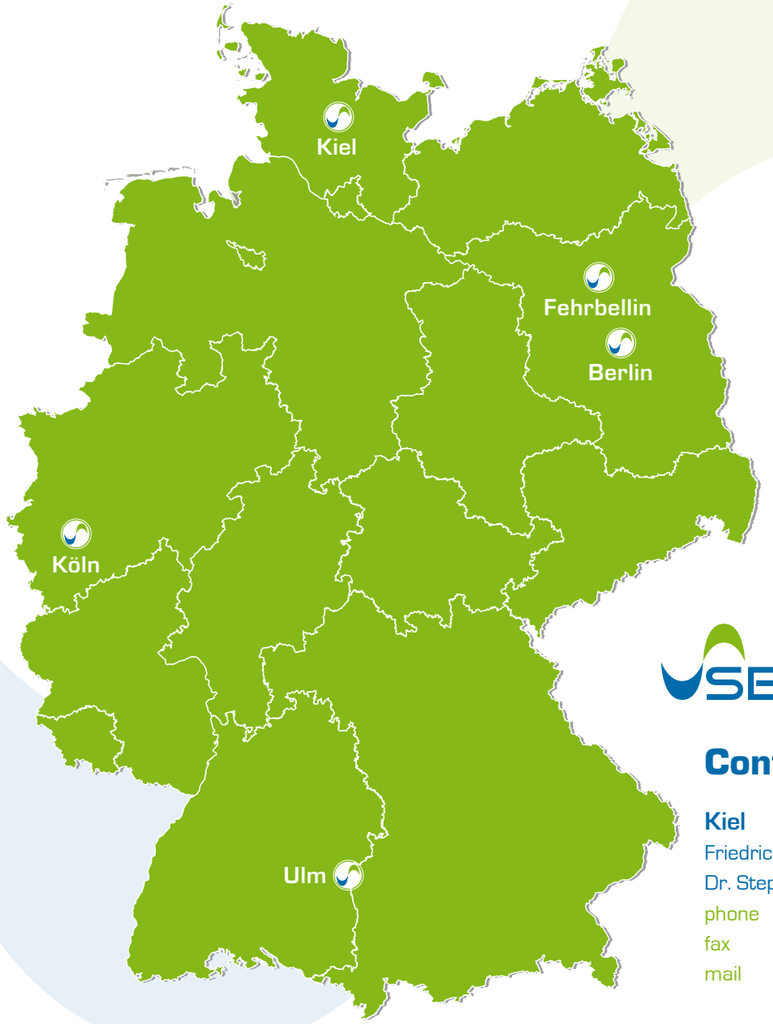

SENSATEC GmbH

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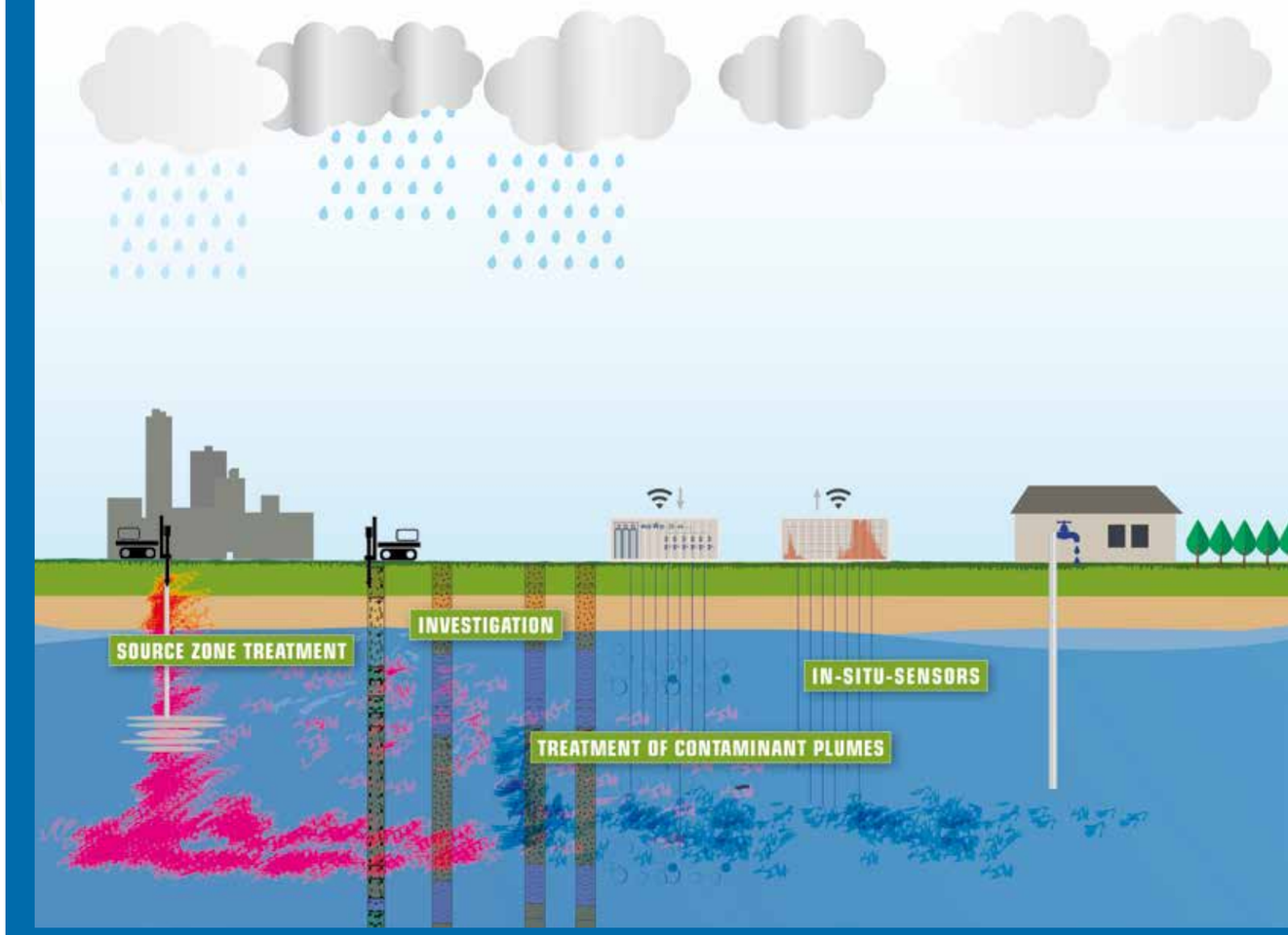
SENSATEC

SMART TECHNOLOGIES FOR CLEAN WATER CYCLES



- **Groundwater Remediation**
- **Drilling Technology**
- **Process Analysis Laboratory**
- **Sensor Technology**
- **Environmental Biotechnology**

www.sensatec.de

SELECTED REFERENCES

Automotive industry & transport sector	AIRBUS, DB AG, VW AG, Daimler AG, Lufthansa
Mining, land reclamation	LMBV, Brandenb. Mining Department
Chemical industry and distribution	Brenntag, Biesterfeld, Dow Chemical, Lehmann + Voss, Wacker
Industrial production	Carl Zeiss AG, OTIS, NXP Semiconductors, Siemens
Military real estate	GMSH (STOV), US Army, BBG
Petroleum industry	Shell, Mobil Oil, Oiltanking, Tanquid, Total, BP
Public entities	Dresden, Duisburg, Bremen, Hamburg, Kiel, Berlin, Potsdam
Project development, real estate developers	DIAG, DIBAG, KiWi, EGNO, S-Immo, Deutsche Annington, Gesa, Kaufland
Public transport	DB Netz AG, BWG Reimer
Insurance agencies	Axa, Gerling, Gothaer, Provinzial
Water companies	Berliner Wasserbetriebe
Energy suppliers	Vattenfall, RWE
Research	BTU Cottbus, TU Dresden, CAU Kiel, EMAU Greifswald, FH Osnabrück, GFI Dresden, TZW Karlsruhe, TU Berlin, UFZ Helmholtz-Zentrum

