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STUDY OF THE MIGRATION OF NANOIRON PARTICLES IN THE 2- AND 3-D HOMOGENEOUS ARTIFICAL AQUIFER

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Abstract

Migration of zero valent iron in the subsurface is a task solved in the long term from different points of view at many workplaces. Experimental equipment in these workplaces mostly enables only one-dimensional assignments (laboratory columns) to be studied in different orders with various levels of detection of migrant substances. The 2- and 3-dimension experimental equipment from the VEGAS research facility, University of Stuttgart with large scale dimensions of approximately 1m x 0.12m x 0.7m and 8m x 1m x 3m (L x W x H) enables the migration and interaction of nanoiron particles to be studied in a homogeneous artificially created aquifer under conditions approaching the real conditions of a contaminated site. The whole experiment is linked to the international research project NANOREM, which aims to show that the application of nanoparticles is a useful and in particular reliable method for remediation of contaminated soil and groundwater.

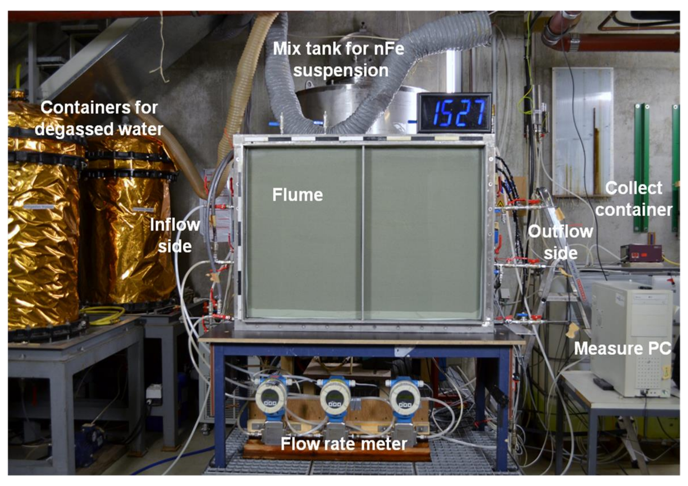
Introduction

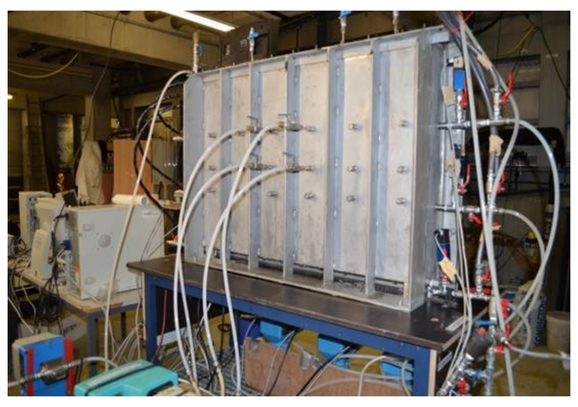
Nanoscale zero-valent iron (nZVI) is a progressive material for in-situ remediation of contaminated sites. Besides testing the reactivity of iron nanoparticles with a given kind of contaminant it is equally important to find out how far the nanoparticles are able to migrate to ensure contact with the contaminant in the subsurface. Artificially created DNAPL (Dense Nonaqueous Phase Liquid) contamination in 2-D and 3-D experimental equipment is treated by zero valent iron nanoparticles using the method of direct-push directly into the contamination source. The use of the direct-push method is economical even in hard to reach areas. The application of reactive zero valent iron nanoparticles, which are pushed as water slurry into the underground, has many advantageous. The nanoscale particles have easier access to the pore space and because of their large specific area react very well with the contaminant. Furthermore, nZVI are applicable to a wide range of pollutants (organic substances, heavy metals, pesticides etc.). The whole large scale system enables the extensive monitoring and visualization of nZVI migration in the subsurface or monitoring of the interaction between the particles and the contaminant. The aim of these experiments is to compare the migration properties of different particles, to calculate the spread efficiency of the particles in the subsurface and in particular to quantify the whole remedial action.

