Influence of Microwave and Ultrasound on Sludge Dewaterability

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***Abstract*—Sludge with large production is difficult to be dewatered without any pretreatment. Pretreatment with ultrasound and microwave can adjust the structure of sludge and change the water form, therefore increase the water content which could be dispelled easily. Dewaterability and morphological of sludge from sewage treatment plant including microwave and ultrasound were studied. Capillary Suction Time(CST), viscosity, Settle Volume(SV), water content, Chemical Oxygen Demand (COD), Zeta potential and morphological characteristics were tested. After microwave modification, the particle size of sludge ranged from 33.55μm to 28.98μm, and fractal dimension was about 2.8. Microscopic image analysis showed that the particle of sludge became coarse. After ultrasound modification, the particle size of sludge ranged from 33.55μm to 9.44μm, fractal dimension was about 2.9. Thus, the smaller particles were observed after ultrasound. The gray associate degree coefficient of viscosity and moisture content is the bigest. Through the analysis of dewatering characteristics of sludge and water content, a model which contributes to predict moisture content of sludge online was established.**

Keywords-sludge, microwave, ultrasound, dewaterability morphology

I. INTRODUCTION

Bio-sludge, which contains large quantities of water, biomass and extracellular polymeric substance, is difficult to be dewatered by normal method [1] Dewatering of sludge is significant of economic and environmental friendly to the minerals, chemicals and water treatment industries. Disposal of sludge is costly, however, the reduction of sludge volumes through dewatering can provide large cost savings [2-4].Due to the presence of solids, all the water within the sludge does not have similar properties in terms of vapour pressure, enthalpy, entropy, viscosity and density. The treatment and disposal of sewage sludge is one of the most problematical issues affecting wastewater treatment in the word. The traditional outlets for sewage sludge are to spread on the agricultural land, or to form a cake for deposit to landfill or incineration. In order to create a sludge cake, water must be removed. Existing dewatering technology based on pressure can only remove a very limited amount of this water because of the way in which water is bound to the sludge particles or flocs. CST characteristics, viscosity, SVx, water content, COD, Zeta potential and morphology can be used to test dewatering characteristics ability [5-9]. The change of flocs in sludge can also be observed when dewatering [10,11].

Lidia Wolny studied sludge conditioning influence on the rheological parameters and determinated correlation with dewatering parameters of sewage sludge [12]. The ruesuts showed ultrasound pretreatment could enhance the filtration progress and decrease the moisture content of the sludge from 99% to 80%. After 2-4 min treatment of ultrasound under intensity of 400 W/m^2, the bound water of sludge decreased from 16.7 g/g (dry base) to above 2.0 g/g (dry base) [13] Raf Dewila reported the extensive investigations using an ultrasonic treatment of wasted activate sludge, and studied its potential to reduce sludge quantities and achieved a better dewaterability[14].

Image analysis procedures are applied in the study of Ewa Liwarska-Bizukojc to measure the morphological parameters of activated sludge flocs, the result showed the decrease of sludge flocs dimensions deteriorates their settleability [15]. Wang Zhijun studied the influence of thermal hydrolysis pretreatment on surplus sludge characteristics, the dissolving rate of volatile suspended solids and protein reached 60.02% and 47.21%, respectively, at 210℃ with 75min. The organic matter further hydrolyzed producing lower molecular substances, in which the volatile fat acids occupied 30%~40% of soluble COD[16]· Stephanie Glendinning described experimentation using electrokinetic geosynthetics (polymer-based materials containing conducting elements). These have been used to minimize the problem of electrode corrosion and create a sludge treatment system that can produce dry solids contents in excess of 30% [17].

It is very important to find Influence of dewaterability and set up the model to predict water content of sludge. First use ultrasound and microwave to pretreat sludge, then test CST, viscosity, SV, water content, COD, Zeta potential and morphological characteristics and establish a model to predict moisture content.

