Ex-situ characterization of two-phase flow regimes in PEMFCs

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Outline

- Motivations and background
- Experimental setup
- Results
- Conclusions and future work

Motivations

➢ Context

- Water management is a major issue for achieving high-performance PEMFCs.
- Water is produced at the cathode (oxygen reduction), transported through the Porous Transport Layer (PTL aka. GDL) and convected away by the air flow in the micro-channels.
- Under certain operating conditions:

Rate of production of water > rate of removal => Flooding

- Flooding of the PTL and/or the micro-channels hinders reactant supply to the reaction sites => decrease in overall performances.

Motivations

➢Motivations

- A better understanding of water transport in the PTL and the flow channels will help improve the performances of PEMFCs.
- It is necessary to investigate the influence of operating conditions on the flow regimes in the micro-channels.
- Experimental data are needed to validate computational models.

Background – Flow in the PTL

Recent experimental and numerical studies:

- Capillary fingering in the PTL: Droplets occur at preferential locations

e.g.: Litster *et al.*, J. Power Sources, 154 (2006).

Sinha and Wang, Electrochimica Acta, 52 (2007).

Ous and Arcoumanis, J. Power Sources, 173 (2007).

Nam and Kaviany, Int. J. Heat and Mass Transfer, 46 (2003)

…

- Compression favors water accumulation under the lands

e.g.: Bazylak *et al.*, J. Power Sources, 163 (2007).

Owejan *et al.*, Int. J. of Hydrogen Energy, 32 (2007).

Zhang *et al.*, Electrochimica Acta, 51 (2006).

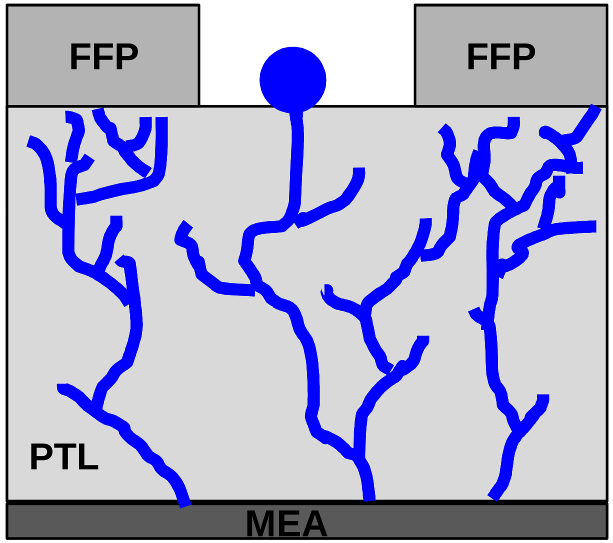
…

- Flow in the PTL is unsteady.

e.g.: Bazylak *et al.*, J. Power Sources, 176 (2008).

Manke *et al.*, Appl. Phys. Letters, 90 (2007).

…



Idealized view
of water pathways in the PTL.

Background – Flow in the channels

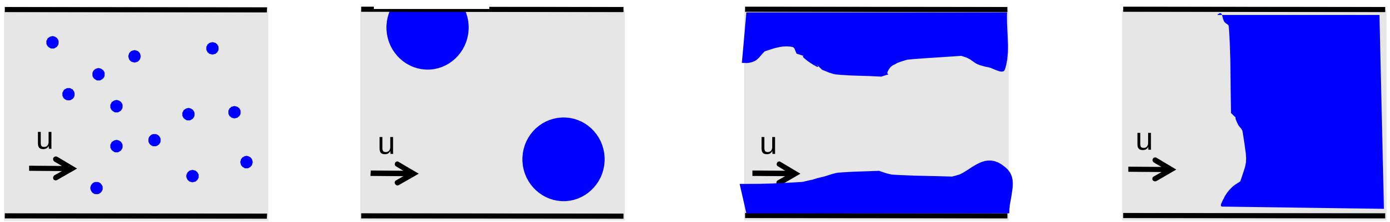
- Most experimental studies are carried on either with
    - visualization in transparent operating fuel cells

      e.g.: Ous and Arcomanis (2007), Spernjak *et al.*, J. Power Sources, 170 (2007), Owejan *et al.* (2007), Yang *et al.,* Electrochemical and Solid-State Letters, 7 (2004) ….

    - x-ray tomography or neutron imaging in operating fuel cells.

      e.g.: Manke *et al.* (2007), Park *et al.,* Int. J. Hydrogen Energy, 33 (2008), Satija *et al.,* J. Power Sources, 129 (2003), Zhang *et al*. (2006), …

- Four main types of flow regimes were observed in fuel cells:



Mist Flow | Droplets | Film flow | Slug flow

- These flow regimes depend on operating parameters (current density, stoichiometry, temperature, air humidity …).
- Performances of fuel cells are affected by the flow regimes in the channels.

