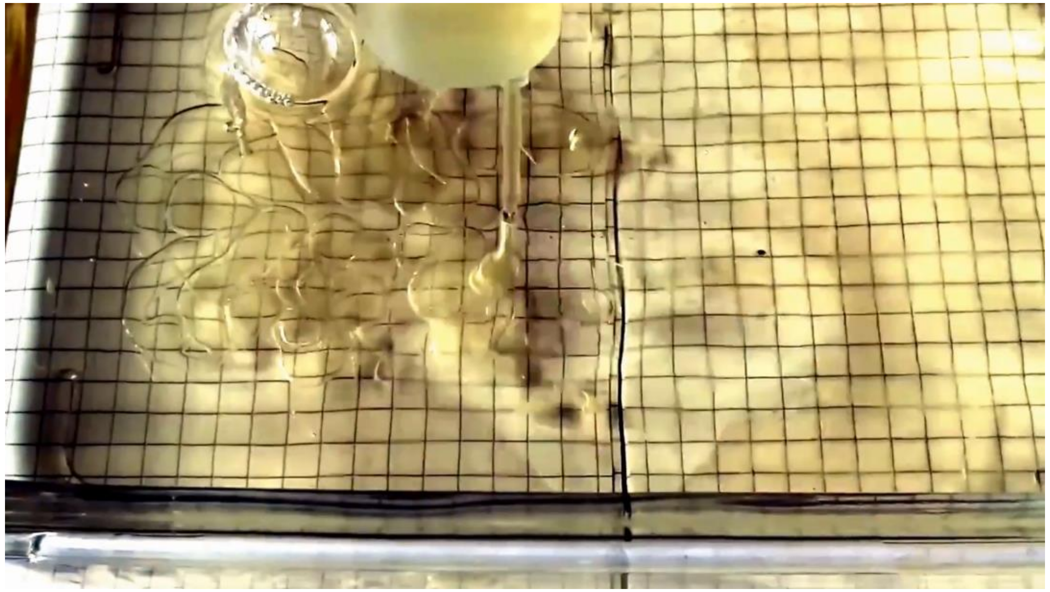
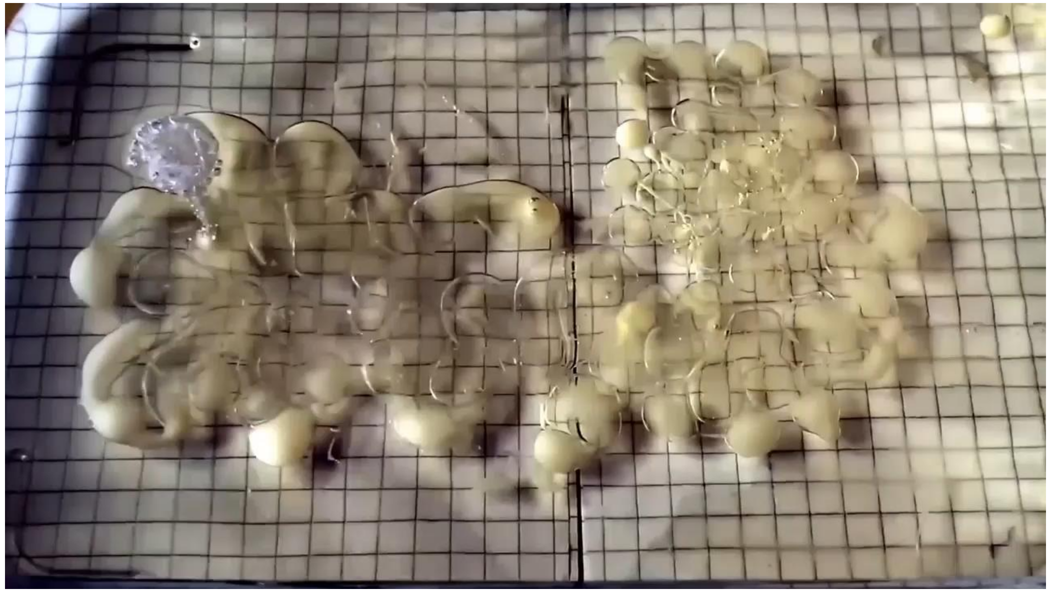
PROBLEM N°13

EGG WHITE PEARLS

Team Ecole polytechnique

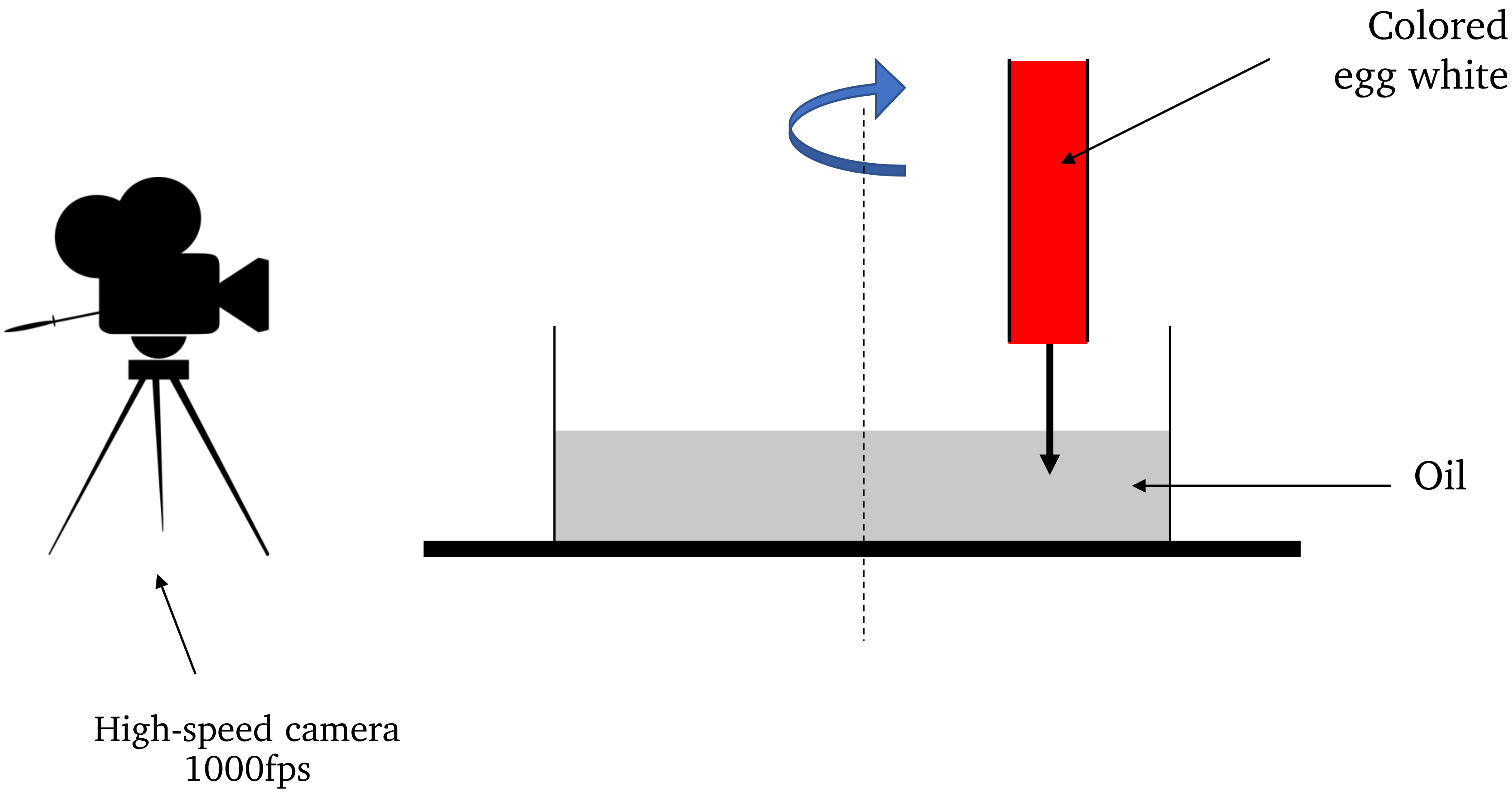
Egg white Pearls





Egg whites are separated from the yolk and put into a syringe. From the syringe, the egg white is ejected into heated oil while the tip is in motion (video on IPT website). How does **the size** of the egg white pearls produced depend on the various parameters such as the **temperature** of the oil, **ejection and motion speed**, nozzle **diameter** or the non-Newtonian properties of egg whites?

