Preparation and Rheological Characterization of Dilute Polydisperse Bubble Suspensions

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Motivation

- Air is entrapped during the manufacturing of toothpastes due to the high-shear mixing of the components.
- Bubbles have been shown to affect the viscosity of the ambient fluid, inducing complex viscoelastic phenomena and leading to density changes and inconsistencies during filling.
- This project aims to investigate the rheology of polydisperse bubble suspensions and help to understand how aeration affects the viscosity during the manufacturing of formulations.

Introduction

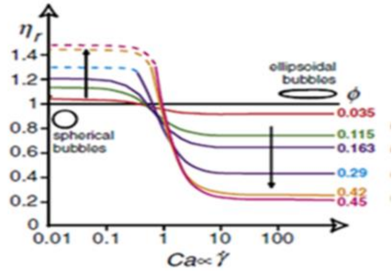

Fig.1: Rheological behaviour of monodispersed bubble suspensions.

For steady shear states, the capillary number (Ca) is defined as follows:

$$Ca = \frac{\eta_0 r}{\sigma}\,\dot{\gamma} = \lambda / t_d$$

λ : relaxation time of the bubbles; t_d : deformation time of the bubbles.

- Ca>>1➔ bubbles deform significantly and the flow around them is facilitated.
- Ca<<1➔ bubbles deform negligibly (being almost spherical) and the flow around them is hindered.
- Ca~1 ➔ onset of shear-thinning behaviour for monodispersed suspensions.

Experimental design

- Aeration systems used: porous membrane set up, coupled with a high shear mixer.
- Ambient fluids tested: viscous mineral oil (9.4 Pa*s)
- The rheology was investigated using an Anton Paar rotational viscometer and simple shear tests.
- **Challenge: i) low bubble volume fractions. Normal stress differences could not be measured. Ii) no control over achieved volume fraction.**
- Solution: design of a new propeller aerator able to increase aeration efficiency.

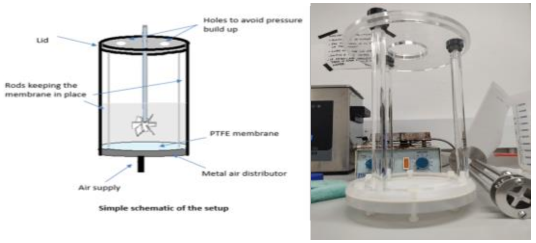

Fig.2: Porous membrane aeration setup

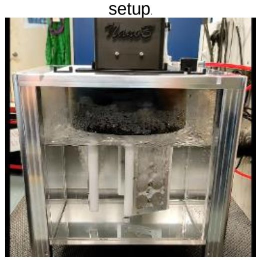

Fig.3: Propeller aerator

Results

- Maximum volume fraction φ=15.08%.

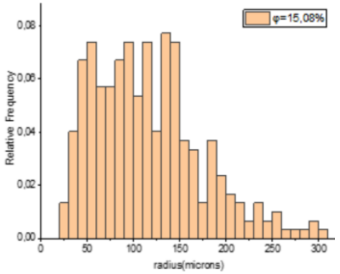

Fig.4: Bubble size distribution

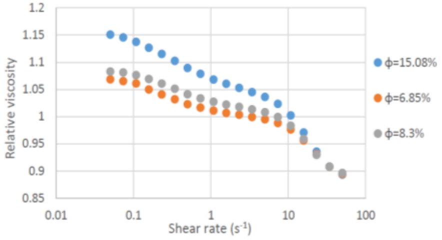

Fig.5: Relative Viscosity VS shear rate

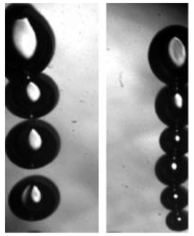

Fig.6: Bubble coalescence and threading for $10 s^{-1}$ and $20 s^{-1}$.

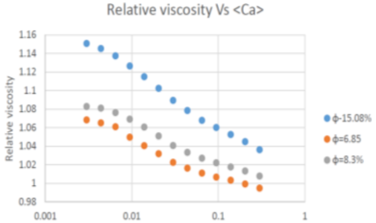

Fig.7: Relative viscosity VS <Ca> in min. oil bubble suspensions.

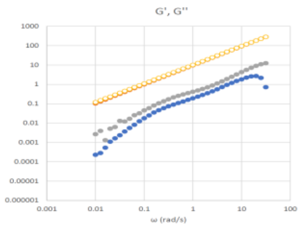

Fig.8: G', G'' for min. oil bubble suspensions.

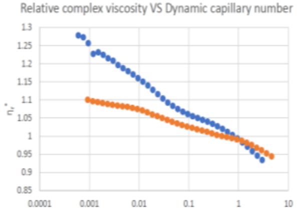

Fig.9: η_r^* VS <Cd>

- The produced bubble suspensions were found highly polydisperse.
- Double power law decay of viscosity.
- Time sweep and rheo-PIV tests revealed bubble coalescence for shear rates larger than $5 s^{-1}$.
- The polydisperse bubble suspensions exhibited a more gradual shear-thinning behaviour, which spanned over a range of <Ca> between 0.001 and 0.01. The bubbles do not deform equally and simultaneously due to their different sizes. When larger bubbles have reached <Ca>=1 and their shear-thinning contribution begins to appear, smaller bubbles are still spherical and resist the flow.
- The elastic character of the suspension increases with the bubble volume fraction.
- For dynamic capillary numbers slightly larger than one, we observed a decrease of the relative viscosity with the bubble volume fraction. The decrease does not follow the suggested trend for the relative infinite-shear complex viscosity, i.e. $\eta_{r*}=1-(5/3)\varphi$.

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