Active Geosynthetic Composites for subaqueous capping

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1. INTRODUCTION

Contaminated sediments are a significant and widespread environmental issue (EPA, 2013). They can seriously impair the navigational and recreational uses of rivers and harbours (EPA, 2005). Possible sites and how to deal with the issue, as well as how active capping can be an additional tool for these issues will be discussed in this paper.

Marine ports are always a source of considerable environmental pollution since their activities are associated with a particular contamination of aquatic areas and bottom sediment (Enton, et al., 2005). Contaminants get into the aquatic environment through shipping traffic, loading and repairs as well as rainwater runoff, effluent discharge and dust (Enton, et al., 2005) (Guerra-García, et al., 2005) (Schiff, 1996).

Former industrial sites that are out of service have already been recognized as potential threat to the environment. This resulted from a lack of knowledge and a lack of regulations regarding harmful substances in the past. Due to the need of water for industrial processes many of these sites are located in close proximity to rivers and lakes which resulted in a steady long term contamination of the waterbodies' sediments. Example sites are former wood treatment plants, gas plants, mining operations and paper mills (Enton, et al., 2005) (Leipzig, 2003).

Different technologies are currently used for addressing contaminated sediments including Monitored Natural Recovery (MNR), enhanced MNR (EMNR), in-situ capping, dredging or excavation and a combination of these approaches. These remedial options all have advantages and limitations for controlling human health and ecological risks associated with contaminated sediment (EPA, 2013). The decision of which remedial technology should be used at a specific site needs to be based on a risk assessment study.

MNR is a remedy that typically uses known, ongoing, naturally occurring processes to contain, destroy or otherwise reduce the bioavailability or toxicity of contaminants in sediments. Key advantages of this method are its relatively low implementation cost and its non-invasive nature. Disadvantages are that contaminants are left in place without engineered containment and that the risk reduction can be slow compared to active remedies (EPA, 2005).

In-situ capping refers to a placement of a subaqueous covering or cap of clean material over contaminated sediments that remains in place. Advantages of this method are quick reduction of contaminant exposure, requirement for less complex infrastructure and less disruption to the site's surroundings. However, the contaminants are left in place and could be dispersed or exposed if the cap is damaged.

The dredging and excavation remedy removes the sediments from the waterbody and also includes the post-dredging treatments like dewatering, water treatment, sediment transport and sediment treatment be it reuse or disposal. This process achieves high levels of clean-up and provides the least uncertainty regarding future exposure as the sediments are removed rather than managed on site. Disadvantages are high costs and the need for transport, storage, treatment - if possible - and disposal facilities. Also residuals may remain in the sediment which could lead to the need of additional actions like backfilling, MNR or capping (EPA, 2005).

This study focuses on the design and function of in-situ caps and the benefits that originate from using active geosynthetic composites as an essential part of them.

2. CAP DESIGN

In-situ caps are used to reduce the risks originating from the contaminated sediments through the following primary functions:

1) Physical isolation - reduce direct contact exposure and prevent bioturbation by benthic organisms
2) Stabilization - provide erosion protection and reduce resuspension and transport of contaminants into the water column
3) Chemical isolation - reduce exposure from dissolved contaminants into the water column (EPA, 2005)

While these functions need to be fulfilled by the cap there are different influences that need to be addressed as well to ensure a proper cap performance. These effects are site specific and range from erosion and advection from currents and ship manoeuvring, subaqueous groundwater discharge, slope stability and bearing capacity, diffusion and consolidation to effects caused by the benthic community.

These caps can be designed and installed in different ways to fulfil these functions. They can consist of mainly sand and provide a barrier to the contaminants of concern (CoCs) within the sediments due to the pure thickness of the cap. Sand caps have effectively contained CoCs and prevented exposure of the benthic and pelagic communities, however their large thickness can reduce hydraulic capacity, flood storage and navigable depth of the water body (EPA, 2013). To increase the effectiveness of the cap and reduce its thickness, active materials such as activated carbon or organophilic clay can be applied in bulk form to additionally bind or block contaminants from percolating the cap. These materials contribute especially to the primary function of the cap, chemical isolation. In a cap consisting of sand only, this function is only accomplished by the pure mechanical barrier provided which reduces diffusion velocity. The installation of light weight bulk material can be difficult as a longer descent in combination with currents or slopes can result in thinner active layers spread over a larger area. This type of cap has been tested in laboratory tests as well as in pilot and full scale projects which have been conducted in the USA (EPA, 2013).

