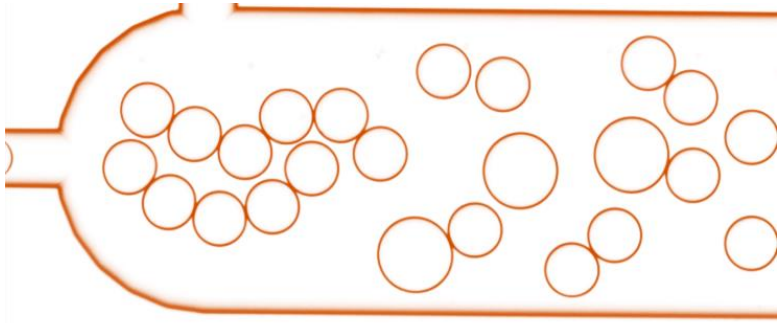
Microfluidics to study emulsifier adsorption and emulsion stability

Kelly Muijlwijk, Claire Berton-Carabin and Karin Schroën

Food Process Engineering Group, Wageningen University

AOCS 2016, Salt Lake City



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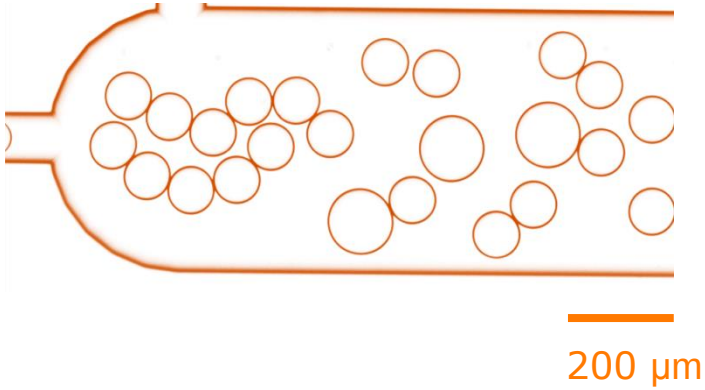
Microfluidic methods to study emulsions

