Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 13	No. 2	pp. 421-424	2014

Original Research Paper

Experimental Study of Ultrasonic Disintegration on Biological Nitrogen and Phosphorus Removal

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 7-3-2014
Accepted: 8-5-2014

Key Words:
Ultrasonic disintegration
Nitrogen
Phosphorus
Internal carbon source
Sludge

ABSTRACT

In wastewater treatment plants (WWTP) in China, the lack of carbon source has become a critical element, which restricts the efficiency of biological nitrogen and phosphorus removal (NPR). This paper analyses the application of ultrasonic disintegration of sludge, exploiting the internal carbon source for the biological NPR. Tests on WWTP have been conducted and the indexes of $COD_{cr,}$ TN, NH_3-N, TP in the raw water and effluent recorded respectively. The efficiency and mechanism of NPR have been analysed. This research shows that with the application of ultrasonic disintegration of sludge, economic and practically high-quality carbon source can be obtained.

INTRODUCTION

In China, the emission standard of WWTP is stricter than before, especially eutrophication of waters has triggered social problems. NPR is bound to be one indispensable function of each WWTP. Carbon source is always one essential element, influencing the efficiency of biological NPR. In order to meet requirements of the emission standard, relatively common practising is dosage of artificial carbon source (such as carbinol, acetic acid) in case of lower carbon source in the sewage, which certainly will increase its operation cost. Sludge is the typical biomass energy (Yang & Gao 2006), among which there are microbial cells and other organic matters, the decomposition and hydrolysis of which can provide carbon source, and it can replace methanol partially or totally (Yang et al. 2012). The exploitation of non-traditional carbon sources is more and more used in economic and effective control of nitrogen and phosphorus pollution in sewage (Yang 2009, Xu et al. 2013).

This experiment studies the application of ultrasonic disintegration technology, preprocessing the excess sludge in WWTP and analysing the effect of nitrogen and phosphorus removal in WWTP, the result of which provides references and basis for the exploration and exploitation of suitable carbon sources (means internal carbon source) in our country's sewage disposal process.

In China, the technology adopted by the urban WWTP is mainly biological treatment, through the life activities of microorganisms to realize the degradation and removal of pollutants. The supernatant, after treatment, reaching the standard, is discharged after disinfection. About 60% ~ 80% of the pollutants in the supernatant took shape of sludge entering into the sludge treatment system. From the perspective of eliminating pollutants, only with thorough treatment of sludge, can the purpose of sewage treatment be truly achieved, otherwise, it only can be regarded as that contaminants are transformed from liquidoid into solidoid (or semi-solidliod). From the analysis on composition, sludge is composed of water and solid particles, and the proportion of biodegradable organic matter content in the solid composition is commonly 40%, while refractory organic matter content 20%, and mineral content 40%. The targets of ultrasonic function are mainly the former two parts, making them being destroyed, transformed and depredated. Common practice is to carry out ultrasonic treatment on one part of the excess sludge, and the treated sludge returns to the beginning part of the biological process. Solid content of sludge into the ultrasonic treatment equipment is better to be 3~6% (Huo & Xu 2008). In the treatment process, for the existing sewage treatment plants, some part of sludge can be taken from an existing excess sludge pipeline, after its ultrasonic treatment, entering into the return sludge pipeline, and then into the biochemical pool (Fig. 1). This approach is mainly used for enhancing biological NPR, as well as the reduction of sludge.

