CL:AIRE

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treatability bulletin

CL:AIRE Treatability Bulletins describe the key factors to be considered in the early stages of designing a remediation project. Treatability studies provide a means of determining, through laboratory- or pilot-scale tests, the practicability and likely effectiveness of remediation, and can be an essential part of a remediation options appraisal.

Permeable Reactive Barriers

Technology Description

A permeable reactive barrier (PRB) is an engineered treatment zone placed in the saturated zone (aquifer) to remediate contaminated groundwater as it flows through. PRBs are therefore installed perpendicular to the direction of groundwater flow and can be designed in a variety of configurations, depending on the contaminants to be treated, the layout of the area requiring remediation and the requirements of the land user(s). There are two basic types of PRB:

- Funnel-and-gate™: contaminated groundwater is directed to a permeable reactive zone (the "gate") by low permeability barriers, such as cut-off walls (the "funnel"); and
- Continuous wall: a reactive treatment zone is placed in the subsurface across the complete width of the contaminant plume.

The use of different reactive media within the reactive zone of a PRB allows the treatment of a wide variety of groundwater contaminants. Reactive media most commonly applied include zero-valent iron and slow release substrates to stimulate biodegradation. Sorbents may also be used. Contaminant types that can be treated include organohalogen compounds (e.g. trichloroethene and other chlorinated solvents), petroleum hydrocarbons, dissolved metals (e.g. chromium VI), radionuclides (e.g. uranium), anions (e.g. nitrate) and acidic mine water or spoil drainage. The applicability of PRB technology to different contaminant categories and ground material types is presented in Table 1.

Table 1: Generic applicability of PRB technology to contaminants and ground materials (Defra, 2010). Key: Usually or potentially applicable Y; May be applicable ?; Not applicable N.

Organic		Inorganic		Materials	
Halogenated VOCs	Y	Metals	Y	Gravel >2mm	Y
Halogenated SVOCs	Y	Radionuclides	Y	Sand 0.06-2mm	Y
Non-halogenated VOCs	Y	Corrosives	?	Silt 2-60µm	?
Non-halogenated SVOCs	Y	Cyanides	?	Clay <2µm	?
Organic corrosives	?	Asbestos	N	Peat	?
Organic cyanides	?				
PCBs	?	Miscellaneous			
Pesticides/herbicides	?	Explosives	?		
Dioxins/furans	N				

The mechanisms involved in the reactive zone may include chemical oxidation/reduction reactions, precipitation, sorption, fixation, and biodegradation. PRB designs may also incorporate additional measures or modifications to enhance hydraulic or treatment efficiency, such as gravel trenches, abstraction boreholes, and reaction vessels.

In 2002, the Environment Agency published guidance for the design, construction, operation and monitoring of PRBs as a risk-management strategy for polluted groundwater. It describes six key, integrated stages – screening; site characterisation; design (including treatability testing); implementation; monitoring; and operation, maintenance and closure.

Treatability studies may be carried out at a number of stages of PRB selection including options screening, PRB design and operation and are carried out:

- To inform the options appraisal process using relatively simple batch tests.
- To assist in the design of the PRB using the results from column testing.
- To investigate reasons for failure or poor operation of a PRB.

Specific objectives will determine the amount of effort, scale and therefore cost, of the treatability studies.

Treatability Testing

The objectives of the treatability tests may include the following:

- Screen and select reactive media;
- Demonstrate that the contaminant(s) are amenable for treatment;
- Determine the physical properties of the reactive material (e.g. surface area, hydraulic conductivity);
- Understand the treatment process and the hydrochemical controls on it (e.g. pH, dissolved oxygen, etc);
- Determine rates of reaction;
- Identify if there are by-products from the treatment process;
- Determine the likely life of the reactive material;
- Determine the significance of precipitation and passivation on long-term reactivity and permeability of the reactive material;
- Consider the possibility of reverse reactions occurring.

The two main types of treatability tests are batch and column.

Batch tests are used to confirm that a contaminant is amenable to treatment and to screen the suitability of a range of potential reactive materials. The advantages of batch tests are that: they can be performed relatively quickly, limited media is needed, limited water is needed, equipment is readily available, and they are relatively low cost. Batch tests provide quantitative results on contaminant sorption and/or degradation rates, but cannot be used to extrapolate the results to dynamic flow conditions experienced in PRBs.

Column tests are undertaken to provide detailed information on the interaction of the reactive media with the contaminant, which can then be used in the design of the PRB. In simple terms, a column test involves passing contaminated water through a column of reactive media at a controlled flow rate and measuring the change in chemical composition of the water. Because they consider reactions within a flow domain, they are likely to be more representative of processes and transport occurring in a PRB than batch tests.

Important considerations in designing treatability tests include the following:

- Analytical suite (including the contaminant, breakdown products, pH, dissolved oxygen, redox and relevant inorganic and organic parameters);
- Ensure contaminant concentrations are comparable with those in the field;
- Ensure the degree of contaminant degradation or removal that is achieved in the laboratory is in line with that required in the field;
- Assess the interaction (i.e. competition) between contaminants and with other constituents in groundwater during the treatment process;
- Chemical composition of the reactive material;
- Physical properties of the reactive material (e.g. surface area, density, grain size and porosity). The test medium should be the same as that proposed for site construction, including grain size and surface area (reaction rates will be dependent on surface area).
- Flow rate through the column;
- Frequency of sampling;
- Geochemical conditions (e.g. temperature and redox). Reaction rates (even when temperature-corrected) and redox conditions in the laboratory may not reflect those experienced in the field.
- Sufficient time needs to be allowed for undertaking the tests in order to demonstrate that the treatment process is complete (i.e. breakdown products have been treated) and that breakthrough of contaminants (particularly in the case of sorption) can be determined.
- Tests should be undertaken using actual site groundwater samples, with at least one test series using contaminated groundwater to determine the effect of multiple contaminants and the significance of competition for reaction sites. Consideration may need to be given to the significance of changes in groundwater geochemistry between collection in the field and laboratory testing and whether pre-treatment of the contaminated groundwater is required prior to the column test.
- Consideration should be given to flushing the column with representative uncontaminated water (e.g. groundwater) at the end of the test to determine whether the treatment process is reversible (e.g. desorption rate);
- Lifetime of the reactive media, whether it can be replaced at the end of its service life and the ease with which this can be done;
- Potential requirements with respect to the treatment or disposal of reactive (sorption) media;
- Long-term tests (3 to 6 months), or accelerated flow tests where the groundwater throughput is increased, can be used to gather information on the likely long-term performance of the material, particular with regard to passivation and fouling (chemical and/or biological). However, accelerated testing (higher water flow) may overestimate the potential for precipitation and clogging.

The results of the treatability tests (column) will be used in the PRB design, including hydraulic residence time, volume, and physical and chemical properties of the reactive material. A suitable factor of safety is often used in the design to overcome foreseeable scaling factors.

Box 1. Health and safety

As always, health and safety issues need to be carefully considered particularly if the treatability studies are at pilot/field scale. Potentially "significant" health and safety issues include working with hazardous materials, consideration of discharges before treatment is carried out and consideration of PPE when carrying out tests.

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