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Thermophilic anaerobic digestion of sewage sludge

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ABSTRACT

In view of the problems of poor sludge treatment effect, low cracking rate and poor VSS (volatile solid organic content) removal effect during sewage treatment, this paper optimizes the high-temperature anaerobic digestion method of sludge to effectively solve the above problems. Analyze the characteristics of sludge and stabilize the sludge; optimize the high-temperature anaerobic digestion process of sludge according to the problems of traditional methods. In order to verify the sludge treatment effect of the method in this paper, the control sludge was designed using the secondary sludge return sludge as the test sample. The results show that through the microscopic image of the sludge floc structure and the characteristics of the three-dimensional fluorescence spectrum, the method in this paper can effectively improve the cracking rate, and the VSS removal effect is obvious.

Keywords: Floc structure of sludge; 3D fluorescence spectral characteristics; High-temperature anaerobic digestion method; Stabilization treatment

1. Introduction

In the process of municipal sewage treatment, sludge disposal becomes more and more important, and the cost of sludge disposal accounts for 20%–50% or even 70% of the operating cost of sewage treatment plants. Sludge from sewage treatment plants must undergo some treatment to reduce sludge volume, improve sludge properties and reduce related environmental problems [1–3]. These treatments include reducing the water content of the original sludge; conversion of highly decaying organic matter into relatively stable or inert organic and inorganic residues; final residue meets the regulatory conditions for treatment and acceptance. More and more attention has been paid to the technology of mixed treatment of sewage sludge due to the strict limitation of the refractory components in the land application of sewage sludge. The essence of the biological treatment of urban sewage (biofilm method or activated sludge method) is the metabolic process in which microorganisms take colloidal and dissolved organic pollutants in sewage as the nutrient substrate. The result of this process is that sewage is purified and microorganisms obtain energy to synthesize new cells [4]. In a stable operating biological system, in order to maintain constant biomass, the newly added biological cell material needs to be discharged as residual sludge (activated sludge process) and detached biofilm [5,6]. With the development of the economy, the growth of population, the constant improvement of municipal services, the sewage treatment in China is developing at an unprecedented rate and expand, the consequent sludge quantity is becoming more and more big, the sludge treatment is greater than sewage treatment cost project, its processing cost of the total cost of sewage treatment plant commonly 25%~40%, even as high as 60%. If the sludge is not properly treated or disposed of, it will cause harm to the environment [7]. Therefore, no matter from the pollutant purification degree, or wastewater treatment technology development in the importance and proportion of investment, sludge treatment plays an important role.

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At present, China has more than 427 urban sewage treatment plants in operation, with an annual treatment capacity of 113.6 × 10^8 m^3. According to relevant estimates, by 2010, the annual output sludge of China's urban sewage treatment plants (75%~80% moisture content) will reach 140 × 10^6 T [8]. A batch of sewage treatment plants built in the early stage have still not found a good treatment and disposal scheme after long-term exploration and test, sludge disposal has become a thorny problem. Therefore, this paper studies the high-temperature anaerobic digestion method of sludge in the sewage treatment process, and analyzes the influence of high-temperature anaerobic digestion treatment on sludge cracking and VSS (volatile solid organic components content) removal efficiency.

2. Characteristics and treatment of sludge

2.1. Characteristics of sludge

The residual sludge is mainly composed of suspended sludge floc, which is composed of a large number of dispersed microorganisms and bacteria via the extracellular polymer (EPS), cation (Ca^{2+}, Mg^{2+}) and other fine particles. Sludge has the following characteristics:

- High water content, perishable, and contains a variety of pollutants;
- Microbes, high content of pathogens, the number of pathogenic bacteria in raw sludge per gram millions, these microbes including coliform bacteria and streptococcus faecalis, e. dung, phage, salmonella, dysentery bacillus, copper green MAO coli, parasitic ovum/larva, roundworm, whipworm, group whipworm, Toxocara, Hymenoptera larvae, intestinal virus, etc. [9,10];
- Sludge gives off a foul odor and releases seriously polluting greenhouse gases into the atmosphere;
- Containing heavy metals;
- Treatment cost is expensive, generally accounting for 15%~30% of the total operation cost of the sewage treatment plant and 10%~25% of the total investment. The key factor is the high water content [11].