A comparison of the three different designs is shown in Figure 1. One advantage of an active cap versus a sand cap is reduced thickness. Lab column testing and modelling illustrate that a thin layer of highly adsorptive material such as activated carbon can have over 100 times the adsorption capacity for PCBs (Polychlorinated Biphenyls) as a sand or organically-rich soil containing 3.8% carbon fraction (Murphy, et al., 2004).

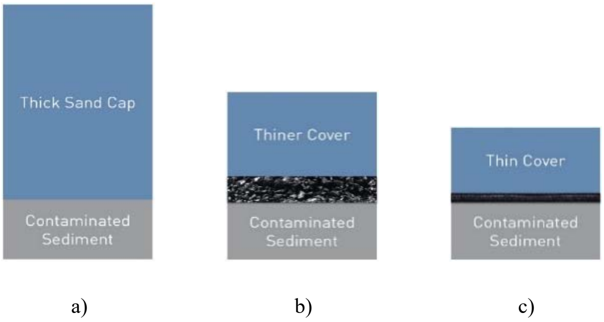

Figure 1. Comparison between three different designs for in-situ caps over contaminated sediments. a) sand cap; b) active cap with bulk active material and a protection layer of sand; c) active cap with active material as a part of an active geo-composite which ensures a constant cap thickness over the whole installation area.

The cap design process can be supported and evaluated using different modelling tools, which have already been developed. A very sophisticated one is CapSIM by Prof. Danny Reible of Texas Tech University. The model has unique capabilities for describing processes at the sediment-water interface including the interface specific processes of bioturbation, benthic mass transfer, consolidation, and deposition as well as advection, diffusion, linear and nonlinear sorption and reaction. The model can simulate behaviour in multiple sediment layers or sediment caps, including active caps (Reible, 2017).

3. ACTIVE GEO-COMPOSITES

Active Geo-Composites consist of one or multiple active materials (active layer), sandwiched between two geosynthetic layers (protection layers) as shown in Figure 2. These Geo-Composites allow accurate placement of amendments with low densities that could otherwise become suspended during placement.

Geo-composites also prevent the mixing of active materials with underlying sediments, allowing more uniform application and erosion protection. Some active materials enclosed in the geo-composite are buoyant. To ensure proper installation it is possible to use geotextiles with a higher specific gravity or to mix a fraction of sand with the active materials to create a mat can be easily installed under water.

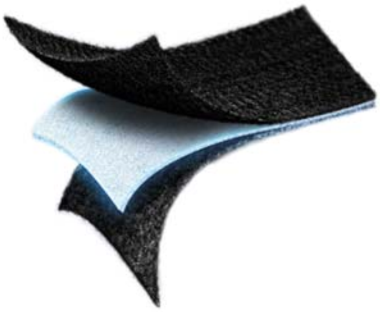

Figure 2. Exploded assembly drawing of an active geosynthetic composite. It consists of two black geotextile protection layers and the white active core layer.

Using active geosynthetic composites enables the installation of a layer of active materials faster, with more ease and as a safer process. A constant active layer thickness is ensured over the whole covered area, independent from currents or slopes; and as a consequence they increase the cap performance. A 10 mm thick active mat can theoretically replace 1 m of sand or soil, which helps maintaining the navigable depths and flow capacities of waterways (Olsta, et al., 2010). Additionally the used geotextiles can reinforce the whole cap performance as well as acting as a filtering layer, preventing mixing of different layers and allowing a uniform construction.

Another benefit of these products is that they are gas permeable. Although this sounds counterintuitive as the active geosynthetic composite is used to cap contaminants and keep them in place, the presence of gas formed below the cap that can lead to a burst and thus failure of the capping system. In a longer test conducted by the Naval Facilities Engineering Command in 2011 this was also tested. In the final report on the system was stated “The selected implementation method including a mat with sand cover is recommended as an effective technology to sequester contaminants in sediments while preventing uplift due to gas accumulation” (Hawkins, et al., 2011).

4. ACTIVE MATERIALS

The materials that can be used as an active layer in geosynthetic composites can vary. Mostly used are well-known products such as activated carbon that has been used in the chemical industry since the 1920s and organophilic clay, which is used in the oil and gas industry to treat oil contaminated process waters.