II. MATERIALS AND METHODS

A. Materials

The sludge was sampled from waste water treatment facility at Huangcun plant of Beijing Drainage Corporation. The pH value of the original sludge is 6.85, the water content of sludge is 99.32%, measured by water content test instrument of MA 100.

B. Method

MD-6 microwave sample treatment system is adopted.

The parameter is as follows: temperature control range: 0 to 300 ℃, temperature control accuracy: ± 0.5 ° C; direct contact pressure measurement; real-time monitoring of 900psi; controlling pressure accuracy: 0.01Mpa; exhaust volume $3m^3$ /min; 10 samples were processed at the same time. Sonics Materials 750 ultrasonic processor is adopted. The parameter is as follows: ENERGE: 50000J; the ultrasonic amplitude AMPL: 35%.

Using conventional dehydration technology for sludge is difficult to reach a higher efficient dewaterablity. Pretreatment method can break up EPS, promote the release of bound water to increase the free water content, and enhance the sludge dewatering characteristics.

The methods such as bound water, capillary suction time, specific filtration resistance, yield stress and zeta potential, solubility COD, distribution of particle size and image analyses of sludge are used to estimate dewaterability of sludge.

- COD

Solubility COD is a vital parameter to estimate dewaterability of sludge after pretreatment. The supernatant of pretreatment sludge after the centrifugation is tested by potassium dichromate method to characterize organic matter release. If the experimental results change significantly, it indicates that pretreatment technique achieves a better dewaterability, provoke a release of COD from solid, preferably transformes into biodegradable organics and possibly destroys EPS of sludge.

- Viscosity

The viscosity of sludge which (like the yield stress or the storage modulus) represent its network strength, should be related to sludge dewaterablity. Previous efforts to verify such a correlation which would allow prediction of full scale dewater ability have not provided strong correlations. The viscosity of sludge was estimated by using Haake RV1 rheological tester.

- Distribution of particle size

Particle size is measured by laser diffraction technique (Mastersizer 2000) where the sludge (without supernatant fluid) is used as the sample, and water is used as dispersion mediator. Particle size distribution before and after the pretreatment are compared to observe sludge particle distribution during the easy dehydration size.

- The slice image of sludge microtome

Electronic microscope (Olympus CX41) and CCD (JVC) are used to observe slice image after different pretreatment (microwave and ultrasound) to evaluate dewaterability. Fractal dimension is analyzed for the images of sludge to characterize the morphological parameters and aggregation state changes of sludge floc.

III. RESULTS AND DISCUSSION

A. *Dewatering Characteristics*

- Microwave pretreatment

Sludge was treated by microwave system under different temperature conditions. The temperature was achieved to 50℃, 60℃, 70℃, 80℃, under 15℃/min heating rate.The sludge dewatering characteristics including SV, viscosity, moisture content, CST and Zeta potential was shown in Table I.

Through a high-frequency microwave heating temperature causes the accelerated motion and collision of the charged sludge particles, and promotes sludge structure destabilization. Simutaniously, the microwave causes the temperature gradient generated inside the sludge, and the destruction of binding ability between combined water and the extracellular polymers, thereby improving the dewatering properties of the sludge. It can be seen from TABLE I that SV, viscosity, moisture content of sludge are reduced accordingly, and the variation of CST and zeta potential is not obvious. The supernatant COD content in the sludge after centrifugation is gradually increased. On the contrary, the excessive microwave energy deteriorates the dehydration effect of sludge.

Calculated the gray associate degree coefficient of dewaterablity parameters and moisture content. It can find the largest coefficient of viscosity and moisture content is 0.69, followed by CST.