2.2. Common disposal methods

The main goal of sludge treatment and disposal is to realize the stabilization, reduction, harmlessness and resource recovery of sludge. Sludge stabilization is a major problem faced by sludge treatment. Through stabilization of sludge, it can be harmless to sludge and reduce the quantity of sludge, thus creating conditions for the reclamation of sludge [12,13]. In sludge disposal, we usually use incineration, landfill and land use [14]. Incineration as the core treatment method is the most thorough treatment method, sludge incineration residue sterile, odorless, volume reduction of 60%, can quickly and greatly reduce the sludge to achieve quantitatively, transportation and final disposal greatly simplified. The heat generated after incineration can also be fully utilized and has a promising application prospect. Sludge must be dehydrated before incineration (limited application and high cost), and harmful gases will be generated during incineration. Heavy metals in sludge will also pollute the air with the diffusion of soot. After incineration, about 1/3 solid weight waste remains in the form of ash [15]. Moreover, incineration is expensive to process, costing about $300 per tonne of sludge treated in the United States (mainly fuel costs). In Japan, an incinerator with a capacity of around 50 m^3/d (including civil works and ancillary equipment) costs up to ¥2.8 billion. In China, it is difficult to widely apply the incinerated flue gas in small and medium-sized towns due to its one-time investment and high treatment cost and the need for further treatment [16]. At present, the main methods of sludge disposal in China are low investment, low operating cost, simple operation and convenient management. However, landfill requires a large area and serious environmental pollution. In addition, the high moisture content and viscosity of sludge bring difficulties to landfill operation. With the reduction of available landfill space, the continuous increase of sludge volume, and the increasingly strict regulatory measures, the proportion of landfills in sludge disposal methods is gradually decreasing [17]. Land use of sludge can improve physical and chemical indexes and biological properties of soil, but nitrogen and phosphorus in sludge may lead to water pollution through hydraulic circulation. Heavy metals can accumulate in the soil; Pathogenic microorganisms and parasitic eggs in sludge may exacerbate disease transmission [18,19].

The sludge of the general municipal sewage treatment plant contains 50%~70% organic matter, more nutrients such as nitrogen and phosphorus, and harmful substances such as pathogenic bacteria and parasitic worm eggs. Its chemical properties are extremely unstable, and if left untreated or improperly disposed of, it will form pollution diversion and even pollute the environment, especially the groundwater environment, emit a stinky smell, and even spread diseases. Therefore, the subsequent sludge disposal process must effectively prevent these problems, that is, the sludge stabilization treatment must be carried out. Sludge stabilization is an important part of sludge treatment and disposal. It can reduce various pathogens, eliminate unpleasant odors, reduce the amount of liquids and solids, and inhibit the potential for decay. The sludge stabilization process is aimed at reducing the content of volatile or organic components in sludge. The usual stabilization methods of sludge are anaerobic digestion, aerobic digestion, sludge composting and chemical stabilization [20–23].

Various sludge stabilization methods have different advantages and disadvantages (Table 1). In the practical application process, the sludge stabilization technology should be selected based on comprehensive consideration of various factors. Anaerobic digestion is a widely used method in various sludge stabilization techniques. Anaerobic digestion can not only reduce the amount of sludge, reduce the organic content of stable sludge, but also can produce methane gas as an energy source.

2.3. Problems existing in traditional anaerobic digestion of sludge

The most widely used anaerobic digestion technology in China is the medium-temperature anaerobic digestion technology. In the construction of large municipal sewage

