In Situ Conditioning and Stabilisation of Dredging and Mineral Sludge

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ABSTRACT: Contaminated (in)organic sludges, coming from river bed sediments or from industrial production processes, are causing worldwide a large threat for humans and ecology. This is not only related to toxic compounds, but also to the large amounts of sludges that are disposed in landfills. Ex situ techniques are commonly practiced to obtain a better dewatering and consolidation of the sludges as pretreatment for disposal in new landfills. Reduction of the water concentration in the sludge would increase the geostability, decrease the leaching of toxic compounds and reduce the sludge volume in the landfill. This leads to an increased disposal capacity, which is of high economic importance, especially for dredging sludge and mine tailings.

In the ‘In situ sludge consolidation’ project, techniques will be studied and developed for the in situ consolidation and stabilization of inorganic sludges, both in landfills as directly in contaminated sediments. The ‘In situ sludge consolidation’ project is executed by a consortium which consists of 4 research centers (Flemish Institute for Technological Research, Catholic University of Leuven, University of Ghent and the Catholic University College of Ostend-Bruges), eight companies (MWH, ENVISAN, Rasenberg Milieu, DEME Environmental Contractors, Ghent Dredging, WVRB, Nyrstar and Tessenderlo Chemie) and two public organizations (Port of Antwerp and the Agency for Maritime and Coastal Services). This paper describes the objectives and specific research goals of the ‘In situ sludge consolidation’ project.
INTRODUCTION

Contaminated inorganic sludges are causing worldwide a large threat for humans and ecology. This is not only related to their often high contents of toxic compounds (heavy metals and organic pollutants), but also due to the huge amounts of sludges that need to be processed or disposed in landfills. Inorganic sludges originate from dredged river bed or harbour sediments and are also produced in several industrial processes (ferro, non-ferro, chemical and mining industry).

Inorganic sludges are often disposed in landfills and are generally characterized by high water contents and low geostability. These landfills are not always safe because of risks for leaching of the contaminants to the groundwater and every year several dam breakages result in large environmental disasters. Several *ex situ* techniques have been developed and are commonly practiced to obtain a better dewatering and consolidation of the sludges as pretreatment for disposal in newly created landfills. However, for existing landfills, *in situ* techniques for improved consolidation and dewatering of the sludge would be needed and very beneficial.

*In situ* dewatering and consolidation of sludge in existing landfills would increase the geostability, decrease the leaching of toxic compounds and reduce the sludge volume in the landfill. This leads to an increased disposal capacity, which is of high economic importance since finding new locations for landfills becomes more and more problematic. Worldwide, sediments in rivers and estuaries are also often highly contaminated with heavy metals and organic pollutants, which may represent a serious environmental and ecological risk. When these sediments do not need to be dredged for nautical purposes, there also arises a need for *in situ* sanitation techniques in order to reduce the risks of these contaminated sediments.

This paper describes the objectives and specific research goals of the ‘*In situ* sludge consolidation’ project which is executed in Flanders (Belgium) in the framework of the *Environmental Technology Platform* (MIP) since October 2007.

THE ‘IN SITU SLUDGE CONSOLIDATION’ PROJECT

The ‘*In situ* sludge consolidation’ project is executed by a consortium which consists of 4 research centers (the Flemish Institute for Technological Research (VITO), Catholic University of Leuven (KUL), University of Ghent (UGent) and the Catholic University College of Ostend-Bruges(KHBO)), eight companies (MWH, ENVISAN, Rasenberg Milieu, DEME Environmental Contractors, Ghent Dredging, WVRB, Nyrstar and Tessenderlo Chemie) and two public organizations (Port of Antwerp and the Agency for Maritime and Coastal Services).

In the ‘*In situ* sludge consolidation’ project, techniques will be studied and developed for the *in situ* consolidation and stabilization of inorganic sludges, both in landfills as directly in contaminated sediments. The *in situ* approach is based on injection of additives into the sludge in order to obtain improved dewatering and consolidation of the sludge and in order to immobilize the pollutants present in the sludge. A schematic overview of the approach for *in situ* sludge consolidation in a pond is shown in Figure 1.
FIGURE 1. Schematic overview of the approach for *in situ* sludge consolidation and stabilisation in a pond: (A) additives are injected into the pond for sludge dewatering and stabilization of the pollutants; (B) Removal of water after improved dewatering creates extra available volume, stabilization of pollutants reduces the risk of leaching to the groundwater; (C) extra volume can be used for additional sludge deposition; (D) improved geotechnical stability enables construction of buildings or a dike on top of the existing pond, creating additional volume for sludge deposition.
A first objective of the project is to study the effect of additives (flocculants, coagulants) on the dewatering and consolidation behaviour and the geotechnical stability of different types of sludges and sediments. Next to obtaining improved consolidation of the sludges, a second objective is to study chemical and biological techniques for stabilization or degradation of pollutants in the sludge. A third objective is to develop suitable injection systems for \textit{in situ} application of the additives. Finally, the \textit{in situ} consolidation techniques which have been developed on lab scale will also be demonstrated by pilot tests. The different research objectives will now be described more specifically.

