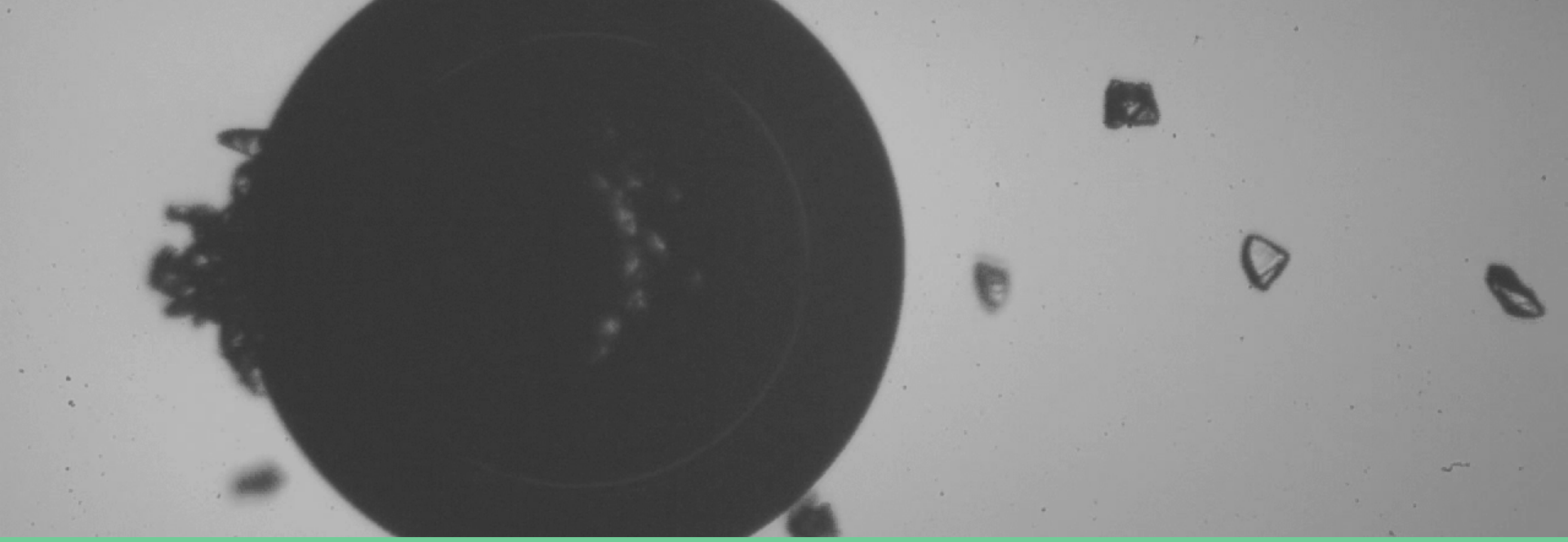

# Influence of particle shape and roughness on the induction period for particle–bubble attachment

**D. I. Verrelli*, W. J. Bruckard, P. T. L. Koh, M. P. Schwarz and B. Follink**

*presented by Dr. Liza Forbes*

**CSIRO PROCESS SCIENCE AND ENGINEERING**
www.csiro.au

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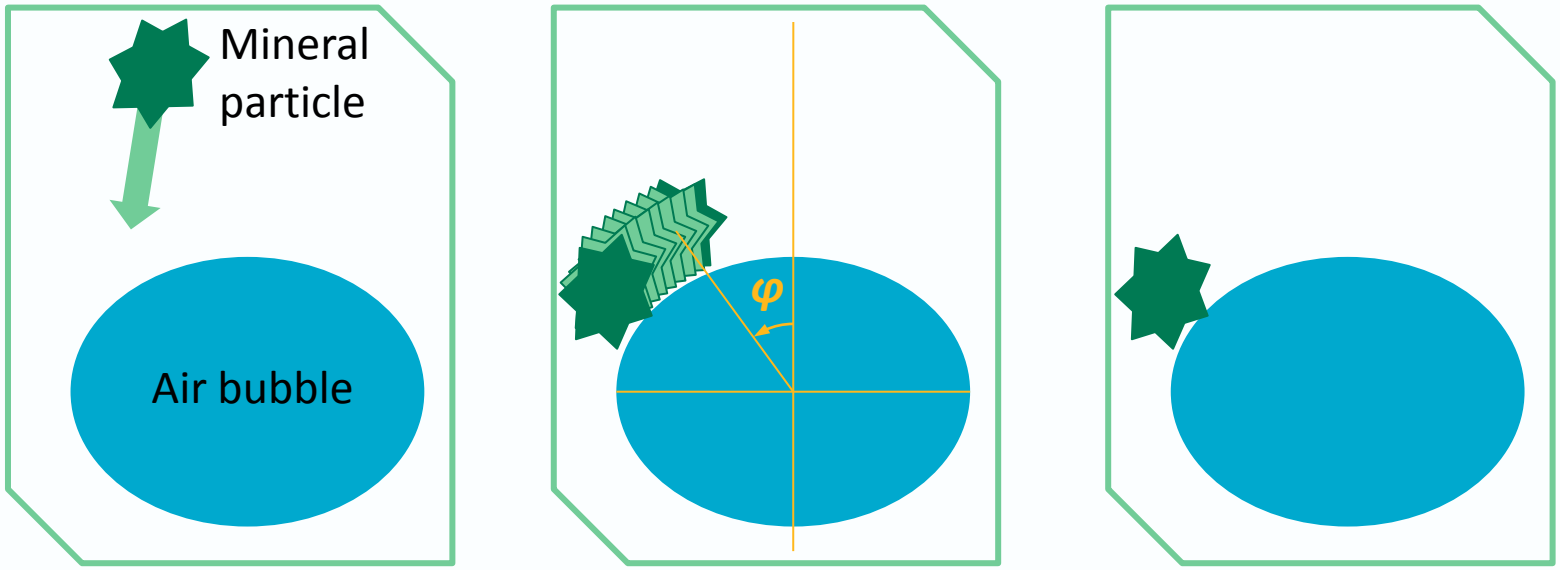
# Particle shape and roughness