Table 1
Comparison of sludge stabilization technologies

Stable technology	Advantages	Disadvantages
Anaerobic digestion	Good volatile solid removal rate, if biogas is used, the net operating cost is low, biological solids suitable for garden or agricultural, low pathogen activity, total sludge reduction	Operators are required to be skilled, prone to some operational problems, and have safety problems related to flammable gases. Foam may be produced, methane formation is slow, the superfluid is rich in COD, BOD, SS and oxygen, cleaning is difficult (scum or coarse sand), may produce foul odor, initial investment is high
Aerobic digestion	Especially for small plants, the initial investment is lower, the equipment cost is lower, compared with anaerobic, the superfluid is less, the operation control is simpler, the operation problem is less, will not produce odor, easy to dispose, the production of sludge is easy to dehydrate, the total sludge reduced	High energy consumption, higher removal rate of volatile solids compared with anaerobic digestion, low temperature seriously affect the operation, may produce foam, the removal of parasitic eggs or pathogenic microorganisms is not effective
Sludge compost	High quality, marketable, low initial investment (static compost)	Filler, strong wind and artificial turning, a lot of land area and carbon source, produce odor alkaline process low investment cost, easy to operate, smell and a health hazard, it is better to kill pathogens, as temporary or emergency method good drug usage is bigger, need to dispose of solid content increased, final disposal of the narrow way.
Alkaline process	Low investment cost, easy to operate, produces odors and health hazards, kills pathogens effectively, as a temporary or emergency method is good	Dosage is large, the amount of solids to be disposed of increases, and the final disposal outlet becomes narrow

COD – chemical oxygen demand; BOD – biochemical oxygen demand; SS – suspended solids.

treatment plants, a sludge anaerobic digester is usually built to use the gas. However, after the sewage plant is completed and put into operation, few sludge digester can function normally. This is mainly due to the disadvantages of the traditional sludge anaerobic digestion process, such as slow reaction rate, long sludge retention time in the tank, a large volume of the tank, complex operation and management, low methane content in the gas, unable to achieve energy balance and so on. Even 20 d to 30 d residence time can only remove some volatile solids (VS). It has been proved that the hydrolysis reaction of the sludge cell wall is the limiting step of sludge anaerobic digestion rate, mainly because: most organic compounds in sludge exist in microbial cells, the cell wall of microbial cells is a stable semi-rigid structure, plays a role of cell protection. The cell wall is an inert material that is difficult to be degraded and hydrolysis is difficult, which leads to a long time of anaerobic digestion of sludge. In order to shorten the time of sludge anaerobic digestion and reduce the amount and volume of sludge, there have been many studies on sludge pretreatment technology abroad, providing more suitable material characteristics for the subsequent sludge treatment and utilization process. For example, sludge cracking prior to anaerobic digestion is performed to promote the digestion rate. The purpose of sludge cracking is to destroy the structure and cell wall of sludge, so as to change the structure of sludge floc, dissolve the contents inside the cell, enter the aqueous phase, and change the hard degradable solid material into the easy degradable soluble material. After cracking the sludge, the content of organic matter in the aqueous phase will be greatly increased in a relatively short time, which will shorten the residence time of anaerobic digestion. In addition, the biogas yield will be greatly increased.

2.4. High-temperature anaerobic digestion of sludge

In 1993, the United States issued 503 rules for biological solids treatment and disposal of sewage sludge, which advocates priority land use for sludge disposal. However, with the development of society, sludge land use technology is restricted by the more and more strict social environment. To protect public health, EPA classifies sludge into A and B. In Category B, the number of fecal *Escherichia coli* is less than 2 × 106 MPN/g, and land use is prohibited. Category A specifies that the number of fecal Escherichia coli should be less than 1,000 MPN/g and the number of salmonellae should be less than 3 MPN/g, which can be used for land use. In order to improve the safe utilization rate of sludge land and effectively kill the pathogenic bacteria of sludge, the anaerobic digestion technology of sludge at high temperature (55°C) has been developed rapidly.

Many original medium – temperature digester have been transformed into high – temperature digester. Compared with the medium temperature treatment, the high-temperature anaerobic technology can degrade organic matter more effectively, increase the discharge of methane in the digested sludge and reduce the volatile matter in the sludge. This not only improves the stability of solid sewage, but also reduces the amount of sludge discharged from the digestive sludge, reduces the load of the digester, and improves the energy balance of the treatment plant. Other advantages of high-temperature treatment are more efficient sterilization and less foam production. The Danish Holbeck Sewage Treatment Plant, the first in Denmark to treat sludge with high-temperature anaerobic digestion, has achieved good results and is the basis for the further development of the process. This process can reduce the original sludge and sludge from sewage treatment plants while removing N and P, it is stable in the range of 50°C~55°C. At eight sewage treatment plants in operation in Denmark, solid sludge reduction and methane production were both above or equal to expectations. The considerable reduction of pathogen content is a favorable by-product of the high-temperature digestion process. The sludge that has been digested at high temperatures can be dewatered to a state of high solids content in existing dehydration facilities, which, combined with a reduction in the amount of sludge in the digester, means a reduction of 30%–40% in the amount of sludge to be disposed of, depending on the type of sewage treatment plant.

