Test methods session II

Measurement of flow quantities and volume

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Overview

- Based on MFMET Deliverable 3 [1] and experiments performed in activity 2.4.3 (to be published)
- Focus on measuring techniques for some flow quantities
- How to get traceable measurements

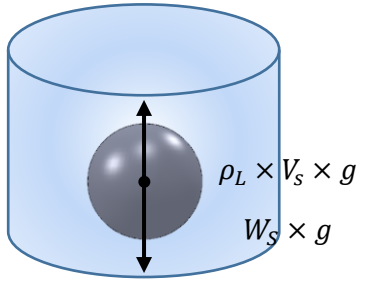
References:
[1] Büker, O. *et al.* (2024) Calibration guide for the evaluation of flow-related quantities in microfluidic devices, https://doi.org/10.5281/zenodo.11164417

Liquid properties

Establishing Metrology Standards in Microfluidic Devices

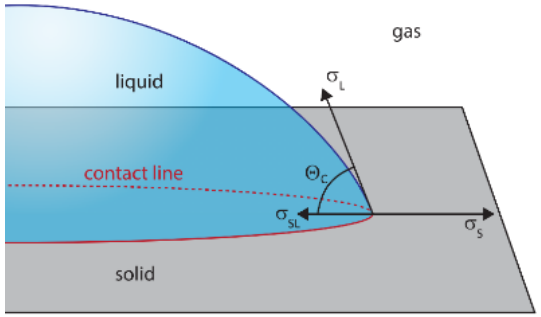
Interest of industry experts for anything that affects pressure drop and flow resistance in the device

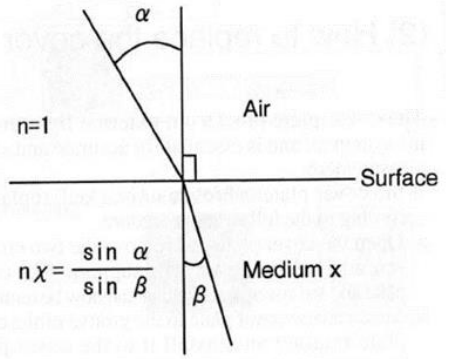
- Viscosity
- Density
- Contact angle
- Refractive index (optical methods)



More information in:

- [2] about normative definitions
- [3] about practical details
  traceability, dissemination of units, instruments
- in the following talk!





References:

[2] Akselli, B. *et al.* (2022) MFMET A2.2.1 - Literature review of existing metrology and normative standards related to the flow properties and microfluidic devices, doi: 10.5281/zenodo.6576473

[3] Batista, E. *et al.* (2023) MFMET A2.3.2: Test protocols for liquid properties related to microfluidic devices, doi: 10.5281/zenodo.7845225

Flow quantities

- Internal volume
- Flow rate
- Flow resistance

Focus

- Dead volume
- Droplet size/volume variation
- Flow pressure (inline pressure)

Reminder: see [1] for more info

References:
[1] Büker, O. *et al.* (2024) Calibration guide for the evaluation of flow-related quantities in microfluidic devices, https://doi.org/10.5281/zenodo.11164417

Internal volume

- Using a calibrated weighing scale…
- The volume is determined gravimetrically by weighing the chip to be calibrated when empty and when filled with a suitable liquid.
- Each channel is tested separately.
- The difference obtained in the weighing measurements gives the mass of the liquid contained in a particular channel.

Filled channels	Iteration 1 (g)	… (g)	Iteration 6 (g)	σ (g)	Average (g)
0	503,3263	…	503,3264	0,00005	503,3274
a	503,3308	…	503,3307	0,00005	503,3318
b	503,3311	…	503,3310	0,00008	503,3321
c	503,3308	…	503,3306	0,00006	503,3317
0	503,3260	…	503,3260	0,00000	503,3270

Filled channels	m (mg)	U (k=2) (mg)	**V (µL)**	**U (k=2) (µL)**
a	4,58	0,74	**4,59**	**1,49**
b	4,88	0,75	**4,89**	**1,50**
c	4,52	0,75	**4,52**	**1,49**