Emulsifier adsorption

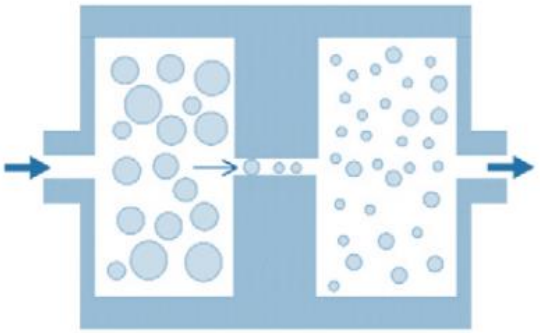
Emulsion stability



Microfluidic methods to study emulsions

Emulsifier adsorption

Emulsifier adsorption



Industrial emulsification

Turbulent flow

Convective mass transfer

Time scale: sub-milliseconds

Drop tensiometer

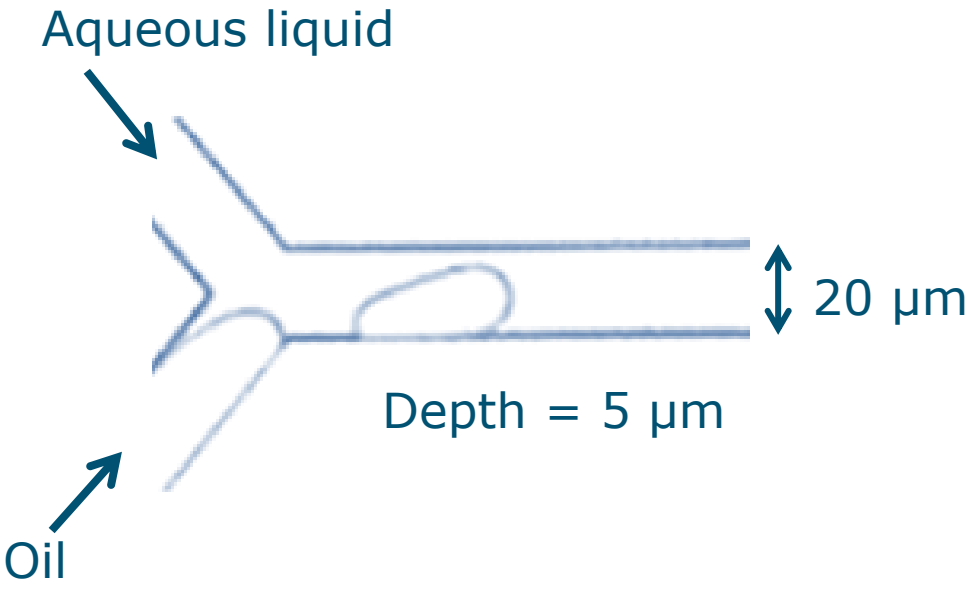
No flow

Diffusive mass transfer

Measurement: seconds

Microfluidic Y-junction

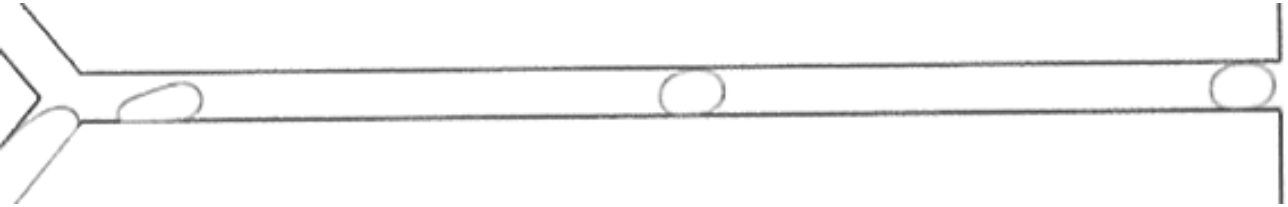
Microfluidic Y-junction

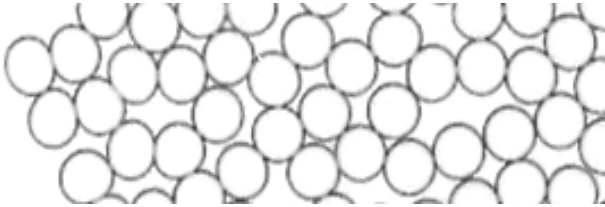


Measure with image analysis

- Droplet size
- Dispersed phase flow rate
- Continuous phase velocity

Microfluidic Y-junction





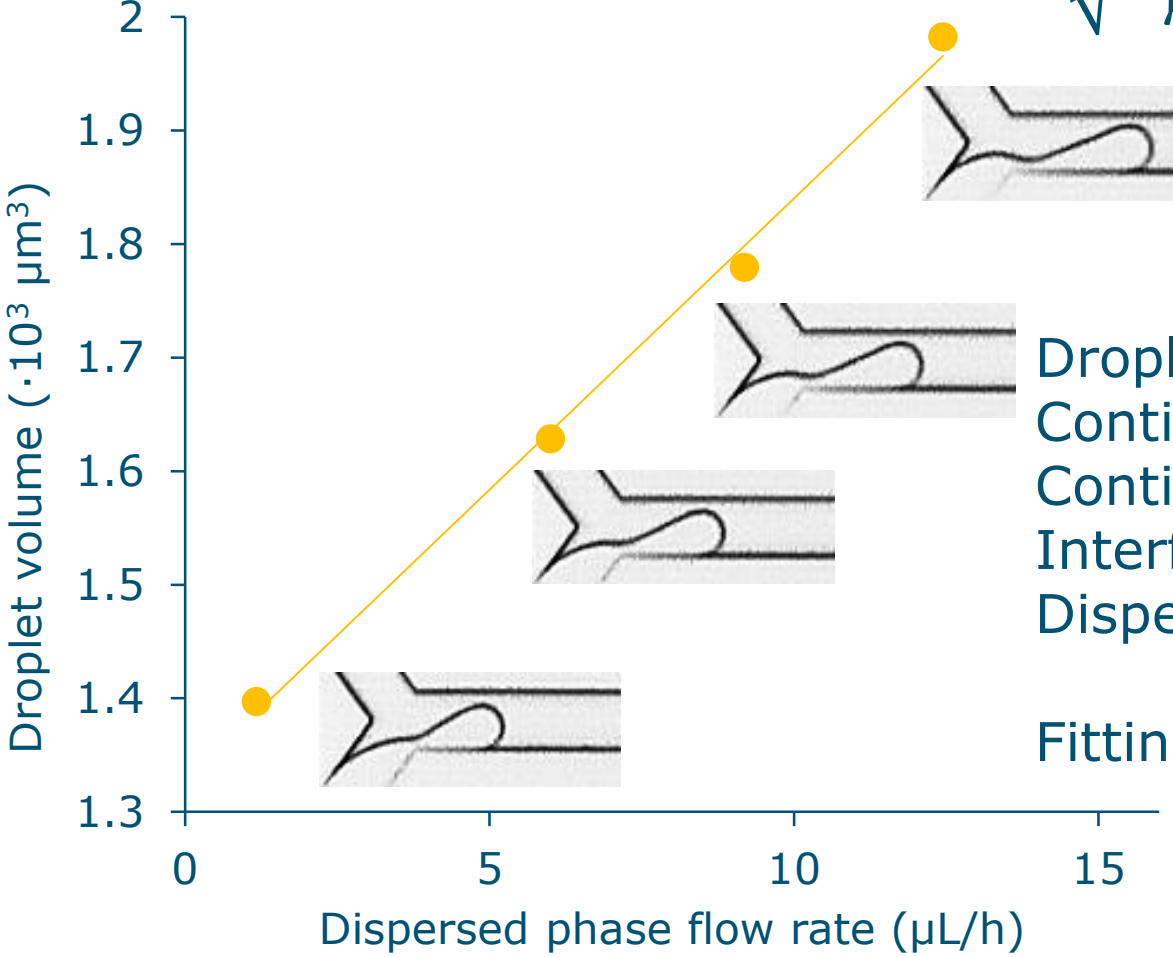
Width = 20 μm
Depth = 5 μm

Droplet formation is a balance between shear force and interfacial tension

Two-step model

Hexadecane droplets formed in water

$$V = V_0 + constant \cdot \varphi_d = \frac{b}{\sqrt{\frac{\eta_c v_c}{\gamma}}} + \frac{c}{v_c}\varphi_d$$