In the absence of oxygen, high-temperature anaerobic digestion relies on facultative or obligate anaerobes to transform organic matter into CO_2 and CH_4, and synthesize their own cellular materials at the same time, so as to realize harmless and resource recovery of solid organic matter. The theory of anaerobic digestion evolved from the two-stage theory, Bryant proposed the three-stage theory, and Zeikus proposed the four-stage theory, which led to a breakthrough in the study of anaerobic digestion mechanism. The two-stage theory divides anaerobic digestion into two stages: acid production and methane production. The three-stage theory is that large molecules of organic matter are firstly hydrolyzed by fermentation bacteria into small molecules such as acetic acid and propionic acid, and then decomposed into acetic acid, CO_2 and H_2 by hydroacetic acid-producing bacteria. Finally, CO_2 and CH_4 are generated by methanogenic bacteria. Based on the three-stage theory, CO_2 and H_2 were synthesized into acetic acid by homologous acetic acid bacteria. The three-stage theory and four-stage theory give a scientific and comprehensive description of anaerobic digestion, which is widely recognized by the industry. Fig. 1 shows the high-temperature anaerobic digestion process.

3. Test items and methods

3.1. Sludge treatment and related parameters

The secondary sedimentation tank reflux sludge from a sewage treatment plant in the study area was used as the original sludge. The retrieved sludge was first filtered with 40 mesh and then settled for 24 h, the supernatant was poured, and then the concentrated sludge was preserved in a refrigerator with a temperature of 4°C. The main parameters of the residual sludge after concentration are shown in Table 2. According to the requirements of the experiment sludge dilution experiment.

3.2. Test equipment

In this test, some instruments are needed for the detection of conventional indicators, including pH meter, chemical oxygen demand (COD) quick digestion instrument, fluorescence spectrometer, etc. Table 3 summarizes the main instruments and equipment used in this subject.

3.3. Detection method

The testing items of this subject include total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total residue (TS), VS, suspended solids, VSS and other indicators.

- *TCOD and SCOD are measured by high-temperature rapid digestion method*: when measuring TCOD, the sludge

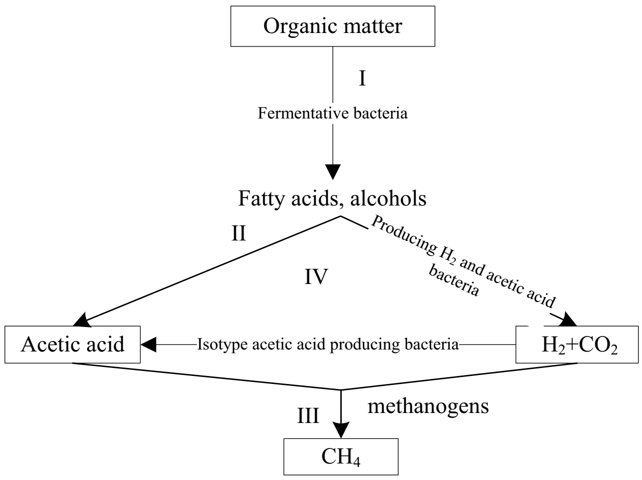

Fig. 1. High-temperature anaerobic digestion process.

Table 2
Main parameters of residual sludge after enrichment

Project	Average	Standard deviation
pH	6.8	0.2
TCOD (mg/L)	31,375	357
SCOD (mg/L)	605.1	23.5
TS (mg/L)	32,720	613
VS (mg/L)	21,586	392
SS (mg/L)	31,855	845
VSS (mg/L)	20,925	367

TCOD – total chemical oxygen demand; SCOD – soluble chemical oxygen demand; TS – total residue; VS – volatile solids; SS – suspended solids; VSS – volatile solid organic content.

