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Dewatering sewage sludge by a combination of hydrogen peroxide, jute fiber wastes and cationic polyacrylamide

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ABSTRACT

This study reported an effective method of using hydrogen peroxide (H_2O_2), jute fiber (JF) wastes and cationic polyacrylamide (CPAM) to precondition sewage sludge to improve its dewatering performance. The sludge preconditioned with H_2O_2, JF and CPAM showed better dewatering performance than the sludge that preconditioned with JF and CPAM and the sludge that preconditioned with CPAM alone. The sludge preconditioned with JF and CPAM showed better dewatering performance but worse settling performance than the sludge that preconditioned with CPAM alone. The filter cake moisture and SRF decreased with JF and CPAM dosages at 2 kg t^{-1} and 300 kg t^{-1} respectively and a rising H_2O_2 dosage below 100 kg t^{-1} but increased when H_2O_2 dosage was above 100 kg t^{-1}. The dewatering performance of sewage sludge was significantly improved by three factors: 1) the release of the bound water and intracellular water of sludge cells caused by H_2O_2; 2) the porous and low compressible structure of the sludge filter cake formed by CPAM, the sludge particle and JF; and 3) the strong, long and hollow structure of JF. The combination of H_2O_2, JF and CPAM was ideal for sludge dewatering, which contributed to filter cake incineration and JF wastes reutilization.

1. Introduction

A huge amount of wastewater has been produced due to the rapid growth of the population and the industrialization in recent decades (Kelessidis and Stasinakis, 2012; Fu et al., 2015; Li et al., 2016). In order to degrade and remove the high content of chemical oxygen demand (COD), nitrogen, and phosphorus, wastewater is always treated by the biological method (Choi and Kwon, 2015; Christensen et al., 2015). High water content of the generated sludge leads to high cost of the subsequent sludge transportation and utilization (e.g. land application, sanitary landfill, incineration and being used as the building material) (Kurade et al., 2014; Yang et al., 2015; Sun et al., 2015), thus the sludge dewatering process is very important.

Sludge dewatering is difficult due to the high compressibility and the low permeability of the sludge filter cake during the filtration process (Qi et al., 2011). Physical conditioners are known as skeleton builders or filter aids, which can reduce the compressibility meanwhile improve the mechanical strength and permeability of the filter cake when the sludge is compressed (Mowla et al., 2013). Physical conditioners like the cement kiln dust (Benítez et al., 1994), lime (Hwa and Jeyaseelan, 1997), diatomite (Jing et al., 1999), gypsum (Zhao, 2006; Shi et al., 2014), fly ash (Wang and Viraraghavan, 1998; Chen et al., 2010), sludge incineration slag (Ning et al., 2013) and zeolite (Shi et al., 2014) have been used to improve the dewatering performance of the sludge. However, they are problematic considering the slag generated from the filter cake incineration. By contrast, carbonaceous physical conditioners, e.g. coal (Albertson and Kopper, 1983; Thapa et al., 2009), bagasse (Benítez et al., 1994; Srivastava et al., 2005), pyrolysed domestic refuse (char) (Smollen and Kafaar, 1997), wood chips and wheat dregs (Jing et al., 1999; Lin et al., 2001), activated carbon (Fang et al., 2006), sawdust (Luo et al., 2013) and synthetic fiber (Nittami et al., 2015) are more suitable to preconditioning the sludge when the filter cake is used for incineration considering their higher porosity, higher calories and lower ash content (Mowla et al., 2013). In addition, sludge containing large amounts of long fibers has better dewatering performance because of the better

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structural rigidity (Nittami et al., 2015).

However, physical conditioners can just reduce the filter cake moisture for a certain extent as reported in the literature, a large amount of physical conditioners were needed to get a lower filter cake moisture (Lin et al., 2001; Luo et al., 2013). It has been proved that hydrogen peroxide (H_2O_2) was able to degrade extracellular polymer substances (EPS), subsequently release the bound water and led to the lysis of the sludge cells to release intracellular water (He et al., 2015). It is possible to improve the dewaterability of the sludge by preconditioning the sludge with H_2O_2 before physical and chemical conditioners were added. Moreover, a few studies have shown that bacterial species in the sludge correlate with the filtration properties of the sludge and these studies showed that the abundance of filamentous bacteria could impair the filtration properties (Kim and Jang, 2006; Meng et al., 2006, 2007; Pan et al., 2010; Gil et al., 2011). While Bugge et al. (2013) found that bacterial species forming strong microcolonies such as *Nitrospira* and *Accumulibacter* had good flocculation and filtration properties. The bacteria species in the sludge should be determined to investigate the potential effects of them on sludge dewatering.

In view of its main components (cellulose, hemicellulose and lignin) and its porous and long fibered structure, the jute fiber (JF) can be a good carbonaceous physical conditioner to improve the sludge dewatering performance. In addition, the JF is widely used as the textile material and occupies the second place of the cellulosic fiber throughout the world (Cai et al., 2000). Each year, a lot of JF wastes is generated but without effective reutilization. Reutilizing the JF wastes as carbonaceous physical conditioner can reduce the disposal expense of both the JF wastes and the sludge. Thus, JF wastes satisfy the standards as Devlin et al. (2011) proposed to evaluate a physical conditioner that technical reliability, cost, environmental sustainability and environmental nuisance.

