Permeable Reactive Barriers (PRBs) at Great Depth – Material Testing and Application

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Abstract: Permeable Reactive Barriers (PRBs) have proven to be an efficient long term method to clean up contaminant plumes in ground water. The deeper they reach to cover the entire extent of a contaminant plume the more normal ground pressure increases within the barrier material. Under these conditions, soil mechanical and hydrogeological aspects become more and more considerable, such as hydraulic long term stability, small deformations, minimal consolidation and swelling effects, high grain strength and erosion stability. Currently, an investigation is being undertaken at a chromate contaminated site to install a PRB with granulated iron ore as reactive filling material. The aquiclude to reach is at a depth of about 40 m. To verify its suitability and to determine the barrier design, batch and column tests are carried out observing the reactive behavior of the candidate barrier material on one hand. On the other hand, soil mechanical tests include combined oedometer- and hydraulic conductivity tests, swelling tests and abrasion tests.

The interest in PRBs has increased eminently over the past years, globally, but implementations of full-scale projects have been realized mostly in North America. So far, the predominant filling material has been *zero-valent iron (Fe^0)* for degrading chlorinated organic compounds on one hand (e.g. Dahmke et al. 1999). On the other hand, it seems to be suitable for a series of heavy metals as well (Cr^{VI}, As^{VI}, As^{III}, Se^{VI} and TC) (Blowes et al. 1996).

Significantly less distributed is the application of *adsorptive PRBs*. With potable water, treatment by adsorption of organic components on solid surfaces is established. For this, activated carbon is used predominantly. Activated carbon has also been used as filling material in first applications of adsorptive PRBs (Grathwohl & Peschik 1997, Teutsch et al. 1996). With the reactive (adsorptive) material showing a finite capacity, in most cases frequent replacement of the adsorptive medium must be considered.

Beside these commercially applied technologies, further ones are being developed, in order to optimize known processes as well as to develop new methods. The US Department Of Energy (US DOE) provides an extensive overview of research and application of Permeable Reactive Barriers (DOE 1998).

Research efforts at the Institute of Geotechnical Engineering (IGT) include the development and testing of novel reactive barrier materials. The research program comprises both laboratory geochemical and geotechnical tests. One aim is to define gen-

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eral geotechnical criteria for PRB filling materials and carry out appropriate experiments. A full scale project is being planned at a chromate contaminated site. From geotechnical point of view, the particular challenge at this site is the great depth that is to be reached with a PRB which is at more than 40 m below surface.

For application in PRBs, relatively coarse grained materials are eligible, categorically, which guarantee high hydraulic permeability. Clogging effects might be caused by precipitants, biomass, swelling or simply if filter criteria are not fulfilled with respect to the aquifer soil. Table 1 gives an overview of the geotechnical criteria and a proposal of suitable test methods. In view of normal ground pressure, only small deformations should occur. Pore volume must remain stable with regard to hydraulic conductivity and flow velocity. The candidate material must not show any consolidation characteristics. To quantify the stress-deformation behavior, oedometer tests are performed.

Thinking of the construction works, the granular barrier material will experience a high mechanical impact during transport and especially while filling the trench. With the groundwater flow, abrasives might be eroded and clog the downgradient section of the PRB or the subsequent soil. To find out about the abrasion behavior in laboratory tests, modified Los-Angeles tests (ASTM standard for road construction). Erosion effects are monitored in the obligatory column tests by simply using filter materials in the columns which are examined at the end of the tests.

Requirements for mineral filling materials	Test method
Hydraulic and mineralogical long term stability	One-dimensional flow tests in columns for quantification of reduction / adsorption characteristics Swelling tests (with clayey materials)
Small deformations Minimal consolidation	Oedometer tests for determination of time dependent stress-deformation behavior Stress-dependent conductivity tests in oedometer apparatuses
Erosion stability of the pellets	Use of filter materials in the columns to be examined at the end of the tests
High grain strength (abrasion behavior)	Los-Angeles test (modified procedure)

Table 1 – Overview of geotechnical criteria and suitable test methods

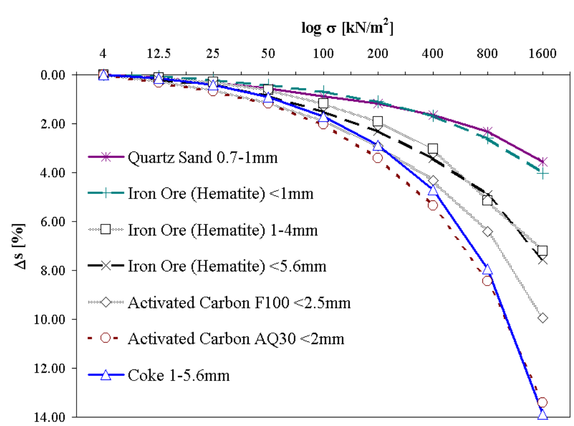

Figure 1 – Results from oedometer tests with selected barrier materials and quartz sand as well known reference

Considering current research activities on laboratory scale as well as commercially utilized barrier materials, currently some geotechnical tests are being carried out at the IGT with respect to the feasibility in PRBs. First results from oedometer tests are shown in figure 1. Table 2 gives an overview of relations between the reactive materials and contaminants.

PRB FILLING-MATERIAL	REFERRING CONTAMINANT CATEGORY
Iron Ore (Hematite)	Chromate (Cr^{VI})
Activated Carbon	Organic Compounds
Coke	PAH

Table 2 – Relation between barrier materials and contaminants

From Figure 1 it can be seen that activated carbon AQ30 and Coke encounter relatively high settlements (13 to 14 % at 1600 kN/m^2), activated carbon F100 little less (10%), well graded iron ore about half of the amount of coke (7%) and quartz sand as well as fine grained ore are least compressible (3 to 4 %). Transferring these results into the natural environment, the different material density and thus the different ground pressure must be considered, though.

Research and development of Permeable Reactive Barriers and of appropriate filling materials in particular, as well as on-site applications, are being promoted continuously at many places. Geotechnical criteria are very rarely considered, though. With respect to applications of PRBs in great depth, the described aspects become important, thinking of efficient operation process and long term performance.

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