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4D Study of Groundwater Remediation Techniques at Pore-scale

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Groundwater remediation is a pressing issue in the modern world. In Brazil, almost 37% of the cities are supplied exclusively with groundwater. In Pakistan, 73% of agricultural irrigation is done with groundwater (Qureshi, 2020). According to Lunardi et al., (2021) groundwater is susceptible to contamination in regions, where pollutant source, such as industry, is present.

In this work, a dataset on nZVI nanoparticle reaction with TCE (trichloroethane) is studied. TCE is a DNAPL – Dense non-aqueous phase liquid. These compounds are challenging to be removed from groundwater aquifers via conventional means, as they are almost immiscible in water, and are difficult to remove from the porous medium. Therefore, nanoparticles used for remediation of such reservoirs must be mobile, to able to reach the contaminant and react with the source of contamination. The dataset was obtained via X-ray microtomographic scanning (X-ray micro-CT) on Diamond Light Source, and allows for 4D (3D + time) study of the processes, happening on the pore-scale. For this experiment, Sibelco sand was used, along with Nanofer 25S and 25DS nanoparticle suspensions.

The studies performed on methods like ones studied in this work usually do not study what is happening on pore-scale. Such study is performed by Pandey, Sharma and Saha (2022) on nZVI nanoparticle production techniques, or by Chen et al., (2021) on slow-release potassium permanganate. This highlights a knowledge gap in the modern understanding of these remediation techniques.

Segmentation process proved to be difficult due to the contrast of resulting images. This was caused by the 4D nature of the study. While this allows us to observe the processes with great precision, it was necessary to make the measurements fast. This, in turn, reduced the contrast of the resulting images. The segmentation was performed using deep learning algorithms in Dragonfly and Annotat3D, and then visualised and analysed in Avizo. Phases, identified during segmentation, included sand grains, water, TCE, nZVI clusters and gas. This is in line with the previous work on the subject by Pak et al., (2020), performed on glass beads.

In addition to this, a new setup has been developed for column experiments. This setup gave us the possibility to investigate liquid and particle dynamics on a larger scale, across a column of approximately 36 cm long 3.5 cm in diameter. With this setup we were able to measure particle distribution through the column after several nZVI injections on different porosities. The novelty of this setup is a magnetic susceptibility sensor, which allows to assess distribution of nanoparticles along the column, as well as to measure the amount of nanoparticles produced from the tube. This method is non-invasive, which allows to re-measure the samples in case of an error, or to obtain greater precision. The objective of these experiments is to perform a series of column experiments on Sibelco sand, using the same nanoparticle suspension as in the 4D micro-CT experiment.

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Primary authors: Prof. ISLAM, Meezanul (Teesside University); LOPES ARCHILHA, Nathaly (Brazilian Center for Research in Energy and Materials); KAZAKOVTSEV, Pavel (Teesside University); PAK, Tannaz (Teesside University)

Presenter: KAZAKOVTSEV, Pavel (Teesside University)

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