REMEDIATION OF CONTAMINATED SITES

Sensatec provides sophisticated technologies for contaminated site analysis and remediation. Furthermore, it offers intelligent sensor-based environmental monitoring systems. With more than 300 successful reference projects, Sensatec belongs to Germany's market leaders in in-situ groundwater remediation services.
We are highly dedicated to providing products and services of very good quality. This includes being highly committed and providing reliable service as well as closely collaborating with our clients and customers. It is our corporate management's and all of our staff's obligation to understand and satisfy our customers' needs.
Our collaboration with our clients is based on mutual respect, trust, close cooperation and open discourse. We commonly strive to create healthy and safe working conditions and successful project outcomes.
Continuous service and procedure improvement and development ensures that our products and services remain highly competitive on the global market. Our working procedures are constantly analyzed and optimized, minimizing process malfunction and avoiding hazardous working situations and injuries.

RANGE OF PRODUCTS / SERVICES

REMEDIATION OF CONTAMINATED SITES	• Passive and actively managed reagent distribution system for in-situ remediation • Injection / emplacement of gaseous, fluid and solid reagents • Pilot test procedures for the determination of hydrogeological and biogeochemical parameters and site characterisation
DRILLING TECHNOLOGY	• MIP-,EC-, HPT-probing • Groundwater-, soil vapor-, and soil sampling • Soil core sampling • Hollow stem auger drilling • Installation of injection, infiltration and monitoring elements
PROCESS LABORATORY	• Feasibility studies • Reagent consumption analysis • Batch tests, soil column test procedures • Molecular biology / qPCR
SENSOR TECHNOLOGY	• Sensor based process monitoring in-situ • Automated plant supervision and remote control • Web access and process visualisation
ENVIRONMENTAL BIOTECHNOLOGY	• Isolation and enrichment of microbes with specific degradation capabilities for use in biostimulation projects • Stock of versatile contaminant degrading microbes • Anaerobic cultivation technology (e.g. *Dehalococcoides*) and aerobic technology (e.g. TPH / PAH / MtBE degraders)

CHARACTERISATION OF SUBSURFACE CONDITIONS

We offer direct sensing drilling technologies for the investigation of contaminated sites with our Geoprobe drilling rigs LT54, 6620DT and 7822DT:

- MIP-drilling (Membrane Interface Probe)
- EC-drilling (Electrical Conductivity)
- HPT-drilling (Hydraulic Profiling Tool)

These technologies enable the collection of relevant in-situ-data for geological and hydraulic site characteristics as well as contaminant profiles during drilling operations. Using direct sense technology the strategy for the investigation of contaminated sites may be adapted dynamically during drilling campaign. This dynamic procedure leads to a considerable reduction of investigation time and investigation costs compared to conventional investigation strategies.

DIRECTPUSH

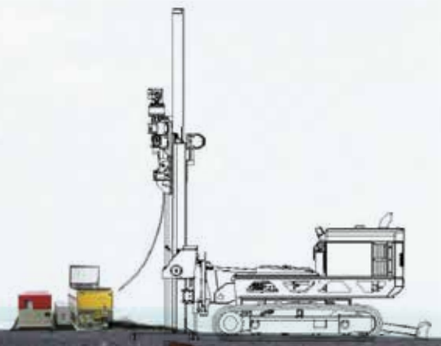
Direct-Push drilling

Sensatec offers direct push drilling with its Geoprobe-rigs LT54, 6620DT and 7822DT. The “disposable tip”-technology is often used in order to quickly and economically establish infiltration points, injection wells and monitoring lances in groundwater and in the unsaturated zone.

Our range of services covers:

- Soil core drilling using Geoprobe - MacroCore and DualTube
- Groundwater sampling with Geoprobe Profiler probe SP16
- Soil gas monitoring
- Installation of injection lances

Moreover, it is possible to inject any type of liquid into an aquifer directly via the drill casing by making use of special injection tips for depth specific source zone treatment based on MIP signals. This technology enables the precise execution of multiple injections within the shortest time possible.



Traditional drilling services

Sensatec offers traditional drilling services, such as:

- Core sampling
- DPH-probing (heavy weight driving rod)
- Hollow stem auger drilling (maximum drilling diameter 320 mm)
- Installation of injection and monitoring wells

Soil profiles are made available in digital form using GeODin software, whereby the site-specific database obtained from each drilling operation is provided to our client/geological consultant for further unlimited use.

