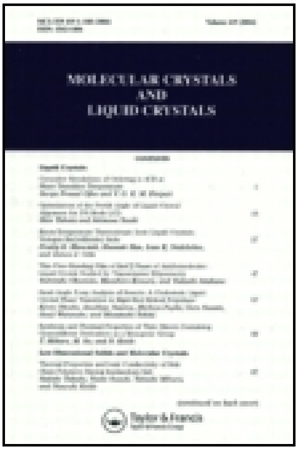

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Flow of Cholesteric Liquid Crystals Normal to the Helical Axis

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FLOW OF CHOLESTERIC LIQUID CRYSTALS NORMAL TO THE HELICAL AXIS

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Abstract Effective viscosity dependence on shear rate was investigated for plane Poiseuille flow normal to the helix axis for MBBA-CN mixtures. Two Newtonian regions for low and high shear rates and an intermediate non-Newtonian interval were observed. Analysis of the results leads to the consistence with the Leslie-Kini theoretical models.

INTRODUCTION

The variety of unusual flow phenomena was observed in cholesteric liquid crystals depending on flow conditions. Helical structure leads to considerable complication in formulation of theoretical models of the viscous properties of cholesterics. There is still insufficiency of experimental data useful for verification of the theories.

For simple shear flow normal to the helix axis Leslie[1] came to the conclusion that effective viscosity depends on shear rate and the pitch. Kini[2,3] solved Leslie's equations ignoring the thermomechanical coupling analytically for low shear rate and numerically for general shear rate both for simple shear flow and plane Poiseuille flow normal to the helix axis. Flow experiments of long pitch cholesterics correspond to the boundary conditions with director firmly anchored at the walls. Below we present briefly conclusions of Leslie[1] and Kini[2,3] models related to our experiments.

At low shear rates the effective viscosity η is independent on shear rate γ and for layer thickness greater than the pitch P it is given[3] by a combination of Leslie's coefficients α_i

$$\eta \cong \frac{\alpha_4(\alpha_4+\alpha_3+\alpha_6)}{2\alpha_4+\alpha_3+\alpha_6}. \tag{1}$$

At higher shear rates according to the flow induced unwinding of the structure η becomes non-Newtonian and subsequently approaches second Newtonian region with the apparent viscosity of untwisted nematic with the director aligned at an angle θ_o[1]

$$\eta = {}^1/_2\Big[\alpha_4 + (\alpha_5 - \alpha_2)sin^2\theta_o + (2\alpha_1 sin^2\theta_o + \alpha_3 + \alpha_6)cos^2\theta_o\Big], \tag{2}$$

where

$$\theta_o = {}^1/_2\, cos^{-1}(-\lambda_1/\lambda_2),\quad \lambda_1 = \alpha_2 - \alpha_3,\quad \lambda_2 = \alpha_5 - \alpha_6.$$

This high shear viscosity is delimited by critical shear stress τ

$$\tau \cong K_{22}4\pi^2/P^2. \tag{3}$$

EXPERIMENTAL

Investigations were carried out for liquid crystal mixtures of MBBA and cholesteryl nonanoate CN with helical pitches of 9,30,50,70μm and small negative dielectric anisotropy.

Special apparatus worked out for determination of the effective viscosities is described elsewhere[4]. Measurements were done for horizontal, flat, glass capillaries of typical dimensions 75x10x0.2mm at shear rates values $5x10^{-1} \div 1.5x10^2 s^{-1}$ and corresponding shear stresses at capillary wall $1x10^{-2} \div 3$Pa, at constant temperature stabilized within ±0.1K. In order to achieve planar orientation the orientational effect of an AC electric field applied to the conducting walls of the capillary was employed. Its typical parameters were $E=1x10^{6}Vm^{-1}$, f=1kHz which excluded EHD instabilities. Capillary walls had been preliminary coated with PVA films rubbered in uniform direction to meet the no-slip boundary conditions.

RESULTS AND DISCUSSION

The effective viscosities measured on MBBA-CN mixtures are plotted as a function of shear rate in Fig.1.a,b.

We made the following observations: (i) For low and high shear rates η is independent on shear rate.
(ii) The intermediate non-Newtonian region occurs. Effective viscosity noticeably decreases and these changes depend on the pitch and the temperature. For lower pitches the characteristic γ value and corresponding shear stress for approaching the second Newtonian region increases. Interval of the viscosity variation becomes wider and the slope of the $\eta(\gamma)$ curves decreases for the mixtures with lower pitch values. (iii) The high γ limit for stabilization of η increases with temperature.

Confrontation of the obtained experimental data with theoretical predictions stated earlier indicates not only qualitative but to the certain degree quantitive consistence as well. Effective viscosities η_T calculated from Eq.1,2 using pure MBBA Leslie coefficients[5] are comparable with those obtained in our experiment η_E for highly untwisted mixture (P=70μm). At T=303K for low shear limit η_T=23.9mPas while η_E=26.2mPas and for high shear η_T=20.3mPas, η_E=20.7mPas, respectively.