Table 3
Summary of instruments and equipment

Name of the instrument	Model
Gas chromatograph	Agilent 7890A, California, USA
COD quick digester	5B-1
Electric drying oven	101A-1
PH meter	Lightning PHS-2F
Electronic balance	Sartorius TE212-L, Gottingen, Germany
Acid burette	–
Constant temperature water bath oscillator	SHZ-A
High-speed centrifuge	TG20WS
Fluorescence spectrometer	Jasco FP-6500, Japan

sample needs to be diluted with deionized water to the range of COD mark and then measured. When measuring SCOD, the sludge sample was first centrifuged in a centrifuge with a speed of 10,000 rpm for 5 min, and then the supernatant after centrifugation was filtered with a 0.45 μm filter membrane, and the filtrate was diluted with deionized water according to the range of the mark determination of SCOD.

- *Measure TS and VS by the gravimetric method*: take the crucible baked to constant weight in 105°C oven, put it in a desiccator, cool and weigh M0, take 10.0 mL sludge sample into the crucible, and put it in 105°C oven bake to constant weight M1, then TS = (M1—M0)/0.01 of the sludge, then burn in 600°C muffle furnace for 2 h, take it out and put it in a desiccator to cool and weigh M2, then the VS of the sludge = (M1–M2)/0.01.
- *Use a weight method to measure VSS*: take 10 mL of sludge and centrifuge in a centrifuge with a speed of 10,000 rpm for 5 min to remove the supernatant. The centrifuged sludge is removed and processed according to the steps in (2). And VSS.

3.4. Three-dimensional fluorescence spectroscopy

The three-dimensional fluorescence spectrum of the sample was extracted and measured with a 10 mm cuvette. The xenon lamp is the excitation light source, the excitation wavelength Ex scanning range is 220–450 nm (step length is 5 nm), and the emission wavelength Em scanning range is 280–550 nm (step length is 1 nm). In order to reduce Raleigh scattering, ultrapure water is used as the blank, and the fluorescence spectrum of each sample is subtracted from the blank solution (ultrapure water).

4. Experiment

In order to study the treatment effect of high-temperature anaerobic digestion of sludge, this paper analyzes the four indicators of sludge floc structure, three-dimensional fluorescence spectrum characteristics, VSS removal rate and sludge cracking rate before and after treatment to give a more comprehensive treatment result. Verify the effectiveness of this method.

4.1. Experimental indicators

- Sludge cracking degree D (%):

$$D = \frac{SCOD_n - SCOD_0}{TCOD_0} \times 100\% \quad (1)$$

In the formula, D represents the sludge cracking rate; $SCOD_n$ represents SCOD in the original sludge treatment process; $SCOD_0$ represents SCOD of the original sludge; $TCOD_0$ represents TCOD of the original sludge.

- VSS removal rate(%):

$$VSS_c = \frac{VSS_w - VSS_x}{VSS_w} \times 100\% \quad (2)$$

In the formula, VSS_c represents the sludge removal rate; VSS_x represents the original sludge digestion VSS; VSS_w represents the original sludge VSS.

4.2. Experimental results

4.2.1. Sludge floe structure change

Figs. 2a and b are photomicrographs of the sludge floe structure before and after sludge pretreatment, respectively. It can analyze the degree of cracking of the remaining sludge by pretreatment. It can be seen from the figure that the floc structure of the original remaining sludge is complete and large in size, forming a dense network structure, as shown in Fig. 2. After high-temperature anaerobic digestion treatment, the structure of the sludge floc was destroyed and became loose, fragmented, and small in size, as shown in b of Fig. 2. The structural changes of the remaining sludge before and after pretreatment indicate that the structure of the remaining sludge floc is destroyed, and the high-temperature anaerobic digestion method has a significant effect on the remaining sludge.

