Active sediment capping

Technology description:
General information & application area

Target Audience: Authorities, site owners, consultants, contractors

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1 Introduction

Active sediment capping is an innovative in-situ remediation technology for contaminated groundwater. This document intends to provide general information about this technology, and its application area and boundary conditions for authorities, consultants and site owners. More details for evaluating the feasibility as well as for designing, implementing and monitoring these caps are described in the associated generic guideline.
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2 General principles of the active sediment capping technology

2.1 Concept

The Hyporheic zone sediment is the area of the streambed which forms an interface between groundwater and surface water (Figure 1). In anaerobic eutrophic river sediments, the high organic matter content can feed a Chlorinated Aliphatic Hydrocarbon (CAH) reductive dechlorination activity. Molecular hydrogen, produced from the fermentation of organic substrates, is known to serve as electron donor for dechlorinating organisms. However, when natural bioattenuation fails to completely dechlorinate CAHs, *in situ* capping is a promising technology. The main objective of this technique is to contain the contamination in the sediment with clean media. For this , passive (sand) or active caps (inducing physicochemical or biological transformation) can be used.

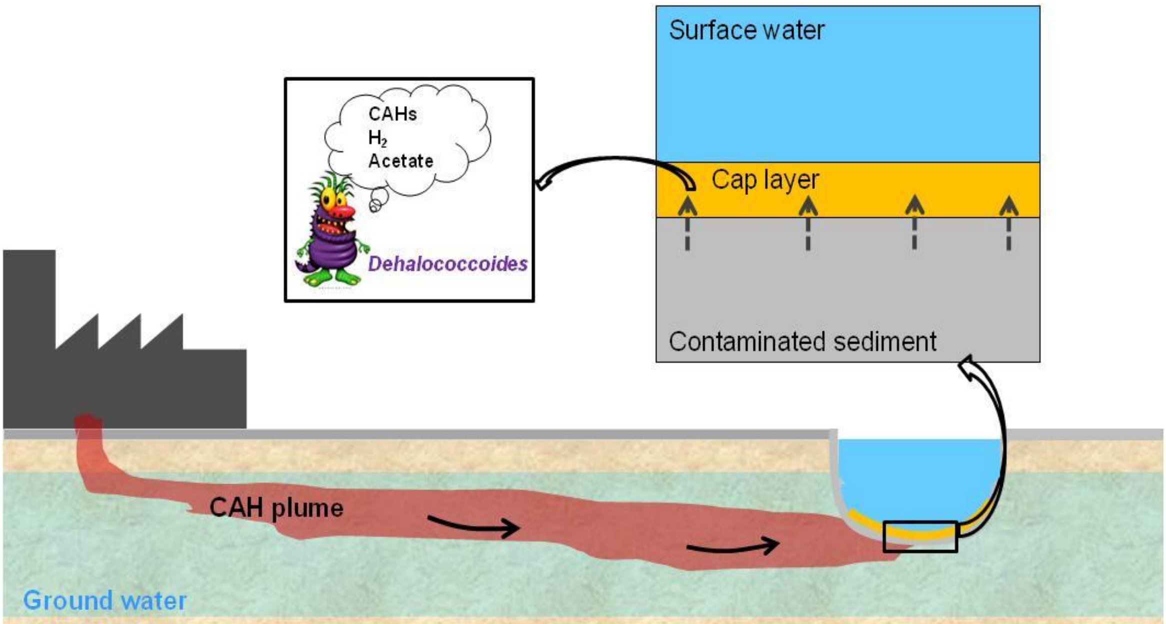

Figure 1. Representation of the bioreactive cap which can be placed on top of the riverbed sediment.

2.2 MORE DETAILED INFORMATION

2.2.1 Technology name

As mentioned above, passive and active caps exist. However, since only the active caps result in a real destruction of the pollutant, this guideline focusses on active caps and more in particular on the use of biologically active caps for the destruction of CAH.

The term biological reactive cap or bioreactive cap was coined for the new capping technology as the bioreactive layer which is integrated into the cap structure can host CAH degrading microbial communities. *Dehalococcoides* is the only micro-organism to date that can completely reduce DCE and VC to non-toxic ethane. It needs acetate and H_2 as the obligate carbon source and electron donor. By providing the necessary carbon and electron sources, bioreactive caps can provide an ideal colonization surface and reaction media for these CAH degrading organisms.

2.2.2 Targeted substances

An overview of the substances that can be targeted by the sediment capping technology are summarized in Table 1, along with potential emission sources of the different substances.

Table 1 Overview of substances that can be tackled by active sediment capping technology.

