Effects of conditioning and electrokinetics on sewage sludge dewatering

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Abstract

In this work a semi-pilot scale recessed plate filter press was used for dewatering of sewage sludge, which has been subjected to the various manners of conditioning such as ultrasonication, acid hydrolysis using various acids, and alkaline hydrolysis using NaOH. To compare with the performance of conventional mechanical dewatering, electrodewatering was also conducted using the same filter press. During the sludge conditioning stage, it was found that ultrasonication resulted in a reduction of about 6.5% of suspended solids while no significant effect on destruction of fixed solids and volatile solids. Ultrasonification was also found to increase the soluble chemical oxygen demand (sCOD) by 40.35%. As for acid hydrolysis using HNO_3, an increase of 81.82% in sCOD was obtained. Contrarily, alkaline hydrolysis using 10 N NaOH yielded a poor performance in sludge dewatering. By coupling acid hydrolysis and electrodewatering, it was found that the moisture content of the sludge cake could be reduced to 71.88% in this study.

Keywords: Sewage sludge, Electrodewatering, Conditioning, Alkaline hydrolysis, Acid hydrolysis, Ultrasonication

Introduction

Along with the development of urbanization, a rapidly increased number of municipal wastewater treatment plants have been built in many developed and developing countries all over the world. Inevitably, a tremendous amount of sewage sludge is also generated. Generally, sludge produced by sewage treatment plants has an initial moisture content of about 95-99% [1-2]. It has been reported that the management and disposal of waste sludge accounted for 25-65% of the cost. By reducing the amount of sludge generated, a significant reduction in sludge disposal expenditure and mitigation of the lack of landfill sites [3-4]. Like other organic sludges, dewatering of sewage sludge is not an easy task. Conventional sludge dewatering equipment can only yield the sludge cake having the moisture content of 80% or greater.

It is well known that sludge is a two-phase slurry consisting of water and solids. Depending on its binding characteristics with solids water in sludge exists in different forms. It has been reported that water in sludge appears to exist in four forms: (1) free water, (2) interstitial water, (3) vicinal water, and (4) water of hydration [5]. Generally, it is believed that by changing the water distribution in sludge through the so-called "sludge conditioning" is a remedy to enhance the dewaterability of sludge. Common sludge conditioning methods are broadly divided into physical, chemical, and biological conditioning. Physical conditioning methods including heat treatment [6,7], freezing and thawing [8,9], and ultrasonication [10,11]. Among others, acid hydrolysis [12] and alkaline hydrolysis [12,13] belong to the category of chemical conditioning. Such chemical conditioning methods might have some effects on the organic matter solubilization, volatile solids destruction and extracellular polymeric substances (EPS) fractionation of the sludge samples. Ultrasonication is generally considered as non-hazardous to the environment. It is an effective method for accelerating hydrolysis of organic matters of sludge, which would yield an enhancement of sludge dewaterability. Since biological conditioning is not used in this work, it will not be introduced further.

Sludge dewatering can be performed using traditional sludge dewatering technology and improved sludge dewatering technology. At present, the traditional sludge dewatering method using the mechanical pressure way is still widely used in industry. The known improved sludge dewatering techniques are mainly combined with heat treatment, ultrasonic and electrohydraulic assisted dewatering [14-16]. As indicated above, organic sludges including sewage are generally not easy to dewater. Electrodewatering using a plate and frame filter press has been reported to be an effective way to significantly reduce the moisture content of sludge cake to about 65% for a biological sludge generated in an industrial wastewater treatment plant [17].

The objectives of this study were two-fold: (1) to evaluate the effects of physical conditioning (i.e., ultrasonication) and chemical conditioning (i.e., acid hydrolysis and alkaline hydrolysis) on disintegration of a sewage sludge, and (2) to evaluate the synergistic effect of sludge conditioning and application of and electric field on moisture content of sludge cake.