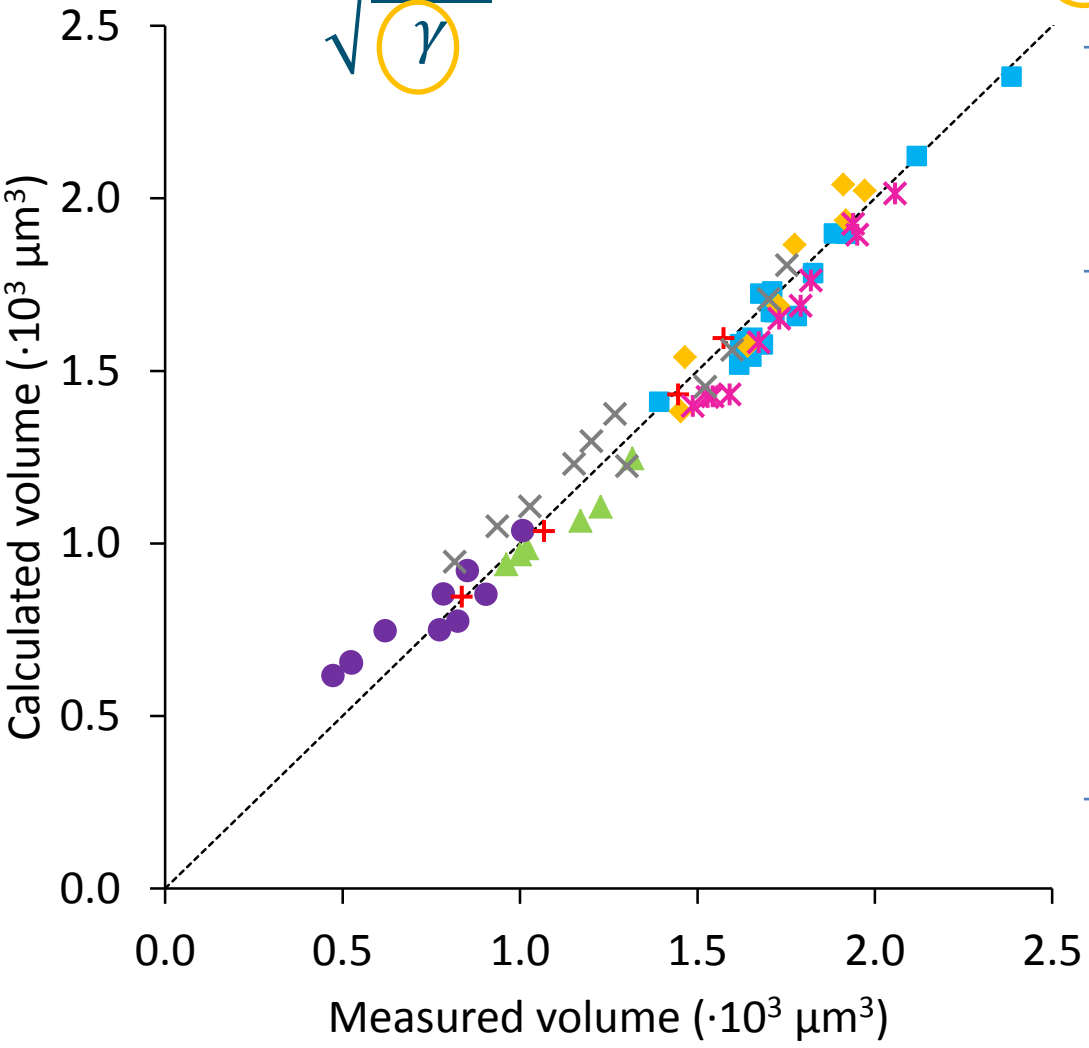


Droplet volume (V)
Continuous phase velocity (v_c)
Continuous phase viscosity (η_c)
Interfacial tension (γ)
Dispersed phase flow rate (φ_d)

