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Study on dewaterability of municipal sludge conditioning by physical conditioners with ultrasonic and magnetic field application

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ABSTRACT

An experimental research on dewaterability of municipal sludge with different mixing ratios was conducted with the use of ultrasonic and magnetization as conditioning means, and quicklime powder and straw fiber as conditioners. Research indicates that conditioning by combination of ultrasonic, physical conditioners (quicklime and straw fiber), and magnetization can effectively improve the dewaterability of municipal sludge. U-O-M (represents treating the sludge successively with ultrasonic, physical conditioners and magnetic field) achieved the best dewaterability of municipal sludge through an experiment under the following conditions: 30 s 40 Hz ultrasonic treatment, 4% quicklime powder content, 1% fiber content, and 40 min magnetization with 20 mT strength. The water content after centrifugal dewatering with a 3,000 separation factor was lower than 60%.

Keywords: Sludge; Dewatering; Magnetic field; Ultrasonic; Quicklime; Straw fiber

1. Introduction

With the rapid development of urbanization, environmental security problems caused by the upsurge of municipal sludge emission load are becoming increasingly prominent [1,2]. The characteristics of municipal sludge, such as high hydrophilicity, high water and organic matter content, and low permeability, lead to its poor use in engineering applications [3,4]. The gel-like structure of the flocculated network and the colloidal nature lead to poor dewaterability of municipal sludge [5]. Therefore, sludge dewatering problems are critical issues in the treatment of municipal sludge. Studies are being conducted on the mechanical, thermal, chemical, electrochemical, and biological treatment of municipal sludge [6–8].

Low frequency ultrasonic has a good cavitation effect on extracellular polymeric substances (EPS) and other similar materials in sludge [9–11]. Ultrasonic ranging from 20 to 100 kHz is used in chemically important systems in which chemical and physical changes are desired [12]. About 80% of currently applied ultrasonic techniques hasbeen used to treat sludge at a frequency of 20–40 kHz [13]. Combination of ultrasonic and other methods could decrease over 10% final sludge water content according to Bien et al. [14]. The method of ultrasonic may be a clean way to treat sludge [15].

Purposefulness of constant magnetic field application has been justified in the case of water treatment [16],

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wastewater treatment, [17] and sludge conditioning [18]. Under magnetic field, sludge specific resistance to filtration (SRF) was indeed reduced and the dewaterability was improved. Magnetic field combined with other conditioning technology can save costs and increase the efficiency of dewaterability. A magnetic field can have a stimulating effect on sludge conditioning, given the proper technological conditions [19].

Physical conditioners are sometimes employed to increase the dewaterability of municipal sludge. The physical conditioners are often referred to as skeleton builders for the reason that, when added to sludge, they can form a permeable and more rigid lattice structure. Such structures can remain porous under high pressure during mechanical dewatering. From the literature, quicklime- and carbon-based materials have been found to be successful as physical conditioners. Quicklime is a cost-effective sludge conditioner, which also has the sterilizing effect [20,21]. Carbon-based material studies include waste wood chips and wheat dregs [22], bagasse [23], rice shell and rice bran [24], and oringa oleifera seeds [25]. Lin et al. [22] observed that increasing the dose of wood chips or wheat dregs as filter aids reduced the moisture content of cake, but did not proportionally increase the total volume of the filtrate removed because of their high SRF. They believed that, at high doses of the skeleton builders, the water permeated into the skeleton builders reducing the total amount of free water to be removed. But straw fiber saturation moisture content is low after treatment and plays a significant role in establishing the skeleton. Meanwhile, straw fiber as a sludge conditioner can achieve the goal of processing waste based on waste.

New economical and effective sludge dewatering method contributes to safe treatment and resource utilization for sludge through rendering dewaterability of municipal sludge with SRF [10,26], allowing macroscopic measurement of the sludge dewatering effect with the water content after centrifugal dewatering, micro-analyzing of the dewatering mechanism with the sludge's scanning electron microscope (SEM) image and fractal dimension, which is combined with the strengths of ultrasonic, magnetic field, quicklime powder, and straw fiber.