## …the view from flotation practitioners

Belief developed that some particle shapes are more ‘floatable’ than others

Attributed to an influence of particle shape or roughness on the *induction period* required to achieve attachment




Particle approaching

Commence ‘sliding’
$t_1$

Attachment occurs
$t_2$

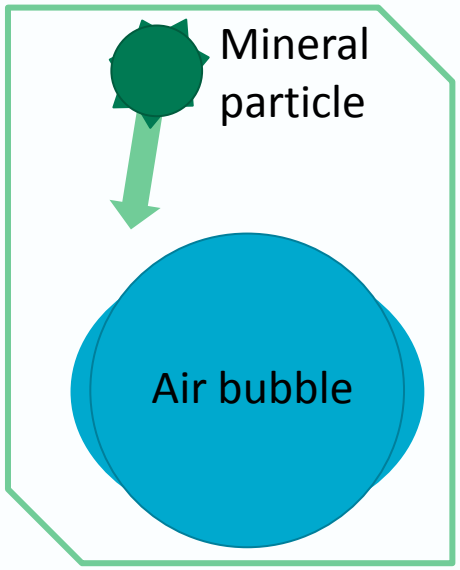
**Induction period**
**$= t_2 - t_1$**

# Particle shape and roughness

## …the traditional view in flotation modelling

Compare *sliding duration* to a constant threshold (induction period)

Induction period from various indirect measurements
— assumed to capture shape/roughness effects




Sliding duration estimated by simplified modelling:

- Particle is *spherical*
- Particle follows *fluid streamlines*
- Bubble is *spherical*

— no shape/roughness effects included

The approximations are more problematic when particle & bubble are close

## Present approach

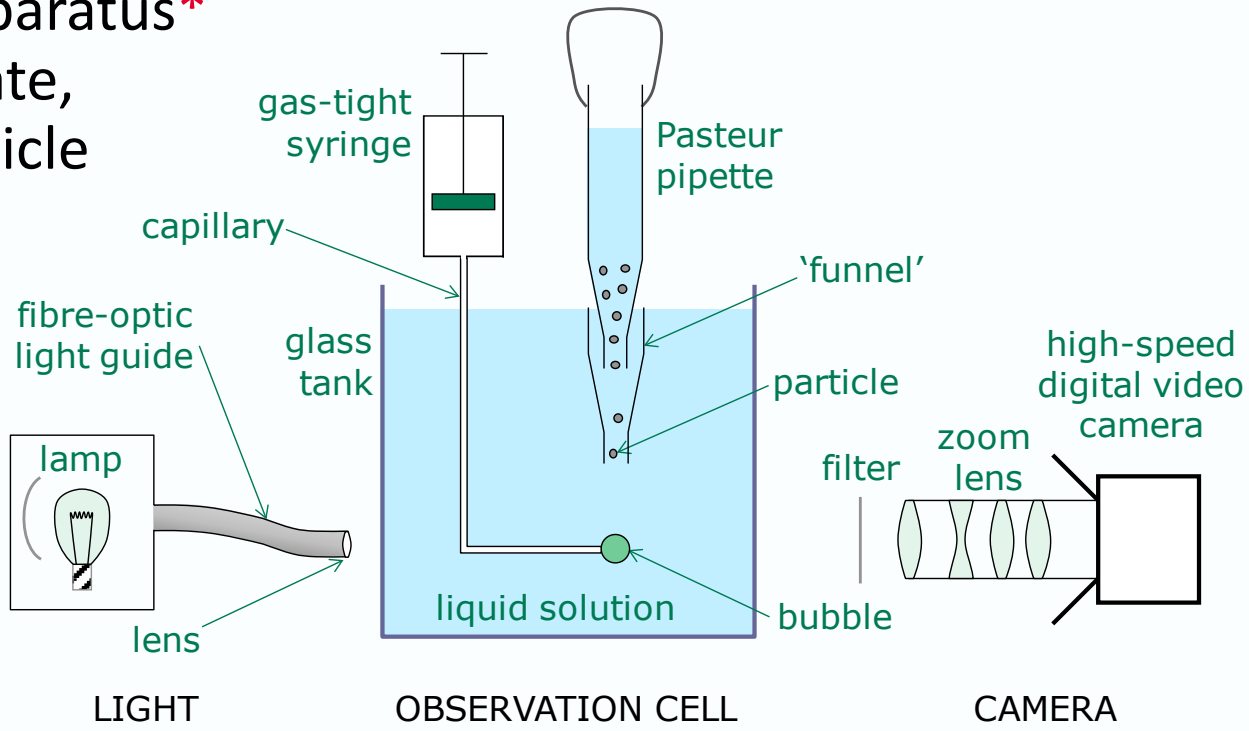
# Directly measure induction period

Traditional techniques provide *indirect* estimates of induction time

- *Hallimond tube*, then back-calculation with *e.g.* GSE
- particle pickup in *Induction Timer* ('forced')

