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Significances of deflocculated sludge flocs as well as extracellular polymeric substances in influencing the compression dewatering of chemically acidified sludge

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ABSTRACT

Sludge extracellular polymeric substances (EPS) are frequently reported as a main factor determining sludge dewatering, but the role of sludge floc structure in influencing sludge dewatering has not been fully understood. The dewatering of chemically acidified sludge was investigated to reveal the respective role of sludge floc structure and sludge extracellular polymeric substances (EPS) in influencing the removal rate of moisture (i.e., dewatering rate) and the removal amount of moisture (i.e., dewatering extent) of acidified sludge. During the chemical acidification of sludge, serious lysis of microbial cells in sludge was induced to result in a decrease of moisture content in dewatered sludge cake, from 81.8% to only 66.7%, but both the significant increase of sludge outer layer EPS content and the deflocculated sludge flocs led to a serious deterioration of dewatering rate of acidified sludge. Further studies revealed that either decreasing sludge outer layer EPS content or modifying the deflocculated sludge flocs could improve both filtration and expression stages of compression dewatering of acidified sludge to enhance the dewatering rate of acidified sludge. Especially, only 5 mg/g dry solid of anionic synthetic organic polyelectrolyte polyacrylic acid (PAA) could condition acidified sludge to improve its dewatering rate at both filtration and expression dewatering stages through re-flocculating the deflocculated flocs in acidified sludge. Therefore, the deflocculated sludge floc structure is as significant as extracellular polymeric substances in influencing the compression dewatering of acidified sludge, and the treatment of sewage sludge through chemical acidification and followed conditioning using synthetic organic polyelectrolyte PAA can enhance the dewatering extent as well as dewatering rate.

1. Introduction

With the rapid growth of industrialization and urbanization, large amounts of waste activated sludge are being produced in wastewater treatment plants (WWTPs) [1], which usually contains more than 98% of moisture [2,3]. Prior to sludge disposal, a dewatering step is generally indispensable to reduce its volume by removing the huge amount of moisture in waste activated sludge [4–6], which can significantly enhance the efficacy of sludge disposal including incineration, composting and landfill [1,7,8]. Although anaerobic digestion not only reduces sludge volume and odor, but also produces methane under less energy consuming condition, in China only less than 3% of WWTPs has adopted anaerobic digestion processes and almost 2/3 of anaerobic digestion facilities did not work properly [6,9,10]. Thus, waste activated sludge is directly dewatered and then disposed in most WWTPs of China. The dewatering of waste activated sludge is usually carried out by using mechanical dewatering devices in WWTPs, but conditioning of waste activated sludge is extremely critical because sludge characteristics seriously determine both the removal rate of moisture (i.e., dewatering rate) and the removal amount of moisture (i.e., dewatering extent) [5,11]. In practice, waste activated sludge is commonly conditioned by synthetic organic polymers or metal ions, prior to mechanical dewatering; nevertheless, these chemical conditioners generally improve the rate of dewatering and marginally impact the dryness of dewatered sludge cake [5,12]. Thus, new conditioning approaches needs to be developed to increase the amount of moisture that can be removed as well as the rate of dewatering.

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To date, many sludge conditioning methods including acid/alkaline treatment [13–15], freeze-thaw treatment [16], enzymatic treatment [3,17], sonication [15,18], and thermal treatment [18,19] have been tested to improve the dewaterability of sludge. Among these, the chemical acidification of sludge is extensively employed as a pretreatment approach because of its easiness and effectiveness in enhancing the dewatering extent of sludge [12,13]. Previous studies found that chemical acidification influenced the dewatering of sludge mainly via changing its physicochemical properties, including the surface charges of sludge flocs and sludge EPS content [12–14]. On one hand, during acidification the negative surface charges of sludge particles can be neutralized by the protons (H^{+}) present to increase the stability of sludge flocs [14,19]. On the other hand, sludge acidification would lead to the lysis of microbial cells in sludge to increase the content of sludge extracellular polymeric substances (EPS), which is usually considered as a main cause of the deterioration of sludge dewatering performance [20–22]. Nevertheless, it is worthy to note that sludge acidification also results in the change of physical structure of sludge flocs, potentially influencing the dewatering of sludge. For instance, Shao et al. [23] found that sludge acidification resulted in the decrease of the median particle sizes of sludge flocs, negatively affecting sludge dewaterability that was measured by capillary suction time (CST). Thus, although sludge acidification may simultaneously change the surface charges of sludge particles, sludge EPS content and the physical structures of sludge flocs, it is still unclear how these factors respectively influence the dewatering rate and extent of acidified sludge.

