure difference Δp_i was removed and the liquid was returned to the initial state (Δh_i=0) under an action of hydrostatic pressure difference

$$\Delta p(t) = \rho \times g \times \Delta h(t) \qquad (2)$$

p – the density of liquid crystal.

The realized decay flow of a liquid crystal lead to the distortions of orientation (θ) which were registered by measuring the light intensity (I) in crossed polarizers

$$I = I_0 \times \sin^2 \frac{\delta}{2} \qquad (3)$$

where δ – the phase difference between an ordinary (o) and extraordinary (e) rays, I_o – the input intensity.

The degree of orientational distortions could be changed by an application of different electric voltages U. The asymptotic time dependencies of I for two values of electric voltage are shown in figure2. In general this dependencies have a lot of local extremes due to rather high thickness of liquid crystal layer and significant difference between the flow induced orientation and homeotropic one. One can see, that the applied electric field stubilizes the dependence I(t) due to a decreasing of the sensitivity of the liquid crystal layer. Restoration of initial intensity requires a very long time (about two hours) as compared with the slowest directror's relaxation time;

$$\tau_0 = \frac{\gamma_1}{k_{33} \times h^2} \approx 10^2\,\mathrm{s} \quad (4)$$

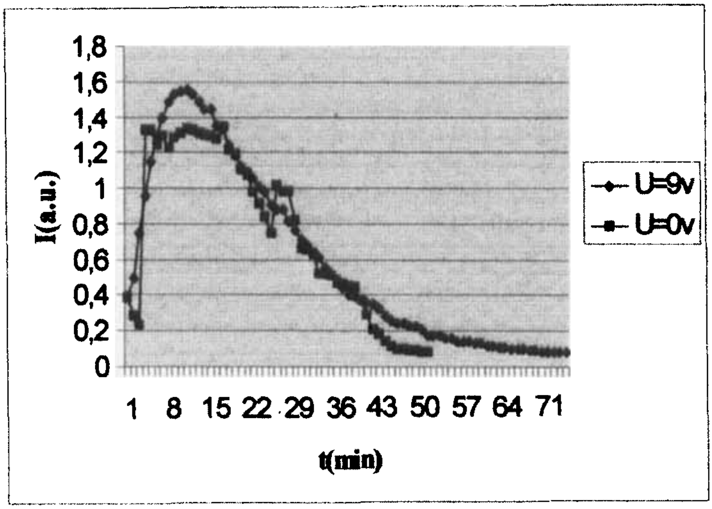

FIGURE 2 The time dependencies I(t) for two values of electric voltages U

It means that there is a quasi-stationary motion of the director induced by slowly varying Poiseuille flow [3].

In this case the time dependence of I is completely determined by the variations of pressure difference $\Delta p(t)$ connected with levels difference $\Delta h(t)$ by eq. (2). For small enough angles Θ the phase difference δ can be expressed as:

$$\delta = \frac{2 \times \pi \times \Delta n \times h \times \overline{\theta}^2}{\lambda} \quad (5)$$

$$\text{where } \bar{\theta}^2 = \frac{1}{h}\int_{-\frac{h}{2}}^{+\frac{h}{2}} \theta^2(z,t)dz \tag{6}$$

$\Delta n = n_e - n_o$ – the difference of refractive indexes, $\lambda = 0{,}63$ mm – a light wavelength.

The solution of linearized hydrodynamic equations under conditions mentioned above [3] gives a linear dependence between θ and $\Delta p(t)$ both in the absence and in the presence of a electric field. It is approved by experimental data obtained by harmonically varied pressure difference . The phase difference δ calculated according to the equation (3) is shown in figure 3 as a function of $(\Delta p)^2$.

