Flipping: A Control Strategy for Centrifugal Microfluidic Systems

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1. Introduction

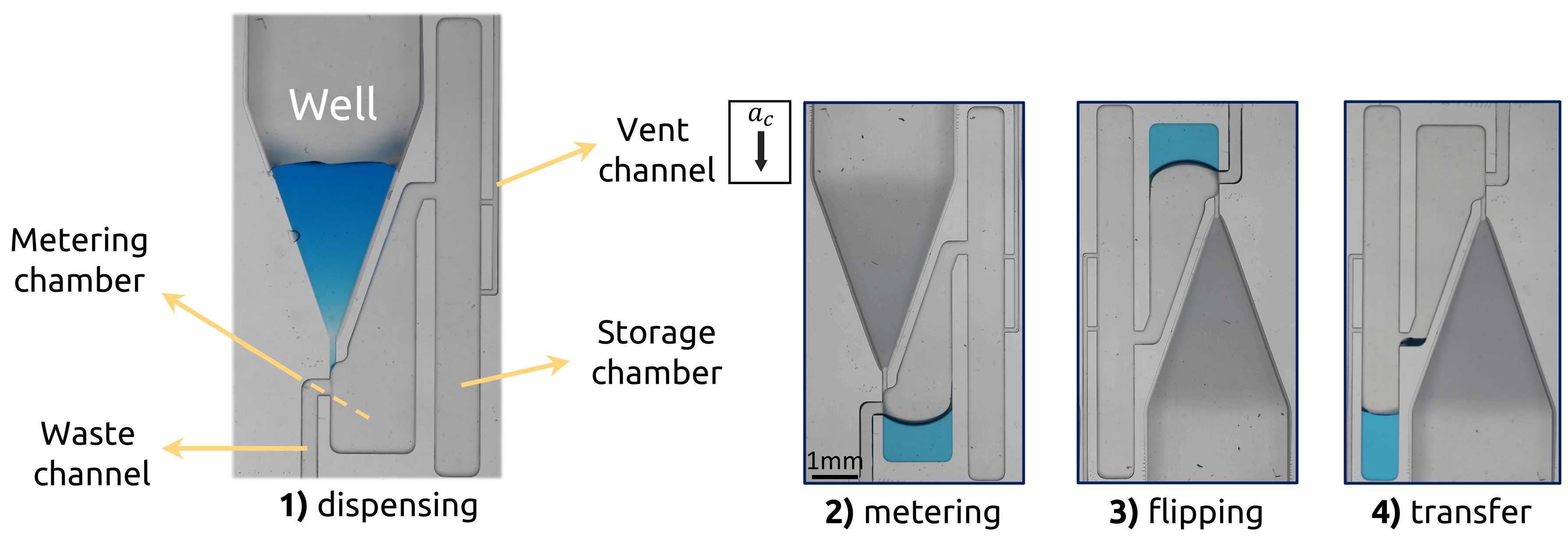
❑ **Valves are usually required for controlling fluid flow in centrifugal microfluidics**

a) Passive valves are:

- Operated by varying the angular speed of the rotating device (e.g., disk)
- Geometry and size-dependent
- Simple and low-cost
- **NOT sufficiently** robust to run complex sequences of microfluidic functions

b) Active valves are:

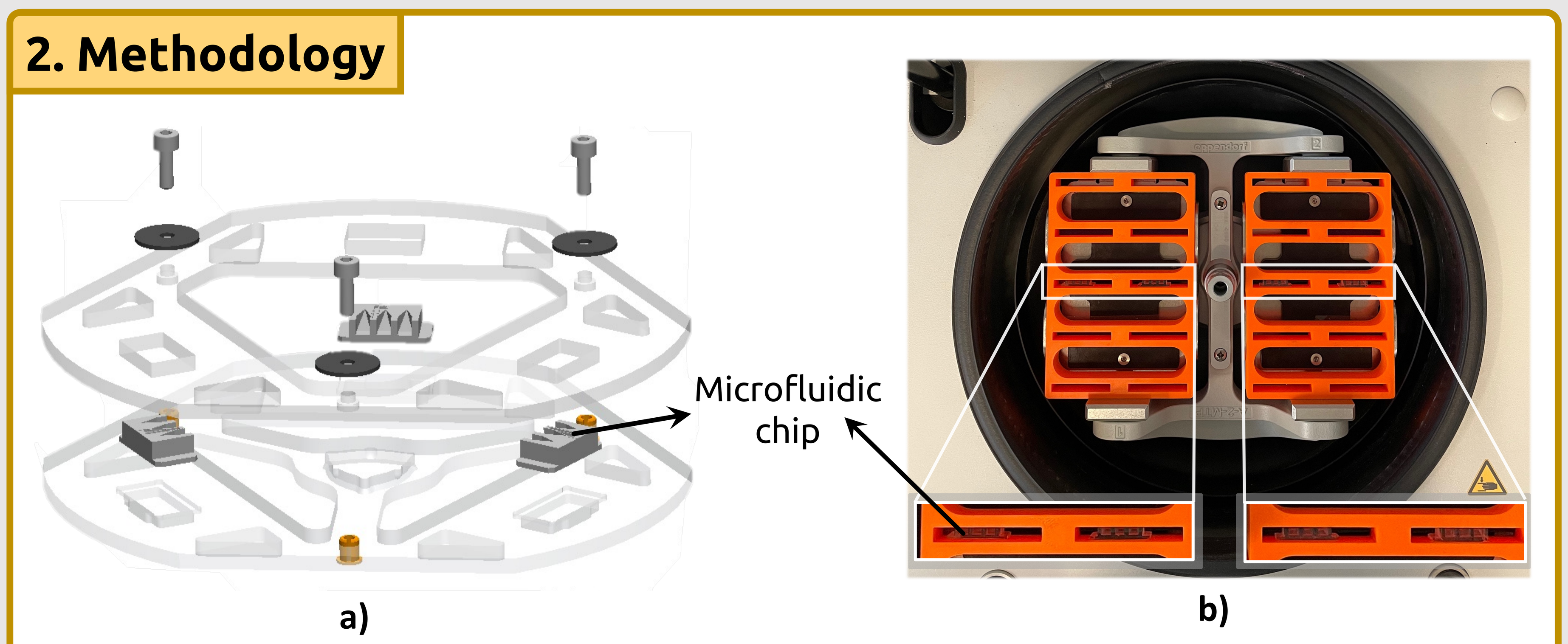
- Operated by external stimulation (e.g., heat, magnetic force)
- Event-triggered and effective
- **NOT** as simple and low-cost to fabricate as passive valves



❑ **Flipping suggested as a valve-free strategy to control fluid flow**

- Metering chamber decoupled from further microfluidic units
- Simple and low-cost for manufacturing
- Robust to run sequential microfluidic functions

2. Methodology



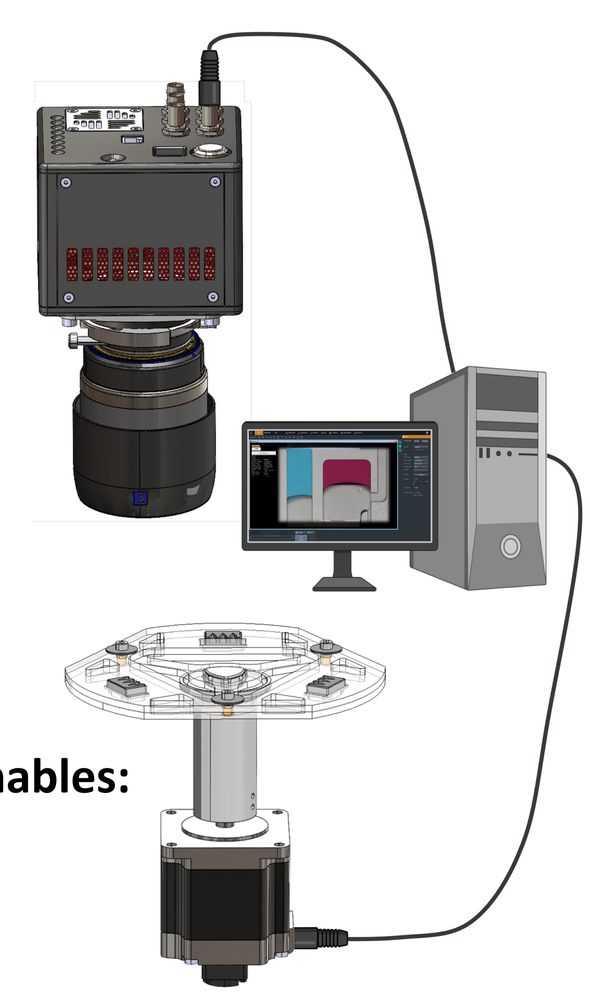
❑ **Microfluidic chips were centrifuged in two configurations:**

a) Chip-*on*-a-disk:

- ➢ Microfluidic chips were clamped between two PMMA disks
- ➢ A home-made setup was developed to centrifuge the disk up to 3000 rpm (chip at 504 *g*)
- ➢ A camera was triggered to image the chip once per rotation

b) Chip-*off*-a-disk:

- ➢ Microfluidic chips were placed within a 3D-printed support
- ➢ This support was adapted to the swinging-bucket rotor of a conventional lab centrifuge for acceleration up to 2204 *g*

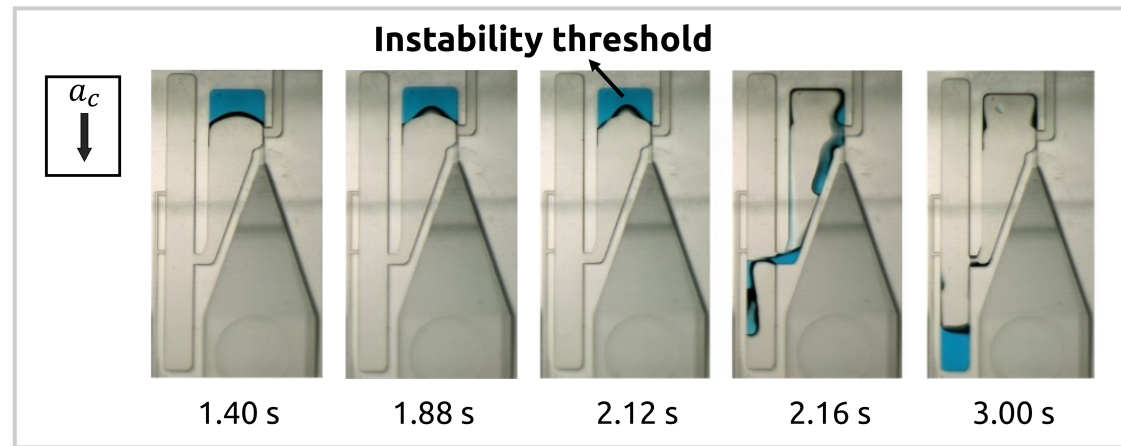


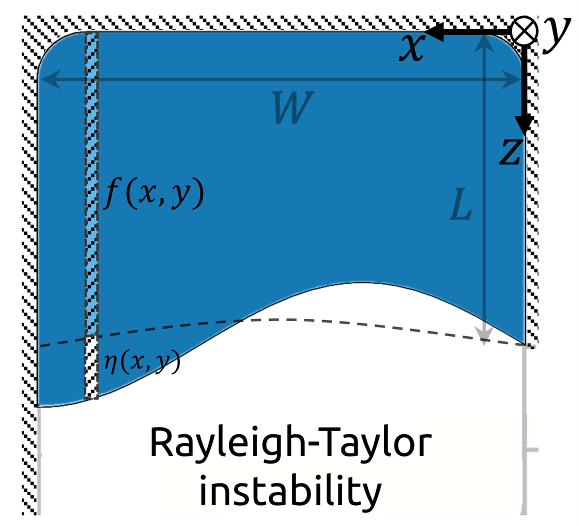
❑ **Decoupling microfluidic chips from rotating support enables:**

- ✓ Centrifugation of several microfluidic chips simultaneously
- ✓ Reorientation of each chip with respect to centrifugal force
- ✓ Fabrication of chips rather than disks at significant cost and time savings
- ✓ Fabrication of these chips out of different materials (e.g., PMMA, PDMS, 3D-printed chips)

3. Analytical Model

❑ **Instability Threshold:** Although the chip is flipped and centrifuged, the metered liquid may remain in the metering chamber below the threshold.





❑ **Instability threshold inferred from an energy analysis**

➢ Liquid transfer to the storage chamber when centrifugal force dominates capillary forces

$$z = f(x,y) + \eta(x,y,t) \longrightarrow a_c = \frac{\sigma}{\rho}\left(\frac{c_1}{W^2} + \frac{c_2}{WH} + \frac{c_3}{H^2}\right) \quad \text{where} \quad \frac{W}{H} > 1$$

