EXPERIMENTAL AND NUMERICAL CROSS-VALIDATION OF FLOW IN REAL POROUS MEDIA. PART 1: EXPERIMENTAL FRAMEWORK

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Summary: In this study, we present the design of a purpose-built test cell, capable of closely mimicking boundary conditions which can be routinely imposed in fluid flow simulators. The test cell permits conducting systematic studies on the influence of unresolved pore-scale wall-roughness and pore space morphology on the hydraulic conductivity: it is therefore an ideal instrument for the generation of validation datasets for the next generation numerical flow models.

1. INTRODUCTION

Many simulators claim to be capable of calculating fluid flow at the pore scale, based on X-ray scans of a porous medium of interest. However, as demonstrated by [1], the predictive power of these simulators remains to be demonstrated. Model validation is challenging, as direct observation of the flow field inside real porous media is generally not possible, and as model and experiment generally exhibit differences in geometry, boundary conditions and/or physics.

In this study, we present the design of a purpose-built test-cell dedicated to the generation of reference data for validating a next-generation flow simulator. The test cell design accounts for typical constraints of simulators, such as the difficulty to treat large datasets (billions of voxels). The design furthermore aims to limit differences between the experimental and numerical setup (precise control of the boundary conditions) and permits conducting systematic studies on key-parameters of models (such as the impact of pore wall roughness).

2. A DEDICATED TEST CELL

An experimental setup has been devised to conduct systematic flow studies (**Figure 1**). It mainly consists of a pump, driving fluid through synthetic or real porous materials confined in a dedicated Hassler cell. Key-parameters like the pressure drop over the medium and the traversing mass flux can be precisely controlled via the pump operating parameters set by the user, and measured by a sensor recording the differential pressure between the cell's inlet and outlet.

The corner stone of the experiment is the design of the Hassler cell capable of handling the constraints of typical numerical models. Furthermore, the cell has to be versatile so that it could handle a wide range of samples with a different degree of complexity. To accommodate both non-consolidated and consolidated cylindrical samples, the Hassler cell is essentially an axisymmetric cylindrical tube made out of polycarbonate. This material was selected as it could handle moderate inner pressure without dramatically attenuating the X-ray beam. The cell's dimensions (**Figure 2**) are determined based on the characteristics of the tomograph used in this study (a Bruker Skyscan 1172). This tomograph is capable to generate datasets with a voxel resolution around 3µm. If no binning is used, this would correspond to a field of view of around 12x8mm. This defines the maximum height of the inner volume of the test cell. The inner diameter can be reduced without compromising the representativeness of the envisaged samples. A diameter of 6 mm was selected as a compromise between representativeness and scan time.

A key design constraint was the need to be able to ensure an isotropic flow through the entrance and exit surfaces of the sample. To that extent, small reservoirs were created at top and bottom (to ensure a uniform pressure distribution) and they are separated from the sample by metal sintered filters (to equalize pressure variations along the surface) with a known pressure drop. The filters are threaded, permitting to impose a slight confinement pressure on non-consolidated samples. The differential pressure inside the top and bottom reservoirs is measured by an adapted probe.

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3. METHODOLOGY

A wide range of configurations, having different levels of complexity, can be investigated. For each studied case a two-step approach is followed. Firstly, the Hassler cell containing the sample is fixed on the tomograph's sample holder and a 3D tomographic scan is started. At this step, the Hassler cell is disconnected from the hydraulic circuit and the sample is in a dry state. Then, the acquired projections are processed, via the reconstruction software supplied with the tomograph, and the beam hardening and ring artifacts are corrected. The resulting image stack is then denoised by a median filter and manually segmented. The binarized cylindrical region of interest, corresponding to the sample, is provided as input for flow and permeability simulations. Depending on the simulator, this geometry can either be meshed, or simulations can be run directly on the voxel data.

In a second step, the Hassler cell is connected to the hydraulic circuit and the pressure drop over the sample is measured experimentally for a given flow rate and gauge pressure. This permits the direct determination of the permeability at a given pressure level (average between inlet and outlet pressure). Numerically calculated and experimentally acquired permeabilities are then compared. By systematically increasing the complexity of the configuration of interest, model deficiencies can be detected and corrected.

4. RESULTS AND OUTLOOK

The first and simplest configuration of interest consists of a pack of smooth micro-spheres (dry soda lime glass, Duke Standards) whose nominal diameter of 553 ± 11 µm is certified. This diameter was selected to have around 10 spheres across the diameter of the test cell. When using binning 4, the region of interest will be around 500^3 voxels, which can be handled by a typical numerical solver, and each sphere is described by around 50 voxels across its diameter, which is sufficient to have an accurate geometrical representation. A voxel size of 15µm has been selected to ensure that the entire sphere pack is within the field of view. Figure 3 depicts a rendering of the reconstructed 3D sphere pack. Spheres at the top and bottom part of the sample are truncated as both metal inlet/outlet filters induce an image artefact. Replacing them by synthetic filters will enable imaging the entire sample, and therefore remove a key uncertainty when comparing to simulations on the same geometry.

Afterwards, a test series on a similar sphere pack will be conducted, whereby the roughness of the spheres is chemically altered. The roughness change will not be visible at the resolution of the scan, yet it will be large enough to affect the differential pressure measurements and hence the permeability. This test therefore allows assessing the impact of unresolved geometrical features on the permeability.

Measurements using different fluids, using multi-modal sphere-packs and at higher spatial resolutions are foreseen as well, and it is anticipated to make the reference data available to the scientific community.

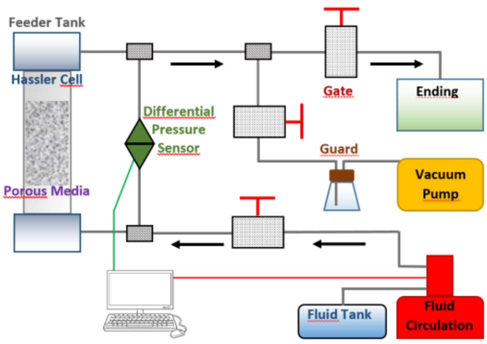

Figure 1: instrumented device

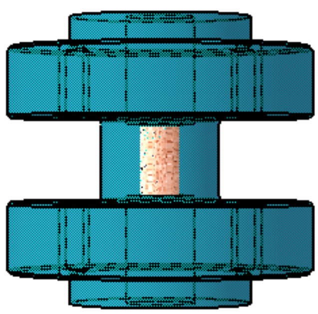

Figure 2: designed Hassler Cell

Figure 3: image rendering of a reconstructed 3D volume of spheres stacked inside the cell

References

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