Water management in the Gas Diffusion Layer of PEM fuel cells: Dynamic breakthrough effects on porous media liquid water saturation

Stéphane CHEVALIER*, Christophe JOSSET and Bruno AUVITY

Laboratoire de Thermique et Énergie de Nantes (CNRS UMR 6607)

Polytech Nantes – The Graduate School of Engineering of the University of Nantes

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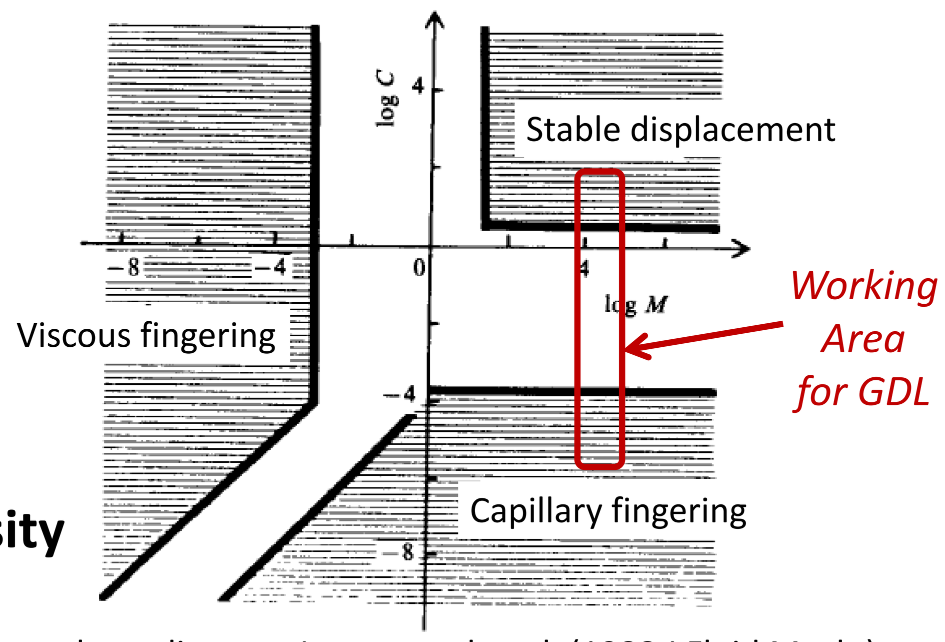
Motivations:

1. From a fundamental perspective:

Gain a better insight into **the transition from the capillary fingering to the stable displacement regime** in the case of GDL.

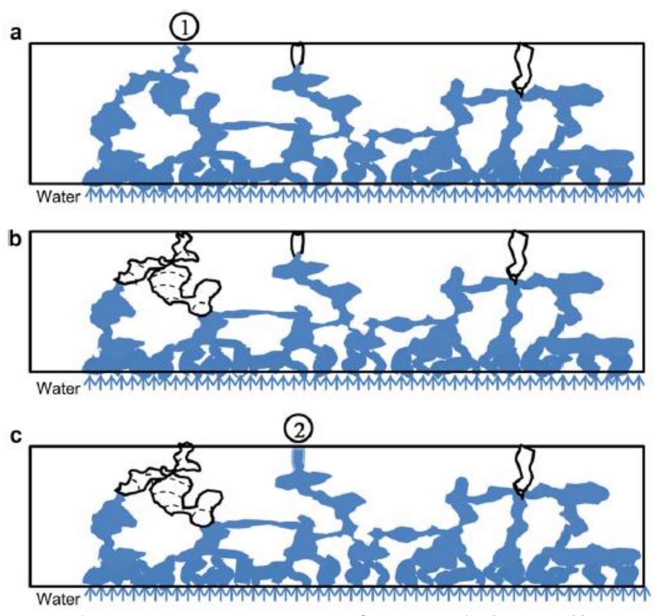
Particularly relevant for **high current density** i.e. high flow rates



Drainage phase diagram, Lenormand et al. (1988 J Fluid Mech.)

