Twelfth Australasian Fluid Mechanics Conference
The University of Sydney, Australia 1995

THE SHEAR VISCOSITY OF FIBRE SUSPENSIONS

V. Ilic
Mechanical Automation Engineering
University of Western Sydney Nepean
Kingswood, New South Wales
Australia

N. Phan-Thien
Mechanical and Mechatronic Engineering
The University of Sydney
New South Wales
Australia

ABSTRACT

Difficulties associated with the viscosity measurement of concentrated suspensions of particulate solids in a liquid solvent can effectively be overcome with the falling needle technique reported in literature. The same technique was applied to fibre suspensions in a Newtonian liquid in the work reported here. The aim of this study was to measure the shear viscosity of mixes of various concentration using the falling needle technique, and ascertain the effect of fibre aspect ratio on the measured shear viscosity.

The initial results show that for low concentrations of fibres, the suspension maintains the Newtonian characteristic of the solvent liquid. However, at higher concentrations this behaviour is modified.

In the opaque suspensions used, the passage of sedimenting needles and spheres was observed using a permeability sensitive particle detector driven by a Colpitts oscillator.

BACKGROUND

Mixing of rod-like particulates into polymer melts prior to forming is already an established procedure (Becraft et al., 1992) used to enhance the load bearing capacity of components made of plastic. Because of its industrial relevance, research into rheological characterisation of such mixes is also applications driven. Earlier efforts have been reported in excellent reviews (Goddard 1977, Ganani and Powell 1985, Milliken and Powell 1994).

While theoretical considerations have advanced substantially (Phan-Thien and Graham, 1991), unambiguous experimental evidence has been difficult to obtain. One reason for this difficulty is associated with the particle size relative to the rheometer geometry. Also, in the case of rod-like particulates at non-dilute concentrations, fibre may align themselves near a solid boundary as well as form an interlocking structure within the body of the suspension.

Following a successful application of the falling needle technique to suspensions of spheres in a Newtonian fluid (Ilic and Phan-Thien, 1994), the same technique was applied here to a suspension of rod-like particulates in a Newtonian fluid. The aim of this work was to ascertain the applicability of the falling needle method to determining the bulk shear viscosity of fibre suspensions for a range of solids fractions. It was also of interest to establish the influence of the aspect ratio of the filler rods on the measured shear viscosity.

EXPERIMENTS

The Experimental Hardware

The Newtonian solvent used in the suspensions was a polydimethylsiloxane (silicone oil having density 0.975 $g\ cm^{-3}$ and dynamic viscosity

Table 1: Needle details

particle	ID	length mm	diameter mm	mass g
needle	1	41.61	1.59	1.4941
	2	41.23	1.54	0.6413
	3	87.25	1.60	3.2159
	4	84.78	1.55	1.3194
	5	131.11	1.60	4.8139
	6	130.05	1.59	2.0032
	7	83.51	1.59	3.0103
	8	86.07	1.59	1.3286
	9	40.35	1.59	1.4569
	10	40.84	1.59	0.6273
	11	84.24	1.55	1.3102
	12	42.20	1.60	1.5469
	13	40.81	1.55	0.6347

14.46 Pas at 20^oC).

The volume of a test suspension was about 1000 cm^3 and was contained in a vertical glass test cylinder 59.09 mm diameter. The cylinder was capped with a flanged, snugly fitting aluminium needle launcher 30 mm deep with a hole drilled through its centre for manual release of needles along the centreline of the cylinder.

The falling particle detector consisted of a Colpitts (LC) oscillator tuned at 523 kHz The oscillator frequency was measured with a Thurlby Thander (UK) TF830 1.3 GHz Universal Counter. An RS232 cable downloaded the frequency counts to a PC for post processing.

Details of needles used in the experiment are given in Table 1. The needles were initially made from a combination of tungsten carbide and brass to ensure downward bias. One needle was made of brass only. They are commercially available as welding rods, and were cut to required lengths with a diamond wheel in a fixture made for preparing transmission electron microscope specimens. Needle ends were ground flat and polished in a special jig to ensure end surface orthogonality with the needle axis. There was no specific reason for doing this, except to maintain consistency between different needles.

