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Sludge remnant treatment based on ultrasound

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ABSTRACT

To solve remaining sludge handling problems, ultrasonic waves were used. In the low C/N wastewater treatment process, a large carbon source needed to be added to maintain a certain nitrogen and phosphorus removal efficiency. After the remaining sludge was dissolved and broken, the internal carbon source was used as an external carbon source, flowing back into the main denitrification process. The change in nitrogen and phosphorus removal efficiency, the reduction of residual sludge and the effect of resource utilization were studied. The residual sludge was pretreated by ultrasonic waves. Under the ultrasonic action, the cell wall of the remaining sludge was cracked, and the contents were released into the system. The SCOD, ammonia nitrogen and total nitrogen in the system greatly increased. An A/O device was used for the rapid acclimation of the denitrification sludge, and the final influent index was 180 mg/L, and the COD was 1200 mg/L. Total phosphorus was 17 mg/L, and the ammonia nitrogen in the effluent was less than 1 mg/L. COD was less than 50 mg/L. The total phosphorus was less than 1 mg/L. The total nitrogen removal rate was about 86%. Regarding sludge reduction, the experimental group accumulated a 783.2 g discharge of residual sludge, while the sludge yield was 0.131 g-MLSS/g-COD, achieving a sludge reduction rate of 23.20%. Therefore, the system can effectively reduce excess sludge.

Keywords: Ultrasonic pretreatment; Internal carbon source reflux; A/O process denitrification; Sludge reduction

1. Introduction

The water content of sludge produced by the activated sludge process is generally high, above 95% [1]. But this method has resulted in great difficulties in treatment and transportation. A dehydration process needs to be carried out first, while at the same time, the sludge produced during sewage treatment projects contains large amounts of organic nutrients. This organic matter is prone to anaerobic reactions, leading to offensive odors and affecting normal work and life [2]. In treatments of industrial wastewater, more than 50% of the heavy metal ions in sewage will be transferred to the sludge and be removed with it. Therefore, sludge has a high heavy metal content. If this kind of sludge is not treated properly, it will easily lead to secondary pollution with heavy metals. Sludge also contains many pathogenic microorganisms, pathogenic bacteria, parasite eggs and other toxic and harmful substances, which can easily spread disease [3–5]. Therefore, it needs to be reasonably disposed of.

Sludge is pretreated harmlessly, and after pretreatment, it is finally filtered. At present, the main pretreatment processes in sewage plants include the following. Water content is reduced 55–80% by gravity concentration and dehydration, which is convenient for subsequent treatment. Digestive fermentation (either aerobic or anaerobic)

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is also a widely used treatment method [6]. The volume of the sludge and the volatile solid organic matter are reduced, and some of the bacteria and pathogens are killed. The main methods of final disposal include sanitary landfill, land use, incineration and reclamation.

2. Experimental materials and methods

In the ultrasonic crushing experiment, the sludge was obtained from the workshop of the Environmental Protection Research Institute of Bluestar Lehigh Engineering Institute Co., Ltd. [7]. Through a three cubic meter A/O device, HDCM denitrification microbial inoculants and residual sludge were produced. The sludge was removed and washed several times with clean water. Then, after natural settlement for 24 h, the supernatant was removed. The characteristics of the sludge are shown in Table 1.

Over the continuing process, a large amount of sewage was used; therefore, artificial water distribution simulated the actual wastewater in the experiment. In using methanol, glucose, ammonium chloride and potassium dihydrogen phosphate, C, N and P elements were added. From these, methanol was calculated to be 1.5 g COD. A small amount of copper, zinc, cobalt, manganese, molybdenum, selenium, nickel and other trace elements were also added. To bring the complexity of the sewage and the simulated wastewater closer to that of their real-world counterparts, a small number of complex carbon sources and refractory substances such as molasses, corn syrup and phenol were added. The apparent yield of sludge refers to the amount of activated sludge produced by the degradation unit mass of COD. This is one of the common indicators that indicate the reduction of residual sludge. The common formulas are as follows [8]:

$$Yobs = \frac{\left[Qs \times Xm + \left(Q - Qs\right) \times Xc\right]}{\left(Q \times \left(Cj - Cc\right)\right)} \tag{1}$$

In the formula, *Yobs* is the coefficient of sludge yield, g-MLSS/g-COD. *Xm* is the concentration of sludge in the treatment system in g/L, and *Qs* is the sludge amount of the system creature in L/d. *Cc* is the concentration of COD in the effluent of the treatment system in mg/L, and *Xc* is the concentration of *SS* in the effluent of the treatment system in g/L. *Cj* is the concentration of influent COD in the treatment system in mg/L.

