Polydispersity and Bubble Interactions: Unraveling the Viscoelastic Nature of Semidilute Bubble Suspensions in Newtonian Media

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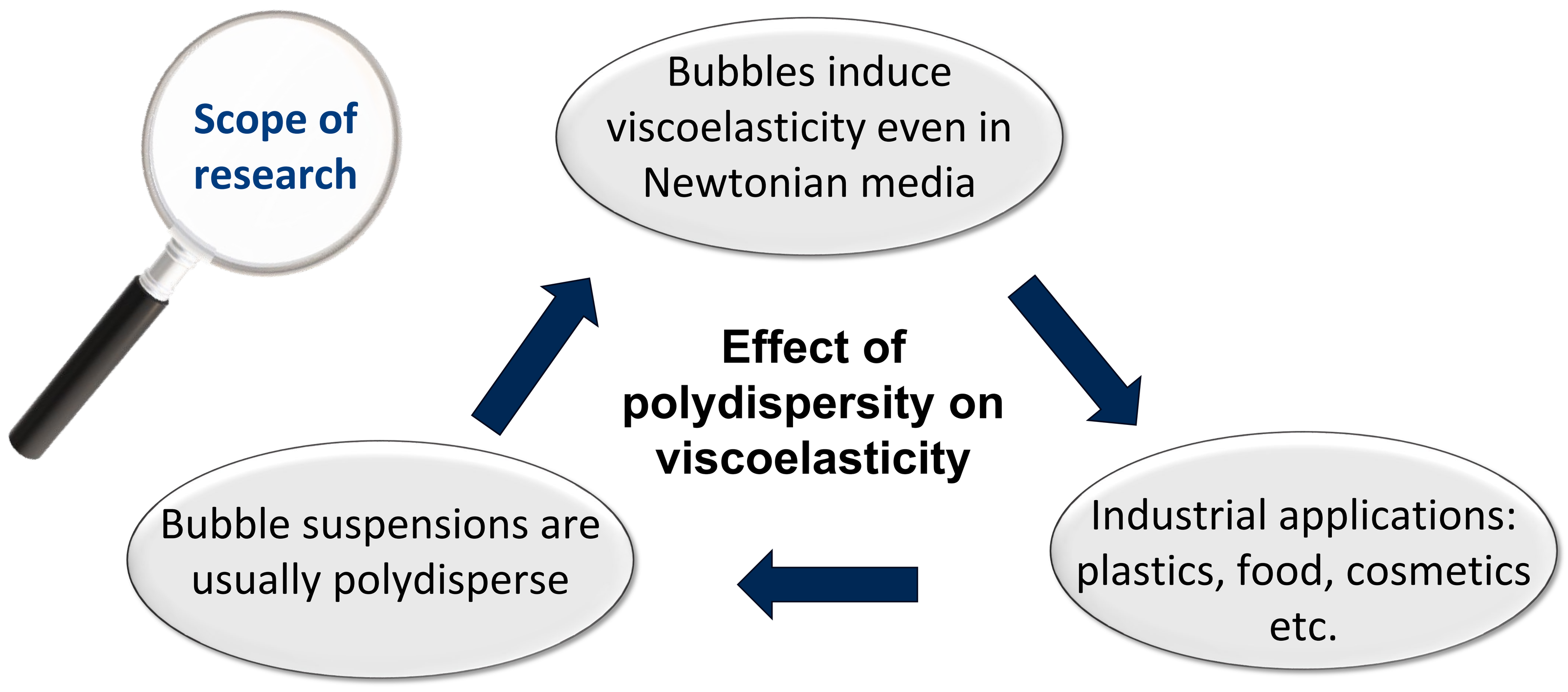
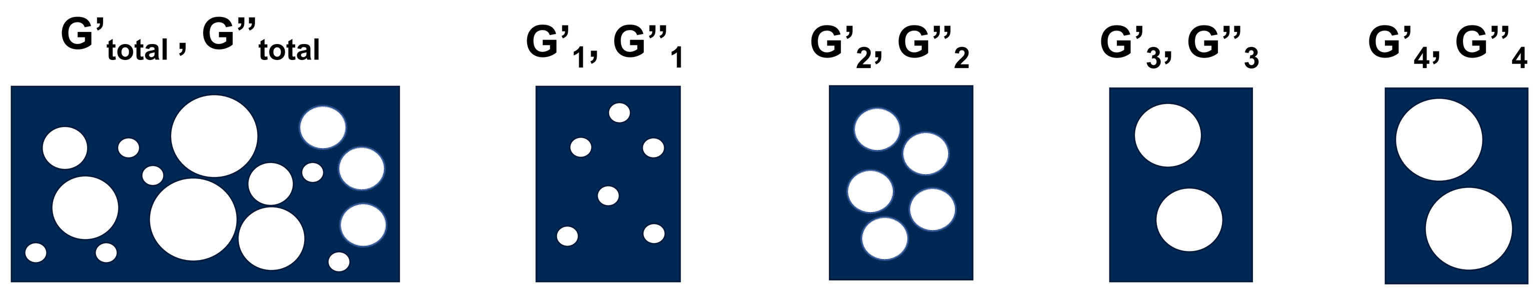
Introduction



