Migration and Reaction of NANOFER STAR in the Large Scale VEGAS Flume

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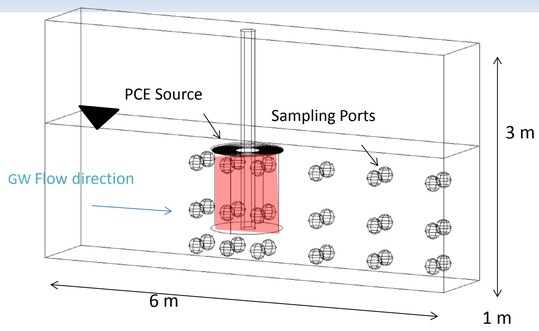
Large Scale Flume

Artificial Aquifer in the Large Scale VEGAS Flume

- Size: L/B/H = 6.0/ 1.0/ 3.0 m
- Homogeneous sand aquifer (K = 4 x 10^{-4} m/s)
- Water table: 1.7 m
- Seepage velocity: 0.2 m/d



DNAPL Source Zone (PCE)

- 3 kg PCE in r = 0.45 m
  z = 1.6 – 2.6 m bgs
  z = 0.3 – 1.3 m below GWT
- Concentration of plume: ~ 150 mg/L
- 34 Sampling ports:
  32 in the aquifer, 2 in/outflow

Goal of Experiment

Remediation of PCE Source Zone

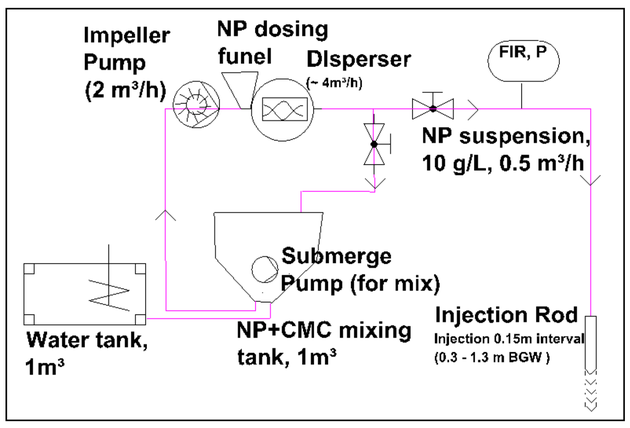
- Remediation of 3 kg PCE (r = 0.45m, h = 1m)

Targeted Transport/Deposition of NP in PCE Source Zone

- Distance of deposition of NP: r = 0.5 m to cover source zone
- Mass of deposition of NP: Based on the stoichiometry 3.9 kg nZVI to treat 3 kg PCE
- Conditions and constraints
  Q_{max} ~ 1.0 m³/h, (unconfined aquifer)
  P_{max} ~ 3.0 bar (shallow injection depth, 1.6 – 2.5 m BGL)

Injection Set-up

Boundary Condition for NANOFER STAR injection	
Injection Method	Direct push
Injection Rod	1” ID with 4 small injection nozzles
$Q_{injection}$	0.5 m³/h
$C_{NP(\ NANOFER\ STAR\ )}$	10 g/L
Volume of Injection	1 m³ (5 x 0.2 m³)
Mass of NP	10 kg
Depth of Injection	1.3 m – 0.7 m BGL 5 inj. at 0.15 m interval)



Injection Results

Depth Nr.	Injection depth (m bgl)	Injected suspension Vol (m³)	Injected mass of NP (kg)	C_{NP} in suspension (g/L)	Average Injection Q (m³/h)	Max injection pressure (bar)
1	1.70	0.27	2.00	7.40	0.41	2.60
2	1.85	0.21	2.30	11.00	0.46	2.50
3	2.00	0.20	2.21	11.00	0.64	2.60
4	2.15	0.20	2.20	11.00	0.67	2.40
5	2.30	0.11	1.25	11.00	0.29	2.90

In total 1.0 m³ of suspension containing 9.96 kg NANOFER STAR particles were injected with the dispersion-circulation-injection system.

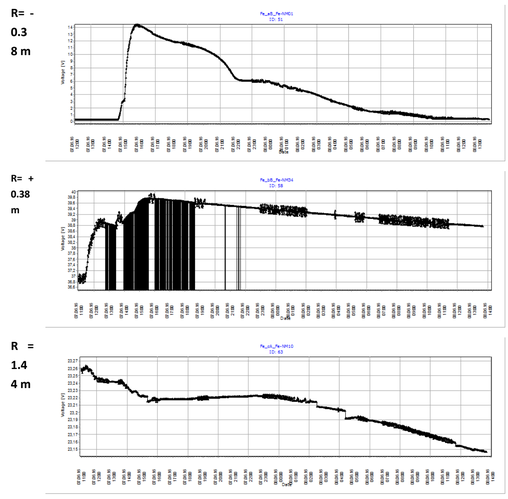
Injection at 5 depths between 1.7 m bgl and 2.3 m bgl at 0.15 m intervals

V = 0.2 m³ suspension per injection point

Injection at constant injection rate (~ 0.5 m³/h) and pressure (~2.5 bar) until depth 4 indicating homogeneouos hydrogeological properties

At 2.3 m bgl pressure increase to > 2.8 bar (slightly denser porous media) necessitating reduction of injection rate to prevent day lighting.