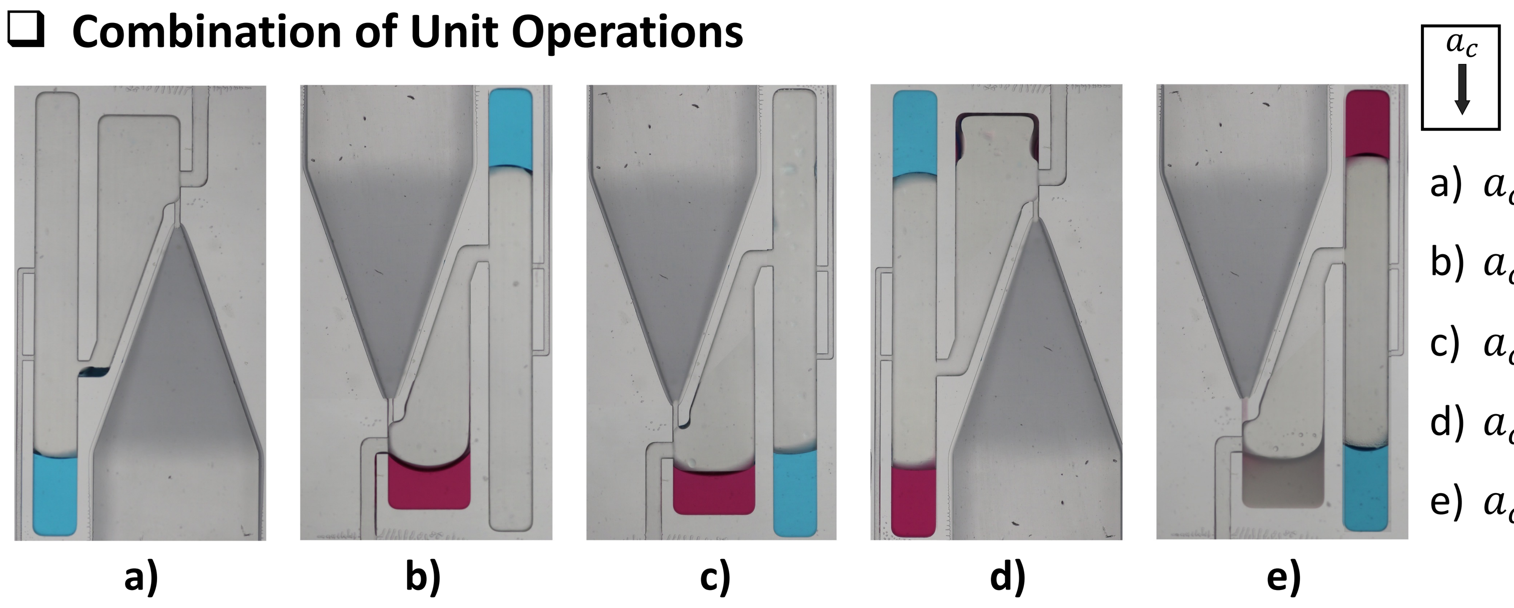
❑ **Involved parameters** c_1, c_2, c_3 = coefficients [-]

W = width [m] a_c = acceleration [m s^{-2}] η = perturbation function [m]

H = height [m] σ = surface tension [N m^{-1}] ρ = density [kg m^{-3}]