*CSIRO Milli-Timer* apparatus* provides *direct* estimate, with unrestricted particle motion (not 'forced')

- also observe incoming particle position & speed




* Verrelli & Koh; *Chemeca 2010*; Adelaide, Australia; 29–29 September 2010; Paper No. 0470.
Verrelli, Koh & Nguyen; *Chem. Eng. Sci.*; 2011; **66**(23): 5910–5921. doi:10.1016/j.ces.2011.08.016

Present approach

# Using methylated glass in different shapes

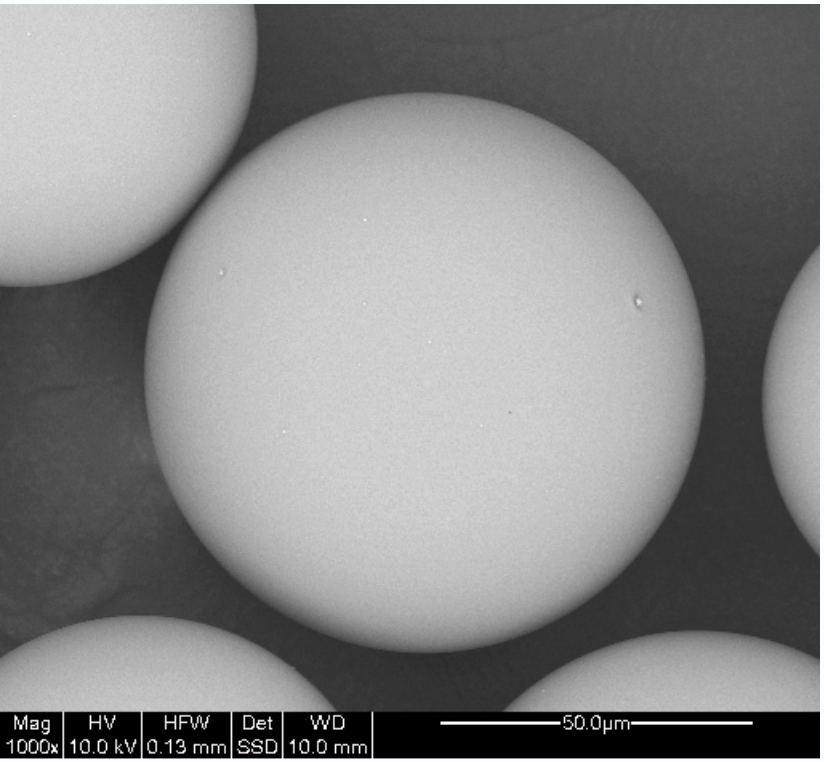
On the plant
…floatability differences for various particle shapes/roughness might be due to other associated factors
*e.g*. composition, liberation, size, *etc*.

In laboratory
…use borosilicate glass:

- tightly sized as 75–90 µm
- two different shapes/roughness (SEM & quantified by BET area)
- same composition (checked by assay)
- same surface hydrophobicity (50 % methylated)

