Sequential Anaerobic and Aerobic Direct Gas Injection for Microbiological In-Situ Remediation of Chlorinated Hydrocarbons

INTRODUCTION

The overall objective of the R&D project, sponsored by AiF Germany, was the development of a new remediation approach to demonstrate which chlorinated hydrocarbons (CHC) in the groundwater can be degraded effectively in-situ using coupled anaerobic and aerobic processes. The specific innovative feature of this new approach consists of the field application of gaseous electron donors in the saturated zone. A multistage direct gas injection technology was to be developed and tested in order to enable sequential reductive and oxidative dechlorination of CHC contaminated aquifers. The technology of coupled anaerobic-aerobic gas injection zones is based on mixed gas injections such as hydrogen, oxygen, argon, and in selected conditions also propane and butane. During application, targeted selective gas distributions in nonhomogeneous aquifers is to be controlled by injection pressure, injection ratio and the time length of injection intervals.

THE CHALLENGE

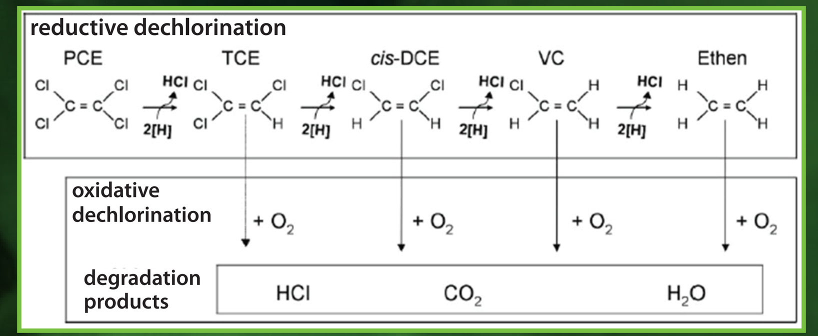

Fig. 1: Scheme of sequential microbial chloroethene degradation steps (THIEM et al. 2008).

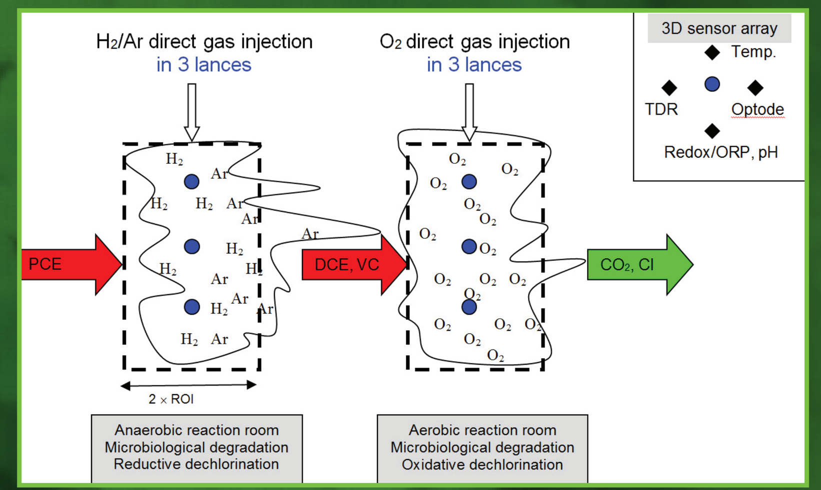

Fig. 2: Scheme of sequential direct gas injection rooms for stepwise reductive and following oxidative dechlorination of CHC

SITE DESCRIPTION

- Down gradient of a former dry cleaning facility in Leipzig, Germany
- Groundwater flow rate: 1 – 10 m/d
- CHC concentrations: 10 – 100 mg/l
- Depth to groundwater: 2 – 3 m
- Aquifer base at a depth of: 7 – 8 m
- Size of test area: 15 x 15 m
- Radius of influence: 5 m