Our approach

Most experimental studies: operating fuel cells

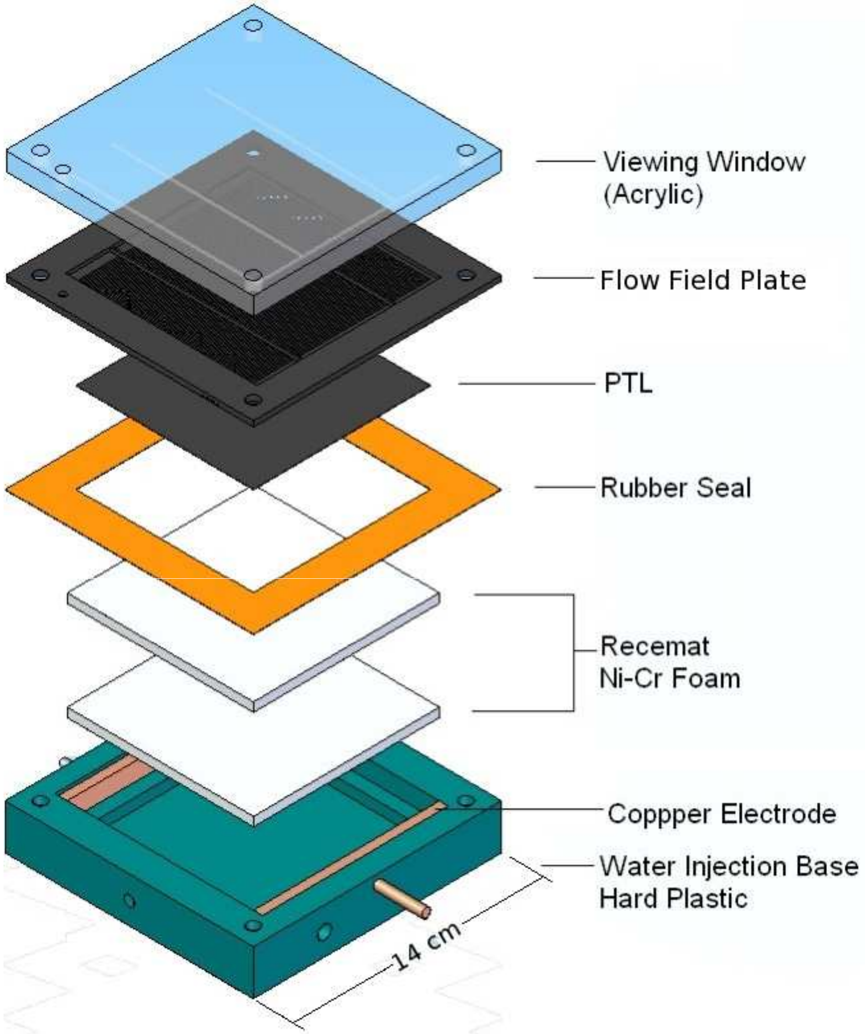
↓

Parameters are interdependent.

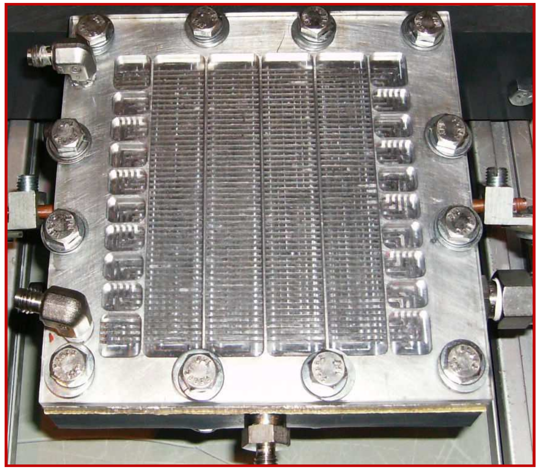
Our approach:

- A model of PEMFC recreates operating conditions of a real PEMFC.
- The influence of each of the following parameters on flow regimes can be studied independently:
    - Mass flow rate, temperature and humidity of air,
    - Mass flow rate and temperature of water,
    - PTL type (carbon paper, clothes, PTFE coating, MPL, thickness …),
    - FFP (geometry, surface chemistry),