Table 1
Characteristics of the sludge

Sludge index	Value
pH	7.04
Moisture content (%)	97.6
MLSS (mg/L)	9667
MLVSS (mg/L)	6385
SCOD (mg/L)	48
Ammonia nitrogen (mg/L)	4.19
Total nitrogen (mg/L)	34.27
Total phosphorus (mg/L)	0.25

Artificial simulated wastewater was used in this experiment, made up of tap water and quantitative nutrients [9]. The calculation of the apparent yield of the sludge can be simplified, and the SS concentration in the effluent can be saved. The concentration of sludge and the COD concentration of water were calculated only in the system [10]. The simplified formula is as follows:

$$Y = \frac{Qs \times Xm}{\left(Q \times \left(Cj - Cc\right)\right)} \tag{2}$$

3. Experimental study on ultrasonic pretreatment of residual sludge

3.1. Experimental method

The remaining sludge from the experimental reserve was settled for 24 h, and the supernatant was removed. Excess sludge of 300 mL was loaded into a 500 mL beaker, and the ultrasonic instrument was put into the crushing experiment. The frequency of ultrasonic breakers is 20 KHz. The sonic energy density was adjusted to 0.05 W/mL, 0.10 W/mL, 0.20 W/mL, 0.40 W/mL and 0.50 W/mL. The measurements for each sonic density were taken at 5 min, 10 min, 15 min, 20 min, 25 min and 30 min. Thus, 5*6 = 30 groups were tested in total. The initial sludge index was used as the control in the experiment. The sludge treated by ultrasonic waves was centrifuged for 10 min. The supernatant was used for the determination of SCOD, ammonia nitrogen, total nitrogen and total phosphorus. At the same time, the structural changes to the sludge floc in different conditions were observed under a microscope.

3.2. Experimental results and analysis

As seen in Fig. 1, the SCOD concentration in the residual sludge in the system obviously increased after the ultrasonic wave pretreatment. The ultrasonic times and ultrasonic energy densities were different, as was the SCOD concentration. The ultrasonic energy density determines the ultrasonic energy, and the time of the ultrasonic is deter-

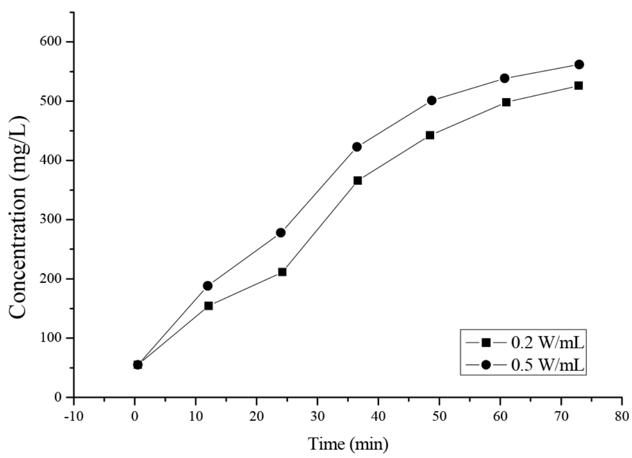

Fig. 1. Change of residual sludge SCOD in ultrasonic treatment.

mined by the ultrasonic time. The combination of the two determines the degree of ultrasonic cracking of the sludge. The sludge cells break and release intracellular substances, resulting in an increase in the COD concentration in the supernatant.

After the excess sludge was broken by ultrasonic waves, the protein and other nitrogen-containing substances in the cells flowed into the liquid phase, and the concentration of ammonia and total nitrogen in the system increased. With the enhancement of sound energy density and the increase of ultrasonic time, the stronger the ultrasonic action and the greater the degree of cell breakage. The concentration of ammonia and total nitrogen in the supernatant also progressively increased. Fig. 2 shows that the growth trend is in line with the growth trend of SCOD in Fig. 1.

