Small Flume Experiment for the Transport Evaluation of Carbo-Iron® Particles in a Confined Aquifer

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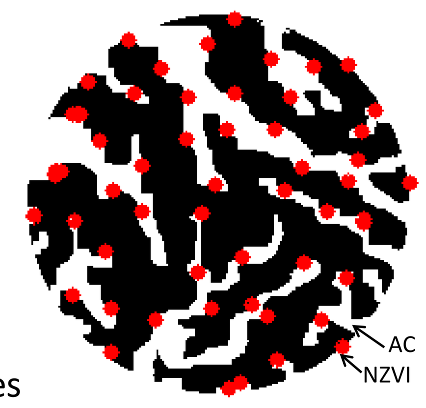
Motivation

- **Carbo-Iron®** is a new injectable **composite** material which targets both chlorinated solvents plume and source remediation:
  - Carbo-Iron particles consist of clusters of **nZVI** embedded in colloidal **activated carbon (AC)** particles
  - The AC framework functions as a spacer between the NZVI structures lowering their agglomeration tendency which leads to **better transport**
  - The addition of the environmentally benign stabilizer **CMC** further enhances suspension stability and mobility by **electrosteric stabilization**



Carbo-Iron

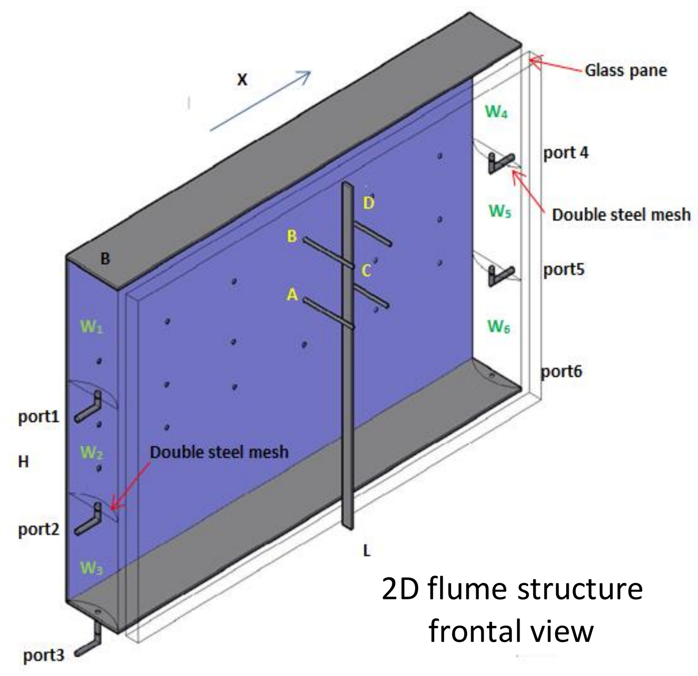
- A suspension containing **20g/L Carbo-Iron** and **4g/L CMC** was identified as the best recipe for fully **optimized transport**
- **Carbo-Iron** contains **10-25w/w% of nZVI**:
  - one single injection (ZVI = 1.48 g/L_{soil}) of the optimized suspension into the source zone (PCE = 0.5g/L_{soil}) does not suffice for a successful remediation (ZVI=2.6 g/L_{soil})

