Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.874134

52 (2014) 5037–5043
July

Taylor & Francis
Taylor & Francis Group

A study on the impact of sludge water on biological phosphorus removal process of the municipal wastewater treatment plant and its treatment process

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Received 2 December 2012; Accepted 25 November 2013

ABSTRACT

At present, the research focus for sludge water was mainly concentrated on nitrogen removal, the study on the impact of sludge water with high concentration suspended solid (SS) and total phosphorus (TP) on phosphorus removal system is rare, and there is a gap in the research of processing technology for this type of sludge water The impact of sludge water on phosphorus removal process was investigated by field investigation and test analysis on an A^2O process of a typical municipal wastewater treatment plant in Xi'an. Based on the sludge water quality characteristics of high concentration SS and TP, the study on coagulation dephosphorization technology was carried out. Through the sludge water coagulation mechanism analysis, the operating conditions of coagulation were optimized. The results of the study showed the appropriate polyaluminium chloride dosage was from 100 to 200 mg/L and the TP concentration after coagulation was about 14–11.6 mg/L. The coagulation process can effectively alleviate impact of sludge water on the system phosphorus removal process, and guarantee the outflow stable up-to-first grade A standards.

Keywords: Sludge water; Biological phosphorus removal process; Municipal wastewater treatment plant; Coagulation dephosphorization process

1. Introduction

With the development of urban water pollution control and governance career in China, based on environment function status of surface water, the effluent of municipal wastewater treatment plant (MWWTP) can meet first grade A standards in "Discharge standard of pollutants for municipal wastewater treatment plant" (GB18918-2002), which is the basic requirements for the sewage treatment plant effluent emissions. The effect of sludge water for MWWTP and sludge water treatment technology is gaining more and more attention in the process of upgrading and reconstruction for first grade A standards. Sludge water is the wastewater generated in

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Presented at the Conference on Water Resources and Urbanization Development, 26–27 September 2012, Tianjin, China the process of sludge thickening, dewatering and digestion. Although the quantity is only 1–3% of influent of MWWTP [1], sludge water has a significant impact on the sewage treatment process, because of its high pollution load [2,3]. The sludge water quality in different sewage treatment plant is quite different, so its effect on wastewater treatment process is also various [4]. At present, a large amount of nitrogen pollutants in the sludge water and its impact on wastewater treatment process are the focus of research. At the same time, a variety of efficient treatment technologies are developed according to the characteristics of low C/N ratio of sludge water. The Dutch Delft University of Technology developed SHARON process and realized shortcut nitrification [5]. The InNitil process [6], the BABE technology [2,3] and the ScanDeNi [7], etc. process were developed based on the concept of nitrifiers accumulation with sludge water to enhanced bio-denitrification. However, there are fewer studies about the impact of phosphorus pollutants in sludge water on biological phosphorus removal and the research on the treatment technology is scarce; furthermore, there is a gap in the research on sludge water with high concentration of suspended solid (SS) and phosphorus pollutants. In this paper, the assessment about impact of sludge water with high concentration SS and total phosphorus (TP) on process system was carried out on a MWWTP in Xi’an and the study on high effective phosphorus removal process was conducted. The process can remove the phosphorus pollutants in sludge water and decrease TP load of biochemical reaction tank, in order to achieve the goal that the effluent of the system can stably meet the first grade A standards.

2. Materials and methods

2.1. The treatment system

The sewage treatment plant is located in the northern suburb of Xi’an, and covers an area of 401 mu, with a treatment capacity of 200,000 m^3/d. The A^2O (anaerobic–anoxic–aerobic) process was adopted and the designed effluent quality was first grade B standards in “Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant” (GB18918-2002). The hydraulic retention time of biochemical reaction tank is 16.4 h (of which anaerobic tank: 2.0 h, anoxic tank: 5.5 h, aerobic tank: 8.9 h). The process is shown in Fig. 1. Because the sewage treatment plant has just run two years, and digester has not been used yet, so the sludge water mainly comes from the sludge thickening and dewatering. Nowadays, the sewage treatment plant effluent performs first grade B standards, but the effluent must achieve first grade A standards from 1 January 2013, according to relevant policy requirements. So, this plant is facing with the requirements of upgrading and reconstruction to meet first grade A standards.