After the ultrasonic sludge pretreatment, phosphorus and other phosphorus elements in the phospholipid bilayer of microbial cells were released to increase the total phosphorus concentration in the supernatant. In Fig. 3, the total phosphorus concentration gradually increases over a longer ultrasonic time and the increase of acoustic energy density.

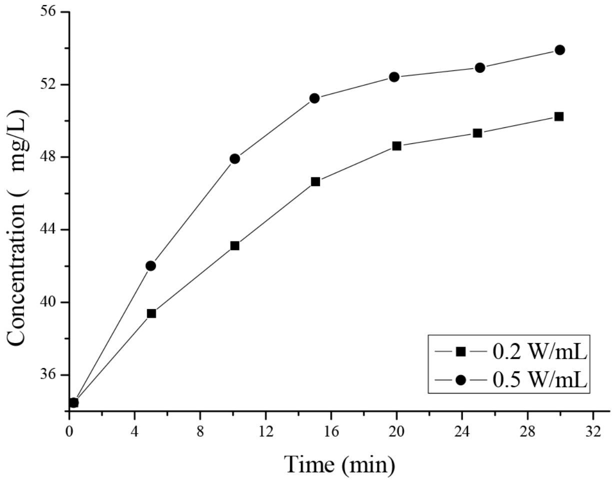

Fig. 2. Change of total nitrogen concentration of residual sludge in ultrasonic treatment.

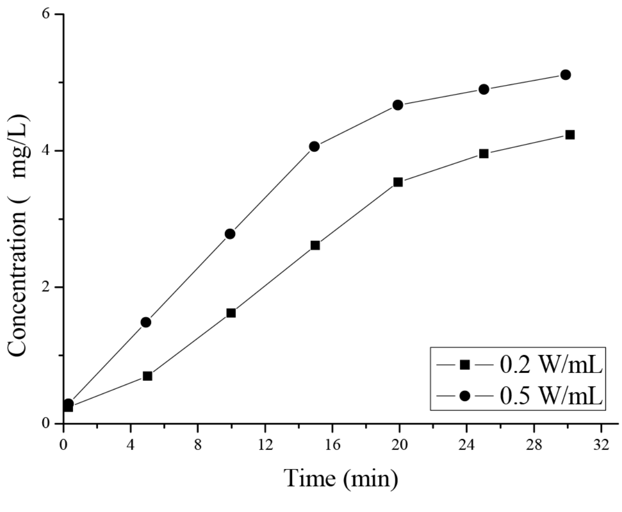

Fig. 3. Change of total phosphorus concentration of residual sludge in ultrasonic treatment.

3.3. The best conditions for ultrasonic pretreatment

The energy consumption of ultrasonic treatment is relatively high. Under the best conditions, the sludge should have reached a higher rate of cracking to meet the requirements of the experiment; this was the focus of the study. From the experimental data, the ultrasonic energy density and reaction time had different degrees of influence on the deciphering of sludge microorganism cells. With the increase of ultrasonic time and sound energy density, the effect of the dissolving of sludge cells was obvious. The concentration of the substance released in the supernatant was improved.

The efficiency of sludge cracking and the energy consumption of the ultrasonic waves were also considered. In the data, the effect of the ultrasonic wave in the first 20 min was more obvious, indicating that the utilization of ultrasonic energy was high at 20 min. After 20 min, the increasing trend of the concentration of each material slowed down, indicating that the ultrasonic efficiency began to decrease after 20 min. The experiment primarily studied the optimum ultrasonic conditions for residual sludge and did not require the release of the maximum concentration of the substance. Therefore, the best ultrasonic parameters were to have an ultrasonic energy density of 0.40 W/mL and an ultrasonic time of 20 min. At this time, the remaining sludge was basically completely broken. The concentration of each index in the mixed supernatant was as follows: SCOD = 517 mg/L, ammonia nitrogen = 17.24 mg/L, total nitrogen = 52.94 mg/L and total phosphorus = 5.17 mg/L.