2. Materials and methods

2.1. Test materials

Municipal sludge, which had 83.4% of water content, 1.14 kg/m^3 natural density, pH of 6.96, and 47.5% of organic matter, was taken from a sewage plant in Wuhan City, Hubei Province, China. Quicklime powder had over 85% calcium hydroxide, $\leqslant$1% humidity, $\leqslant$1% HCl dissolution, and $\leqslant$ 5% 200-mesh screen residue. The straw fiber had 4.85% of saturated water content, a diameter of 0.023 mm, and was 6 mm long with 970.1 MPa tensile strength and a 34.58% crack growth rate.

2.2. Test methods

Dewaterability of the municipal sludge was measured with an independently developed sludge SRF apparatus. The diameter of the Büchner funnel was 60 mm with a 70.8 mL volume and a 0.98 MPa experimental differential pressure. The experimental time for vacuum breakdown was 20 min.

The experimental samples are dewatered sludge (83% water content), and the liquid is acquired drop by drop fromsuction filtration to the cylinder. In order to record the drip infusion time accurately, a high definition video was installed at the liquid outlet recording the whole experiment process. The generation time of every liquid drop was acquired through videos processing after finishing the test. The volume of every liquid drop was acquired via the cylinder scale (under the same environment, every liquid drop has the same volume).

The processed sludge was dewatered through a centrifugal machine with a separation factor of 3,000, and then placed in an oven for drying to measure the water content. Fractal dimension can describe the bioflocculate structure, and the floc structure of the sludge is closely related to the dewatering character. SEM experiment was conducted based on the dewatered municipal sludge sample processed with different mixing ratio schemes, and the floe structure of the sludge was expressed by its fractal dimension. Therefore, dewaterability of municipal sludge different mixing ratio schemes was shown.

Fractal dimension applies the area–perimeter relation, which measures the area (A) and corresponding perimeter (P) continuously under different periods or states of the fractal structure to create the $\ln A - \ln P$ curve. The area–perimeter relation also uses the slope of the straight-line portion of the $\ln A - \ln P$ curve to estimate the fractal dimension of the fractals. The test picture was obtained by SEM, whereas A and corresponding P were obtained by image analysis software to calculate the fractal dimension. The fractal dimension was used to describe the associated literature [27,28].

Ultrasonic processor adopts groove water bath ultrasonic, and the samples are placed in a beaker and then in a water bath for ultrasonic treatment.

The magnetic field was provided by two magnets. The magnetic field strength of the magnet surface is 280 mT, and of the intermediate position is 20mT. Square samples were magnetized in the middle of magnetic field.

Do each test three times and take the average as the test value. Data have good reproducibility and the data error is less than 3%.

3. Results and discussion

3.1. Dewaterability of municipal sludge conditioning by ultrasonic, magnetic field, straw fiber, and quicklime, respectively

The experimental sample was placed in an ultrasonic water bath for 5, 10, 20, 30, 40, 60, and 80s to obtain the SRF shown in Fig. 1(a), and the dewatering speed and accumulated volume shown in Fig. 2(a). The optimal ultrasonic processing time was 30s. Ultrasonic treatment of the municipal sludge exerted a time effect, because ultrasonic energy had difficulty crushing its EPS within a short processing time; over a long processing time, its crushed EPS materials formed new materials that lead to the poor dewaterability of municipal sludge. Fractal dimension expression of the SEM micro-image is shown in Fig. 3(a), which indicates that dewaterability of the municipal sludge is in accordance with the variation law of fractal dimension.

The municipal sludge was processed with magnetic field for 5, 10, 20, 30, 40, 50, and 60 min to obtain the SRF shown in Fig. 1(b), and the dewatering speed and accumulated volume shown in Fig. 2(b).

