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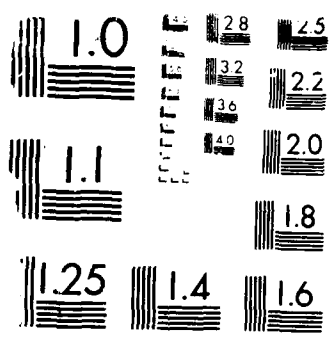

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HIGH SHEAR RATE RHEOMETRY OF LOW-VISCOSITY LIQUIDS

Final Report to the U. S. Army Research Office

on Contract/Grant Number DAAG29-84-K-0046

to the University of Wisconsin-Madison

by

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4A. Statement of Problem

In steady shear flow, polymeric liquids in general and multigrade oils in particular generate a *first normal stress difference* N_1 in addition to a shear stress σ ($= \eta\dot{\gamma}$, where η & $\dot{\gamma}$ denote viscosity and shear rate). In principle, N_1 should aid journal bearing lubrication and perhaps make possible the use of oils with lower viscosity; this could lead to improved fuel economy and an increase in the range of motorized vehicles. Unfortunately, however, theoretical estimates suggested that the N_1 effect would be far too small in practice; before 1986, direct vehicle tests were inconclusive, in part because there was no method available to measure N_1 under conditions ($\dot{\gamma} = 10^6 s^{-1}$; 100C to 150C) matching those of journal bearing operation.

In 1986, Shell and General Motors found[1] a strong correlation between h, the minimum oil film thickness measured in an instrumented main bearing, and N_1 for a set of 13 commercial multigrade oils. N_1 was measured using a new instrument - the LODGE STRESSMETER(R) FOR HIGH SHEAR RATES. The surprising result (as yet unexplained) was that the data showed that the N_1 contribution to h could be as much as 75% of the contribution from η. Values of $\dot{\gamma}$ up to $6x10^6 s^{-1}$ were calculated. This work has revitalized the development of low-viscosity oils and showed that it is essential to measure N_1 as well as η if fuel economy is to be maximized by lubricant formulation changes.

The Stressmeter was invented by the Principal Investigator in 1967. A high shear rate version was developed by the PI at the request of Exxon Chemical Co.; a commercial version was sold to Shell Research (UK) in 1983 and used in the above investigation.

In 1983, the PI obtained data which suggested that (a) the Stressmeter could give values of N_1 for a multigrade oil up to $\dot{\gamma} = 3x10^5 s^{-1}$ at temperatures up to 60C; (b) at higher shear rates and temperatures, the method was suspect; (c) the η data showed an anomalous increase with increase of $\dot{\gamma}$ above $5x10^5 s^{-1}$. The above Shell/GM investigation was somewhat hampered by these restrictions which made it necessary to extrapolate in order to get N_1 for the range ($\dot{\gamma}$ up to $6x10^6 s^{-1}$ at 150C) indicated by their measurements. Extrapolation was also required for η because of an upper limit ($\dot{\gamma} = 10^6 s^{-1}$) imposed by the concentric-cylinder viscometer used; this is also the present upper limit for all other commercially-available oil viscometers.

The goals of the present investigation were:

I. to make further tests of the range of validity of the Stressmeter method of measuring N_1;

II. to extend the range of measurement (for multigrade oils, in particular) of N_1 and η to higher shear rates and temperatures.

4B. Summary of the most important results

Experimental evidence has been obtained which supports the following conclusions[2] in regard to the Stressmeter:

1. For N_1 measurement, the shear rate range has been increased by a factor of 4 (up to $\dot{\gamma} = 1.2x10^6 s^{-1}$) for $\eta = 10$ cP.

2. For viscosity measurement, the shear rate range has been increased by a factor of 5 (up to $\dot{\gamma} = 5x10^6 s^{-1}$) for $\eta = 2.5$ cP.

3. The 1983 restriction ($\dot{\gamma} < 3x10^5 s^{-1}$) for N_1 measurement was unnecessary, being based on an insufficiently accurate measurement of a certain flush transducer characteristic combined with an incorrect comparison of data obtained at different temperatures.

4. The 1983 viscosity anomaly was due to coalescence of microbubbles in the test liquids; thorough prior degassing by slow filtration into a high vacuum removes the anomaly, and makes possible the use of much smaller Stressmeter dies (length 2 mm; height 25 μm) for viscosity measurement.

5. The shear stress range should be increased by a factor of 15 or more up to about 200 kPa) by use of a new pressure-controlling servo system which has been developed using digital electronics. This will make possible the testing of the Stressmeter method over a wider range of conditions.

4C. List of publications and technical reports

"On using Rubber as a Guide for Understanding Polymeric Liquid Behavior", in *Viscoelasticity and Rheology"*, (Academic Press, 1985; ed. Lodge, Renardy, & Nohel), p.181.

"Normal Stress Differences from Hole Pressure Measurements", invited chapter in a book entitled "*Rheological Measurement"*, Elsevier, edited by Collyer and Clegg. In press; publication expected in 1988.

"Measurement of the first normal stress difference at high shear rates for a polyisobutylene/decalin solution "D2" ", *Rheol. Acta*, with T. S. R. Al-Hadithi and K. Walters. In press, 1987.

"The Weissenberg Effect at Finite Rod Rotation Speeds", with J. D. Schieber and R. B. Bird, submitted to J. Chem. Phys., 1987.

"A New Method of Measuring Multigrade Oil Shear Elasticity and Viscosity at High Shear Rates", SAE Paper No.872043, Nov. 1987.

4D. Participating scientific personnel

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5. Bibliography

1. T. W. Bates, B. Williamson, J. A. Spearot, & C. K. Murphy, SAE Paper No.860376 (1986).

2. A. S. Lodge SAE Paper No.872043, Nov. 1987.

NOTE Reference 2 contains an extensive bibliography.

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