Laboratory test methodologies

2-D experiment (small flume):

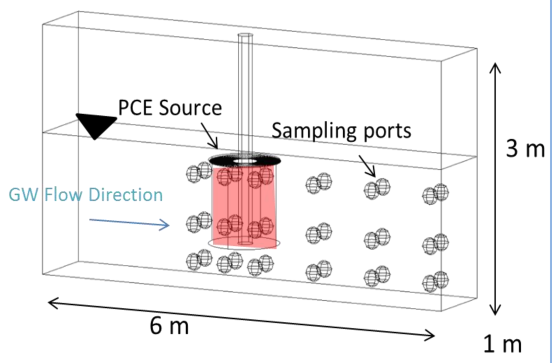
- stainless steel walls
- safety glass front
- 1m x 0,12m x 0,7m (l x w x h)
- Confined aquifer, Homogeneous soil structure (sand DORSOLIT®Nr.8)
- Inflow DO concentration: < 1mg/L
- BC: 2 constant heads
- Used contaminant: tetrachlorethen (PCE), red coloured
- Used nZVI particles: NANOFER 25S (NANO IRON s.r.o.) (with c = 10 g/L)





3-D experiment (large scale flume-LSF):

- stainless steel walls, safety glass front
- 18m x 1m x 3m (l x w x h)
- Division into two compartments, each 8m long
- 36 sampling ports in each compartments
- Unconfined aquifer, Homogeneous soil structure
- Inflow DO concentration: < 1mg/L
- Used contaminant: 2kg of PCE (free phase), red coloured



Monitoring set-up:

- Inflow/Outflow: Measuring parameters → Q, pH, ORP, DO, EC, head
- Flow Domain:
  - 12 magnetic susceptibility sensors (MSS), 3 micro pump, 36 sampling points, 12 piezometer/pressure transducer
  - Measuring parameters → NP concentration (in bulk); PCE, TCE, DCE, VC, ethene, chloride; H2; Acid/base capacity; EC, ORP, pH; Fe diss.

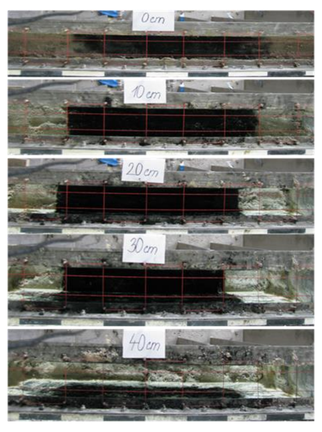
nZVI injection:

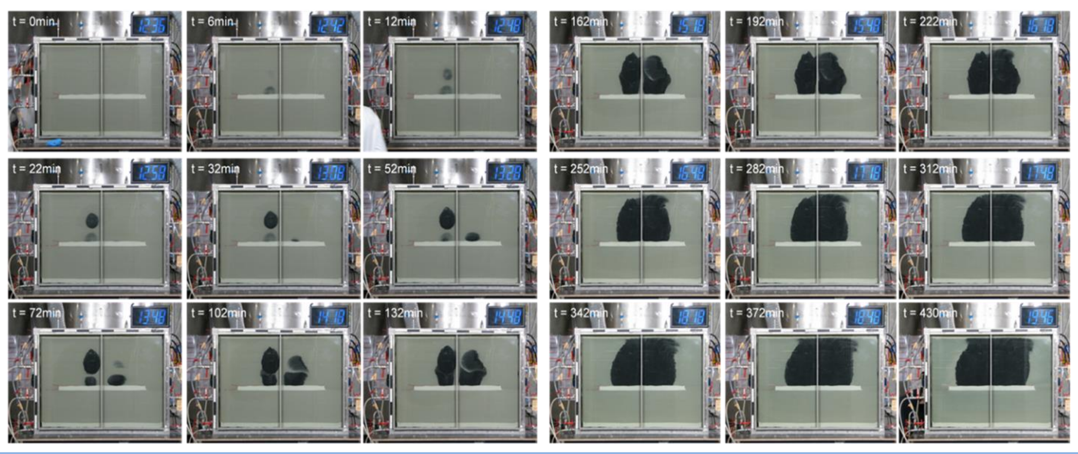
- 1st injection – used nZVI particles NANOFER 25S (NANO IRON s.r.o.)
- 2nd injection – used nZVI particles NANOFER STAR (NANO IRON s.r.o.) with organic modifier Carboxymethyl celullose

