Effect of fibres on wet foams

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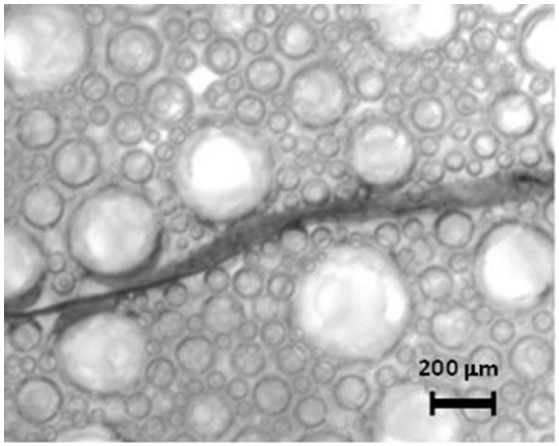
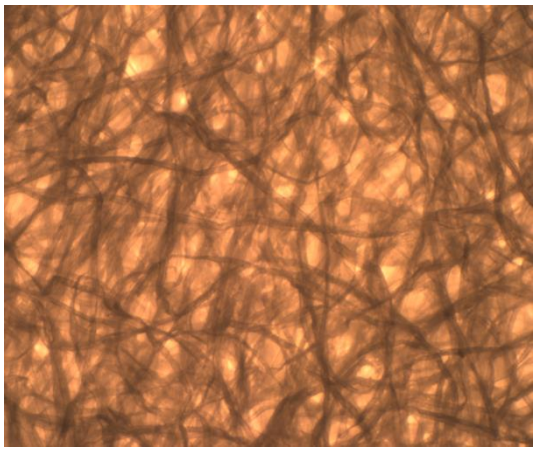
Foam, fibres and mixing

- Structure forming requires large volumes of wet fibre-laden foam generated by axially agitated mixing