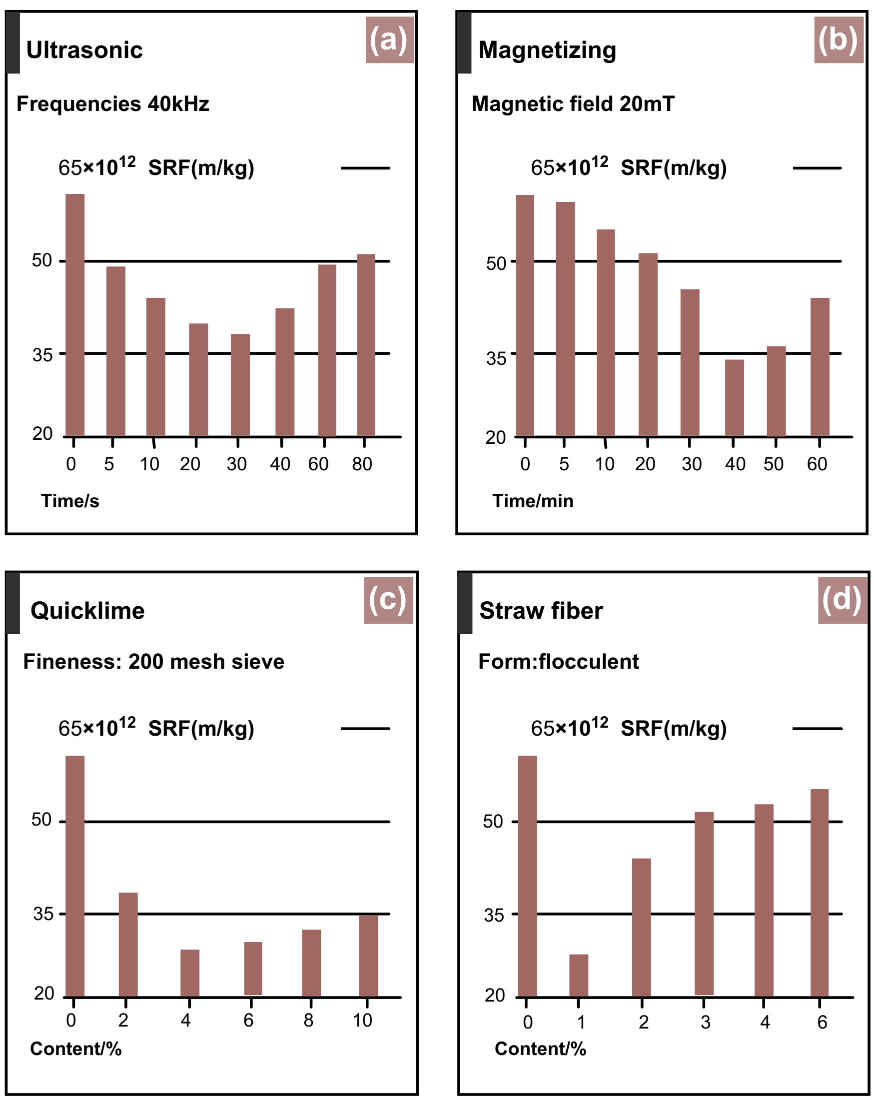

Fig. 1. Sludge dewaterability under different operating conditions in ultrasonic, magnetic field, quicklime, and straw fiber.