TABLE I. DEWATERING CHARACTERISTICS AFTER MICROWAVE

T /℃	SVx /%	CST /s	Viscosity /mPa s	COD /(mg/l)	Zeta potential /mV	Moisture content /%
0	40	36.9	12.880	290	-3.42	87.24
50	40	38.3	13.982	400	-3.20	86.60
60	31.25	40.9	14.836	429	-3.23	85.55
70	28.57	36.00	11.270	480	-2.86	83.12
80	23.33	37.83	12.938	576	-2.26	83.21
Degree	0.48	0.57	0.69	0.56	0.50	-

- Ultrasonic pretreatment

Sludge was treated by ultrasonic under 0s, 20s, 40s, 60s, 80s. The resultant dewatering characteristics of sludge was shown in TABLE II.

Ultrasonic cavitation caused tremendous hydraulic shear, which broke the extracellular polymer in sludge system, thereby under mining powerful molecular force between original flocs. It can be seen from TABLE II that SV, viscosity, moisture content are reduced accordingly. CST and Zeta potential did not change significantly, and COD content was gradually increased. Excessive ultrasonic energy will deteriorate sludge dewatering effect.

Calculated the gray associate degree coefficient of dewaterablity parameters and moisture content. It can find the largest coefficient of viscosity and moisture content is 0.70, followed by Zeta potential.

TABLE II. DEWATERING CHARACTERISTICS AFTER ULTRASOUND

T /s	SVx /%	CST /s	Viscosity /mPa s	COD /(mg/l)	Zeta potential /mV	Moisture content /%
0	40	32.1	10.756	296	-3.42	90.51
10	27.5	182.5	5.803	762	-3.40	91.05
20	25	180	5.616	925.6	-2.89	89.40
40	20	198.5	5.276	1562.4	-3.00	89.33
60	12.5	178.2	5.224	1984	-2.20	86.85
80	15	215.4	5.308	2130	-2.21	86.98
Degree	0.62	0.60	0.70	0.55	0.63	-

B. Particle Size Distribution

- Particle size of the sludge after microwave

The particle size distribution after 50℃, 60℃, 70℃, 80℃ microwave heating is measured, the corresponding data is recorded in TABLE III. It can be seen from TABLE III, The average particle size of the sludge is 33.55μm without microwave pretreatment, however, the particle size is reduced significantly after microwave. The size of the sludge increased gradually with the increasing of temperature. It can be concluded that microwave can change the internal structure and the nature of sludge. With the increase of the temperature of the microwave heating, the sludge particle size increased gradually, which indicated that the thermal effects of microwave increased molecular motion and collisions among sludge particles, therefore, small particles aggregated into larger particles.

- Particle size of the sludge after ultrasound

The sludge after 0s, 10s, 20s, 40s, 60s, 80s ultrasound is selected as samples. The average particle size of the sludge was measured, and the data is recorded in TABLE IV. It can be seen from Table IV, the particle size of the sludge is gradually reduced with increasing ultrasonic time. Without ultrasonic treatment, the particle size of the sludge was 33.55μm, however, the smallest particle size can be achieved to 9.44μm after ultrasonic. With the increase of the time of ultrasound, the sludge granularity tended to be stabilized.

TABLE III. PARTICLE SIZE AFTER MICROWAVE

T/℃	20	50	60	70	80
Particle size /μm	33.55	28.06	28.93	28.98	29.21

TABLE IV. PARTICLE SIZE AFTER ULTRSOUND

T/s	0	10	20	40	60	80
Particle size /μm	33.55	12.63	10.47	9.73	9.68	9.44

C. The Sludge Fractal Dimension Analysis

The morphological parameters of the sludge, including particle size distribution of floc, fractal dimension and filamentous index, can effectively measure the sludge dewatering characteristics. To study the particle size distribution of sludge floc is studied using fractal theory to observe the effects of pretreatment on sludge fractal dimension of floc.

The particle distribution of sludge floc is tested by application laser particle size analyzer. The curve of accumulated sludge sieve and particle size in double logarithmic coordinate system is established. Origin8.0 software is used for linear fitting, thereby slope b values are obtained. According to D = 3-b, the fractal dimension D can be calculated.

