# *SOIL WATER FLOW DYNAMICS STUDIED BY NEUTRON IMAGING*

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**Summary:** This paper presents the water content distribution in an artificial soil sample obtained from neutron tomography during two infiltration experiments with the different boundary condition. The boundary condition has an important effect on the water content distribution, so the water infiltration rate.

## 1. INTRODUCTION

The wetting dynamics of the water infiltration into a porous soil system has a strong influence on the amount of entrapped air inside the soil. Simultaneously, a higher volume of entrapped air obstructs a water flow. This effect is more noticeable in soils with preferential pathways because the soil matrix has a higher capillary forces and therefore the air is accumulated in preferential pathways.

In the presented study, two experiments were conducted on the same sample. The first experiment was performed under the constant water level condition (CWL) and the second experiment under the constant water flux condition (CWF) at the top of the sample. Infiltration experiments were monitored by neutron radiography and tomography at Paul Scherrer Institut in Switzerland (stations BOA and NEUTRA). From series of corrected radiograms taken at different angles three-dimensional (3D) image was reconstructed. Then the series of 3D images mapped the wetting of the porous system over the corresponding phase of infiltration process.

## 2. EXPERIMENTAL METHOD

### Sample

The sample was composed of coarse and medium coarse fractions of sand and fine porous ceramics. All components were packed into the quartz glass column of the inner diameter of 29 mm and 34mm height. The coarse sand represented a hydraulically highly conductive region connected from the top to the bottom of the sample with the exception of three thin (2-3 mm) separation layers made up of the medium coarse sand. Three discs of fine ceramics formed slow flow regions.

### Experiment and neutron imaging

Two infiltration experiments were conducted on the same sample. The CWL infiltration experiment simulates the ponding infiltration, that in nature occur during heavy rainfalls. The second experiment CWF simulated infiltration during light rain of the intensity (0.027 mm/min) smaller than soil's saturated hydraulic conductivity.

Table 1: Overview of experiment settings

| | **CWL** | **CWF** |
|---|---|---|
| Top boundary condition | Pressure head of 7 mm | Constant flow 0.003 $cm^{-3}$ $s^{-1}$ |
| Time to ponding (s) | 4 | 2760 |
| Experiment duration (hours) | 16 | 2 |
| Acquisition time of a radiogram (s) | 16 | 0.25 |
| Acquisition time of a tomogram (min) | 50 | 2 |

### Image processing

The raw images were normalized for background noise and for spatial non-homogeneities of the detector, for fluctuations of the neutron flux in time, and for spatial non-homogeneities of the neutron beam. Dry sample image was subtracted from normalized images to obtain water thickness map.

When beam hardening and the neutron scattering effects are neglected, the attenuation coefficient is assumed to be constant. If the beam hardening artefacts cannot be neglected, the empirical formula developed by Kang [1] can be utilized to adjust the attenuation coefficient according to the water thickness. Image processing is in detail described in [2]. Water thickness maps were reconstructed by back filtered projection in Muhrec software [3] to obtain tomograms with water content distribution.

## 3. RESULTS

The results show a higher steady state infiltration rate during the CWL experiment. Neutron images showed that in this case, the air was mostly pushed out from the sample by rapidly moving wetting front. Furthermore, the infiltration rate was continuously decreasing during the infiltration up to the value of steady state infiltration rate. When the wetting front has reached the bottom of the sample the air was moving from matrix domain to preferential domain. Similar effect was earlier observed by Snehota [4]. The steady state flux rate during CWL infiltration was still higher than steady state flux during CWF infiltration experiment. During the CWF infiltration experiment the water infiltrated slowly into the fine ceramics first and then into the medium coarse sand attracted by forces that were stronger in comparison to the coarse sand. Due to this effect a significant amount of air was trapped in preferential pathways, and consequently blocked the water flow primarily due to the presence of medium coarse sand regions.

The selected results of time-lapse neutron tomography are shown in Figure 1. Tomograms include the water content distribution in the sample and show the imbibition process of CWF experiment. Ceramics get wet first and close the air in the area filled with coarse sand.

## 4. ACKNOWLEDGEMENTS

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### References

[1] Kang, M., H. Z. Bilheux, S. Voisin, C. L. Cheng, E. Perfect, J. Horita, and J. M. Warren (2013), Water calibration measurements for neutron radiography: Application to water content quantification in porous media, Nuclear Instruments & Methods in Physics Research Section a - Accelerators Spectrometers Detectors and Associated Equipment, 708, 24-31

[2] Sacha, J., Snehota M., Hovind, J., (2016), A quantitative evaluation of the water distribution in a soil sample using neutron imaging [online]. Acta Polytechnica. 2016, 56s. 388-394

[3] Kaestner, A. P. (2011), MuhRec - A new tomography reconstructor, Nuclear Instruments & Methods in Physics Research Section a - Accelerators Spectrometers Detectors and Associated Equipment, 651(1), 156-160

[4] Snehota, M., V. Jelinkova, M. Sobotkova, J. Sacha, P. Vontobel, and J. Hovind (2015), Water and entrapped air redistribution in heterogeneous sand sample: Quantitative neutron imaging of the process, Water Resources Research, 51(2), 1359-1371

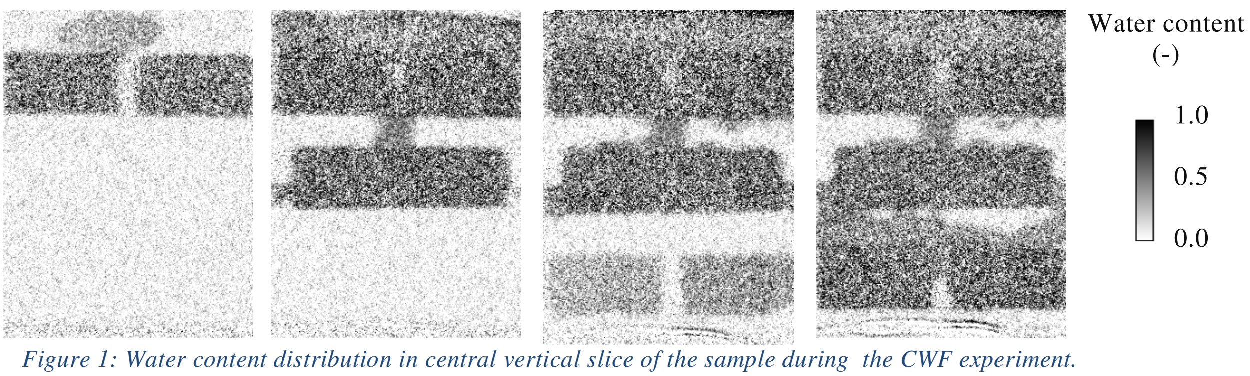


*Figure 1: Water content distribution in central vertical slice of the sample during the CWF experiment.*