2. From the application:

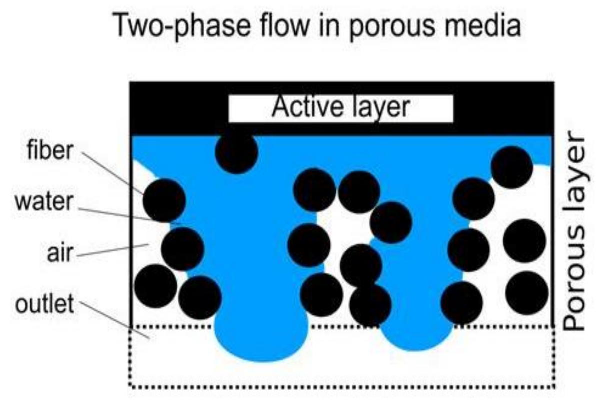
How to explain the **change in preferential path** for liquid invasion in GDL?

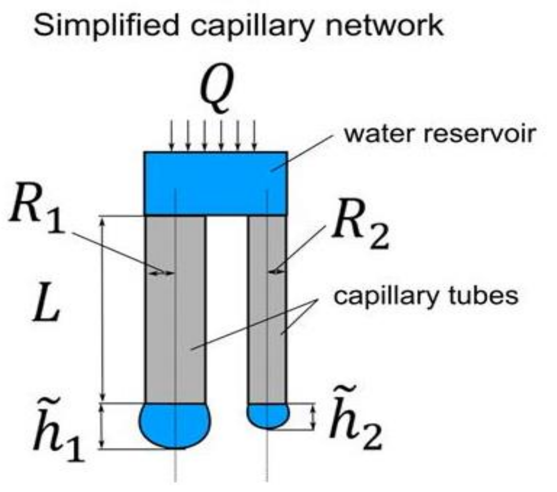


Water drainage process of a model capillary system as water emerges from the GDL surface, Lu et al. (2010 Int. J. Hydrogen Energy)

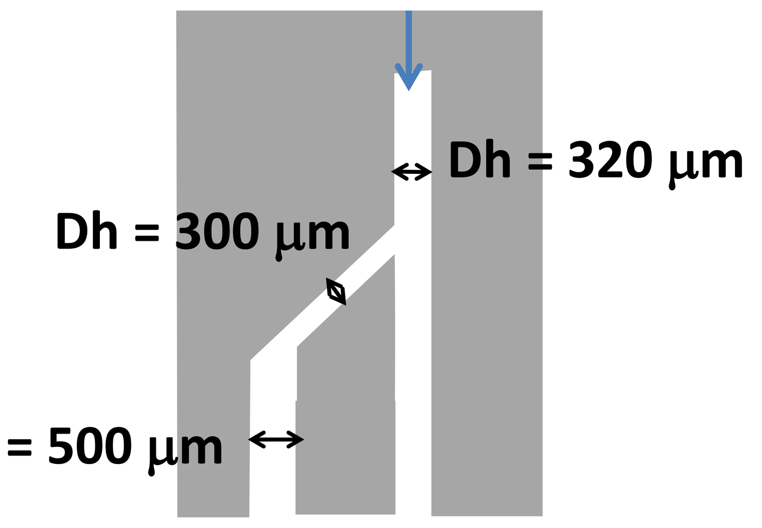
Methodology:

1st step: Modelization of a pore network typically encountered in GDL into a 2 interconnected capillary tubes system





2nd step: The inverted Y network to **highlight the change in preferential path** in a simple capillary network



The «two-drops» model

Flipo et al. Eruptive water transport in PEMFC: a single drop capillary model, Int. J. Hydrogen Energy, 2015