Dilute and semidilute systems



Jeffreys model

$$\boldsymbol{\tau} = \boldsymbol{\tau}_s + \boldsymbol{\tau}_b \quad (s{:}\,solvent,\ b{:}\,bubbles)$$

$$G' = \frac{\eta_s\,\varphi\,\lambda\,\omega^2}{1+(\lambda\,\omega)^2}\ ;\ G'' = \frac{\eta_s\,\varphi\,\omega}{1+(\lambda\,\omega)^2}$$

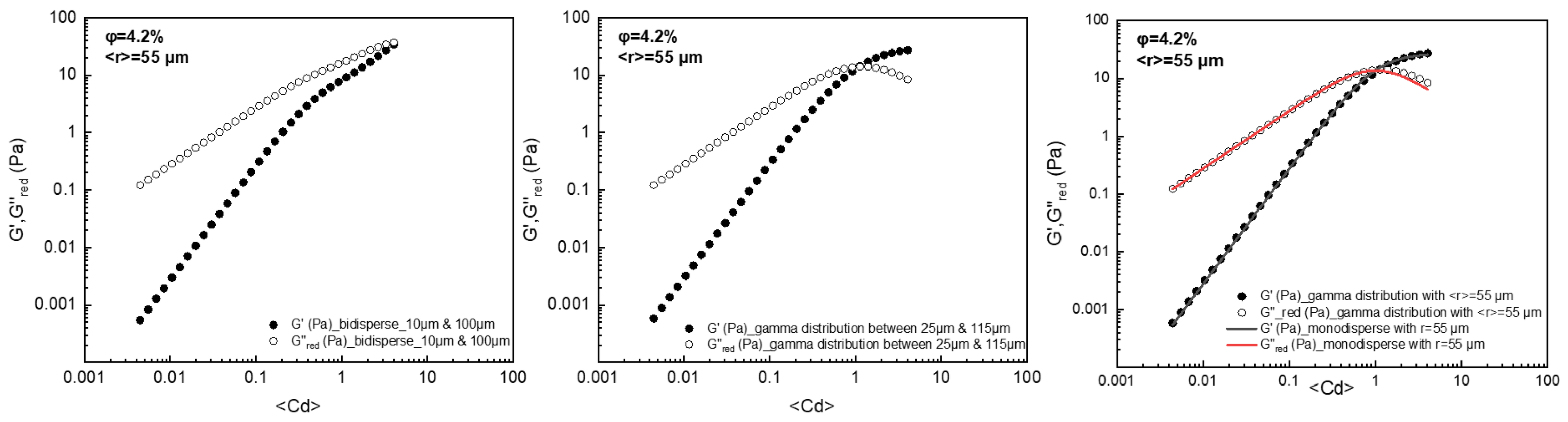
(η_s: solvent viscosity; λ: bubble relaxation time; φ: bubble volume fraction)

Effect of Polydispersity

Compare:

a)Bidisperse bubble suspension with volume-weighted average radius <r>=55μm.
b)Bubble suspension with bubble radii following the gamma distribution between 25 μm and 115 μm and volume-weighted average radius <r>=55μm.
c)Monodisperse bubble suspension with bubble radius r=55μm.