Currently, the dewatering rate is usually measured in the laboratory using a capillary suction time (CST) test or a filtration device that measures the specific resistance to filtration (SRF), while the dewatering extent is usually measured by the moisture content of the dewatered cake solids [5]. However, compression dewatering commonly employed in WWTPs consists of both filtration and expression stages [22,24], and both CST and SRF tests cannot adequately describe the behavior of sludge in conventional compression dewatering processes [14,25]. Because the CST measurement is far from realistic since no pressure is applied and the sludge SRF only characterizes the ability of the cake to let water go through during the filtration stage [26,27]. Thus, in addition to SRF test and the measurement of the moisture content of dewatered cake solids, filtration-compression cell test, a more powerful tool capable of assessing both filtration and compression stages in sludge compression dewatering [14,28], was used in the present study to fully characterize the sludge dewatering process.

Therefore, the objectives of the present study are to (1) investigate the effect of sludge acidification on the dewatering rate and extent of acidified sludge, and the changes of sludge physicochemical properties including the surface charges of sludge particles, sludge EPS content, and the physical structures of sludge flocs during sludge acidification, (2) evaluate the respective influence of sludge EPS and sludge flocs of acidified sludge on its dewatering performance, especially in the filtration and expression stages of compression dewatering process, and (3) explore the feasibility of improving the dewatering performance of acidified sludge by using chemical conditioners or surfactants, thus developing a new conditioning method based on chemical acidification and conditioning to improve the compression dewatering of waste activated sludge.

2. Materials and methods

2.1. Municipal sewage sludge sample

The municipal sewage sludge used in this study was collected from the sludge thickening-pond of the Taihu New City Wastewater Treatment Plant in Wuxi City, Jiangsu Province, China. Sludge pH (7.53), solid content (3.54%), and organic matter content (48.7%) of the sludge were determined immediately after collection according to their respective Standard methods [29]. The sludge SRF, 1.15×10^{13} m/kg, was determined using the Buchner funnel test [30,31]. Municipal sewage sludge was stored in polypropylene bottles at 4 °C before use.

2.2. Effect of chemical acidification on the dewatering rate and extent of sludge and its physico-chemical properties

The experiment was conducted in a series of 500 mL Erlenmeyer flasks, each containing 300 mL of municipal sewage sludge. The sludge pH was adjusted to 6.50, 5.50, 4.50, 3.50, 2.50, and 1.50, respectively, by adding 9.20 M sulfuric acid (AR) with shaking in a gyratory shaker at 28 °C and 180 rpm for 30 min. Then each sludge sample was kept stable for 20 min to ensure the efficiency of acidification. Due to the buffering capacity of sludge, above procedures were repeated till the stable pH values of acidified sludge were close to the objective sludge pH, and the pH values of resulting acidified sludge were 6.50 ± 0.01, 5.49 ± 0.02, 4.48 ± 0.02, 3.50 ± 0.01, 2.49 ± 0.01 and 1.49 ± 0.01, respectively. It can be seen from Table S1 that the volume of 9.20 M sulfuric acid consumed during sludge pH adjustment ranged from 3.50 to 33.8 mL/L raw sludge, depending on the final pH of resulting acidified sludge. A volume of 150 mL acidified sludge sample was withdrawn from each flask for the determination of sludge SRF using the Buchner funnel test [30,31], the moisture content of dewatered sludge cake using filtration-compression cell test [14,28], zeta potential of sludge particles, N-acetyglucosamine content in the liquid phase of sludge, and sludge EPS content in layers of slime EPS, loosely-bound EPS (LB-EPS) and tightly-bound EPS (TB-EPS). Meanwhile, the floc properties of raw sludge and acidified sludge with pH value of 2.49 were further characterized by sludge particle size distribution and scanning electron microscopy (SEM) analysis to show the change of sludge floc structure after sludge acidification.

All treatments were done in triplicate throughout the present study unless otherwise noted, and data presented were the mean values of the triplicate samples with standard deviations.

2.3. Respective influence of sludge EPS and deflocculated sludge flocs on the dewatering of acidified sludge

Sludge EPS and sludge floc of either raw sludge or acidified sludge with pH 2.49 were separated using filtration or centrifugation method, respectively. Briefly, raw sludge was filtrated in a lab filtration-compression cell [14,28] fitted with a filter paper (Whatman No. 1) under 0.5 MPa pressure until no additional water flowed out of the sludge. Through the above method, the filtrate and dewatered sludge cake could be obtained, which contained the outer layer EPS (slime EPS + LB-EPS) and flocs of raw sludge, respectively. The acidified sludge with pH 2.49 was centrifuged at 14,000*g* for 20 min to obtain the sludge supernatant containing the outer layer EPS (slime EPS + LB-EPS) of acidified sludge and the sludge pellets mainly composed of flocs of acidified sludge [31]. Preliminary study shows that the filtration or centrifugation method employed did not significantly change the respective dewatering property of these two sludge samples. The SRF and the moisture content of dewatered sludge cake of filtration-affected raw sludge, which was obtained through re-mixing the filtrate of raw sludge and the filtrated sludge cake, were respectively 1.29×10^{13} m/kg and 79.7%, which were insignificantly different from those of raw sludge. Similarly, the SRF and the moisture content of dewatered sludge cake of centrifugation-affected acidified sludge, which was obtained through re-mixing the supernatant