Processing the Vane Shear Flow Data from Couette Analogy

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Abstract:
A new procedure is described to convert the vane torque and rotational velocity data into shear stress vs shear rate relationships. The basis of the procedure consists in considering locally the sheared material as a Bingham fluid and computing a characteristic shear rate from Couette analogy. The approach is first applied to experimental vane data of Newtonian fluid, then used to process vane experimental data of non-Newtonian and yield stress materials. Results, which are favourably compared with torsional flow, show that the approach correctly predicts the rheological behaviour of the materials investigated.

Zusammenfassung:
Eine neue Methode zur Bestimmung von Schubspannung und Scherrate aus Drehmoment und Umdrehungsgeschwindigkeit einer Flügelgeometrie (Vane) wird beschrieben. Diese beruht darauf, dass das gescherte Material lokal als Binghamsche Flüssigkeit angesehen und eine charakteristische Scherrate mittels einer Couette-Analogie berechnet wird. Die Methode wird zunächst auf experimentelle Resultate für eine Newtonsche Flüssigkeit und im folgenden auf nicht-Newtonsche und Materialien mit Fließgrenze angewandt. Der Vergleich der Ergebnisse mit Resultaten aus Torsionsversuchen zeigt, dass die Methode die rheologischen Eigenschaften der untersuchten Materialien korrekt voraussagt.

Résumé:
Une nouvelle procédure est développée afin de convertir les données de couple et vitesse de rotation en géométrie vane sous la forme d'une relation contrainte vitesse de cisaillement. Cette procédure consiste à considérer le fluide en écoulement comme étant un fluide de Bingham, et à évaluer la vitesse de cisaillement caractéristique du fluide par une analogie de Couette. Cette approche est premièrement appliquée aux données expérimentales en géométrie vane d'un fluide newtonien, puis à celles de fluides non newtonien et à seuil d'écoulement. Les résultats, qui sont favorablement comparés à des écoulements de torsion, montrent que la procédure prédit correctement le comportement rhéologique des matériaux étudiés.

Key words: vane test, rheometry, Couette analogy, Bingham model, flow curve

1 INTRODUCTION

Vane geometry was initially used in soil mechanics for the measurement of the shear strength of soils. It has now become a standard technique in rheometry [1, 2], in particular to measure the yield stress of very shear-thinning liquids and structured fluids [3-8]. In this way, the vane is used in rotational controlled mode and tests are carried out at a constant and low rotational velocity. An alternative procedure is to operate the vane in a constant-stress controlled mode [1, 9]. So, the vane is basically a creep test where wall slip is far away or subsequently reduced. Moreover, an oscillating mode may be applied to investigate viscoelastic properties of fluids [10, 11]. In practice, vane tests are relatively easy to perform and the four-bladed probe may be attached on existing rheometers. With this geometry, the fluid structure is not disturbed prior the measurement, which is an advantage for sensitive fluids and semi-solid structures. Vane shear flow interpretation is commonly based on the following considerations. It is assumed that (1) the material is sheared along a cylindrical surface defined by the vane height h and diameter D and (2) the stress distribution is uniform over the cylindrical sheared surface. As a consequence, vane geometry appears as a Couette system, varying thickness of sheared material following material structure and cup size, where wall slip effect is

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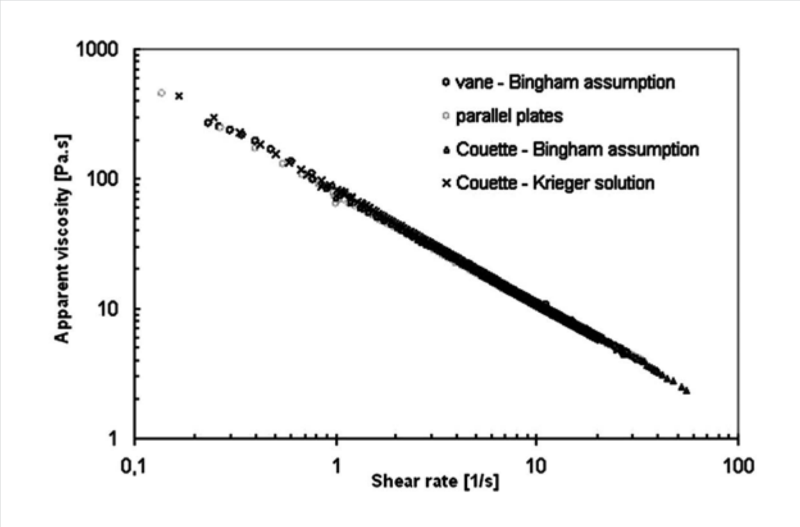

Figure 3:
Flow curves for 0.15 wt% of carbopol dispersion.

pH 7 with a common base of sodium hydroxide (1.3 wt% NaOH). The mixing is then stopped when a visually water-clear homogenized gel suspension is achieved with air bubbles essentially absent. The 0.15wt% Carbopol suspension was placed at rest for 48 h at 25°C before rheological testing.

Rheological measurements were performed at 25°C using a Malvern Gemini 200 rheometer. Geometries such as a 40 mm plate-plate (gap 1 mm), a vane attachment (vane diameter 25 mm, vane length 37.6 mm, cup diameter 44.3 mm) as well as a Couette geometry (bob diameter 25 mm, bob length 37.6 mm, cup diameter 27 mm) were used. Both plates, vane cup, and bob and cup cylinders are roughened to avoid slippage. Rate-controlled measurements were performed in the same shear rate range, 0 - 30 s^{-1}, from the rheometer software, applying a linear up-and-down ramp. During experiments, the top of the vane and bob cylinder was placed at the fluid surface.

As a result, Figure 3 compares the apparent viscosity prediction of Carbopol between parallel plate measurement, vane and Couette data computed from the procedure described above, as well as the apparent viscosity curve obtained from the first Krieger's solution in Couette geometry. As can be seen, the three geometries compare well over the shear rate range investigated. This shows first the relevance of the proposed approximation technique in shear rate calculation with yield stress material. Moreover, we can notice the independency of system used with yields stress fluid, as vane and Couette systems provide the same result, independently of gap size and shear flow condition in the annulus. Actually, it was checked that with vane system, the fluid is always partially sheared due to the large gap used. Inversely, the Carbopol is quickly fully sheared in the Couette narrow gap. As a consequence, Bingham assumption was also here compared to the Krieger's shear rate solution. Figure 3 shows the good correlation between these both shear rate solutions. Finally, Carpobol dispersion show yield stress and shear thinning behaviour as predicted in previous works [22, 23]. It should be noted that some discrepancy between parallel plates and vane or Couette flow curves appears at low shear rate. This can be explained by the initial state of the material before testing, as no pre-shearing has been performed before the experiments.

4 CONCLUSION

In this paper we have evaluated the rheological behaviour of fluids in vane system from Couette analogy. We have used a Bingham model to locally describe the vane rotational shear flow of fluids and compute an average shear rate and the corresponding shear stress from torque-rotational velocity data. Experimental results show the correct predictions of the proposed analysis with Newtonian, non-Newtonian and yield stress materials under moderate and large gap vane systems. The developed procedure provides a practical and alternative method to conventional treatment of vane shear flow data. Indeed, it does not require shear factor calculations and prespecification of rheological constitutive model, as well as small or wide gap assumption. The proposed approach is also interesting because it provides a way to evaluate the material rheology of a suspension with large particles.

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