

Status and Research Progress on Sludge Reduction Technologies

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Abstract. With wastewater treatment capacity increasing rapidly, the issue of excess sludge treatment becomes serious for wastewater treatment plant. Sludge reduction technology becomes one of the effective ways to resolve excess sludge issue at present. Application status of wastewater treatment with sludge reduction were elaborated from uncoupling, cryptic growth and predation of micro faunal three aspects. The principles and characteristics of these techniques were introduced, and their research.

1. Introduction

Wastewater treatment facilities in China have been significantly improved. The sewage treatment efficiency is also getting better year by year, and the amount of sludge is significantly increased. Conventional treatment method of excess sludge is as follows: concentration, dehydration, incineration, landfill and other final disposal methods, but investment required for traditional disposal is too high, the cost used by above disposal methods is 40%-65% of total operation cost. It would bring the sewage treatment plant to overload the heavy cost. As excess sludge contains harmful chemicals, bacteria, macrobiotics, parasites, and heavy metals, etc., these may be brought serious consequences if handled improperly. So regardless of sanitary landfill or incineration, they will encounter difficulties in site selection problem and meanwhile will encounter the risk of secondary pollution. So, the concept of surplus sludge reduction was proposed in 1990s. sludge reduction is to reduce sludge production from source by using appropriate physical, chemical and biological methods under the condition of ensuring sewage treatment efficiency of sewage treatment. Sludge reduction technology is one of the most important ways to solve the problem of surplus sludge in urban sewage treatment at present, so far, the current sludge reduction technology has become domestic and foreign hot filed in wastewater treatment.

2. Sludge reduction technologies research and application

2.1. Sludge reduction technology based on uncoupling

2.1.1. Uncouple addition. For metabolic uncoupler usage in activated sludge process, sludge anabolism is inhibited, but the catabolism ability is not affected. The choice of uncoupling agent is the key, how to choose a decoupling agent with good efficiency, low price and less harm is concern for people. At present, uncouples of research focus on phenols, and tetrachlorosalicylamine (TCS), etc.



Xue et al. [1] had experiment on four uncouples, the results showed that metachlorophenol had the best effect. Strand et al. [2] compared twelve uncouples and the result showed trichlorophenol (TCP) had the best effective. C. Aragon [3] et al. compared 2, 4-dinitrophenol, TCS, Cu and Zn, and results indicated that only TCS has good sludge reduction effect. besides the uncoupling agent selection, the dosage amount is also concern. Xue et al [1] added 20 mg/L metachlorophenol and sludge reduction reached about 80%. Fenxia Ye [4] et al found TCS dosage was 0.5 mg/gVSS, sludge was reduced to about 30%. And C. Aragon [3] found that sludge yield can be reduced to 30% when adding 0.8 mg/LTCS. It is obvious that sludge yield has improved when TCS dosage added.

At present, there are different explanations for the mechanism of uncoupling agents. Fenxia Ye [5] believed that uncoupling metabolism was occurred with little TCS dosage, but in much TCS dosage conditions microorganism would be dead, this resulted in sludge reduction. In 2010, Ye [6] raised questions: Can the chemical uncoupler supplement loss energy consumption through OSA process, how process affected the microbial community and mechanism combination. her illustration showed that much are unknown in the field of sludge production reduction using of metabolic uncoupling and further research is needed. WenMing Xie et al. [7] further studied the uncoupling agent method. He studied dynamic parameters with the maximum specific growth rate, the energy overflow rate and sludge yield. mathematical model was established to explore mechanism. Many uncoupling agents are harmful substances such as refractory organics or heavy metals. It might have environmental risks in the process of usage at the same time; following with the production of microbial resistance will increase the dosage of uncouples. Strand et al. [2] found that the sludge yield of adding TCP was 50% of the non-dosage at the initial stage during the experiment, but after 80 days, the microbial adapted TCP. At present, the choice of uncoupling agent only keeps in comparing with sludge reduction effects on economics, but still no clear benchmark for risks to environment.

2.1.2. OSA process. Aerobic-precipitation-anaerobic (OSA) process is essentially added anaerobic reactor during the sludge recirculation process of traditional sludge process, and not pre-treated or added any chemical agents by physical or chemical method for the sludge, and this was proven that sludge reduction can be achieved and meanwhile can improving sludge settling performance in the condition of no effect on the quality of the effluent [8]. Westgarth Et al. [9] first discovered the oxygen section can reduce half excess sludge emissions with the insertion of anorexia in activated sludge process.

