

NanoRem is a four year, €14 million research project funded through the European Commission FP7.

Motivation

Nanoscale iron-oxide particles (Goethite) can effectively enhance microbial degradation of a wide range of contaminants.

Due to their small size, Goethite nanoparticles can be dispersed in water and directly injected into the subsurface to create reactive zones to promote contaminant degradation.

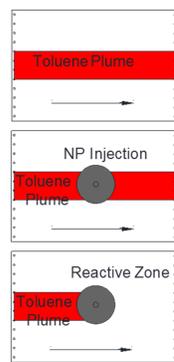
→ Experimental proof of Goethite injection as promising technology for in situ remediation of contaminated aquifers is required.



Large Scale Container at VEGAS research facility

Goals

- Remediation of a BTEX (toluene) plume utilizing iron-oxide (Goethite) nanoparticles
- Transport and targeted deposition of Goethite nanoparticles (NP) in the subsurface ($r = 1.5$ m with sufficient concentration)
- Quantification of remediation (degradation) rates and longevity of NP (reinjection intervals)



BTEX plume intercepted by injected Goethite NPs

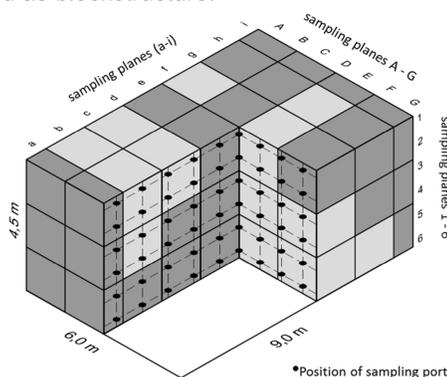
Set-Up of Large Scale Container Experiment and Monitoring

The Large Scale Container at VEGAS is built of high grade stainless steel and has the dimensions 9.0 x 6.0 x 4.5 m (L x W x H), with a volume of 243m³. The container is filled with two types of sand as blockstructure.

- 60 sand blocks in 3 layers (1.75m, 1.45m, and 1.3m high)
- Random distribution of coarse (0-4mm) and medium (0-8mm) sand blocks

Boundary Conditions

- Unconfined aquifer
- Inflow BC: const. head, $h_{in} = 3.782$ m
- Outflow BC: const. head, $h_{out} = 3.775$ m
- Flow rate: $Q = 3.1$ m³/d ($q \sim 0.14$ m/d)
- Inflow DO concentration: < 1 mg/L



Geometry of block structure in large scale experiment: (Light grey = coarse sand, dark grey = medium sand, black dots = location of liquid sampling points)

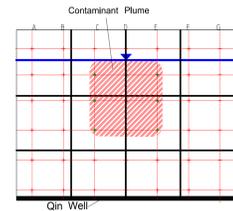
Monitoring strategy of each location (inflow, outflow, flow domain)

	Monitoring set-up	Parameter
Inflow/Outflow	Installed sensor for continuous monitoring	Q, pH, DO, EC, ORP, T
Flow domain	378 liquid sampling points, piezometers	h , C_{NP} , $C_{toluene}$, CO_2 , buffer capacity, TIC, pH, anion, Fe^{2+} , Fe^{3+}

Plume Emplacement

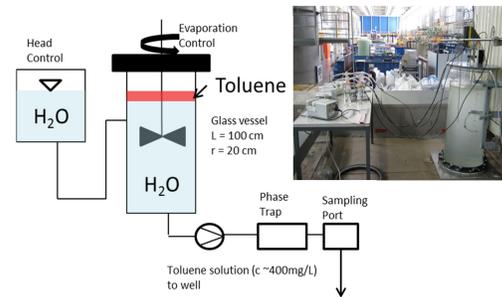
Requirements

- Toluene plume to be located in upper and middle block layer
- Cross-sectional area: $2\text{m} \times 2\text{m} = 4\text{m}^2$
- To be intercepted by 9 sampling ports on a vertical sampling plane



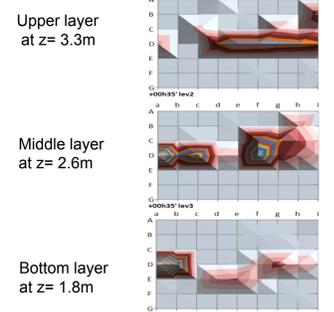
Cross section depicting sampling positions (where red lines cross), block geometry and plume

Set-up of continuous toluene solution supply system



Mixing unit and injection pump for concentrated toluene solution (left: Flow chart, right: set-up)

Distribution of C_{tol} in the container

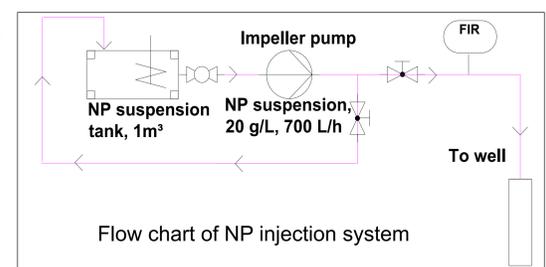


C_{tol} in the container before NP injection: Orange > 200 mg/L, dark red > 100 mg/L, light pink < 20 mg/L

Nanoparticle Injection

Design parameters (based on MODFLOW)

- **Reactive zone**
 $r = 1.50$ m, $z = 2.20$ m, $PV \sim 6$ m³
 → residence time of toluene: $t \geq 7$ days
 @ $v \sim 0.4$ m/d base flow
- **NP Injection system**
 Gravity driven injection
 → Injection well: ID = 3",
 $L_{screen} = 2.0$ m,
 $z = 1.7 - 3.7$ m
 → Injection suspension $Q = 700$ L/h,
 $t = 8.5$ h, $c_{NP} = 20$ g/L, $m_{NP} = 120$ kg

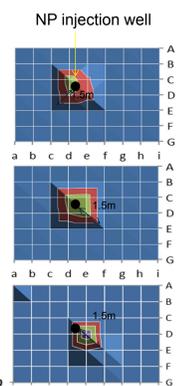


Flow chart of NP injection system

Preliminary Result

NP transport (based on gravimetry method of liquid samples)

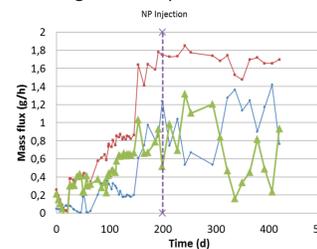
- NPs were transported around 1.5 m from the injection well with sufficient concentration of NP (~ 13 g/L)
- Slight migration of unsedimented NPs by baseflow was observed until 5 weeks after the injection



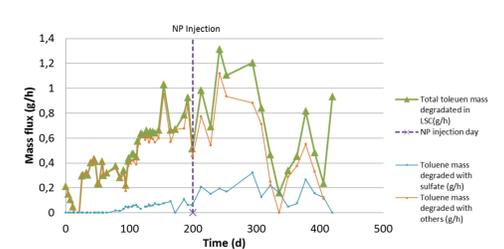
Distribution of NP concentration during NP injection (at 4h of injection): yellow: ~ 13 g/L, red: ~ 5 g/L, blue: < 1 g/L

Remediation (Enhancement of biodegradation)

- Toluene degradation in the container was $\sim 20\%$ increased for 100 days after NP injection (left graph, green curve)
- However the sand in the container contains geogenic Fe^{3+} , and the inflow GW contains sulfate, so high toluene degradation was observed even before NP injection. Therefore no clear enhancement of biodegradation by NP was observed (right graph, orange curve)



Toluene mass flux in/outflow



Degraded toluene mass in LSC