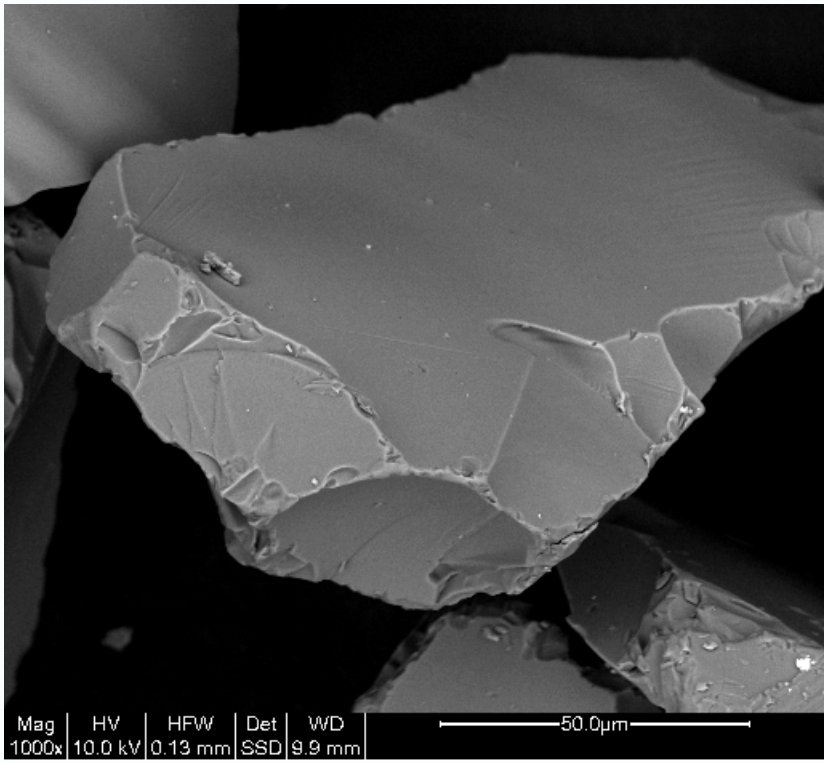
## Present approach

# Using methylated glass in different shapes




Spheres

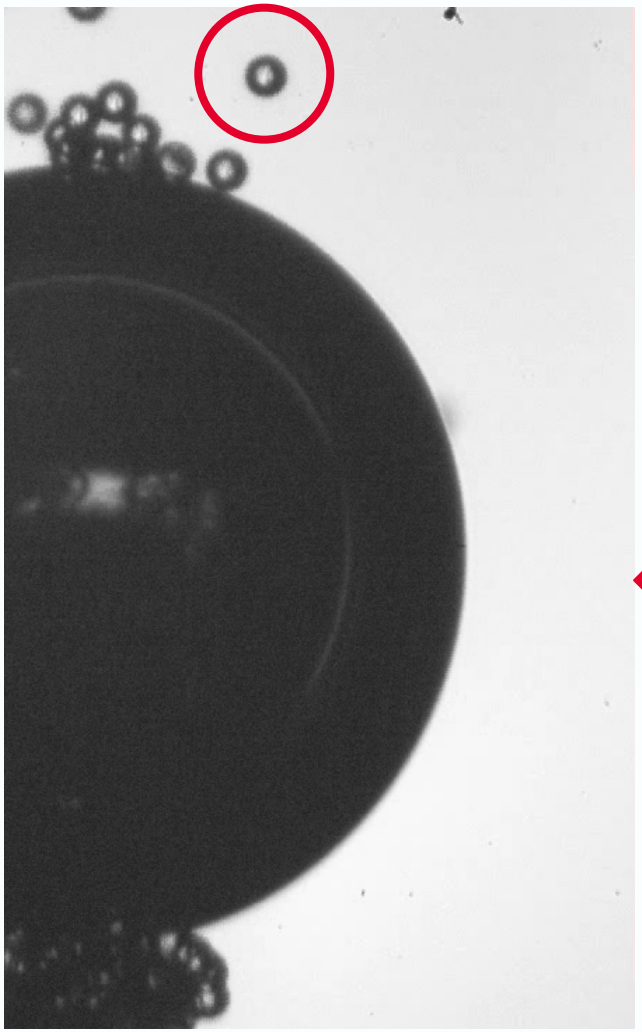
BET surface area ~ 0.04 $m^2/g$




Frit

0.06 $m^2/g$

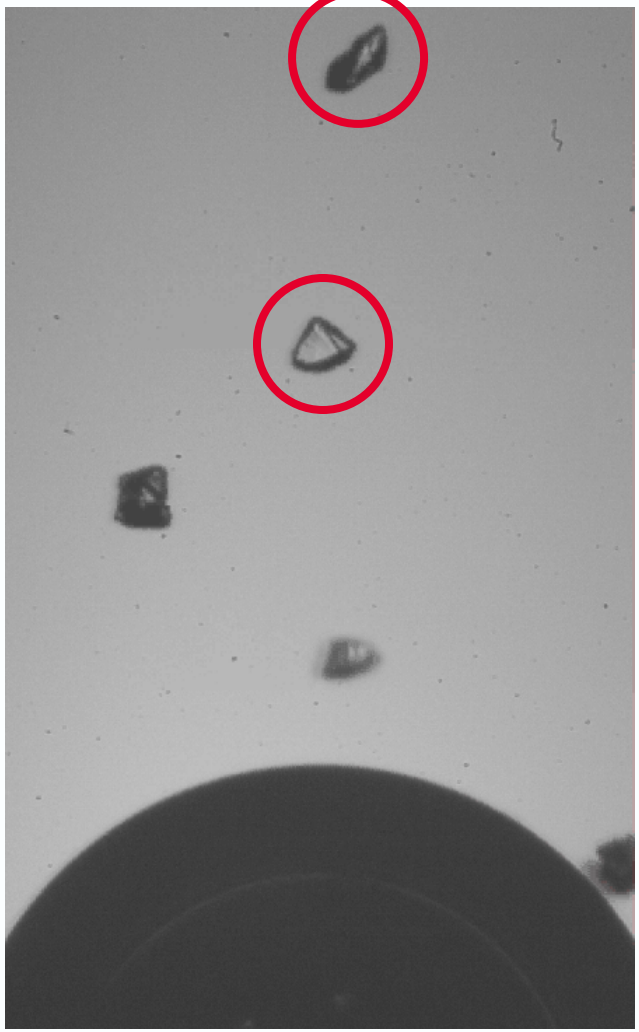
# Videos



Jumps in