Materials and methods

The post-anaerobic-digestion sludge samples were collected from a local municipal wastewater treatment plant. Immediately after the collection, each sludge sample was characterized using standard methods whenever applicable. Characteristics of concern include but not limited to moisture content, pH, total solids, volatile solids, and fixed solids. Ultrasonication of sludge sample was performed using an ultrasonic processor (Sonics VCX-750) with a specific energy input of 333 KJ/kg. Acid hydrolysis of sludge was conducted for 30 min using 11 N H_2SO_4, concentrated HCl, and concentrated HNO_3 separately for pH adjustment to 0.1 unit, whereas 10 N NaOH was used for alkaline hydrolysis. Cationic polyacrylamide (CPAM; Zetag 8147, BASF, Germany) was used as to form flocs for the attachment of sludge particles. 400 mg/L was determined to be the optimal flocculant dosage in a preliminary jar test. However, when ultrasonication was performed prior to flocculation, the optimal flocculant dosage was reduced to 300 mg/L. When acid hydrolysis or alkaline hydrolysis was to be performed prior to flocculation, the respective optimal flocculant dosage was also determined by the jar test.

In this work a semi-pilot scale recessed plate filter press with one sludge holding compartment was used for all tests of sludge dewatering. In this work the mechanical dewatering of sewage sludge was conducted under 5 kgf/cm^2 feeding pressure for 50 min unless otherwise specified. The filtrate was collected at a constant time interval and stored in the dark at 4 °C for later analysis. When an external electric field of 30 V/cm^2 was applied to the said filter press system, an additional 20 min of electrodewatering was conducted after the prior 50-min mechanical dewatering. The filtrate collected at this stage was also stored for later analysis. No matter whether or not the external electric field was applied to the filter press system, the sludge cake obtained from each dewatering test was analyzed for its average moisture content for three specimens collected from three spots of the filter cake. Further, the freeze-dried specimens of the filter cake were subjected to examination of scanning electron microscopy (SEM) to compare the difference in morphology of sludge particles before and after electrodewatering.

Results and discussion

The characteristics of sewage sludge before and after ultrasonic conditioning are given in **Table 1**. As shown, the content of volatile solids (VS) were determined to be 53.48 wt%. According to Taiwan EPA, any sludge containing VS greater than 30 wt% is categorized as an organic sludge. The sewage sludge studied in this work meets the criterion and is an organic sludge by definition. It was also noticed that ultrasonic conditioning rendered sludge disintegration yielding a lower concentration of suspended solids as compared with that of raw sludge (i.e., 28,180 mg/L vs. 30,140 mg/L).

Table 1

Characterization results for sewage sludge before and after ultrasonic conditioning

Item	Raw sludge	Ultrasonicated sludge
Moisture (%)	96.87	96.85
pH	7.02	6.99
Suspended solids (mg/L)	30,140	28,180
Total solids		
Volatile solids (wt%)	53.48	52.88
Fixed solids (wt%)	46.52	47.12

To better understand the effect of ultrasonic conditioning of sludge disintegration, which might be beneficial to later sludge dewatering, the concentration of soluble COD (sCOD) was determined before and after ultrasonic conditioning. It was found that ultrasonication yielded 40.35% increase of sCOD in this study. But the effect of ultrasonic conditioning of sludge on its dewaterability is not studied in this work. In a study concerning the effect of ultrasound pretreatment on sludge digestion and dewatering characteristics, however, it was reported that ultrasound pretreatment of waste activated sludge resulted in an increase in capillary suction time (CST) and specific resistance filtration (SRF) parameters, thus showing an adverse effect on dewaterability [18]. In a separate study concerning the effects of different sludge disintegration methods on sludge moisture distribution and dewatering performance, it was concluded that ultrasound treatment deteriorated the sludge dewaterability [19].

Fig. 1 showed the effects of acid hydrolysis of sewage sludge on capillary suction time (CST) under various pHs adjusted by HCl, H_2SO_4, and HNO_3. In the pH range of 2-5, it was found that nitric acid yielded the best performance among three acids tested in terms of the percentage of CST reduction. At pH=2, nitric acid gave rise to an about 50% reduction in CST. In other words, if said sewage sludge is subjected to acid hydrolysis using HNO_3 under the condition of pH=2, its dewaterability would substantially increase. In this study, sCOD was determined to increase 81.82% by acid hydrolysis using HNO_3. This is ascribed to the sludge disintegration rendering the release of cellular matter inside the organic particles of sludge to the sludge slurry.

