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Dewaterability of five sewage sludges in Guangzhou conditioned with Fenton's reagent/lime and pilot-scale experiments using ultrahigh pressure filtration system

Jialin Liang [a, b, 1], Shaosong Huang [a, b, 1], Yongkang Dai [a, b], Lei Li [a, b], Shuiyu Sun [a, b, *]

[a] School of Environmental Science and Engineering, Guangdong University of Technology, Guangzhou 510006, China
[b] Key Laboratory of Resources Comprehensive Utilization and Cleaner Production, Guangdong University of Technology, Guangzhou 510006, China

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ABSTRACT

Sludge conditioning with Fenton's reagent and lime is a valid method for sludge dewatering. This study investigated the influence of different organic matter content sludge on sludge dewatering and discussed the main mechanism of sludge conditioning by combined Fenton's reagent and lime. The results indicated that the specific resistance to filterability (SRF) of sludge was reduced efficiently by approximately 90%, when conditioned with Fenton's reagent and lime. Through single factor experiments, the optimal conditioning combinations were found. In addition, the relationship between VSS% and consumption of the reagents was detected. Furthermore, it was also demonstrated that the SRF and filtrate TOC values had a significant correlation with VSS% of sludge (including raw and conditioned). The main mechanism of sludge dewatering was also investigated. Firstly, it revealed that the dewaterability of sludge was closely correlated to extracellular polymeric substances (EPS) and bound water contents. Secondly, the results of scanning electron microscopy (SEM) stated that sludge particles were to be smaller and thinner after conditioning. And this structure could easily form outflow channels for releasing free water. Additionally, with the ultrahigh pressure filtration system, the water content of sludge cake conditioned with Fenton's reagent and lime could be reduced to below 50%. Moreover, the economic assessment shows that Fenton's reagent and lime combined with ultrahigh pressure filtration system can be an economical and viable technology for sewage sludge dewatering. Finally, three types of sludge were classified: (1) Fast to dewater; (2) Moderately fast to dewater; (3) Slow to dewater sludge.

1. Introduction

Municipal wastewater treatment plants (WWTPs) produce large amounts of sludge commonly containing over 95% water. Large amount of sludge has been a great trouble and raised significant concerns in China (Yang et al., 2015). To reduce the cost of treatment and disposal, it is necessary to reduce the sludge volume, making reduction of sludge produced and improving the dewaterability of paramount importance (Colin and Gazbart, 1995; Neyens and Baeyens et al., 2003a, 2003b; Zhang and Yang, 2014; Ning and Chen, 2014). Sludge dewatering is generally achieved through pretreatment with an inorganic coagulant or a synthetic polyelectrolytes, such as polyacrylamide (PAM), followed by centrifugation or filter pressing. However, these methods can only achieve 75–80% water removal. Furthermore, the PAM is expensive and can cause secondary pollution (Chang and Abu-Orf, 2005; Ho and Norli, 2010; Citeau and Larue, 2011). Physical conditioners including coal fine, fly ash and gypsum are commonly used to reduce the compressibility of sludge. But more often the addition of a physical conditioner follows coagulation or flocculation with a chemical conditioner. So it has some limitations (Qi et al., 2011).

Abbreviations: DS, dry solids content; PSs, polysaccharide; PNs, protein; RS, raw sludge; CST, capillary suction time; DSC, differential scanning calorimetry; EPS, extracellular polymeric substances; SEM, scanning electron microscope; SRF, specific resistance to filterability; TOC, total organic carbon; TSS, total suspended solids; VSS, volatile suspended solids; SCOD, soluble chemical oxygen demand; TCOD, total chemical oxygen demand; WWTPs, wastewater treatment plants; VSS/TSS%, organic matter contents.

* Corresponding author. School of Environmental Science and Engineering, Guangdong University of Technology, Guangzhou 510006, China.
E-mail address: sysun@gdut.edu.cn (S. Sun).

[1] Co-first authors contributed equally to this work.

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However, Neyens and Baeyens et al. (2003a, 2003b) advocated over a decade ago that Fenton oxidation was effective for dewatering. Fenton's reagent is a mixture of ferrous iron, and H_2O_2 with the former catalyzing the decomposition of the latter, to yield highly reactive hydroxyl radicals. The generated radicals react on the surface of the sludge, subsequently reducing the volume of the sludge. Since then, numerous researchers have studied sludge detwatering by Fenton oxidation. For instance, Buyukkamaci (2004) reported that sludge dewatering was optimal at dosages of 5000 mg/L Fe^{2+} and 6000 mg/L H_2O_2. Dewil and Baeyens (2005) stated that Fenton peroxidation improved the dewaterability and drying of waste activated sludge. Debowski and Zielinski (2008) showed that the application of the Fenton method to the conditioning process enhanced the sludge. Recently, Liu and Yang (2012) found that sludge conditioning with a combination of Fenton's reagent and skeleton builders was an efficient means to achieve deep dewatering. Fenton treatment resulted in partial destruction of extracellular polymeric substances (EPS) and decreases in sludge floc size. Subsequently, lime and Portland cement were added to serve as skeleton builders and transmit the stress to the internal parts of floc and provided channels for water release under high pressures (Liu and Yang, 2013). Therefore, sludge conditioning with Fenton's reagent and skeleton builders has been shown to be a valid method for sludge dewatering.

