

CHARACTERIZATION OF VISCOPLASTIC MATERIALS WITH ROTATING VANE AND BOB RHEOMETRY

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Abstract. In rheometry studies, the success in characterizing a non-Newtonian material with the aid of a rotational rheometer can depend strongly on the geometry chosen to perform the measurement. In particular, when viscoplastic materials such as pastes and slurries are to be characterized, the undesirable phenomenon of wall slip often occurs when standard geometries are employed. In this paper, we present comparisons of flow curves for viscoplastic materials as obtained with different geometries. Specifically, we employed the standard bob-and-cup geometry, the bob-and-cup geometry with a roughned surface, and the vane-and-cup geometry. Preliminary results are presented which illustrate the dramatic effect of wall slip for certain cases. The obtained results also suggest that care should be taken while employing the vane-and-cup geometry at high shear rates.

***Keywords**. Rheometry, viscoplastic behavior, yield stress, vane geometry*

1. Introduction

The existence of yield stress has been under discussion among rheologists for a long time. Recently, Barnes (2000) provided a comprehensive discussion on the subject, where he argues that “everything flows,” and that the flow at low stresses is sometimes not observable due to the insufficient resolution of the measuring device. Nevertheless, for the so-called viscoplastic materials, as the stress reaches a certain level (the yield stress), changes occur in the material microstructure that cause a sharp decrease in viscosity.

The bob-and-cup device (the Couette geometry) is common in rotational rheometry. However, for viscoplastic materials a bob with roughened surface or a vane are often needed instead of the bob, in order to eliminate wall slip due to the disturbance of the solid boundary on the material microstructure (wall depletion). Wall slip is usually important at low shear rates, because wall depletion effects increase fast with particle size (or floc size), and often in multiphase systems the particles flocculate, and the floc size usually decreases dramatically as the shear rate is increased.

Chhabra and Richardson (1999) showed that it is important to choose the appropriate height-to-diameter ratio of the vane, because the vane-ends contributions to the torque may not be negligible. This ratio is acceptable when the height is higher than diameter. However, it cannot be too high, to avoid non-negligible torque contributions of the shaft surface. Most articles on this subject investigate the use of the vane mainly at low shear rates.

The vane is considered as the best solution to avoid wall slip during the characterization of viscoplastic materials, because it is also appropriate to fiber suspensions, which the roughened surfaces usually cannot handle. Barnes and Nguyen (2001) presented a review about the use of the vane. Barnes (1995) reported an extensive review about slip in viscometry, where he discusses the different methods employed in the past to eliminate wall slip. In this paper, flow curves obtained with smooth and roughened surfaces illustrate how erroneous the data can be due to wall slip.

In the present paper we present a limited set of viscosity results for three different viscoplastic materials. The data were obtained both with the bob-and-cup and the vane-and-cup geometries. We discuss the performance of these geometries at low and high shear rates.

2. Results

For the sake of illustration, Tab. (1) shows a typical set of results obtained for a 0.2% aqueous solution of Carbopol 676, a commercially available polymer, with a bob-and-cup geometry of one of our rotational rheometers (the PHYSICA UDS-200). The measurements were performed with a logarithmical torque ramp from 3.0E-04 up to 1.5E-01 Nm. The internal and external radii (r_i and r_o) of the annular space were 2.25E-02m and 2.44E-02 respectively, and the bob height (L) was equal to 6.75E-02m.

Table 1. Experimental data for Carbopol 676 (Goodrich) aqueous solution 0.2 % concentrated

Measured point no.	ω (rad/s)	$\dot{\gamma}$ (1/s)	Γ (Nm)	τ (Pa)	η (Pa.s)	$\frac{\dot{\gamma}}{\omega}$
1	5.15E-02	6.35E-01	6.05E-03	23.7109	3.7334E+01	1.2328E+01
2	6.93E-02	8.55E-01	7.40E-03	28.9694	3.3885E+01	1.2328E+01
3	9.06E-02	1.1164973	9.04E-03	35.3946	3.1701E+01	1.2328E+01
4	1.43E-01	1.7650854	1.10E-02	43.2447	2.4500E+01	1.2328E+01
5	2.06E-01	2.5342905	1.35E-02	52.83570	2.0848E+01	1.2328E+01
6	2.75E-01	3.3933131	1.65E-02	64.5543	1.9024E+01	1.2328E+01
7	3.70E-01	4.5599212	2.01E-02	78.8712	1.7297E+01	1.2328E+01
8	5.17E-01	6.375719	2.46E-02	96.3640	1.5114E+01	1.2328E+01
9	1.06145891	1.31E+01	3.01E-02	117.7369	8.9973E+00	1.2328E+01
10	2.6455097	3.26E+01	3.67E-02	143.8491	4.4106E+00	1.2328E+01
11	6.21813868	7.67E+01	4.49E-02	175.7526	2.2927E+00	1.2328E+01
12	1.33E+01	1.63E+02	5.48E-02	214.7321	1.3139E+00	1.2328E+01
13	2.62E+01	3.23E+02	6.70E-02	262.3567	8.1268E-01	1.2328E+01
14	4.88E+01	6.02E+02	8.19E-02	320.5473	5.3275E-01	1.2328E+01
15	8.95E+01	1.10E+03	1.00E-01	391.5955	3.5510E-01	1.2328E+01

Table (1) shows that the viscosity of this polymeric solution undergoes a dramatic change as the shear stress reaches about 100 Pa (between points 8 and 9). This is better observed when we plot viscosity as a function of the shear stress, as we present below for three different viscoplastic materials which were tested with four different geometries. These geometries were a vane-and-cup, two bob-and-cup with two different lengths, and a bob-and-cup with the surface covered by very fine sandpaper. The three materials were the 0.2% aqueous solution of Carbopol 676 (Fig.(1)), a commercial fabric softener (Fig.(2)), and a commercial liquid floor wax (Fig.(3)).