Experimental setup

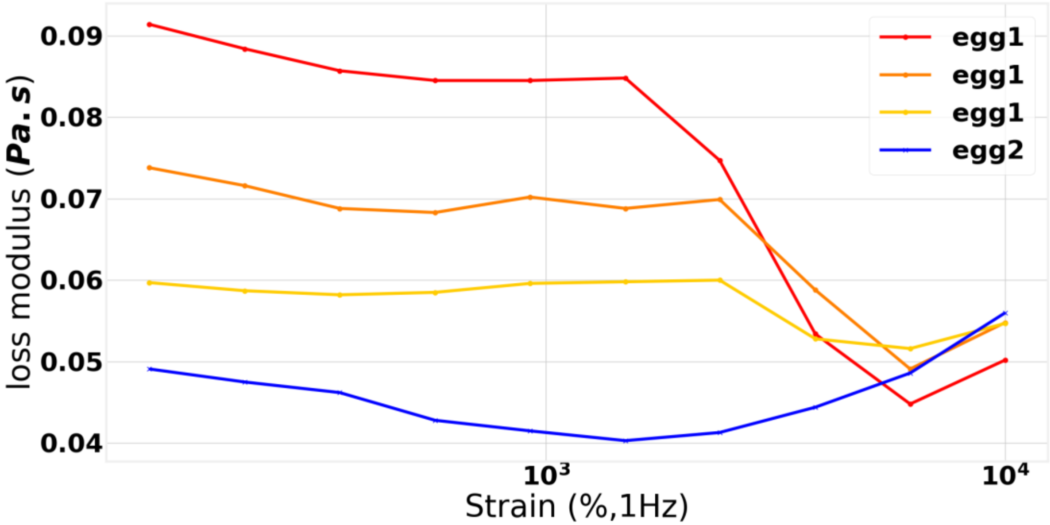


Variability between experiments

Egg white: approx. 90% water, 10% proteins (ovalbumin)

Viscoelastic, shear-thinning fluid

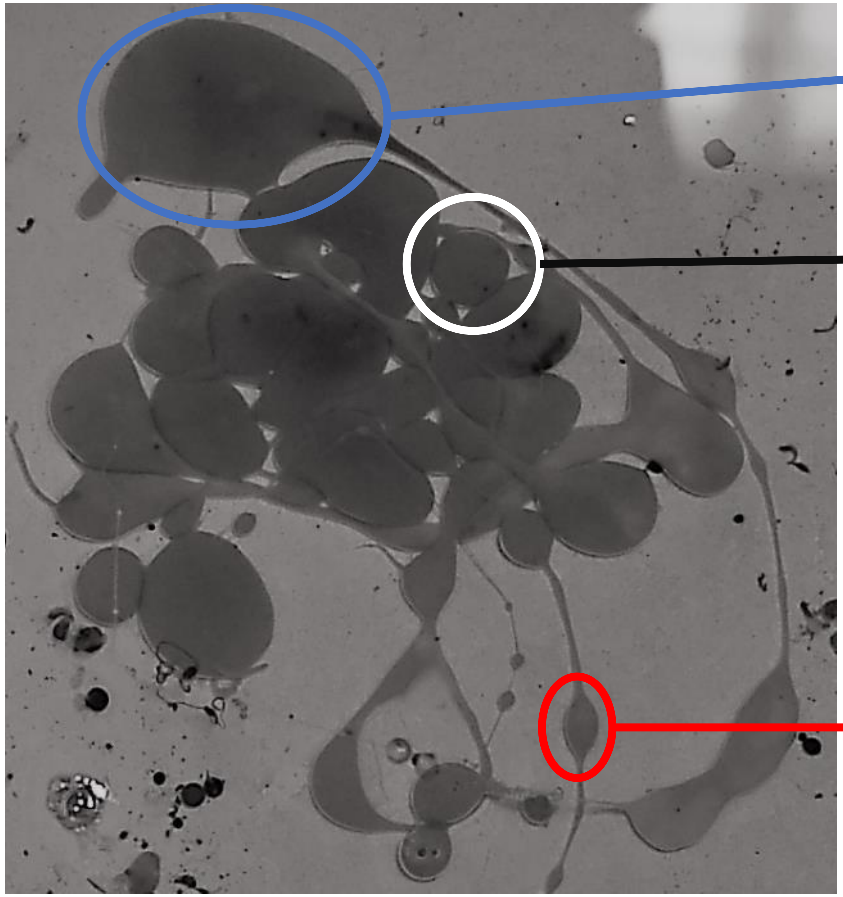
Inhomogeneous repartition of proteins



Variability :