**RESEARCH OBJECTIVES OF THE ‘IN SITU SLUDGE CONSOLIDATION’ PROJECT**

**Dewatering and consolidation of sludge.** The research at UGent (Laboratory of Geotechnics) will mainly focus on the effect of flocculants and coagulants on the dewatering and consolidation behaviour of sludges. The geotechnical behaviour of the sludges after consolidation will also be investigated. Different types of flocculants (organic, inorganic, anionic, cationic, non-ionic) will be tested on different types of sludges in order to get better understanding of their effect on sludge consolidation. The goals are to decrease the time for sedimentation and consolidation, to increase the final density and final shear resistance and to decrease the leachate production of the sludges. It is very important to consider that all of these purposes are not necessarily compatible between each other. The effect of different types of flocculants, amount of flocculant added, mixing method and initial density of the sludge are investigated for different sludge types based on the sedimentation parameters, large-strain parameters (small and medium sedimentation columns, SIC or seepage induced consolidation tests) and shear strength parameters. In a first phase of the research, the initial density of the sludge material is kept very low, making sure that all soil structures are destroyed before testing. In a second phase the impact of larger densities and of existing sub-structures on the behaviour of the sludge is examined. In the third and final phase UGent will study, in co-operation with the industrial partners, the impact of different mixing methods on the resulting sub-structures in the sludge. UGent (LabMET) will also investigate how gas formation during and after sludge consolidation can be prevented, since this can disturb the sedimentation and long-term consolidation behaviour after flocculant addition.

The research at KHBO is focused on the potential of a biological \textit{in situ} sludge consolidation technique, based on microbial encapsulation of the sludge into calcite in order to increase the dewatering of the sludge and to decrease the leaching of pollutants. In this microbial approach, ureolytic bacteria, either already present or added to the sludge, can convert added urea into ammonium and carbonate (Figure 2). Due to the pH increase the carbonate equilibrium in the sludge shifts to $\text{CO}_3^{2-}$, and in the presence of calcium ions, calcium carbonate precipitates are formed that will encapsulate the sludge. This may result in a stabilisation of the sludge and the pollutants present. KHBO will investigate the presence of these ureolytic bacteria in different sludge types and their activity by means of batch tests. The effect of the microbial encapsulation on sludge consolidation and stability will also be assessed.
Chemical and biological stabilisation and degradation of pollutants. Next to improving the consolidation of sludges, the project also aims at stabilising or removing toxic pollutants, in order to reduce their risks towards the environment. Dredging sludges or sediments are often contaminated with heavy metals and/or different types of organic pollutants (e.g. PAHs, PCBs, dioxins, TBT). Stabilisation of pollutants can be achieved through immobilization (e.g. heavy metals), by adsorption (e.g. organic pollutants) or by precipitation reactions (e.g. nutrients) and thus be stimulated by chemical additives. Degradation of organic pollutants could also be achieved both by biological processes or chemically induced processes (e.g. chemical oxidation or reduction).

The research objectives at KUL are (1) to examine whether biodegradation can be applied as a methodology to degrade organic contaminants in contaminated dredging sludge and (2) to examine the compatibility of sludge chemical consolidation/compaction methods with biodegradation activities in dredging sludge. The research focuses on anaerobic biodegradation of two groups of environmental pollutants: polycyclic aromatic hydrocarbons (PAHs) and chlorinated benzenes (CB). Under anaerobic conditions, CBs are mostly degraded by reductive dechlorination while PAHs are degraded by anaerobic oxidation. KUL will examine the potential for biodegradation of the organic contaminants in dredging sludge and the potential for stimulation of microbial activity in batch tests. Since the concentration measurements of naphthalene and phenanthrene can be associated with large errors and the degradation products (methane and CO$_2$) are not specific for these compounds (e.g. they can originate from biodegradation of organic matter present in the sludge), a different approach has to be applied to examine their biodegradation. Therefore, experiments with labeled compounds will be performed ($^{13}$C labeled naphthalene and probably $^{14}$C labeled phenanthrene). In these cases, the production of labeled methane and CO$_2$ will be indicative for biodegradation.

VITO will investigate the potential for degradation of organic pollutants and the immobilization of heavy metals by means of chemical additives. Chlorinated organic compounds (e.g. VOCIs, PCBs) can be dehalogenated to less toxic or harmless compounds by means of chemical reduction (biological or chemical). Several organic compounds like PAHs, BTEX and chlorinated compounds can be removed by in situ chemical oxidation techniques (oxidation with Fentons reagent, permanganate, persulfate, etc.). The potential and efficiency of different chemical in situ oxidation and
reduction techniques will be evaluated for the degradation of organic pollutants in different sludges and sediments by means of lab-scale batch tests. The potential of several chemical additives to stimulate immobilisation of heavy metals chemically or biologically (*in situ* bioprecipitation by sulphate reducing bacteria) will also be investigated. Since sludges and sediments are often contaminated both by organic pollutants and heavy metals, the effect of additives for *in situ* chemical oxidation on the stability of heavy metals will also be evaluated by means of column tests.

**In situ injection techniques and pilot tests.** In this part of the project, different *in situ* injection techniques will be compared and evaluated in large scale pilot tests executed in sludge depots. It will be investigated what the influence of the injection techniques is on (1) the original structure of the sludge, (2) the distribution of the additives on micro- and macro-scale and (3) the properties or stability of the additive. The injection techniques that will be evaluated include in situ fracturing, SSI (Soft Soil Improvement) and in line injection. Finally, the optimal combinations of additives as determined in the batch tests will be tested and demonstrated in a large scale pilot test in sludge depots.