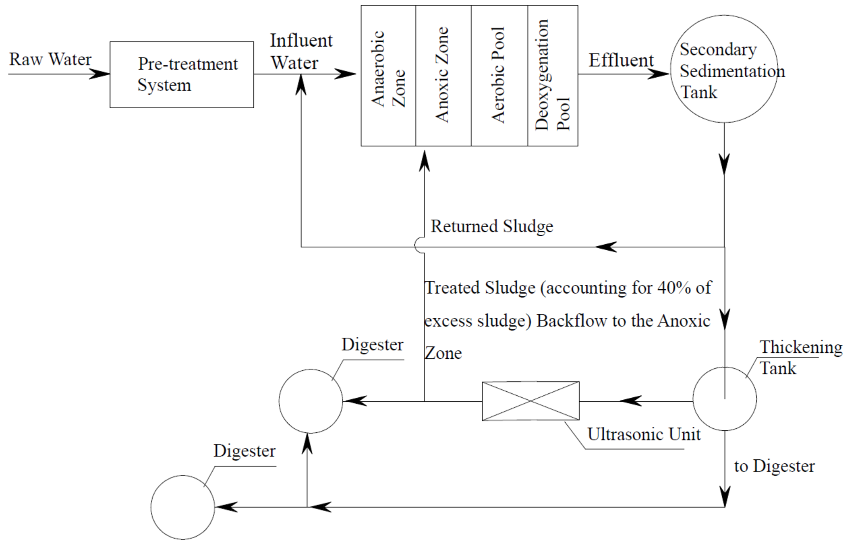

Fig. 1 Process sketch map.

EXPERIMENTAL DATA AND ANALYSIS

COD_{cr}: The concentration of COD in influent and effluent of the nitrogen and phosphorus removal system (NPR) is illustrated in Fig. 2, which reveals a fluctuation within 300 and 1000 mg/L. Such a fluctuation is determined by the operational conditions of the WWTP. The influent water is from the primary tank, and the COD-concentration in April and May was at higher level and dropped to and stabilized at 400 mg/L middle May. Effluent COD-concentration is normally 30~50 mg/L in the time before the dosage of the disintegrated sludge, and mostly under 40 mg/L thereafter with a mean value at 34.9 mg/L. These data of COD-concentration in effluent indicate stable treatment, and all criteria are met.

The ultrasonically disintegrated sludge is pumped to the anoxic influent as carbon source. It was worried at the beginning, such returned volume might increase loading of the system, so that the removal of COD negatively will be influenced. The actual operation results show that the dosage of disintegrated sludge is not significant to the removal of COD which is kept low and stable.

Total nitrogen: The total nitrogen index in effluent in this experiment directly reflects the influence of disintegrated sludge on anoxic zone's denitrification effect, which can be seen in Fig. 3. From April to early May, the total nitrogen in effluent was about 30 mg/L, and the removal efficiency of total nitrogen was not ideal. There are mainly two reasons deciding the relatively high level of total nitrogen in effluent. One is that the total nitrogen in raw water is always at a very high level, always at 70 mg/L, and the system loading is very high. In the case of the limitation of carbon source, the removal of total nitrogen is not ideal. Another reason is that during this time, ammonia nitrogen in effluent is always at a very high level, which means the digestion efficiency is limited, resulting in that decreasing total nitrogen into a lower level is impossible. In early May, with the raw water quality's tendency to be in a stable condition, ammonia nitrogen in effluent was also controlled within 5 mg/L, and total nitrogen was basically stabilized at about 20 mg/L. On May 14, disintegrated sludge was added. On May 17, fluctuation had appeared in total nitrogen in effluent, which was mainly due to the power maintenance on May 16. The system stop running for nearly eight hours, and after the system restoration, total nitrogen data began to rise, then to fall. After three weeks of running, total nitrogen in effluent dropped to around 10 mg/L. Compared with the average 15.1 mg/L of total nitrogen in effluent in the previous experiments. It shows that with the dosage of disintegrated sludge, NPR system's removal ability of total nitrogen has been increased.

From the microcosmic point of view, the improvement of total nitrogen in effluent is greatly due to the following reasons:

After being disintegrated by ultrasonic device, sludge's solubleness COD is increased, and among the increased solubleness COD, quite part of it is high-quality carbon source-VFA (volatile fatty acid). Under the condition of the existence of the VFA, denitrifying bacteria in anoxic environment can quickly transform nitrate nitrogen into nitrogen; therefore, complementary VFA promotes more nitrate nitrogen being converted into nitrogen gas and overflow.

Table 1: Data table of total phosphorus.