Transport of Particles



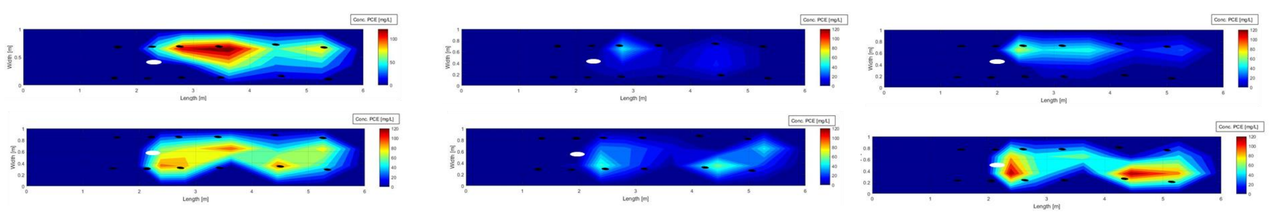
- NP injection monitored by 12 magnetic susceptibility sensors (MSS).
- NP transport distance (ROT) more than 0.38 m in all directions
- Some NP detected at 1.44 m.
- Monitoring of degradation product chloride (Cl^-) showed that the reactive zone extended to cover the whole contaminated source zone.

PCE and Cl^- Concentration Distribution in LSF

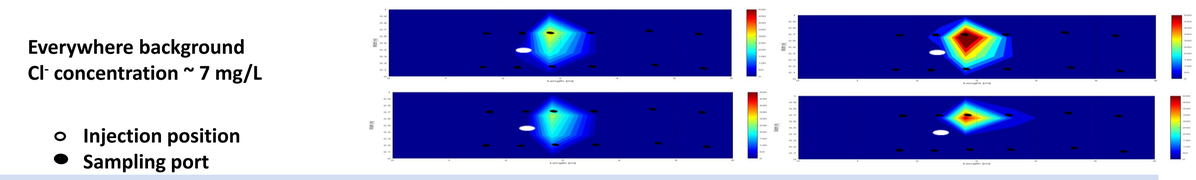
- Right after NP injection PCE concentrations (c_{PCE}) in flume were low → dilution
- After 1 week additional decrease of c_{PCE} → clear indication of chemical reduction due to NP injection
- After 2 weeks gradual rebound of c_{PCE} in some areas. In other areas continuously low after that.
- Cl^- detected after 1 week in all sampling planes → indication that the NP deposition extended further than 0.38 m in all dimension and fully covered the contaminant source zone.

1 week before the injection | **1 week after the injection** | **4 weeks after the injection**

PCE

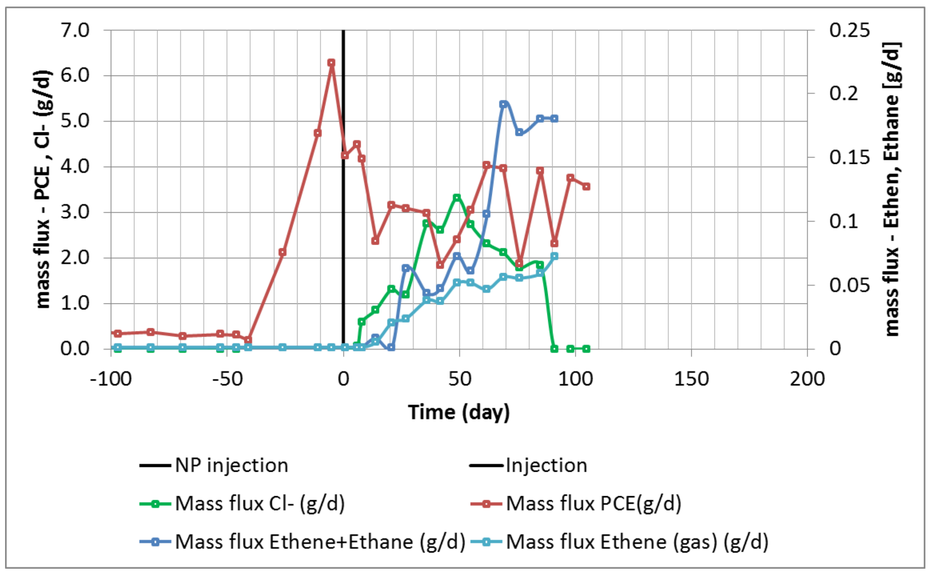


Chloride



Remediation

After the injection of NANOFER STAR, an increase in PCE degradation could be observed. Production of degradation products Cl^-, ethene and ethane were also observed 1 week after the injection (graph below). Even after 90 days of the injection, the PCE degradation is still in progress. As a preliminary result, the STAR particles had degraded m = 190.3 g of PCE after 90 days, based on the produced mass of Cl^- in the outlet.



Conclusion: The colloidal suspension with high concentration of NANOFER STAR was successfully injected achieving transport and deposition goal. Whole contaminant source zone was covered by the particles, thus particle reactivity to attack PCE source zone in the aquifer could be investigated.

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NanoRem - Taking Nanotechnological Remediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment

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