4. Acclimation of denitrogenation sludge

4.1. Acclimation of denitrogenation sludge

The system started to run steadily after continuous influent, and the temperature of the reactor was 28°C–30°C. The dissolved oxygen in the aerobic pool was 2–4 mg/L. The pH of the sodium carbonate was maintained at 7.5–8.5, and that of the anaerobic pool was controlled at 7.0–7.5. The reflux ratio of the nitrification solution was 1.5–2.5, and the sludge reflux ratio was 0.5–1.0. The two reflux ratios were slightly adjusted during the experimental process. The system residence time was about 30 h. The initial inlet ammonia nitrogen = 20 mg/L, and the COD = 200 mg/L. When the effluent ammonia nitrogen was <1 mg/L, the COD was <50 mg/L. When the total nitrogen removal rate was above 80%, the concentration of ammonia nitrogen and COD increased gradually, and the C/N decreased gradually. In the end, an ammonia nitrogen equaling 200 mg/L, COD equaling 1200 mg/L, ammonia nitrogen less than 3 mg/L and COD less than 50 mg/L of the effluent were reached, according to the requirements of the simulation of actual wastewater. The total nitrogen removal rate was over 80%. The sludge was less than or equal to 100 mL/g SVI, and sludge sedimentation was good. The microorganisms could be observed under the microscope, and there were no filamentous bacteria. Domestication was completed.

4.2. Experimental results

Finally, under the conditions of influent COD 1200 mg/L, ammonia nitrogen = 180 mg/L, total phosphorus = 17 mg/L and C/N = 6.67, the effluent COD = 30.6 mg/L, the ammonia nitrogen = 0.44 mg/L, total nitrogen = 24.38 mg/L and total phosphorus = 0.68 mg/L. The removal rate of COD was 97.45%, and that of ammonia nitrogen was 99.75%. The removal rate of total nitrogen was 86.44%, and that of total phosphorus was about 95%. The sludge SVI was stable at 88–105 mL/g, and the sedimentation performance was good. The expansion of the nonfilamentous bacteria indicated that the acclimation of the denitrogenation sludge was successful.

4.3. Test of actual wastewater

The actual wastewater was obtained from the effluent of a factory's ink wastewater after pretreatment; this could be used for biodegradability. In the raw water, the COD = 1967 –241 mg/L, TOC = 652.1–774.4 mg/L, ammonia nitrogen = 324–330 mg/L and total nitrogen = 378–393 mg/L. The concentration of each index in the wastewater was high. Therefore, the original water was diluted once and then was continuously influent; the residence time was 20 h, and the sludge reflux ratio was 240%. The installation was small, and no nitrification solution was reflued. The sludge concentration was controlled at 3700 mg/L and pH = 7.0–8.0, and the temperature was 28°C. The aerobic pool dissolved 2–3 mg/L of oxygen. The process ran 25% wastewater and 75% tap water for 3 d. After the sludge was adapted, the ratio of water intake to the wastewater was increased, running 50% wastewater and 50% running water for four days. The ammonia nitrogen, total nitrogen and COD were measured every day.

The experimental effluent data in Table 2 show that when the actual wastewater was twice diluted, the difference of the final influent concentration was not significant when the concentration of the influent was basic and the water was domesticated. On the seventh day, the concentration of ammonia nitrogen in the effluent was below 1 mg/L, and the concentration of COD was 37 mg/L. The removal rate of COD was 96.79%, the total nitrogen in the effluent was 31.53 mg/L and the total nitrogen removal rate was 83.53%. Compared with the taming data, the removal rate of COD, ammonia and total nitrogen was lower than that of the acclimatization. The carbon source and nitrogen source components of the actual wastewater were more complex than those of the water distribution. There were some refractory substances that could not be removed, resulting in a high effluent concentration and reduced removal rate. However, in general, the acclimated denitrification sludge had a better treatment effect on the actual wastewater, as shown by the effluent data from the test. The experimental results also show that quickly acclimated denitrification sludge can be used in future experiments.