Fitting parameters: b and c

Validation

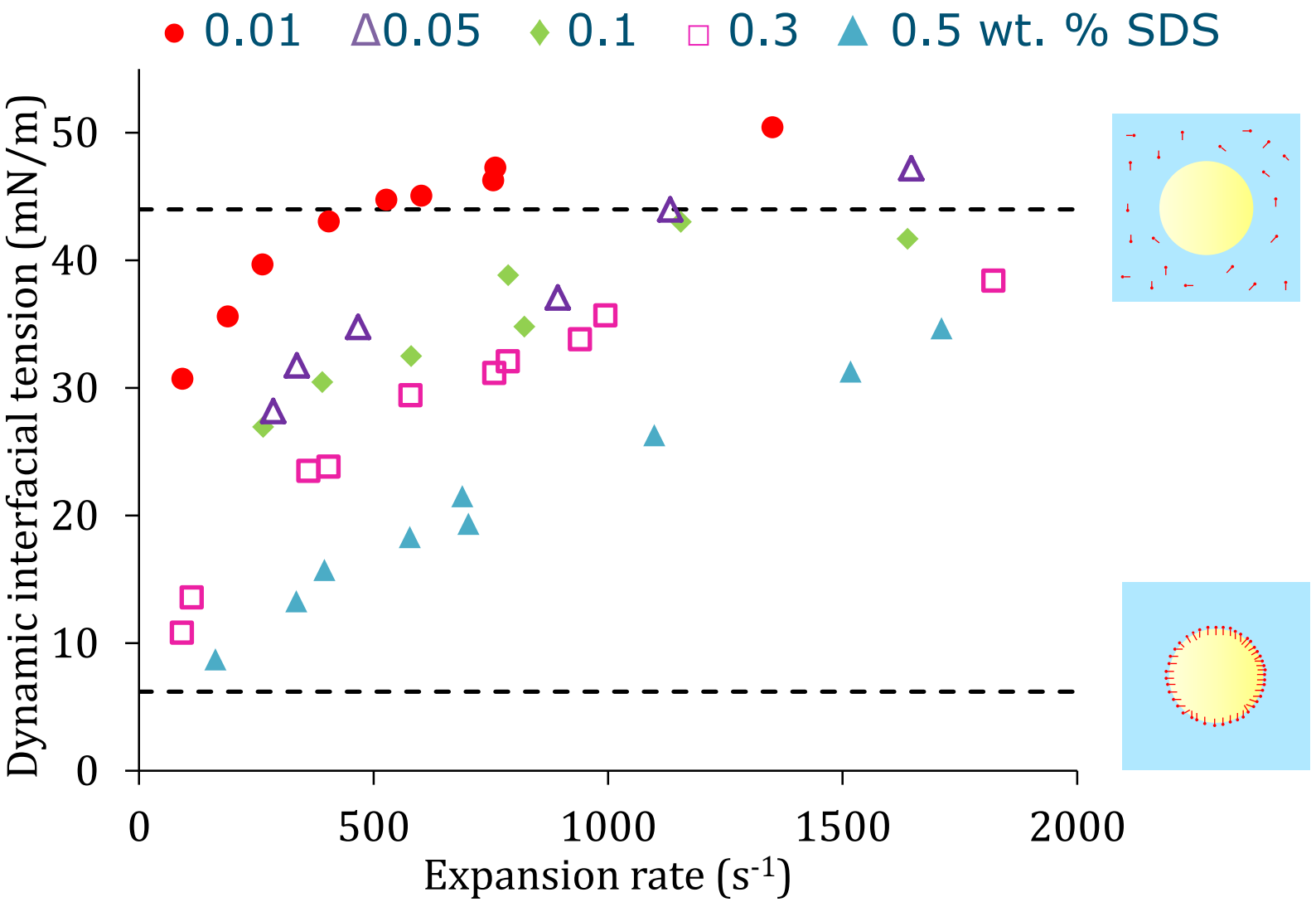
$$V = \frac{b}{\sqrt{\frac{\eta_c v_c}{\gamma}}} + \frac{c}{v_c}\varphi_d \quad \Rightarrow \quad \gamma = \eta_c v_c \left(\frac{V - \frac{c}{v_c}\varphi_d}{b} \right)^2$$



Continuous phase	η_c (mPa s) 20 ºC	$\gamma_{hexadecane}$ (mN/m) 20 ºC
■ Water	1.0	46
▲ 9% ethanol	1.5	27
● 28% ethanol	2.5	15
♦ 20% glycerol	1.8	37
+ 30% glycerol	2.6	35
* 20 % sucrose	2.1	47
X 25 % sucrose	2.4	47