Bonus slide: details on the uncertainty budget

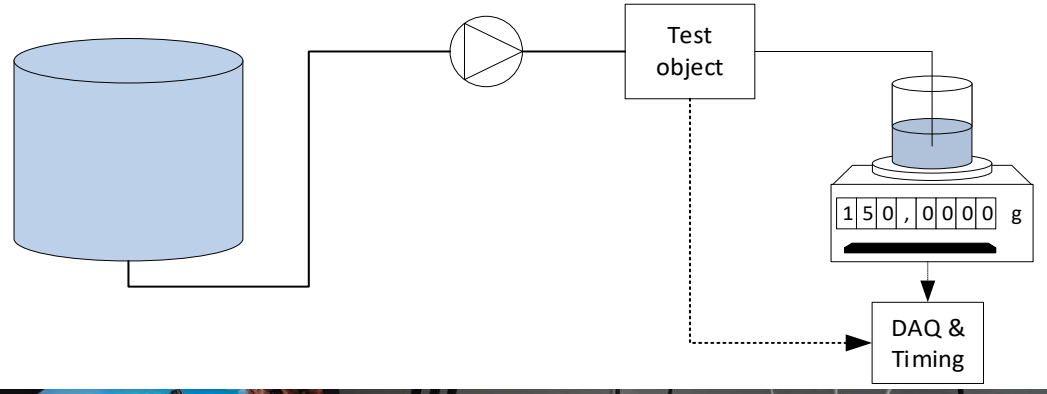
Flow rate: gravimetric method

- collection of liquid on a weighing scale while timing
- kg/s (density needed for m^3/s)
- factors of influence (uncertainty):

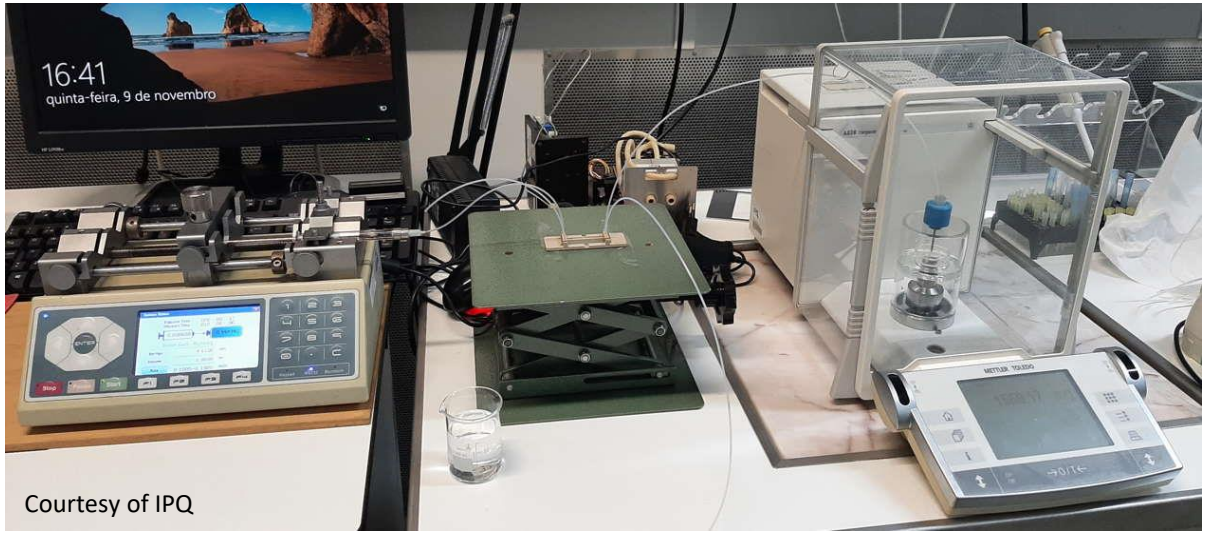
Evaporation
Ambient temperature and humidity

Buoyancy (Archimedes' principle with air)