- between successive experiments
- between different eggs

First observations



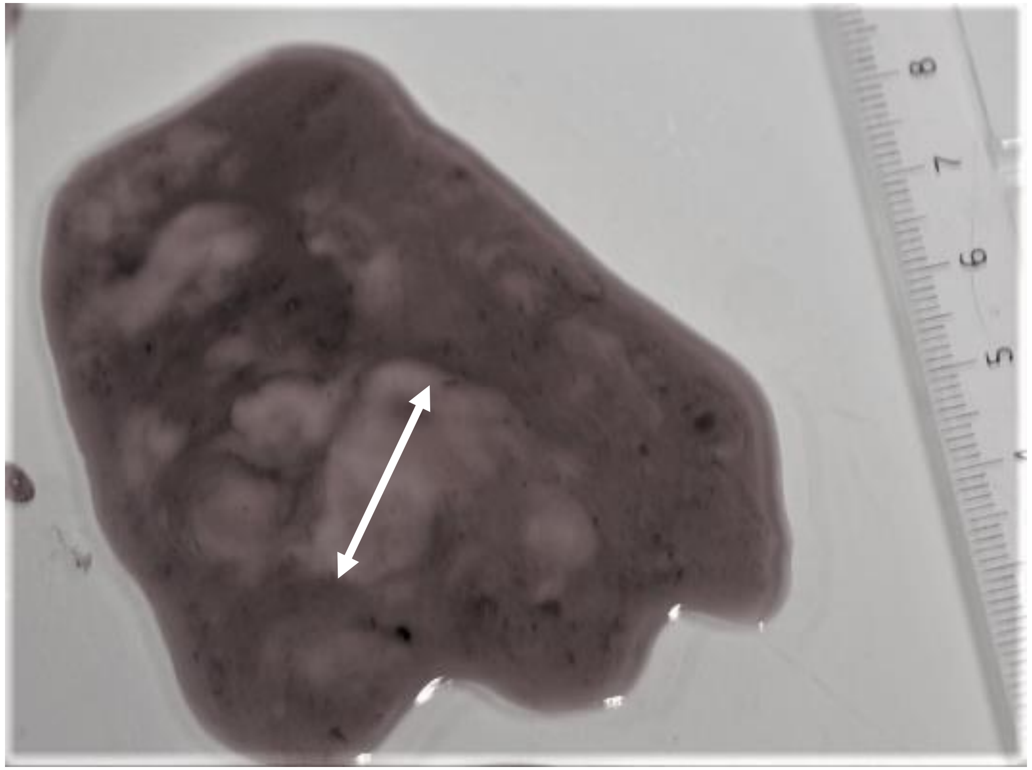
Big pearls: free shape, several cm

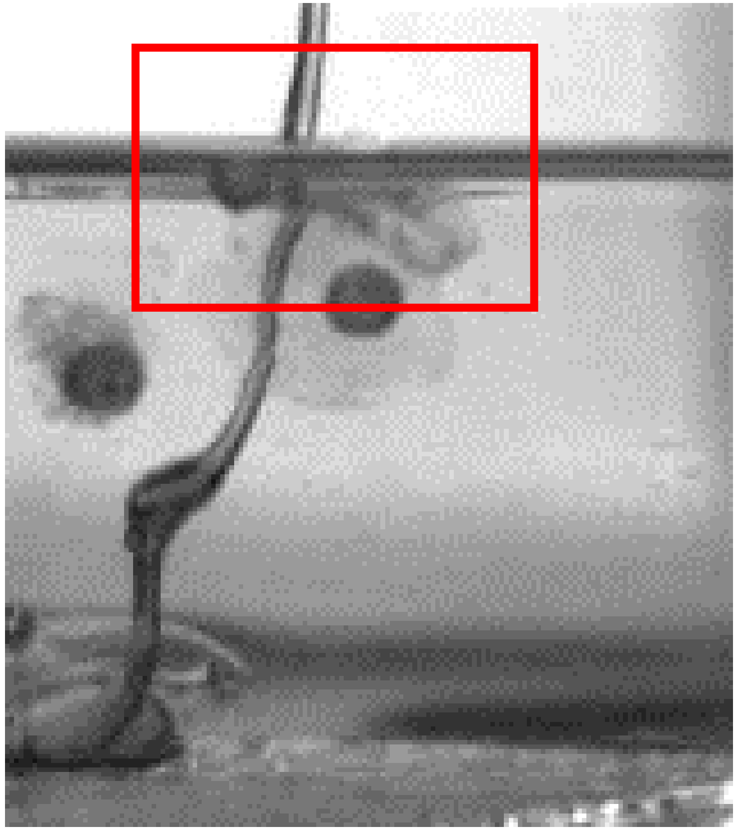
Medium pearls: rounded shape, 1-2cm

Small pearls: elongated, <1cm

Formation of big pearls

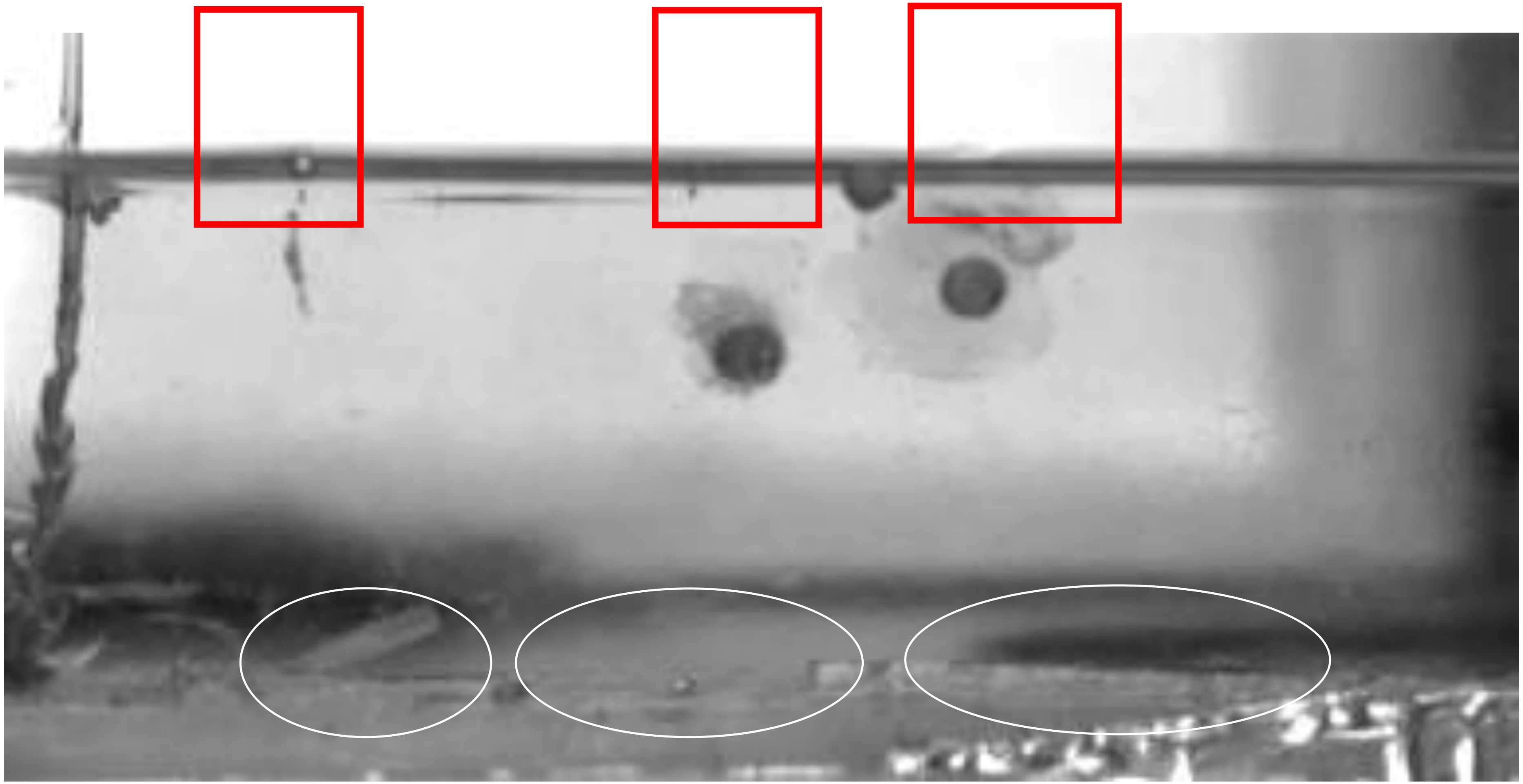
Inhomogeneities



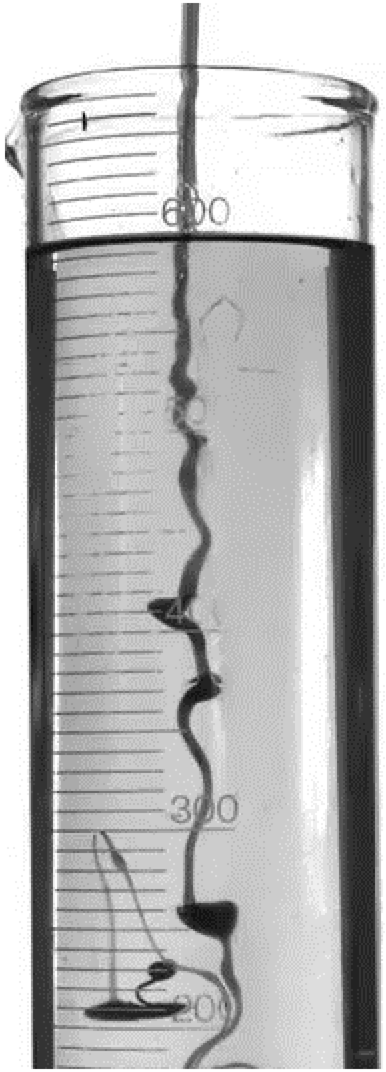


Formation of big pearls

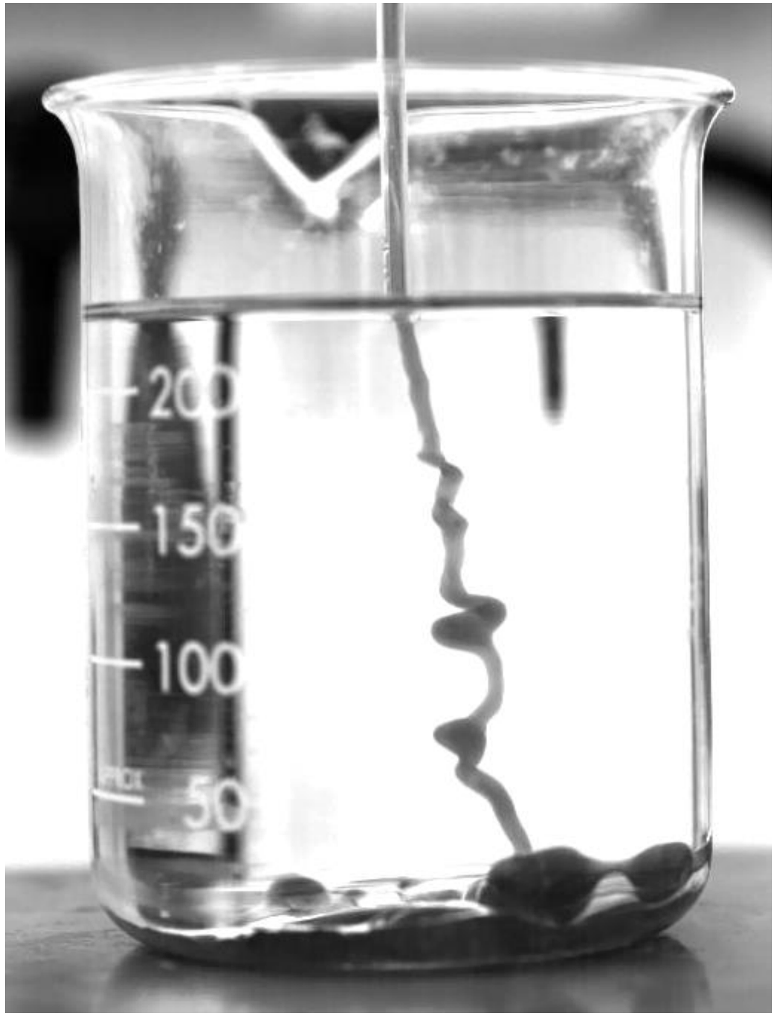
Inhomogeneities



Formation of medium pearls