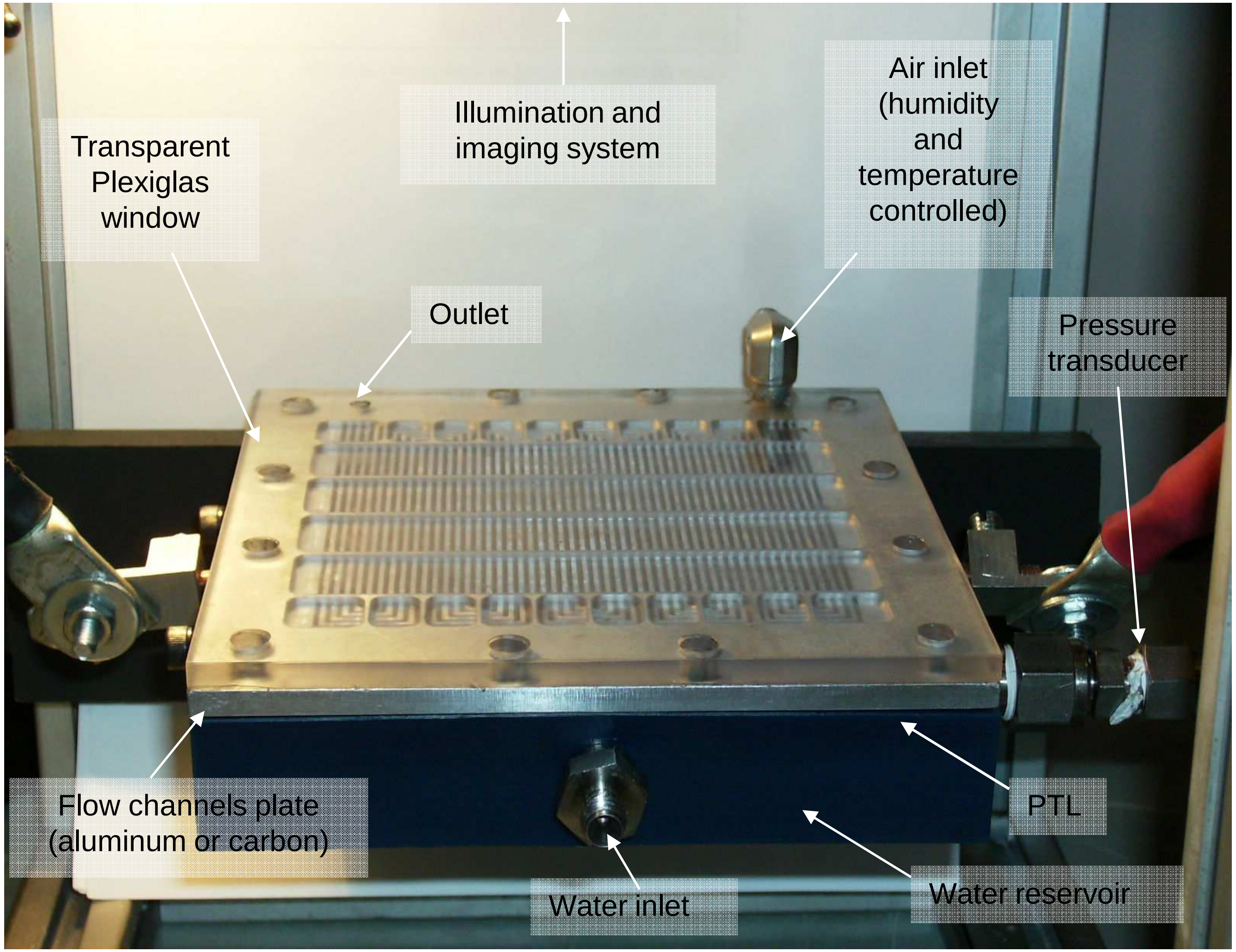
Experimental setup – Flow visualization cell