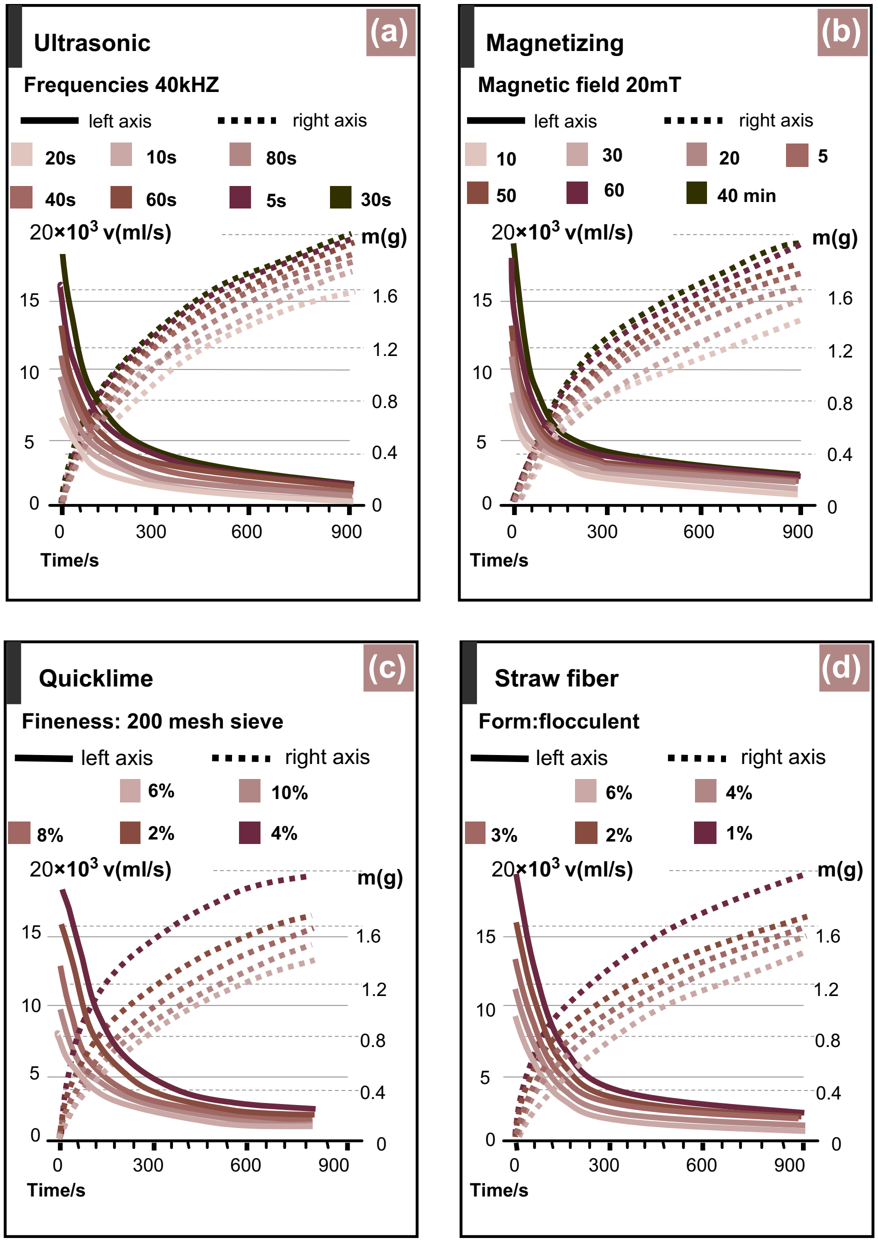

Fig. 2. Sludge dewatering speed and accumulated volume under different operating conditions in ultrasonic, magnetic field, quicklime, and straw fiber.

The optimal magnetic field processing time was 40 min. Magnetic field treatment of the municipal sludge exerted a time effect, because the magnetic field had difficulty changing certain surface characteristics of the municipal sludge particles within a short processing time; over a long processing time, certain surface characteristics of the municipal sludge particles were over-exchanged, which was disadvantageous to the dewaterability of the municipal sludge. Fractal dimension expression of the SEM micro-image is presented in Fig. 3(b), which indicates that dewaterability of the municipal sludge is in accordance with the variation law of fractal dimension.

