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Research article

Evaluation of hydrocyclone and post-treatment technologies for remediation of contaminated dredged sediments

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ABSTRACT

There are many disposal and treatment methods for contaminated dredged sediments, depending on their properties. In this study, treatment methods for the remediation of dredged sediments as well as the reduction of pore water generated from dredged sediments were optimized. The efficiency of separation using hydrocyclone as the pre-treatment increased with greater inflow velocity of hydrocyclone, deeper insertion of the vortex finder, and smaller hydrocyclone diameter. In the post-treatment of hydrocyclone overflow, the chemical coagulation and membrane filtration methods had high efficiency with regard to the removal of solid and organic compounds, but the former was less feasible, due to its excessive operation and sludge disposal costs. The membrane filtration was easily applicable in the field, based on its convenience of installation and lower cost of operation despite low removal efficiency of trace organic contaminants.

1. Introduction

Contaminants in rivers and lakes often accumulate in the sediment and are extracted back into the water through physiochemical and biological reactions, such as dispersion, resuspension, and bioturbation. These contaminants directly or indirectly affect the water ecosystem and water quality (Abrams and Jarrell, 1995; Santschi et al., 1990; US EPA, 1993). As contaminants and soil are discharged due to rainfall, the accumulation of contaminated sediment rises. The overflow and degradation of water quality due to poor control of rivers also increase the accumulation of contaminated sediment (Chung et al., 2009; Devault et al., 2009; Jones and Knowlton, 2005; Wildi et al., 2004).

Particularly, in Korea, 18,687 small impoundments have been estimated to exist for agricultural purposes, most of which experience more rapid vertical accretion and loading of contamination (Korea Ministry of Environment (2007). Thus, to recover the water storage capacity and reduce the contamination in small reservoirs (impoundments), the sediments must be remediated.

Generally, contaminated sediment is remediated through dredging, natural attenuation, biological/chemical treatment, solidification/stabilization, and capping (US Army, 2000; US EPA, 1993; Mulligan et al., 2001). Of these methods, the removal of contaminated sediments by dredging is inherently preferential, because it is perceived to mitigate future environmental risks. In particular, the contaminated sediments sometimes contained the pesticide, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) (Koh et al., 2004; Zhang et al., 2004; Echols et al., 2008). These compounds have been suspected to cause a variety of adverse effects, including hormone-dependent cancers, compromised reproductive fitness, and abnormal reproductive system development in wildlife and humans (Tyler et al., 1998; Giesy and Kannan, 1998).

Unlike securing a waterway by sediment dredging, dredging contaminated sediment requires advanced treatment techniques to reduce the contaminant source from sediment. Because contaminated sediment by dredging is classified as hazardous waste and because its disposal is expensive, reducing such contamination levels is cost-effective (US Army, 1987; US EPA, 1992, 2005).

The remediation of dredged sediments comprises a pretreatment to separate solids and liquids and the primary treatment to reduce contamination levels. Pretreatment methods include slurry injection, dehydration, and particle separation. There were a few

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commercial facilities for dehydration such as Volute (Amcon Co., Japan) and Nemeau (Sedigate Co., France). However, the most common method that is based on solid–liquid separation is the use of a hydrocyclone. A hydrocyclone uses centrifugal force to separate solids from liquid streams (Svarovsky, 2000). It has no moving parts, operates simply, has less space requirements, and is a less expensive device. Many groups have tried to improve the efficiency of the hydrocyclone for solid–liquid separation (He et al., 2013; Liu et al., 2015a; Silva et al., 2015; Vieira and Barrozo, 2014; Wu et al., 2012). The application of hydrocyclone on sediments has been reported by several researchers (Liu et al., 2015b; Park et al., 2006; Park et al., 2013; Yan et al., 2014). Especially, Park et al. (2006) reported the volume reduction ratio of dredged sediments by hydrocyclone was approximately 90% (v/v) and 60% of chemical oxygen demand (COD) and volatile solids were separated at operating pressure of 250 kPa. However, hydrocyclone must be customized to match the cut size or reach the desired capacity according to the characteristics of sediments.

The primary treatment step includes thermal treatment, chemical treatment, extraction, and physical treatment. Thermal desorption is the most effective technology for destroying organic compounds, but it requires high investment cost (Kribi et al., 2012; Reis et al., 2007). Chemical treatments are divided into chelation, dechlorination, oxidation, and coagulation, of which the latter is the most effective process that is applicable toward the suspension that is generated from solid–liquid separation.