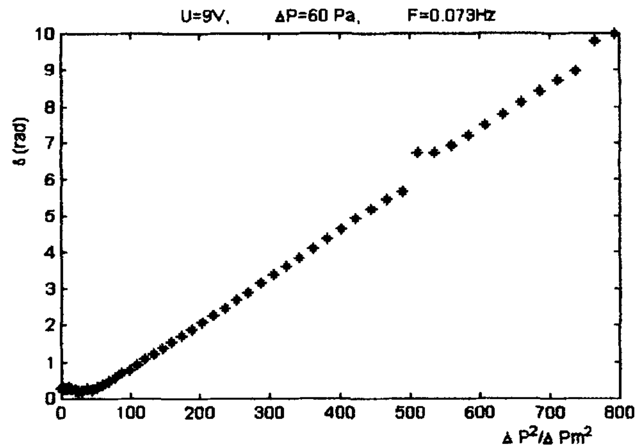

FIGURE 3 The phase difference δ as a function of $(\Delta p)^2$

The presented results are in a good agreement with the theoretical dependence

$$\delta = k \times (\Delta p)^2 \tag{7}$$

where k – a coefficient which depends on electrical voltage, geometrical sizes of the capillary and material constants of liquid crystal [3]. The established connection between δ and Δp (7) may be used to determine the shear viscosity of a liquid crystal. An estimate of the mean value of $\bar{\theta}^2$ for the thickness h=100 μm and Δn=0,15 shows, that it is equal to 0,04 at δ=π (last maximum on dependence $I(t)$). Assuming an orientational dependence of the viscosity as:

$$\eta(\Theta) = \eta_2 - \Delta\eta \times \sin^2\theta \tag{8}$$

we obtain (for $\Delta\eta \cong \frac{1}{2} \times \eta_2$) that the possible changes of the shear viscosity at the last stage of the orientational relaxation (after the last maximum of $I(t)$) doesn't exceed 2%.

Taking into account the equation (1) and neglecting viscous losses in tubes one can easy obtain the next time dependence for the difference of levels (Δh) in tubes:

$$\Delta h = \Delta h_m \times e^{-t/\tau} \tag{9}$$

where
$$\tau = m \times \frac{\eta}{\rho \times g} \tag{10}$$

– the decay time for the flow under considiration

$$m = \frac{3 \times L \times \pi \times d^2}{2 \times a \times h^3} \tag{11}$$

– the constant of the viscosimeter.

The expressions (9), (2) and (7) lead to the next asymptotic dependence $\delta(t)$:

$$\delta(t) \sim e^{-2t/\tau} \tag{12}$$

The experimental dependencies $\delta(t)$ for different voltages are presented in figure 4. They are in accordance with the expression (12).

Moreover the equal slope of the presented lines shows that the value of the viscosity η_2 can be obtained both in the presence and in the absence of stabilizing field. In the last case the orientation is stabilized by boundaries at very low values of the pressure difference ($\Delta p \sim 1$ Pa) and of volume ($\Delta Q/\Delta t$ ($\sim 2.6 \times 10^{-12}$)), passing through the channel. So the described method can be in principle applied for measuring the shear viscosities of lyotropic nematics, as they are hardly oriented by fields.

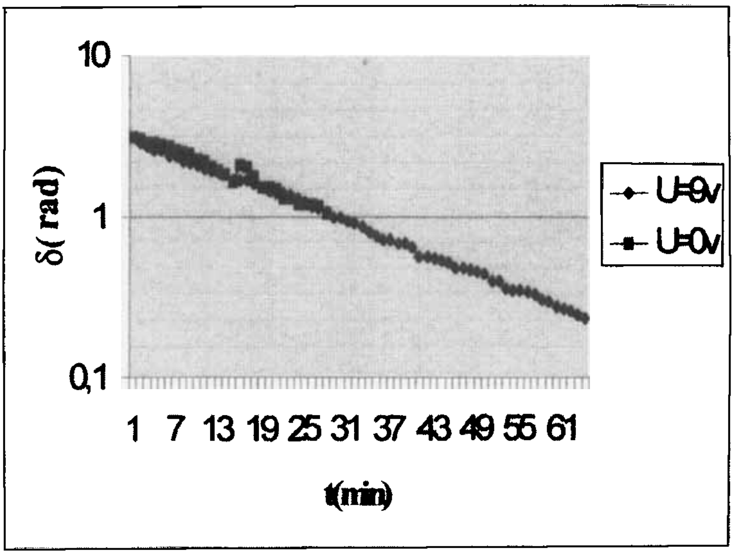

FIGURE 4 The experimental dependencies δ(t) for different voltages

References

[1] Ghwiller Ch., Mol. Cryst. Liq. Cryst. 20, 301 (1973).
[2] Kneppe H., Schneider F., Mol. Cryst. Liq. Cryst. 65, 23 (1981).
[3] Pasechnik S.V., Torchinskaya A.V., Mol. Cryst. Liq. Cryst. 331, 314 (1999)