Viscosity Function for Yield-Stress Liquids

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Abstract:
A viscosity function for highly-shear-thinning or yield-stress liquids such as pastes and slurries is proposed. This function is continuous and presents a low shear-rate viscosity plateau, followed by a sharp viscosity drop at a threshold shear stress value (yield stress), and a subsequent power-law region. The equation was fitted to data for Carbopol aqueous solutions at two different concentrations, a drilling fluid, an water/oil emulsion, a commercial mayonnaise, and a paper coating formulation. The quality of the fittings was generally good.

Zusammenfassung:
Eine Viskositätsfunktion für stark scherverdünnende Flüssigkeiten oder Flüssigkeiten mit Fliessgrenze wie Pasten und Schlämme wird vorgeschlagen. Diese Funktion ist stetig und besitzt bei kleinen Scherraten ein Viskositätsplateau, an das sich ein abrupter Viskositätsabfall bei einem Grenzwert der Schubspannung (Fliessgrenze) anschliesst, und von einem nachfolgenden Potenzgesetzbereich abgeschlossen wird. Die Gleichung wurde an Daten von wässrigen Carbopollösungen, Bohrlochspühlung, Wasser/Öl Emulsion, kommerziell vertriebener Mayonnaise und einer Formulierung für Papierbeschichtung gefittet. Die Qualität der Fits war allgemein gut.

Résumé:
Une fonction pour décrire la viscosité est proposée pour des fluides fortement rhéo-fluidifiant ou à seuil de contrainte d'écoulement comme des boues et des pâtes. Cette fonction est continue et caractérisée par un plateau aux taux de cisaillements faibles, suivi d'une abrupte diminution de la viscosité au seuil de contrainte d'écoulement et un régime final en loi de puissance. La fonction est appliquée aux solutions aqueuses de Carbopol à deux concentrations, à un fluide de forage, une émulsion eau/huile, une mayonnaise commerciale et à une formulation pour le revêtement du papier. La qualité de la description est généralement très bonne.

Key words: Viscosity function, viscoplastic liquid, yield stress measurement

1 INTRODUCTION

Viscoplastic or yield-stress liquids are materials that have an yield stress below which they behave as a high viscosity liquid, and above which they behave as a shear-thinning liquid. At the yield stress, an often dramatic drop of the viscosity level is observed.

Most of the viscoplastic materials that appear in processes of interest are viscoplastic liquids. A few examples of viscoplastic liquids are: cement slurries, drilling muds and heavy oils in the petroleum industry; mayonnaise, butter, creams, pastes and many dairy products in the food and cosmetics industries; clay, mud and other concentrated suspensions in nature.

With the technological advancement in rheometry, high (but finite) Newtonian viscosity

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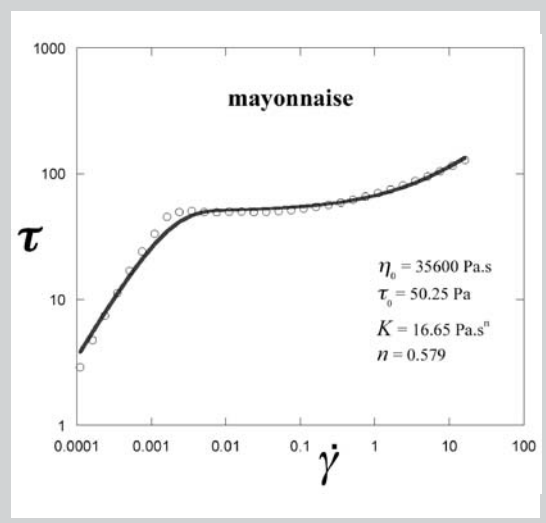


