Feasibility Study and Pilot Remediation for In-Situ Reduction and Immobilization of Cr(VI) Contaminations in a Former Coal-Mine

Introduction / Objectives

In Bochum-Gerthe (Ruhr Region, in the Western part of Germany) wood products have been impregnated using chromium salt and tar oil on a former coal mining area.

Fig.1: Historical transport to impregnation using chromium salt and tar oil

This procedure resulted in an extensive contamination of soil and groundwater, which is addressed separately in three different areas:

1. Contamination center area:
   Demolition of tanks and pipelines, surface sealing
2. Contaminated groundwater plume:
   Planned in-situ remediation (see here)
3. Contaminated spring water of the East Creek:
   Water treatment, reduction with Dithionite

The overall objective of the project in the contaminated plume was to identify an efficient remediation option under difficult site conditions. This involved a comparison between in-situ-reduction and in-situ-immobilization of soluble chromium by either chemically or biologically induced processes, an approach from laboratory tests via small scale field testing to full scale remediation.

Site Description

In the upper layer of the inhomogeneous aquifer (so called Castroper Höhenschotter, silty gravel) different contaminants such as Chromium-VI (approx. 10,000 µg/l), EPA-PAH (approx. 100,000 µg/l) and NSO-heterocyclic compounds (approx. 1,000 µg/l) have been detected in groundwater samples. The investigated area is situated in a residential area.

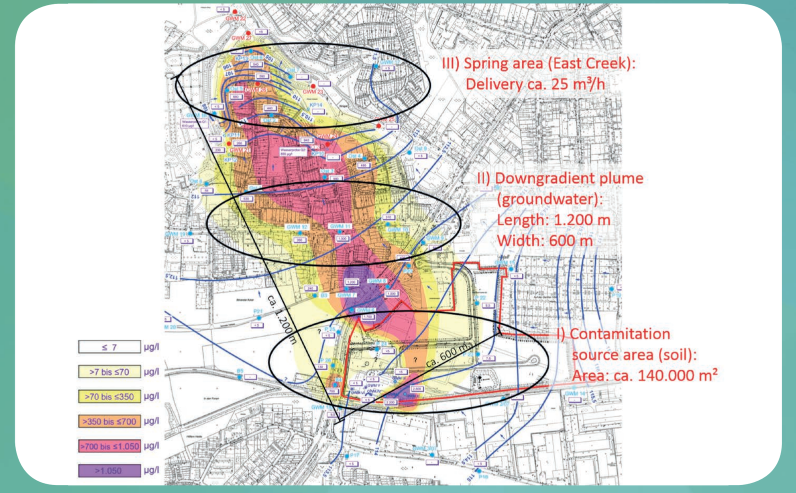

Fig.2: Location of the 3 remediation areas, here with focus to area II) Downgradient plume

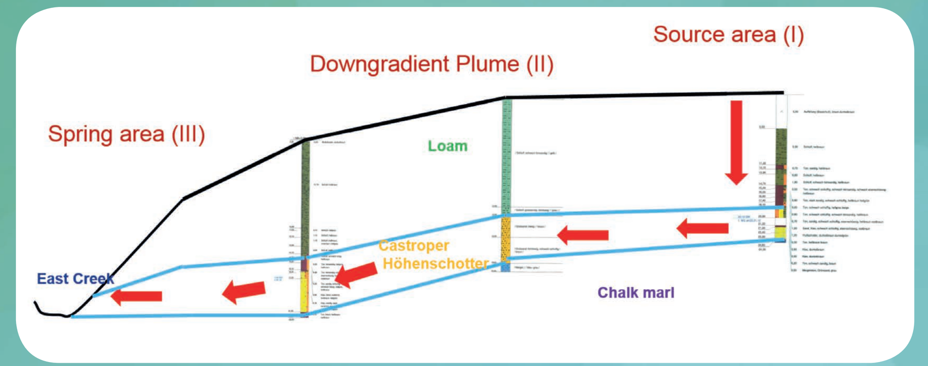

Fig.3: Schematic cross section (base of Quarternary aquifer, well point locations, soil profiles)

Remediation Option Investigation

As a result of a remediation option investigation an innovative technology was chosen which was based on in-situ-reduction and in-situ-immobilization of soluble chromium by either chemically or biologically induced processes or in combination of both processes.