	Type of water	March 26	April 7	April 12	May 3	May 9
Total phosphorus (mg/L)	Raw water	5.12	5.45	5.93	6.45	6.46
	Effluent	1.73	1.60	1.83	1.85	1.85

According to research of Barnard and others, in denitrifying process, there are three different types of denitrification rates, respectively representing three stages of denitrification: 5~15 minutes after the beginning of denitrification is the first stage, and the reaction rate is the fastest, reaching 50mg NO_3^-/(L×h). At this stage, denitrifying bacteria make use of easily degradable materials, such as VFA and alcohol, as carbon source, thus the reaction rate is fast. Followed is the second stage, and the denitrification rate is about 16mg NO_3^-/(L×h) . The direct cause of low rate in the second stage is that easily degradable carbon source has been consumed in the first stage, and this stage can only use particle carbon source and complex organic matter as denitrification carbon source. In the third stage, the external carbon source has been depleted, and denitrifying bacteria conduct denitrification by endogenous respiration. Its rate is even more lower, only 5.4mg NO_3^-/(L×h) (Zheng 2005). Because the complementary VFA directly strengthens the first phase of denitrification, so the effect is obvious.

Sludge, after being treated with ultrasonic, can speed up the process of hydrolysis in hypoxia environment. Some macromolecular organic matter, even having not been directly converted into VFA under ultrasonic function, after being added into anoxic zone, can also be rapidly hydrolysed, and form VFA, which will be used by the system.

Under the action of ultrasonic, *Zooglea* and some cells are disintegrated, and the released enzymes of cells in the anoxic zone effectively promote the denitrification reaction, playing a catalytic role, and eventually reducing the index of total nitrogen in effluent. The released enzymes by ultrasonic effect in anoxic zone can increase its biological efficiency in several times, which may mean that particulate matter in the second stage of the mentioned denitrification can been transformed into carbon source in a much faster speed, making the denitrification rate higher in the second stage.

Ammonia nitrogen: Ammonia concentration in both influent and effluent is illustrated in Fig. 4. At the start of the experiment, the raw water contains a lot of inorganic impurities, causing the rapid rise of the sludge concentration in the aerobic pool. In order to ensure the stability of sludge concentration in the aerobic pool, the amount of spoil disposal in the system has to be increased, which not only affects the growth of nitrifying bacteria, but also makes the sludge's inorganic substances in the aerobic pond more and more, and the removal efficiency of ammonia nitrogen is not very ideal, the ammonia concentration in effluent even reaching more than 20 mg/L. In early May, after the improvement of raw water quality, new sludge was inoculated in the aerobic pond, and the amount of spoil disposal was strictly controlled at the same time, to guarantee the growth time of nitrifying bacteria. After that, the removal efficiency of ammonia nitrogen in NPR system was gradually improved. After the reflux of the dosage of disintegrated sludge, the removal of ammonia nitrogen was not affected, being relatively stable all the time. From the data, under the condition of relatively large changes of influent water's concentration, the ammonia nitrogen in effluent remains basically at about 1mg/L.

Total phosphorus: The continuous monitoring of total phosphorus data begins with the dosage of disintegrated sludge, at previous time, only occasional assay was carried out. From Fig. 5, it can be seen that after adding disintegrated sludge, the total phosphorus in effluent in NPR system's secondary settling tank remains below the level of 1mg/L. Compared with monitoring data above, it can be known that disintegrated sludge owns a great help to the removal of phosphorus in the system.

Because the dissolved oxygen in anaerobic pool is only 0.4 mg/L, the facultative zymophyte converts biodegradable macromolecular organic matter in sewage into VFA, the middle fermentation product with smaller molecular weight. Phosphorus accumulating bacteria can disintegrate polyphosphate accumulated in thallus bodies and release energy for the subsistence of obligate aerobic phosphorus accumulating bacteria under the "depressed" anaerobic environment, while another part of the energy can also be supplied to phosphorus accumulating bacteria to actively absorb VFA, a kind of small molecule organic compound, which is stored as poly-beta hydroxy butyrate (PHB) in bacteria bodies (Lin et al. 2002). Into the aeration aerobic area, in addition to the absorption and utilization of the residual biodegradable organic matter in sewage, phosphorus accumulating bacteria can disintegrate PHB being stored up in the bodies and release energy for itself growth and reproduction. Phosphorus accumulating bacteria can also take the initiative to absorb the solubility of phosphorus in the surrounding environment, and store them in their bodies in the