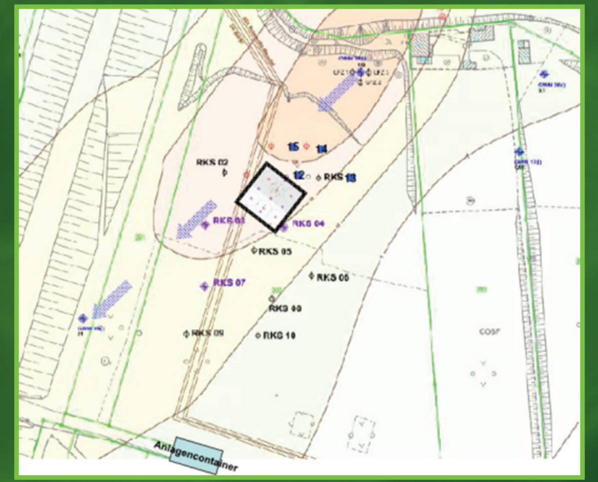

Fig.3: Location of the Test area in the contaminated downgradient plume

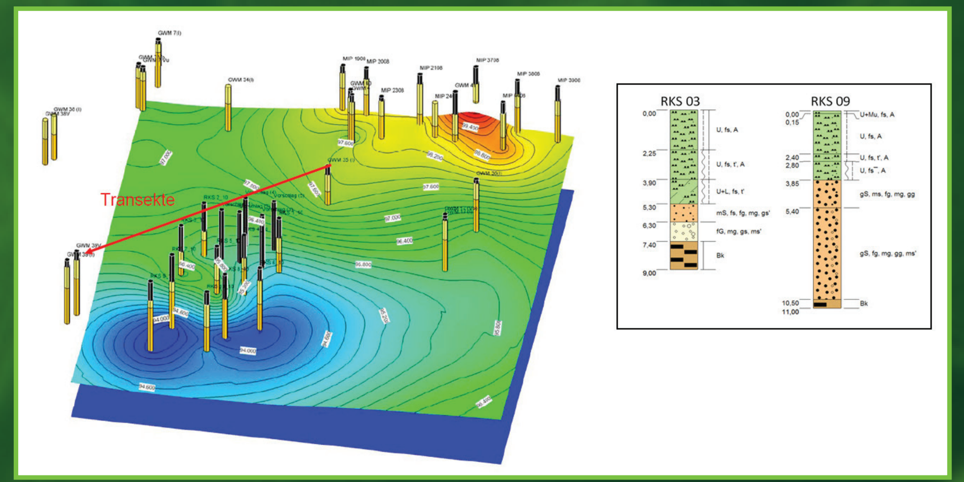

Fig.4: Base of Quaternary aquifer, well point locations, and soil profiles.