Each of the procedures were tested in the laboratory in batch tests as well as in soil column tests. The implementation of the technology in the field was to be carried out with two different reactants in a pilot test phase as well.

Feasibility Study / Upscaling Remediation Steps

Laboratory Tests

In a first step of the feasibility study laboratory tests for reductive chromium immobilization were carried out. Different chemical and biological reducing agents were tested in 3 different concentrations using 48-h-shaked batch tests.

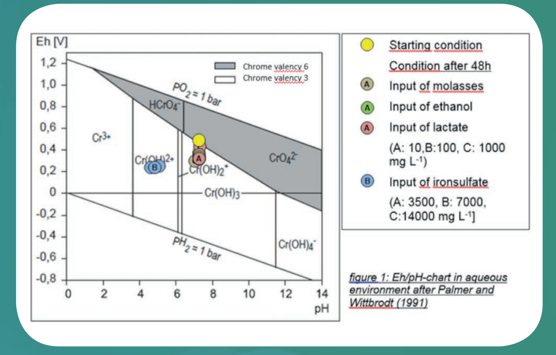

Fig. 4: Scheme Eh-pH related to the 48-h-shaked batch tests

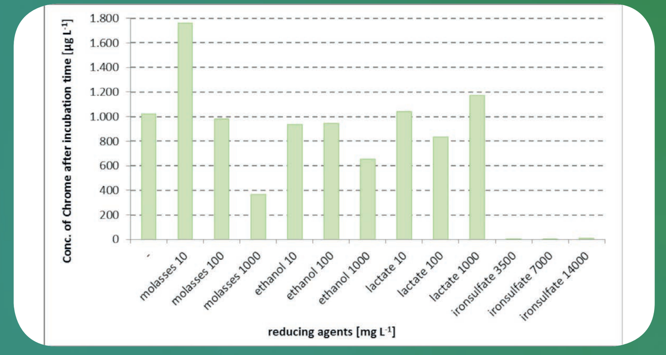

Fig. 5: Different chemical and biological reducing agents tested in 3 different concentrations using 48-h-shaked batch tests

The reducing agents with most effective Cr-VI-reduction potential were identified as

- Molassis (concentration 1 g/l) – strong reduction of ORP at minor decrease in pH
- Iron(II)sulfate (concentration 3.5-14 g/l) – strong reduction of ORP at strong decrease in pH

In soil column tests soil and groundwater from the site were used to examine the performance of reductive chromium immobilization over a period of 8 weeks followed by an oxidative phase over a period of 2 weeks to evaluate for fast remobilization effects.

As a result molassis (1 g/l) as well as iron(II)sulfate (3.5 g/l) were capable of reducing and immobilizing all chromium present in the soil columns. No remobilization effects were observed in the oxidative phase.

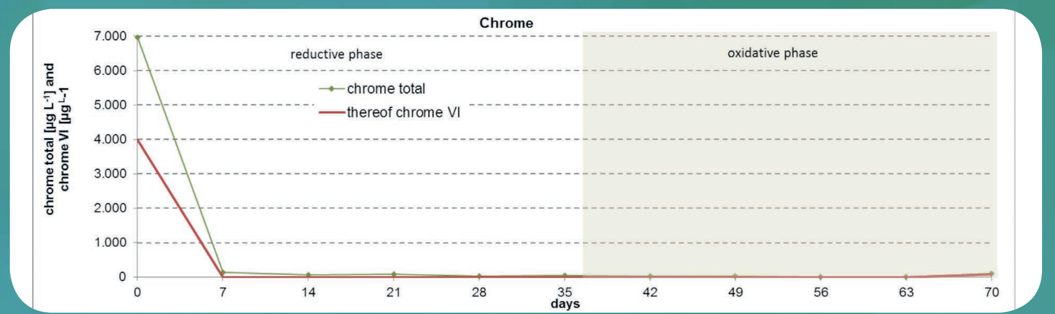

Fig.6: Microbiological induced reduction of chromium with molassis in the laboratory tests