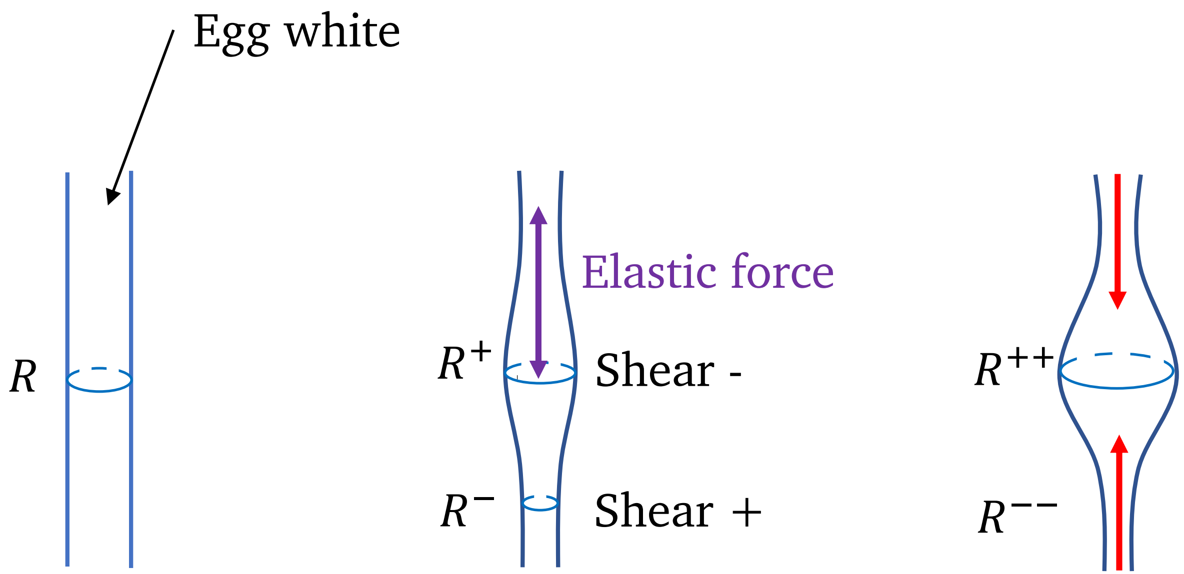


Instability similar to
Kelvin-Helmholtz



Formation of medium pearls

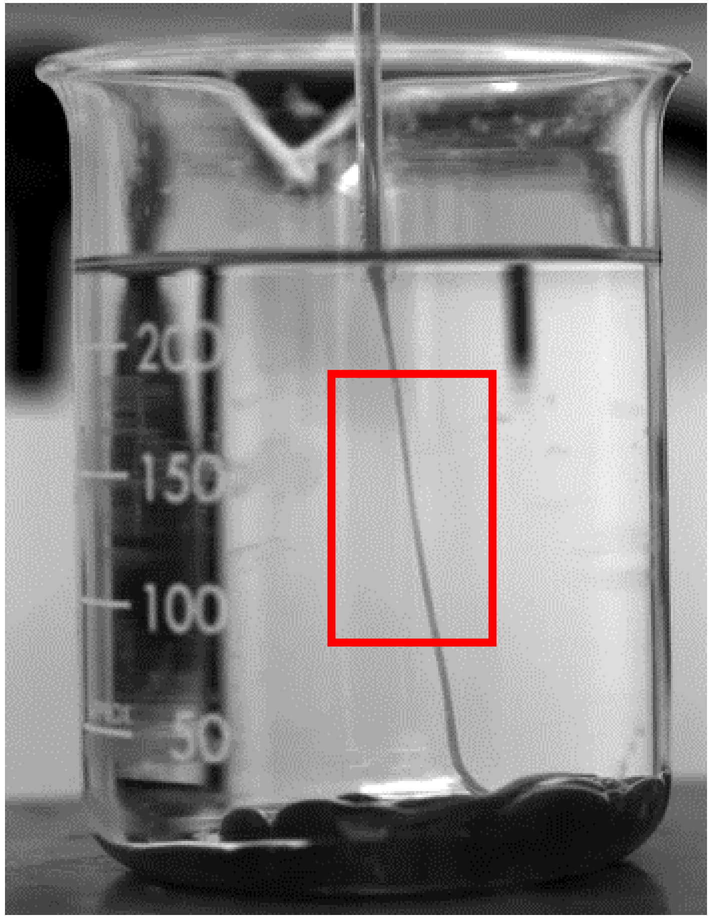
Maizena in oil



Transition medium to big pearls

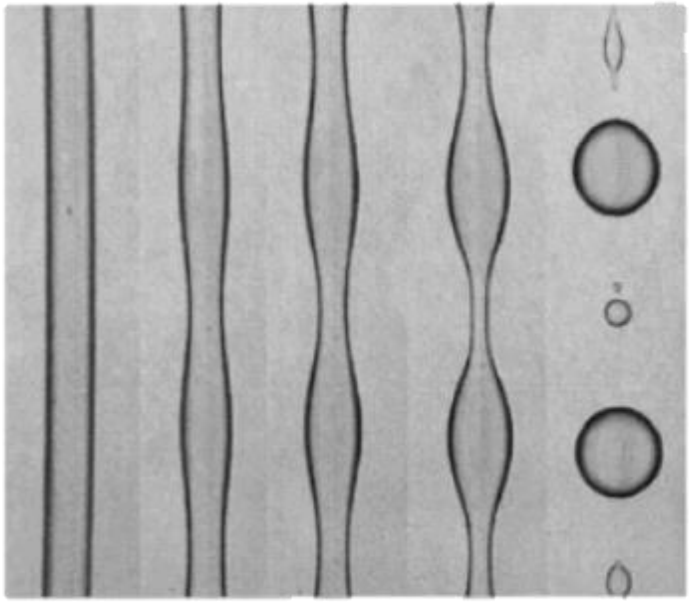
Formation of small pearls

Small pearls



Formation

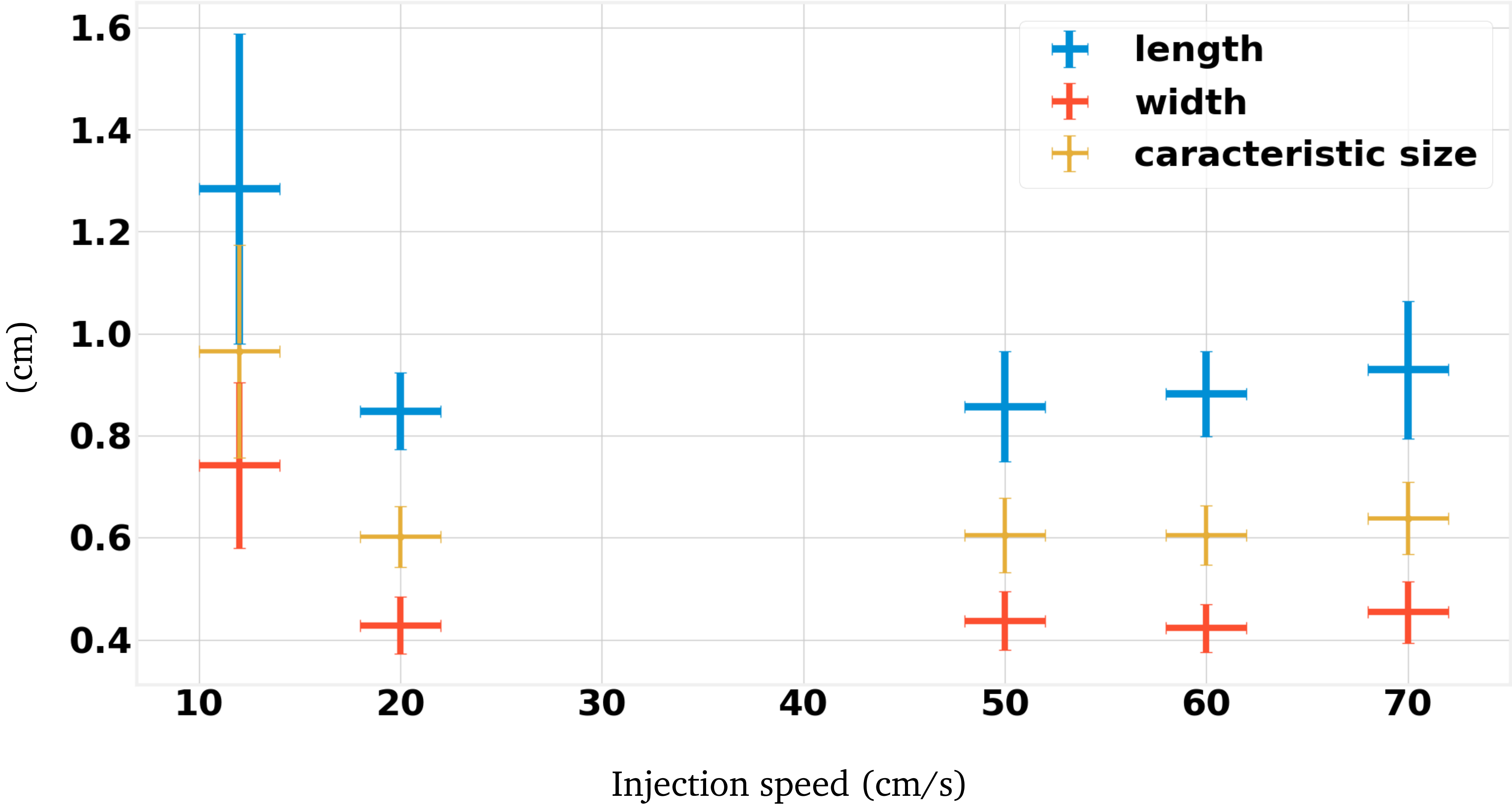
Rayleigh-Plateau instability



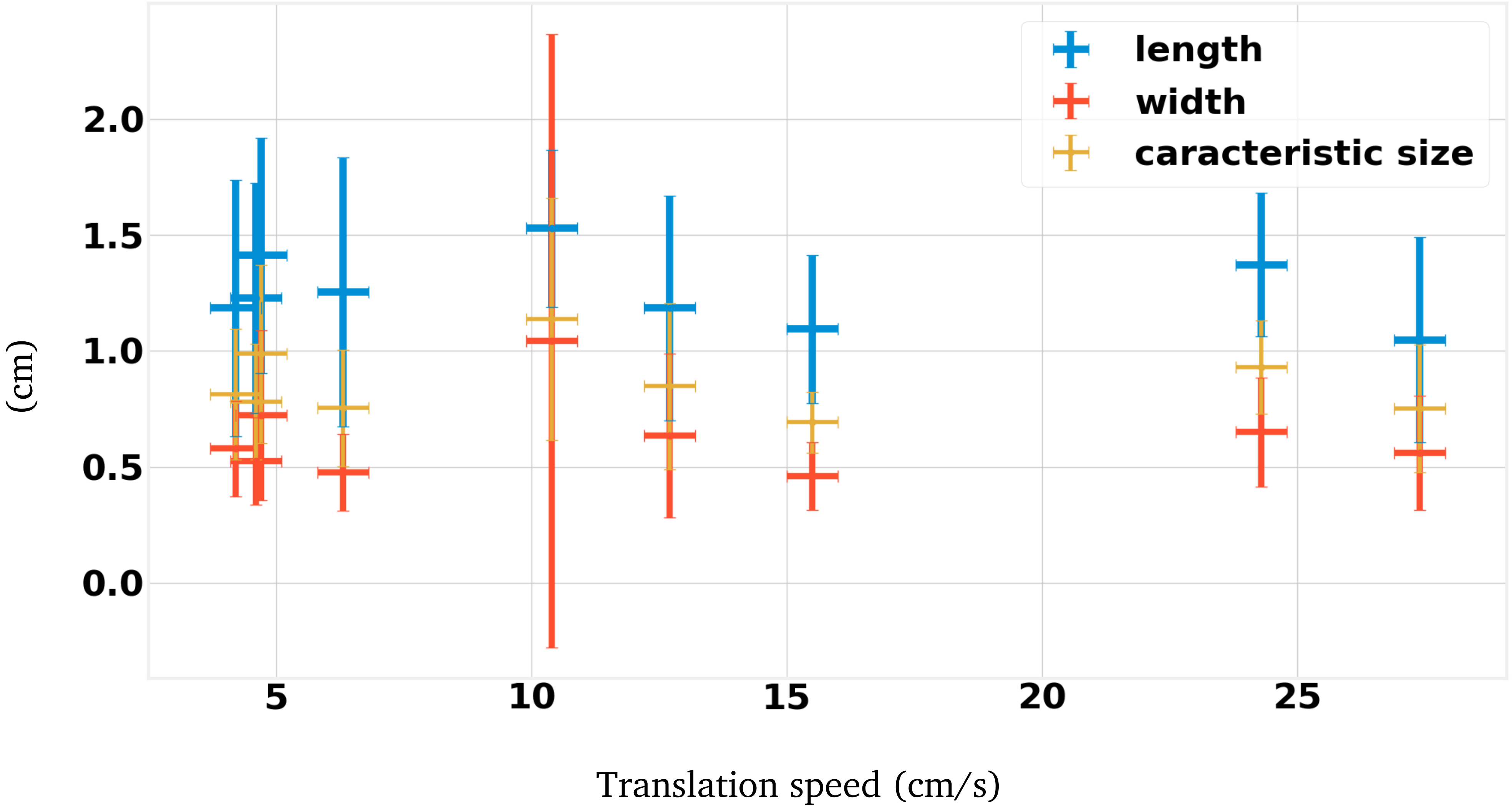
Elastic behavior ↔ surface tension