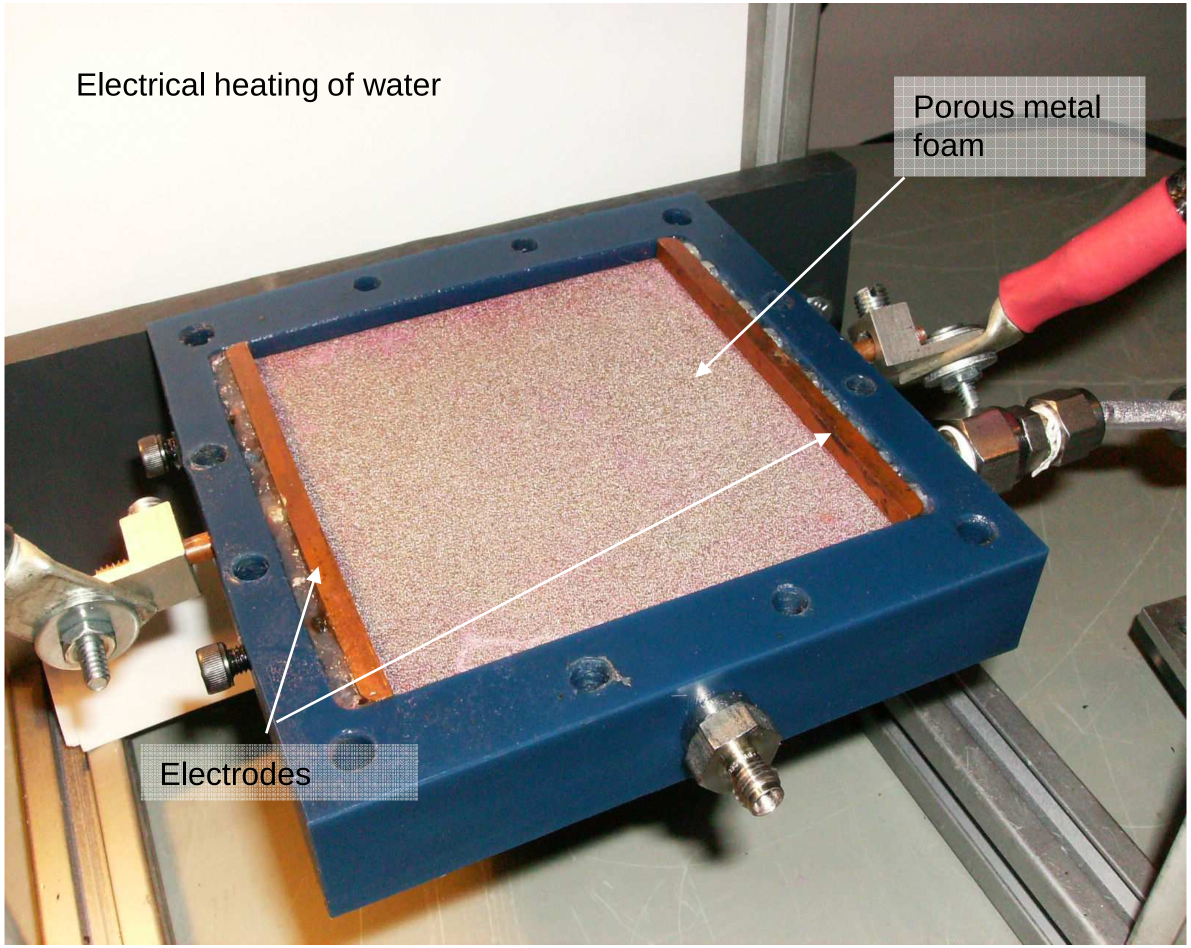
- Transparent window
- Sandwiched elements: various types of FFPs and PTLs possible.
- Metal foam provides even distribution of water.
- Electrical heating of porous metal
- Cell assembled in a press and tightened by 10 screws at 100 lb.in



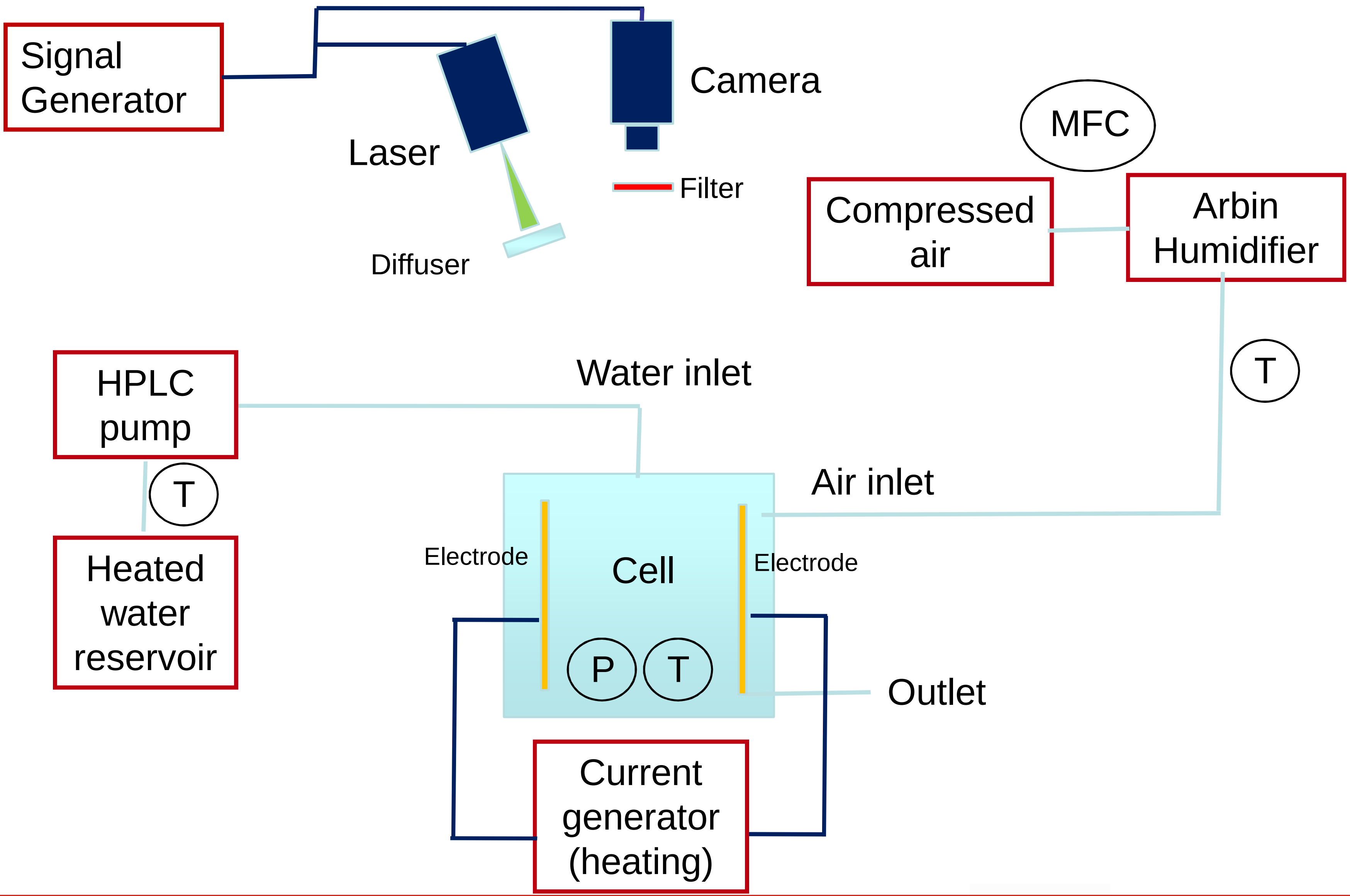
Experimental setup – Flow visualization cell 2