5. Operation of reflux A/O system and sludge reduction

5.1. Experimental method

In the experiment, two sets of A/O devices ran simultaneously. In the control group, the intake of water was raised by a peristaltic pump into the anoxic pool in the A/O device of the control group. After the aerobic pool entered the vertical flow sedimentation tank, the nitrification liquid partially refluxed into the anoxic pool. Some of the excess sludge was discharged, and some returned to the A/O to maintain the activated sludge concentration in the system. In the A/O device of the experimental group, the intake of water was raised by the peristaltic pump into the anoxic pool. After the aerobic pool entered the vertical flow sedimentation tank, the nitrification liquid partially flowed into the anoxic pool. The remaining sludge was partially discharged, and the remainder was returned to the A/O to maintain the sludge concentration in the system. The difference was that the remaining sludge was pretreated with ultrasonic waves (the sound energy density was 0.4 W/mL, and the action time was 20 min). Then the remaining sludge was treated by anaerobic hydrolysis and acidification, and the reacting supernatant was reflued into the A/O. In the experiment, the operating conditions of the control group were consistent with those of the experimental group. The concentrations of sludge in the anoxic pool and aerobic pool were 3600–3800 mg/L. The dissolved oxygen in the aerobic pool was 2–4 mg/L, and the temperature was 28°C–30°C. The aerobic pool pH was maintained at 7.5–8.5, while that of the anaerobic pool was 7.0–7.5. The reflux ratio of the nitrification solution was 1.5–2.5, and the sludge reflux ratio was 0.5–1.0. The system residence time was about 30 h. The conditions of the influent flow, system pH, dissolved oxygen and system temperature were observed and adjusted every day, both to ensure that the experimental group and the control group worked in consistent and stable conditions and to reduce errors caused by human factors.

5.2. Experimental results

Two sets of A/O device influent water were simulated after the dilution of the ink wastewater. The COD was kept at 1200 mg/L. The same water bucket was used for inflow to ensure that the water quality was consistent. After domestication, the system of activated sludge was steadily run for

Table 2
Effluent index of actual wastewater verification experiment

Index/time	Diluted raw water	Effluent –1st day	Effluent –2nd day	Effluent –3rd day	Effluent –4th day	Effluent –5th day	Effluent –6th day	Effluent –7th day
COD mg/L	1152	268	87	42	348	108	45	37
Ammonia nitrogen mg/L	162.80	38.52	10.97	1.78	54.81	13.96	2.63	0.95
Total nitrogen mg/L	191.43	60.44	33.16	24.47	93.42	55.27	37.45	31.53

a period of time and entered the comparative experiment stage. The whole process ran steadily for 75 d. The changes in the COD concentration of the system are shown in Fig. 4.

In Fig. 4, the effluent COD concentration in the control group fluctuates up and down in a small range. It is basically in a stable state, and the COD concentration in the effluent is low. The lowest COD concentration in the effluent was 28.6 mg/L, and the highest was 31.5 mg/L. The average effluent COD concentration in 75 d was 30.3 mg/L, and the average COD removal rate was 97.47%. The removal rate of COD was high and stable; that in the experimental group was higher than in the control group. After the excess sludge was added, the reflux of the anaerobic hydrolyzed supernatant had no significant effect on the removal of COD; it even improved. The carbon source in the system itself was no higher than the theoretical value. Active microorganisms are hungrier for carbon sources, and to a certain extent, this affects the denitrification reaction. To improve the efficiency of denitrification, most sewage plants or denitrification facilities often add carbon sources such as glucose or methanol. The hydrolysate supernatant contains rich and easily degradable carbon sources, and reflux enters the system to make up for the low carbon source of the system. This process can quickly can be used by starving microorganisms, thus improving the overall efficiency of the organic use of the system.

During the experiment, the concentration of ammonia nitrogen in the water was kept at 180 mg/L. Ammonium chloride is a single nitrogen source, and the concentration of ammonia nitrogen in the anaerobic hydrolysate was 16.92–19.04 mg/L. The concentration of ammonia nitrogen in the effluent of the two sets of A/O units during stable operation is shown in Fig. 5.

In Fig. 5, the concentration of ammonia nitrogen in the effluent of the control group has been kept below 1 mg/L. The effluent concentration is very low. Although there is a small fluctuation range, the yielding water is basically stable. The lowest ammonia nitrogen concentration in the effluent was 0.39 mg/L, and the highest was 0.54 mg/L. The average ammonia nitrogen concentration in the effluent was 0.46 mg/L over 75 d, and the average ammonia nitrogen removal rate was 99.74%. From the data, the average ammonia nitrogen concentration in the experimental group was a little higher than that of the ammonia nitrogen in the control group. The addition of anaerobically hydrolyzed supernatant increased the load of ammonia nitrogen. Some of the refractory substances in the influent ammonia nitrogen failed to react in time, which resulted in little increase in the concentration of ammonia nitrogen in the effluent. The removal rate of ammonia nitrogen in the experimental group and in the control group was basically the same. This shows that the increase of the ammonia nitrogen load caused by the reflux of the supernatant did not affect the nitrification effect of the system.