A fractal dimension of the microscopic images of the sludge is calculated using Fractalfox2.0 software. The sludge fractal dimension after microwave andultrasound pretreatment using two methods is obtained as shown in Figure.1 and Figure.2.

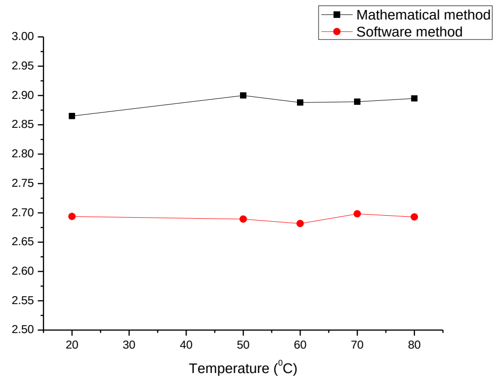

Figure 1. The fractal dimension analysis after microwave

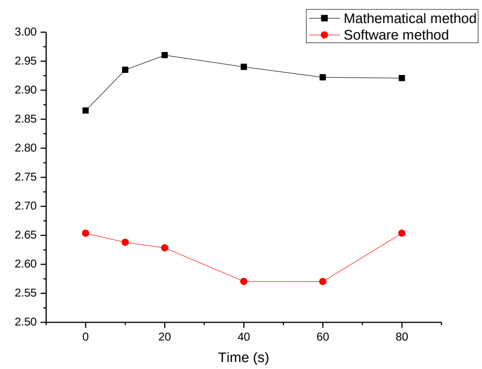

Figure 2. The fractal dimension analysis after ultrsound

The fractal dimension D characterized floc structure that represents the degree of filling of the floc particles, and therefore D can be used to measure the state of aggregation of the floc. The fractal dimension of sludge after pretreatment technology with a mathematical calculation methods and Fractalfox2.0 software analysis methods is compared. It can be seen sludge fractal dimension of the two methods have the similar trend.

D. Establishing the Model of Sludge Dewatering Characteristics

From the data in Tables I, II the comprehensive four parameters, including viscosity, SV, particle size and the fractal dimension are identified. The model of sludge dewatering characteristics is established between moisture content of sludge and four parameters. The relationship between sludge moisture content and four parameters is assumed to be multivariate linear.

The model of sludge dewatering characteristics after microwave pretreatment is:

$$Y=0.59602A+0.18513B+0.28991C+19.45685D+8.35249$$

The model of sludge dewatering characteristics after ultrasound pretreatment is:

$$Y=3.54981A+0.32184B+0.60511C2.31709D+129.49702$$

A——viscosity.

B——SV.

C——particle size.

D——fractal dimension.

The results of multivariate linear model show that correlation coefficient is close to 1, and residual E is smaller. The multivariate linear model established by Origin8.0 software between sludge moisture content and four parameters is effective.

IV. CONLUSIONS

From the experiment of the water content, concentration of COD, CST and structure of sludge after microwave and ultrasound were studied

(1) The experiments show that sludge SV, viscosity, sludge moisture content is reduced accordingly, and the supernatant COD content increased with increasing radiation energy. Appropriate microwave and ultrasound radiation are conducive to improve the dewatering characteristics of the sludge. When the radiation energy is too high, the sludge dewatering effect will deteriorate.

(2) The morphological characteristics of the sludge changes significantly. After microwave modification, the particle size of the sludge ranged from 33.55μm to 28.98μm, and the fractal dimension was about 2.8. The microscopic image analysis showed that the particle of the sludge became coarsening. After ultrasound modification, the particle size of the sludge ranged from 33.55μm to 9.44μm, and the fractal dimension was about 2.9.

(3) The gray associate degree coefficient of viscosity and moisture content is the bigest. The dewatering characteristics model of the sludge was established between moisture content and characterization parameters.

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