Dissolved gas in the liquid



Surface tension between the liquid and the needle

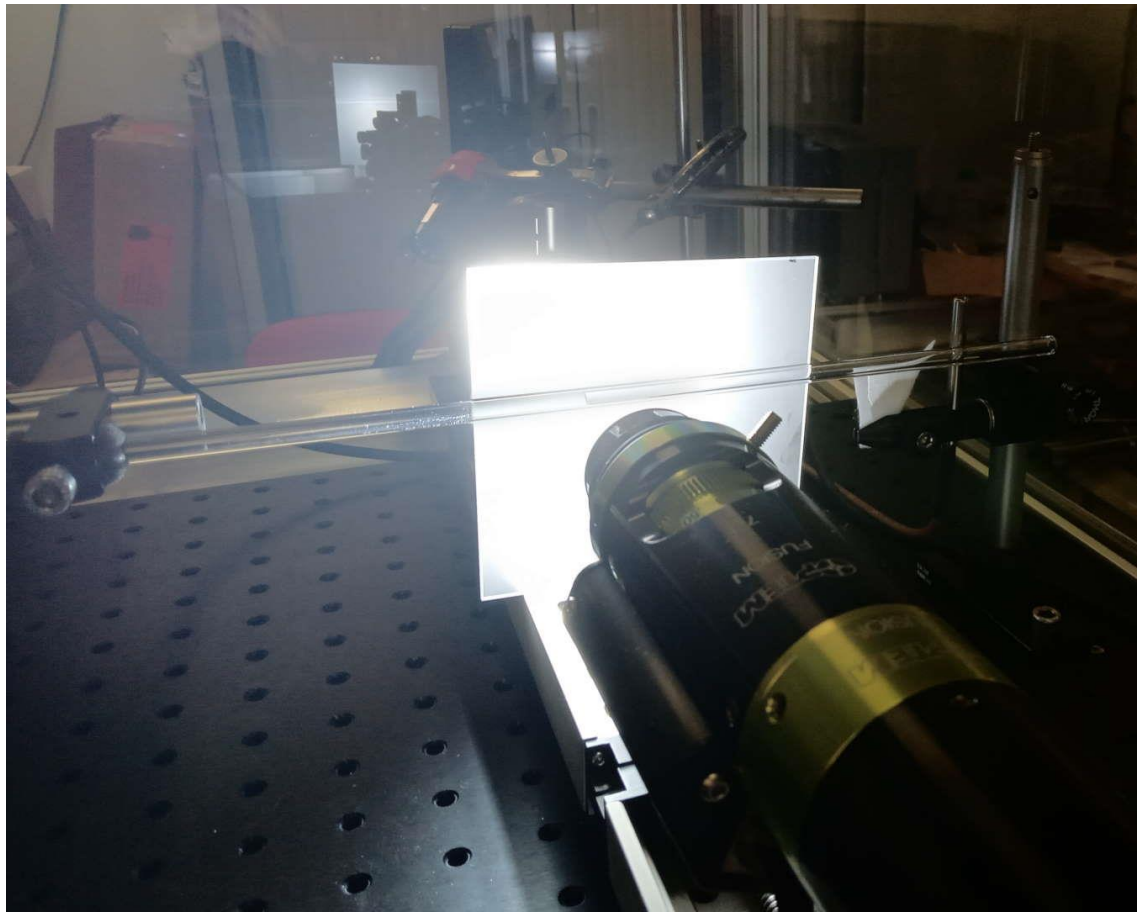


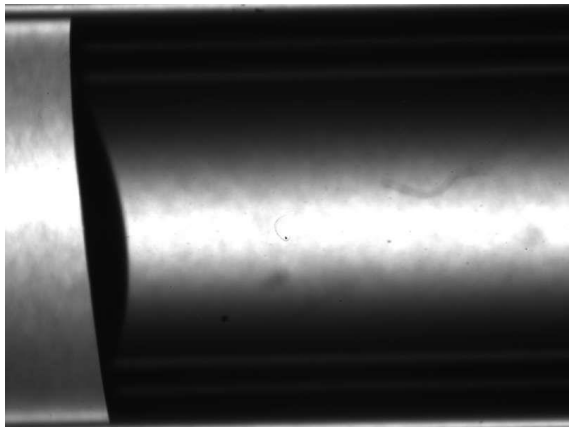
Courtesy of IPQ

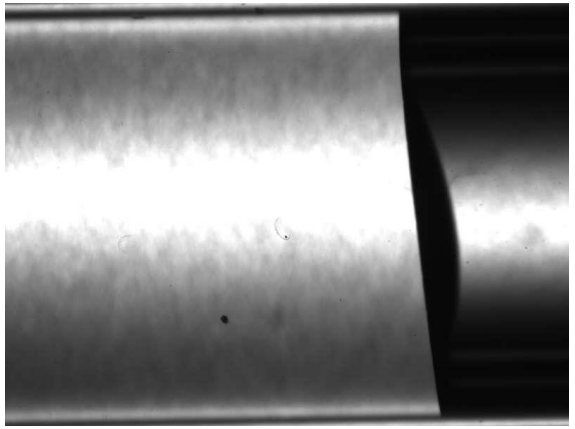
[Bonus slide: detailed uncertainty budget from [1]]