This study investigated the settling and dewatering performances of the sludge that preconditioned with the CPAM alone, the sludge that preconditioned with the JF and the CPAM, and the sludge that preconditioned with H_2O_2, the JF and the CPAM. The supernatant volume, special resistance to the filtration (SRF), filter cake moisture, changes on the filter cake structure, the compression height of the filter cake, the nucleic acid concentration in the EPS, and the main bacteria species in the sludge were tested. The possible mechanism of the JF and H_2O_2 on improving the sludge dewatering performance was speculated.

2. Materials and methods

2.1. Test materials

Sludge samples used in this study were collected from the sludge thickener at Xinjiang Wastewater Treatment Plant (Shanghai, China). All the sludge samples were transferred to our laboratory within 3 h after sampling and stored at 4 degrees Celsius (°C). A desired amount (5L) was taken from the refrigerator 4 h before the tests to warm to around 18 °C. Moreover, the sludge was stirred before each test. The characteristics of the experimental ones were analyzed as follow: dry solid content, 22.0 ± 0.4 g L^{-1}; supernatant volume, 5% ± 0.5 mL (per 100 mL).

The JF wastes was obtained from Anji Jute Textile Plant (Zhejiang, China) and made into small pieces (0–3 mm) by crushing for 30 s in a disintegrator (FW100, Taisite Instrument Co., Ltd., Tianjin, China). The water content of the JF was 6% ± 0.3%.

The CPAM (FO4240SSH, INF FLOERGER, Andrézieux, France) and H_2O_2 (Huikang Industrial Co., LTD, Nanchang, China) were used as chemical conditioner and oxidizing agent to precondition the sewage sludge. The CPAM and H_2O_2 solutions were prepared freshly in deionized water at a mass concentration of 0.05% and 3% respectively.

2.2. Sludge preconditioning

The dosages of the JF, the CPAM or the H_2O_2 were expressed as the weight ratio to the sludge dry solids (kg t^{-1}).

2.2.1. Sludge preconditioning with CPAM

A certain dosage of the CPAM (0.5 kg t^{-1}, 1 kg t^{-1}, 1.5 kg t^{-1}, 2 kg t^{-1}, 2.5 kg t^{-1}, and 3 kg t^{-1}) was added to a 1000 mL beaker containing 400 mL sludge.

The mixture was stirred at 300 revolutions per minute (RPM) for 2 min with a stirrer (HJ-4A, Guohua Electric Appliance Co., Ltd, Changzhou, China), and then at 60 RPM for another 1 min.

2.2.2. Sludge preconditioning with JF and CPAM

A rising JF dosage (50 kg t^{-1}, 100 kg t^{-1}, 150 kg t^{-1}, 200 kg t^{-1}, 250 kg t^{-1}, and 300 kg t^{-1}) was added to 400 mL sludge in a 1000 mL beaker. The mixture was stirred at 300 RPM for 2 min before 2 kg t^{-1} of the CPAM (determined in 2.2.1) was added, then the mixture was again stirred at 300 RPM for 2 min and at 60 RPM for another 1 min.

2.2.3. Sludge preconditioning with H_2O_2, JF and CPAM

A certain dosage of the H_2O_2 (50 kg t^{-1}, 100 kg t^{-1}, 150 kg t^{-1}, 200 kg t^{-1}, 250 kg t^{-1}, and 300 kg t^{-1}) was added to 400 mL sludge in a 1000 mL beaker. The mixture was stirred at 100 RPM for 10 min and still standing for another 50 min before 300 kg t^{-1} of the JF (determined in 2.2.2) was added, then the mixture was stirred at 300 RPM for 2 min, followed by adding 2 kg t^{-1} of the CPAM (determined in 2.2.1). Then the mixture was again stirred at 300 RPM for 2 min and at 60 RPM for another 1 min.

2.3. Sludge settling and dewatering

100 mL of the preconditioned sludge was poured into a 100 mL cylinder and the supernatant volume was recorded after 30 min settling. Meanwhile, 300 mL of the preconditioned sludge sample was poured into a Buchner funnel (diameter, 90 mm) and filtered under 0.8 bar vacuum pressure (Fig. S1). The filtration time and the filtrate volume were recorded for 1 h when the latter kept relatively stable over time. The settling performance of the sludge was evaluated through the supernatant volume after settled for 30 min while the evaluation of the sludge dewatering performance was through the filter cake moisture and the specific resistance to the filtration (SRF):

$$M = \frac{W_2}{W_1} \times 100\% \tag{1}$$

where M is the filter cake moisture, W_1 is the weight of wet sludge filter cake and W_2 is the weight of sludge filter cake after drying at 105 °C for 8 h with a hot plate (SKML-2-4, Zhongxingweiye Instrument Ltd., Beijing, China);

$$SRF = \frac{2PA^2b}{\mu\omega} \tag{2}$$

where SRF is the specific resistance to the filtration (m kg^{-1}), P is the filtration pressure (N m^{-2}), A is the filter area (m^2), b is the slope of the filtrate discharge curve (t V^{-1} versus V, s m^{-6}), μ is the viscosity of the filtrate (N s m^{-2}), ω is the weight of cake solids per unit of filtrate (kg m^{-3}).