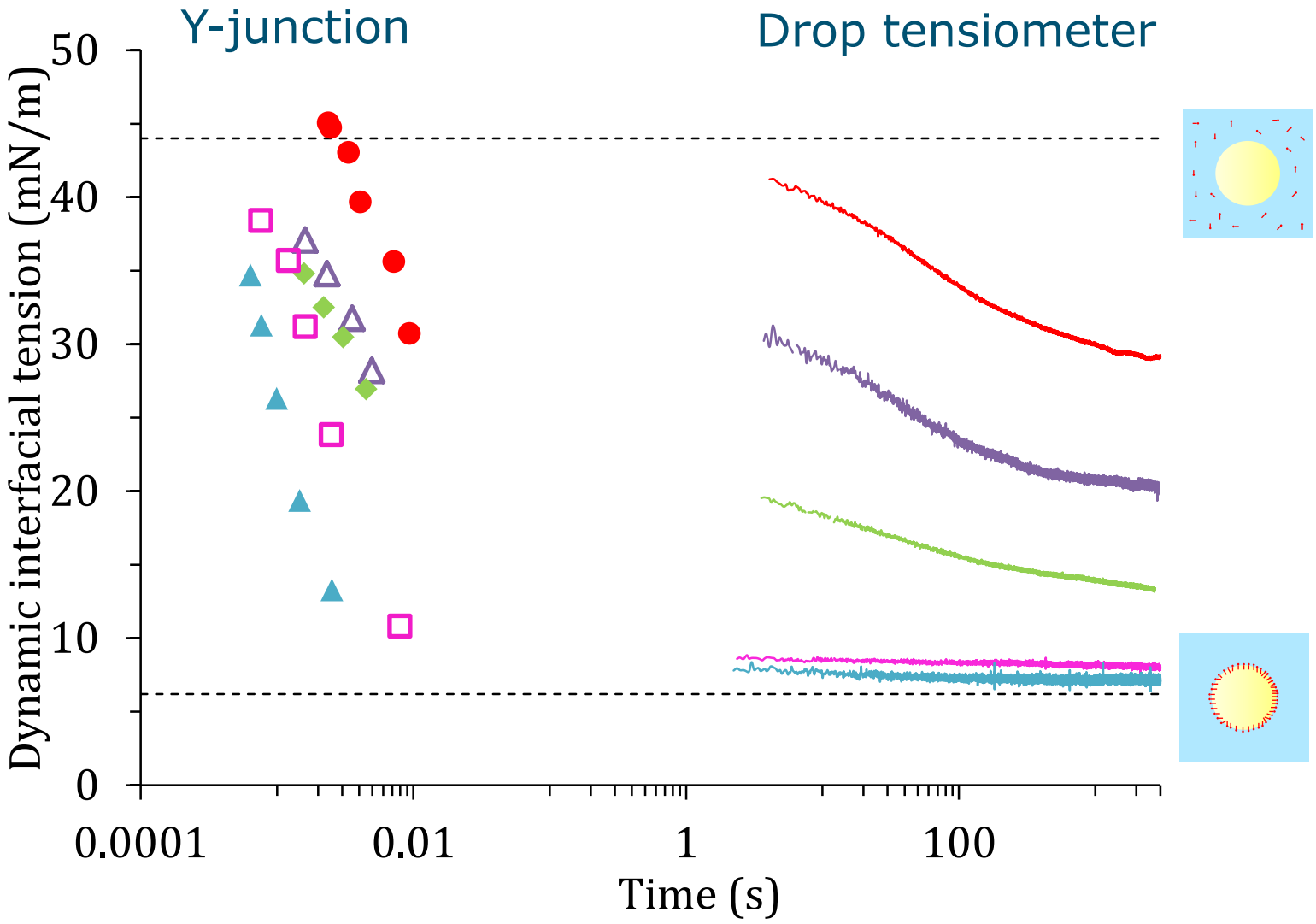
Dynamic interfacial tension

Sodium dodecylsulphate (SDS)