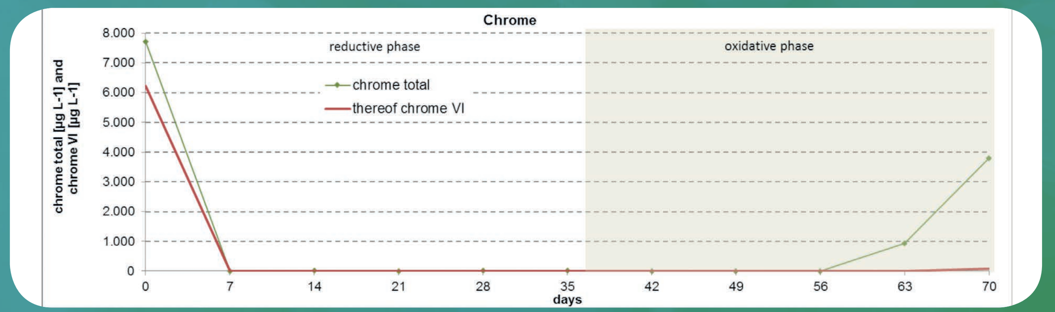

Fig.7: Chemical induced reduction of chromium with iron(II)sulfate in the laboratory tests

Pilot Remediation Test Fields

In a second step of the technical feasibility study two pilot test fields were established next to each other, each equipped with 5 vertical groundwater circulation wells for short term infiltration and extraction perpendicular to the natural groundwater flow direction for fast distribution of molassis or iron(II)sulfate. Reactants were added to the groundwater in stoichiometric quantities and the reactivity of the system was monitored in a series of observation wells in three different distances downstream of the injection area.

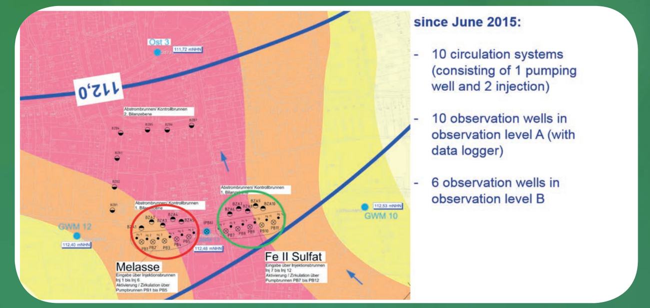

Fig. 8: Starting remediation test fields

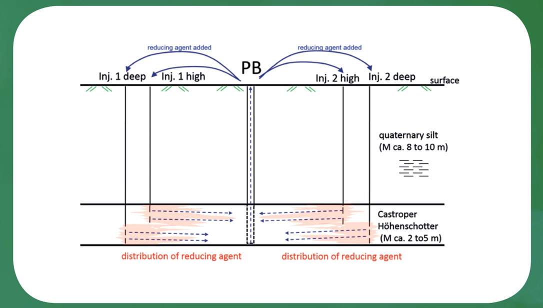

Fig. 9: Groundwater circulation cells for short term infiltration and extraction

Quick chromium reduction and immobilization was observed in the molassis injection field over a period of 5 months, but not uniformly.

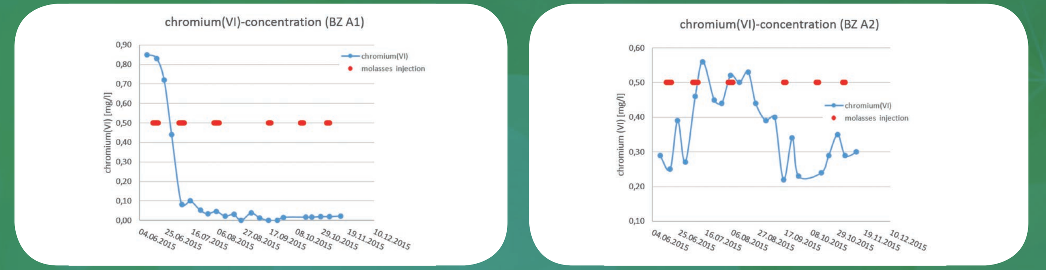

Fig. 10: Quick chromium reduction and immobilization with molassis in the field test area 1

Contrastingly, the injection of iron(II)sulfate in 4 injection series did not lead to a significant decrease of chromium downstream of the injection/circulation wells.