Goals


Small Flume Experiment

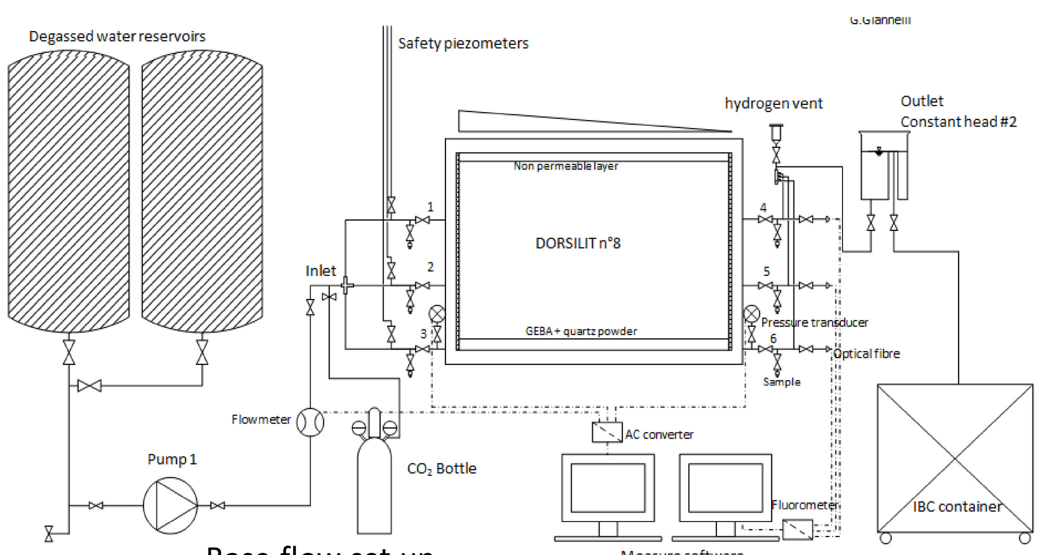
- Test of a **multi-step injection strategy** to emplace and accumulate a sufficient mass of Carbo-Iron in a predefined target zone
- Optimization of the injection interval needed to let the previous particles settle
- Confirmation of the Carbo-Iron **enhanced mobility** features in a quasi 2D system
- Procedure for **comparison of particle migration** using suspensions of different particles

2D Flume



2D flume structure frontal view

- **Stainless steel flume**:
  - L / W / H = 1.00 / 0.12 / 0.70 m (quasi 2D)
  - Frontal glass pane for visual observation
- **Confined aquifer** simulation:
  - Dorsilit n°8 sand (0.3-0.8mm), degassed water
  - Horizontal base flow
  - Inflow BC: constant flux, outflow BC: constant head
  - Porosity: 0.37, PV_{flume}= 26 L
  - average hydraulic conductivity: 5.87 10^{-05} m/s

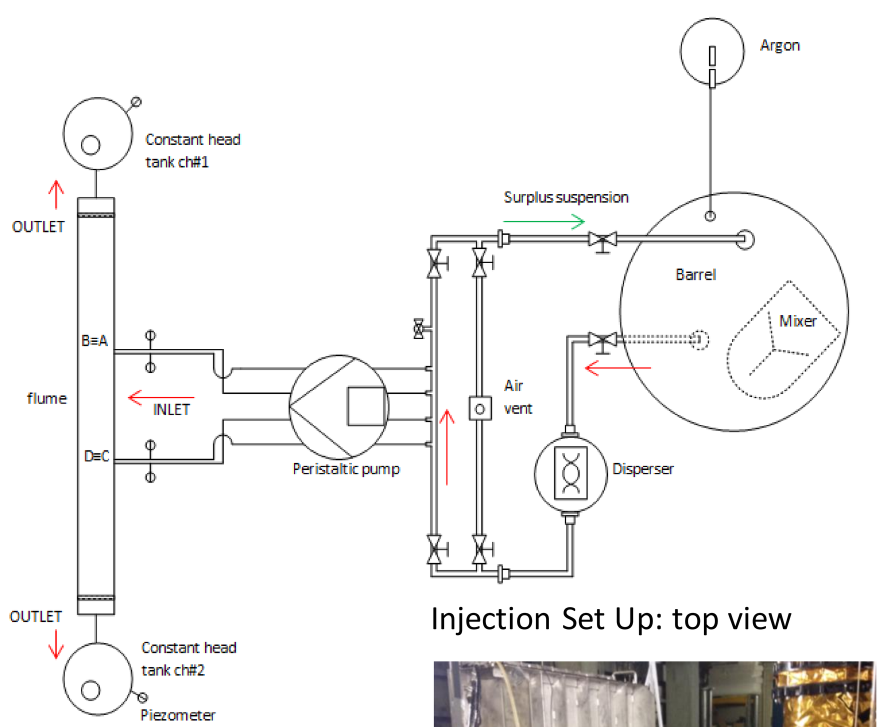


Base flow set up

- **Measurements:**
  - MID (total base flow)
  - pressure transducers (Δh in-out)
  - optical fibers (fluorescence)
- **Uranine Tracer Test:**
  - visual
  - Using optical fibers