Experimental setup – Flow visualization cell 3



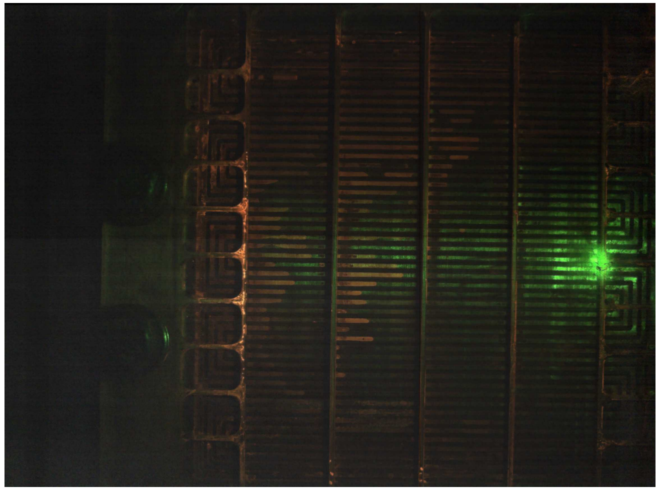
Experimental setup – Controllers and sensors



Experimental setup – Imaging

- Imaging: High-speed camera IDT M5 (up to 170fps at full resolution).
- Illumination by Nd:YAG double pulse laser equipped with fiber optics (wavelength 532nm, green).
- The laser and the camera are synchronized using a signal generator.
- Water colored with fluorescent dye (Rhodhamine B, emission wavelength ~570nm, orange)
- Light emitted by dyed water is filtered for a better detection of water.