4.2.2. Comparison of three-dimensional fluorescence spectrum characteristics

The fluorescence characteristics of organic matter are related to the unsaturated fatty chain and aromatic ring structure with functional groups in the structure. It reflects the information of the organic matter in terms of structure, functional groups, heterogeneity and molecular dynamics. The organic matter in the supernatant of sludge can be qualitatively and quantitatively analyzed by fluorescence analysis. The three-dimensional fluorescence spectrum is obtained by performing a fluorescence scan on the analyzed sample, and projecting it on the plane with the excitation light wavelength and the emission light wavelength as the coordinate axis in the form of contour lines, and then obtaining the three-dimensional fluorescence spectrum. Fluorescence spectroscopy to identify and characterize objects with overlapping fluorescence spectra in a multi-component complex system.

There are five main areas of fluorescence spectrum absorption peaks of organic matter in sludge: the area with Ex wavelength of 220–230 nm and the wavelength of Em

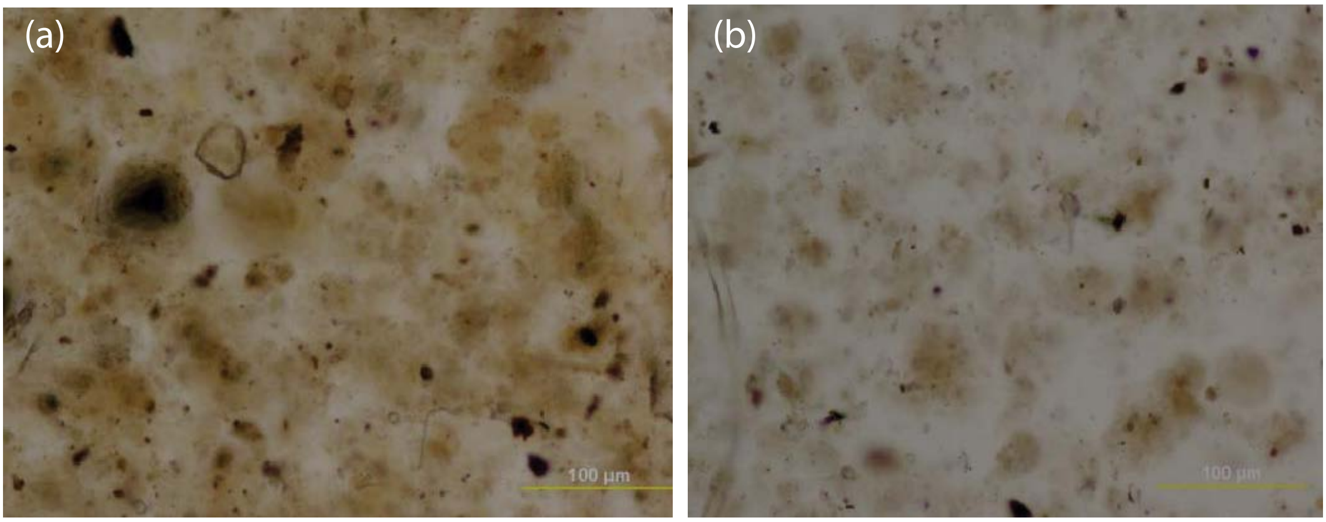

Fig. 2. Structure changes of sludge flocs: (a) raw mud and (b) after processing.

with 290–320 nm is the I area, which mainly indicates the presence of aromatic protein-like substances; The regions with Ex wavelengths of 220–240 nm and Em wavelengths of 320–360 nm are zone II, which mainly indicates the presence of aromatic protein-like substances; the regions of Ex wavelengths 230–250 nm and Em wavelengths 380–430 nm are zone III, which mainly indicate the presence of Fulvic acid-like substance; The regions with Ex wavelengths of 260–290 nm and Em wavelengths of 320–370 nm are the IV region, which mainly indicates the presence of soluble cell by-products; the regions of Ex wavelengths > 265 nm and Em wavelengths > 380 nm are the region V, which mainly indicates the presence of humic acid-like substances.