Z. Liu - Instability of a viscoelastic liquid jet with axisymmetric and asymmetric disturbances, ijmulflow 2008

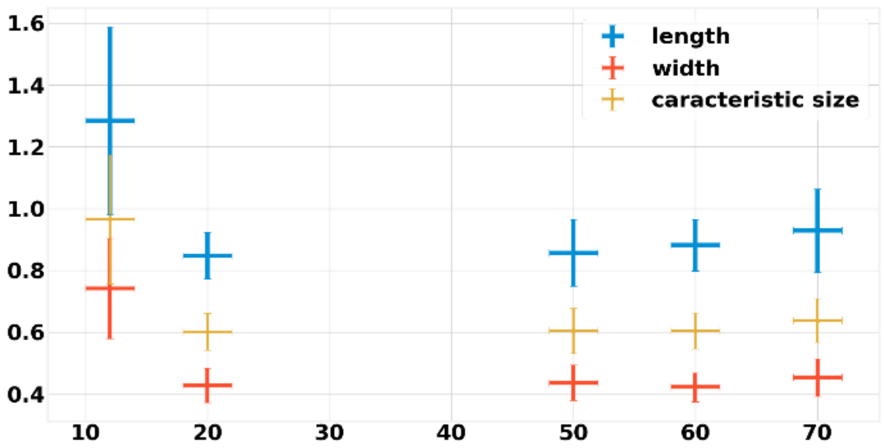
Translation and injection speed

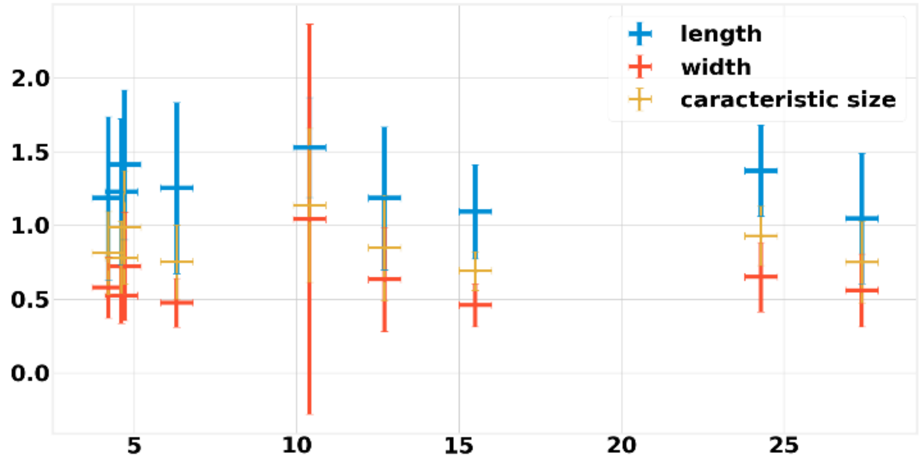


Translation and injection speed



Speed does not influence pearl size

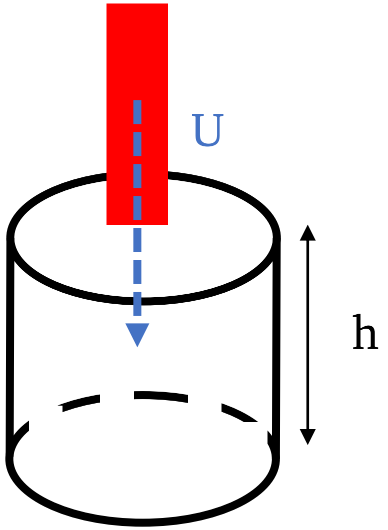




Kelvin-Helmholtz dispersion relation for speed: $\omega \propto kU$

Time spend falling: $t = h/U$

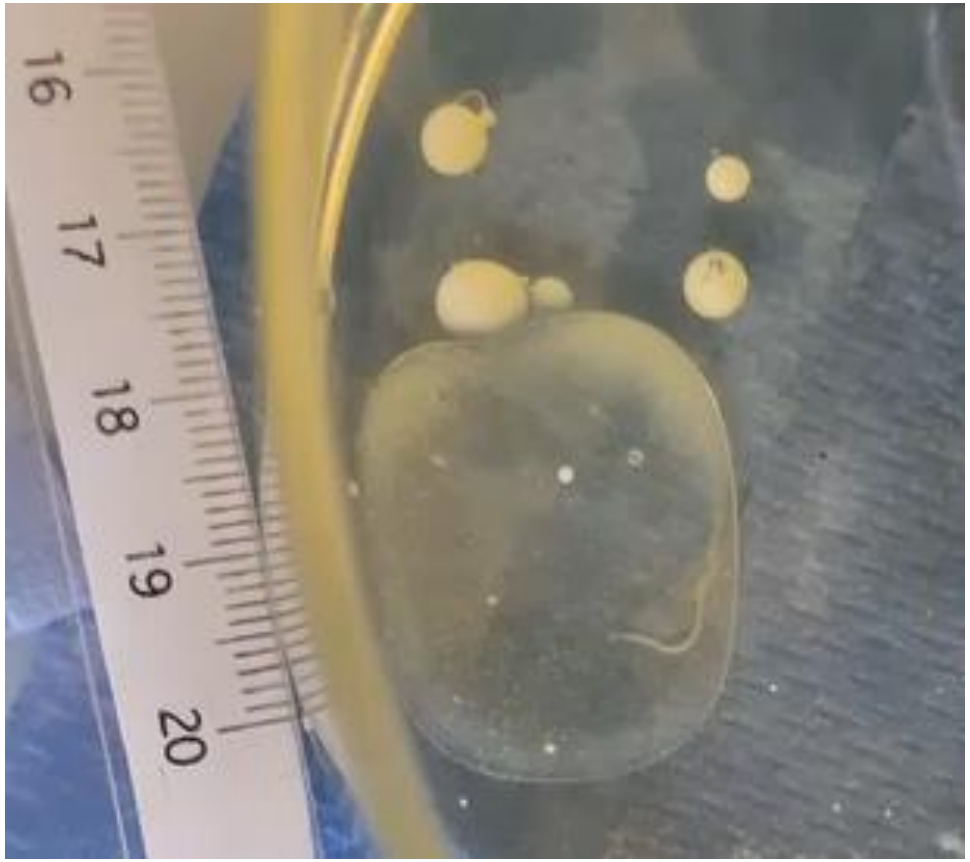
Growth of instability: $\omega t \propto kh$ no speed dependence !