Straw fiber was mixed in proportions of 1, 2, 3, 4, and 6% dry weight of the municipal sludge and stirred mechanically and evenly to obtain the SRF shown in Fig. 1(c) and the dewatering speed and accumulated volume shown in Fig. 2(c). The optimal fiber content was 1%. Changing the dewatering channel of the sludge was difficult with low straw-fiber content; however, the channel was easily penetrable with a high straw-fiber content. Although

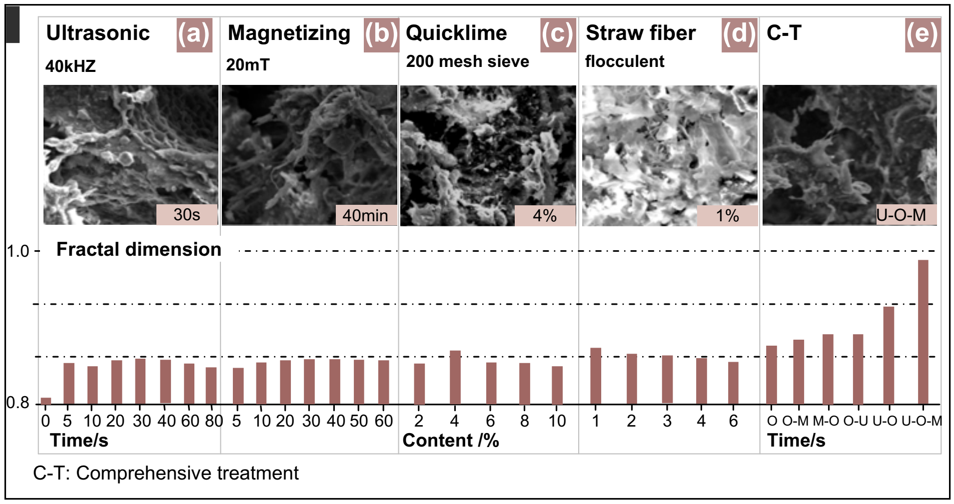

Fig. 3. The fractal dimension of the sludge under different operating conditions in ultrasonic, magnetic field, quicklime, and straw fiber.

beneficial to extrusion of dewatering, this property was disadvantageous not only to vacuum filtration but also to engineering applications, because of increased dewatering costs. Fractal dimension expression of the SEM micro-image is presented in Fig. 3(c), which indicates that dewaterability of the municipal sludge is in accordance with the variation law of fractal dimension.

Quicklime powder was mixed in proportions of 2, 4, 6, 8, and 10% dry weight of the municipal sludge and stirred mechanically and evenly to obtain the SRF shown in Fig. 1(d), and the dewatering speed and accumulated volume shown in Fig. 2(d). The optimal quicklime powder content was 4%. The chemical reaction of the quicklime powder formed a skeleton that could bear high pressure, which significantly improved the dewaterability of the municipal sludge. With a low quicklime powder content, the formation of a skeleton that could bear high pressure was difficult, whereas with a high quicklime powder content, dewatering costs increased, which was disadvantageous to engineering applications. Fractal dimension expression of the SEM micro-image is presented in Fig. 3(d), which indicates that the dewaterability of the municipal sludge is in accordance with the variation law of fractal dimension.

3.2. *Dewaterability of municipal sludge combined conditioning by ultrasonic, magnetic field, straw fiber, and quicklime*

The ultrasonic (U) processing time was 30 s, whereas the magnetization (M) processing time was 40 min. The municipal sludge was added with straw fiber equal to 1% of the municipal sludge dry weight and quicklime powder equal to 4% of the municipal sludge dry weight (O). O-M represents dosing conditioning the municipal sludge first and then treating it with magnetic field, whereas M-O represents treating the municipal sludge with magnetic field first and then dosing conditioning it. The municipal sludge was processed with O-U, U-O, and U-O-M.

The SRF of the municipal sludge is shown in Fig. 4(a), and the dewatering speed and accumulated volume are presented in Fig. 4(b). The figure indicates that the treatment effect of O-M is better than that of M-O, and the treatment effect of U-O is better than that of O-U. Magnetic field by the combination of ultrasonic, quicklime powder, and fiber (U-O-M) produced optimal dewaterability. A reasonable ultrasonic treatment can crack the EPS of the sludge, which is beneficial to dose conditioning. Improving the physicochemical character of the solid–liquid surface of the sludge is convenient under the magnetic field effect after dose conditioning.

A comparison of the above treatments is shown in Fig. 2, which indicates that the combination of quicklime powder and fiber produces a better effect than their separate use. Their combination is beneficial to the formation of the skeleton and dewatering channel.