Adsorption dynamics

● 0.01 Δ0.05 ♦ 0.1 □ 0.3 ▲ 0.5 wt. % SDS



Mass transfer conditions

$$Pe = \frac{v_c L}{D}$$

v_c = 0.3 m/s

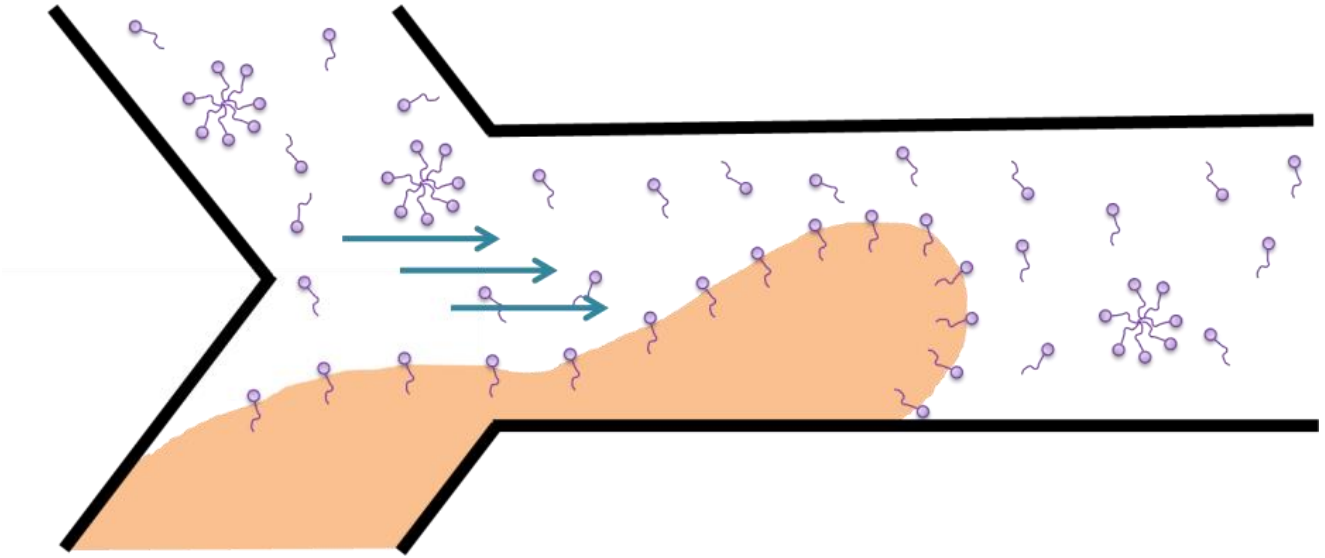
L = $5 \cdot 10^{-6}$ m

D = $7 \cdot 10^{-10}$ m^2/s

Péclet number > 1 Convection

Péclet number < 1 Diffusion

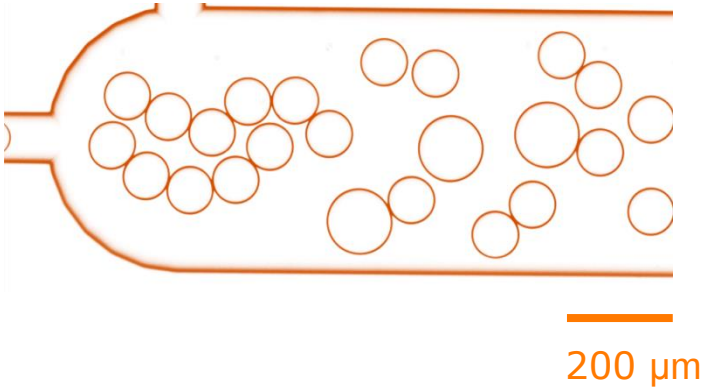
→ Pe = $2 \cdot 10^3$



Microfluidic methods to study emulsions

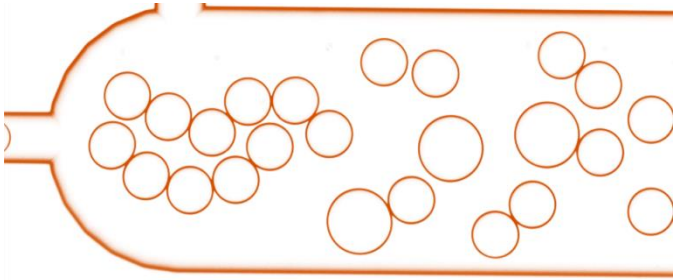
Emulsifier adsorption

Emulsion stability

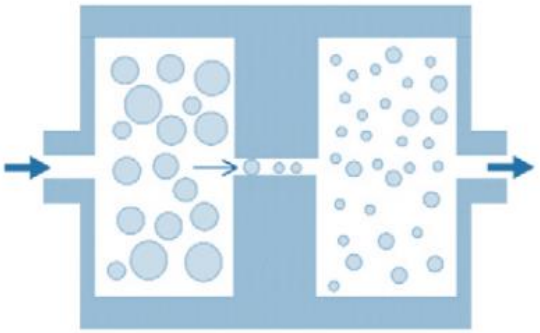