Dilute the sludge supernatant by a certain multiple for fluorescence spectrum analysis. As can be seen from Fig. 3, the fluorescence peaks of the undisturbed remaining sludge supernatant are mainly in Zone I and Zone II, so the main presence in the sludge supernatant. It is a kind of aromatic protein. After low-temperature heat pretreatment, the fluorescence peaks of the sludge supernatant are mainly in Zone I, Zone II and Zone IV. Therefore, there are mainly aromatic-like proteins and lytic cell pairs mainly present in the sludge supernatant Product substances. Compared with the fluorescence spectrum of the remaining residual sludge supernatant, the fluorescence intensity in Zone I and Zone II increased significantly, indicating that the amount of aromatic-like protein in the sludge supernatant increased, and Zone IV is a newly emerging Fluorescent area, indicating that after pretreatment of undisturbed residual sludge, soluble cell by-products are produced. After analysis, it can be concluded that the high-temperature anaerobic digestion method can rupture the microbial cells in the sludge, thereby dissolving the substances in the cells into the liquid phase, and thus confirms that the high-temperature anaerobic digestion method has a good cracking effect on the sludge.

4.2.3. Sludge cracking rate (D%) comparison

Enzymatic treatment method, thermal hydrolysis method and the method in this paper are used to treat

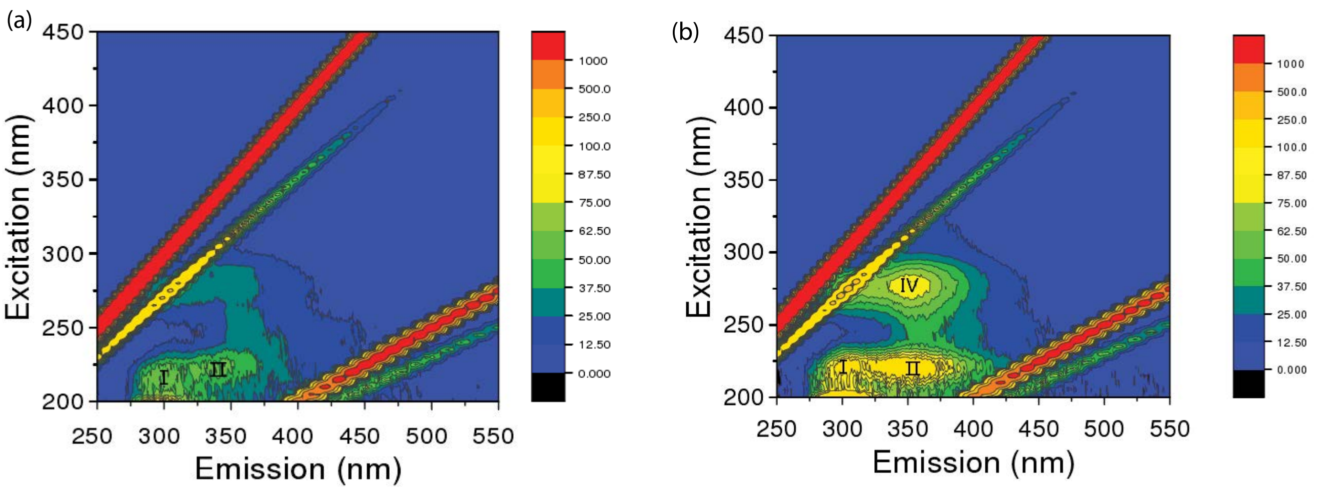

Fig. 3. Three-dimensional fluorescence spectrum characteristics: (a) raw mud and (b) after treatment.

sludge, and the cracking rate of the treated sludge is detected. The results are shown in Fig. 4.

The column in the figure above is the cracking rate of the sludge without treatment, and the line segment protruding from the upper part represents the lifting value. Analysis of Fig. 4 shows that the sludge cracking rate of different methods is different. When the treatment time is 10 min, without any treatment, the sludge cracking rate is 5%, the enzyme treatment method increases the sludge cracking rate by 4%, and the thermal hydrolysis method increases the sludge cracking rate by 8%. The rate has increased by 21%. When the treatment time is 50 min, without any treatment, the sludge cracking rate is 26%, the enzyme treatment method increases the sludge cracking rate by 8%, and the thermal hydrolysis method increases the sludge cracking rate by 6%. The rate has increased by 34%. The method of this paper has the best effect on improving the sludge cracking rate.