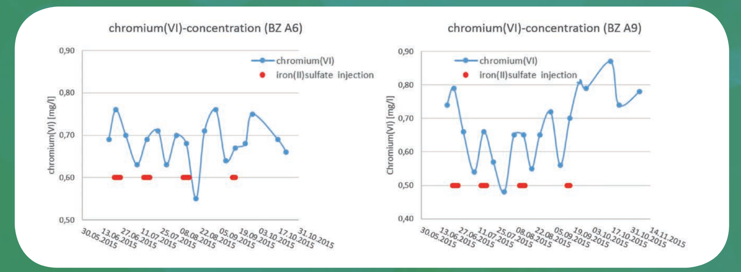

Fig. 11: Insufficient chromium reduction / immobilization with iron(II)sulfate in the field test area 2

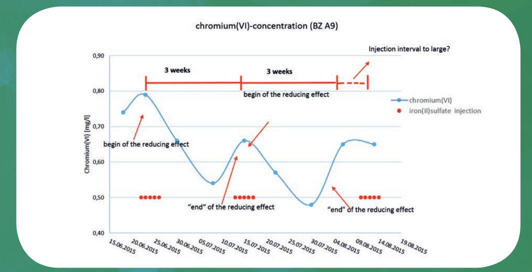

Fig. 12: Insufficient chromium reduction with iron(II)sulfate in detail

Possible reasons for the discrepancy between the results of the biological and chemical field test are discussed as caused by

- Geological "Fingering" effects
- Insufficient less exposure time
- Insufficient reactant distribution (more und larger wells)
- Insufficient low reactant concentration
- Difference between theory (laboratory) and practice (field)
- Trying changing the reactants (first molassis, than iron(II)sulfate)

Adaptation and Enlargement of the Test Fields

Solution approaches are deducted by

- Improvement of another well construction – with larger diameter ⇨ successfully
- pressurized pulse injection
  ⇨ successfully
- combination of reactants
  – step 1 molassis, step 2 iron sulfate
  ⇨ not successfully

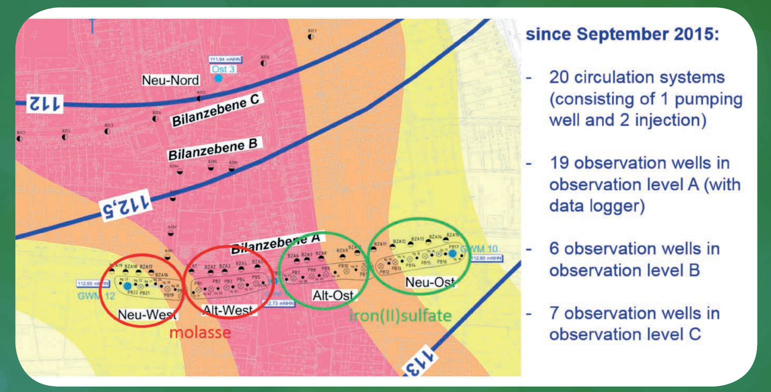

Fig. 13: Enlarged remediation test fields

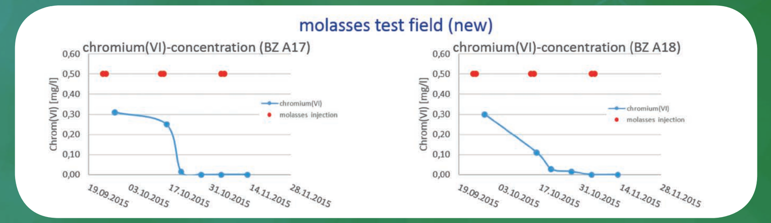

Fig. 14: Very good reduction results with molassis in the new larger test field

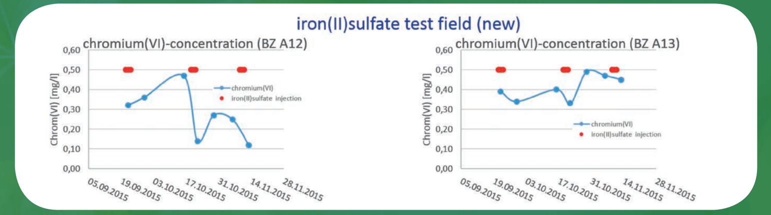

Fig. 15: : Insufficient chemical reduction results downstream

The preparation of a decision for extending the pilot phase into full scale operation is pending.

Results and Conclusions

Substantial differences in lab test reactions compared to field scale results were observed for chemical reduction processes. In general, the feasibility of a microbially induced chromate reduction was successfully proven in the field, while chemical reduction worked nicely in the lab but did not when applied in the field.

The reasons for the discrepancy in the results of the biological and chemical field tests are discussed (e.g. Fingering-effects) and solution approaches are deducted in this paper in preparation of a decision for extending the pilot phase into full scale operation.

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