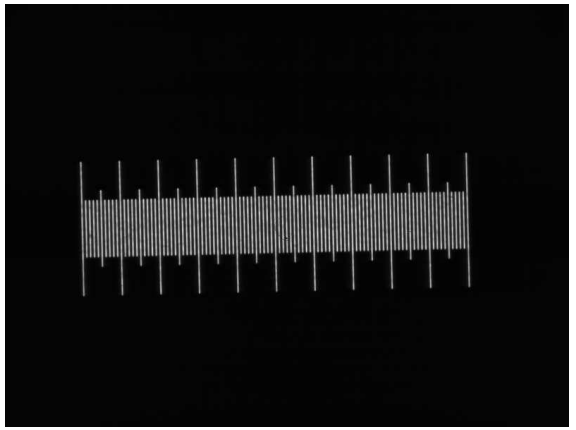
Flow rate: front track method

- Pictures from CETIAT bench, more info in PhD thesis [4]
- Method also available at IPQ, ask Elsa during the visit of IPQ this afternoon!







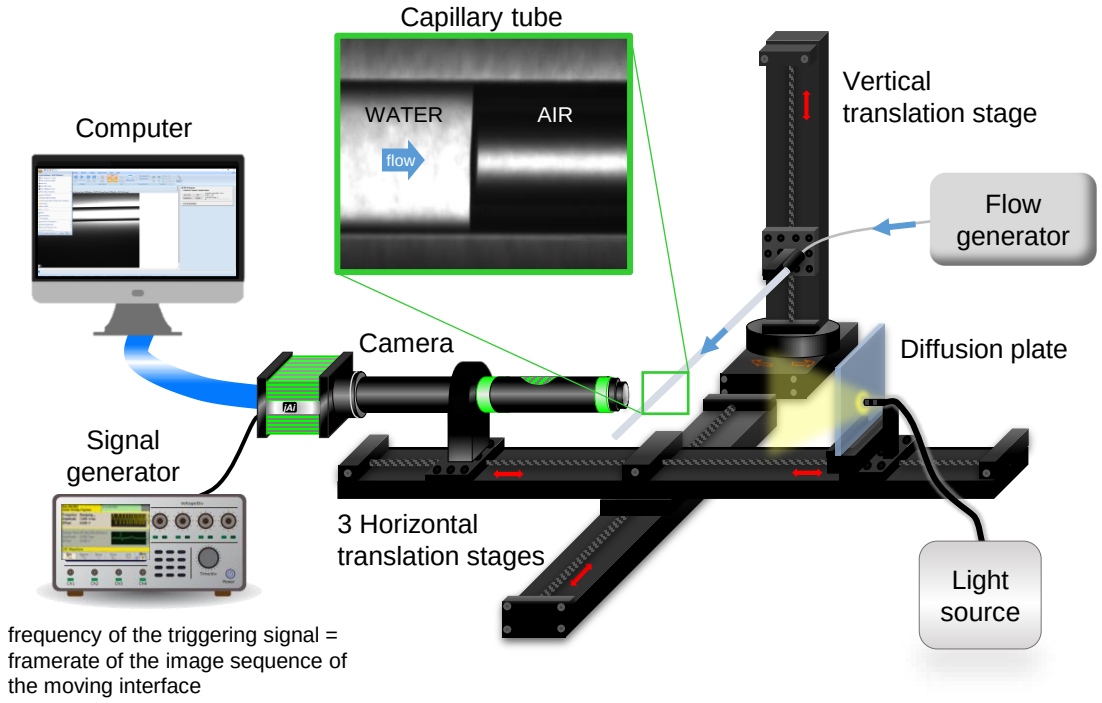


References:

[4] Boudaoud, A. (2022) Development of a Primary Standard for the Measurement of Nano-Flow Rates of Liquids, PhD thesis available at https://pastel.hal.science/tel-04187912

Flow rate: front track method

- filming the position of the meniscus over time + inner dimensions of capillary
- m^3/s (density needed for kg/s)



Q_v	flow rate
v	flow velocity
R	capillary's inner diameter
Δx	interface displacement
Δt	time interval between 2 images

$$Q_V = v.\pi R^2 = \frac{\Delta x}{\Delta t}\pi R^2$$

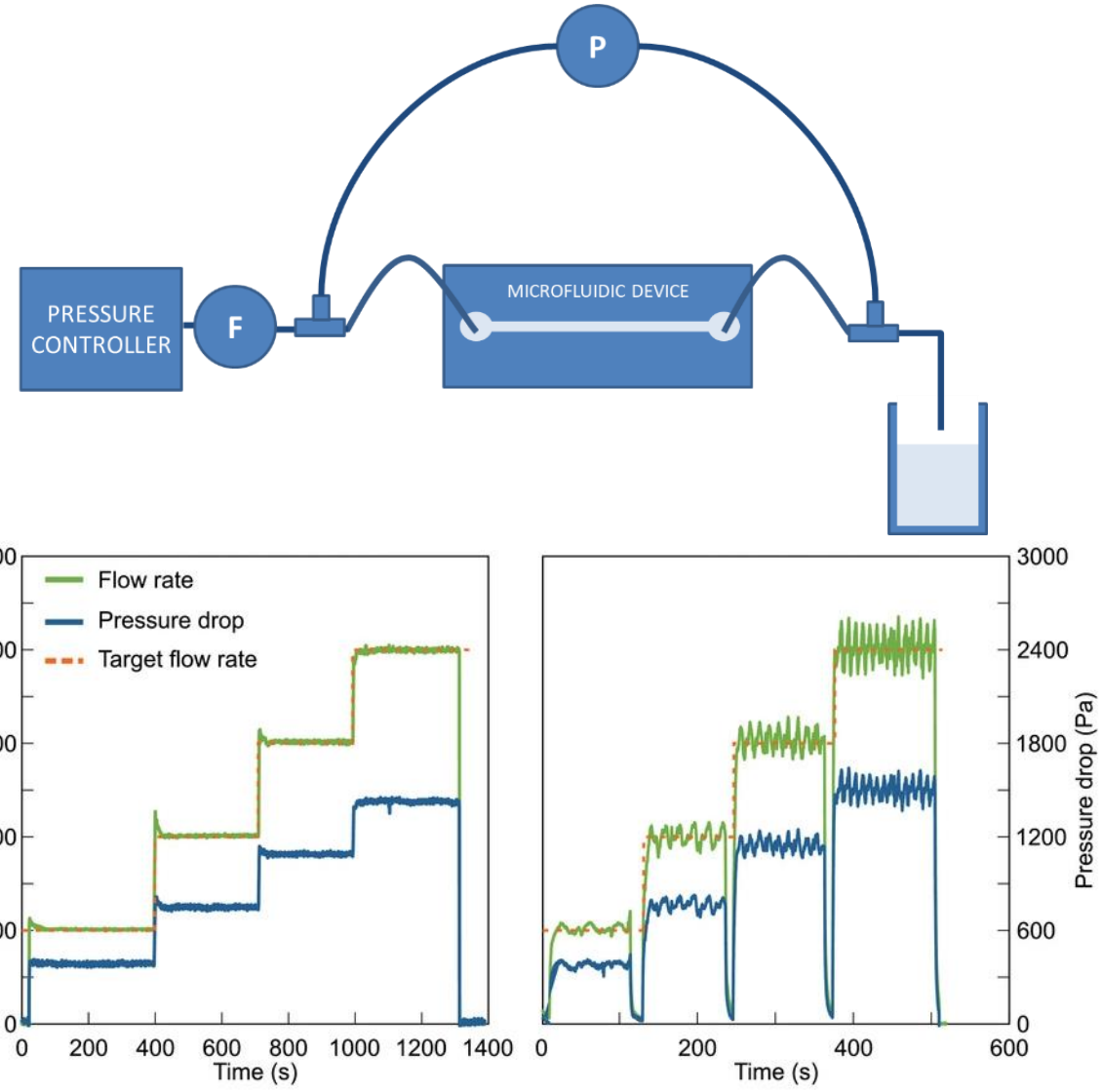
Bonus slide: detailed uncertainty budget from [1]