OSA process have attracted much attention due to many advantages in actual production, low operating cost, large processing scale, etc. In order to achieve better practical effect, people have undergone a lot of research in influences factors for OSA by optimizing operating parameters. Saby et al. [8] found that oxidation reduction potential (ORP) levels is an important parameter to control the degree of sludge anoxic treatment, when ORP in the anoxic tank is less than 100mV, there is a decrement effect; and when ORP is from 100mV drops to 250mV, the reduction rate increases from 23% to 58%. Bin Zhang et al. [10] found that the sludge yield can be reduced by increasing the difference (Δ ORP) between the aeration tank and the ORP of the uncoupling pool, and there is a linear relationship between Δ ORP and apparent coefficient (Yobs). Fenxia Ye [11] and others studied the influence of OSA process with different mud retention time, the experimental results showed that the most good sludge residence time is 6~7h, and the more longer residence time to make sludge production increased. Lianpeng Sun et al. [12] thought that the frequency of anaerobic-aerobic should be an important parameter in OSA process, the more frequency replacements, the more sludge reduction, when alternating 4 times in a day, sludge volume can be reduced to 77.4%.

There are different explanations for the sludge reduction mechanism of the OSA process. The main reason for this is the uncoupling of anaerobic-good nutrition and the self-decay of the sludge. To define the mechanism of OSA clearly is the main research content in the future. Guanghao Chen et al. [13] confirmed by experiments that sludge reduction caused by the metabolism of microorganisms uncoupling accounts for a small part of the sludge loss, the main reason is system sludge reduction caused by sludge decay. Wenbiao Jin et al. [14] clearly believed that sludge decay is decisive cause to

make sludge reduction on OSA process and may account for about 66.7% of the OSA sludge reduction effect, sludge reduction due to energy uncoupling contributes only about 7.5%; sludge reduction due to recessive growth accounts for approximately 23.5%. In 2008, Kyoungjin an [15] and others studied OSA sludge reduction mechanism through COD conservation, the results showed that 50% of COD is used for production of CH_4 and CO_2 , therefore, it is concluded that the sludge reduction on OSA process is mainly due to the decay of the sludge itself.

Besides research on the influencing factors and mechanisms, people are also concerned with the combination of OSA and other processes that can be achieved better nitrogen and phosphorus removal effect as sludge reduction at the same time. Jian fang Wang [16] et al. concluded used staining that 35% of microorganisms have the characteristics of polyphosphate-accumulating bacteria, Light in situ hybridization (FISH) analysis showed that 28% of the bacteria were polyphosphate bacteria, the main microbial population in the OSA process, has a significant phosphorus removal effect up to 60%. Fenxia Ye and Ying Li[17] through adding TCS and OSA process and the combination of the two were compared experimentally, and the experimental results showed that adding TCS alone can effectively reduce sludge production, but it will result in the increase of water COD and TN, at the same time can make the sedimentation performance worse; OSA process can get better effluent quality and enhance sludge sedimentation, but the sludge reduction effect is only 26%; Combination of the two process can overcome these short, not only can ensure the quality of effluent, but also the sludge reduction effect reached 46.9%. G. N. Lau et al. [18] studied sulfate on effect of denitrification in alternating aerobic and anaerobic systems, the experimental results showed that HRT in anaerobic tank was at 3h, 77% to 85% of TOC can be removed and generate 70-90 mg/L of soluble sulfides, which provide the possibility for subsequent denitrification; The sludge yield of anaerobic tank was 0.15-0.18 g/g (VSS/COD), the sludge yield of the oxygen tank was 0.22 to 0.31 g/g (VSS/ $\text{NO}_3\text{-N}$).

2.2. Sludge technology based on cryptic growth

Microorganisms based on the growth pattern of their own cell are called cryptic growth. this process contains lysate and growth, lysate is rate-controlling step. Therefore, lysate efficiency improvement can lead to sludge reduction production. Using various physics, chemistry, and other lysate techniques can make the bacteria die rapidly and decompose into matrix by other bacteria absorption, it is widely used in the sludge reduction process.

2.2.1. Ozone-oxidation sludge reduction technology

Ozone oxidized sludge reduction is based on making some activated sludge into carbon dioxide and water, partially dissolved into biodegradable organics that are biodegraded by macromolecules, ozone addition could even establish zero-emission system for sludge. to reduce the production of excess sludge, Yasui et al. [19, 20] introduced ozone oxidation into conventional activated sludge system and test results showed that part of the return sludge is oxidized by ozone and then returned to the aeration tank can reduce 40% to 60% of amount of sludge remaining. Ruihong Jin et al. [21] make up the sewage treatment system which used SBR and the sludge ozonation and reflux device, when the ozone dosage is 0.05 gO_3/gSS and the sludge return flow is 0.4 $\text{L}/(\text{L}\cdot\text{d})$, the apparent yield of sludge can be close to zero, and the system did not change significantly for the COD removal rate and sludge settling performance. Lee et al. [22] combined the activated sludge process and ozone oxidation process group together at low temperature, achieved sludge zero emissions within 112 days by optimizing the ozone oxidation rate and frequency. In a conventional sludge reduction system, the carbon in the sludge can be oxidized to CO_2 by ozone, but due to ozone oxidation nitrogen and phosphorus are dissolves in the sludge supernatant and accumulates in the system, resulting in water nitrogen and phosphorus concentrations increased. In response to this problem, Dytczak et al. [23] will adopt part of sludge in A/O-SBR Process renew back into the system after ozone oxidation and used extra carbon which is released by ozone oxidized sludge to increase system denitrification efficiency by 60%. Saktaywin et al. [24] had explored phosphorus accumulation issue in system and developed a new sewage treatment system integrating sludge reduction and phosphorus recovery. This system contains conventional A/O phosphorus