2.2. Coagulation conditions

The coagulation technology was adopted to remove phosphorus in sludge water and the coagulant was industrial polyaluminium chloride (PAC), in order to save the processing cost.

Coagulation conditions: fast mixing lasted for 1 min with stirring intensity of 300 rpm, slow mixing lasted for 10 min with stirring intensity of 60 rpm and then static settling for 30 min.

2.3. Analytical methods

2.3.1. Chemical analysis

The SSs, chemical oxygen demand (COD), dissolved COD, biological oxygen demand (BOD), total nitrogen (TN), ammonia nitrogen (NH_3-N), nitrate (NO_3-N), TP and dissolved TP were chosen as parameters representing the main impurities encountered in the sludge water, inlet and outlet of WWTP. Regarding each kind of impurity, a 0.45 μm filtration method was applied to classify it into dissolved and suspended matters. These conventional indexes were determined by national standard method.

2.3.2. Zeta potential

The zeta potential of raw sludge water was determined by ZEN3690 Zeta Sizer (Malvern, England). The samples were taken after fast mixing with different PAC dosages and zeta potential was determined. The variation of zeta potential at different PAC dosages was analysed, and the relationship between coagulation and zeta potential was investigated.

2.3.3. Particle size distribution

The sludge floc particle size distribution was determined by LS230/SVM + Laser Particle Size Analyzer (Beckman Coulter, USA).

2.3.4. Fractal dimension and flocculation index (FI)

The fractal dimension and FI experimental system is shown in Fig. 2. The floc samples of raw sludge

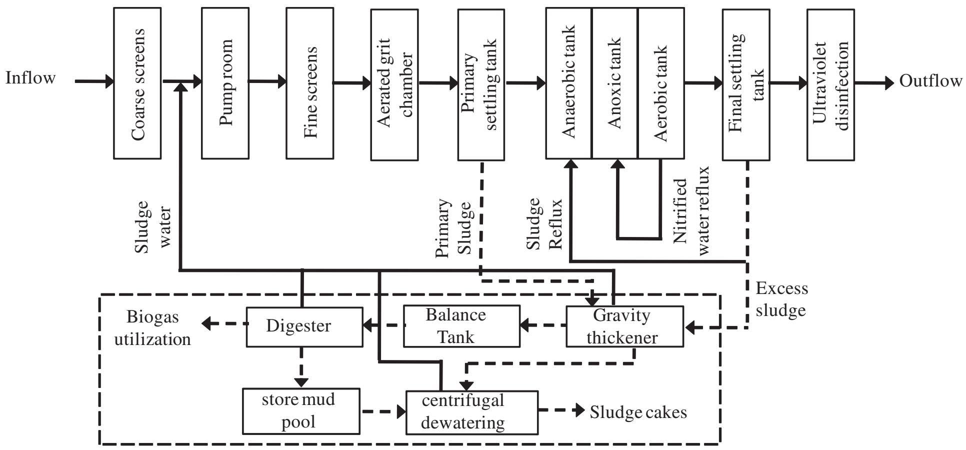


Fig. 1. Process flow diagram of wastewater treatment plant.

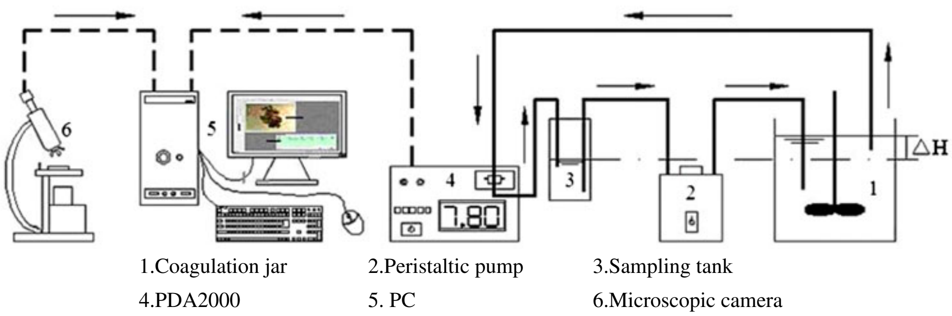


Fig. 2. Diagrammatic representation of the fractal dimension and FI experimental system.

water were collected and determined the 2D fractal dimension using image analytical method [8].