- Fibre network structure can be affected by foam properties



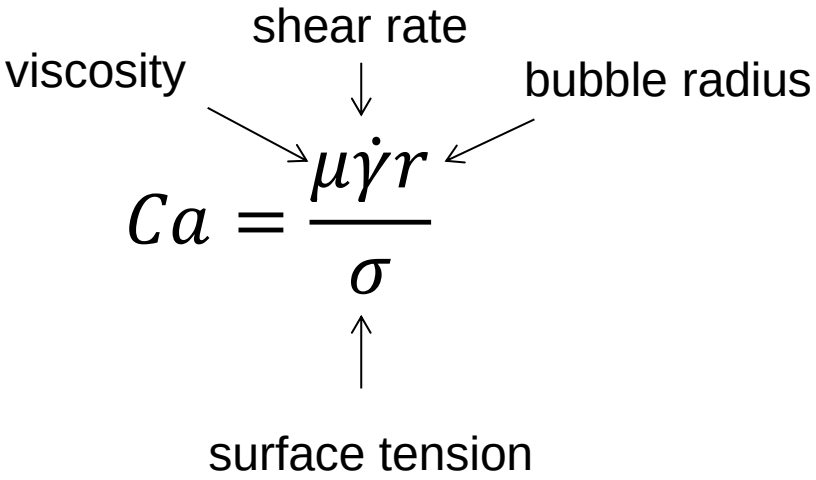


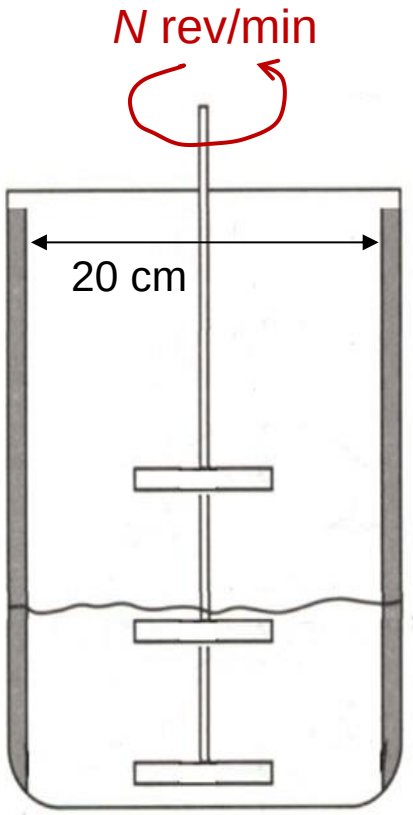
permeability
stiffness
strength
…

FOAM PROPERTIES → ***FIBRE NETWORK STRUCTURE*** → ***MATERIAL PERFORMANCE***

Laboratory mixing experiments

- Low SDS amount (well below CMC)
- Several impellers to broaden the range of rotation speed *N*
- High capillary number *Ca* $\sim 10^{-3}$