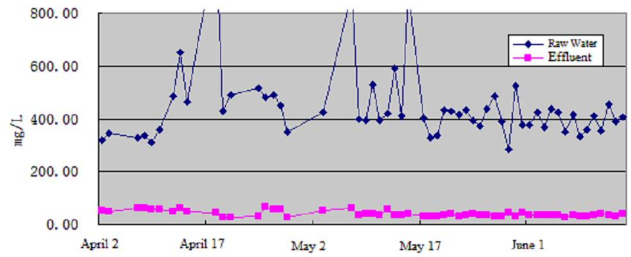

Fig. 2: CODcr data map in NPR (nitrogen and phosphorus removal) technology.

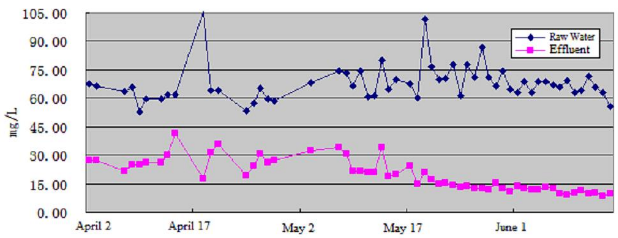

Fig. 3: Total nitrogen data map in NPR technology.

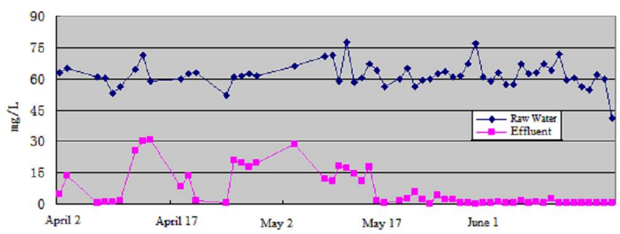

Fig. 4: Ammonia nitrogen data map in NPR technology.

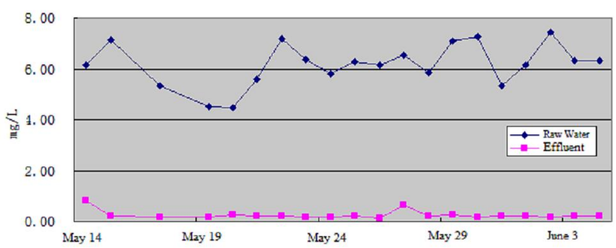

Fig. 5: Total phosphorus data map in NPR technology.

form of polyphosphate (Han 2006).

The high level or low level of phosphorus concentration in effluent mainly depends on the ratio between the available energy of the fermentation substrate VFA needed by dephosphorus bacteria and the amount of phosphorous which must be removed. While, to a great extent, the disintegrated sludge can just supply VFA and macromolecular organic matter which can be transformed into VFA quickly by facultative zymophyte, and which greatly improves system's processing ability of phosphorus, and further effectively reduces the total nitrogen in effluent.

CONCLUSION

Disintegrated sludge returns to the anoxic zone of A^2/O, having no obvious effect on COD and ammonia nitrogen in effluent of the system's secondary settling tank, while this sludge improves the effect of nitrogen and phosphorus removal, increasing the system's removal rates of total nitrogen and total phosphorus, thus, improving the total nitrogen and total phosphorus indexes in effluent of the system's secondary settling tank. Under the condition that in the raw water, total nitrogen is relatively higher, sludge treatment technology with ultrasonic, combined with NPR and A^2/O technology, can make the total nitrogen index in the secondary settling tank's effluent being controlled at the levels around 10 mg/L. Disintegrated sludge plays a positive role for both NPR's and A^2/O system's dephosphorization, and the provided high-quality carbon source can effectively help system reduce the total phosphorus in effluent. Ultrasonic disintegration on biological NPR has a positive role to solve the lack of carbon source in nitrogen and phosphorus removal process in current domestic sewage treatment plants, and to improve the comprehensive utilization of sludge as well.

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