The total nitrogen concentration in the influent was kept at 180 mg/L. The total nitrogen concentration in the anaerobic hydrolysate was 49.85–53.26 mg/L. The concentration of total nitrogen in the effluent of the control group and the experimental group had changed after 75 d of continuous operation, as shown in Fig. 6.

In the experimental group, the concentration of total nitrogen in the effluent was significantly higher than that in the control group. The total nitrogen concentration in the

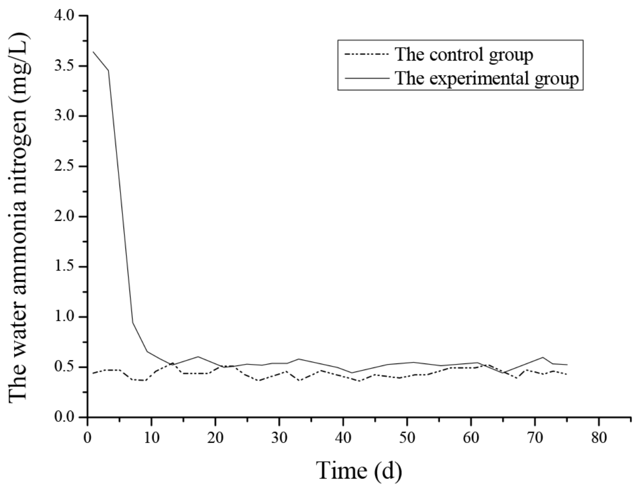

Fig. 5. Changes of ammonia nitrogen in A/O effluent.

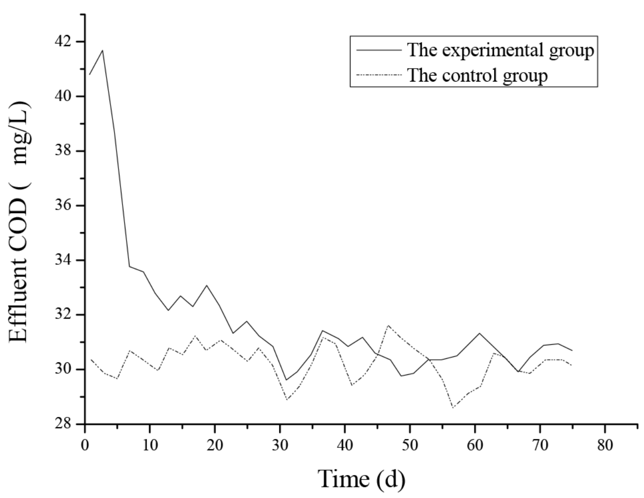

Fig. 4. COD changes in A/O effluent.

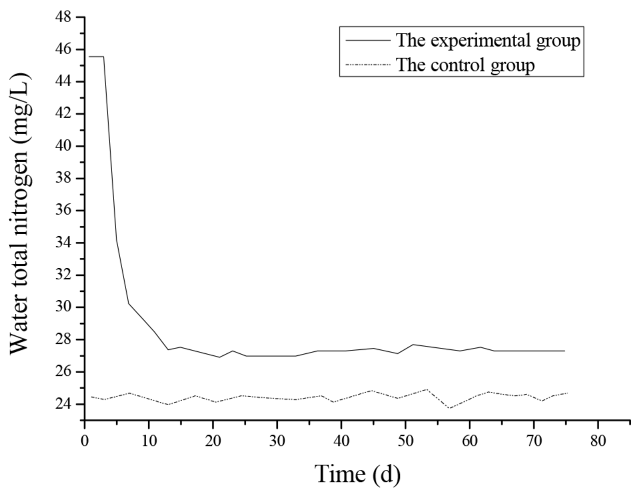

Fig. 6. Change of total nitrogen in A/O effluent.

