INSTALLATION OF PRBs USING PNEUMATIC INJECTION

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Abstract: Several methods of installing permeable reactive barriers (PRBs) have been developed over recent years. These techniques have evolved in order to address deeper contaminant plumes. One method that was developed to address this issue uses the patented pneumatic fracturing to emplace dry media such as iron filings. The technology, pneumatic injection, was patented by the New Jersey Institute of Technology (NJIT) in 1999. This technology offers several advantages, especially with iron PRBs. It allows the installation of media much deeper than conventional methods and over a greater lateral distance. The second advantage eliminates the concerns associated with solid iron walls (i.e., biofouling, precipitation, and unachievable reductions). The third advantage is the installation of the media at targeted depths, which, in turn, reduces the amount of iron and hence, the cost. A column study was conducted for the preliminary design of an iron PRB in California. The site has the highest VOC contamination in three transmissive zones between 20 to 100 feet bgs. Pneumatic injection can target the transmissive zones, while achieving reduction, and eliminate 60% of the iron required for treatment, if a solid or continuous iron wall were installed.

The Site

A manufacturing facility considered treating their groundwater, contaminated with chlorinated solvents, with an iron PRB. The site geology consists of an alluviated coastal plain with stratigraphic units of silty sands. A continuous core was collected to 100 feet below ground surface (bgs) as part of the design of the PRB identifying three primary transmissive zones:

- Interval between 26 and 31 feet bgs is a silty sand, described as well graded, fine to coarse, and saturated. This is the shallow zone.
- Interval between 42 and 60 ft bgs includes several lithologies and since there are several material changes within short vertical distances, they are grouped together as one zone. Two units appear to be the primary transmissive intervals, described as a fine to medium sand and saturated. This is the mid-depth zone.
- The third interval is between 81 and 92 feet bgs. This interval includes a saturated, silty sand between 85 and 92 feet bgs. This is the deep zone.

Most of the impacted groundwater lies within these three zones, particularly the upper two. Isolating the groundwater flow to selected transmissive intervals has important consequences for the PRB design and even more importantly, to the installation cost.

The Study

Targeting the impacted zones that are actually transmitting the groundwater and have the elevated concentrations of contamination can provide a substantial cost savings. If only the three stratigraphic zones are targeted, approximately 60% less iron (not including the associated labor and materials) would be saved compared to a PRB installed at the entire depth. In addition, if a PRB were constructed throughout the entire stratigraphic column (which is assumed to be between 20 and 100 ft bgs), almost 50% of the PRB would be located in lower permeable units which are not transmitting or minimally transmitting groundwater and would therefore, serve no purpose. Utilizing the pneumatic injection method enables the emplacement of iron into the

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three transmissive zones with a high degree of accuracy and control. Therefore, the treatability study was designed to address the reaction kinetics within these three zones.

The objectives of the treatability study were to determine degradation rates, half-lives and required residence times in order to effectively design a full-scale PRB at this site. The permeability of the columns increased in all three zones, thereby, enhancing the transmissive zones and attenuating the groundwater to flow towards these zones. The shallow zone increased 64% and the mid-depth and deep zones increased 115%.

Site-specific degradation rates were calculated from these column studies, especially since there is a mix of iron and soil, rather than solid iron. Based on first order decay kinetics, the following half-life calculations are located in Table 1. Also, the thickness of the PRB is dependent upon the residence time required to achieve complete degradation to the required MCLs and the groundwater flow velocity. Based upon the maximum residence time necessary in each transmissive zone, the following thicknesses were determined for the PRB in each transmissive zone.

Table 1. Half-Life Calculations from Treatability Results

Compound	$t_{½}$ (hours)		
	Shallow	Mid-Depth	Deep
PCE	26.7	22	14.3
TCE	13.8	8.6	9.7
cis-1,2-DCE	47	47	47
Thickness (feet	6	1.3	0.9

Note that vinyl chloride was not present in any of the columns.

The Installation

There are four basic equipment components of the pneumatic injection system: injection nozzle and associated piping, compressed gas source, dry media feed system, and system operation controls.

The pneumatic injection method is achieved by first advancing the injection nozzle to the maximum depth required for the PRB. This is achieved by jetting the nozzle into place or utilizing a temporary drill casing. The nozzle is designed to inject the media in a horizontal or planar format in a 360° circumference. The nozzle itself is directional so that each injection covers 90°. The nozzle is rotated between injections four times to achieve the full circumference. After the four injections, the nozzle is retracted at an appropriate distance and repeated. In this manner, cylinders of iron/soil mixtures are "stacked" to build a zone of soil/iron mixture covering the desired interval. Each injection interval is six inches to one foot thick.

The carrier gas stream utilized for emplacement of the dry media should be compatible with the type of material being injected. In the case of iron filings, nitrogen gas is used. A tube trailer or liquefied nitrogen trailer is the source of the gas. It is inexpensive, readily available, and easily transported to the site. The dry media system is an aboveground apparatus, which consists of pressurized holding tanks, piping, and valves. The compressed gas source is upstream of the dry media system. The operator establishes a starter path for the dry media (within seconds) and then introduces the dry media into the gas stream.

Full-Scale PRB at the Site

Based on the success of the treatability study for this site, three options were evaluated for a full-scale PRB at the site utilizing the pneumatic injection emplacement method. The unique aspects of this method, particularly the precision in directing the dry media placement, allow for significant flexibility in placing iron within the geologic formation present at the site.

The first option would be to install iron throughout the entire thickness of the geologic material between 20 and 100 feet bgs. This would provide complete coverage of the overall zone, but a significant portion (approximately 50%) would be placed in intervals with minimal or no groundwater flow. Under this scenario, the costs of iron would be significant and much of the PRB would not be necessary or effective.

The second option would be to emplace iron in the more transmissive zones. As discussed earlier, three transmissive zones were identified from the continuous core. By placing iron in these zones, it will actually intercept most of the impacted groundwater. This approach reduces the iron requirement by 60% and is much more efficient and cost-effective than containing iron throughout the entire 20 to 100 foot thickness.

The second option can be advanced further, taking full advantage of the ability of the pneumatic injection method to emplace iron with a high degree of precision. As depicted on Figure x, the pneumatic injection method can allow placement of iron in only those permeable stringers identified as silty sands and sands. This would reduce the iron required even further and provide the most efficient and cost-effective PRB since iron would be placed only in those geologic units where it was necessary.

Cost

Installation of the PRB utilizing the pneumatic injection method is now compared to emplacement by vertical fracturing in Table 2. In each instance, the target depth is between 20 and 100 feet bgs and the length of the wall is 300 feet.

Table 2. Comparison of Installation Costs

Installation Method	**Cost ($)**
Vertical Fracturing	$6M
Pneumatic Injection (20 to 100 feet bgs)	$5M
Pneumatic Injection (targeting transmissive zones)	$3.4M
Pneumatic Injection (targeting stringers)	$3M

Based on the cost comparison alone, the advantage of using pneumatic injection is cost-effective when compared to vertical fracturing. Conventional methods such as trenching cannot even be compared due to the depths required for emplacement of the PRB. Additional advantages of pneumatic injection not only include achievement of greater depth, but also allowing the target of certain more transmissive zones; thereby reducing the amount of iron required for the entire depths.