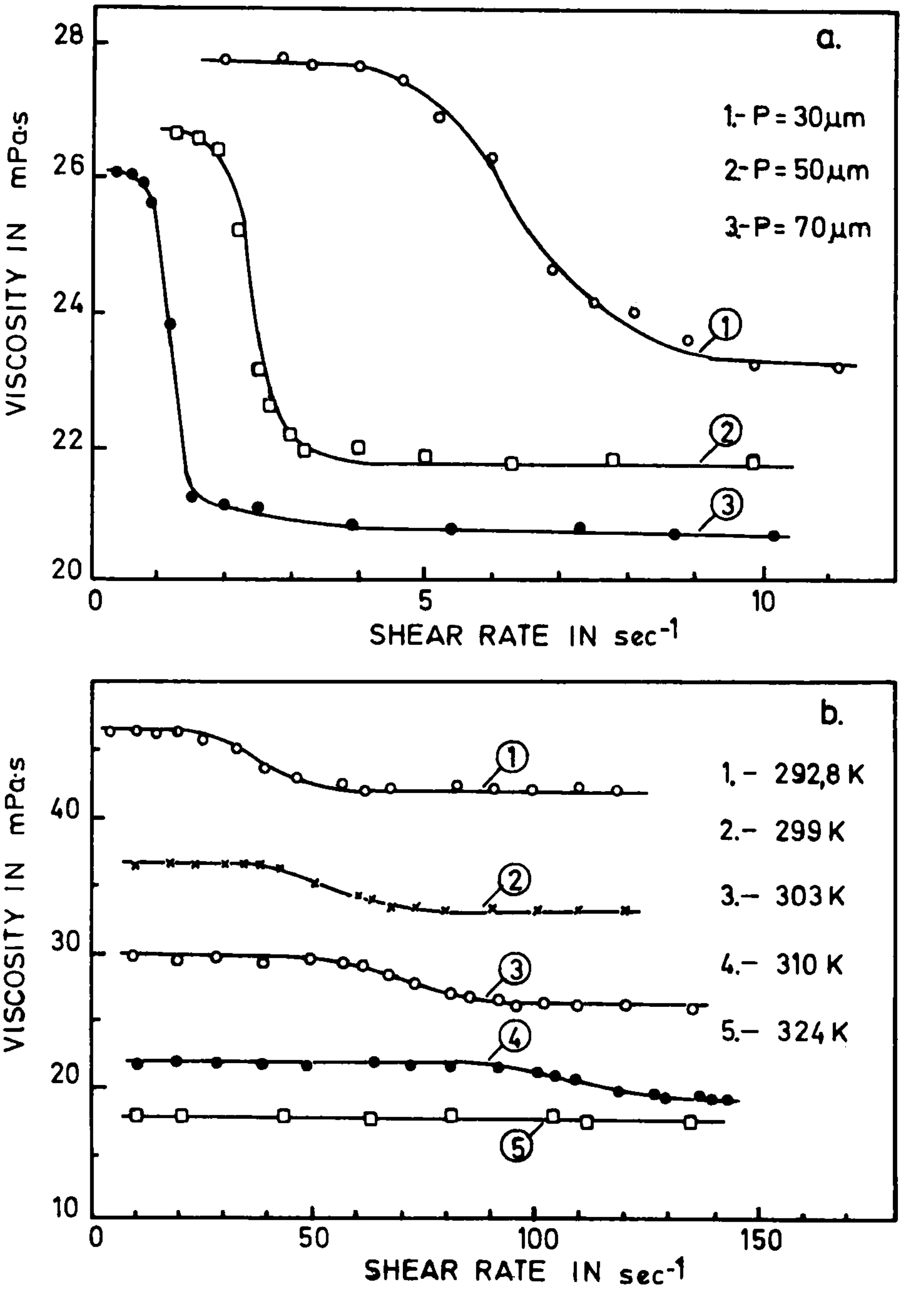

FIGURE 1 Effective viscosity as a function of shear rate
(a). at constant temperature T=303K
(b). for pitch P=9µm; 5–isotropic

Shear stress values that correspond to the transition to the second Newtonian region are plotted as a function of P^{-2} in Fig.2. The twist elastic constant K_{22} estimated from these data (according to the Eq.3) is about $5x10^{-12}$N while usually reported[6] values for MBBA-CN mixtures are within the range $3-5x10^{-12}$N.

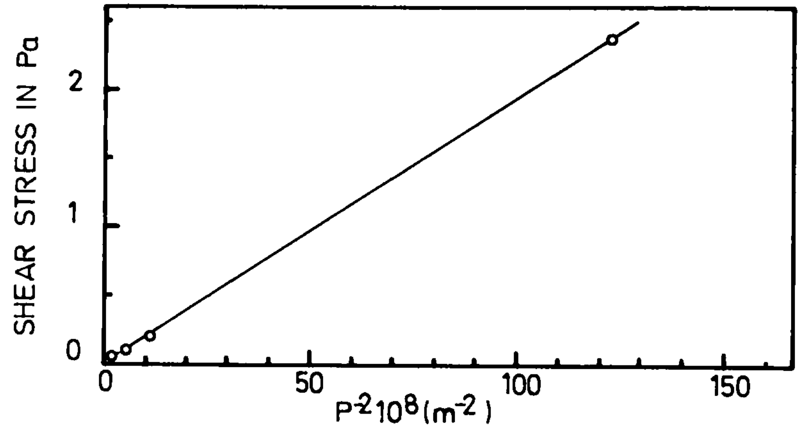

FIGURE 2 Critical shear stress for second Newtonian regime vs P^{-2} at T=303K

In conclusion, we have observed confirmation of theoretical predictions concerning the shear rate dependence of the effective viscosity of long pitch cholesterics for flat capillary flow normal to the helical axis.

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