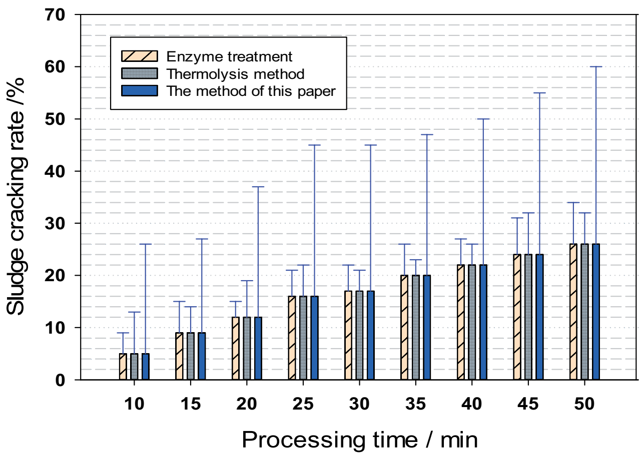

Fig. 4. Cracking rate of sludge under different methods.

4.3. VSS (%) removal rate comparison

Enzymatic treatment method, thermal hydrolysis method and the method of this article were used to treat sludge, and the VSS removal rate of the treated sludge was detected. The results are shown in Fig. 5.

Analysis of Fig. 5 shows that the VSS removal rate of sludge is different in different methods. When the amount of sludge is 200 kg/d, the sludge VSS removal rate of the enzyme treatment method is 68%, the sludge VSS removal rate of the thermal hydrolysis method is 65%, and the sludge VSS removal rate of this method is 98%. When the amount of sludge is 800 kg/d, the VSS removal rate of the sludge by the enzyme treatment method is 76.25%, the VSS removal rate of the sludge by the thermal hydrolysis method is 77%, and the VSS removal rate of the sludge by this method is 96.25%. The VSS removal rate of sludge in this method is maintained at a high level and has better treatment effect.

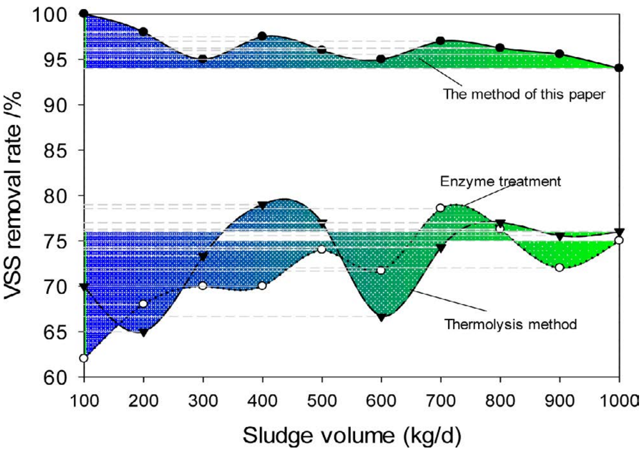

Fig. 5. Comparison of sludge VSS removal rate.

5. Conclusion

This paper studies the high-temperature anaerobic digestion of sludge in the sewage treatment process, analyzes the treatment efficiency of sludge treatment by different methods, and draws the following conclusions through specific experiments:

- Analyze the degree of cracking of the remaining sludge by high-temperature anaerobic digestion method from a visual perspective. After the treatment in this paper, the structure of the sludge floc is obviously destroyed, and the high-temperature anaerobic digestion method has an obvious cracking effect on the remaining sludge.
- By analyzing the characteristics of the three-dimensional fluorescence spectrum, it can be seen that the amount of aromatic-like proteins in the supernatant of the sludge increased, and after the pretreatment of the remaining untreated sludge, lysed cell by-products were produced. The high-temperature anaerobic digestion treatment method can rupture the microbial cells in the sludge, thereby dissolving the substances in the cells into the liquid phase. The high-temperature anaerobic digestion treatment method has a good cracking effect on the sludge.
- The sludge cracking rate of this method is the best. When the treatment time is 50 min, the sludge cracking rate of this method increases by 34%.
- The sludge VSS removal rate of this method is higher. When the sludge amount is 800 kg/d, the sludge VSS removal rate of this method can reach 96.25%.

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