DEVELOPMENT STEPS

LABORATORY TESTS

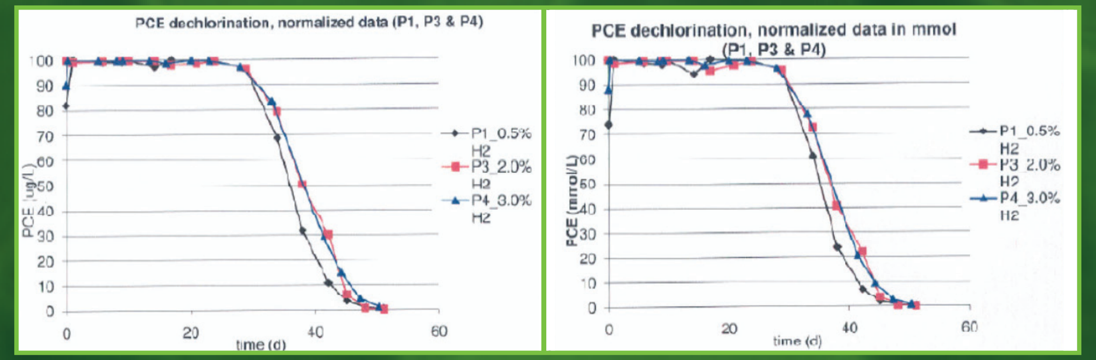

Fig. 5: PCE degradation kinetics for various hydrogen concentrations

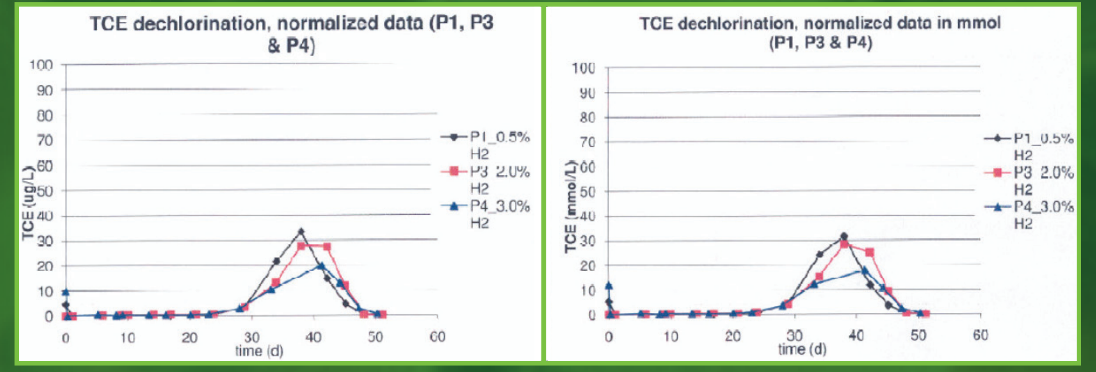

Fig. 6: TCE degradation kinetics for various hydrogen concentrations

RESULTS

- The successful anaerobic biodegradation of PCE and TCE as a result of applying hydrogen was proven.
- The laboratory tests provided the kinetic decay reaction factors for modeling and the dimensional basics for field application.
- An optimized Ar-H_2 gas mixture for anaerobic in-situ-degradation of PCE and TCE was identified.
- Addition of CO_2 was shown to accelerate the CHC degradation.

CONSTRUCTION AND OPERATION OF REMEDIATION TEST FIELD INSTALLATIONS

- Field installations using fast SONIC drilling method
- 6 gas injection lances
- In-situ 3D sensor array consisting of 5 sensor chains with optodes, pH sensors, ORP sensors (Oxidation-Reduction Potential), temperature sensors
- 3 TDR measuring pipes (time domain reflectometry)
- 5 gas monitoring wells
- 5 groundwater monitoring wells
- Gas dosing station with remote control.

Fig. 7: Construction of test area using SONIC drilling method and gas dosing station

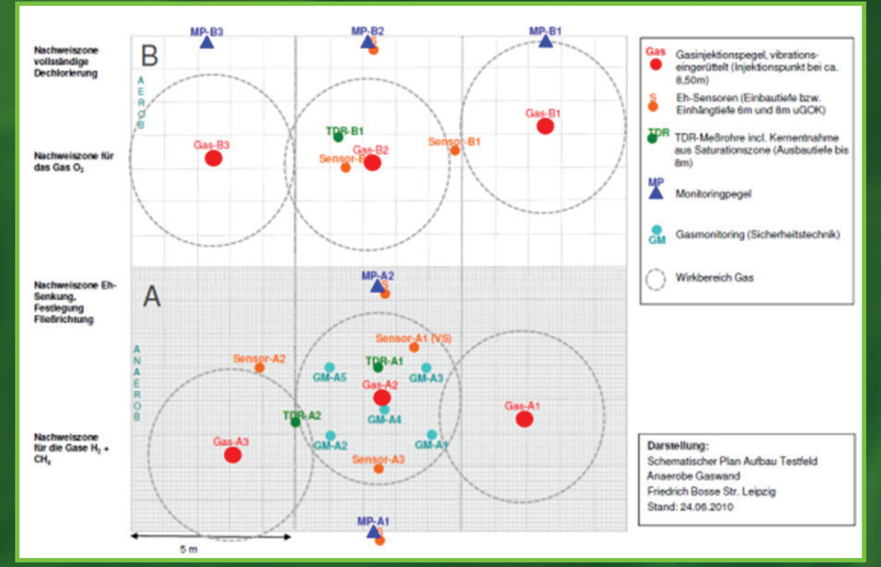

Fig. 8: Overview of the gas injection and monitoring area

Three gas injection series, including a successful SF_6 gas tracer test during the first injection, demonstrated the safe and faultless operation of the system components by remote control.