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DIRECTSENSE

Injection technologies

Sensatec is a provider of sophisticated injection technologies. In-situ-remediation projects require a careful, site-specific adaptation of the injection technology suited to the complexity of the aquifer in order to achieve success. To help meet site specific remedial objectives, we offer the following system components:

- Multilevel-injection systems
- Pressure and oxidant-resistant fluid injection systems
- Profiler probes
- Construction and installation of in-situ-sensor-systems for groundwater and soil monitoring
- Construction and installation of gas lances
- Permeation injection drillings

Sensatec is an experienced service provider for implementing hollow stem auger and sonic drilling technologies.

LABORATORY PROCESS ANALYSIS

Our process technology lab is specialized and highly experienced with the execution of chemical and biological feasibility studies and bioprocess analysis of environmental remediation projects as well as investigations linked with ENA- and MNA strategies. Moreover, the laboratory can analyse for geobiological processes in soil and groundwater. The general objective is to considerably improve success rates for any biological or chemical in-situ-treatment by providing site-specific data on geochemistry, biology as well as reaction kinetics and potential critical side-reactions.

BENEFITS FOR THE CLIENT:

- A detailed feasibility study considerably improves the success rates of an environmental remediation project!
- Feasibility studies deliver accurate data for site-specific reagent consumption and degradation process speed – These data are highly relevant for a realistic prognosis on remediation speed and remediation costs.
- A well executed feasibility study will identify potential biological or geochemical weak spots in any remediation plan that need to be addressed.

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PROCESS ANALYSIS

WE OFFER THE FOLLOWING ANALYTICAL METHODS:

- Complete biotechnological feasibility studies on contaminant degradation in groundwater, soil and waste water
- Microbiological analyses (specific bacterial counts, cell counts, microbial metabolic capacities, physiological analyses)
- Microorganism cultures with specific contaminant degradation abilities
- Implementation of ISCO feasibility studies, Soil Oxidant Demand (SOD), solid phase buffer response, reactant consumption computations

- Reactant migration analyses / contaminant dispersion scenarios in column and channel systems

Molecular biology

The biostimulation of microbial contaminant degradation is a core element of different approaches for in-situ remediation of DNAPL contaminated sites. However, when this technology is applied on site an accumulation of metabolites (c-DCE and VC) may be observed despite of careful process control.
EPA-led studies have proven a direct correlation of complete reductive dechlorination of chlorinated solvents in the presence of the enzymes tceA, vcrA and bvcA (Reductases). These enzymes are produced exclusively by microorganisms of certain *Dehalococcoides* strains. They catalyse the dechlorination of TCE, c-DCE and VC to Ethene. For aerobic (cometabolic) biodegradation however the catabolic process is based on oxygenase enzymes (sMMO, etnE, etnC) which are produced by a vast number of different aerobic microorganisms.
The capability for the production of such enzymes is based on the specific DNA of these microorganisms. So it goes without saying that the most powerful tool for the analysis of the microbial capability to degrade the relevant contaminants is in fact the site-specific analysis of the microbial DNA. Moreover, molecular markers for *Dehalococcoides* (16SrDNA) and the microbial biomass (BactQuant) are applied.

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MOLECULAR BIOLOGY

CONTAMINANT-DEGRADING MICROORGANISM ISOLATION, ENRICHMENT, OPTIMIZATION AND MAINTENANCE FROM ENVIRONMENTAL SAMPLES

Our microbiological laboratory in Cologne, Germany, is specialized on contaminant-degrading microorganism isolation, enrichment, fermentation and commercial propagation. Microorganisms that are naturally abundant in soil samples and that are able to degrade certain contaminants are cultivated in controlled laboratory environments. These degradation specialists are selectively grown and enriched under optimal growth conditions for further use in our biotechnological remediation procedures. Subsequently, mixed culture bulk stocks are produced in bioreactors. This enables us to preserve the respective specialist culture for different contaminant groups and to strategically implement them if necessary.

