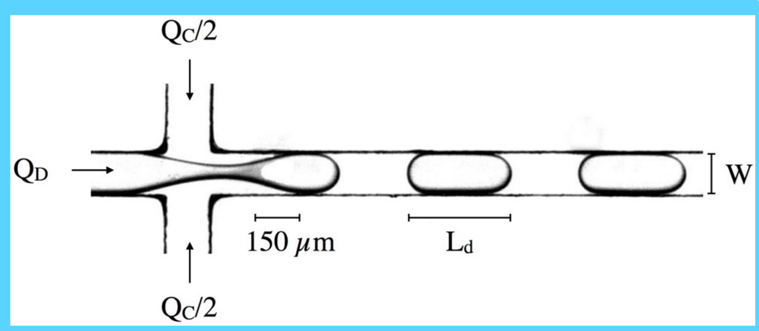
How do droplets form ?

Stéphanie van Loo [1,2], Serguei Stoukatch [2], Michael Kraft [2] & Tristan Gilet [1]

1 Introduction

- Experimental study of droplet formation in a microfluidic cross-junction, the simplest geometry.
- Two configurations: with and without surfactant.
- Two steps identified during squeezing: filling and pinching.
- Different production regimes are observed as Capillary number (Ca) and flow rate ratio (ϕ) are varied in a large range.



2 Parameters

Fixed: H, W, μ_D, μ_C, σ Varied: Q_D, Q_C

$$W^* = \frac{W}{H} \qquad Ca = \frac{1}{WH}\frac{\mu Q_C}{\sigma}$$

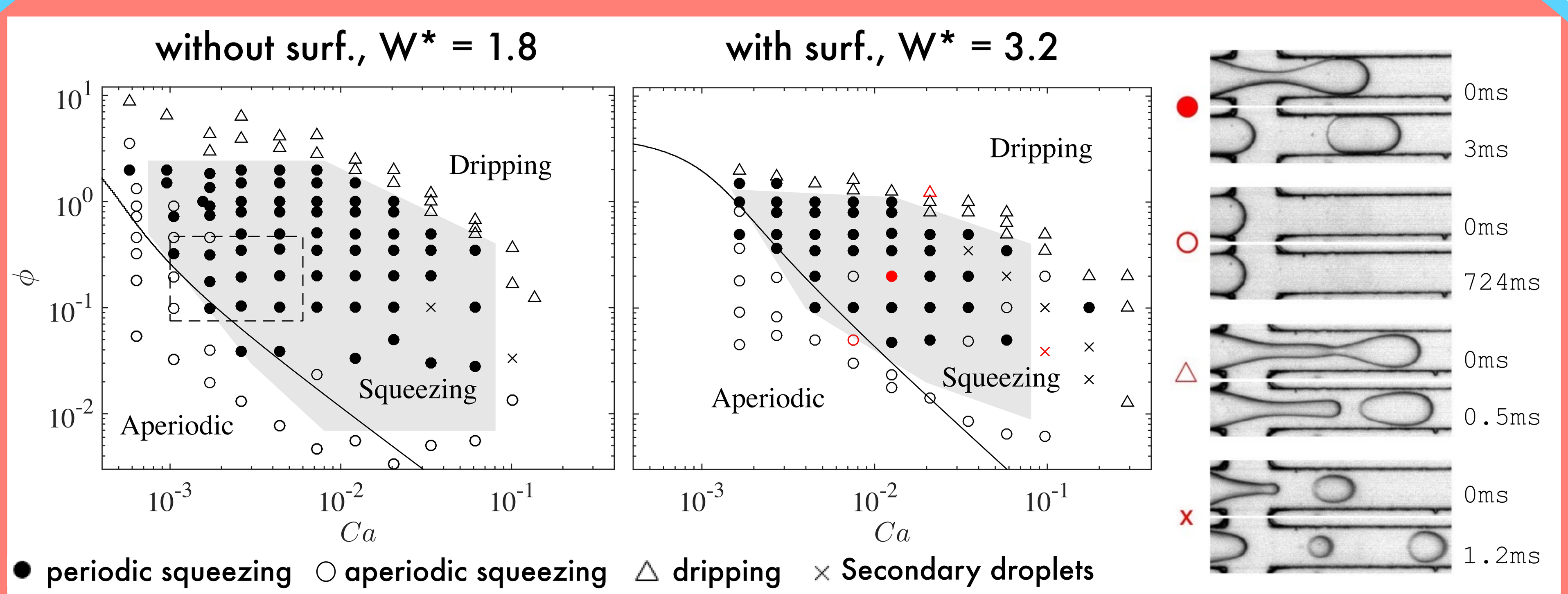
$$\eta = \frac{\mu_D}{\mu_C} \qquad \phi = \frac{Q_D}{Q_C}$$