Flow resistance

- also called hydrodynamic resistance [5], in Pa·s/m³

$$\Delta P = Q \times R_H$$

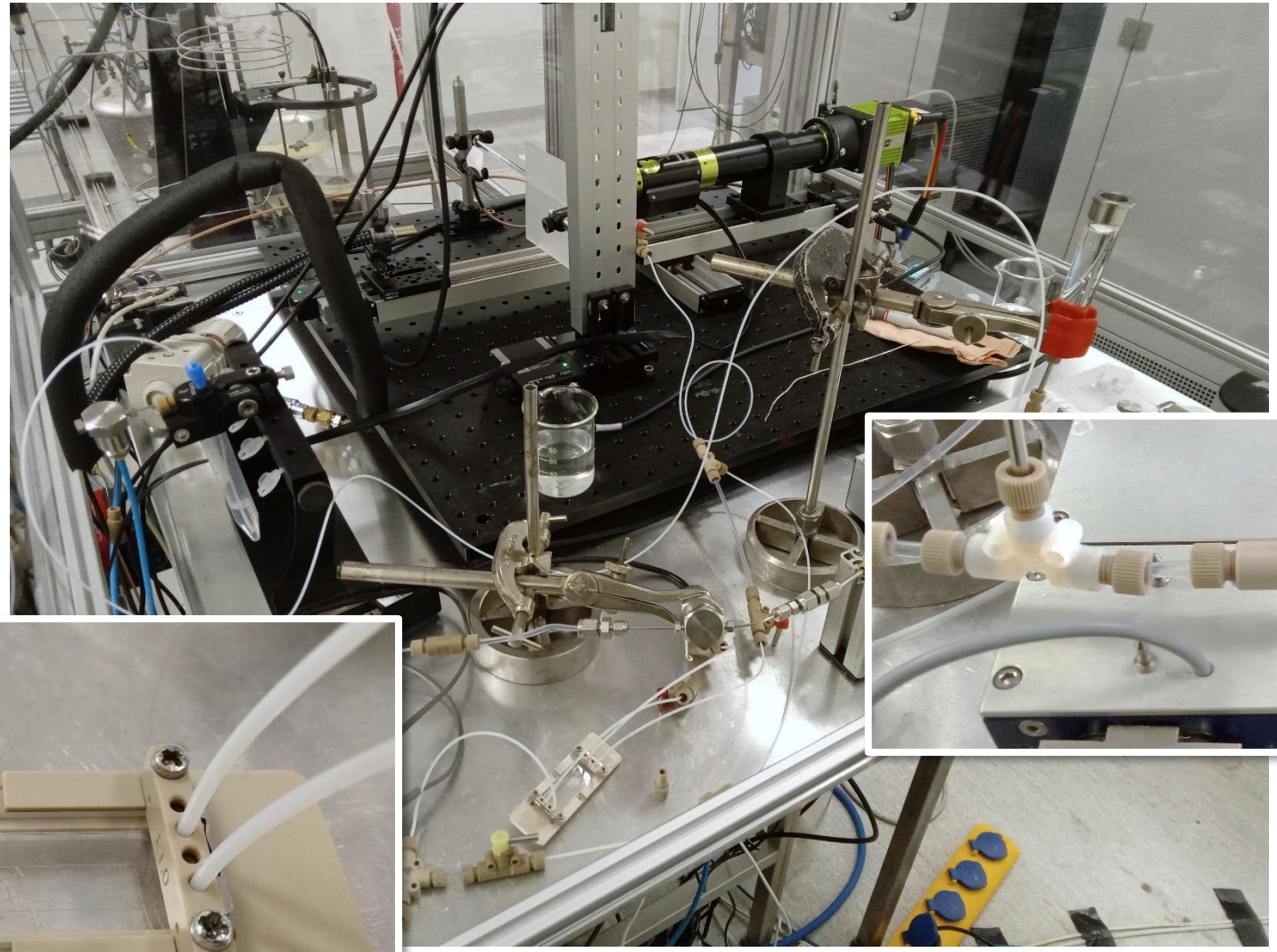
- chart of 'flow rate vs pressure'
- R_H depends on flow rate, dimensions, viscosity
- models for R_H depending on the shape of channels, common hypotheses:
  - Low Re number
  - Incompressible fluid
  - Unidirectional flow
  - Steady flow along the channel
  - Small fluid mass per distance unit, so gravity is negligible
  - Negligible surface tension forces
  - Negligible friction forces from the wall of the channel