Recently, the mechanism of sludge dewatering has become the focus of the researches in this area. Many investigations have been conducted on the role of EPS in bioflocculation and dewaterability. Li and Yang (2007) demonstrated that EPS was essential to sludge-floc formation. However, excessive EPS could weaken cell attachment and the floc structure, resulting in limited dewaterability. EPS produced by sludge microorganisms played a definite role in sludge flocculation (Bala Subramanian and Yan, 2010). From these, sludge dewaterability is related to EPS content. Alternatively, some researchers focus on the bound water. Vaxelaire and Cézac. (2004) reported that the behavior of a molecule of water during the dewatering process was widely dependent on its proximity to the solid. Bound water was generally considered a gross estimate of several states of water including vicinal (or surface) water, water of hydration and interstitial water. Zhang and Yang (2014) clearly showed that bound water was released and converted into free water due to the degradation of EPS. Thus, mechanistic study of the sludge dewatering would be beneficial to sludge dewatering technological advances.

Pilot-scale experiments are used to verify the laboratory results. Zhang and Yang (2015) and Liu and Yang (2013) operated the pilot-scale filter press dewatering experiment for Fenton treatment. However, these experiments might lack of representativeness due to the limitations of their dewatering equipment. In previous studies, the pressure of the common pressure filtration was lower than 2Mpa and it did not reach the high pressure requirements, which will cause dewatering incompletely. In order to simulate the real industrial condition and obtain better results, a novel spring pressure filtration was utilized in the pilot-scale experiments. The ultrahigh pressure filtration could achieve pressure to 40Mpa, which further improved the sludge dewatering rate and dewatering efficiency.

Generally, the organic content of sludge differs between WWTPs. Although many experiments have proved that Fenton's reagent and skeleton builders are effective for sludge dewatering, but few researchers studied the consistency of this dewatering effect across sludges of various composition. Furthermore, many previous studies indicated that sludge dewaterability could be greatly improved via peroxidation, but the responsible mechanism was not fully reported. Hence, this study systematically researched dewaterability of variously composed sewage sludge via conditioning with a combination of Fenton's reagent and lime. Specific objectives of this study were to: (1) conduct single factor tests in sludges containing different levels of organic matter conditioned with Fenton's reagent and lime to find out the optimal conditioning combination; (2) get more comprehensive insights into the respective roles of reagents in sludge containing different amounts of organic matter and research the inner connection between VSS% and SRF or TOC; (3) investigate the dewatering mechanism of the EPS, bound water content, wastage rate (iron, calcium) and the morphological structure of the sludge; (4) conduct pilot-scale experiments with ultrahigh pressure filtration system and verify the feasibility of these sludge treatment technology; (5) show a schematic changes in sludge flocs treated with Fenton's reagent/lime and then construct different types of sludge models.

2. Materials and methods

2.1. Materials

2.1.1. Raw sludge

Raw sludge (RS) samples were collected from the secondary sedimentation tanks of five different municipal WWTPs (GZ-1, GZ-2, GZ-3, GZ-4 and GZ-5) across Guangzhou, China from August to October, 2014 (Fig. S1). The various WWTPs are summarized in Table 1. Before being used in the tests, the sludge sample was settled by gravity for about 12 h to increase the concentration (water content about 95%). Since the characteristics of sludge are volatile, two batches of fresh sludge were used from each plant. All the experiments were completed within 3 days and the sludge was placed in a freezer at 4 °C. The main characteristics of the RS are listed in Table 2.

In the WWTPs of China, A/A/O process is a widely used technology and the ratio of WWTPs that choose A/A/O was 25.45% (Jin and Zhang, 2014). Therefore, we researched sludge samples of municipal WWTPs, which chose A/A/O process. And the combined total effluent volume in WWTPs of GZ-1, GZ-2 and GZ-3 accounts for more than 50% of the total wastewater volume from Guangzhou. In order to obtain more information about other types of sludge in Guangdong that makes the research comprehensively, the other two sludge types (GZ-1 and GZ-5) were also collected separately.

As shown in Table 2, the sludge samples (GZ-1, GZ-2, GZ-3, GZ-4 and GZ-5) represent different organic matter content sludge. The reason of the difference might be associated with the influent COD_{Cr} concentration (Table 1). Municipal WWTPs (GZ-1) was located in suburbs of Guangzhou and the different influent COD_{Cr} was relatively low. Municipal WWTPs (GZ-5) was located in Huadu, which was the automobile manufacturing center, so the influent COD_{Cr} was high because of 10%–15% industrial wastewater. And municipal WWTPs (GZ-2, GZ-3, GZ-4) were located in urban center, which almost 98% of the wastewater was domestic, so the influent COD_{Cr} concentration was relatively high.

2.1.2. Conditioner

In Fenton experiments, H_2SO_4 (analytical grade, Guangzhou Chemical Reagent Factory, China) was used to adjust the initial pH of sludge. Fenton's reagent was prepared by mixing a solution of $FeSO_4 \cdot 7H_2O$ (50 wt.%) (analytical grade, Damao Chemical Reagent Factory, China.) with H_2O_2 (30 wt.%) (analytical grade, Guangzhou Chemical Reagent Factory, China). Lime (analytical grade, Tianjin Fuchen Chemical Reagents Factory, China) was used as a neutralizer and also a skeleton builder.

2.2. Sludge conditioning and dewatering

2.2.1. Laboratory-scale investigations

Initially, 300 mL of sludge samples were carefully transferred to