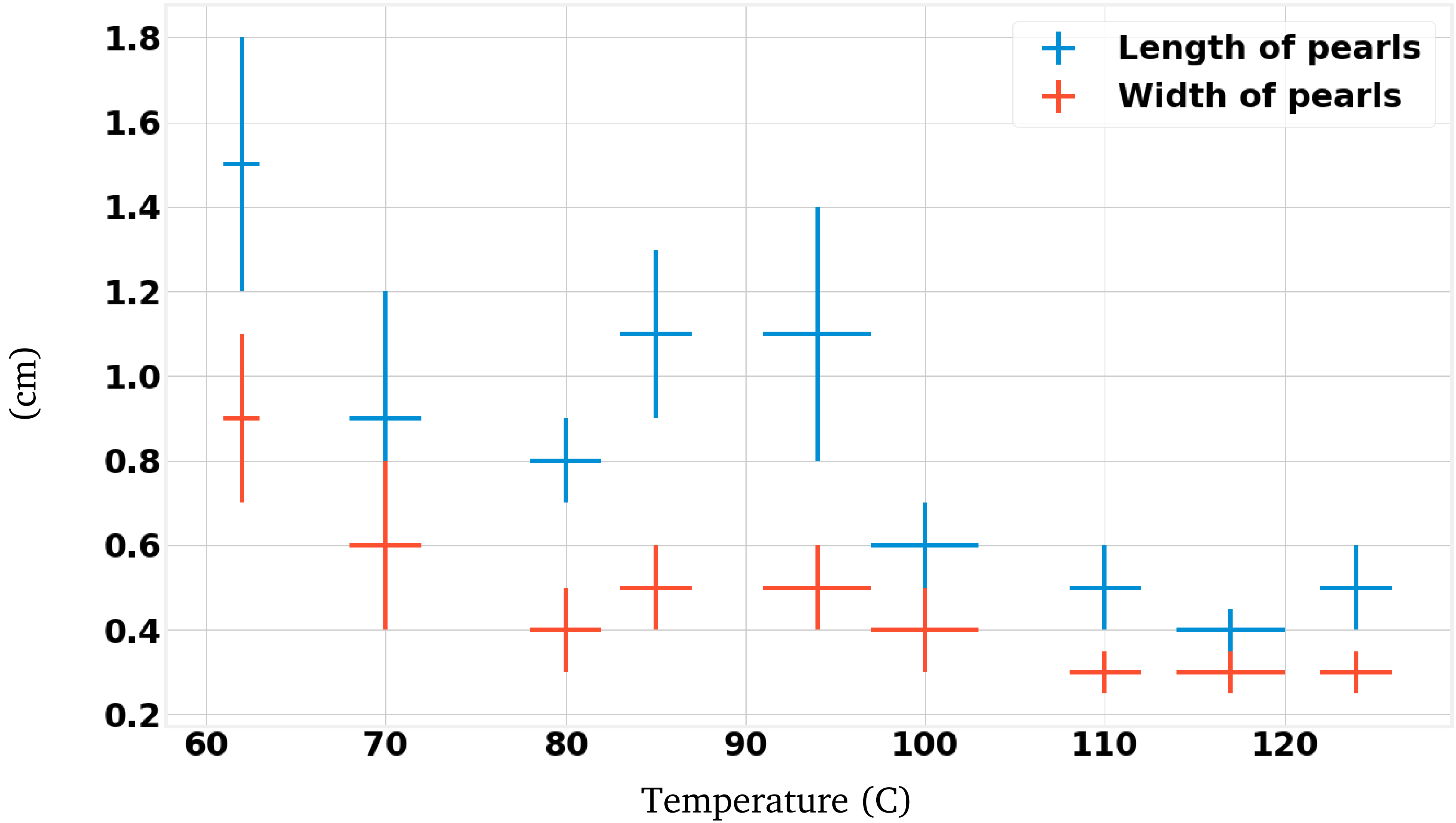
True for injection speed ≫ translation speed

Influence of oil temperature

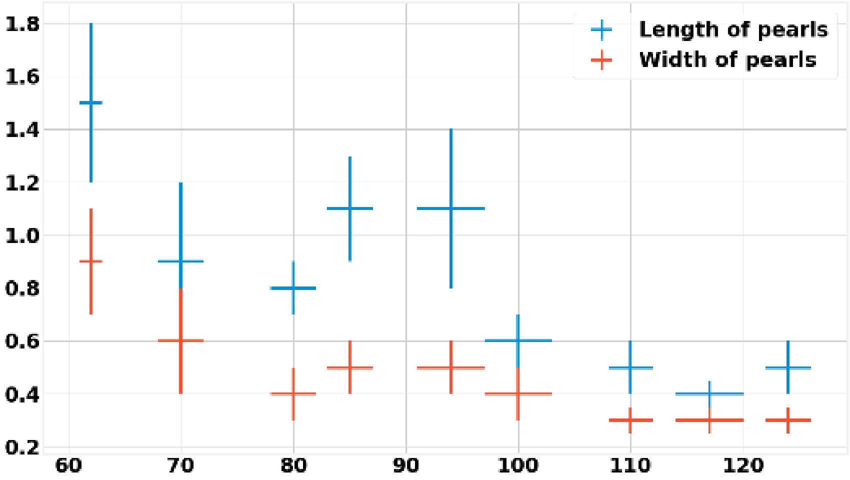
Dilatation is negligible

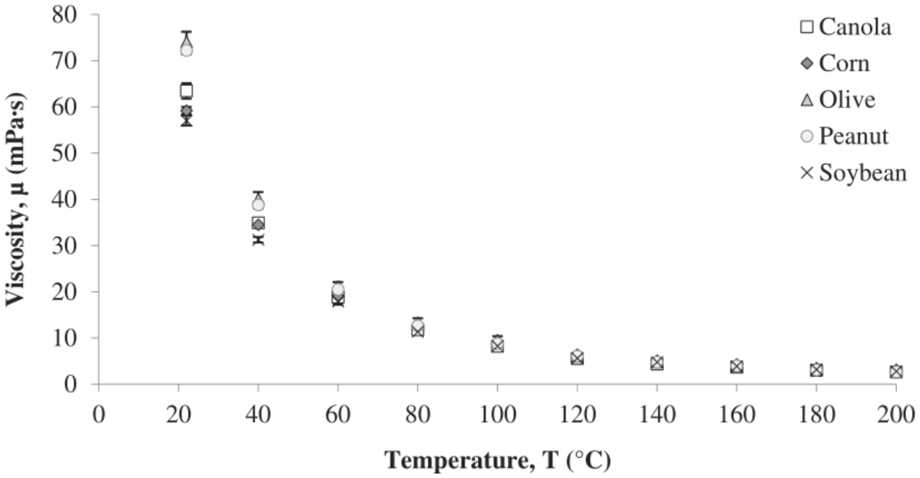


Influence of oil temperature



Influence of oil temperature





Temperature increases ⇒ viscosity decreases

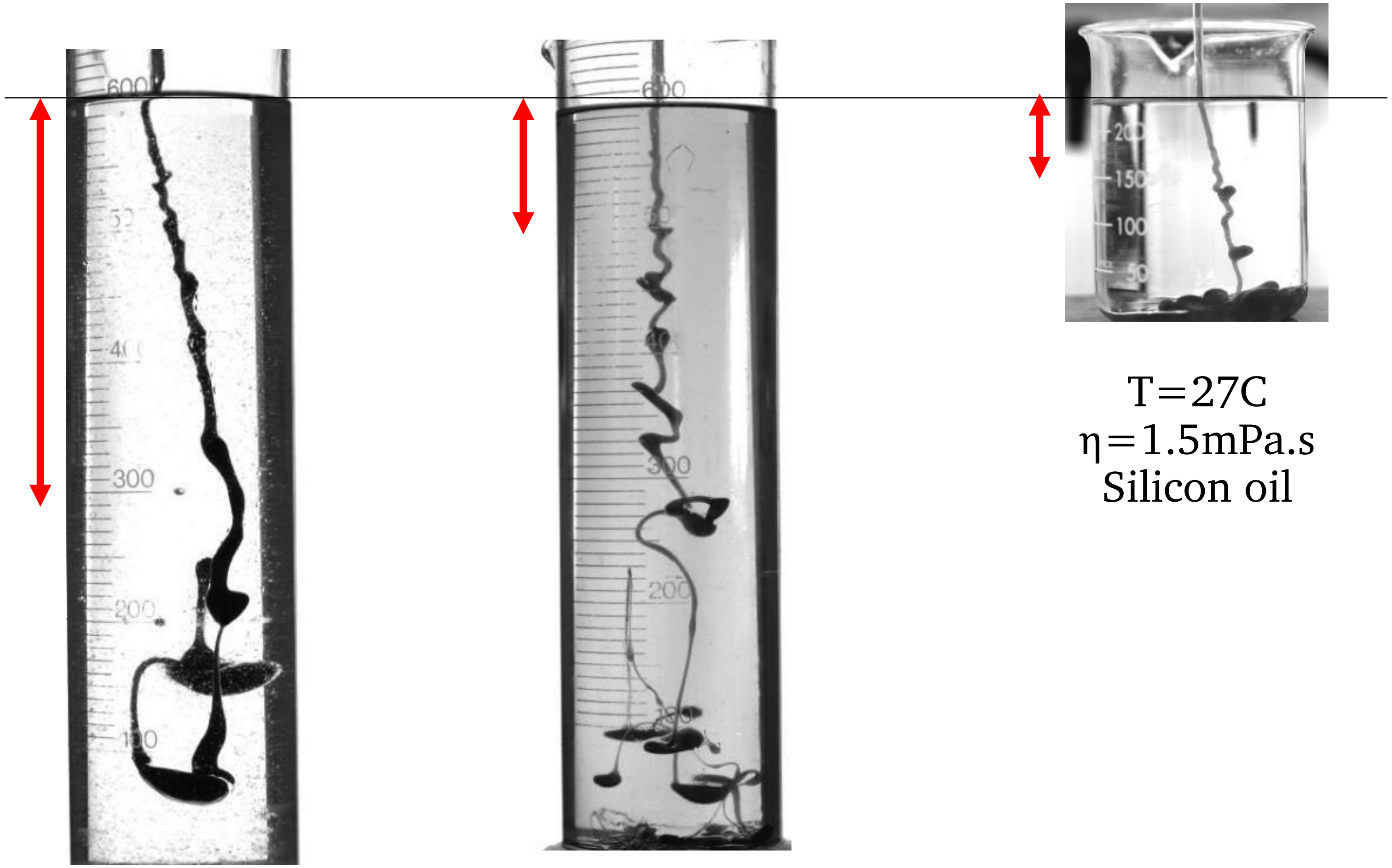
Viscous K-Helmholtz dispersion relation: $\omega \approx k^2\mu - f(k)$