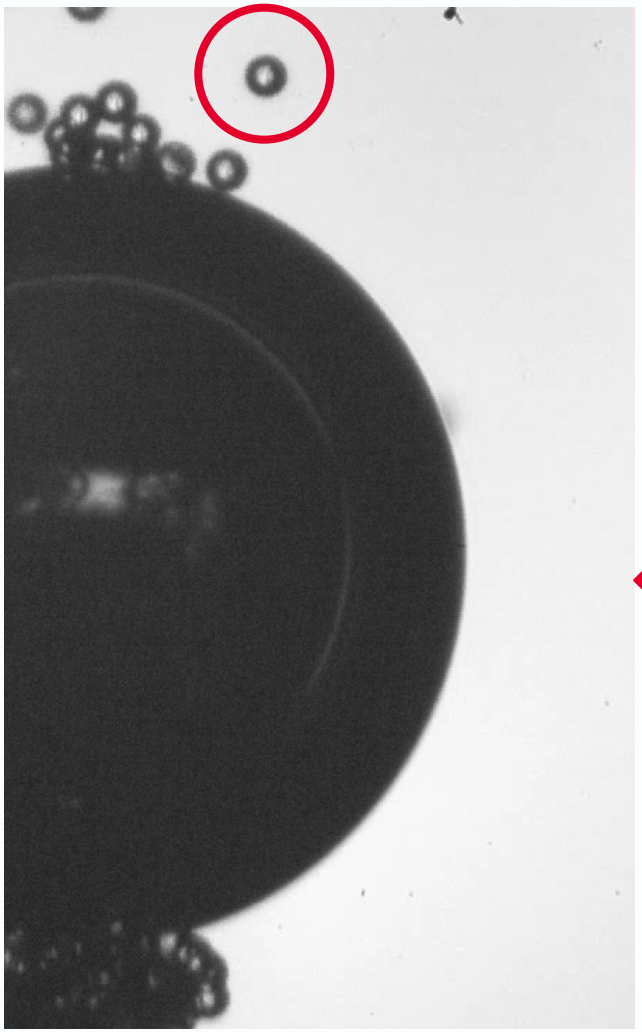
Spheres

Frit



Bubbles ~ 1.5 mm diameter.  Particles 75–90 µm.

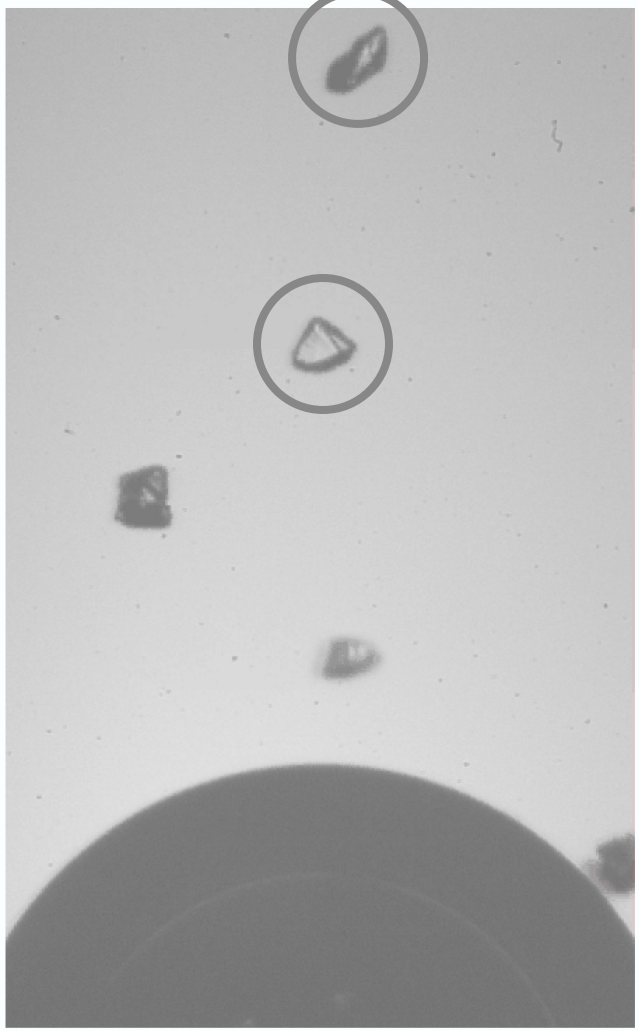
# Videos — spheres



Spheres

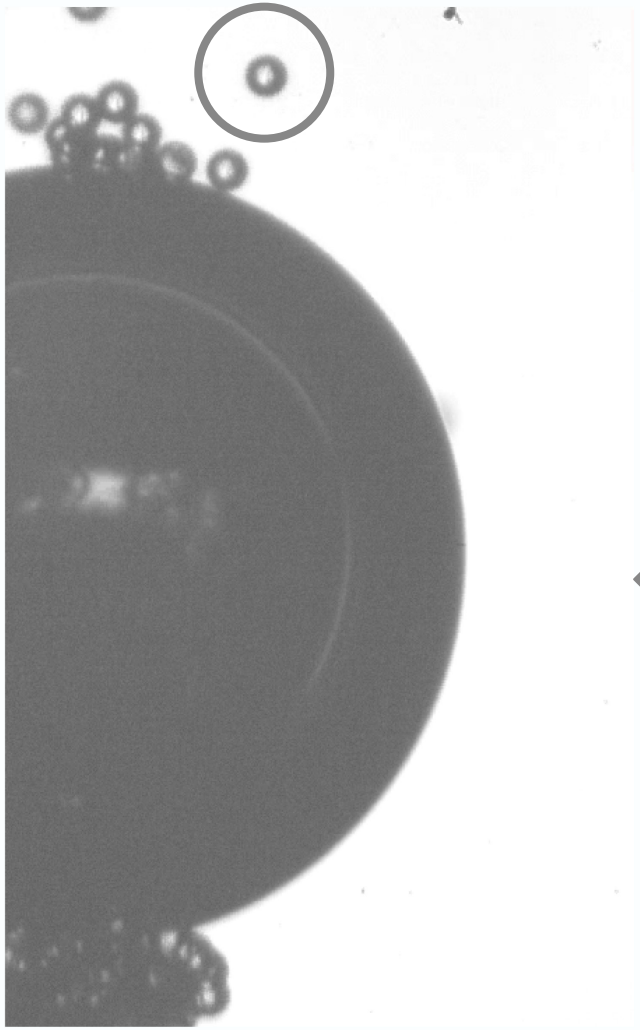
Jumps in

Frit



Both videos played back at 1/50$^{th}$ of actual speed.