Dimensionless

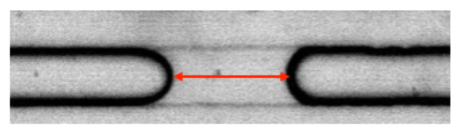
Output: L_d, F_d (droplet frequency)

$$\Omega = \frac{Q_D}{F_d W^2 H}$$

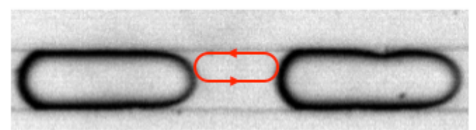
3 Phase diagrams



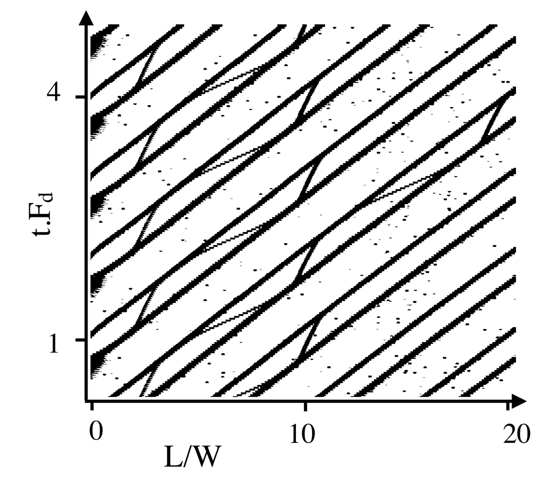
4 Satellite droplets



Satellite droplet looping in the vertical plane between two main droplets.

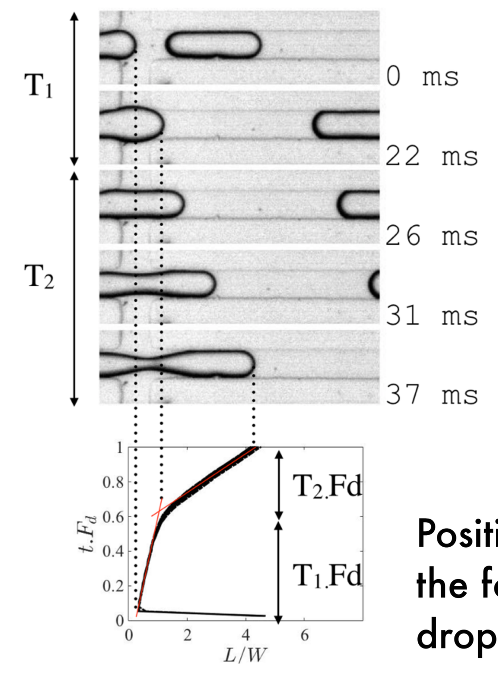


Satellite droplet looping in the horizontal plane between two main droplets.



Spatio-temporal diagram

5 Time decomposition



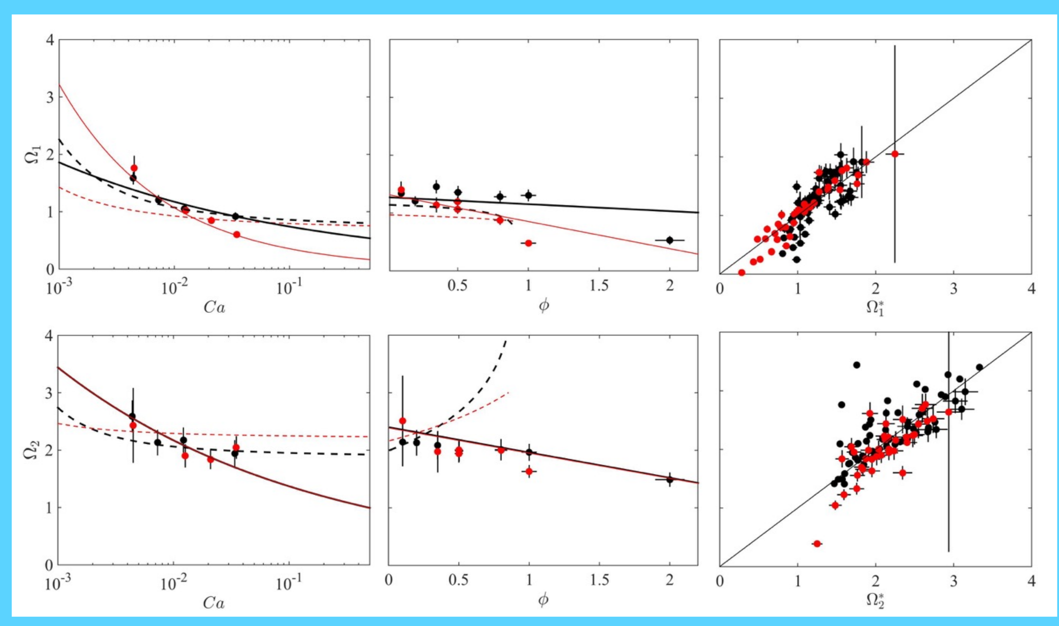
Two steps during squeezing: Filling (T_1) and pinching (T_2).