Exp.	Description	Gas Type and Amount	Duration of Injection
1	SF_6 tracer test	SF_6 (4%), H2 (3%), Ar (93%) Amount: 1,28 m^3	100 min
2	H_2 injection in 3 lances	H_2 (3%), Argon (97%) Amount: 3 x 6 m^3	1,740 min
3	Parallel injection of O_2 and H_2 in 2 lances	A1: Gas mixture H2 (3%), Ar (97%) A2: O_2-Gas (100%)	A1: 171 min A2: 226 min

Tab. 1: Type of Gas Gas Amount and Duration of Injections for 3 Field Phases.

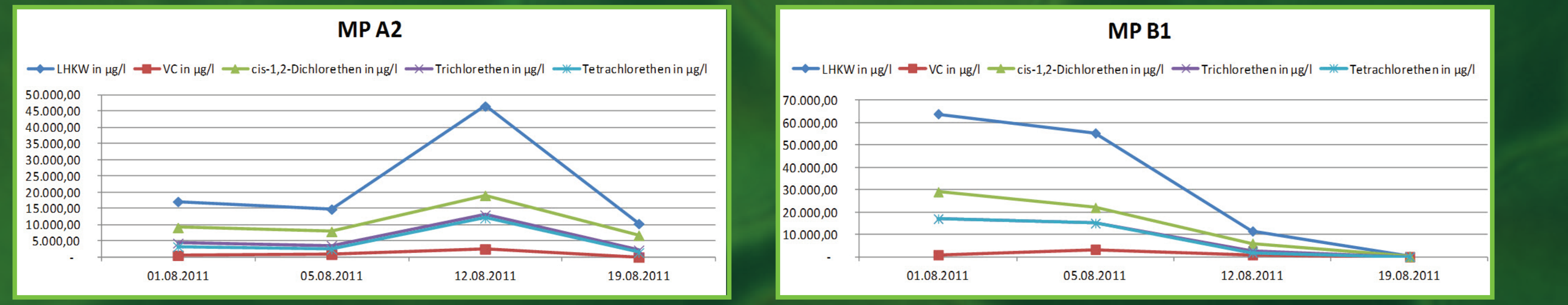

Fig. 9: CHC development, 3rd injection phase, anaerobic (left) and aerobic (right) influenced destination

ACCOMPANYING MODELING WITH DIFFERENT 3D MODELING COMPONENTS

- Geological 3D structural model (GMS)
- Hydrogeological 3D flow model (MODFLOW)
- Reactive transport model GMS-RT3D
- Reactive 2-phase transport model (TOUGH II)