φ=4.2% for the three suspensions

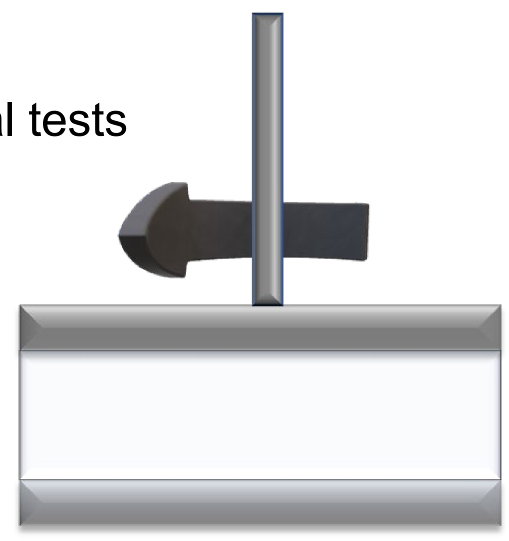


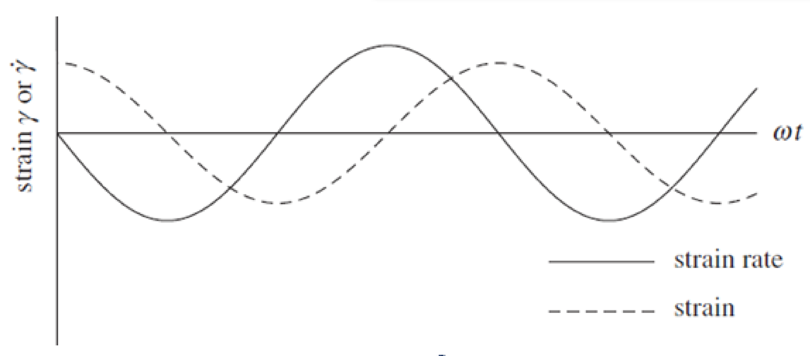
Conclusion:

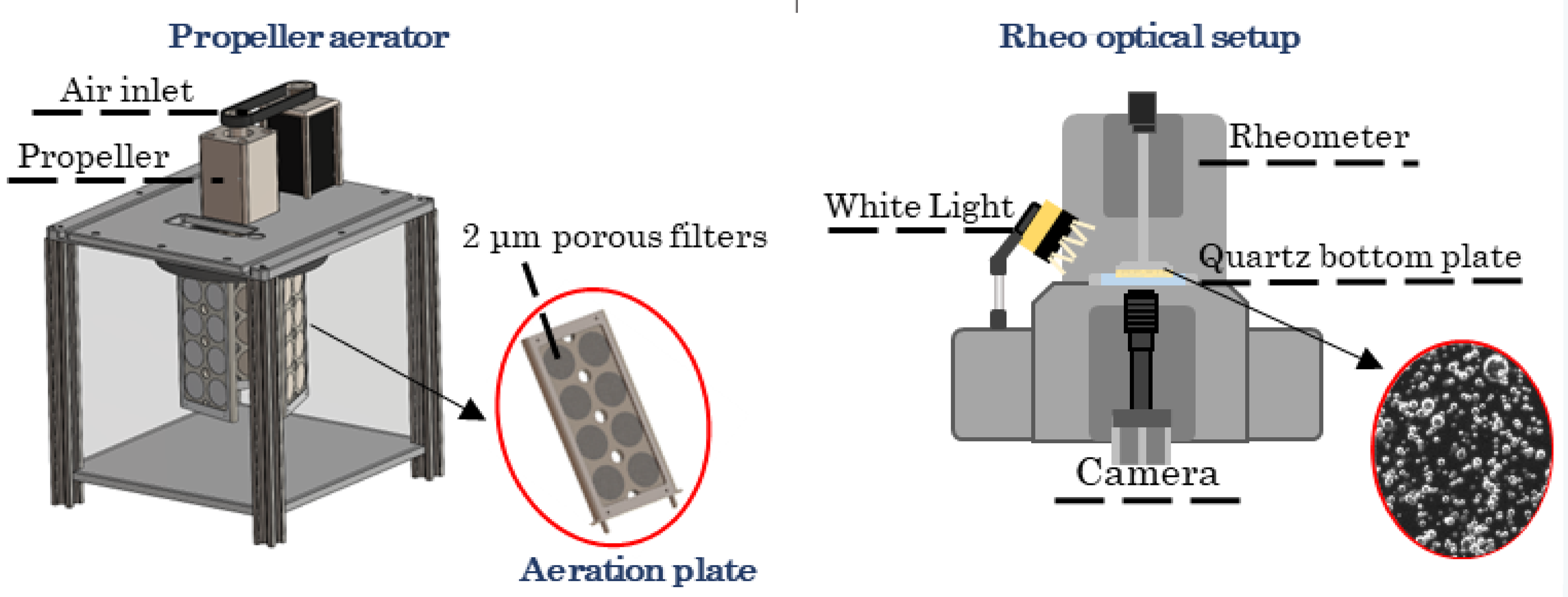
Polydispersity affects G´ and G´´ only if the bubble size distribution is bimodal with equal volume fractions of small and large bubbles.
Otherwise, **polydisperse suspensions can be treated as monodisperse with a volume-weighted average bubble radius**.