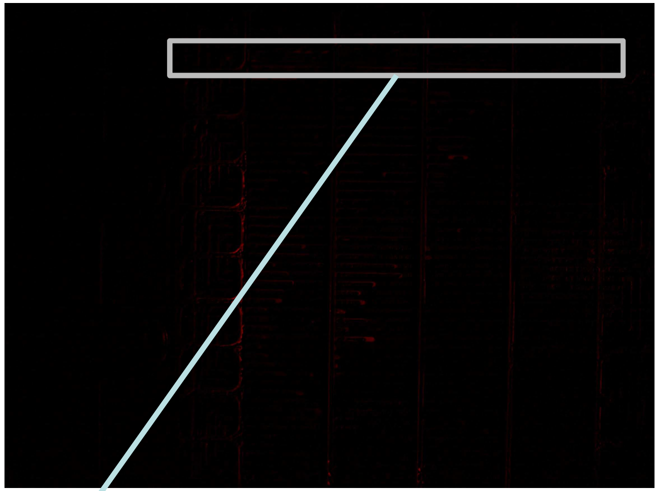
Experimental setup – Post-Processing



Raw image

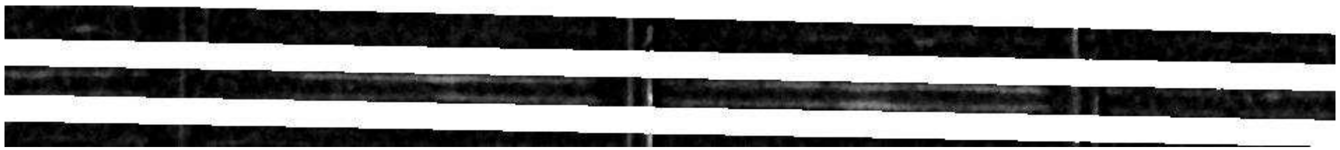
Background removed

Green and blue components set to zero



Select area of interest

Grayscale Intensification Masking

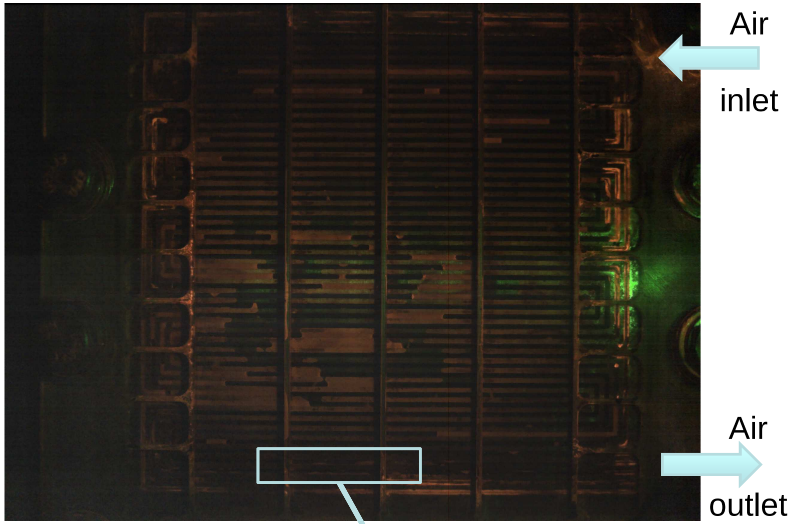


Results – Operating conditions

First results obtained for the following cases:

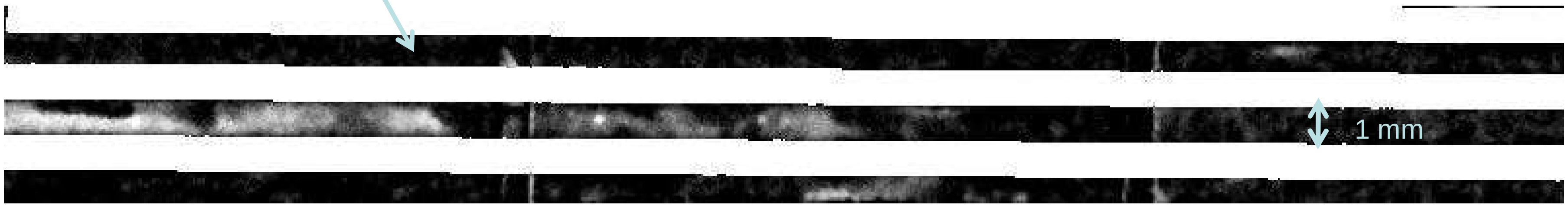
- Cell area: 100 x 100 mm.
- FFP: aluminum (contact angle ~90°), 5 parallel serpentine channels, cross section: 1mm x 1mm.
- PTL: SGL 31BC (5% PTFE with MPL).
- Isothermal conditions: air and water temperatures are at room conditions (~22°C). No heating of the porous metal.
- Tested mass flow rates:
  - $\dot{m}_{H_2O} = 0.5 \text{ mL/min and } \dot{m}_{Air} = 500 \text{ mL/min } (\mathrm{I} = 0.9\mathrm{A/cm}^2, \lambda = 0.35)$
    ➔ slug flow.
  - $\dot{m}_{H_2O} = 0.5 \text{ mL/min and } \dot{m}_{Air} = 2000 \text{ mL/min } (\mathrm{I} = 0.9\mathrm{A/cm}^2, \lambda = 1.2)$
    ➔ film flow.
  - $\dot{m}_{H_2O} = 0.5 \text{ mL/min and } \dot{m}_{Air} = 3000 \text{ mL/min } (\mathrm{I} = 0.9\mathrm{A/cm}^2, \lambda = 2)$
    ➔ single-phase flow.
- The setup was operated for at least 30 min in order to reach a stationnary state before measurements were performed.

Results – Slug flow



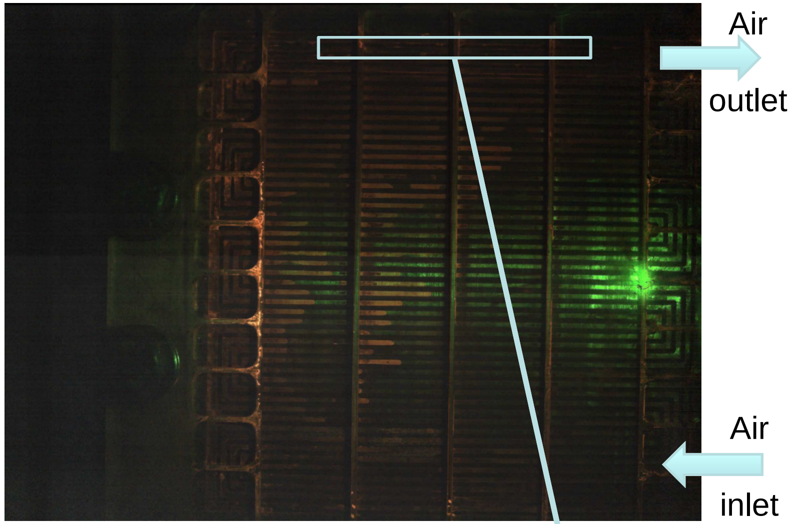
- At high water production and low air flow rate, plugs are formed in the channel.
- Plugs might hinder fuel distribution.

