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XTM Imaging of GDLs During Pressure Driven Water Imbibition and Drainage

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Objectives

- In polymer electrolyte fuel cells (PEFC), water is a product of the cathode oxygen reduction reaction.
- Liquid water accumulates in the porous gas diffusion layers (GDL) ➡ efficiency loss due to mass transport limitations.
- Better understanding of the liquid water transport mechanisms in the GDL:
  - Influence of the material morphology?
- Use X-ray tomographic microscopy[1,2] to image water during ex-situ water imbibition/drainage of GDL.
- Design more efficient GDL for a better water management and higher cell efficiency.

Experimental

- Two GDL materials investigated: Toray TGP H 060 and SGL 24BA (sample size = 5.6 mm diameter).
- Injection/withdrawal of liquid water from the bottom of the GDL using a syringe pump.
- Capillary pressure $p_c = p_{liquide} - p_{air}$ across the static liquid/air interface.
- Capillary pressure controlled by a relative pressure sensor.

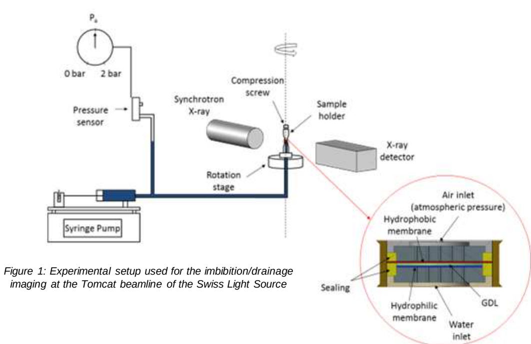


Figure 1: Experimental setup used for the imbibition/drainage imaging at the Tomcat beamline of the Swiss Light Source

- Synchrotron based tomographic imaging at the Swiss Light Source:
  - Absorption contrast
  - 13.5 keV, 2001 exposures
  - 15 ms exposure time
  - Resolution = 2.2 µm/pixel

Results

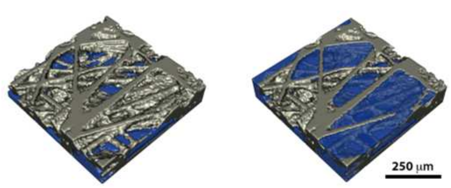


Figure 2: Surface renderings of X-ray tomographic microscopy images of water imbibition into SGL 24BA gas diffusion layer; left: low water saturation (capillary pressure 14 mbar); right: high water saturation (capillary pressure 39 mbar).

Results

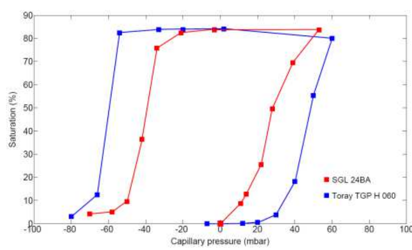


Figure 3: Capillary pressure – saturation curves for the SGL 24BA (red) and Toray TGP H 060 (blue).

- Water starts invading the GDLs when p_c is increased.
- Plateau between the end of the imbibition and the beginning of the drainage ➡ inversion of the contact angle of water on solid.
- Water is removed from the GDLs when p_c is decreased.
- Similar imbibition and drainage curves for the both GDLs.
- Imbibition curve of the Toray shifted to higher capillary pressure compare to those of the SGL.

Void structure characterization

1st step: Division of the 3D image into stacks of slices

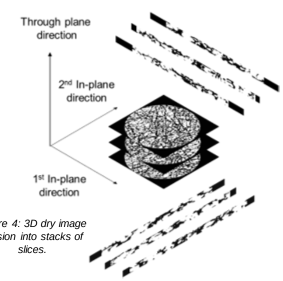


Figure 4: 3D dry image division into stacks of slices.

2nd step: Analysis of the void structure in each slice using local thickness

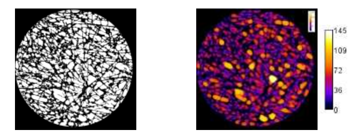


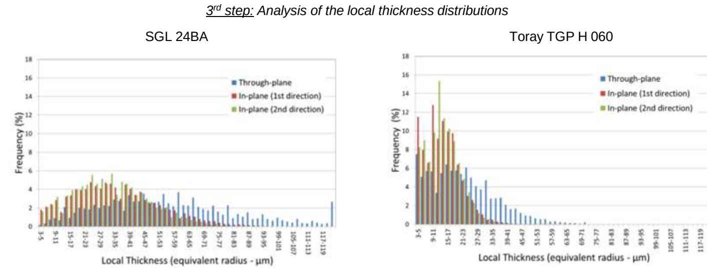
Figure 5: left: slice of the dry structure. Fiber in black and void in white. Right : Identical slice after local thickness mapping. Thickness is color coded.

$\Omega \subset R^2$ = set of all points in the 2D void structure and $\underline{p} \subset \Omega$

Local thickness $\tau(\underline{p})$ = the diameter of the largest disk which contains the point $\underline{p}$ and which is completely inside the structure:

$$\tau(\underline{p}) = 2.max\left(\left\{r|\underline{p} \in disk(\underline{x}, r) \subseteq \Omega, \underline{x} \in \Omega\right\}\right)$$

3rd step: Analysis of the local thickness distributions

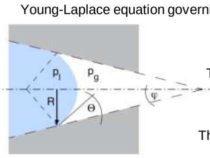


- Anisotropy in-plane/through plane directions.
- Isotropy in the in-plane direction.

} SGL 24BA & Toray TGP H 060

- Mean in-plane and through-plane local thicknesses: SGL 24BA > Toray TGP H 060

Young-Laplace equation governing capillary transport:



$$p_c(R) = p_l - p_g = -\frac{2\xi}{R}\cos(\theta + \varphi)$$

The smaller the pore or throat, the higher the necessary capillary pressure to fill it with water.

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The higher capillary pressure to start the imbibition of the Toray material is in line with the lower mean local thickness (characteristic of the pore or throat size).

Figure 4: Schematic of a tapered pore filled with liquid water.

Conclusions

- Water invasion and withdrawal in different GDLs have been observed using XTM imaging.
- Different capillary pressures are required to start imbibing the different GDL materials.
- This is in line with the material properties:
  - Similar characteristics (in-plane/through-plane anisotropy and in-plane isotropy for the local thicknesses)
  - Difference in scale for the local thickness sizes.
- The difference in scale is responsible for the capillary pressure shift between the two imbibition curves.
- Anisotropy is responsible for predominantly filling in the through plane direction.

References

[1] Flückiger, R., et al. (2011). "Investigation of liquid water in gas diffusion layers of polymer electrolyte fuel cells using X-ray tomographic microscopy." Electrochimica Acta **56**(5): 2254-2262.

[2] Gostick, J. T., et al. (2010). "Tomographic Imaging of Water Injection and Withdrawal in PEMFC Gas Diffusion Layers." Polymer Electrolyte Fuel Cells 10, **33**(1): 1407-1412.