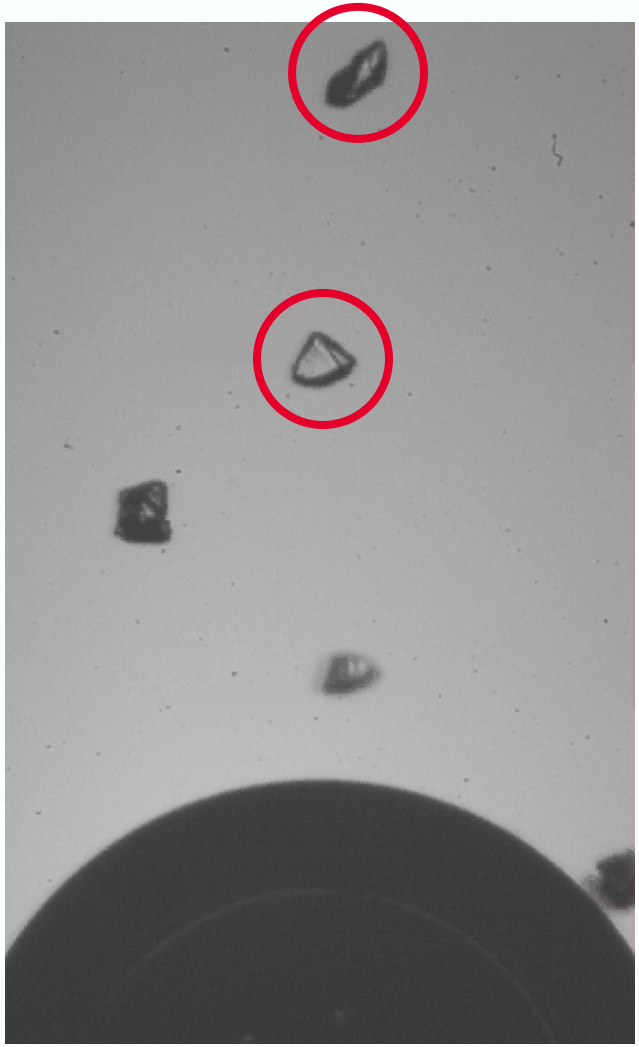
# Videos — frit



Jumps in

Spheres

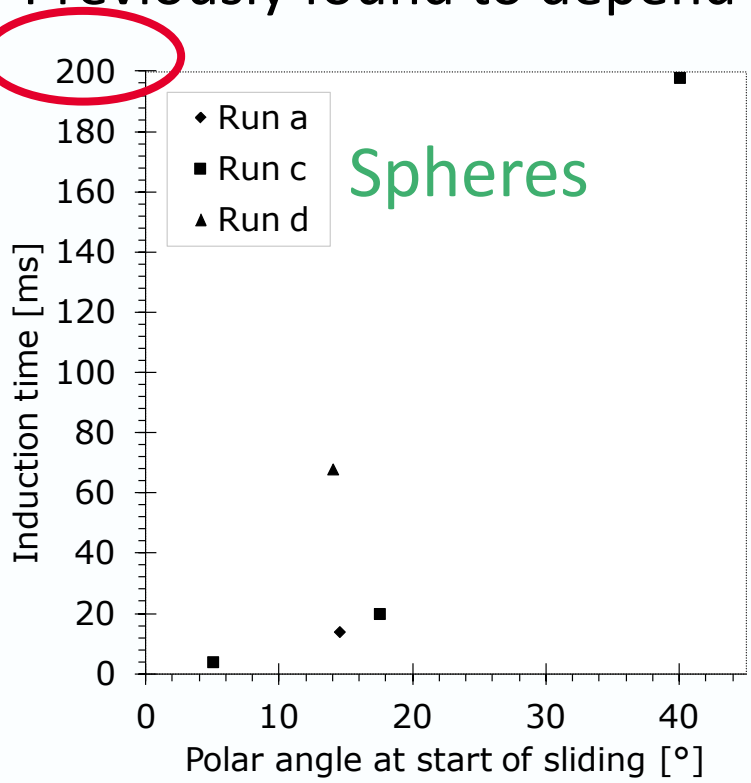
Frit

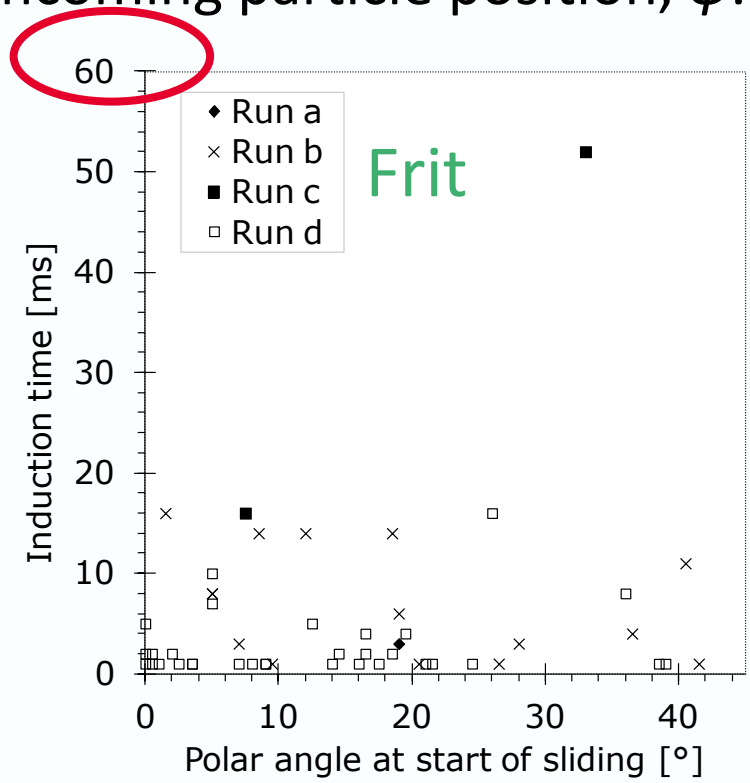


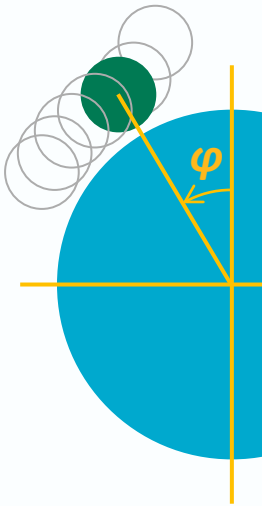
Both videos played back at 1/50$^{th}$ of actual speed.