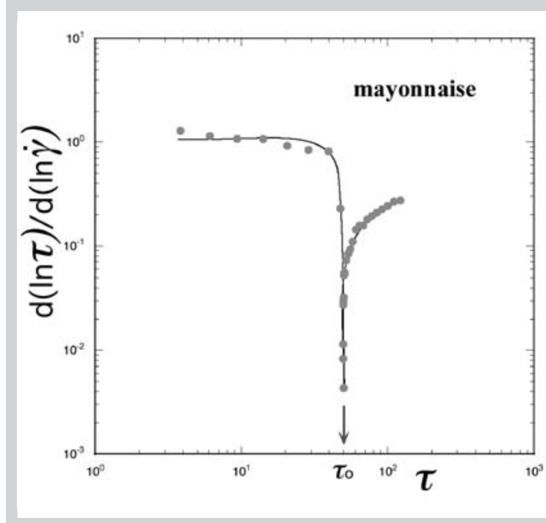
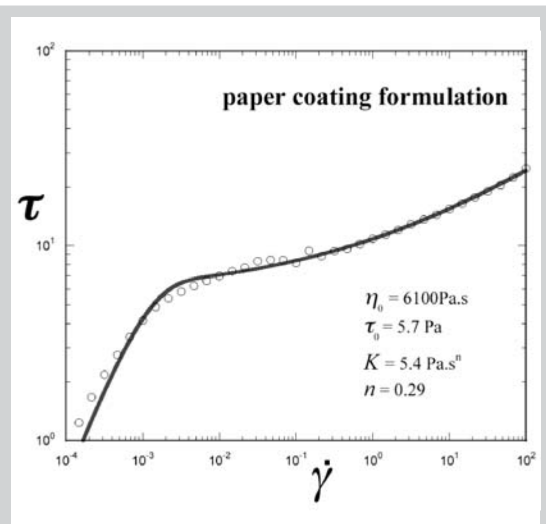


Figure 14 (left above): Flow curve of mayonnaise.

Figure 15 (right above): Derivative of the logarithm of the shear stress with respect to the logarithm of the shear rate as a function of shear stress, for the data presented in Figure 14.



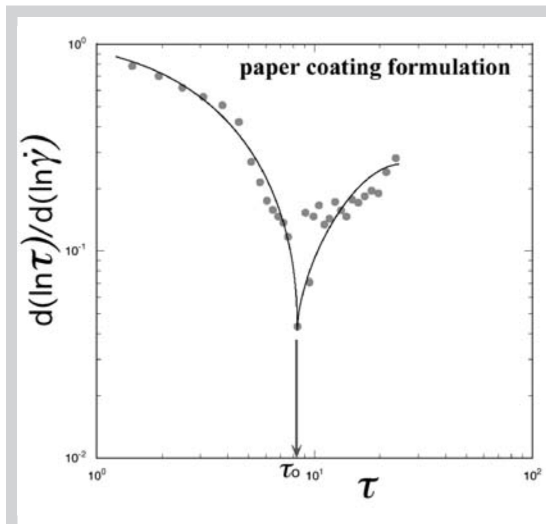


Figure 16 (left below): Flow curve of a paper coating formulation.

Figure 17 (right below): Derivative of the logarithm of the shear stress with respect to the logarithm of the shear rate as a function of shear stress, for the data presented in Figure 16.

rithm of the shear stress with respect to the logarithm of the shear rate as a function of shear stress are shown in Figs. 7, 9, 11, 13 , 15, and 17, respectively. These plots illustrate, for different materials, the success of the method for obtaining an unambiguous value for the yield stress. In some cases the $\tau \times \dot{\gamma}$ plot presents some waviness, which leads to more than one local minimum of the derivative $d\ln\tau/d\ln\dot{\gamma}$, as seen in Figs. 9, 11, and 13. In these cases the lowest stress at which a minimum occurs should be taken as the yield stress. It is interesting that this first minimum was the lowest for all viscoplastic materials examined in this research. Lastly, it is worth commenting the remarkable agreement between the τ_O values obtained in the two different ways, namely, via curve fitting and via the derivative method.

CONCLUSION

A viscosity function for yield-stress liquids is proposed. It is continuous and has continuous derivatives, as it is convenient for numerical simulations and curve-fitting procedures. Its qualitative behavior is the same as the one observed for most viscoplastic liquids of interest, *i.e.* a high-viscosity plateau at low shear rates, followed by a sharp drop of the viscosity level, and then a power-law region. A simple method to determine the yield stress is also proposed, which is independent of the viscosity model chosen.

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