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Effects of different sludge disintegration methods on sludge moisture distribution and dewatering performance

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ABSTRACT

A key step in sludge treatment is sludge dewatering. However, activated sludge is generally very difficult to be dewatered. Sludge dewatering performance is largely affected by the sludge moisture distribution. Sludge disintegration can destroy the sludge structure and cell wall, so as change the sludge floc structure and moisture distribution, thus affecting the dewatering performance of sludge. In this article, the disintegration methods were ultrasound treatment, K_2FeO_4 oxidation and $KMnO_4$ oxidation. The degree of disintegration (DD_{COD}), sludge moisture distribution and the final water content of sludge cake after centrifuging were measured. Results showed that three disintegration methods were all effective, and K_2FeO_4 oxidation was more efficient than $KMnO_4$ oxidation. The content of free water increased obviously with K_2FeO_4 and $KMnO_4$ oxidations, while it decreased with ultrasound treatment. The changes of free water and interstitial water were in the opposite trend. The content of bounding water decreased with K_2FeO_4 oxidation, and increased slightly with $KMnO_4$ oxidation, while it increased obviously with ultrasound treatment. The water content of sludge cake after centrifuging decreased with K_2FeO_4 oxidation, and did not changed with $KMnO_4$ oxidation, but increased obviously with ultrasound treatment. In summary, ultrasound treatment deteriorated the sludge dewaterability, while K_2FeO_4 and $KMnO_4$ oxidation improved the sludge dewaterability.

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Introduction

Activated sludge process has long been the standard method for sewage treatment with the production of large amounts of excess biomass in the form of activated sludge (Kim et al., 2013). The expense for the treatment of the excess sludge has been estimated to be as much as 50%–60% of the total expense of wastewater treatment plant (Nowak, 2006). However, the high water content and biological gel structure properties of sludge lead to difficulties in dewatering (Zhang et al., 2012a), so appropriate sludge pretreatment technologies should be chosen prior to dewatering. Disintegration is a common pretreatment

method for sludge, which can destroy the sludge floc structure and releases the cell and EPS contents into the liquid phase.

Several disintegration methods have been investigated. Physical methods included ultrasound treatment (Tiehm et al., 2001), mills treatment (Kampas et al., 2007), homogenizer treatment (Müller et al., 1998), and thermal treatment (Eskicioglu et al., 2006). Chemical methods included ozone treatment (Dytchak et al., 2007), acid or alkali treatment (Lin et al., 1998), K_2FeO_4 treatment (Ye et al., 2012a), and $KMnO_4$ treatment (Wu et al., 2014). Biological treatment included the addition of microorganism or enzyme (Guellil et al., 2001). In addition, there are some combined methods including alkaline-thermal hydrolysis (Sawayama et al., 1996), photo-Fenton

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reaction (Tokumura et al., 2007), alkaline-ultrasonic pretreatment (Kim et al., 2010), and alkaline + high pressure homogenization (Zhang et al., 2012b).

The sludge floc structure was destroyed in the process of disintegration, so the sludge dewaterability was influenced at the same time. Besides, the representation of the moisture distribution within sludge has always been (and it is still) considered to be essential for the examination of dewatering problems (Vaxelaire and Cézac, 2004). Kopp and Dichtl (2000, 2001) proposed the existence of a correlation between the moisture distribution in sludge and the efficiency of sludge dewatering in full-scale process. Smollen (1990) stated that commonly used dewaterability measurements did not appear to be linked to moisture retention characteristics with centrifuged sludge samples. Barber and Veenstra (1986) tried to research the relationship between the sludge volume index and water distribution but found nothing, while Robinson and Knocke (1992) reported that there were some potential relationships between the sludge water distribution and SRF. Thus studying the sludge moisture distribution has important significances for sludge dewatering performance.

Usually, according to the physical bonding of water to the sludge particles, sludge moisture can be divided into four categories (Kopp and Dichtl, 2000; Smith and Vesilind, 1995): (1) free water, which is not bound to the particles; (2) interstitial water, which is bound by capillary forces between the sludge flocs; (3) surface water, which is bound by adhesive forces; and (4) bound water, which is the smallest water content that can only be removed thermally. The surface water and bound water can be grouped as bounding water. Different techniques are used to measure water distribution within activated sludge, including drying test (Smollen, 1990), dilatometric test (Robinson and Knocke, 1992), water activity test (Vaxelaire, 2001), and differential thermal analysis (DTA) and differential scanning calorimetry (DSC) tests (Lee et al., 1975).