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FIELD TEST PROCEDURES

Pilot test

A hydrogeological site analysis is a very important contribution to a successful in-situ-remediation. Sensatec offers well-established technologies and the necessary equipment (low-flow/high-flow pumps, dataloggers, in-situ-sensors, mobile water treatment units) for the technical execution of hydrogeological investigations. The collected data are passed on to the geotechnical experts for evaluation and reporting.

TRACER, PUSH PULL, PUMPING TESTS

Pumping tests

The execution of pumping tests serves the determination of the hydraulic conductivity of an aquifer. These data form the basis of a suitable concept for a setup of infiltration and exfiltration wells for efficient reagent distribution for in-situ-remediation.

The development of the concentrations of groundwater contaminants may be measured by field instruments online or may be analysed in the laboratory by means of groundwater sample extraction.

Step drawdown pump test

The execution of pumping tests at different extraction rates (with/without reinfiltration) include the measurement of extraction rates and constant analysis of the resulting water level by data loggers until a steady state is reached. This procedure allows the identification of the hydraulic capacity of an extraction well. The execution of such tests before and after its use for infiltration allows an identification of biofouling, birnesite deposits and other risks for well ageing. Actions for the regeneration of wells affected by clogging may then be initated in due time.

Tracer tests

The execution of tracer tests is a highly accepted method for the analysis and validation of hydraulic conductivity and groundwater flow velocity in sandy aquifers as well as in fractured bedrock.
The use of tracer substances can be a valuable method to determine the pore volume exchange in groundwater circulation projects. Electrical conductivity sensors and ion-selective sensors may be used for online- measurement of the tracer signal in-situ. Thus, the natural groundwater flow conditions are not disturbed in any way by active pumping.

Sensatec offers the technical execution of tracer tests (based on electrical conductivity measurement) using mobile technology, sensor equipment and data logger units. Tests that include multiple tracer compounds and a more extensive monitoring programme may be executed by making use of autosampler units and a fluorimeter. For the execution of complex tracer test scenarios highly specialized partners from industry and academia are available.

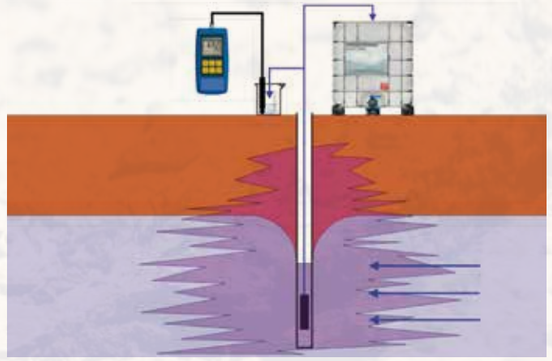
Free product mobilisation using Push-Pull test procedures

A very reliable technical option to check for the existence of free non aqueous phase liquids (LNAPL, DNAPL) in an aquifer is the execution of push-pull tests. This test procedure may be performed in existing monitoring wells (if filter screens are short enough) or in newly built and specially designed monitoring wells.

The test procedure must always be adapted to the site in question. In a first step a large amount of groundwater (usually several m^3) is extracted from the well, then amended with surfactants and tracer compounds and finally reinjected. After an incubation period of several days groundwater from this well is extracted again for analysis with reference to the fundamentals of IPV-technology with permanent sensor-based data recordings.

The contaminant and tracer concentrations are analysed in the extracted water in intervals. Mobilized contaminant mass from residual free product are evaluated with regard to the spatial test coverage, the contaminant and tracer concentration development during the extraction phase.

Advantages:
Improved spatial recognition of free product in the investigated area compared to core sampling
High test reliability
Spatial information on free product distribution at the site
Better economics compared to technical alternatives (no drilling, no installations)



IN-SITU-REMEDIATION

Sensatec offers a broad range of services for in-situ-remediation technologies, which can be applied as a stand-alone solution or in combination with other technologies.

Apart from oxidative technologies (ISCO, aerobic biostimulation) and reductive technologies (ISBR, ISCR) Sensatec also offers sophisticated solutions for the technical execution of AirSparging, Surfactant cosolvent flushing, Methane biostimulation, direct gas injection, Pump & Treat, immobilization of heavy metal contaminations and thermal desorption. During the application of thermal treatment the subsoil or groundwater is heated up. The spatial distribution of heat is monitored by in-situ-temperature sensors. Due to the increase in water solubility with increasing heat organic contaminants are transferred into the aqueous phase much faster resulting in a much higher contaminant extraction rate compared to conventional Pump & Treat.