# Induction periods

Previously found to depend on incoming particle position, $\varphi$. *



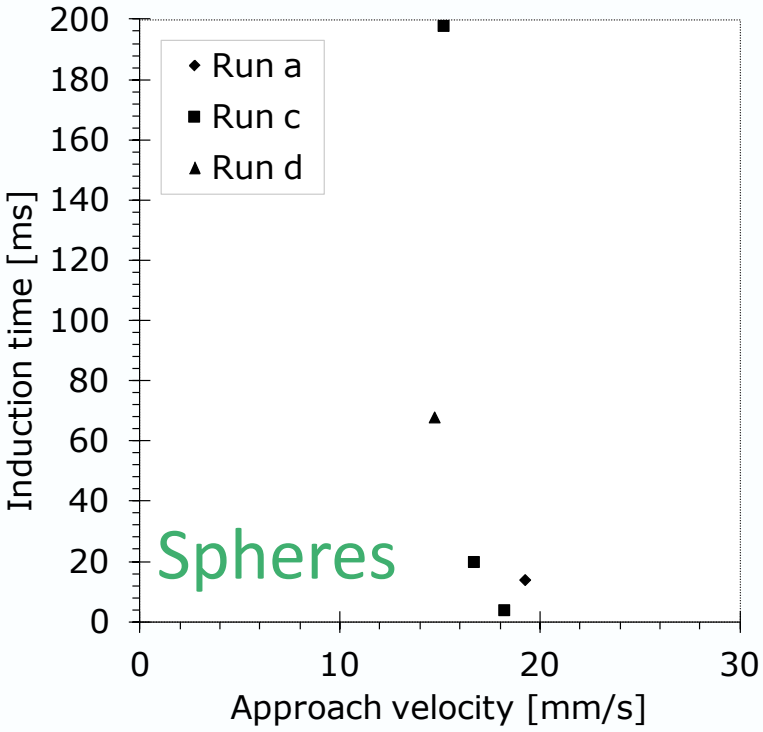



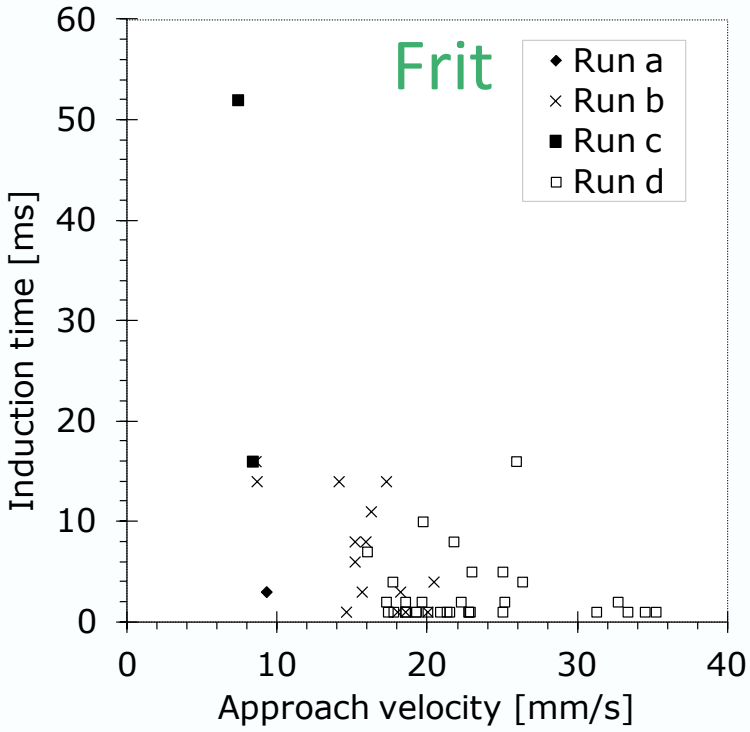




Now accounting for change in particle shape/roughness, $f$, with further correction for particle's approach speed, $v_a$ ….