effluent of the control group was basically stable, similar to that of the COD and ammonia nitrogen. This shows that the system of the control group was in a steady state. Compared with the control group, the concentration of total nitrogen in the experimental group increased by 2.88 mg/L on average. The anaerobic hydrolysate contained a higher carbon source and nitrogen source, and more carbon sources increase the denitrification effect, thereby increasing the total removal rate of nitrogen. From experimental observation, there were many more air bubbles in the anoxic pool of the experimental group than in the control group. Although the concentration of nitrate nitrogen in the experimental group was lower than in the control group, the total nitrogen concentration was higher than that of the control group. However, the removal rate of total nitrogen was higher than that of the control group. At the same time, the material composition ratio of components of the water released from the sludge after crushing was more complex. This was more suitable for the growth of a variety of microbes. To a certain extent, the biological diversity increased, and the stability of the system was improved.

The concentration of total phosphorus in the influent was kept at 17 mg/L during stable operation. The total concentration of phosphorus in the anaerobic hydrolysate of the experimental group was 4.98 mg/L–5.45 mg/L. Usually, the phosphorus removal process involves the excessive absorption of phosphorus in the aerobic zone in the reactor. In the experiment, the dissolved oxygen in the aerobic tank was sufficient for the growth of microbes. Phosphorus-rich sludge was discharged into the sedimentation tank and was regularly removed. A sufficient carbon source was contained in the anaerobic hydrolysate, causing reflux due to ultrasonic cracking. The denitrifying phosphorus-accumulating bacteria could be used with nitrate oxygen as the electron acceptor. Dephosphorization was carried out under anoxic conditions, and part of the phosphorus was removed. At the same time, the growth rate of sludge increased, because of the increase of nutrients in the influent. In the experimental group, the frequency of sludge discharge was slightly higher, and all phosphorus was eliminated, thus improving the overall phosphorus removal efficiency of the system.

The sludge settling performance is generally reflected by the SVI value, which shows the coagulability of activated sludge. During the stable operation of the experiment, the sludge settling performance in the aerobic tank of the A/O system was measured every other day. First, the phenomenon of showing low or high SVI values was prevented, and the activity of the sludge was guaranteed. The differences in sludge settling performance in the control group and the experimental group could be compared. The result is shown in Fig. 8.

As shown in Fig. 8, the sludge settling performance of the control group and the experimental group was good during stable operation. The broken sludge, which may have been reflux, accounted for less total sludge and high biochemistry, and the entry system was quickly diluted. The system sludge also had a strong ability to resist load. Although the inflow of the hydrolytic acidification supernatant increased the system load, the initial stage of the effluent was abnormal. But the settling performance of the sludge was not greatly affected, and the sludge settlement performance was good. During the entire experiment, the SVI values in the control group and the experimental group were all stable, and the sludge settling was good. This shows that the addition of water solution had no obvious influence on the sedimentation performance of the sludge; the system could still run steadily.

After crushing, the remaining sludge released the carbon source into the A/O system. The broken sludge was partly used after the anaerobic hydrolysis reaction, which had a certain removal effect on SS and VSS. Sludge reduction and resource utilization were realized. The sludge concentration of the system was kept at 3600 mg/L–3800 mg/L. A comparison of the cumulative sludge production between the control and the experimental groups during the stable operation time is shown in Fig. 9.

Under the ultrasound action, the cell walls of the remaining sludge microorganism cells were broken, and large bacteria micelles became small flocs. The amount of the sludge was reduced. Some of the released organic macromolecules were hydrolyzed into small molecules and easily degradable materials at the anaerobic hydrolysis stage. The opportunity for contact between oxygen and sludge

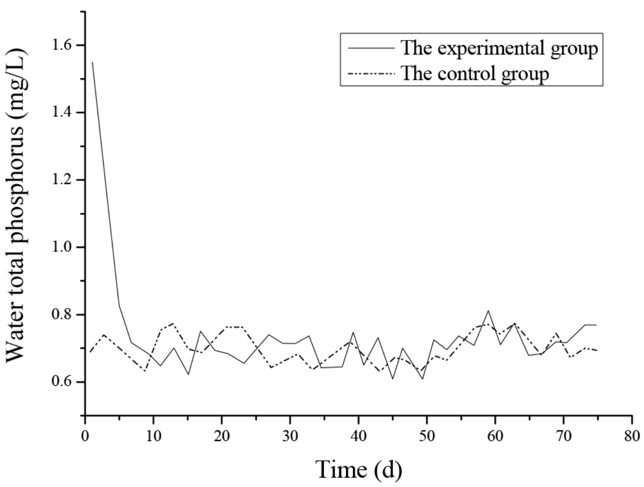

Fig. 7. Change of total phosphorus in A/O effluent.