The following biological and chemical reagents are applied for the purpose of in-situ-elimination of contaminants:
Oxidizing agents (such as Permanganate, Persulfate, Peroxides, Ozone etc.)
Reducing agents (such as zero valent iron, Sulfides, Fe(II))
Organic biostimulants (such as molasses, lactate, microemulsions, protein solutions)
Cosolvents (such as surfactants, alcohols, microemulsions)

The application of the reagents depends strongly on the site-specific requirements:
Infiltrations and injections followed by passive distribution along with the natural groundwater flow
Circulation cells including the use of extraction and injection wells as well as automatized reagent dosage or periodic pulsed injections
Dynamic pressure pulse injections for optimized reagent distribution

REMEDIATION TECHNOLOGY

The maintenance and support of fully automated systems is done during periodic inspection visits by Sensatec employees.

The remediation technologies can be installed below surface completely in order to allow unlimited use of the site free from restrictions.

Advantages:	
Unlimited use of the site during remediation	Cost reduction resulting from the use of the aquifer itself as a bioreactor for cleanup purposes
No restrictions for activities on site	Site-specific adaption of scalable remediation technology
No disturbances from noise or from occupation of space	

IN-SITU-REMEDIATION USING LIQUID REAGENTS

IN-SITU-BIOLOGICAL REDUCTION (ISBR) AND IN-SITU-CHEMICAL OXIDATION (ISCO) USING ACTIVELY MANAGED CIRCULATION CELLS

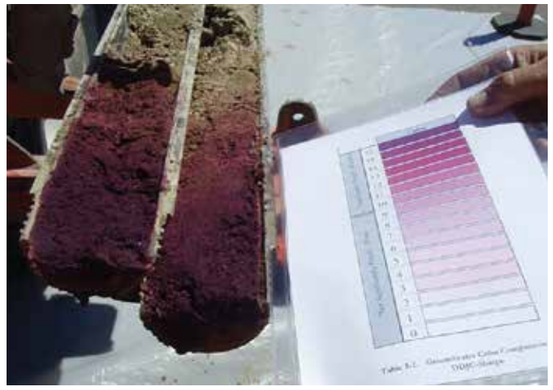
In-situ-biological reduction (ISBR) is a well-approved technology for in-situ-treatment of contaminanted sites. Organic biostimulants, such as molasses, lactate, microemulsions (Sensamulsion®), biosurfactants and nutrient solutions are introduced and distributed within the contaminated zone to create favourable conditions for maximum biodegradation of the contaminants. This technology is mainly applied for reductive dechlorination of DNAPL but may also be used for aerobic treatment of organic contaminants such as petroleum hydrocarbons or aromatic contaminants.
Sensatec maintains its own collection of highly efficient contaminant degrading microbial cultures (*Dehalococcoides spec*, MtBE-degraders, Hydrocarbon degraders) which are used for bioaugmentation purposes for efficient and biologically safe remediation. Feasibility studies for each site help to identify site-specific factors that limit biodegradation speed and help to specifically address these limitations.
The in-situ-chemical oxidation (ISCO) is used to destroy contaminants in the groundwater in a chemical reaction. This technology is most often used for the elimination of small and medium sized contaminant source zone areas. The most suitable oxidizing agent is identified with regards to site-specific characteristics (such as geohydrological conditions, predominat geochemistry, site accessibility). Prior to the application on site there must be a lab feasibility study to determine site-specific oxidant consumption, reactivity and potential side-effects.
Both technologies have in common that there must be a direct contact between the introduced biological or chemical reagents with the contaminants to ensure an efficient contaminant degradation process. The demand for maximum contact requires an efficient, spatial distribution technology for the introduced reagents, which are preferably added in actively managed, horizontal or vertical hydraulic circulation cells. Technically, the application of hydraulic circulation cells can be executed by a Container-based stationary remediation facility or as a mobile injection unit.
The container-based treatment unit is used for automatized dosage of reagents into the circulation cell. Most often, the injection is spread over a series of injection lances to reach maximum coverage of the contaminant zone.
When using a mobile injection technology reagents are injected periodically during each site visit. The actively managed circulation cells are managed for hours or days. The duration and frequency of the injections are very site-specific and may be adapted according to changing requirements during the remediation process. Existing wells as well as newly built injection lances may be used for this purpose.