Hyp: constant water flow, spherical meniscus/drop

$$\begin{cases} p_i = \underbrace{\frac{8\mu L}{\pi . R_i^2}.\dot{V}_i}_{\text{Poiseuille flow}} + \underbrace{\frac{4\gamma\cos\theta}{R_i}}_{\text{Laplace law}} + p_0 \\ p_1 = p_2 \\ Q = \dot{V}_1 + \dot{V}_2 \end{cases}$$

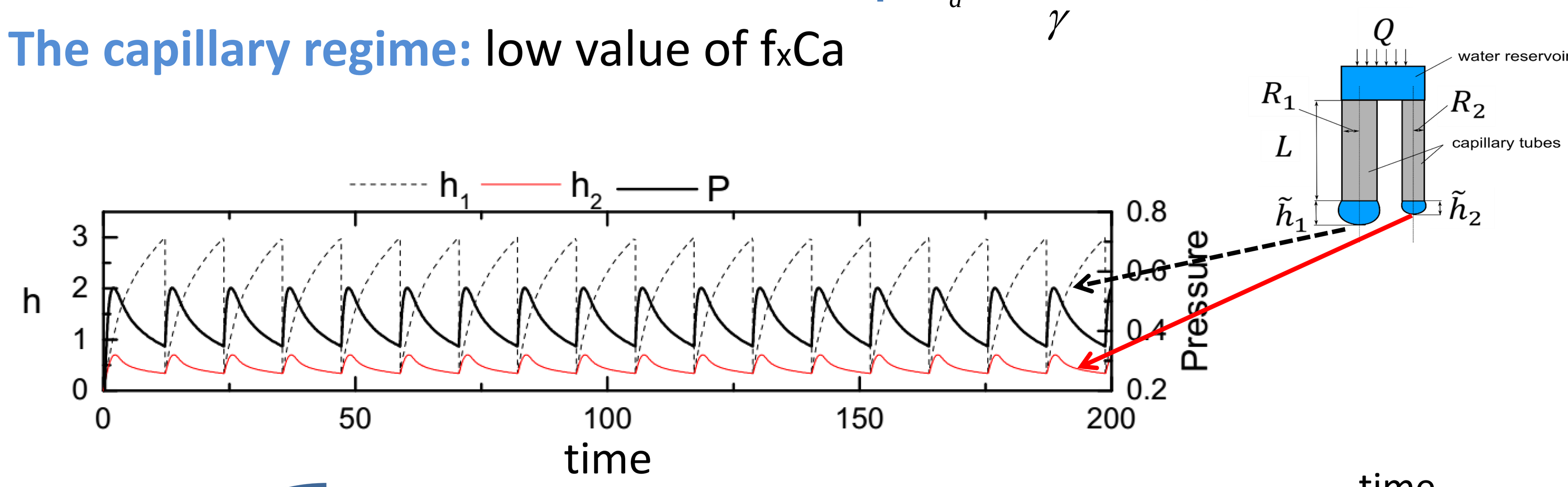
Once non-dimensionalized, it becomes:

$$\begin{cases} f\left[\dot{h}_1(h_1^2+1) - R\dot{h}_2(h_2^2+1)\right] = \frac{1}{Ca}\left[R\frac{h_2}{h_2^2+1} - \frac{h_1}{h_1^2+1}\right] \\ \dot{h}_1(h_1^2+1) + \frac{1}{R^3}\dot{h}_2(h_2^2+1) = 1 \end{cases}$$

Problem driven by ***3 parameters***:

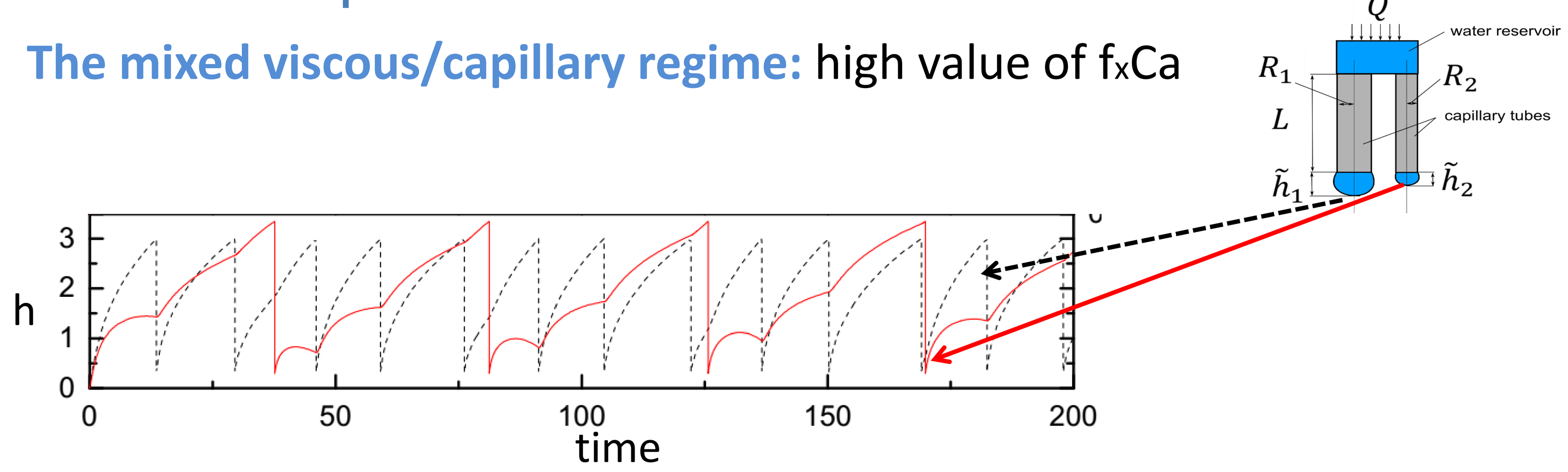
- $f = L/R_1$, pore aspect ratio
- $R = R_1/R_2$, pore radii ratio
- $C_a = \frac{U_0.\mu}{\gamma}$, capillary number

The capillary regime: low value of fxCa



The meniscus/drop growth in the bigger pore does act upon the meniscus in the neighbouring pore

The mixed viscous/capillary regime: high value of fxCa

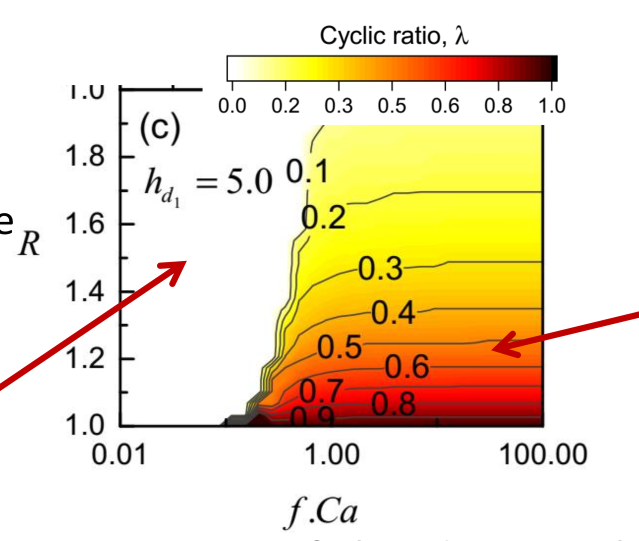


As the viscous effects get more important, a change of « preferential path » appears

The transition map

The duty cycle:

$$\lambda = \frac{\text{Drops emitted from the smaller tube}}{\text{Drops emitted from the larger tube}}$$