As for alkaline hydrolysis of sewage sludge, it was noticed that as the dosage of NaOH increased, sludge gradually became gel state yielding an abrupt decrease in dewaterability. That is, alkaline hydrolysis of said sludge appeared to be detrimental to its dewatering performance. In this study it was also noticed that the content of fixed solids (FS) slightly decreased from 46.52 wt% (for raw sludge) to about 40 wt% as pH decreased to a value of 2-3 adjusted by HNO_3, whereas FS increased to about 50 wt% at pH =10 adjusted by NaOH.

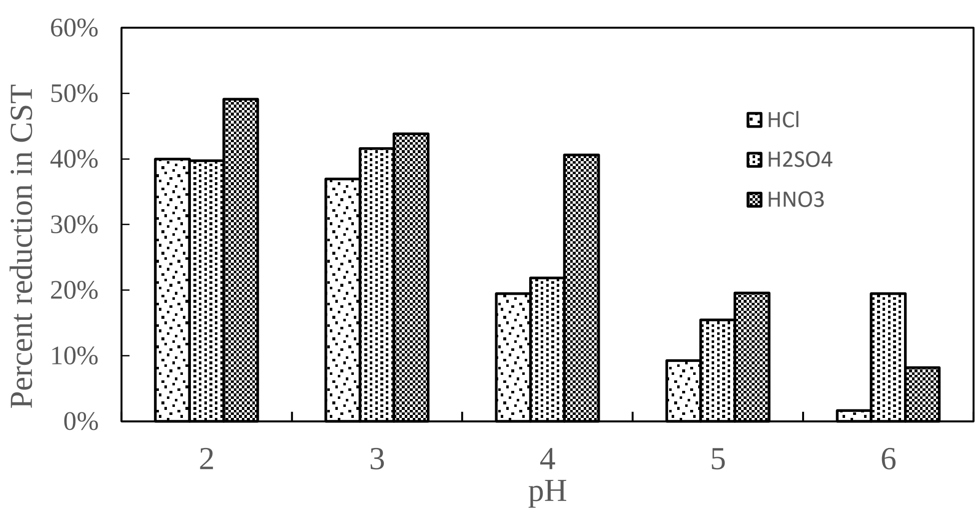

Fig. 1. Variation of CST reduction with different pHs resulting from acid hydrolysis of sewage sludge.

In this work physical conditioning (i.e., ultrasonication), chemical conditioning (i.e., acid hydrolysis and alkaline hydrolysis), and application of electrokinetics were evaluated for their effects on the residual moisture content of sludge cake under various dewatering tests. Detailed operating conditions are given in **Table 2.**

Table 2

Test program for dewatering of sewage sludge under various operating conditions and the corresponding moisture contents in filter cakes

Test No.	Flocculant dosage (mg/L)	Ultrasonic specific energy input (KJ/kg)	Adjusted pH	Mechanical dewatering pressure [c] (kgf/cm^2)	Electrodewatering time (min)	Applied electric field strength (V/cm)	Moisture content of filter cake (%)
1	400	-	-	7	-	-	75.36
2	400	-	-	5	-	-	76.41
3	400	-	-	5	20	30	74.28
4	300	333	-	5	-	-	76.23
5	300	333	-	5	20	30	72.01
6	300	-	pH 3 [a]	5	-	-	82.07
7	300	-	pH 3 [a]	5	20	30	71.88
8	600	333	pH 10 [b]	5	20	30	81.59

[a] pH adjustment by nitric acid.

[b] pH adjustment by sodium hydroxide.

[c] 50-min mechanic dewatering in all tests and followed by 20-min electrodewatering in some tests specified.