IN-SITU-REMEDIATION USING LIQUID REAGENTS

The remediation of contaminants in challenging geologic conditions such as low permeability soils and bedrock is often cost-prohibitive or impractical when using conventional methods. Sensatec's TSE® technology overcomes these limitations by enabling the targeted emplacement of solid remedial amendments (e.g. sand proppant, oxidant and reductant solids, particulate bio-substrates) within contaminant plumes. The TSE® process enables large quantities of treatment amendments to be optimally distributed within soil or bedrock contaminant plumes to maximize contact with contaminants and serve as long term „Remedial Source Zones".

TSE® – advanced in-situ-technologies:

- Targeted emplacement of remedial reagents
- Enhanced performance of in-situ-remediation technologies
- Applicable for the emplacement of solid or liquid treatment amendments (oxidative, reductive, chemical, physical, and biological)
- Effective for virtually all contaminants and all geologic conditions, including bedrock
- Proven applications (over 20 years) globally
- Verifiable remediation using tiltmeters
- Cost-effective and sustainable alternative to conventional approaches



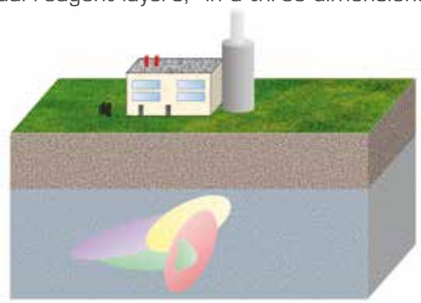
TSE TARGETED SOLIDS EMPLACEMENT

Technology Description

The core element of the technology is its ability to accurately emplace highly concentrated slurries of treatment reagents through drilling rods directly into defined contaminant zones in soil or bedrock. The targeted emplacement of treatment reagents is conducted in boreholes using our proven Geoprobe® Drills and customised injection probes. Injection is carried out during drilling to create an interconnected network of thin layers of treatment reagents across a large radius of emplacement. This ensures that the treatment reagents are brought into direct contact with contaminants.

Verification of Reagent Distribution

It is extremely useful to know the subsurface distribution of injected reagents or treatment substrates in order to assess the effectiveness of in-situ-remediation measures, especially when chemical or biological treatment reagents are being emplaced into contaminated subsoils or bedrock.
The subsurface distribution of injected reagents is mapped using high resolution tilt sensors set up around each injection boring. This technology helps verify the areal extent of distribution from the point of injection and enables the visualisation of the emplaced network of treatment reagents, as well as individual reagent layers, in a three dimensional model.



IN-SITU-REMEDIATION USING REAGENTS IN GASEOUS FORM

Underground drinking water reservoirs play an important role in meeting future needs for freshwater supplies. Due to pollution these drinking water resources have partially been rendered useless. Sensatec has developed efficient methods, such as the patented BIOXWAND technology, for restoring these resources and effectively protecting them from new contamination. This lasting method aims at shielding drinking water protection areas from inflowing contamination by removing contaminants in bioreactive, underground zones. This remediation technology is designed to suit the needs of long-term protection goals, with its high efficiency and ist minimal requirements for reactants and energy. Biological in-situ-remediation zones may be established upstream of drinking water extraction zones for the formation of underground biological water purification zones by simply injecting gaseous reagents. The technology proved highly effective for the removal of anorganic contaminants such as ammonium, nitrate or iron as well as for organic contaminants

such as PAH, Petroleum Hydrocarbons, chlorinated solvents and monoaromatics. The BIOXWAND technology is a well proven technology with excellent application references.