* Verrelli, Koh, Bruckard & Schwarz; *Flotation '11*; Cape Town, South Africa; 14–17 November 2011.
Verrelli, Koh, Bruckard & Schwarz; *Minerals Eng.*; 2012; **accepted**. doi:10.1016/j.mineng.2012.03.034

# Induction periods



# Statistical analysis

Equation evaluated for all possible regressions

Suggested fit to data

$$\tau = \left[ \left( \frac{73.8\,\text{mm/s}}{v_a} \right)^2 + \left( \frac{\varphi}{3.11^\circ} \right)^2 \right] \left( 0.0792\, f + (1 - f) \right)$$

with $\tau$ in milliseconds

$f$ = 0 for spheres
$f$ = 1 for frit

Shape effect is ~one order of magnitude

# Conclusions

Direct experimental observation of induction period:

- value for frit is ~one twelfth the value for spheres
- increasing with $\varphi^2$ — for spheres and for frit
- inversely related to $v_a^2$ — ~ kinetic energy

Particle shape *does* have an effect on induction period.

Findings to be used to improve applied & theoretical modelling of flotation:

- control of grinding to influence particle shape
- extend range of applicability and reliability of predictive CFD–flotation models

# Acknowledgements

Cathy Edwards — sample preparation

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Matthew Glenn — microscopy

Liza Forbes — discussions

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# Present approach

## Overview

Directly measure induction period

- using *CSIRO Milli-Timer*
- see variation with incoming particle position & speed

Using methylated borosilicate glass in different shapes

- smooth spheres
- rough “frit” shards
- variation with particle shape/roughness — other properties constant

Statistical analysis

- multiple non-linear regression
- coefficients chosen by regression over all possible combinations

# Statistical analysis

## Multiple nonlinear regression

Induction period

- increasing with $\varphi$
- inversely related to $v_a$
- value for frit is a fraction of the value for spheres

Precise functional form not known *prima facie*.

## Apply general equation

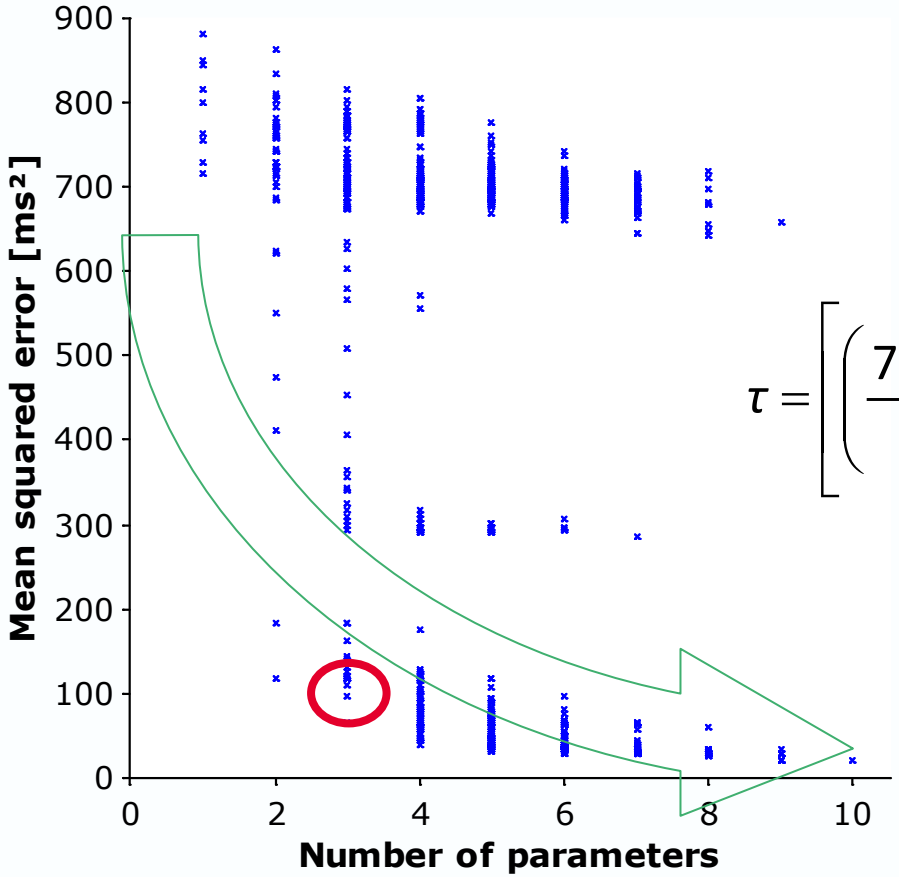
$$\tau = \left(\beta_1 v_a^{-10} + \beta_2 v_a^{-2} + \beta_3 v_a^{-1} + \beta_4 v_a + \beta_5 v_a^{2} + \beta_6 \varphi + \beta_7 \varphi^2 + \beta_8 \cos(\varphi) + \beta_9\right)\left(\beta_{10} f + (1-f)\right)$$

$f = 1$ for frit, $f = 0$ for spheres

Retain only terms providing a good fit to the data….

# Statistical analysis

Equation evaluated for all possible regressions




Suggested fit to data

$$\tau = \left[\left(\frac{73.8\,\text{mm/s}}{v_a}\right)^2 + \left(\frac{\varphi}{3.11°}\right)^2\right](0.0792\,f + (1-f))$$

with $\tau$ in milliseconds

Shape effect is ~one order of magnitude