Fastest growing wavenumber: $k = \frac{-f'}{2\mu}$

Wavelength $2\pi/k$ decreases with temperature

Sahasrabudhe - Density, viscosity, and surface tension of five vegetable oils at elevated temperatures: Measurement and modeling, IJFP 2017
Funada - Viscous potential flow analysis of Kelvin-Helmholtz instability in a channel, JFM 2001

Influence of oil temperature

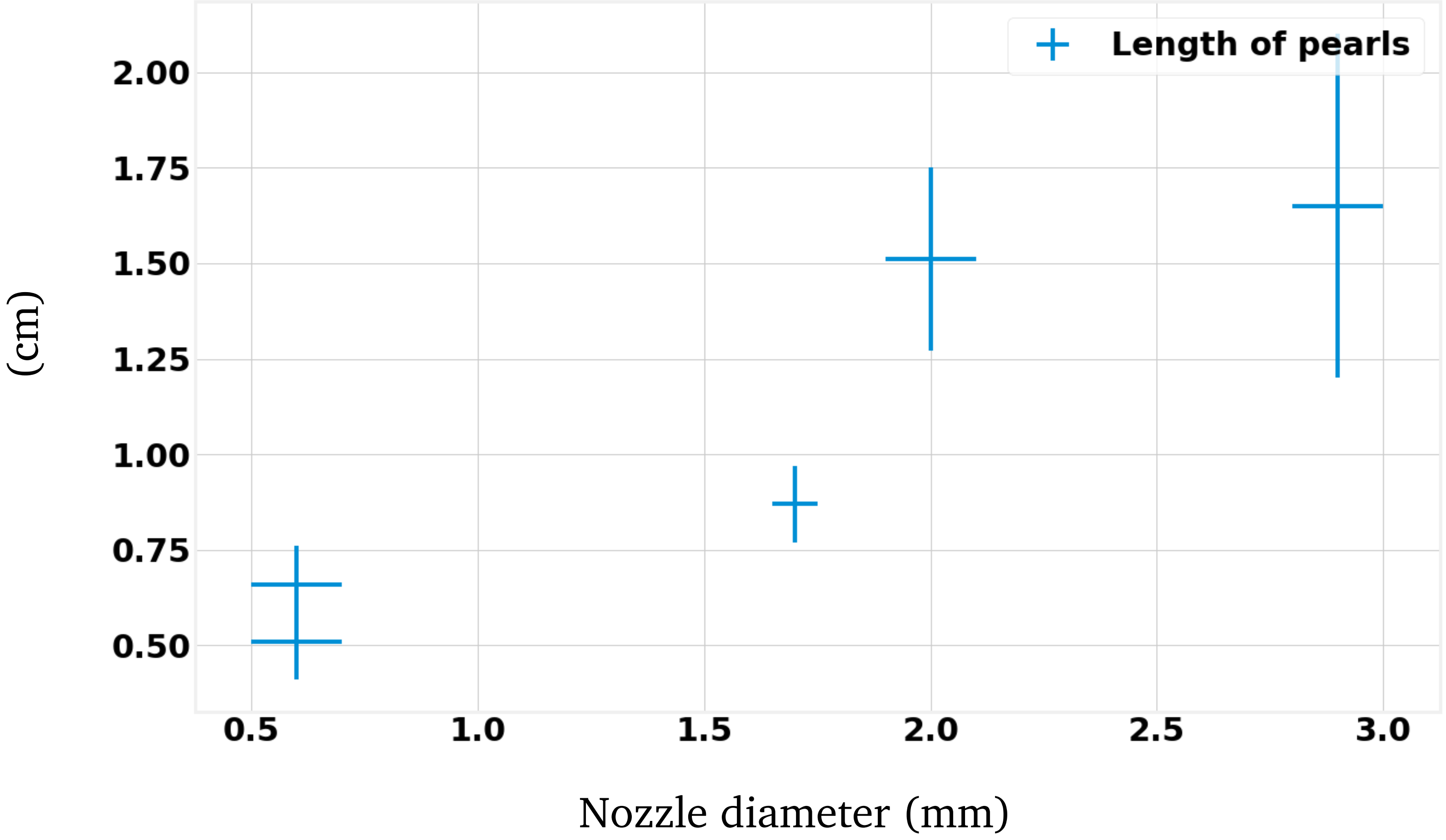


T=38C
η=40mPa.s

T=107C
η=7mPa.s

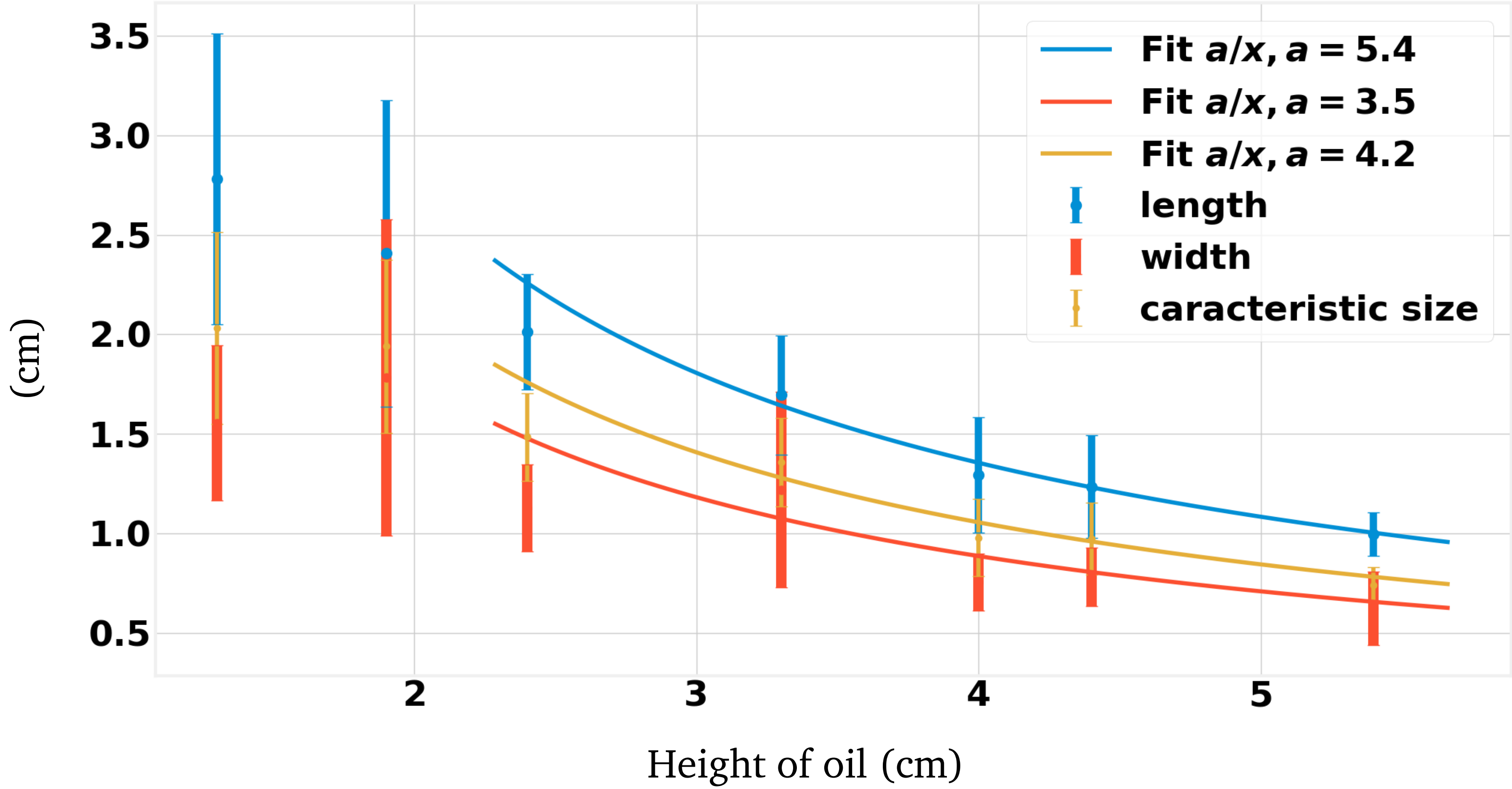
T=27C
η=1.5mPa.s
Silicon oil

Influence of nozzle diameter

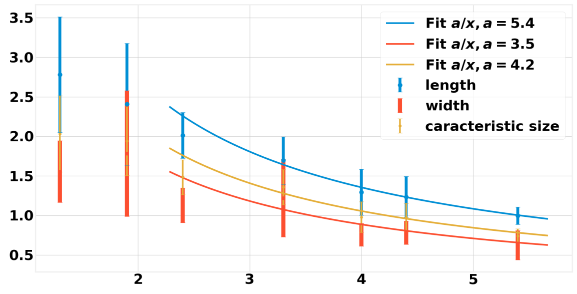


Diameter increase ⇒ Shear reduction
⇒ slower instability ⇒ less small pearls

Height of oil

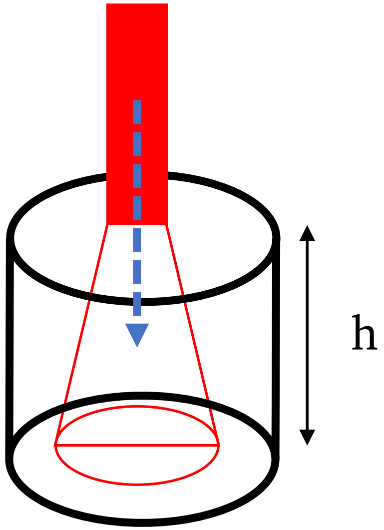


Height of oil



Low heights: instability creates droplets
decrease of big pearls

Higher heights (>3cm): instability has stabilized
more dispersion of pearls
less merging



Hypothesis:

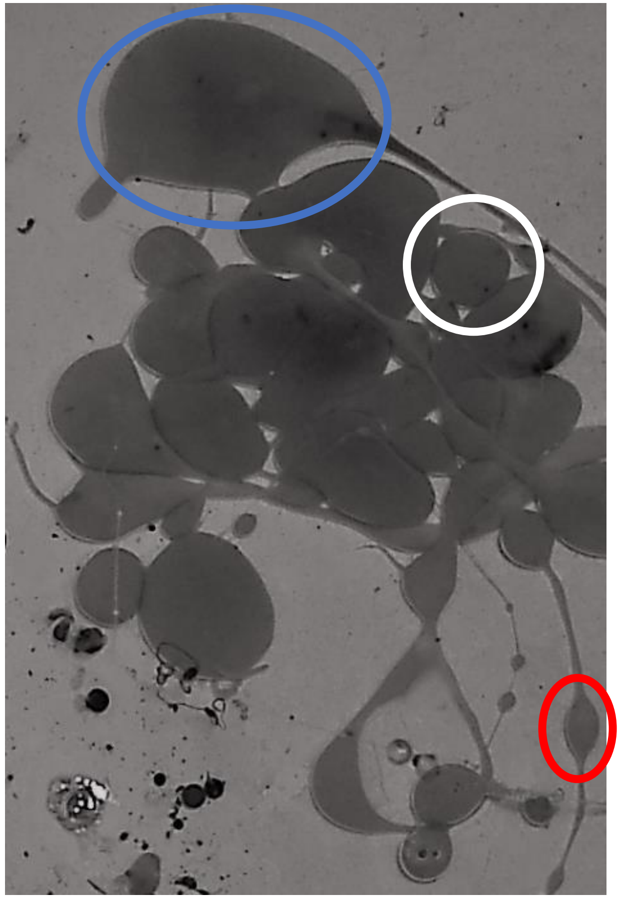
- Fixed pearl size before merging
- Uniform diffusion of pearls in a cone
- Fixed height of pearls

$$\frac{number\ of\ pearls\ before\ merging}{number\ of\ pearls\ after\ merging} \approx \frac{\sum area\ of\ one\ pearl}{bottom\ area}$$