Video: 5 fps



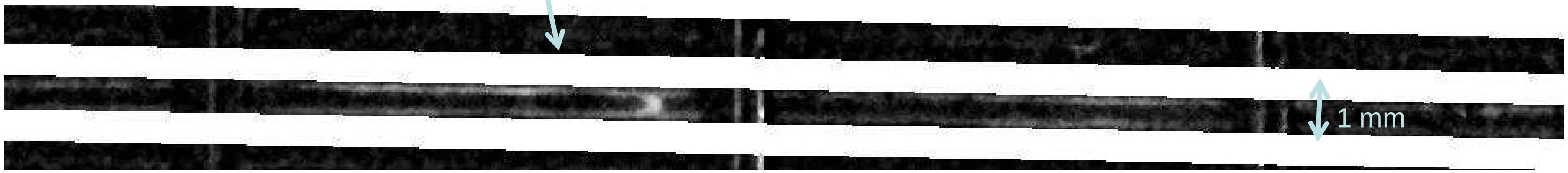
$$\dot{m}_{H_2O} = 0.5 \text{ mL/min and } \dot{m}_{Air} = 500 \text{ mL/min } (\mathrm{I} = 0.9\mathrm{A/cm}^2, \lambda = 0.35)$$

Results – Film flow



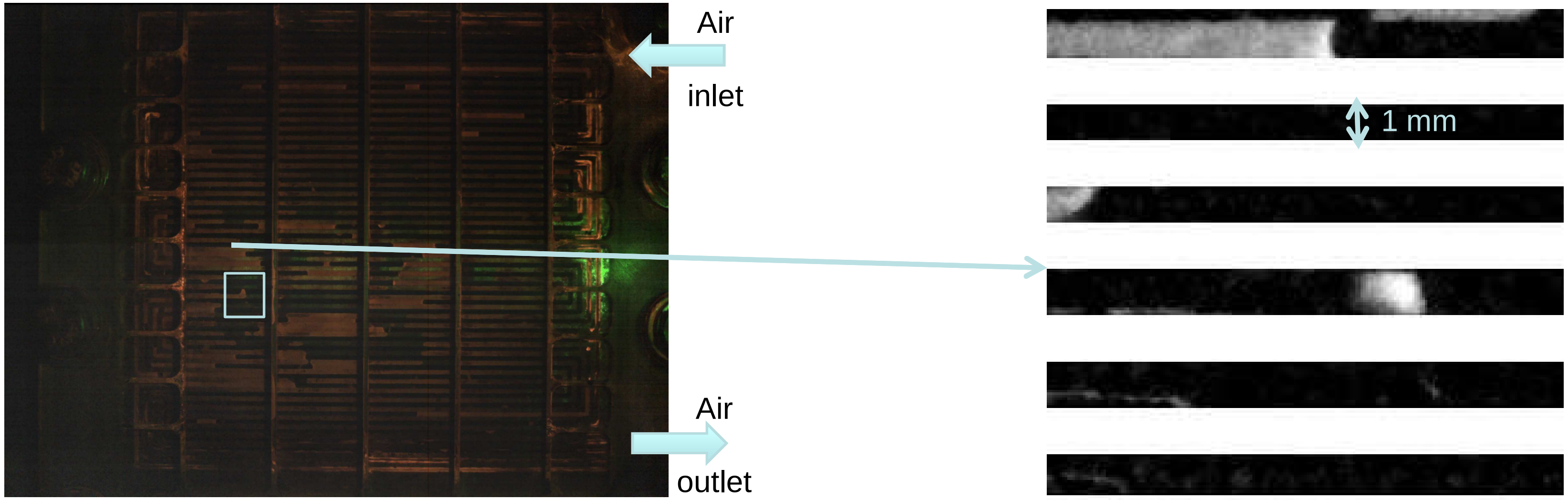
- Inlet and outlet were switched: water still appears near the outlet.
- At higher air flow rate, water is evacuated along the channel walls forming films.

Video: 2 fps



$$\dot{m}_{H_2O} = 0.5 \text{ mL/min and } \dot{m}_{Air} = 2000 \text{ mL/min } (I = 0.9 A/cm^2, \lambda = 1.2)$$

Results – Droplet oscillations



Video: 5 fps

- Pulsating droplet: comes out of the PTL and goes back in periodically.
- Consistent with observations of dynamic flow in PTL from the literature (Bazylak (2008), Manke(2007), …).

$$\dot{m}_{H_2O} = 0.5 \text{ mL/min and } \dot{m}_{Air} = 500 \text{ mL/min } (I = 0.9 A/cm^2, \lambda = 0.35)$$

Conclusions

- Understanding two-phase flow in the PTL and the flow channels is key to the improvement of PEMFCs.
- We built a setup that mimics a PEMFC, with similar operating conditions, and allows the visualization of flow regimes in the channels.
- Input parameters can be varied independently, on contrary to setups using operating fuel cells.
- The cell can host various types of flow field plates and PTLs.
- First results obtained for isothermal case, with SGL 31BC and aluminum FFP. We distinguish different types of flow regimes: single-phase flow, film flow, and slug flow.
- The flow in the PTL and the channels is dynamic: periodic oscillation of some droplets.