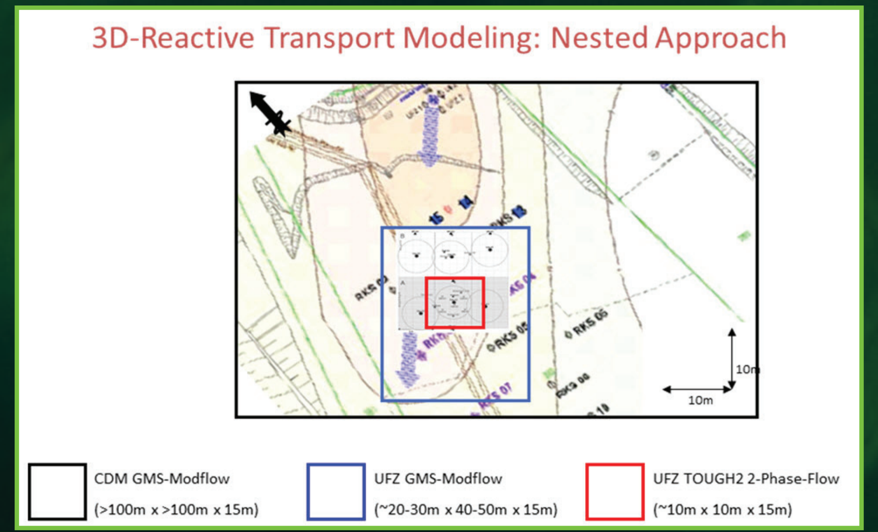

Fig. 10: Applied computer models -at different modeled areas

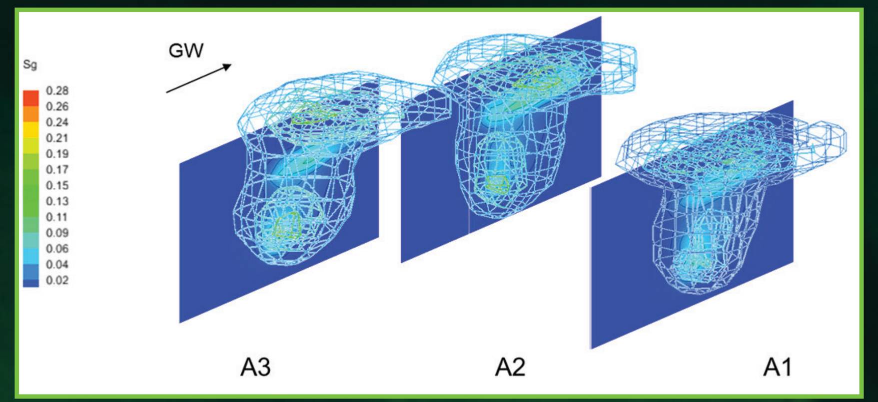

Fig. 11: Visualization of calculated initial heterogeneous gas distribution after 100 min injection

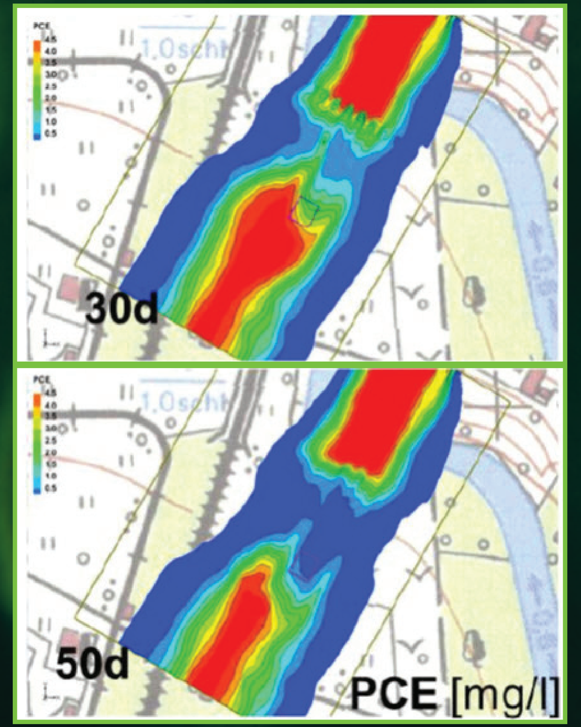

Fig. 12: Simulated PCH degradation, 30 and 50 days after hydrogen injection

RESULTS AND CONCLUSIONS

The application of the new gas injection technology was designed, built and tested on a site down gradient of a large CHC contaminated aquifer in Leipzig, Germany. In general, the functionality of the efficient and low cost gas injection approach was proven; however, the process of CHC degradation was strongly influenced by other competing reaction processes due to the complex local site conditions. Therefore the quantification of a single processes was difficult to show and further development work is necessary. In addition, the results showed that the complete remediation scenarios can be accurately simulated by modeling.

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