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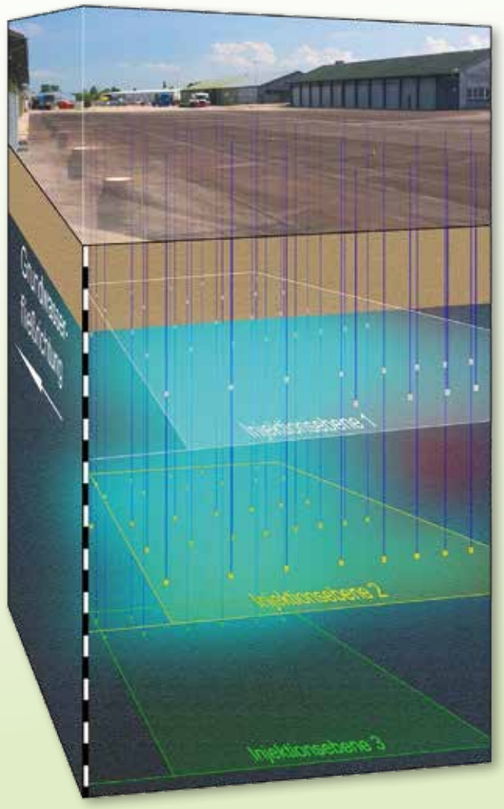
BIOXWAND

Gas storage technology BIOXWAND, Pat. DE102004001802 – Clean gases or gas mixtures are stored in the pore space of the soil matrix, forming permeable gaseous reactor curtains. Upon contact with inflowing, contaminated groundwater, the reactants change phase and are chemically and microbially degraded passing through a multi-level in-situ flow-through reactor.

Specially designed gas injection lances, aquifer-integrated sensors as well as spatially-integrated monitoring elements are used for gas injection and for detecting, monitoring, and balancing the injected reactive gas concentrations. For purposeful gaseous wall management, reactants are injected based on their consumption, which is derived from a clocked geological structure model, including site-specific pressure and volume flow rate regimes.

PROCESS CONTROL AND OPTIMIZATION



In-situ-sensor techniques

The efficient control of environmental impacts requires thorough knowledge of relevant underground process dynamics. Added reactant degradation and dispersal processes, microbial processes and migration dynamics need to be recorded precisely, in order to physically control and properly manage all procedures applied. Very often, it is only possible to precisely capture processes using online-sensor techniques. For this reason, Sensatec has been using in-situ-sensor techniques right from the start and has acquired comprehensive knowlege in this field, assisting in highly efficient and economical environmental impact remediation procedures.

IN-SITU-SENSORS	DETECTION
Redox potential **(Eh)**	Aerobe or anaerobe conditions, reactant dispersal detection, ISCO processes
Temperature **(T)**	ISCO reaction temperature or biological specific heat generation
Oxygen content **(O_2)**	Oxygen content (O2) Free oxygen in groundwater, oxidation fronts, oxygen transport during gaseous wall technology application
pH value **(pH)**	For instance, biological acidification during anaerobe treatments, pH decrease during Fenton's reaction, pyrite oxidation in oxidation processes
Conductivity **(EC)**	Increase in dissolved salts, e.g. during pyrite oxidation
Pressure **(p)**	Pressure increase with chemical gas formation during groundwater ISCO reactions, temporal ground water gas injections dynamics
Selective ion sensor	E.g. for tracer tests: chloride (Cl), bromide (Br), nitrate (NO_3)

SENSOR TECHNOLOGY

IN-SITU-METHODS CAN ONLY FULLY DEVELOP THEIR HIGH POTENTIAL, IF THE CONTAMINATION SITE IS PROPERLY MANAGED AND SPECIFIC SITE CHARACTERISTICS ARE TAKEN INTO ACCOUNT. THESE ARE EVALUATED USING:

- Biotechnical monitoring (bioactivity, bacterial counts, biomass analysis, biomolecular evidence, biotoxicity screenings, among others)
- Automated, sensor-based in-situ-monitoring (e.g. spatially monitoring reagent fronts in aquifers, the intensity of biological uptake processes, reaction speeds)
- Geophysical and geochemical analyses (e.g. detection and temporal analyses of aquifer gas storage, geohydraulic process analysis, considering concominant geochemical processes)

WEB VISUALIZATION