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Non-colloidal Suspensions: Relations Between Theory and Experiment in Shearing Flows

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Dedicated to Professor Ken Walters FRS on his 80th Birthday

Abstract

This paper considers the relation between theory, computation and new experiments in noncolloidal suspensions with Newtonian and viscoelastic matrices in shearing flow. One expects from creeping flow theory that a suspension of rigid spheres in a Newtonian fluid matrix at negligible Reynolds number and large Péclet number would exhibit a constant shear viscosity. However, one usually sees shear-thinning behaviour in experiments for larger volume fractions ($\varphi > 0.3$). Experiments with a Boger fluid matrix of constant shear viscosity on the other hand , show mild shear thickening at higher shear rates. Explanations for this behaviour are unsatisfying.

There are also puzzles for the normal stresses in sheared suspensions. For a suspension with a Newtonian matrix in a simple shear flow various workers have found experimentally that the bulk stress field is no longer a shear plus an isotropic pressure, and that both first and second normal stress differences (N_1 and N_2) occur and are negative. Our own experiments using an open semi-circular trough to find N_2 agree reasonably well with previous experimental results and the Brady-Morris theory of 1997 (J.Fluid Mech.348,p103). However, this theory predicts that N_1 is zero, whereas it is measured to be negative but smaller in magnitude than N_2..

The viscometric functions (η, N_1 and N_2) for non-colloidal suspensions of spheres in a Boger fluid matrix were also measured. Volume fractions (ϕ) from 5% up to 40% were investigated. The relative viscosity ($\eta_r = \eta / \eta_0$) and the (positive) first normal stress difference N_1 showed increases with ϕ which were larger than the dilute suspension theory predictions of $1 + 2.5\phi$, indicating semi-dilute suspension behaviour, even down to 5% concentration.

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