Experimental

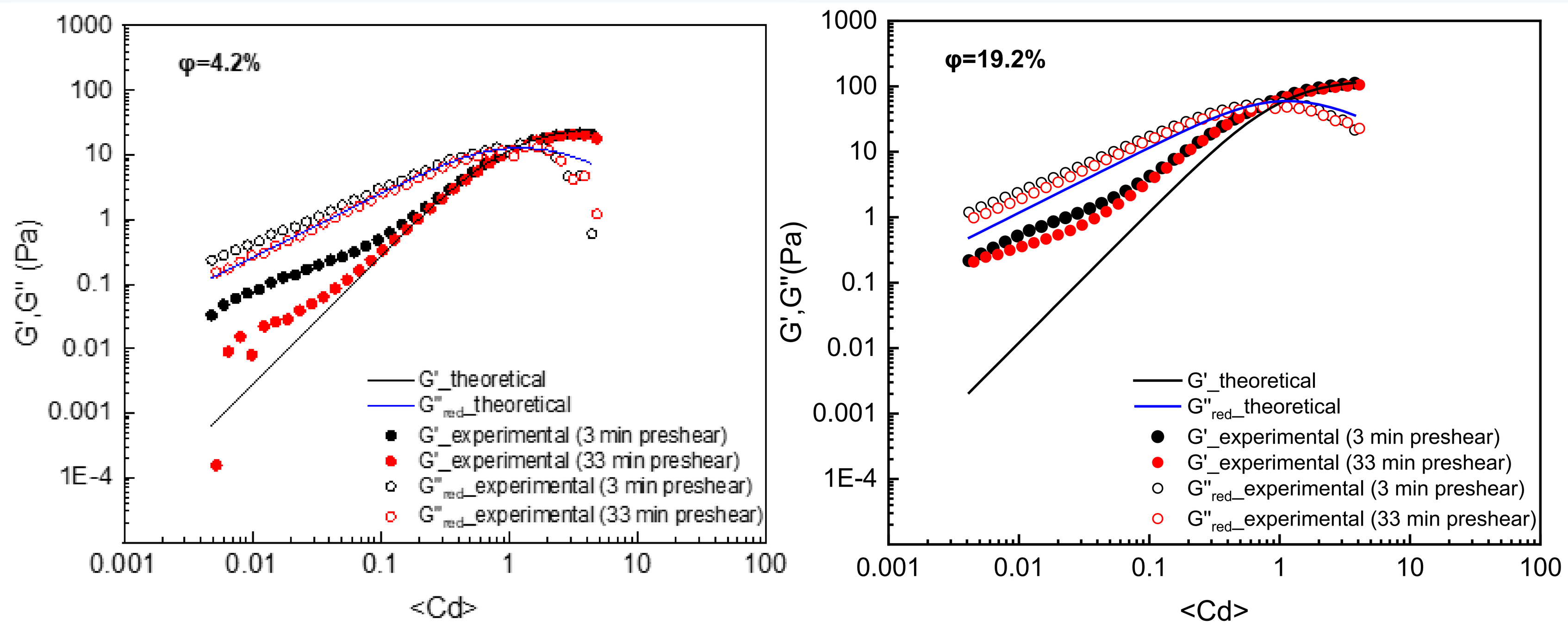
- Ambient fluid: mineral oil + 5% w/w span 80 (η=53.063 Pa·s)
- Aeration system: **propeller aerator**
- Small-amplitude oscillatory shear (SAOS) rheological tests
- Frequency range: 50 - 0.05 rad/s
- Pre-shear: 3 min at 0.1 s^{-1} and 33 min at 0.9 s^{-1}
- Visualization of bubbles under oscillatory shear using a rheo-optical setup