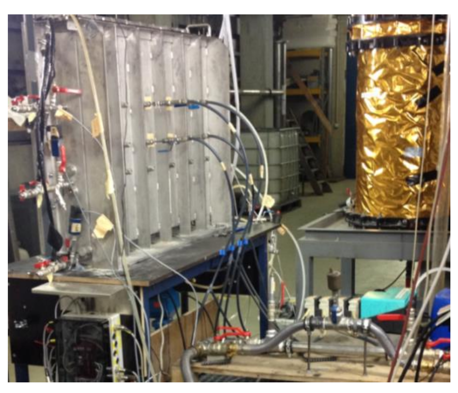
Experimental Procedure

- Suspension preparation:
  - **20 g/L Carbo-Iron, 4 g/L CMC**
  - Hydraulic mixer, disperser, argon supply
- Three Carbo-Iron **Multi-Step injections**:
  - **no base flow,** outflow BC: constant head
  - 4 **injection ports** at the back side of the flume
  - liquid samples from outflow
  - continuous monitoring of injection pressure
- **Recovery intervals**:
  - No base flow
  - 1st recovery: d = 24 h, 2nd recovery: d = 48 h
- **Restoration** of the base flow:
  - horizontal base flow
  - q = 1.1 *10^{-05} m/s , d = 33 h



Injection Set Up: top view

n° inj	V [L]	d [min]
1	15	48
2	10	34
3	10	35

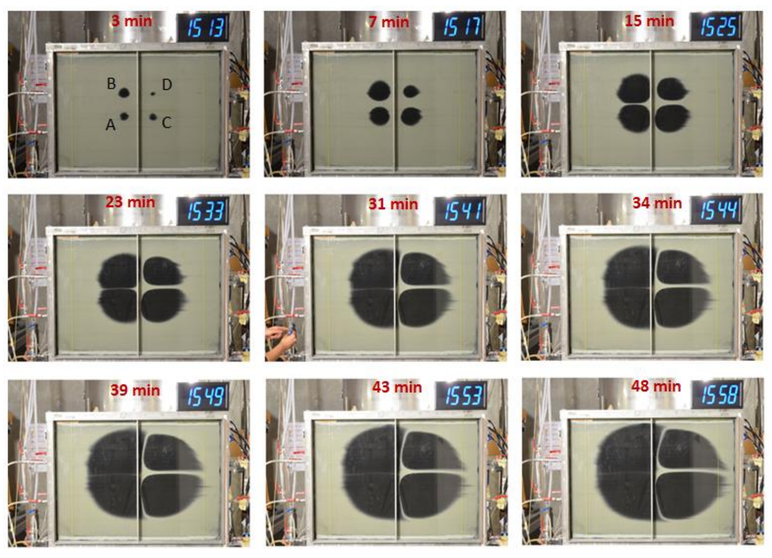

Back side of the flume

Mobility of Carbo-Iron

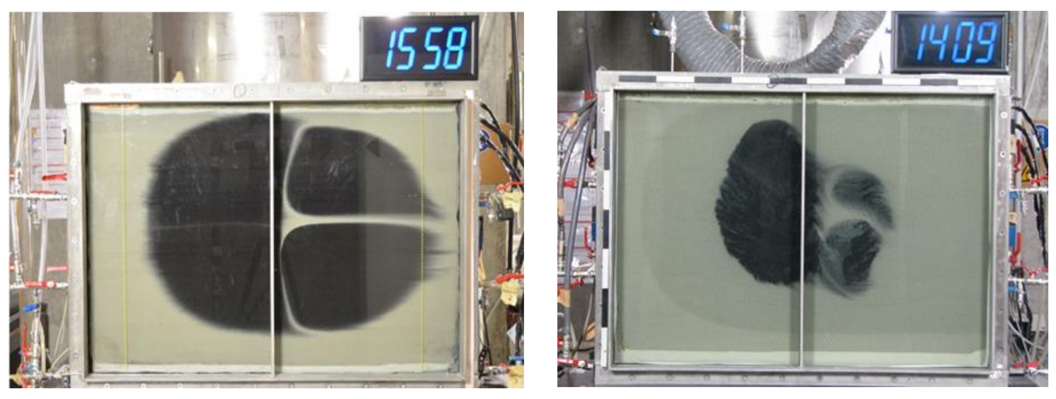
- Homogeneous and fast spreading of particles
- No pore clogging
- **Mobility Factor** for transport assessment:

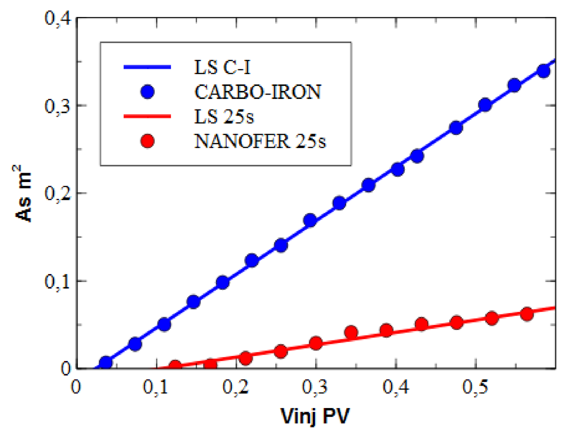
$$M\,[-] = \frac{V_{NP}}{V_{inj}} = \frac{A_{spread} * W * n}{V_{inj}}$$

  - Ratio between volume from the visual spreading and volume injected
  - M = 0: infinite retention
  - M = 1: conservative tracer


Time lapse analysis from the first injection. (Relative time in upper centre)

- Migration comparison between Carbo-Iron and NANOFER 25s®
  - **Carbo-Iron** may be considered **perfectly mobile** particles


Spreading area at the end of Carbo-Iron (left) and N 25s (right) injection



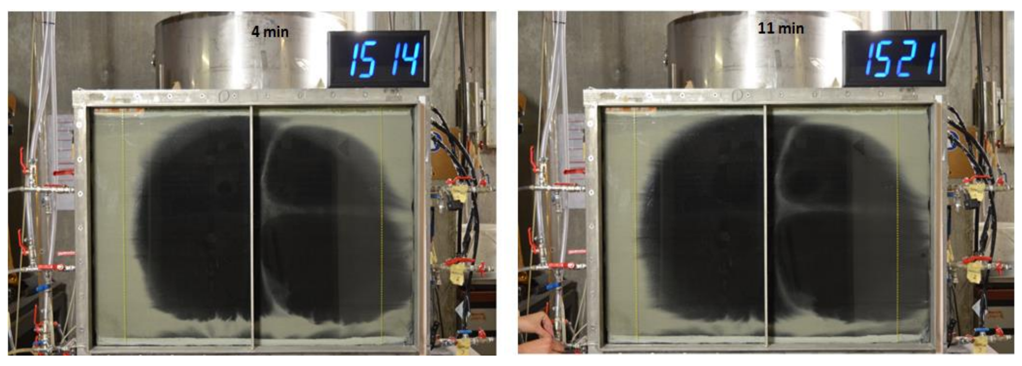
A_s [m²] over PV of injected suspension (α angular coef.)

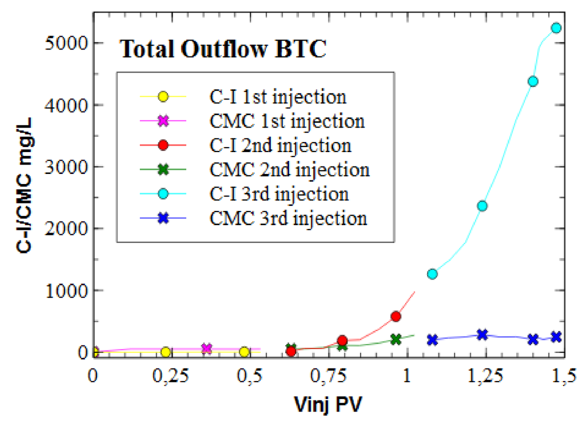
Parameter	Carbo-Iron	NANOFER 25s
PVinj [-]	0.58	1.64
final As [m²]	0.34	0.16
M [-]	**0.95**	0.11
α [-]	0.61	0.14
Fe(0) [$_{w/w}$%]	**10-25**	80-90