FI of PAC in neutral pure water was also analysed by the system. Stirring after coagulants dosing, the water sample in coagulation tank passed the 3 mm transparent rubber tube which was linked with Photometric Dispersion Analyzer (PDA2000) at a constant velocity by the constant pressure to realize the online monitoring of coagulation process. After low speed stirring, the suction tube cut head (inner diameter: 5 mm) was used to collect aluminium hydroxide floc samples from the sampler, and then the growth process of floc was analysed by PDA.

3. Results and discussion

3.1. Problem analysis for meeting first grade A standards

Through water monitoring and analysis along the process from May to September 2012, inlet and outlet water quality is shown in Table 1. According to the monitoring results in Table 1, the A^2O process has good removal effect on various pollutants. All the indexes can basically achieve first grade A standards except TP; therefore, the TP was the limiting factor for restricting effluent up to first grade A standards.

3.2. Sludge water quality characteristics and impact on the system

The sludge water of this WWTP mainly came from the sludge thickening and dewatering, the quality is shown in Table 2. Due to design flaws of sludge thickening tank, the SS concentration in sludge water was very high, and its main composition was primary and secondary sludge. The floc structure of suspended sludge was analysed by image analysis system, the results are shown in Fig. 3. It can be found that the 2D fractal dimension was only 1.426, which indicated that the structure of flocs in sludge water was very loose. The settling property of the SS was very poor, and its sludge settlement ratio was between 50 and 90%, so it was very difficult to precipitate removal in natural condition. As the sludge water contains a lot

Table 1
The inlet and outlet water quality

	COD/mg L^{-1}		BOD$_5$/mg L^{-1}		TP/mg L^{-1}		TN/mg L^{-1}		
Indexes	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble	NH$_3$-N/mg L^{-1}
Inlet	367 ± 178	151 ± 62	175 ± 84	96 ± 41	3.4 ± 1.2	2.0 ± 0.6	46.3 ± 26	38.7 ± 21	36.6 ± 19
Outlet	38.45 ± 22	–	8.6 ± 3.3	–	0.7 ± 0.4	0.6 ± 0.3	12.6 ± 4.3	11.4 ± 3.8	0.8 ± 0.5
Standard rate/%	97.46	–	78.65	–	34.34	–	92.75	–	98.35

Table 2
Sludge water quality

Indexes	Concentration	Indexes	Concentration
SS/mg L^{-1}	3,000–6,000	TN/mg L^{-1}	500–800
Total COD/mg L^{-1}	4,000–8,000	Soluble TN/mg L^{-1}	20–60
Soluble COD/mg L^{-1}	150–400	NH$_3$-N/mg L^{-1}	20–50
TP/mg L^{-1}	100–260	NO$_3$-N/mg L^{-1}	1–10
Soluble TP/mg L^{-1}	30–70	SV/%	50–80

of sludge, TP concentration in sludge water increased up to 100–260 mg/L, and the soluble TP also increased up to 30–70 mg/L.