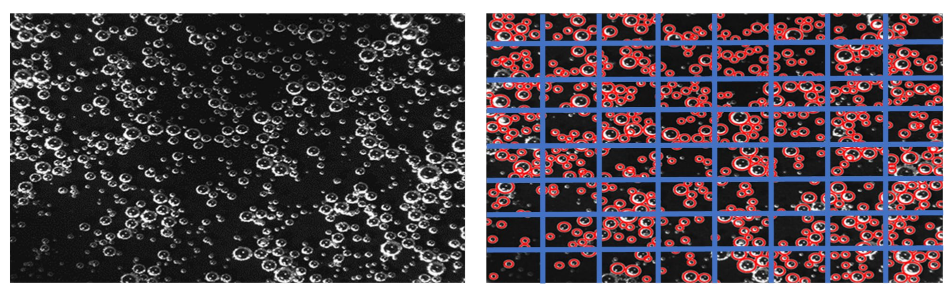




Results

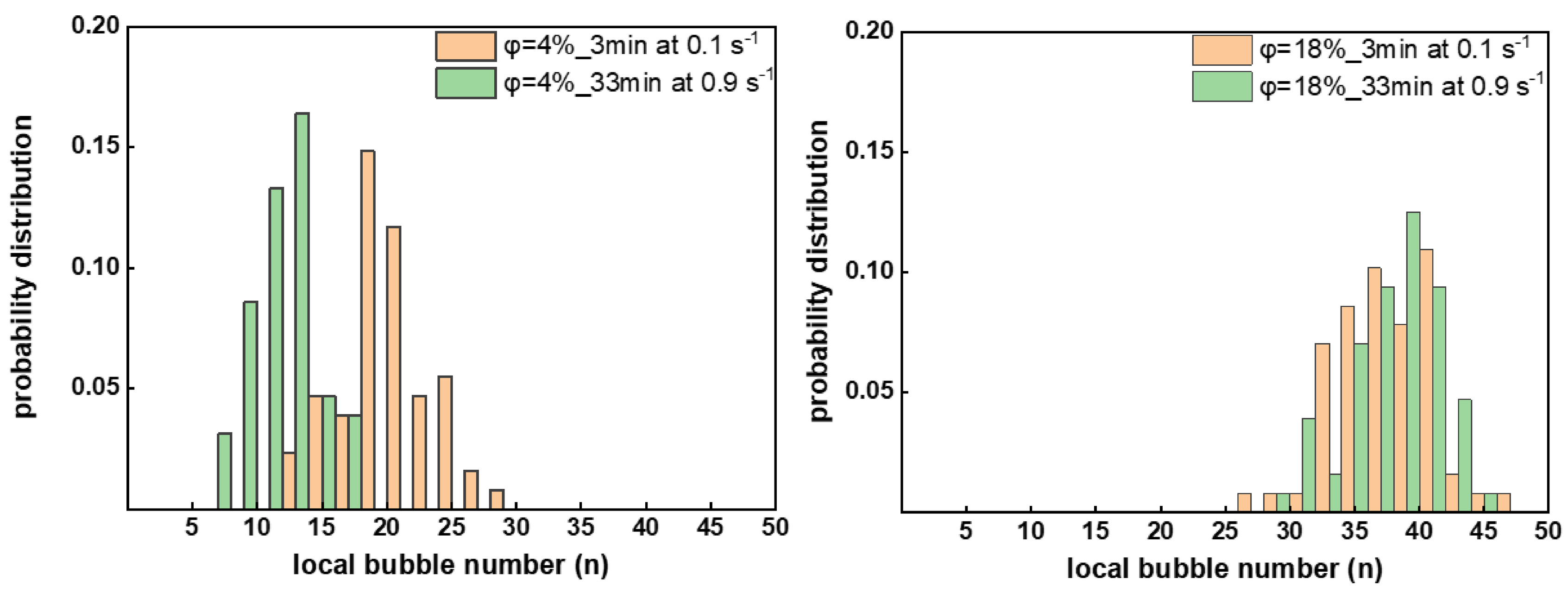


- **Increased elasticity for $<Cd> \ll 1$**
- **The effect of pre-shearing depends on the bubble volume fraction.**
- Bubble sizes follow the gamma distribution. ➔ The G' trend cannot be attributed to polydispersity.
- Increased elasticity caused by **bubble fluid dynamic interactions**, manifesting themselves at **longer characteristic flow times**.
- Visualization experiments revealed no changes in the microstructure of the suspension during the rheological tests.
- The spatial distribution of bubbles affects the fluid dynamic interactions.
- Statistical image analysis to quantify the effect of pre-shearing on the spatial distribution of bubbles for different volume fractions.



Method:
Calculate the probability distribution for the local bubble number, n.

Assumption:
Less bubbles per square ➔ larger inter-bubble distance ➔ weaker bubble interactions



- **Low bubble volume fractions**: the n distribution becomes narrower and shifts to lower values ➔ pre-shearing affects the spatial distribution of the bubbles ➔ **weaker bubble interactions**
- **High bubble volume fractions**: the n distribution is not affected by pre-shearing ➔ **bubble interactions remain the same**

References

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[2]: Llewellin, E.W., Mader, H.M., Wilson, S.D.R., 2002a. The rheology of a bubbly liquid. Proceedings of the Royal Society A 458, 987–1016.
[3]: Mader, H.M., Llewellin, E.W., Mueller, S.P., 2013. The rheology of two-phase magmas: A review and analysis. Journal of Volcanology and Geothermal Research 257, 135–158.

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