Microfluidic methods to study emulsions

Emulsion stability



Emulsion stability



Industrial emulsification

Turbulent flow

Convective mass transfer

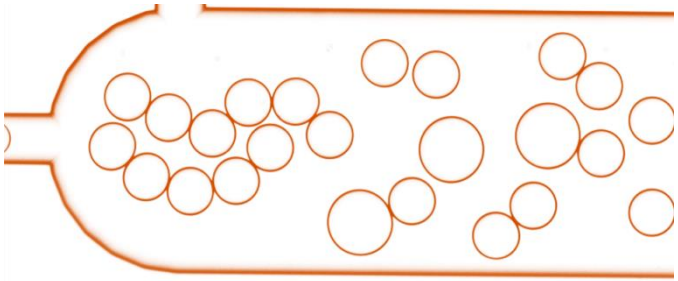
Time scale: sub-milliseconds

Stability measurements

No flow

Low dispersed phase fraction

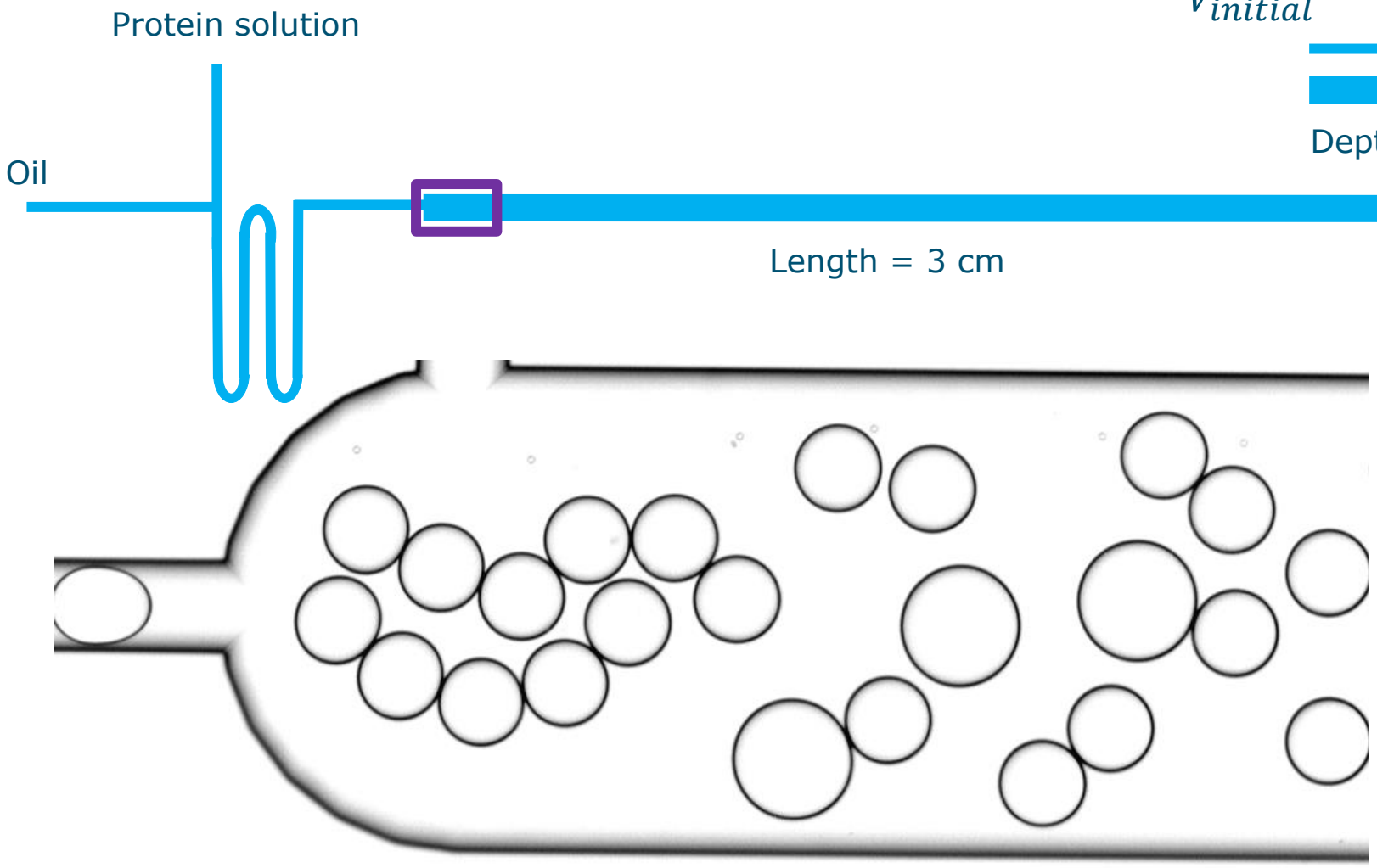
Longer time scale



Coalescence channel

Coalescence channel

$$Number\ of\ coalescence\ events = \frac{V_{final}}{V_{initial}} - 1$$



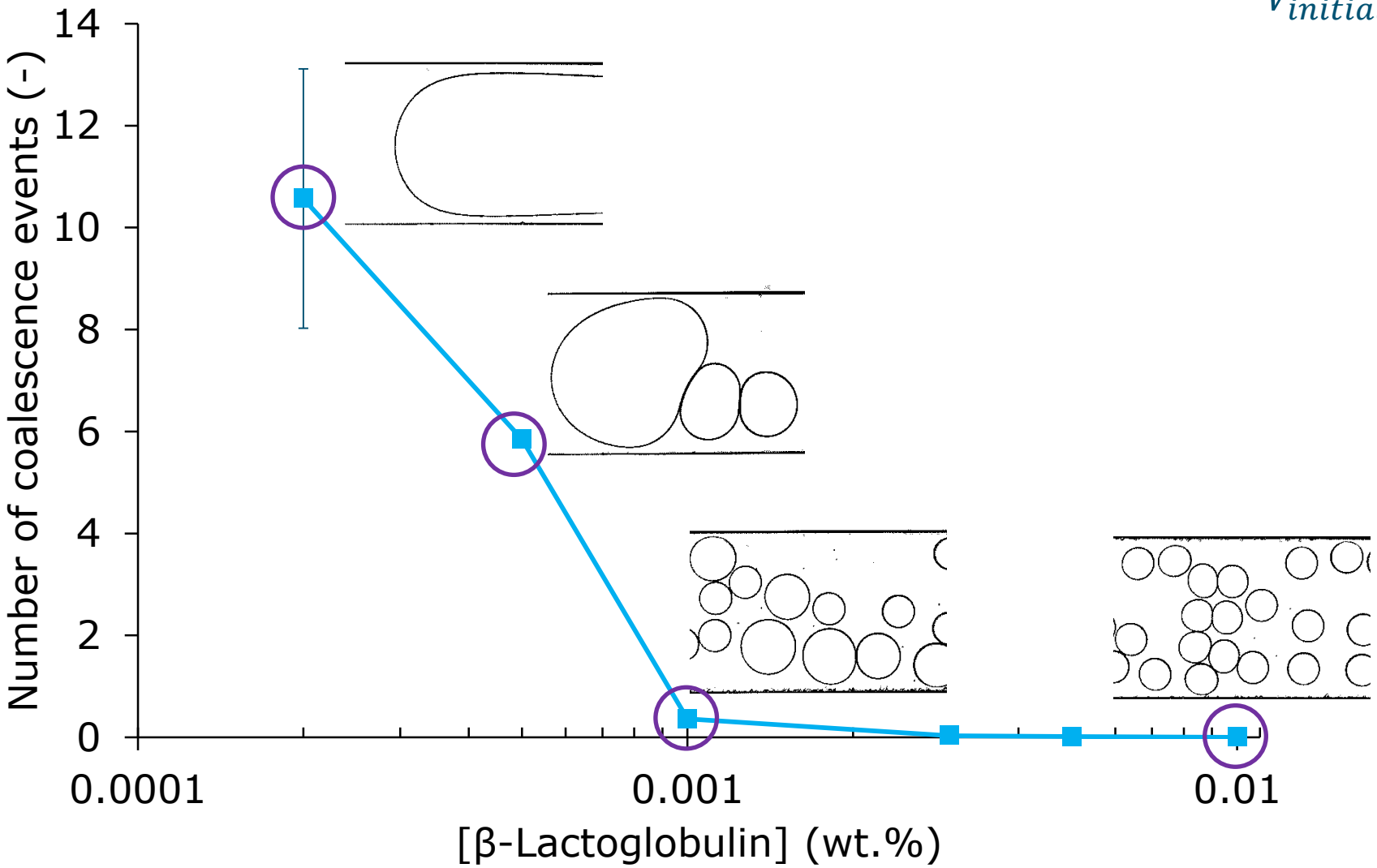
Krebs et al., Soft Matter, 2012, 8, 10650-10657