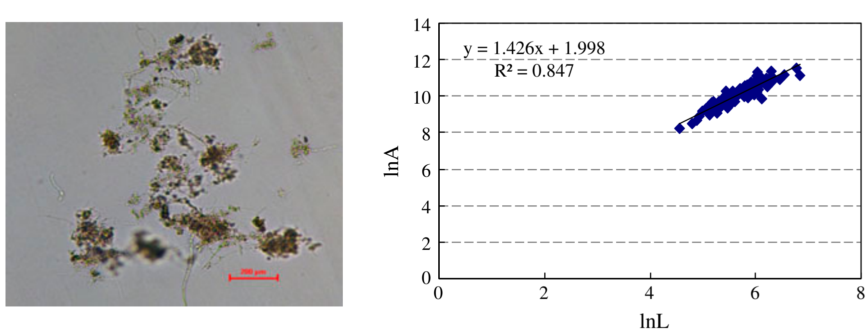
Through monitoring and analysis, the concentration variation of TP along the process is shown in Fig. 4. It was obvious that the TP concentration increased rapidly after sludge water flowed into pump room and mixed with raw water. The TP concentration in raw water increased sharply from 3.43 to 7.68 mg/L, and dissolved TP also increased from 2.03 to 3.07 mg/L. Therefore, the sludge water flowing into the front of process had made certain load impact for the process system and biochemical reaction tank was overloaded by TP (design load: 6 mg/L), which led to the effluent TP beyond first grade A standards.

3.3. Coagulation dephosphorization effect

The concentration of SS in sludge water was too high to coagulate very well, so the sludge water was diluted twice before coagulation. Fig. 5 shows the phosphorus concentration variation in coagulation supernatant fluid under different PAC dosages. It can be found that with the increase of dosage of PAC, TP concentration in the coagulation supernatant fluid constantly decreased. When PAC dosage was up to 300 mg/L, the TP in coagulation supernatant fluid tended to be stable (about 16 mg/L). It can be found that lots of PAC dosage was consumed in the coagulation, but phosphorus removal effect was unsatisfactory, and the cost of PAC will increase processing costs of WWPT.

3.4. Coagulation mechanism analysis

Fig. 6 shows the variation of zeta potential with different PAC dosages after fast mixing. It can be found that negative zeta potential of particle decreased with increase of PAC dosage, so the role of charge



(a) floc morphology **(b) 2d fractal dimension**

Fig. 3. Floc structure of suspended sludge in sludge water.

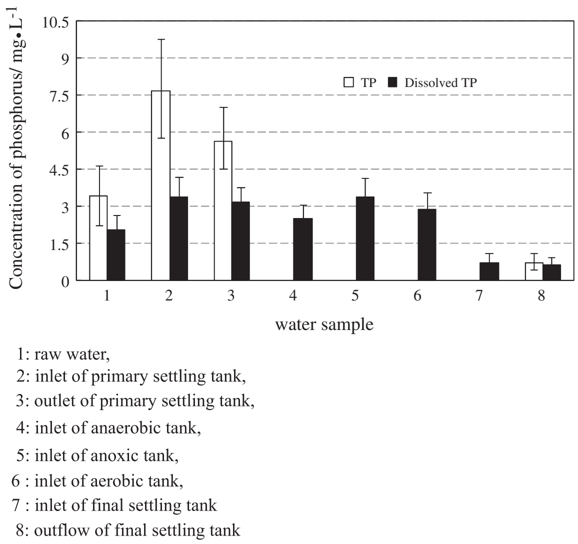


Fig. 4. Concentration variation of TP along the process.

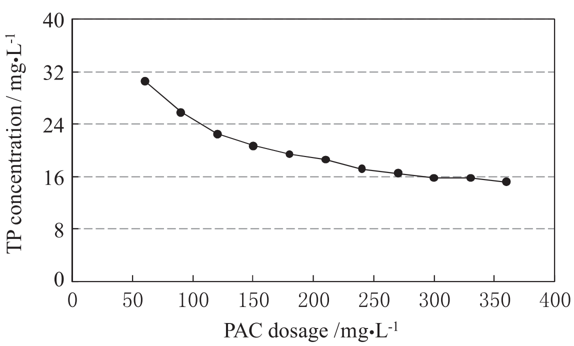


Fig. 5. Phosphorus removal effect of coagulation.

