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The Effect of Capillary Trapping of Air on Quasi-Saturated Hydraulic Conductivity of Sands Interpreted by X-Ray Microtomography

Tomáš Princ (1), Helena Maria Reis Fideles (2), Michal Sněhota (1), and Johannes Koestel (3)

(1) Czech Technical University in Prague, Prague, Czech Republic (tomas.princ@fsv.cvut.cz), (2) Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, (3) Swedish University of Agricultural Sciences, Uppsala, Sweden

The aim of this study is to experimentally determine the relationship between the gas residual saturation (SGR) and corresponding hydraulic conductivity (K) in samples of two coarse sands. The SGR indicates the global ratio of volume of entrapped air bubbles to pore volume of the sample.
Two replicated samples were prepared for the experiments for each sand. The height of cylindrical samples was 5.0 cm and diameter was 7.2 cm. The samples were packed under deionized water and then were evacuated at -95 kPa in a vacuum chamber to achieve full water saturation.
Measurement of the K was done in a series of constant head infiltration-outflow experiments, where the value of K was determined by Darcy's law from measured steady-state flux. Amount of the entrapped gas was determined gravimetrically. The first infiltration-outflow experimental run was conducted on fully saturated sample. Then the sample was drained under tension on a sand box. Repeating the drainage and imbibition cycles caused gas bubbles trapping while the infiltration-outflow runs provided corresponding K values. Thus, the K(SGR) relationship was developed.
The experiments were done in two steps. Each step starts with fully saturated sample. Firstly, the 11 infiltration runs were done in a laboratory. As the second step, the same samples were used in the same experiments that also involved micro computed tomography (CT) scanning at samples. Three infiltration-outflow runs were done for each sample at this step. The CT scanning was done on samples at state of full saturation and then after each drainage and imbibition was applied.
The results of the CT images reconstruction were the stacks of 16-bit slices with 46 μm resolution. Fiji (Imagej) software was used for the image analysis. The segmentation was done in order to separate the gas phase from the solid and water phases. The binarized images were used to determine the distribution of the entrapped gas within the sample. The histograms of gas bubble volumes and gas volume total content were calculated from the 3D CT image. The total gas volume ratio determined by CT was smaller than the SGR value determined gravimetrically by 10 - 80 % due to low resolution of the images.
Relationship between hydraulic conductivity and the amount of the entrapped gas was developed for both steps of experiment and was fitted by Faybishenko relationship [1] and by a van Genuchten-Mualem model [2][3]. The value of K decreased from 0.074 to 0.040 cm/s (when SGR = 0.3) for first sand and from 0.042 to 0.021 cm/s (when SGR = 0.4) for second sand. Better fitting was achieved by the Faybishenko equation. 3D CT images from second step show that the gas bubbles were predominantly distributed in the upper part of the samples. CT imaging have proven that air clusters size was increasing with each drainage-imbibition cycle, possibly due to effect of Otswald ripening.
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