$$\Omega = \frac{Q_D}{F_d}\frac{1}{W^2 H} = (T_1 + T_2) Q_D \frac{1}{W^2 H}$$

$$\boxed{= \Omega_1 + \Omega_2 \phi}$$

Position of the front interface during the formation of 10 successive droplets.

6 Ω_1, Ω_2



Ω_1 & Ω_2 vs. Ca (resp. ϕ) with fixed ϕ (resp. Ca).
Solid line = fit on the whole dataset.
Dashed line = model of Chen et al. [1].
● without surf. ● with surf.

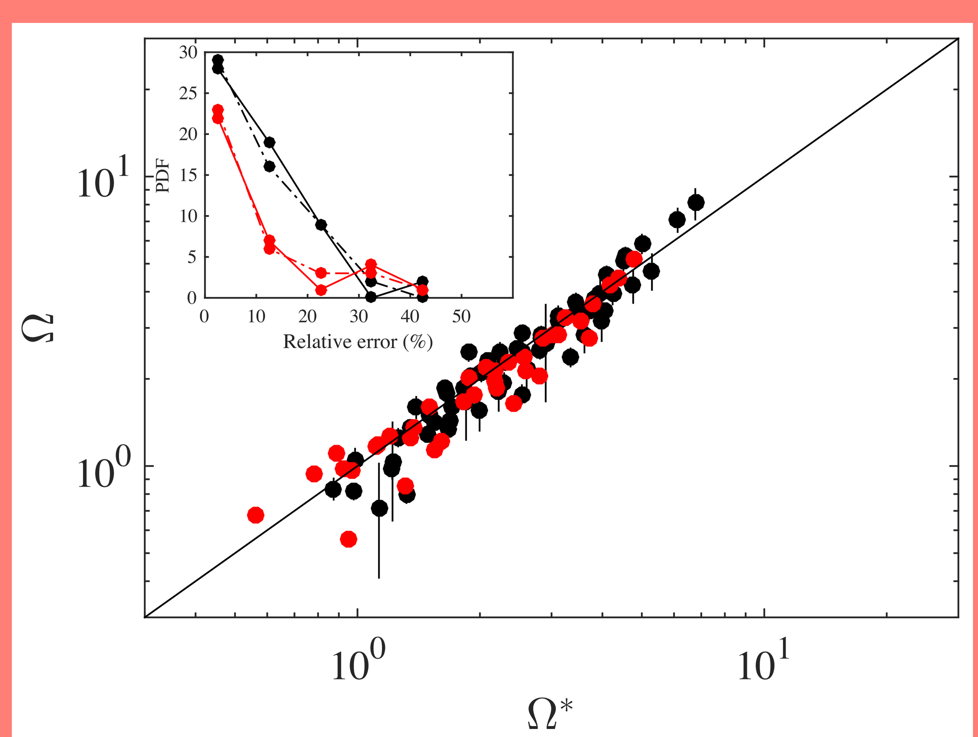
→ Ω_1 & Ω_2 expressed as the product of a function of Ca and a function of ϕ

$$\Omega_i^* = Ca^{-A_i}(C_i - B_i\phi), \qquad i \in \{1, 2\}$$

Step i	1: Filling		2: Pinching
Surfactant	S_o	S_w	S_o or S_w
A_i	**0.20**	0.48	**0.20**
B_i	*0.045*	*0.045*	0.16
C_i	0.48	0.13	0.90

Simplified fitting parameters.

7 Prediction of Ω



Parity plot of measured dimensionless volume Ω vs. empirical Ω^*

8 Conclusion

- Model valid for large range of Ca & ϕ (extended range compared to previous models - limits of Chen's model)
- Influence of surfactant mainly on T_1
- Aspect ratio W* determined thanks to satellite droplets.

MICROFLUIDICS LAB
University of Liège

Stéphanie van Loo (svanloo@ulg.ac.be)
(1) Microfluidics Lab, department of Aerospace and Mechanical Engineering, University of Liège, Belgium
(2) Microsys Lab, department of Electrical Engineering and Computer Science, University of Liège, Belgium

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References

[1] Chen et al., Microfluid. Nanofluid., 2014, 18.
[2] S. van Loo et al., Microfluid. Nanofluid 2016, under review.