Mixed capillary/viscous regime

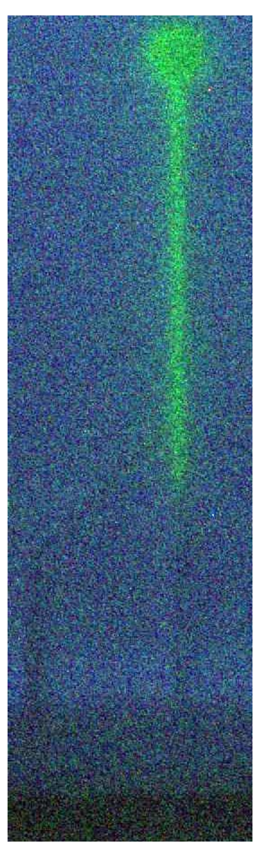
Capillary fingering

2D map of the duty cycle

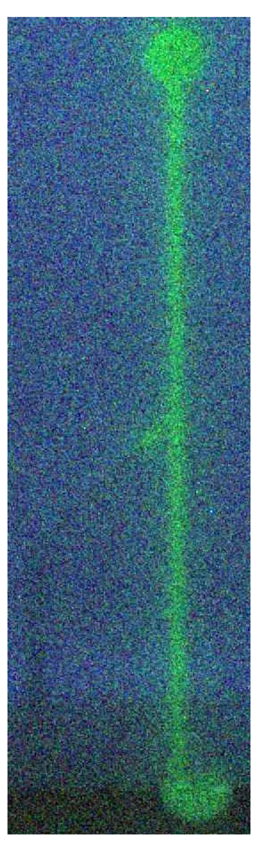
The inverted Y experiment

Experimental conditions:

- Machined channels in teflon block
- Upper side in PDMS (for visualization)
- Inlet water flow rate: 50 µl/min
- R = 1,07 (hydraulic diameter ratio)
- Ca = 1.6 10^{-4}



t_0+40s

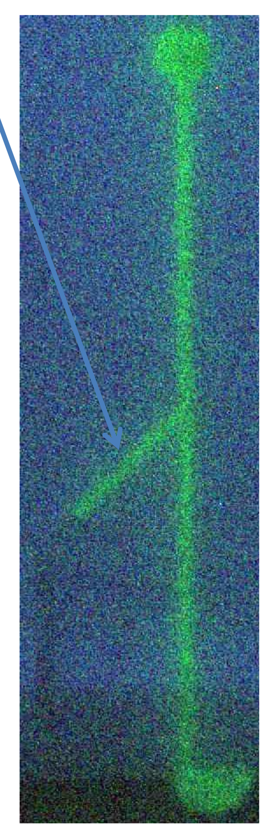


t_0+ 1 min

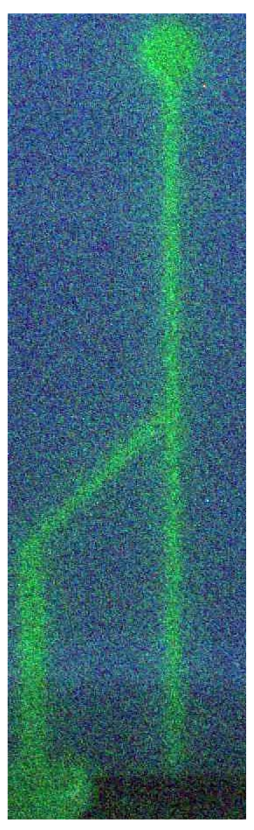
At first, only the larger tube is invaded, as **predicted by the Invasion-Percolation mecanism.**

But.....

Progressive motion of the meniscus in the smaller tube



t_0+ 8 min



t_0+ 6 min

As the time flows, due to the **eruptive nature** of the droplets emissions at the tube outlet, the smaller tube gets invaded....

To the point where the whole network is invaded. This is **not predicted by the Invasion-Percolation mecanism.**

Conclusion: The **dynamic breakthrough alters the invaded pore networks.** The **transition from the capillary to the stable displacement regime depends on Ca**, the **network geometry** and **viscous effects**.