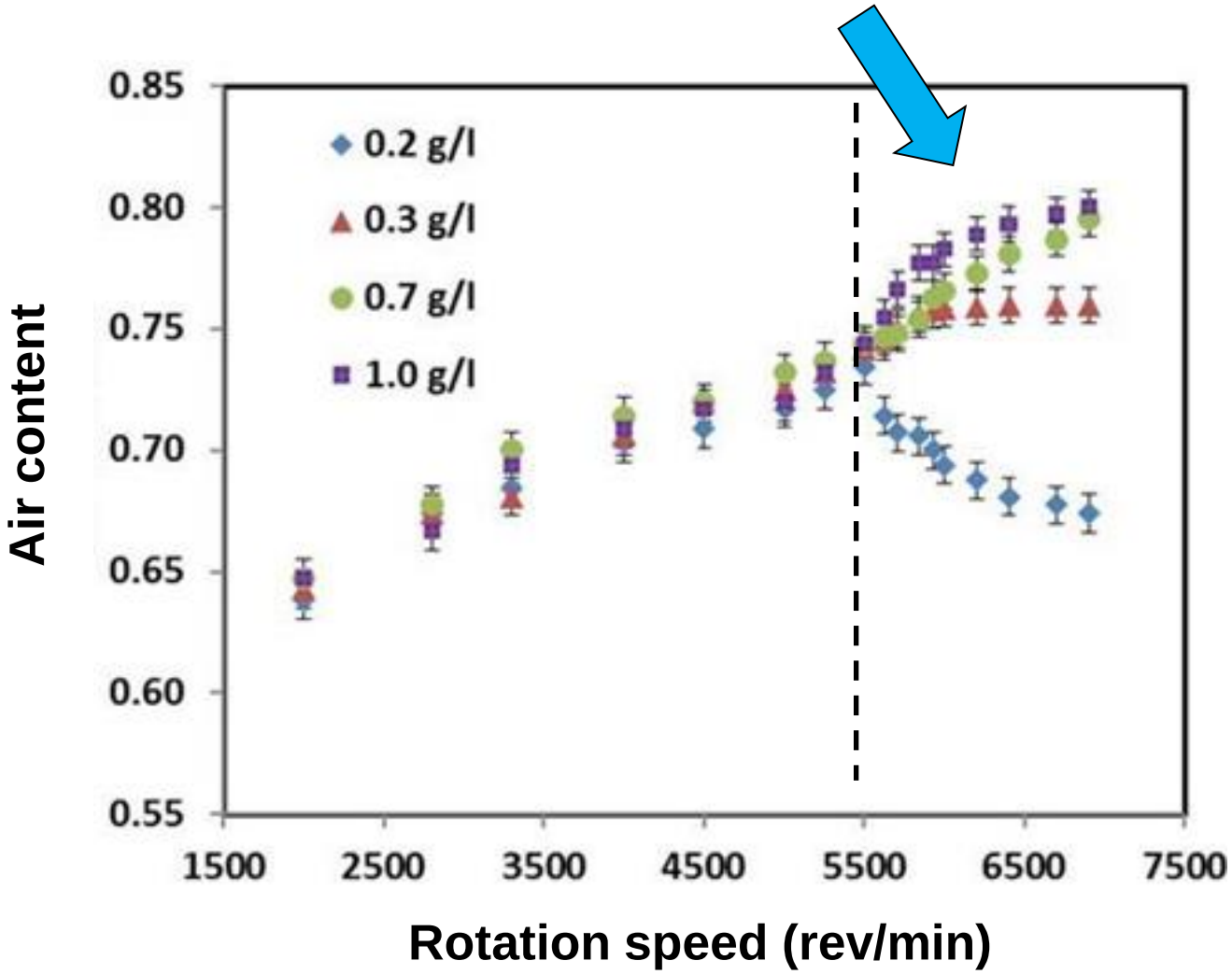




$$\langle\dot{\gamma}\rangle = kN$$

Metzner, Otto 1957
Sánchez Pérez et al. 2006

Flow macro-instability makes air content sensitive to surfactant concentration



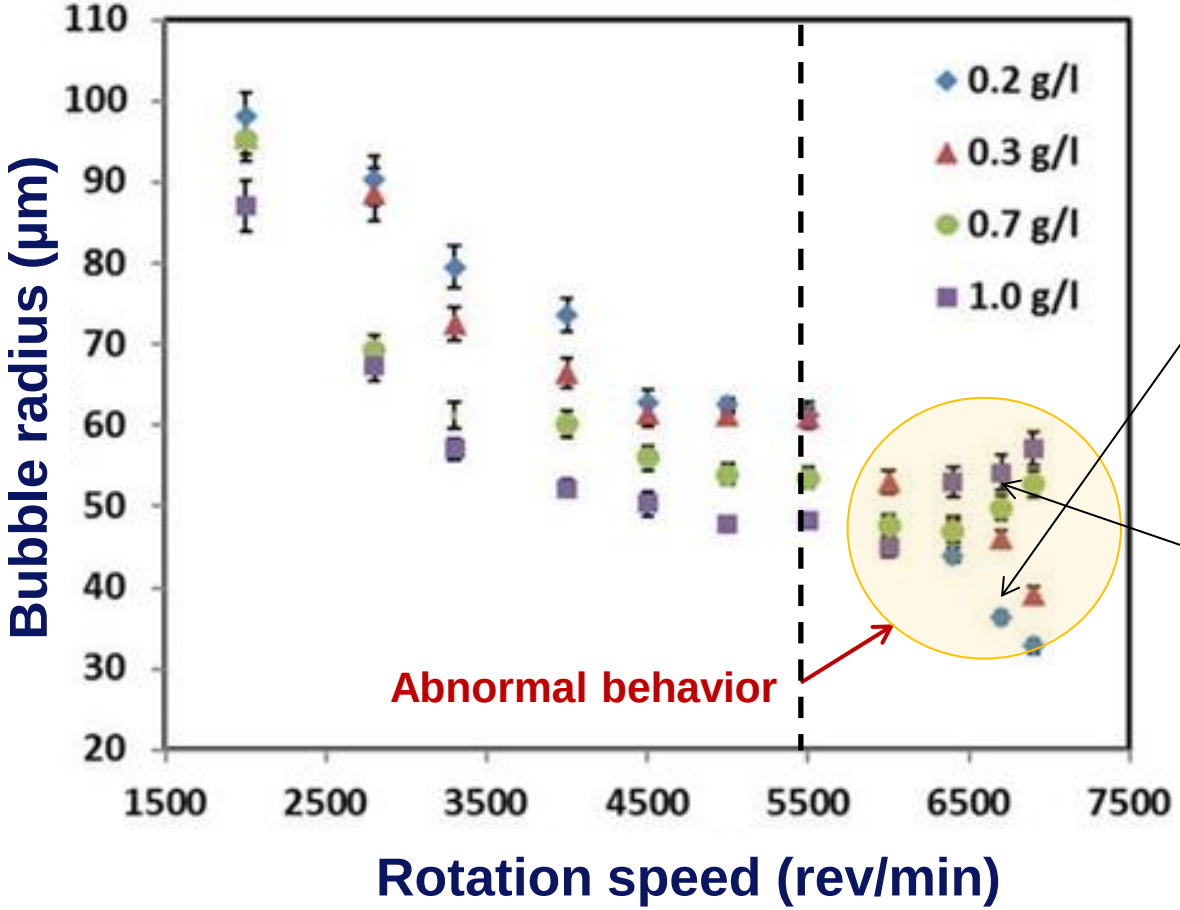
Similar instabilities observed for liquid flow:

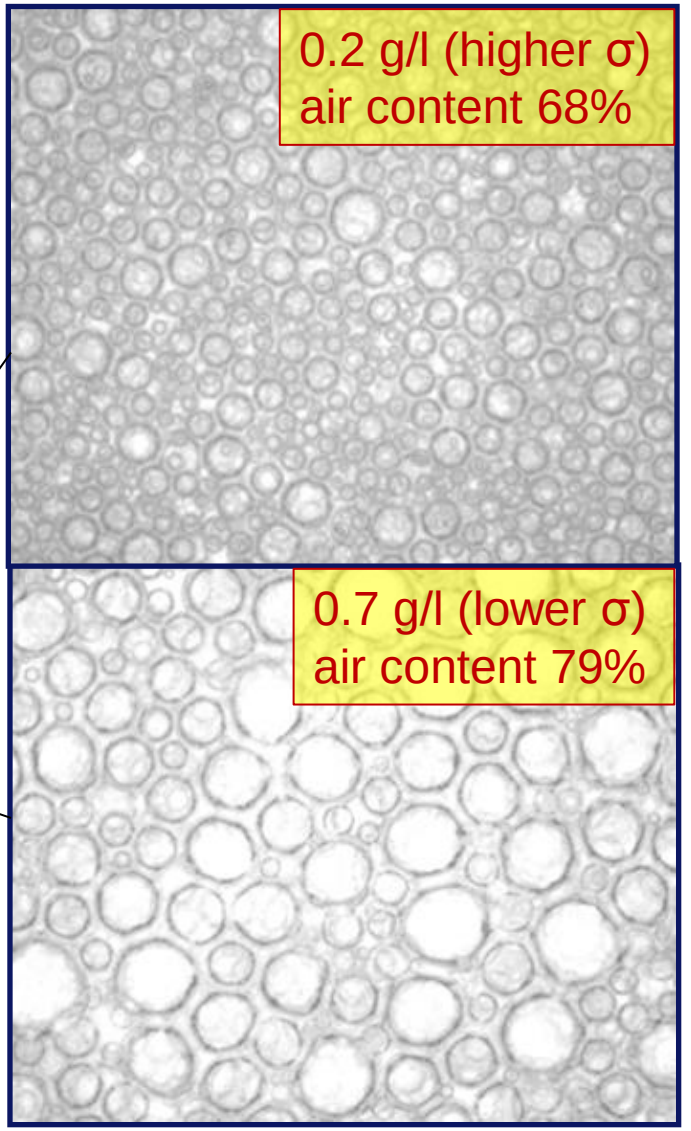
T. Bruha et al. 2011
C. Galletti et al. 2004
J.-L. Montes et al. 1997

Bubble size responds ”abnormally”

6700 rev/min

$$r_{max} \sim \frac{Ca_{crit}\sigma}{\mu\dot{\gamma}} \sim \sigma$$ surface tension





Air content correction

$$r_{32} = \frac{\sum r^3}{\sum r^2} \sim \frac{\phi V_T}{A_I}$$

ϕV_T ← total volume

A_I ← total interface area of bubbles

Mass balance for surfactant:

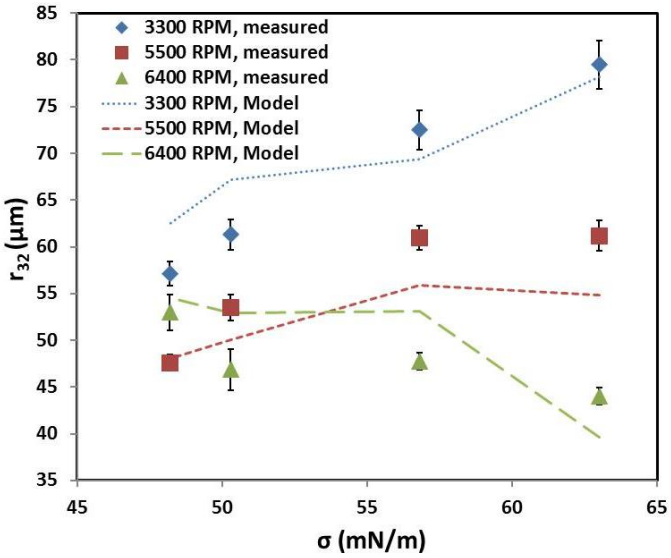
$$c_s(1-\phi)V_T = \Gamma A_I + \underbrace{c_f(1-\phi)V_T}_{\text{foam lamella}}$$

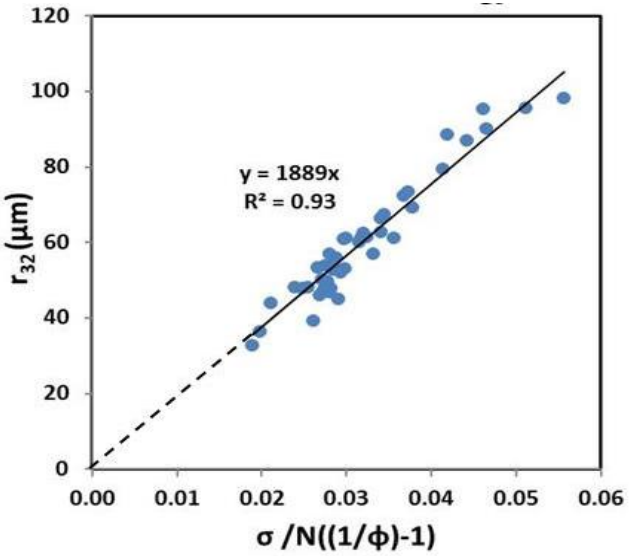
$$r_{32} \sim \frac{c_f K_L \Gamma_m \phi}{(c_s - c_f)(1-\phi)}$$

Combine with capillary number:

N rotation number
σ surface tension
ϕ air content

$$r_{32} \sim \frac{\sigma}{N(\frac{1}{\phi} - 1)}$$

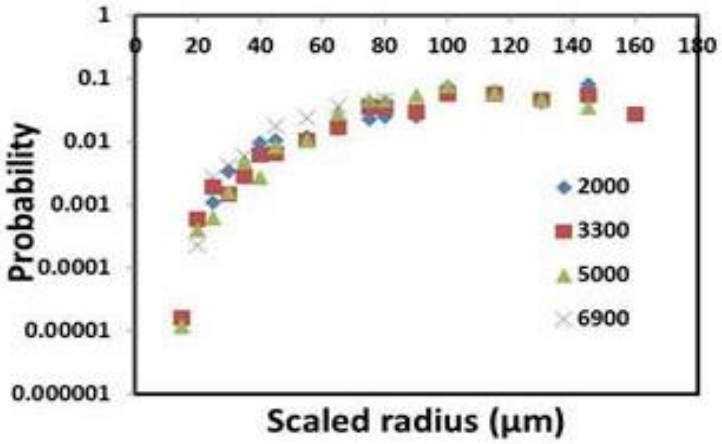




Things to be understood better

1. Why $c_f \sim c_s - c_f$?

2. Why does the whole bubble size distribution scale similarly?

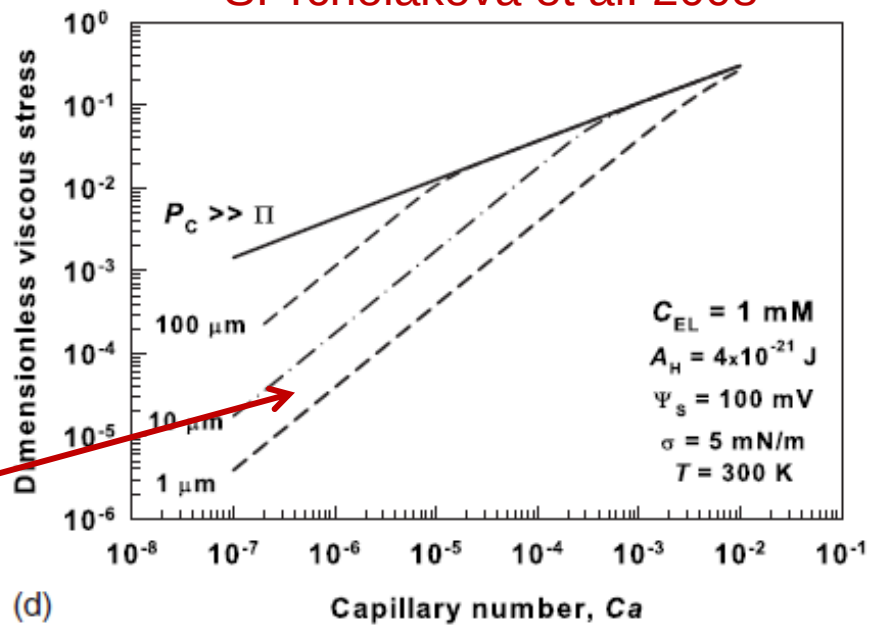


3. μ vs. μ_{eff}: Is n=1 (i.e. not ~ ½) in

$$\mu_{eff} = \frac{\tau_0}{\dot{\gamma}} + K\dot{\gamma}^{n-1} \; ?$$

surface forces important
for small bubble size

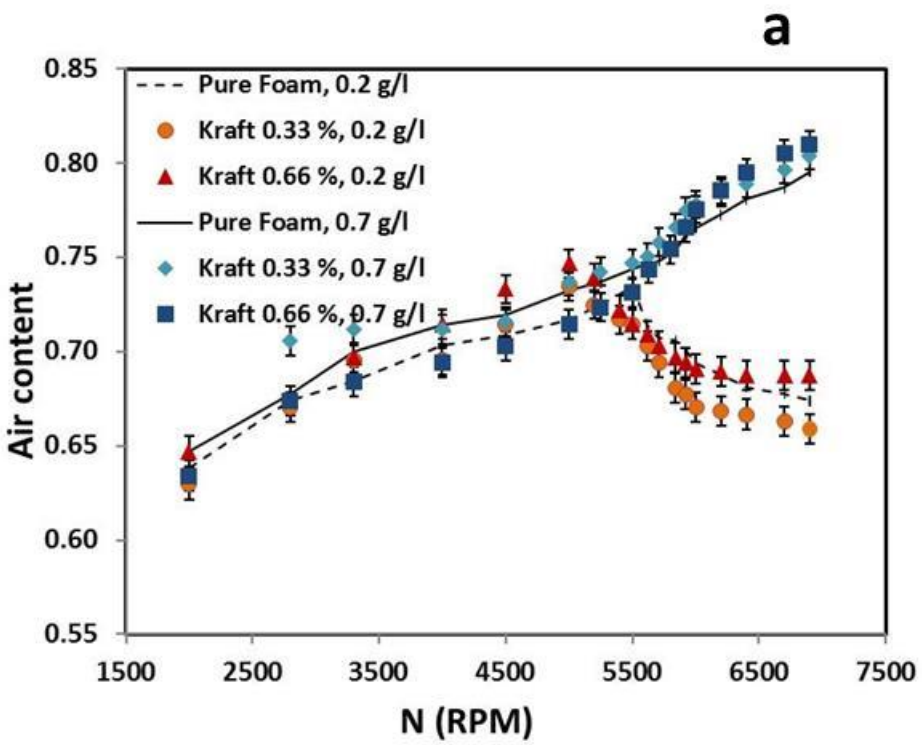
S. Tcholakova et al. 2008

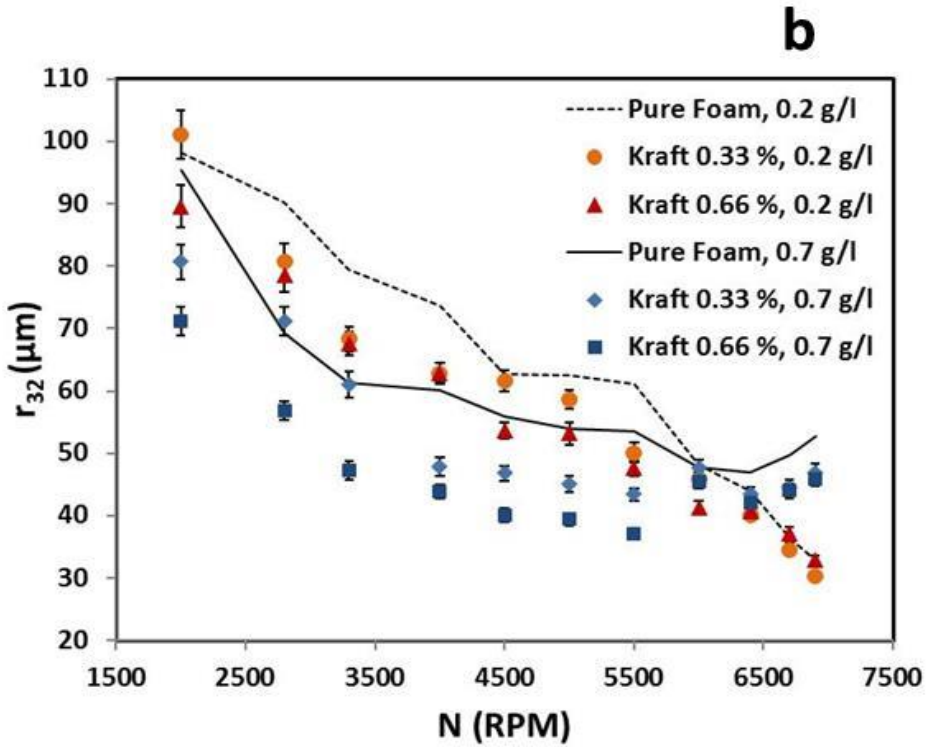


Fibre foams

Cellulose fibres (wood or viscose), length 0.3-6mm, diameter 10-30 µm

- Slighly increased air content at low σ and high N
- Typically reduced bubble size
- Some complex effects from fibre dimensions (on-going studies)





Foam properties affect homogeneity of structures formed with very long fibres

Viscous fibre, 24mm

Summary

- In axial mixing, bubble size is…
  - dominated by **rotation speed**, **air content** and **surface tension**
  - explained by a simple model for varied conditions
  - often reduced by added fibres even though the fibres do not change the model trends

A.M. Al-Qararah, T. Hjelt, A. Koponen, A. Harlin, J.A. Ketoja,
Bubble size and air content of wet fibre foams in axial mixing with macro-instabilities.
Colloids and Surfaces A: Physicochem. Eng. Aspects 436, 1130 (2013).