The representation of the water distribution within sludge is theoretically an interesting parameter for studying sludge conditioning (Vaxelaire and Cézac, 2004). Erdinçler and Vesilind (2000) disrupted biological sludge cells by different methods including alkali treatment, NaCl treatment, heat treatment, and sonication; and found that disruption of sludge cells changed the sludge water distribution and released 60%–80% of interstitial water. Halde (1979) reported the impacts of freezing–thawing on sludge water distribution. Robinson and Knocke (1992) noted that bound water content decreased with freeze–thaw conditioning of waste chemical and biological sludge. Katsiris and Kouzeli-Katsiri (1987) found that heat treatment of activated and digested sludge at 130°C resulted in a reduction of bound water by 30% whereas freezing and thawing reduced the bound water by 70%.

On the other hand, though ultrasound treatment and chemical oxidations were known to be effective for sludge disintegration, their impacts on sludge moisture distribution during sludge disintegration were still unknown. Therefore, this article studied the changes of sludge moisture distribution after three disintegration methods, namely ultrasound treatment, K_2FeO_4 oxidation, and $KMnO_4$ oxidation. The objectives of this study were to investigate the relationship between sludge moisture distribution and dewatering performance, and to compare the changes caused by mechanical and chemical methods. Mechanisms behind these observed changes were also discussed.

1. Materials and methods

1.1. Materials

Sludge was collected from sewage treatment plant in Beijing and then was cultured in the laboratory. The sludge total

solid content was 5860 mg/L, the volatile solid content was 4310 mg/L, the total chemical oxygen demand was 6840 mg/L, the supernatant chemical oxygen demand was 134 mg/L, the pH was 6.7, and the temperature was 19–27°C. Sludge was concentrated to a total solid content of 8000 mg/L through thickening. K_2FeO_4 and $KMnO_4$ were prepared with 0.1% solution.

1.2. Apparatus and operations

According to previous study, the sonication time was more important than the ultrasonic intensity in determining the sludge disruption degree (Zhang et al., 2007a), so in the study, the ultrasound intensity was certain of 0.8 W/mL, and the sonication time was set as 5, 10, 15 and 30 min. Sludge sonication was performed using a cell device that emitted 25 kHz ultrasound waves (JY-92-II-N, Ningbo Haishukesheng Ultrasonic, Ltd., China). For each experimental run, 100 mL of sludge was treated in the ultrasonic device. The chemical doses of $KMnO_4$ and K_2FeO_4 were both 0.1% total solid (TS), which were determined by previous experiments (Wu et al., 2014).

1.3. Analysis

Sludge disintegration efficiency was represented by disintegration degree (DD_{COD}), which was calculated as: $DD_{COD} = (SCOD - SCOD_0) / (TCOD - SCOD_0)$, where $SCOD_0$ (mg/L) and soluble COD (SCOD) (mg/L) were the soluble chemical oxygen demand (COD) before and after the treatment, respectively, and total COD (TCOD) (mg/L) was the total COD of untreated sludge (Zhang et al., 2012b).

According to previous experiments, sludge dewatering was achieved by centrifuging the sludge at 3000 r/min for 10 min. The pH was measured using a Hach pH meter, Hach Inc., Beijing, China. All other parameters were obtained according to the standard methods for the examination of water and wastewater (APHA, 1995).

In this study, drying test was applied to determine sludge moisture distribution (Vaxelaire and Cézac, 2004). This technique assumes that the rate of water evaporation depends on the type of bond between water and solid particles. Some sludge sample was introduced to the balance dish. The dish was dried in an air dry oven at 30°C and at a controlled humidity by sparging the oven with 400 mL/min of compressed dry air (Deng et al., 2011). The sludge mass was recorded at 10 min intervals at earlier stage, and later it was recorded at 5 min intervals. When there was no change in sludge mass, the sludge sample was heated at 105°C for 12 hr. By this method, a typical drying curve could be gained. In the sludge drying curve (Appendix A Fig. S1), there is a short period of increasing drying rate at the beginning for increasing temperature. The drying curve can be divided into a constant-rate period (line AB), first falling-rate period (line BC), second falling-rate period (line CD), and equilibrium stage. The first critical point B is the transition from the constant-rate period to the first falling-rate period, while the second critical point C is the transition from the first falling-rate period to the second falling-rate period. The moisture content is removed during the constant-rate period, and the first falling-rate period and the second falling-rate period are regarded as free water, interstitial water, and surface water, respectively. The residual

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