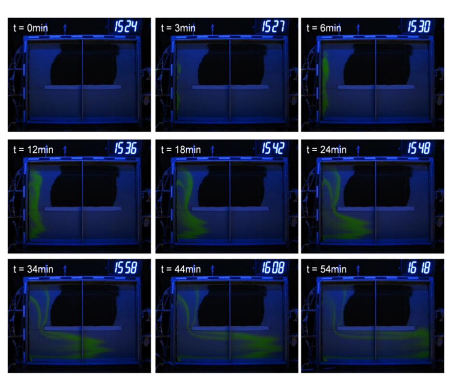
Boundary conditions (Contaminant zone = 0.64 m³)	
Inflow/ Outflow	Constant head
Water Table	1.7 m
Base flow discharge (Q)	0.005 m³/h
Darcy Flux (Seepage Velocity)	0.07 m/d (0.22 m/d)
NP suspension concentration	10 g/L (mixied online)
Concentrate concentration	240 g/L
Dillution	with degassed water (1:25)
Total volume of suspnsion	1m³ (10 kg Fe0)
Injection depth	10 depths (from 140cm to 50 cm)
volume of suspnsion at each depth	0.1 m³
NP injection rate (Q_{inj})	0.1 m³/h (10 h)

Results

- Radially spread of iron nanoparticles (NANOFER 25S) from injection point
- The transport distance approximately 0.4 meters within 7 hours
- nZVI particles reached areas of PCE contamination → providing necessary contact for onset of PCE reaction with nZVI
- Water flow completely changed after nZVI injection (by nZVI injection affected area bypassed)
- Limitation: accumulation of gases in upper part of box

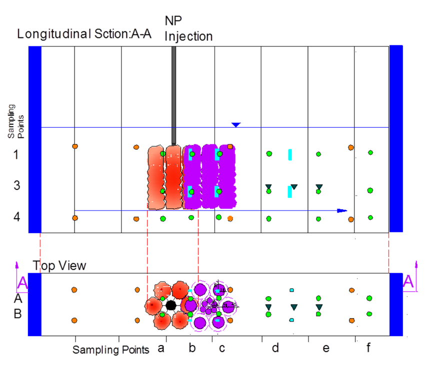






1st injection:

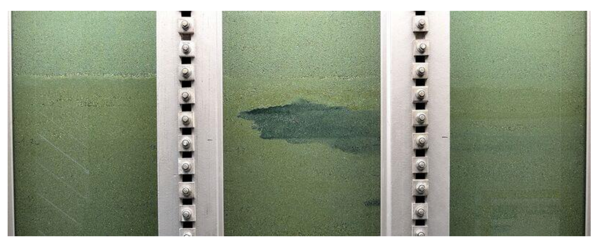
- NP Transport insufficient
- Most of PCE flushed out due to nanoparticles injection
  - MSS (r= 26cm) no detection
  - Soil samples (r=15cm) only at z=90 - 70cm, nZVI detected
  - → NP transported max.15cm → Reinjection necessary

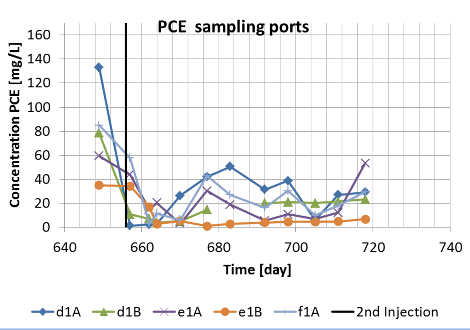


2nd injection:

- nZVIs detected from 6 MSS
  - 5 inside of the source zone
  - 1 at 1.44 m down stream
- Temp. changes detected from 7 MSS
  - 4 inside of the source zone
  - 3 at 1.44 m down stream

- Particles found at glass front after 2 months of injection
- PCE decline at downstream of injection observed
- PCE degradation still going on, experiment still running





The 2D-experiment designed for the purpose of comparing the migration properties of different types of nanoparticles fulfils its task. The experiment can be repeated to determine how the individual particles behave in the given porous medium. By maintaining the same initial conditions of the experiment (the same porous medium, the concentration of particles in the suspension etc.) not only can the migration ability of the particles be compared but also the spread efficiency in the medium. The 3-D large scale experiment enables the study of migration of nZVI particles, its interaction with the contaminant and quantification of the whole remediation in a homogeneous artificially created aquifer under conditions close to those encountered at field sites. The first pilot test verified the whole experimental system and initial conditions. The transport of the NANOFER 25S particles from the injection point was insufficient. During the 2nd injection with use of other type of nZVI particles NANOFER STAR modified with CMC to enhance the migration properties in the porous media was achieved better transport of nZVI in the system. After two months the particles discovered at the LSF glass front. The LSF experiment was designed for a deeper understanding of a real remediation action and to show that the application of nanoparticles is a useful method for remediation of contaminated soil and groundwater.

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