Site Remediation with Iron NanoParticles

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Nanotechnology holds great promise for meeting environmental challenges

- Improve environmental technologies (treatment, remediation, sensing, etc.)
- Improve manufacturing processes (efficiency, waste reduction, etc.)
- Dematerialization
Environmental Technologies at the Nanoscale

Nanotechnology could substantially enhance environmental quality and sustainability through pollution prevention, treatment, and remediation.

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Site Remediation
Industrial Waste Treatment

Brick Field Sludge Disposal Cell at Iron Mountain Mine
Environmental Remediation
with
Nanoscale Iron Particles
Lab and Field Experience

\[ \text{C}_2\text{HCl}_3 \quad \text{C}_2\text{H}_6 + 3\text{Cl}^- \]

\[ \text{Fe}^{2+} \quad \text{Fe}^0 \]

\[ 5[\text{H}] \]

\(<100 \mu\text{m}\)
Why Nanoparticles?

- Small size for easy subsurface injection
- Large surface area
- Extremely high reaction rates
- Low temperature reaction
- Added Catalytical functions
Methods of Synthesis

Precursors Fe\(^{2+}\), Fe\(^{3+}\)

Fe\(^{0}\) Reduction

Cluster Formation

Stabilization CMCD (Sugar)
Size (50-100 nm)
50 nm nanoparticle

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
Iron particles (100-200 nm)
Iron particles (3-5 nm)
Nano Iron Wire
(dia 50-75 nm, 10-20 µm long)

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
Iron Rod (dia ~50 nm)
Iron Tube (~ 50 nm)
Nano Iron Antenna (~50 nm)
Contaminant Transformation
With Reactive Iron Nanoparticles

- Organic solvents (TCE, PCE)
- Pesticides (DDT, lindane)
- Fertilizers (nitrate)
- Heavy metals (Pb, Hg, Cr, As)
- Explosives (TNT, RDX)
- Radioactive materials (U)
- Perchlorate (ClO$_4^-$)
Perchlorate Reduction

Perchlorate Level vs. Time @ T = 25 °C

Initial perchlorate concentration 200 mg/L
Most effective Eh regulator
Field Test -1
(1.7 kg nanoFe applied, 2000)

- A 27-acre NJ manufacturing site
- Continuous production since 1930s
- $C_2HCl_3$ (TCE), $CCl_4$ (CT), etc.
- >$1.0$ million has been spent on the site
- Active remedy is needed
Test Area Schematic

Flowmeter

Nanoparticle Suspension (400 L)

Groundwater

3.0 – 4.5 m

DGC-15

PZ-1

PZ-2

PZ-3

2.4 – 3.6 m

4.8 – 6.0 m

1.5 m  1.5 m  1.5 m
Setting Up!

- 2-165 gal tanks
- Recirculation from PZ-3S, 3D to DGC-15 or storage tank
- Dedicated low-flow pumps in each well
- Goal = Gravity Feed!
The Nano Fe Slurry
TCE Reduction %

Day 1  Day 9  Day 17  Day 22

DGC-15  1S  1D  2S  2D  3S  3D

Day 1
Day 9
Day 17
Day 22
Field Test - 2
(Nano Fe 10 kg, 2002)

Total volume injected = 1,600 gallons (6,056 L)
Nano Fe concentration = 1.9 g/l
Average injection rate = 0.6 gpm

Injection Well B-4
Monitoring Wells
- B-3: 20 feet north of B-4
- B-2: 40 feet northeast of B-4
- GW-4: 63 feet north-northeast of B-4
Conceptual Geologic/Hydrogeologic Model

VIEW LOOKING SOUTHWEST

Gentle, southeast-dipping Sandstone with interbedded Siltstone grading downward into Mudstones

Combination of down-dip and strike-parallel fracture-controlled flow, in the shallower, water-bearing units

Likely strike-parallel flow toward T.W. Alexander Drive in the lower, water-bearing units

CONCEPTUAL DIAGRAM OF GROUNDWATER FLOW
Conceptual Model - Injection Area
Field Test - 2 (10 kg Nano Fe)
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