Targeted substances		Emission sources
Class	Specific substance	
e.g. CAHs (chlorinated aliphatic hydrocarbons)	Tetrachloroethene (PCE), Trichloroethene (TCE), dichloroethene (DCE), vinylchloride (VC), Dichloroethane (DCA), 1,1,1-trichloroethane (111TCA)	Drycleaner activities Degreasing activities Electronics …
Polychlorinated biphenyls PCB	Biphenyl Aroclor	Electrical transformers Coolants and lubricants
Polyaromatic hydrocarbons PAH	Naphthalene, acenaphtene, pyrene, …	Power generation Wood burning Waste incineration Coal tar
Heavy metals	Zn, Cd, Cu, Ni, Pb	Metallurgy Waste water Agriculture
Nutrients	Ammonium, nitrate	Agriculture

2.2.3 Development stage of the technology

The sediment capping technology is very emerging.

The permeable and reactive nature of bioreactive caps are generally analogous to permeable reactive barriers (PRBs), a common groundwater remediation technology used for *in situ* treatment of contaminants contained within flowing ground water. However, unlike PRBs and physicochemical capping technologies, application of the bioreactive caps for *in situ* bioremediation of the CAH contaminated sediments seems to be in its infancy. Considering the fact that *in situ* capping with inert or chemically reactive materials is rapidly gaining international recognition, it is expected that bioreactive caps soon will reach full implementation stage. The reasons for this can be their relatively lower cost, lower environmental impact and rapid and significant effect on pollutant degradation.

Although some examples of *in situ* applications of physicochemical caps exist (Fredette et al. 1992; Brannon and Poindexter-Rollings 1990; Sumeri et al. 1994), to the best of our knowledge, no bioactive cap has already been installed *in situ*. Most studies focus on the selection of appropriate capping materials in the laboratory (both batch and column tests) but did not proceed yet to the *in situ application* level.

2.2.4 Applicability and boundary conditions of the technology (EPA-540-R-05-012)

The active sediment capping technology is recommended under the following conditions:

- Location where contaminated groundwater in discharged in surface water (or where polluted surface water is seeping into the groundwater).
- The pollutants present in the groundwater are degradable under anaerobic conditions since these are the prevailing conditions in the cap. The preferred degradation process is reductive dehalogenation because in this process the carbon source which is present in the cap is being used as an electron donor. Other anaerobic degradation processes such as anerobic oxidation are feasible, but a competition between the applied carbon source and the pollutant for the electron acceptor might occur. The processes do not result in the accumulation of non-degradable harmful metabolites.
- When pollutants are present in the dissolved phase.
- With respect to the hydrogeological characteristics of the site:
    - The groundwater flow direction is known and relatively stable during the year.
    - In principle, the active sediment capping technology is applicable for a wide range of groundwater flow velocities. For higher flow velocity, larger dimensions of the cap are generally needed (mainly achieved by increasing the thickness of the cap to ensure sufficient contact time); the longevity of the system may be lower, resulting in higher costs. In addition, increased flow velocities and turbulence can impact cap stability as they will result in higher shear stresses.
- The hydraulic conductivity of the cap is equal or higher than the permeability of the surrounding sediment.The site is accessible for the installation of the cap, which implies the enrollment and attachment of the cap to the riverbed/river sides. Caps may be most suitable where water depth is adequate, slopes are moderate, contaminants are not mobile, substrates are capable of supporting a cap, and an adequate source of cap material is available.
- Selection of cap placement methods should minimize the resuspension of contaminated sediment and releases of dissolved contaminants from compacted sediment. There are needs to stay accessible for monitoring and potentially for renewal of the cap/cap-filling.
- The geochemical characteristics of the groundwater do not lead to large quantities of precipitates that can block the cap over time.

The use of the active sediment capping technology is not recommended in the following cases:

- For pollutants that have not been shown to be degradable under anaerobic/reductive dehalogenating conditions, or that are transformed in harmful reaction products.
- For sites where free product is expected to migrate into the cap.
- High oxygen concentrations in the groundwater/surface water might lead to fast oxidation of the carbon sources present in the cap (side reactions) and eventually to the inhibition of the pollutant degrading microbial population.
- If the water body is shallow, the cap can suffer from disturbances such as boat anchoring and keel drag. Potential cap erosion caused by propeller wash should be evaluated.

Positive co-effects of the active sediment capping technology:

- An effective rehabilitation technique for the abatement of organic hydrocarbons in stream sediments is most likely to have a positive effect on both above-sediment and sediment biota on the long term. Especially benthic invertebrates can benefit from a reduction of the pressure by chlorinated hydrocarbons.

