Tech Data Sheet

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Advances in Permeable Reactive Barrier Technologies

Permeable reactive barriers (PRBs) are passive groundwater treatment systems that decontaminate groundwater as it flows through a permeable treatment medium under natural gradients. PRBs currently are being used to treat a wide variety of groundwater contaminants, including chlorinated solvents, other organics, metals, inorganics, and radionuclides. Zero-valent iron currently is the most common reactive material used in a PRB, but a variety of other adsorptive, reactive, and biodegradation-enhancing materials also are being used.

Advantages of PRB treatment systems include:

- In situ remediation
- Passive operation
- No required aboveground structures
- Potentially less expensive than pump-and-treat systems in the long term

PRB technologies are advancing rapidly, as the treatment method gains popularity as an alternative to pump-and-treat systems. In fact, permeable barriers have evolved into a whole new class of technologies, as new PRB configurations and new barrier media are being developed to treat a variety of contaminants, including solvents, metals, and radionuclides. Recent advances in PRB design, innovative installation methods, and new treatment media are summarized in the following pages.

DESIGN AND MONITORING CONSIDERATIONS

PRB configuration refers to the manner in which groundwater is directed through the treatment unit. The most common configurations are continuous reactive barriers, where the treatment wall extends across the entire width and depth of the contaminant plume; and the funnel-and-gate, where impermeable walls guide the influent groundwater through one or more treatment gates.

Thorough site characterization, including characterization of the plume, hydrogeology, and geochemistry, is required on the more local scale of a prospective PRB location. Groundwater flow and solute transport modeling help address the variability and uncertainty inherent in most aquifers and PRB systems.

Thorough compliance and performance monitoring also is critical to successful implementation of PRBs. Monitoring wells are typically located on all sides of the PRB, within the treatment medium, and at numerous upgradient and downgradient locations (see Figure 1). Normal compliance monitoring parameters include the target contaminants, degradation products, and general water quality parameters. Typical performance monitoring parameters include hydrologic parameters, Eh, dissolved oxygen, and geochemical parameters (e.g., calcium, magnesium, and alkalinity). These parameters are used to monitor for potential loss of reactivity, decrease in permeability, decrease in residence time in the treatment zone, short-circuiting, and leakage.

Figure 1. Monitoring wells for evaluating the reactive and hydraulic performance of a PRB at Seneca Army Depot.

LONGEVITY AND HYDRAULIC PERFORMANCE OF ZERO-VALENT IRON PRBs

In a recent study by the Naval Facilities Engineering Service Center, performance monitoring data for four PRBs that have been operational for several years were analyzed to assess the longevity and

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hydraulic performance of iron PRBs (Battelle, 2002).

The longevity assessment looked at groundwater data, iron cores, deposits from silt traps, accelerated long-term column tests, and geochemical modeling from two sites where PRBs were installed more than 5 years ago: former Naval Air Station (NAS) Moffett Field and former Lowry Air Force Base (AFB) (see Figure 2). Both PRBs are currently performing as designed, removing chlorinated solvents from groundwater to below detection limits, and are predicted to perform acceptably for at least 30 years. However, the longevity evaluation observed that the reactivity of the iron deteriorates progressively with exposure to groundwater.

Figure 2. Evaluating longevity of the zero-valent iron PRB at Lowry AFB.

The mass flux of certain native dissolved solids was linked to a decrease in PRB longevity. The dissolved solids precipitate out and cover iron reactive surfaces. In this study, the acceptable life of a PRB was defined as the time required for the reaction rate of the iron to decline by a factor of two. Beyond this time, natural attenuation or some other measure, such as regeneration or replacement of the iron, would be required for continued management of the plume.

Hydraulic performance of PRBs was evaluated in detail at four sites (former NAS Moffett Field, Lowry AFB, Seneca Army Depot, and Dover AFB) with different flow characteristics and PRB designs. Water level measurements, in situ flow sensors, colloidal borescopes, groundwater modeling, tracer tests, and downhole flow sensors were the tools used to evaluate flow at these sites. The evaluation noted that measuring water levels is still the best method for site characterization and PRB design (see water level map generated for the PRB at NAS Moffett Field in Figure 3). Water level measurements indicate bulk flow, whereas the various flow sensors measure point flow, which can be much more variable, spatially and temporally. Sensors can be used, if required, to further elucidate flow at sites with highly heterogeneous geology.

