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TEMPERATURE INFLUENCE IN USE OF AN INTERFERENCE METHOD TO STUDY THE EFFECTS OF NORMAL STRESSES

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It can now be considered established that deviations in fluid behavior from the classical theory predictions appear mainly in the normal stress effects [1]. For fluids with structural viscosity which varies with the change in the velocity gradient, these effects (Weissenberg effects [2]) are observed at comparatively low velocity gradients and extensive experimental material exists [3].

On the other hand, for fluids which do not exhibit changes in viscosity even for high velocity gradients in both the classical [4] and much later experiments, there are no data on a study of the normal stresses at high velocity gradients in the literature. The absence of such experiments becomes understandable if it is taken into account that while measurement of the viscosity imposes no great demands on the adjustment of the apparatus, a study of the normal stresses requires ultimately accurate surfaces and careful adjustment to reduce the dynamical errors, which is difficult to achieve at those high velocity gradients when the appearance of second-order effects could be expected in fluids with Newtonian viscosity. The influence of nonparallelism in the mounting of disks in a torsion flow was studied in [5].

Small gaps (on the order of tenths of a micron) must be used to achieve high velocity gradients in a torsion flow, and this does not permit application of traditional methods of measuring the normal stresses since both manometer orifices and piezosensors distort the microgeometry of the gap.

A contactless method of investigating the normal stresses in a torsion flow by using the interference of a large path difference and the property of epoxy resin to change the index of refraction with the change in load was proposed in [6].

Since heat is generated in a fluid mass subjected to a shear stress and interference methods are quite sensitive to the thermal shift of optical surfaces, it is necessary to

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TABLE 1

n \ t, sec	0	45	90	135	180	225
20	0,818	0,816	0,816	0,819	0,818	0,819
40	1,643	1,642	1,633	1,637	1,638	1,634
60	2,462	2,469	2,460	2,461	2,458	2,453
80	3,295	3,292	3,295	3,286	3,288	3,278
100	4,107	4,112	4,106	4,102	4,098	4,092
120	4,928	4,930	4,926	4,924	4,922	4,912
140	5,758	5,753	5,752	5,740	5,739	5,727
160	6,571	6,572	6,566	6,559	6,549	6,546
180	7,377	7,375	7,371	7,372	7,356	7,348
200	8,177	8,182	8,173	8,162	8,148	8,142
220	8,998	9,000	8,989	8,982	8,970	8,961
240	9,790	9,793	9,787	9,777	9,757	9,755

establish the degree of influence of the heat generated and the limits of reasonable application of the method.

The dependence of the time shift of the interference fringes in the domain of the maximum velocity gradient was investigated experimentally for an alcohol—glycerine mixture (20% alcohol) at room temperature for an $h = 150$ μ gap, an $R = 2.7$ cm radius of the rotating disk, and an angular velocity $w = 34.6$ rad/sec. The position of the interference fringes was photographed at the 10-sec intervals needed to eliminate the influence of normal stresses on the position of the fringes. The fringe displacement was measured on a UIM-21 universal microscope. Construction of the apparatus is described in detail in [7].

The fringe positions measured (in millimeters) relative to the marks outside the gap at 45-sec intervals of rotation are presented in Table 1 (t is the time and n is the number of fringes from the mark), which on the whole affords a possibility of judging the change in position of the interference fringes with time because of energy dissipation in the gap. The first three rows of numbers refer to interference fringes located far from the gap and not subjected to the influence of the heat being generated in the gap; hence they can be used to calculate the error of the method.

The relative error is

$$\delta\Delta l/\Delta l = 10/(60\cdot 41) = 0.004.$$

The maximum error in measuring the position of an individual fringe (10 μ), referred to the number of fringes (60) over which the average is performed, is taken as the error $\delta\Delta l$ in determining the fringe width. The mean fringe width Δl is 41 μ.

The last three rows of numbers in the table refer to the interference fringes located in the maximum velocity gradient domain, and their shift with time during operation can be an estimate of the influence of heating because of heat generation in the gap.

According to the classical theory of hydrodynamics, the thermal power liberated per unit volume of fluid equals the product of the viscosity η by the Rayleigh dissipation function. In this case this function can be considered simply proportional to the square of the maximum velocity gradient $\varkappa^2$. The thermal power passing through unit area from a gap of thickness h and heating an optically sensitive layer is proportional to $\eta\varkappa^2 h$. Since $\varkappa = wR/h$ in a torsional flow, the heat obtained $Q \sim (\eta w^2 R^2/h)t$ grows linearly with the time t.

In combination with the results of the experiment represented in Fig. 1, the dependence obtained permits not only an estimation of the instant when the influence of heat generation in the gap becomes substantial and starts to distort the results of measurements for a given fluid, gap, and rotational velocity, but also execution of a conversion for other cases.

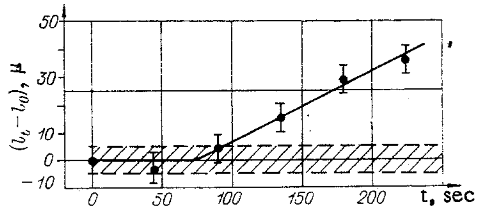

Fig. 1

For instance, for distilled water (viscosity one-sixtieth and a gap one-fifteenth) the influence of heating in the same apparatus and for the same rotational velocity is still not manifest after 1.5 min, but only after 6 min. It is seen in the figure how the influence of self-heating of the fluid on the shift of the interference fringes is accumulated with time (l_0 is the position of the fringe at the initial time, and l_t is the position at the time t).

The results of the experiment permit the assertion that despite its high sensitivity to a temperature change, the interference method is suitable for measurements of normal stresses if the experiment is conducted during a sufficiently short time while the heating has still not been felt.

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