removal process, ozone contact reactor and phosphorus recovery process; the process was proven to be feasible by mathematical simulation. Sludge can be reduced and phosphorus is recycled at the same time. With new sewage treatment process occurrence, ozone oxidation sludge reduction technology is in rapid development. Song et al. [25] first introduced ozone Oxidation technology combined with MBR and compared two sets of MBR test. it was found that sludge yield is about 1.04 g/d without ozone oxidation sludge reflow, but sludge yield is almost zero with ozone oxidation sludge reflow; MBR with ozone oxidization sludge reflow is better in nutrient removal aspects. total nitrogen removal rates in the two systems are 70.4% and 68.7%, phosphorus removal rate is 54.4% and 46.2%. OhYK et al. [26] research showed that it could reduce the dosage of ozone when adding alkali. MBR is in stable operation for 200 days without biomass accumulation at the condition pH 11, 0.02 g ozone dosage O₃/gSS. At present, ozone sludge reduction technology is applied in second class sewage treatment plants at abroad. but production investment in processing system is large, so how to reduce its dosage is attracting researcher's attention.

2.2.2. Chlorine Oxidation Sludge Reduction Technology. the principle of sludge reduction using chlorine is the same as that of ozone microorganisms cell walls was ruptured by its oxidization ability and promote cryptic growth. Saby et al. [27] studied the feasibility of replacing chlorine with chlorine, when the amount of chlorine is 133 mg/(g·d), sludge can be reduced to 65%; but the sedimentation performance of sludge became worse, the average diameter of sludge decreased from 15 μ m to 3 μ m, and the concentration of dissolved COD in the water increased significantly. Although chlorine is cheaper compared with ozone, but chlorine reacted with organic matter in sludge to produce chlorine organic poisons cannot be ignored.

2.2.3. Ultrasonic Sludge Reduction Technology ultrasonic technology is an effective method to break sludge flocs, break down cells, release cell material and extracellular polymer. high Ultrasonic power can enable water to produce cavitation phenomenon, small bubbles is generated in the process of cavitation. shear strength of cavitation would crack sludge flocs. sludge dewatering performance and biodegradability can be improved after generated OH reacted with extracellular polymer. Yoon et al. [28] used ultrasound to dispose part MBR reflow sludge, the results showed that actual organic load F/M of MBR was significantly higher than the apparent value. and also, people studied the effects of ultrasonic combined with SBR on sludge reduction. Sludge was disposed with strength of 120 kW/kg DS for 15min, the excess sludge was reduced to 91.1%. sludge sedimentation performance was not improved, COD removal rate is 81.1%, total Nitrogen removal rate is about 66%, but the effluent phosphorus concentration is high. The disadvantage of ultrasonic sludge reduction are sound energy utilization low efficiency and high energy consumption, but ultrasonic sludge reduction combined with other sludge treatment technology will have broad application prospects.

2.3. Sludge reduction technology based on micro faunal predation

organic wastewater process is equivalent to small artificially constructed ecosystem. many micro-organisms exist in activated sludge, such as protozoa and metazoan. Among them, protozoa and metazoan at the top of the food chain in this ecosystem, it depended on swallowing tiny creatures, mainly bacteria. Energy is transmitted from the bottom of the food chain, the longer the chain is, the greater the energy loss, and hence less sludge is produced. Therefore, sludge reduction can be achieved through this principle [29]. A large number of studies have shown that the micro faunal predation sludge reduction process has these characteristics: low operating costs, low energy consumption, no by-products, no secondary pollution and so on; so, it is a typical representative of green sludge reduction technology. However, for micro faunal predation sludge reduction, removal efficiency of total nitrogen and total phosphorus in wastewater is not good, so nitrogen and phosphorus removal combined with sludge reduction is an important research direction. In addition, efficiency stability in sludge reduction is also further studied [30].

3. Conclusion

Compared with above technologies, uncoupling method is the most mature and effective, but it also has obvious disadvantage. High S_0/X_0 uncoupling with strict conditions under is suitable for handling special wastewater. for OSA application, it has lower cost, simple process, low energy consumption, no secondary pollution, and is especially suitable for large-scale production, but its mechanism needs to be further identified. From development trend, Sludge reduction technology based on cryptic growth have great potential, especially ozone and ultrasonic technology have significant effect, but its application encountered much difficulty, such as high energy consumption and influencing factors control. Therefore, research should be focused on several sludge reduction technologies combination; different sludge reduction technologies get benefits from each other at the same time, aimed to achieve economic and environmental benefits maximum. Together with solving nitrogen and phosphorus exceeding issues in micro faunal predation sludge reduction process, green sludge reduction technology based on micro faunal activity might be developed into hot topic in future.

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