Negative co-effects linked to the active sediment capping technology:

- Release of dissolved organic carbon (DOC) into the surface water might result in eutrophication of the surface water. A good design of the cap is needed so that the released DOC can be captured by the pollutant degrading population.
- Next to the pollutant degrading population, also other bacteria growing under anaerobic conditions might be stimulated. These bacteria will capture part of the applied carbon sources. A phenomenon often encountered in these caps is the stimulation of methanogenic bacteria resulting in the production of the green house gas methane.
- The capping procedure is expected to have a negative impact on sediment biota on the short term. The technique involves covering the sediment with a solid layer, thus severely disturbing the local habitat of the sediment biota. Especially if anaerobic conditions are established under the layer in the sediment, this may affect the sediment biota considerably at the covered location if it used to be aerobic before.
- To provide erosion protection, it may be necessary to use coarse cap materials that are different from native soft bottom materials, which may alter the biological community. In some cases, it may be desirable to select capping materials that discourage colonization by native deep-burrowing organisms to limit bioturbation and release of underlying contaminants.

2.2.5 Performance of the active sediment capping technology

The **abatement rate** can be defined as the substance concentration after the technology implementation divided by the substance concentration before implementation of the technology. The active sediment capping technology aims at an abatement rate close to 100%, which means that the mass flux reduction rate of the pollutants in the active sediment cap is almost 100%. The local regulatory limits are determining for the exact targeted abatement rates. Note that in general the active sediment cap does not affect the pollution upstream and does not deal with the pollution that is already downstream of the barrier.

Efficiency drivers are (1) the degradation rates of the different pollutants and their breakdown products, which are function of the type of carbon source used in the cap and the colonisation efficiency of the microbial population, (2) the groundwater flow velocity and (3) the decrease in carbon over time.

Longevity of the technology is influenced by (1) the composition of the groundwater, (2) the groundwater velocity through the barrier and (3) the mass, type and grain size of the carbon source used. Until now, no *in situ* results of the longevity of bioreactive caps exist.

2.2.6 Cost of the technology

Cost drivers for active sediment capping technology comprise (1) the required dimensions of the cap (depth, length and thickness), (2) the price of the capping material, (3) the local situation on the site (accessibility, surrounding buildings, underground constructions, type of subsurface ...), and (4) the amount of maintenance that is needed to keep the cap active and permeable.
The cost of the capping material ranges from 0.086 EUR/kg to 11 EUR/kg.

3 Generic approach to determine applicability of an active sediment cap for a specific site or area

For a successful application of the active sediment capping technologies, the following steps are to be followed:

Step 1: site characterization
A site characterisation is required for multiple reasons:

- To identify the location of the pollution in the sediment zone
- To identify the type and concentration of pollution that is present in the sediment zone but also in the inflowing groundwater
- To collect information on the physicochemical characteristics of the sediment zone and the inflowing groundwater (Total organic carbon, electron acceptors, electron donors, pH, grain size distribution, permeability, …)
- To collect hydrological data (groundwater flow direction, groundwater and pore water flow velocity, ...)
- To collect information on the ecological characteristics of the sediment and pore water zone and the inflowing groundwater (microbial and overall ecology parameters).

Step 2: Feasibility tests at laboratory scale
To select the most appropriate capping material, batch and column tests should be performed in the laboratory. In these tests, a certain amount of capping material is brought in contact with the sediment in the presence of the groundwater or surface water. The concentration of CAH and their degradation products as well as the bacterial numbers are monitored in function of time. From these tests, the effect of the different capping materials on the CAH degradation constants as well as the microbial cell numbers can be determined. By performing column experiments, the effect of the groundwater velocity on the CAH degradation, microbial activity and (longterm) performance of the cap can be investigated.

Step 3: design & dimensioning of the active sediment capping technology
Based on the degradation rate constants and microbial numbers obtained in step 2, as well as the CAH concentration and hydrological parameters (groundwater velocity, hydraulic conductivity,

and hydraulic gradient) measured in the field, an active sediment cap can be designed. The most important parameter is the thickness of the cap.

Step 4: implementation of the active sediment cap in the field

This step comprises the installation of the active sediment cap. Reactive material is encapsulated in a geotextile composite that can be easily unrolled over the sediments. To keep the cap in place, it can be attached to the river shores or covered with sand.

Step 5: monitoring performance and corrective actions

Monitoring of the sediment active cap is performed at the physicochemical, hydrological, and ecological level. These parameters are being determined in groundwater, pore water and surface water samples.

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5 References

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