β-lactoglobulin

Residence time = 0.9 s

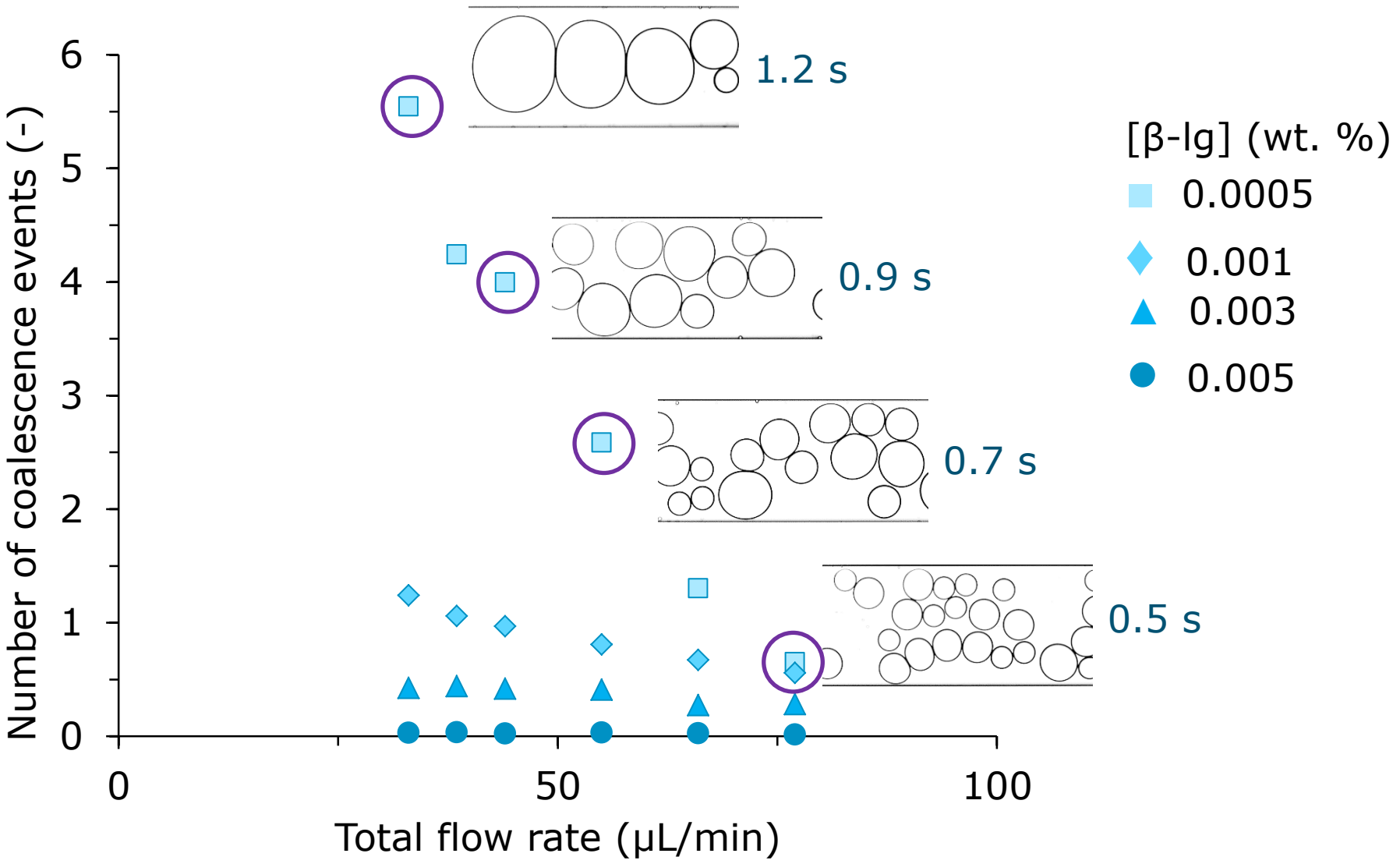
Oil volume fraction = 30%

$$Number\ of\ coalescence\ events = \frac{V_{final}}{V_{initial}} - 1$$

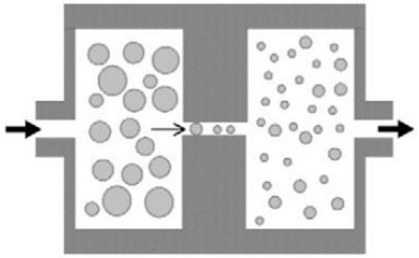


Flow rate

Oil volume fraction = 25%



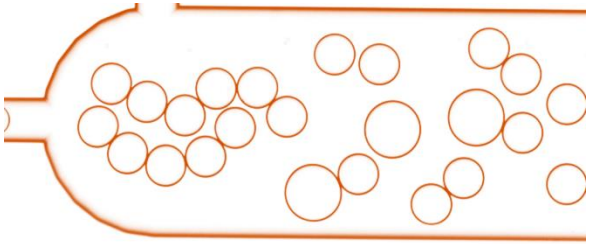
Highlights



Microfluidic method developed to measure interfacial tension

- At high expansion rates
- Within milliseconds
- Mass transfer determined by continuous phase velocity

Muijlwijk et al., Journal of Colloid and Interface Science, 2016, 470, 71-79



Microfluidic method to measure coalescence stability

- Dense system (oil fraction 25-60%)
- Flowing conditions (2-6 mm/s)
- Food-grade ingredients (β-lactoglobulin)

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