α [-]	angular coefficient
C-I	0.61
N25s	0.14

Emplacement of Carbo-Iron

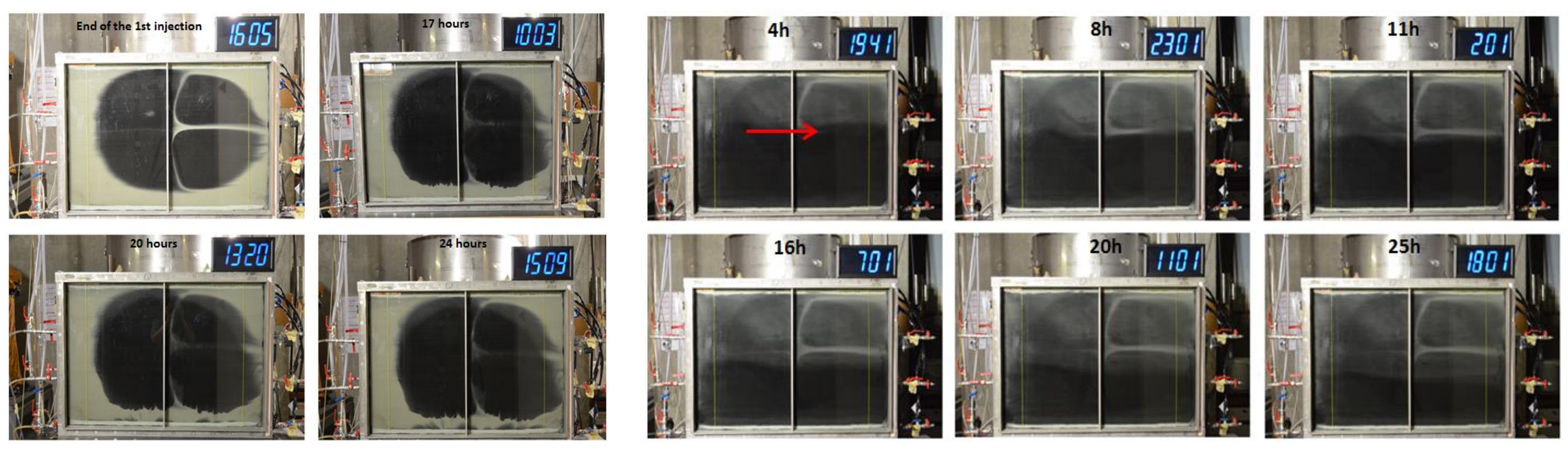
- Particles which are still suspended in the pore water are pushed away by the new injected suspension


Expansion of the particle zone during the 2nd injection; (left) 4 min and (right) 11 min after start of the 2nd injection



CMC and Carbo-Iron breakthrough curves in the outflow Carbo-Iron BTC shows a rising trend

- Particles migrate downwards during the recovery intervals in the absence of external gradients as well as during the restoration of the base flow (presumable due to higher density of the suspension)
- After restart (restoration) of base flow particles not yet immobilized are further transported in the direction of flow


Time lapse analysis during the 24h recovery interval (left) and the restoration of the base flow (right)

- Analysis of solid samples and **concentration mapping**
  - **Max ZVI** available with a **single injection** of 1PV (15 L): **1.48 g/L_{soil}**
  - **Max ZVI remaining** in the target zone after injection of 2.3PV (35 L): **1.36 g/L_{soil} < 1.48 g/L_{soil}**

Conclusions and Outlook

- For perfectly mobile particles the **Multi-Step Injection** method does **not** increase the amount of ZVI emplaced
- The **suspension** needs to be **tuned for better control**. **"Deoptimization"** of the suspension is achieved **adjusting CMC** concentration from 4g/L to 1g/L (presentation S. Bleyl).

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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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