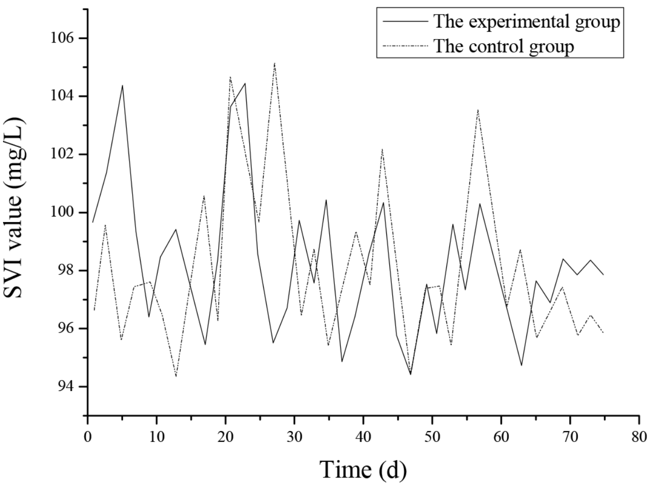

Fig. 8. Change of sludge settling performance in A/O system.

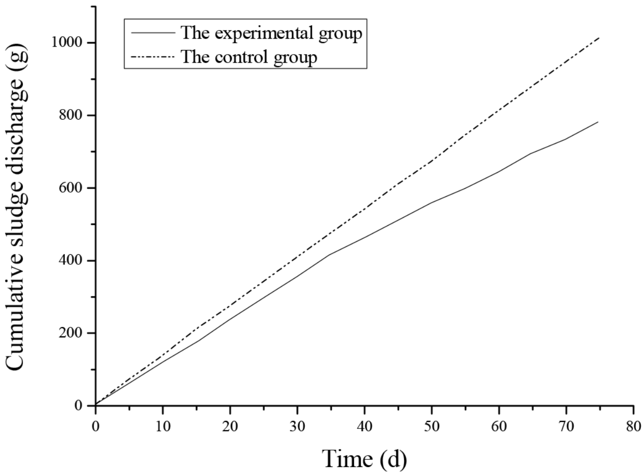

Fig. 9. Sludge reduction.

microorganisms and organic matter increased, accelerating the metabolism of cells. The content of organic matter released by some sludge cells was reused by microorganisms in the system; this also reduced the apparent sludge yield. The discharge of the residual sludge in the system was significantly reduced. The above results indicate that the residual sludge was broken through anaerobic hydrolysis. The reflux of the supernatant achieved a certain sludge reduction effect.

6. Conclusion

In the ultrasonic wave breaking experiment on residual sludge, the optimum ultrasonic technology parameter was the sound energy density of 0.4 W/mL, with an action time of 20 min. At this time, the concentration of SCOD in the supernatant of the system was 517 mg/L, and the concentration of ammonia nitrogen was 17.24 mg/L. The total nitrogen concentration was 52.94 mg/L, and the total concentration of phosphorus was 5.17 mg/L. At the same time, the residual sludge after ultrasonic breakage was observed under the microscope. Compared with the original mud, it was found that the bacteria micelles of the remaining sludge were disintegrated after ultrasonic pretreatment. The cells were broken, the content was logistics, and the particle size was reduced.

During the experimental process, two months of control experiments were also carried out. In addition to having a high concentration of effluent in the initial stage, the experimental group basically maintained a stable state. The cumulative excess sludge discharge and apparent yield of the two sets of systems were calculated. In the experimental stage, the control group discharged 1019.8 g of sludge, its yield being 0.242 g-MLSS/g-COD. The experimental group discharged 783.2 of sludge, its yield being 0.131g-MLSS/g-COD. A sludge reduction rate of 23.20% was achieved during the experiment.

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