Chemical treatment is safer and more convenient than biological treatment and can be used to remove phosphorus and organic and floating matter (Rulkens, 2005). Also, Pétavy et al. (2009) reported that the attrition scrubber can be removed fine particles and contaminants from stromwater sediment. However, it has a higher operating cost than biological treatment, because it needs chemical agents and requires excessive sludge to be disposed. The most cost-effective physical process is microfiltration, which has the benefit of particle-associated contaminant removal (Averett et al., 1990). This process is advantageous, effecting stable removal of suspended solids and having lower operational cost—it requires no settling chemicals and less sludge to be disposed. Until now, there was little information or research about the removal capacity of contaminants (pesticide, PAHs and PCBs) in dredged sediments by the combined process of hydrocyclone and physical/chemical treatment.

In this study, the separation of pore water generated from dredged sediments using a hydrocyclone as pretreatment was examined, based on various design factors. Also, chemical coagulation and membrane filtration were evaluated to remove various contaminants (organics, nutrients, pesticide, PAHs, and PCBs) as primary treatments under several operational factors and compared to determine the most desirable technology.

2. Materials and methods

2.1. Preparation of sediments

Standard screens (ASTM, 1969) with average particles sizes of 1.5, 0.86, 0.61, 0.46, 0.36, 0.26, 0.16, 0.08, 0.05, and 0.03 mm were used to measure the separation of particles in artificial sediments under various pressures, flow velocities, and specifications of the hydrocyclone. Sediments with average particles sizes of 1.5 mm, 0.86 mm, 0.61 mm, 0.46 mm, 0.36 mm, 0.26 mm, 0.16 mm, 0.08 mm, 0.05 mm, and 0.03 mm were fabricated and used. The specific gravity of the collected sediment was 2.51, which was passed through a 500-μm standard screen to prepare a sample with a total solid concentration of approximately 3%. Experimental results using raw sediments cannot be easily reproduced due to site-specificity and variable composition when take at different times. Furthermore, the separation efficiency of hydrocyclone can be exactly evaluated because artificial sediment had the same physical features.

Raw sediments were collected from Shingal Lake (Yongin, Korea) using a grab sampler and core sampler. The grab sampler was made of stainless steel, and the core sampler comprised a acryl-based body and a stainless steel-based core head. Acryl tubes were equipped inside the core sampler to take sediment samples easily. The average concentration of heavy metals in dredged sediment was Cd 1.04, Cr 10.2, Cu 73.4, Mn 29.7, Hg 1.54, Zn 136, and Fe 295 mg/kg, respectively. Also, diazinon, alachlor, and phosmet were detected below 0.122 mg/kg and parathion, quintozene, dichlorane, and polyvinyl chloride were little detected. Based on these results, there is no consideration for the removal of heavy metal and micro-pollutants. Also, average pH in dredged sediments was 5.8. The average total chemical oxygen demand (TCOD), total suspended solid (TSS), total nitrogen (TN), and total phosphorus (TP) was 6.1, 162.8, 1.2, and 0.8 g/L, respectively.

2.2. Hydrocyclone-based process

Fig. 1 shows the schematics of the hydrocyclone and post-treatment system. To determine the optimal design factors and operating conditions for the dredged sediments, we fabricated hydrocyclone #1 (inner diameter and height of cylinder section: 100 mm and 100 mm; inner diameter of inlet nozzle: 28 mm; and cone angle: 9.5°) and #2 (inner diameter and height of cylinder section: 50 mm and 50 mm; inner diameter of inlet nozzle: 7.8 mm; and cone angle: 9.5°). In addition, the depth of the vortex finder was made to be adjustable to measure treatment efficiency by depth of the vortex finder, and the height of the cylinder section was made to be extendable to an additional 100 mm.

A centrifugal pump with a 250-L/min capacity and a 32-m head was used to feed dredged sediments into the hydrocyclone, and a pressure gauge and flowmeter were installed. Ball valves were installed ahead of the flowmeter and after the centrifugal pump to control flow rate. The hydrocyclone was installed on top of the gravity clarifier to allow the overflow that was discharged through the vortex finder and the underflow that was discharged through the apex to the concentrated solid tank.

2.3. Treatment of overflow discharged from hydrocyclone

Although the hydrocyclone had high separation efficiency of liquid–solid matter in the dredged sediment, the overflow of the hydrocyclone still contained high levels of suspended solids (SS). Because high SS levels can decrease the efficiency of the secondary process, such as chemical coagulation and membrane filtration, SS levels in the overflow that was discharged from the hydrocyclone were reduced using a gravity clarifier (retention time: 30 min). In addition, we investigate the removal of PCB, PAH and pesticide using both processes.

2.3.1. Chemical coagulation

In removing the floating matter and COD matter in water that was discharged during the pretreatment, we examined the efficiency of coagulation and precipitation. The jar test was performed to determine the appropriate coagulant and its optimal quantity using a 6-paddle stirrer (Miyamoto Co., LTD) in 1-L jars under the following conditions: mixing at 200 rpm for 10 min, settling for 20 min, and decantation. Four inorganic coagulants—alum, ferric chloride, ferric sulfate, and polyaluminum chloride (PAC)—were used for the coagulation.