$$L \propto \frac{1}{h}$$

Conclusion

Three kinds of pearls:



Big pearls ▸ accumulation and **inhomogeneities**

Medium pearls ▸ Kelvin-Helmholtz **instability** driven by **shear-thinning behavior**

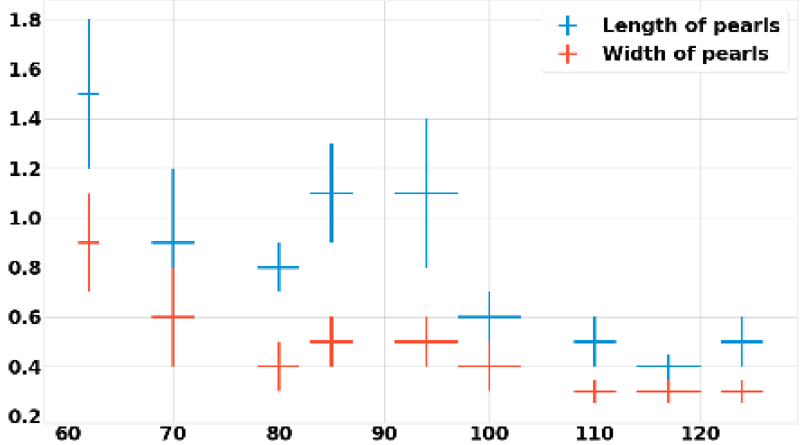
Small pearls ▸ Rayleigh-Plateau **instability** driven by **viscoelastic behavior**

Conclusion

How does **the size** of the egg white pearls produced depend on the various parameters such as the **temperature** of the oil, **ejection and motion speed**, nozzle **diameter** or the **non-Newtonian properties** of egg whites?

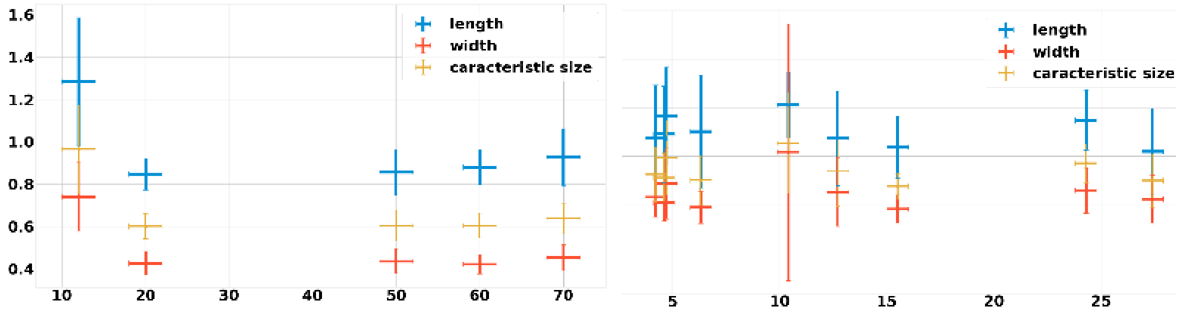
Influence on the size of pearls :

Decreases with **temperature** of the oil ▸ Viscosity decreases

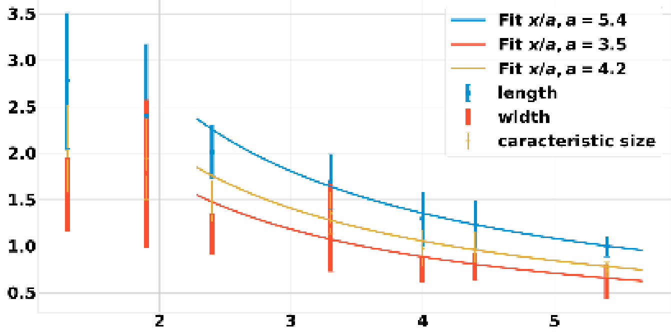


Constant with **speed** (translation/injection)

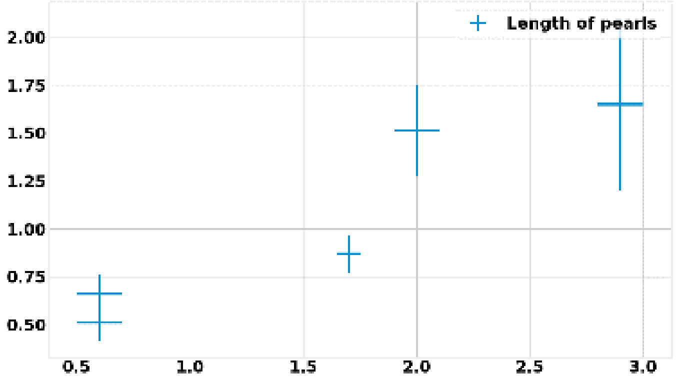
▸ $\omega t = kh$



Decreases with oil **height** ▸ merging of pearls $L \propto \frac{1}{h}$



Decreases with **diameter** ▸ Slower instability



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ADDITIONAL SLIDES

Team Ecole polytechnique