4. Results

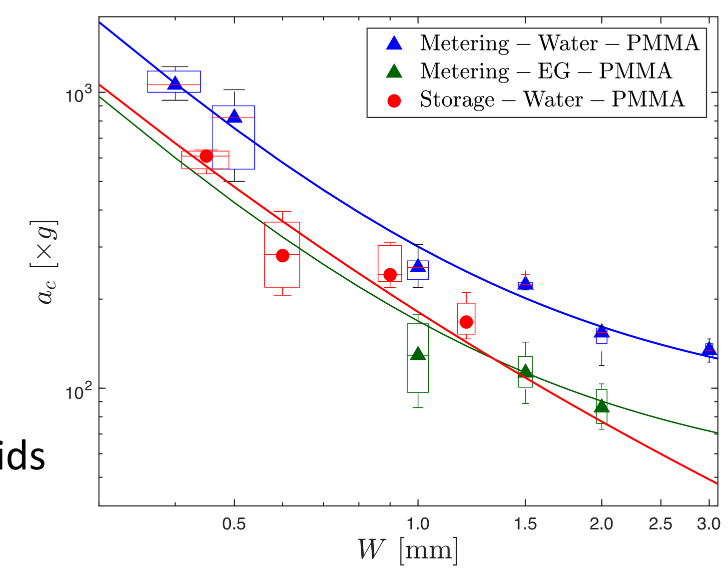
❑ **Combination of Unit Operations**

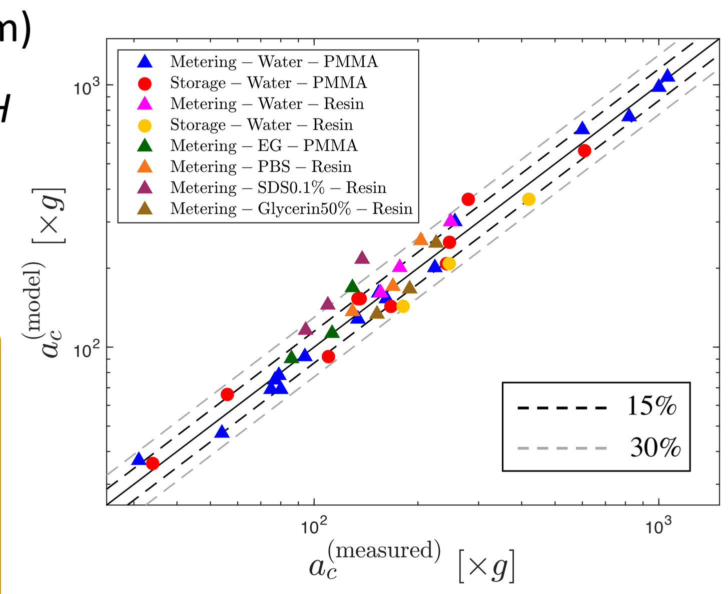


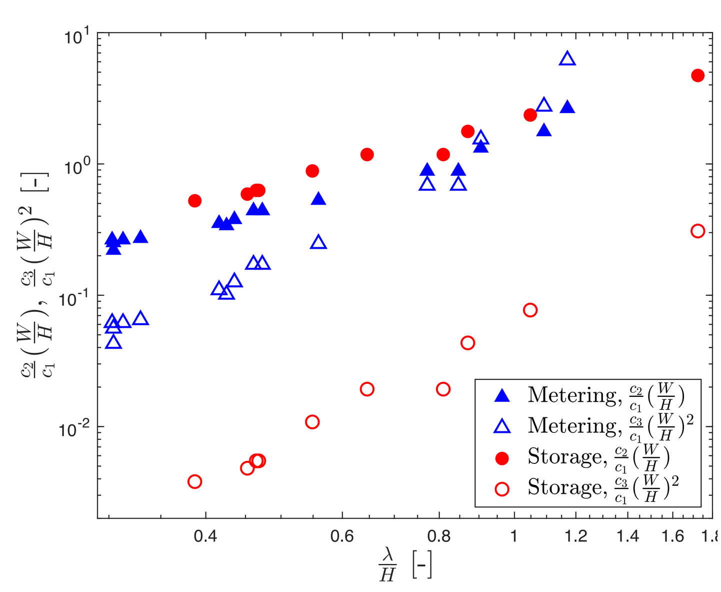
a) $a_c = 110\ g$
b) $a_c = 56\ g$
c) $a_c = 162\ g$
d) $a_c = 110\ g$
e) $a_c = 56\ g$

❑ **Linear fit of experimental data for different chambers**

- ➢ Smaller W and H yield a higher threshold (a_c)
- ➢ For given W and H the acceleration threshold (a_c) is:
  - ✓ Different for chambers with different boundary conditions
  - ✓ **NOT** dependent on liquid volume
- ➢ Dependence of a_c on σ/ρ validated for different liquids
- ➢ For effective capillary length $\lambda = \sqrt{\sigma/\rho a_c}$ at which:
  - ✓ $\lambda < H$ ➔ Flat interface ➔ a_c depends on W (c_1 term)
  - ✓ $\lambda > H$ ➔ Curved interface ➔ a_c depends on W & H
- ➢ **Metering:** $c_1 = 15.97, c_2 = 2.82, c_3 = 0.44$
- ➢ **Storage:** $c_1 = 8.17, c_2 = 3.21, c_3 = 0.017$







5. Conclusions

❖ **Clamping** microfluidic chips is an efficient strategy to test and develop microfluidic designs

❖ **Flipping** validated quantitively as a robust strategy to control fluid flow

❖ **No back flow** to inlet *well* guaranteed by the asymmetric boundary conditions in chamber

❖ **Chamber's *width* & *height*** are the key parameters setting the instability threshold

❖ **Physical model** predicts instability threshold

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Reference
Gholizadeh, Ali; Mazzucchelli, Gabriel; & Gilet, Tristan; (2024). Flipping: A Valve-Free Strategy to Control Fluid Flow in Centrifugal Microfluidic Systems. *Sensors and Actuators B: Chemical, 135778.*

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