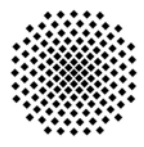


# Injection of Nano-Scale Iron for the In-Situ Remediation of Chlorinated Hydrocarbons in Soil and Groundwater

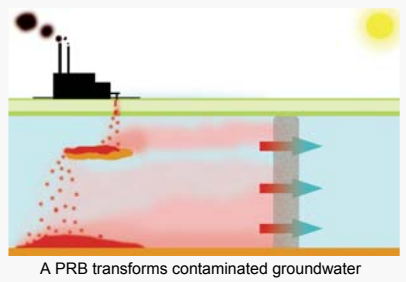


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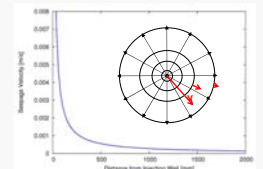
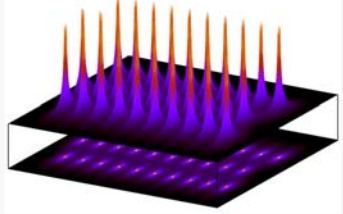
Cjestmir de Boer, Juergen Braun, Norbert Klaas, Stefan Steiert

## Zero Valent Iron for In-Situ Remediation

- Granular reactive iron ( $Fe^0$ ) is used in Permeable Reactive Barriers (PRB)
- $Fe^0$  can reduce chlorinated hydrocarbons such as TCE and PCE
- Nano-scale  $Fe^0$  particles are assumed to be injectable in aquifers to create a PRB in situ
- No excavation is necessary and after the  $Fe^0$  is consumed, it can be re-injected
- Goal of this research is to experimentally proof this method



## Velocities in the Vicinity of Injection Wells



Concentration distribution of an injected  $Fe^0$  barrier.

The concentration decreases rapidly from the injection point (observed in 1-D and 2-D)

Column experiments showed that the iron could be moved only by very high flow rates. Hence, for radial flow, transport distances are limited



Spreading of nano-iron as seen in 2-D experiments (radius of plume app. 5cm)

## Column Experiments

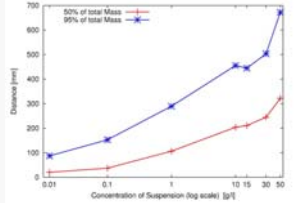
Horizontal 1-D column experiments ( $\varnothing=3.6$ cm,  $L=200$ cm) to investigate individual factors influencing transport

Qualitative and quantitative determination of transport behavior of a nano-iron suspension during injection

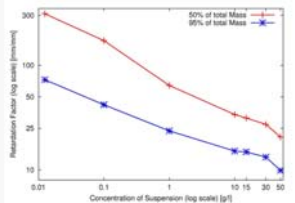
Transport of nano-iron particles influenced by:

- The flow velocity in the porous media
- The concentration
- The age of the suspension - i.e., aggregation of nano-iron particles
- Gravity - i.e. direction of flow
- Viscosity of the carrier fluid
- The grain size, grain size distribution and heterogeneity of the porous media

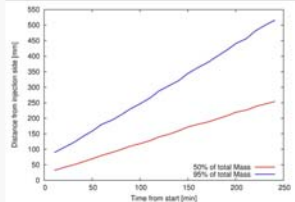
Iron is mainly retarded due to gravitational settling and filtration in the porous media



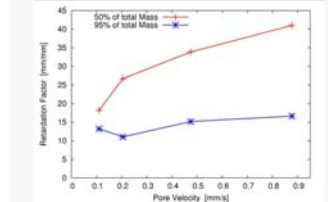
Transport for different concentrations after 240 min (3 PV injected)



Retardation factor as a function of injected concentration (after 3 PV)

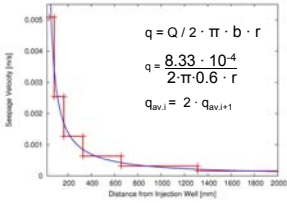


Transport as a function of time. (240 min correspond to 3 PV)



Retardation factor as a function of flow velocity (after 3 PV)

## Transfer Column to Container



The horizontal lines cross where average velocity equals the real velocity

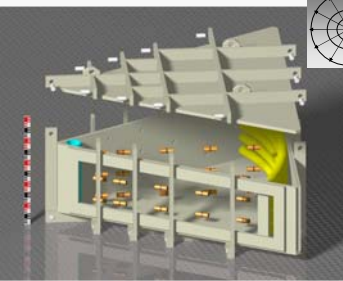
Method required to predict the transport behavior in 3-D field scale injection based on the results of 1-D lab experiments

- Discretize the flow field in velocity steps
- Determine relevant injection concentration for each step
- Experimentally investigate transport behavior (at 1-D) for each velocity step
- Optimize injection rate and concentration for 3-D (radial) flow

Mathematical description of transport is needed

Numerical model can then be set up based on the measured and deduced parameters influencing the transport

## Field-scale Container Experiment



Container with sensors. ( $r = 200$  cm,  $h = 60$  cm)



A 60° piece of a confined aquifer around an injection well was built

Minimize injection and setup size without loss of generalization

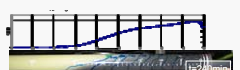
Cross section with glass plate for visual observation

Sensors in the sand measure the concentration of iron

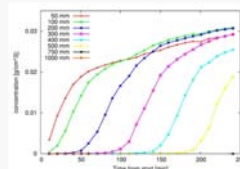
Confined and unconfined experiments are possible

## A New Technique to Determine $Fe^0$ Concentrations in a Column

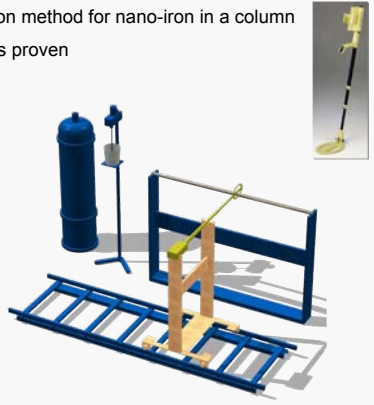
- Development of a non-destructive detection method for nano-iron in a column
- Application of modified metal-detector was proven



Column injected with nano-iron for 240 min, above the concentration measurement

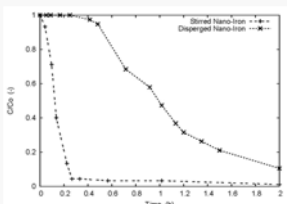


Breakthrough curves of iron at different distances from the injection side



Current work: Modification for 3-D and down-hole applications

## Nano Particle Behavior and Characterization



Sedimentation of dispersed and fresh nano iron particles



Particles settle at low velocities. (Tube diameter: 5 mm)

- Agglomeration due to the age of the suspension could partly be reversed by dispersing the suspension
- Good particle characterization is needed
- Size distributions are going to be measured



Nano-iron suspensions in different concentrations

Literature: De Boer, C.V., 2007: "Characteristics and Mobility of Zero-Valent Nano-Iron in Porous Media", MSc-Thesis, University of Utrecht



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