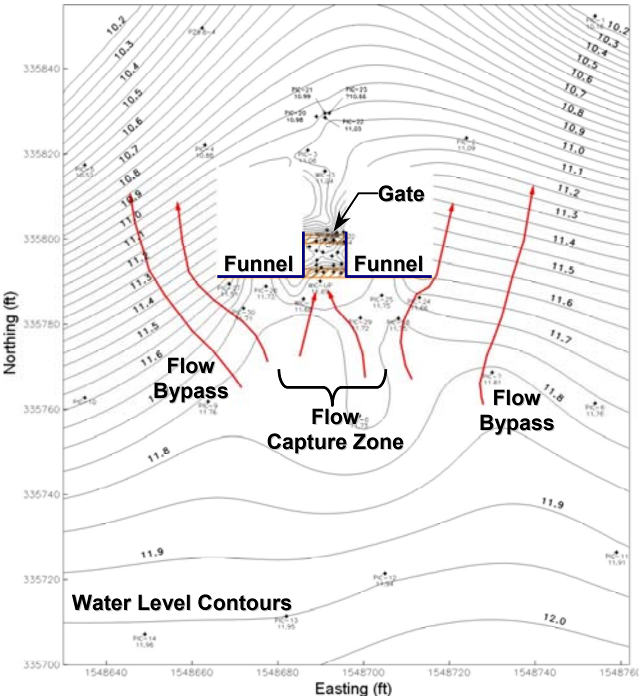

Figure 3. Computerized flow modeling helps elucidate groundwater flow patterns for the PRB at NAS Moffett Field.

Even with water level measurements, determining the hydraulic capture zone in the upgradient aquifer and residence time in the PRB can be challenging. The distances involved are short and, at most sites, water level differences may not be significant over a few feet, which is the scale of a PRB's flowthrough thickness. Groundwater flow and solute transport modeling can be used to model various flow scenarios and obtain a more robust design. Dover AFB is one site where relatively large seasonal fluctuations in groundwater flow were successfully addressed through modeling during the design of the PRB. Appropriate safety factors need to be incorporated into the design in order to address inevitable uncertainties in hydraulic flow and long-term plume influent concentrations.

ADVANCED CONSTRUCTION METHODS

As the number of PRB field applications has grown, so too has the sophistication, reliability, and number of commercially available construction techniques adapted to PRB installation. The use of special geotechnical methods, such as jetting and hydraulic fracturing, has improved the ability to access deeper aquifers. Table 1 describes the established and innovative construction methods used at approximately 50 PRB sites in the United States.