The needle Reynolds number in the solvent only, defined as $\rho_f UL/\eta_f$, where U denotes the terminal velocity of a needle and L its length, varied between 0.010 and 0.058. For the fibres settling in solvent only, the Reynolds number based on length was typically 0.006.

Experimental Method

The test needle was introduced through the orifice in the launcher centre, and in line with the cylinder axis. The launcher was 30 mm thick, and a test needle was partially immersed in the test fluid before its release. This ensured that the launched needle was vertical as it left the launcher.

A permeability method was used to detect and monitor needle progress through the suspension. The sensing coil spool was placed around the test cylinder containing the suspension to be characterised, and the needle launcher was then placed in position.

A PC resident data acquisition program was activated before a needle was manually released through the orifice in the needle launcher. The proximity of the falling needle to the coupling coil changed the permeability of the coil's core, resulting in a change in the oscillator frequency. Reversion to the initial frequency indicated the completed passage of the needle through the coil detection zone, and the data acquisition was then terminated.

The ratio of the needle "detection time" through a given suspension to the "detection time" through solvent alone was taken to be equivalent to the (suspension/solvent) viscosity ratio, η_r, of the mixture. This ratio was then corrected for the dissimilar densities of the solvent and the suspension fibres. The error associated with η_r is about 2.5% based on a needle detection time ratio. It should be noted that a change in the oscillator frequency of the order of 50 Hz in 5×10^5 Hz was being measured here.

RESULTS AND DISCUSSION

The Figure 1 shows variation of the viscosity ratio with volumetric fraction of particulate solids in the test fluid for two aspect ratios of suspended fibres 5.47 and 19. At concentrations less than 2% the viscosity is similar to that of the solvent as might be expected. In addition, it is apparent that the fibre aspect ratio does not influence the measured viscosity in this concentration range. This is probably the result of the uninhibited Jeffrey orbitals expected at low fibre concentrations. Coincidence of experimental points in this region also indicates Newtonian behaviour of the fluid, as each point corresponds to a different shear rate.

For the short fibres, the shear viscosity increases almost linearly with solids fraction, maintaining the Newtonian fluid characteristic. In addition, agreement with experimental data of Ivanov et al. 1982 is apparent.

It is also apparent from the Figure 1 that the shear viscosity of a suspension of long fibres is