Activated carbon uses its large inner surface area to bind the contaminants via adsorption. This high surface area is a result of the microporous structure of the material which is roughly sketched in Figure 3. The percentage in which the different pore types occur depend especially on the base material. If this already has a fine carbon structure, like for example coconut shell then the manufactured activated carbon will have a larger amount of micro pores. A fine porous structure of course has its limitations against larger molecules, for example oil. These material can block the pore network and reduce the adsorption capacity. Other starting materials for activated carbon can be wood, bituminous coal or other materials with a carbon base structure.

Not only does activated carbon bind contaminants it also supports the biological degradation of the contaminants. Data show that granular activated carbon (GAC) was the most successful of the capping materials investigated and facilitated naphthalene degradation under oxic conditions (Pagnozzi, et al., 2017).

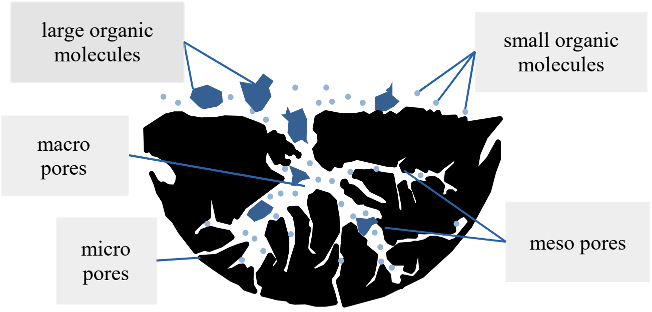

Figure 3. Micro porous structure of activated carbon. The different pores are classified by pore diameter. Macro pore > 50 nm, meso pore > 2 nm and < 50 nm, micro pore < 2nm.

Organophilic clays are surface-modified clays that have been shown to be effective adsorbents for insoluble and partially insoluble compounds like creosote or coal tar. The production of organophilic clays replaces the surface cation of bentonite or hectorite clay with an organic molecule. Quaternary amines based upon tallow are the most commonly used organic compound. The resulting clay is oleophilic, hydrophobic and permeable. A properly compounded organophilic clay will exhibit minimal swelling upon organic adsorption and maintain high permeability (Olsta, et al., 2010). In treatment of produced water from offshore crude oil production organophilic clays have removed polyaromatic hydrocarbons to non-detect levels (Darlington, 2002).

Another active material that can be used in an active geocomposite is calcium phosphate, available in different forms, to bind heavy metals by precipitation. Additionally there are potential applications for zeolites that are used in water treatment to remove nitrates and metals such as lead, zinc and copper (Thomas, et al., 1998). Zero valent Iron (ZVI) has also been successfully used in permeable reactive barriers for dechlorination of chlorinated hydrocarbons and the reductive precipitation of Chromium (VI) to Chromium (III) shows possible applications (Powell, et al., 2002).

5. ACCOMPLISHED AND RUNNING PROJECTS

At the former wood treatment plant run by McCormick & Baxter located at the Willamette River in Portland, Oregon, USA some 2300 m² of an active mat filled with organophilic clay were installed in 2005. Covering the sediments contaminated with PAHs (polycyclic aromatic hydrocarbons), diesel, creosote, pentachlorophenol and a variety of heavy metals (EPA, 2013).

The surrounding area to this remediation site is also subject to forthcoming further remediation. This area is part of the US EPA (US Environmental Protection Agency) Super Fund Site Program and the record of decision regarding the remediation of almost 10 miles (ca. 16 km) of the river has been released in January 2017. The remediation as currently planned will include 1.5 km² of capping and 7 km of river banks that either need dredging or capping or both (EPA, 2017).

6. CONCLUSION

The combination of geotextiles and active materials provides an additional solution for many kinds of environmental engineering projects. The contaminant binding features and the spectrum of active materials ranging from activated carbon, organophilic clay and zeolites to different polymers combined with the mechanical and chemical stability of geotextiles ensures an even broader field of application. Remediation of contaminated sediments using active geo-composite caps has been conducted successfully over the last years at different sites across the USA. In Europe capping projects have been conducted especially in Norway. The installed caps have mostly been conventional sand caps for example in the Oslo Fjord but also geotextile reinforced without active materials for example in the Odda Fjord were installed. With new production possibilities for active geo-composites in Germany this remediation technology for contaminated sediments might experience a boost in Europe over the next couple of years.

7. REFERENCES

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