Tests 1 and 2 in **Table 2** mainly concerned the effect of feeding pressure on residual moisture content of the filter cake. The results showed that the difference in moisture content was not significant. Thus, a feeding pressure of 5 kgf/cm^2 was adopted for all subsequent sludge dewatering tests. By comparing the results of Tests 2 and 4, it was found that the difference in moisture content of filter cake is trivial. This is ascribed to that a greater dose of flocculant in Test 2 yielded a comparable effect with ultrasonic conditioning adopted in Test 4. The result of Test 3 showed that application of an external electric field (i.e., electrodewatering) yielded a filter cake of lower moisture content as compared with that of Test 2. Test 5 showed the synergistic effect of ultrasonic conditioning and electrodewatering on removal of water from sludge. It yielded the lowest moisture content among Tests 2-5. It is, generally, believed that acid hydrolysis might enhance the sludge disintegration rendering the release of cellular matter inside the organic particles of sludge to the sludge slurry. However, conventional mechanic dewatering was found to be incompetent to separate it from solids as shown in the results of Test 6. Moreover, the release of cellular matter seemed to yield an even worse dewatering performance in terms of moisture content of filter cake. An abrupt change in final moisture content was observed when acid hydrolysis and electrodewatering combined. It yielded the filter cake with the moisture content of 71.88%. Further testing was performed in Test 8. Here physical conditioning by ultrasonication, chemical conditioning by alkaline hydrolysis, and application of an external electric field were all combined and adopted for sludge dewatering. Surprisingly, it yielded a pseudo-filter-cake with final moisture content of 81.59%. Such a poor dewatering performance might be ascribed to (1) deterioration in sludge dewaterability due to ultrasonication [18,19], and (2) the fact that sludge became gel state after alkaline hydrolysis, which was detrimental to solid/liquid separation. To solve this problem of poor sludge dewatering, further studies are needed.

Morphology of sludge particles are of interest in this study. SEM micrographs showed that the particles in raw sludge appeared to be larger with flaky surface (see **Fig. 2(a)**). When an external electric field was applied, the sludge particles appeared to be broken into smaller pieces rendering easier removal of water from sludge. More studies have to be conducted to further verify this finding.

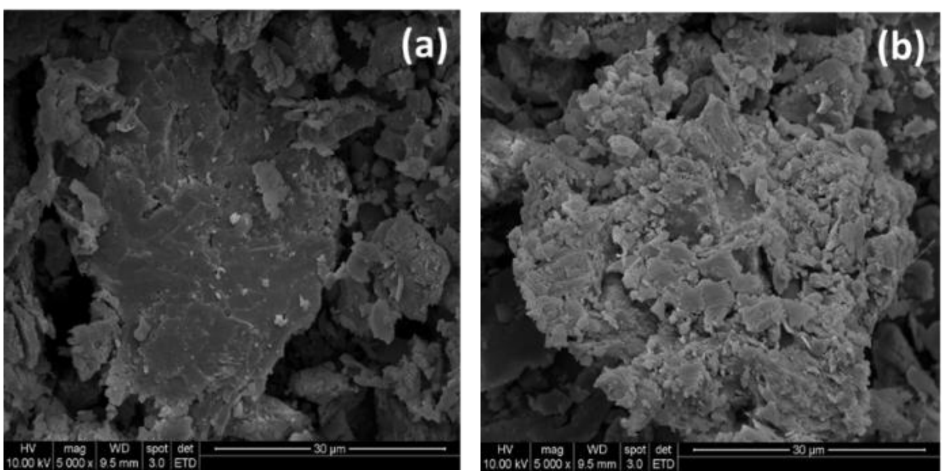

Fig. 2. SEM micrographs: (a) raw sludge and (b) sludge after electrodewatering as performed in Test 3.

Conclusions

In this work the effects of physical conditioning, chemical conditioning and application of electrokinetics on sewage sludge dewatering were studied using a semi-pilot scale recessed plate filter press. It was found that ultrasonication yielded 40.35% increase of soluble COD. Whether this would cause deterioration in sludge dewaterability is not certain and verified in this work. Chemical conditioning through acid hydrolysis using HNO_3 was determined to yield the best performance among three acids tested in terms of the percent reduction in capillary suction time (CST). This is an indicator for enhanced sludge dewaterability. In contrast, chemical conditioning through alkaline hydrolysis using NaOH rendered sludge in gel state. This would be detrimental to sludge dewatering. As for application of electrokinetics, SEM micrograph showed that the size of sludge particles might become smaller. Such a phenomenon of sludge disintegration and/or destruction of cell wall would be beneficial to sludge dewatering. In this work the synergistic effect of acid hydrolysis using HNO_3 and electrodewatering yielded the lowest moisture content of filter cake. However, further studies are needed to have in-depth understanding of said effects and reduce the moisture content of filter cake to 65% (as reported elsewhere [17]) or lower to be comparable with other studies.

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