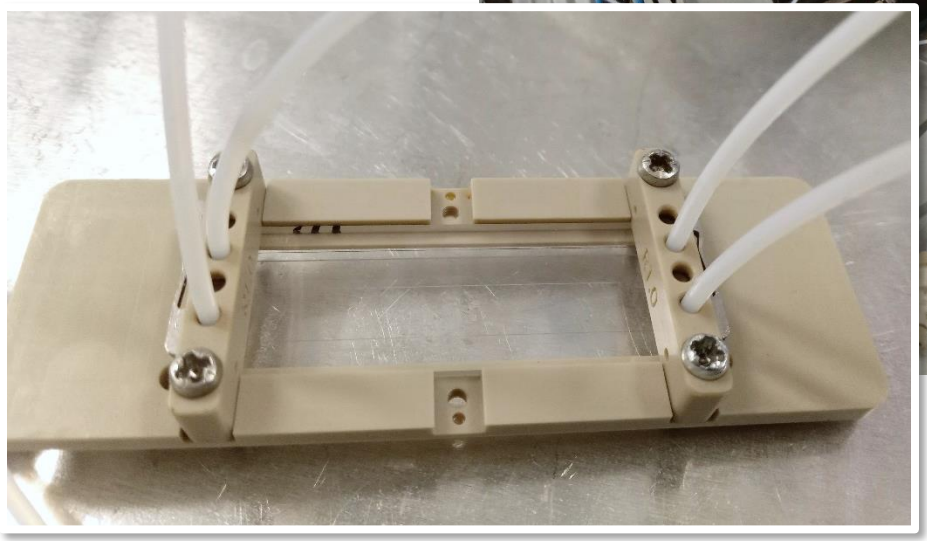


References:

[5] ISO 10991:2023(en) Microfluidics — Vocabulary, definition 3.2.8
https://www.iso.org/obp/ui/en/#iso:std:iso:10991:ed-2:v1:en:term:3.2.8