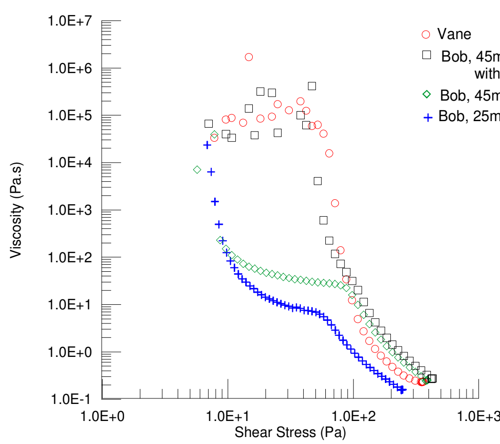

Figure 1. Comparison of flow curves obtained with different geometries. 0.2% aqueous solution of Carbopol 676. The torque was varied according to a continuous log ramp from 1E-04 up to 1.5E-01 Nm.

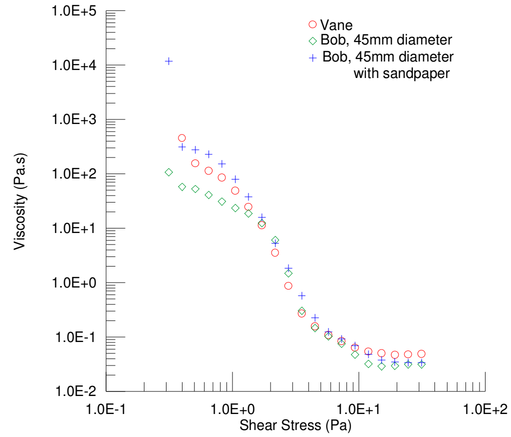

Figure 2. Comparison of flow curves obtained with different geometries. Fabric softener. The torque was varied according to a continuous log ramp from 8.0E-05 up to 8.0E-03 Nm.

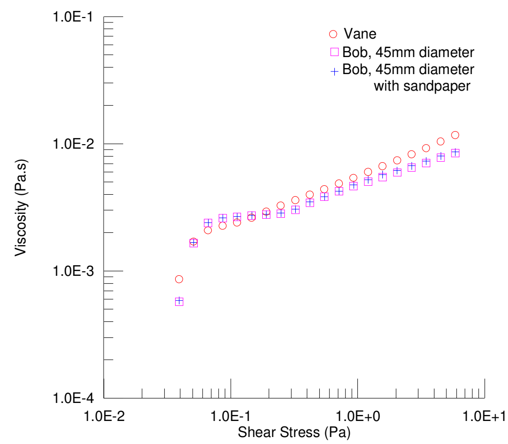

Figure 3. Comparison of flow curves obtained with different geometries. Liquid floor wax. The torque was varied according to a continuous log ramp from 1E-05 up to 1.5E-03 Nm.

Figures (1), (2) and (3) illustrate the importance of choosing the appropriate geometry, especially at low shear rates (or low shear stresses). Firstly it is noted in Fig. (1) that the short bob yielded erroneous results throughout the shear-stress range investigated for the Carbopol solution. This indicates that the torque generated by the viscous force at the bob lower surface played an important (and undesirable) role in the measurements.

From Figs. (1) and (2) it is observed that the wall slip effect was present for the standard bob-and-cup geometry in the low-shear-rate range, especially for the Carbopol solution. It is also seen that the data for the vane-and-cup geometry agreed well with the surface-roughened bob-and-cup geometry, indicating that both methods were effective in eliminating the wall-slip artifact.

At higher shear rates, the data obtained with the vane-and-cup geometry for the three materials differ somewhat from the ones obtained with the standard and surface-roughened bob-and-cup geometries. This is probably due to secondary flows that should appear behind the vanes when the stress level in this region reaches values above the yield stress. However, more measurements are needed in order to better assess the reasons for this discrepancy.

3. Conclusions

This article present preliminary results of an ongoing research which aims at developing an experimental procedure for characterizing viscoplastic materials. The main problem that appears in this endeavor is the wall-slip effect due to wall depletion in multiphase systems. This effect introduces an artifact which can spoil the data obtained. We tested the two remedies most recommended in the literature, namely, the surface-roughened bob-and-cup geometry, and the vane-and-cup geometry. Our preliminary results indicated that, overall, the surface-roughened performed better, because at high shear rates the data obtained with the vane-and-cup geometry differed from the data obtained with the other geometries. However, this preliminary conclusion lacks more experimental evidence to support it and to determine the reasons for this fact in the case that it is confirmed.

4. Reference list

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