ESRF	**Experiment title:** Real-time 3D imaging of interfacial dynamics in porous media two-phase flow	**Experiment number**: ES 997
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Report:

Multiphase flow within porous media represents a complex interplay of numerous physical phenomena, manifesting a hierarchical arrangement in both spatial and temporal domains. Despite remarkable advancements in real-time 3D imaging techniques, the rapid fluid dynamics occurring at the pore-scale remain elusive to full native temporal resolution. Of particular significance is the Haines jump, an abrupt pore-filling event driven by capillary forces, which transpires within milliseconds and has thus far eluded comprehensive experimental 3D characterization within porous media. In this study, we successfully achieved 4D (3D+time) visualization of multiphase flow within a consolidated porous medium, utilizing stroboscopic X-ray micro-computed tomography conducted in situ. Our innovative measurement approach enabled the acquisition of data with a temporal resolution as fine as 0.5 milliseconds, spanning a total observation duration of 6.5 seconds. This offered unparalleled insights into the intricate dynamics of multiscale liquid behavior, under the assumption that the flow patterns remain repeatable during the imbibition-drainage cycle within a consolidated porous medium.
The porous sample cell utilized in this study was a borosilicate capillary with 1 mm in thickness, featuring an inner diameter of 5 mm and height of 90 mm. This capillary tube was densely packed with sintered borosilicate glass shards. At the base of the capillary tube, an inlet was present to facilitate the periodic injection and withdrawal of liquid water. The upper extremity of the capillary remained open to the surrounding environment.

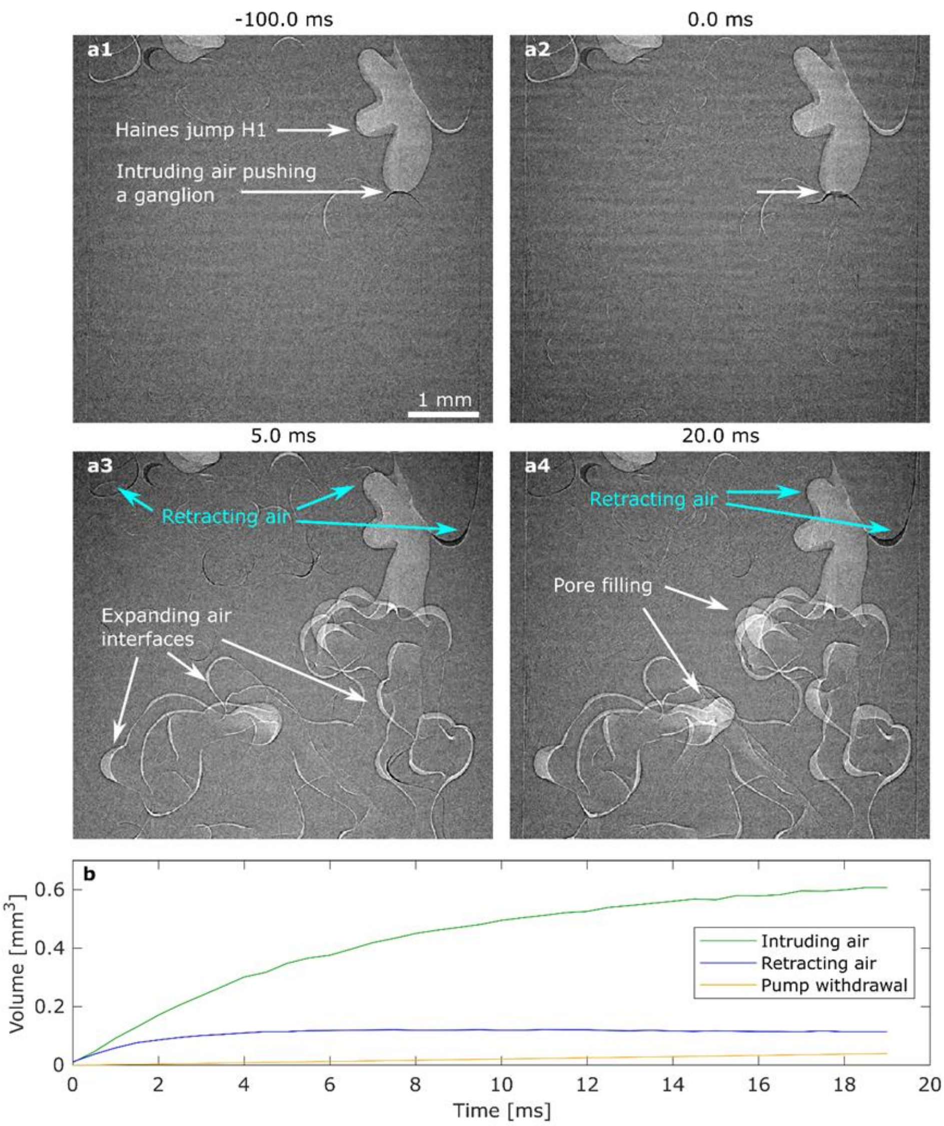

Fig: Radiographic projections of selected timesteps of the intruding air phase (white regions) pushing the ganglion downwards (dark region in **a1**) and eventually breaks the water layer separating them, causing an avalanche of water-air interfacial movements. In addition to the expansion of air phase, two new pore bodies separated by pore-throats are invaded by the air. A reference frame from the start of the stroboscopic projection series was subtracted from the radiographic images, and the time denotes the onset of the reconnection event. **b** The displaced volume increases steadily and reaches 0.6 mm3 within 19 ms. The volume changes are computed from the reconstructed tomograms.

The sample was initially saturated with 0.5 M potassium iodide (KI) doped water through a process of spontaneous imbibition, resulting in an initial water saturation level of 78 ± 2%. The sample was securely affixed to a custom-designed stage that featured a gas-tight, high-precision syringe for controlled manipulations. The thermodynamic parameters were carefylly regulated to ensure that these repetitive events occurred under gradual and deliberate dynamics.

Micro CT measurements were conducted at ID19 using a pink energy x-ray beam peaking at 70 keV. The imaging setup included a PCO Edge 5.5 CMOS detector connected to a 500 µm LaAG:Ce scintillator via a 2x objective. During stroboscopic measurements, 90 µL of doped water was cyclically injected and withdrawn at a flow rate of 125 µL/min, resulting in a periodicity of approximately 86 seconds, with a predominant capillary-driven flow regime. Imaging was performed using a PCO Dimax S7 detector with a 3x objective coupled to a 500 µm LuAG:Ce scintillator, providing an effective pixel size of 3.66 x 3.66 µm² and a framerate of 2.0 kHz. The measurement spanned for approximately 6.5 seconds before saving the images to permanent storage.

When the sample was rotated to the next projection angle, and the detector was prepared for the next trigger signal. Projection angles were selected using a golden ratio scheme. The reconstruction process employed the PICCS reconstruction algorithm, which relies on compressed sensing and utilizes prior knowledge of the sample, along with iterative reconstruction techniques.

This experiment was successful. We were able to record the millisecond scale pore level phenomena with their native time and space scale.. This proposed stroboscopic measurement strategy provided 0.5 ms resolution that was clear sign that user demonstrated a good job and the beamtime was fruitfully utilized. These promising results have been submitted in prestigious high impact journal, currently under review [1]. The users expects that it will be published soon. The users are continuously exploring fundamental dynamics happening during multiphase flow at their original time scale using the recorded data and planning to apply for beamtimes further.

[1] K.R. Tekseth, F. Mirzaei, B. Lukic, et. Al., Multiscale drainage dynamics with Haines jumps monitored by stroboscopic 4D X-ray microscopy under review (2023).

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