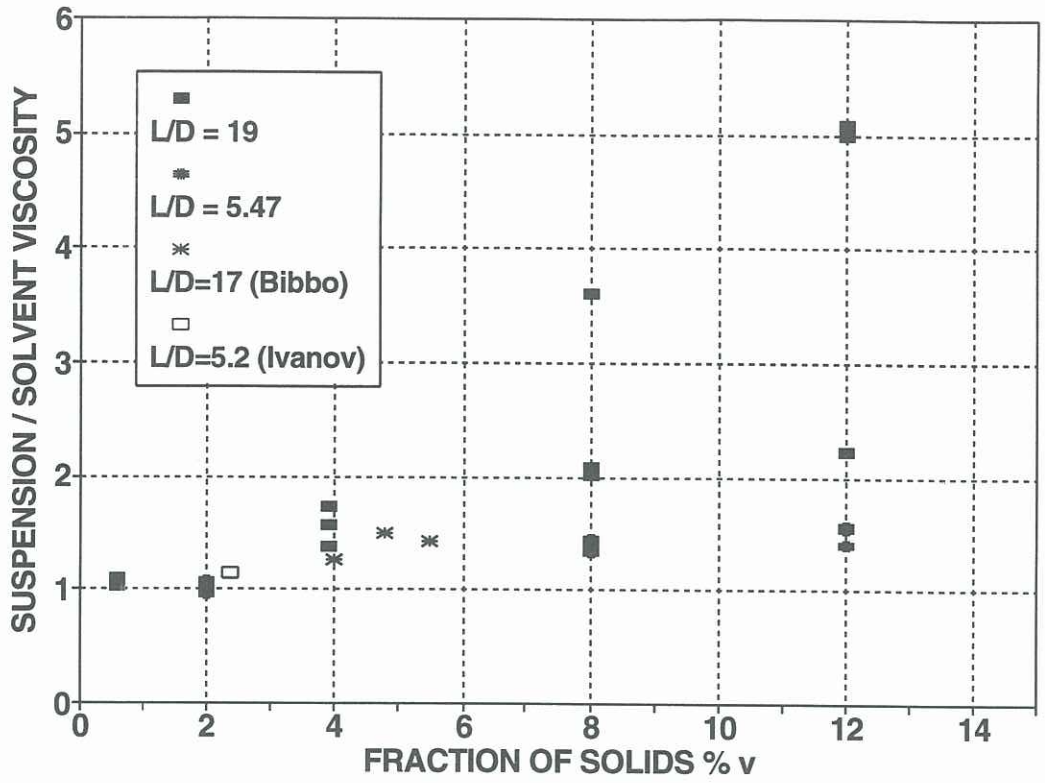

Figure 1. Variation of the relative shear viscosity with solids concentration

greater than that of short fibres at a given solids fraction. This seems reasonable as, for a given solids fraction, the likelihood of an interlocking structure is enhanced with increased rod aspect ratio. However, unlike with short fibres, there is a diverging spread of experimental data with increasing solids fraction. This is probably related to the structure formation within the fluid. Further tests are required to ascertain this.

As might be expected, the experimental data of Bibbo et al. 1985, having an intermediate aspect ratio, fall between our experimental data.

CONCLUSIONS

The falling needle technique can successfully be applied to a suspension of fibres to determine the bulk shear viscosity of the fluid.

The shear viscosity is smaller in magnitude for the short fibres than long fibres, perhaps reflecting greater propensity for the latter to form structures because of their larger Jeffery orbitals.

Diverging spread of data with solids fraction for the long fibres may be associated with the formation of particulate structures in the fluid. This should be ascertained in future tests.

Acknowledgments

Artel Industries Ltd (NZ) provided the nylon fibres used in the experiments, while the silicone oil solvent was donated by the Rhône-Poulenc Australia Pty Ltd.

REFERENCES

Becraft, M.L. and Metzner, A.R., 1992, "The rheology, fiber orientation and processing behaviour of fiber-filled fluids", *Journal of Rheology*, Vol. 36(1), pp. 143-174.

Bibbo, M.A., Dinh, S.M. and Armstrong, R.C., 1985, "Shear flow properties of semiconcentrated suspensions", *Journal of Rheology*, Vol. 29, pp. 905-929.

Ganani, E. and Powell, R.L., 1985, "Suspensions of rodlike particles: literature review and data correlations", *Journal of Composite Materials*, Vol. 19, pp. 194-215.

Goddard, J.D., 1977, "A review of recent developments in the constitutive theory of particulate suspensions", *SM Archives*, Vol. 2(4), pp. 403-431.

Ilic, V. and Phan-Thien, N., 1994 "Viscosity of concentrated suspensions of spheres", *Rheologica Acta*, Vol.33, pp. 283-291.

Ivanov, Y., van de Ven, T.G.M. and Mason, S.G., 1982, "Damped oscillations in the viscosity of suspensions of rigid rods. I. Monomodal suspensions", *Journal of Rheology*, Vol. 26, pp. 213-.

Milliken, W. J. and Powell, R .L., 1994, "Short-fiber suspensions" in 'Flow and rheology in polymer composites manufacturing', Advani, S.G. (ed), pp. 53-83. Elsevier.

Phan-Thien, N. and Graham, A.L., 1991, "A new constitutive model for fibre suspensions: flow past a sphere", *Rheologica Acta*, Vol. 30, pp. 44-57.