The fractal dimension expressions of the SEM micro-image of the municipal sludge processed with different operating conditions are shown in Fig. 3(e). The figure indicates that the dewaterability of the municipal sludge is in accordance with the variation law of fractal dimension.

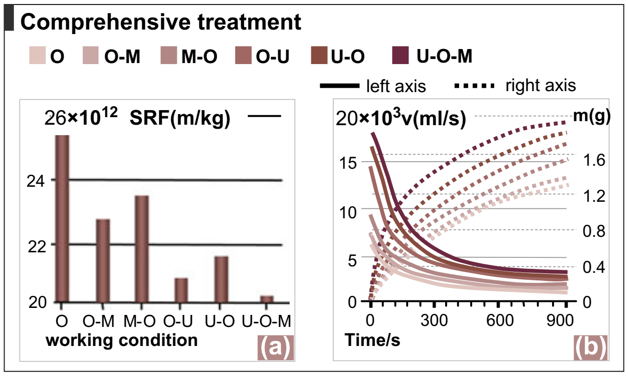

Fig. 4. Sludge dewaterability, dewatering speed, and accumulated volume under the conditions of comprehensive treatment.

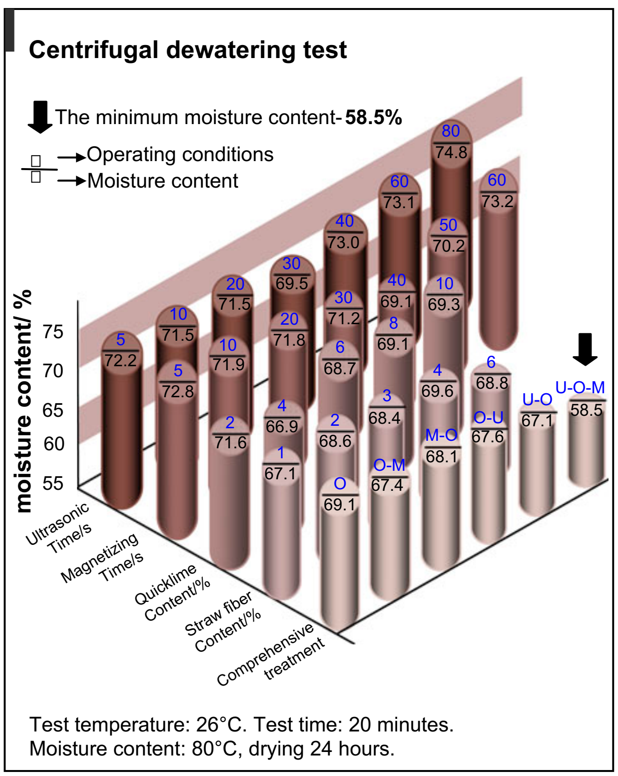

Fig. 5. Sludge moisture content under different operating conditions.

3.3. Moisture content analysis of each working condition after dewatering

The centrifugal dewatering results of the different operating conditions are shown in Fig. 5. The figure shows close correspondence between the dewatering result law and the dewaterability of all operating conditions as well as the fractal dimension. The higher is the fractal dimension; the lower is the SRF of the sludge. On the contrary, the lower is the fractal dimension, the more difficult is the dewatering of the sludge (The SRF of the sludge becomes large. Sludge dewatering speed and accumulated volume become smaller). The sludge treated with U-O-M obtained the highest fractal dimension of 0.98, and the water content after centrifugal dewatering was 58.5%, which favored the smooth implementation of subsequent municipal sludge process engineering.

4. Conclusions

In summary, U-O-M achieved the best dewaterability of municipal sludge through an experiment with the following conditions: 30 s 40 Hz ultrasonic treatment, 40 min magnetization with 20 mT strength, 4% quicklime powder content, and 1% fiber content. The water content after centrifugal dewatering with a 3,000 separation factor was lower than 60%, which satisfies various engineering applications such as landfills, ecological slope protection, and landscaping.

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