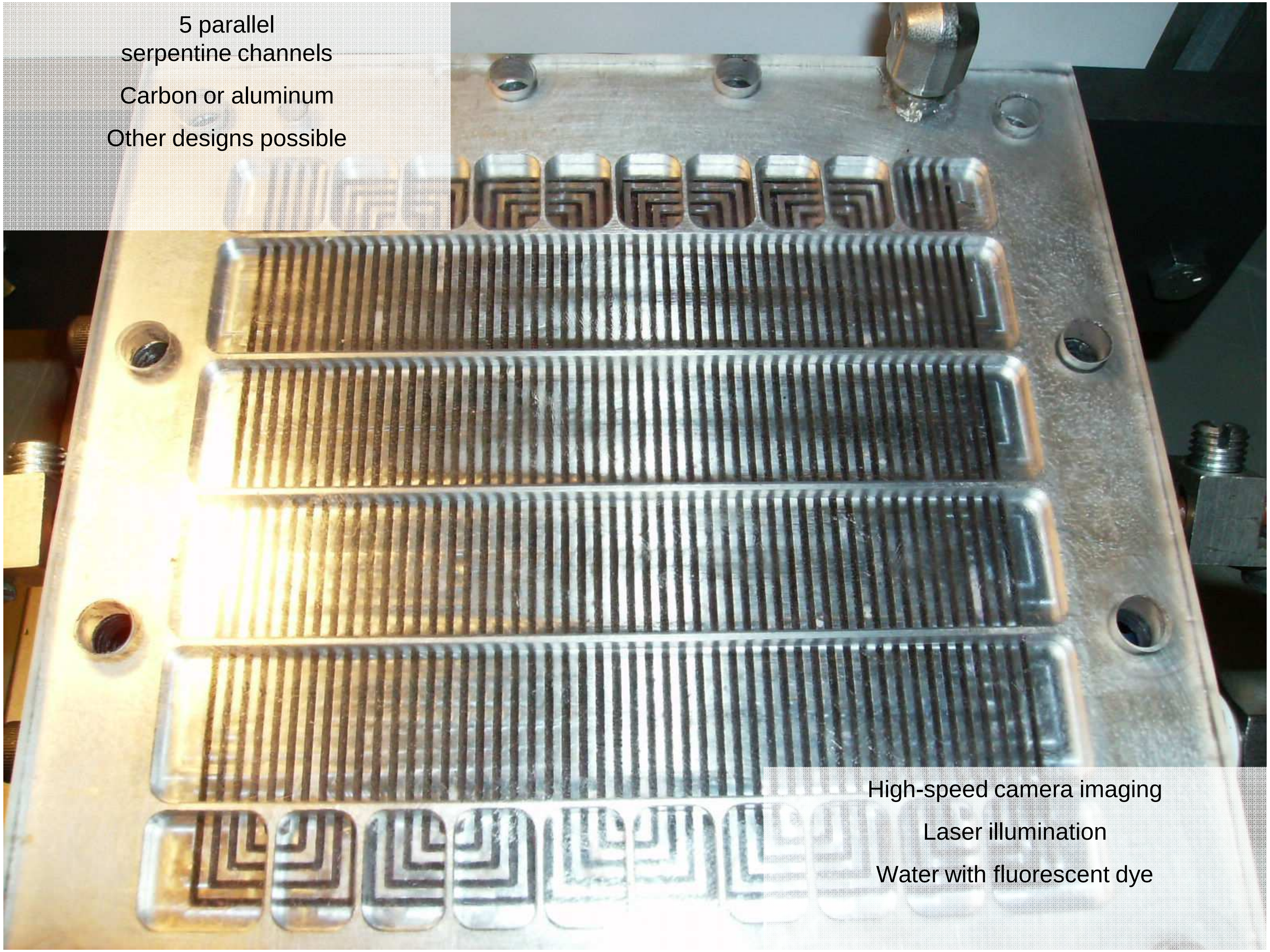
Future work

- Measurements will be performed for a wider range of input parameters and compared with numerical simulations.
- Pressure sensors will be added in the flow channels to monitor the evolution of capillary pressure.
- Better spatial resolution will be achieved using 12x optical zoom.

Thank you for your attention !

Additional slides

Additional slides


5 parallel
serpentine channels
Carbon or aluminum
Other designs possible
High-speed camera imaging
Laser illumination
Water with fluorescent dye