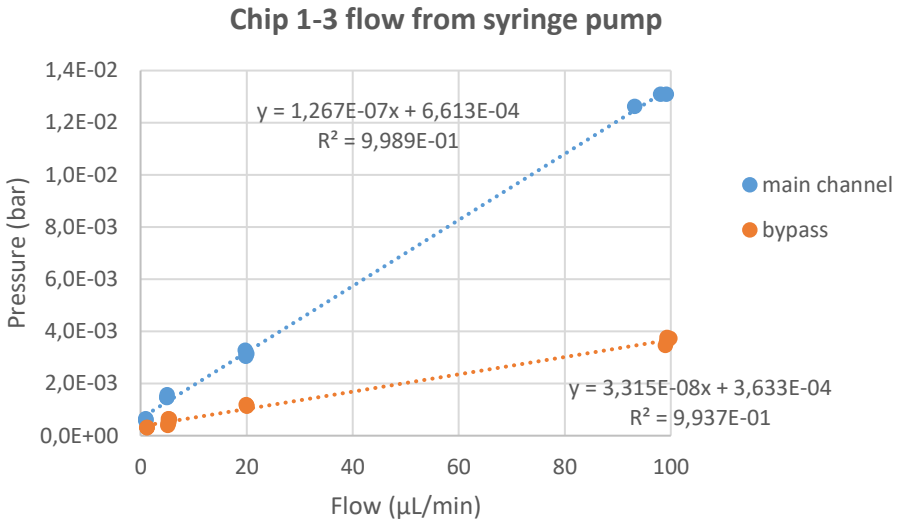
Flow resistance: setup at CETIAT

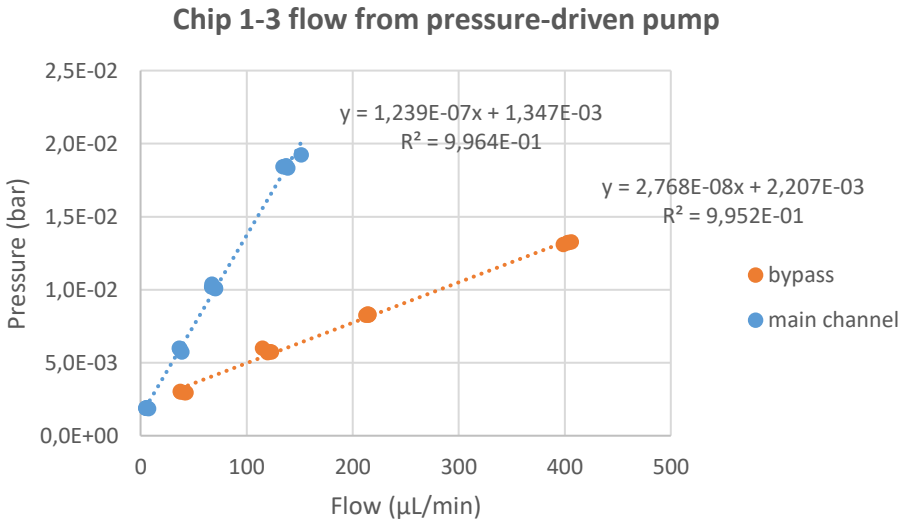




Flow resistance: results

- Syringe pump: $R_H = 5.61 \cdot 10^{11}$ Pa·s/m^3
- Pressure-driven pump: $R_H = 5.77 \cdot 10^{11}$ Pa·s/m^3
- Uncertainty:
  - to be carefully evaluated
  - can be up to 50 % of the indicated value, see [6] with a similar study
- Experiments also performed by other partners: results will be discussed in coming papers
  - report of MFMET activity 2.4.3
  - paper for CIM 2025
  - EURAMET pilot study 1613



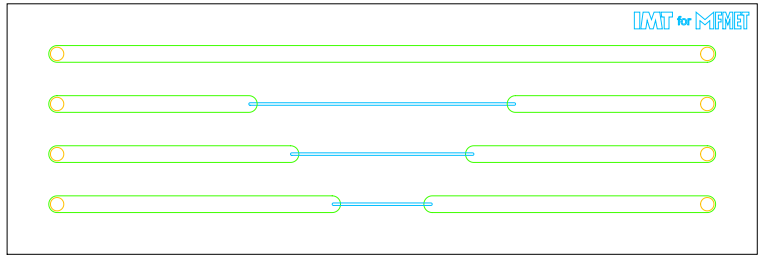


References:

[6] Ogheard, F. *et al.* (2024) Documented example of the test protocol for hydrodynamic resistance, flow rate and volume, https://doi.org/10.5281/zenodo.11090346

How to get traceable measurements?

- publicly available reports (references below) with protocols and guidelines
- MFMET designed several microfluidic transfer standards (glass and polymer):
  - known characteristics (measurements on reference test bench in labs)
  - to be available for users for calibration of their own instruments
  - check mfmet.eu for updates and the final reports



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[4] Boudaoud, A. (2022) Development of a Primary Standard for the Measurement of Nano-Flow Rates of Liquids, https://pastel.hal.science/tel-04187912

[5] ISO 10991:2023 Microfluidics — Vocabulary

[6] Ogheard, F. *et al.* (2024) Documented example of the test protocol for hydrodynamic resistance, flow rate and volume, https://doi.org/10.5281/zenodo.11090346

Thank you!


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