Table 1. Advances in PRB Construction Techniques

Construction Technique	Maximum Depth (ft bgs)	Description
Backhoe/ Modified Backhoe Clamshell	30 80 120 or more	Conventional backhoes excavate trenches up to 5.6 feet wide and up to 30 feet bgs. Trench boxes or sheet piling are used to stabilize the excavation prior to backfilling with treatment medium. Modified backhoes used recently at PRB sites have reached depths of 80 feet, although slurry is required to keep the trench open. Crane-operated clamshells have been used to excavate trenches to depths of 120 feet bgs with the help of trench support slurry. Used at PRB installations in Sunnyvale, CA, and NAS Moffett Field, CA.
Biodegradable Slurry	65	The use of biodegradable slurry (bioslurry) is a recent advance in PRB trenching. The jelly-like guar gum/water mixture is added to the trench to stabilize the excavation walls. Preservatives and pH adjustments prevent bioslurry breakdown during construction. After the reactive medium (iron) has been installed, bioslurry degradation is initiated by adding a liquid enzyme breaker. Used at several sites, including Pease AFB, NH and Somersworth Landfill Site, NH.
Caisson Excavation	50	Caissons are large-diameter, load-bearing enclosures that are driven into the ground. Once installed, the native material is excavated and replaced with the treatment medium, and the caisson then is removed. Caissons were used to install the Savannah River Site Geosiphon (25 feet deep), and the Dover AFB treatment gates (40 feet deep).
Continuous Trenching	25 to 30	The continuous trencher is equipped with a boom apparatus similar to a chainsaw for excavation, a trench box for stabilizing the trench walls, and a hopper to backfill the excavation with reactive medium. It can excavate and immediately backfill trenches 1 to 2 feet wide. Used at several sites, including U.S. Coast Guard, NC and Naval Weapons Industrial Reserve Plant, TX.
Deep Soil Mixing	40 or more	Two or three special augers equipped with mixing paddles are lined up in series. As the augers penetrate the ground, they mix fine iron and soil together. The iron can also be introduced in biodegradable slurry. Alternatively, iron-filled casings can be driven into the ground with a vibratory hammer, and the iron later mixed with the soil using the mixing paddles. A variation of this method was used at Launch Complex 34, Cape Canaveral Air Station, FL.
Hydraulic Fracturing	120	A series of wells are installed along the length of the PRB. A vertical fracture is propagated within each well, and the fractures are filled with granular iron/guar gum slurry. The reactive iron slurry in one fracture coalesces with the adjacent fracture, creating a continuous vertical wall. Used at the Massachusetts Military Reservation and the Caldwell Trucking Co. Site, NJ.
Jetting	50 or more	Jet grouting involves the injection of grout or slurry at high pressure into the ground. A triple-rod injection system delivers a high-pressure mixture of granular iron, guar gum, air, and water to the subsurface. Injection starts at the bottom of the PRB wall and continues as the rod is lifted, creating a column or panel of reactive medium. Multiple rows of overlapping columns or panels create the continuous passive treatment wall. Used at Travis AFB, CA.
Vibrated Beam/ Mandrel	26 43	This technique involves driving an H-beam or mandrel with a sacrificial shoe at the bottom to create a void space. As the beam is raised, a slurry or grout containing the reactive medium is injected into the void space through a special nozzle at the bottom of the beam. By driving beams in an overlapping panel, a continuous treatment wall is created. This barrier can be installed at an angle up to 45 degrees to avoid utilities or structures. Vibrated beam was used at an industrial site in Tifton, GA and a mandrel was used at Hangar K, Cape Canaveral Air Station, FL.

One important advance in the use of backhoe trenching is the use of a biodegradable slurry (or bioslurry) to shore up the excavation (see example in Figure 4). Bioslurry is a highly viscous solution of guar gum that keeps the excavation open and eliminates the need for sheet piling or trench boxes. The PRB reactive material, usually iron, is tremied into the excavation and allowed to settle through the slurry. Caution must be exercised to ensure that the guar gum slurry does not degrade before the installation of the reactive medium is complete. A biocide typically is added to the bioslurry in order to delay the degradation of the slurry, but the introduction of biocides below ground may cause regulatory concern at some sites. Following installation of the iron, an enzyme breaker is added to the trench to hasten degradation of the guar gum and to establish flow through the PRB. Bioslurry was used to install iron in a 65-foot-deep PRB trench at Lake City Army Ammunitions Plant, MO.

Figure 4. Biodegradable slurry (guar gum) is added to a trench to shore up the excavation until the PRB medium is installed.

ADVANCES IN TREATMENT MEDIA

The range of contaminants that can be treated through PRBs is increasing due to the use of new reactive media. PRB media are classified as reactive, adsorptive, or biodegradation-enhancing.

Bimetallics are one group of new reactive media being studied; examples include iron-nickel, iron-copper, and iron-palladium. Adding the second metal enhances the reaction rate due to galvanic or catalytic reactions. The higher reaction rate of these media could potentially allow very thin PRBs to be installed. This is especially helpful with deep installation methods, such as hydraulic fracturing, where the barrier installed is just a few inches thick. A second, new type of reactive media uses limestone, bone char phosphate, or apatite to precipitate out dissolved metal contaminants.

Adsorptive PRB media adsorb organic or metallic contaminants, such as methyl-*tertiary*-butyl ether (MTBE) or arsenic. New adsorptive media include powdered activated carbon, basic oxygen furnace slag, and natural zeolite.

Biodegradation-enhancing PRB media stimulate the biodegradation of contaminants such as perchlorate and explosive residues. New biodegradation-enhancing media include compost, vegetable oil, mulch, peat moss, and sawdust.

Other innovative PRBs under development include electrochemical barriers that generate oxidation-reduction reactions for treatment, and nanoscale iron, a highly reactive form of zero-valent iron.

REFERENCE

Battelle. 2002. *Evaluating the Longevity and Hydraulic Performance of Permeable Reactive Barriers at Department of Defense Sites*. Final Report prepared for NFESC. April 24.

FOR FURTHER INFORMATION

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