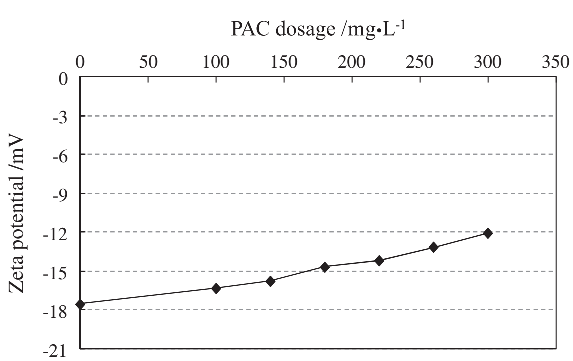


Fig. 6. Variation of zeta potential with different PAC dosages.

neutralization gradually increased. However, the zeta potential only decreased to −12 mV when PAC dosage was 300 mg/L, so the charge neutralization only played the part of the effect. Fig. 7 is the FI curve of

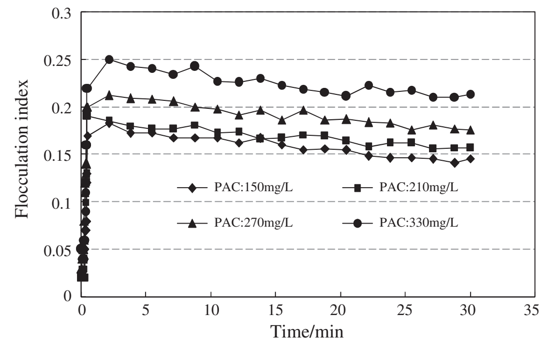
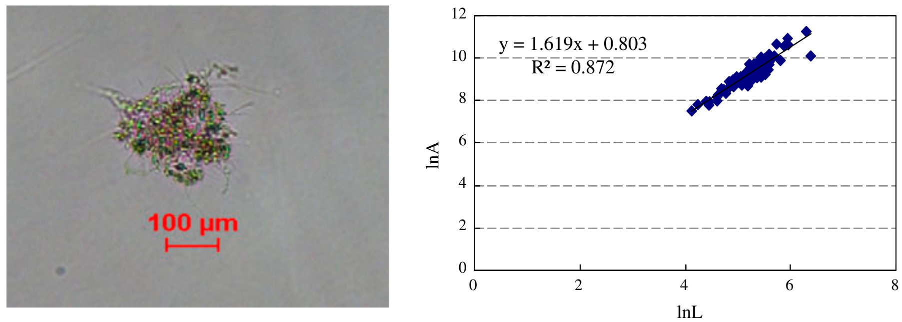


Fig. 7. FI curve of different PAC dosages.

different PAC dosages in pure water (pH = 7.0), FI shows the formation process of flocs after dosing coagulant to the pure water. When the dosing amount of coagulant is little, floc could not form in this condition. While with the dosing amount of coagulant increasing, the floc is gradually formed, and the more dosing amount of coagulant, the faster is the formation and larger size of floc. It was obvious that aluminium hydroxide floc was produced in 150 mg/L PAC dosage. Therefore, sweep coagulation was another coagulation mechanism. Moreover, pH was about 7 in the coagulation of sludge water, aluminium hydroxide floc was the main produce of PAC hydrolysis, and sweep coagulation dominated the coagulation mechanism in coagulation process. At the same time, the concentration of SS in sludge water was very high, so the settling after coagulation was congested sedimentation. However, as the sludge floc in sludge was large size, loose structure and adhering to one another, degree of freedom of particle was small, which led to small mutual collision probability. Secondly, loose structure of particle floc impacted floc mutual penetration and the effect of congested sedimentation. Therefore, the coagulation dephosphorization effect was not good, although PAC dosage was large.

3.5. Dephosphorization process optimization

The particle size and structure have a great influence on effect of coagulation and sedimentation, especially on sweep coagulation and congested sedimentation. The average particle size of sludge floc in sludge water was about 184.3 μm determined by Laser Particle Size Analyzer which was much larger than aluminium hydroxide floc produced by PAC hydrolysis, so it reduced the coagulation effect, and loose structure was against congested. In order to decrease these adverse impacts, rapid mechanical



(a) floc morphology **(b) 2d fractal dimension**

Fig. 8. Floc structure of suspended sludge in sludge water after rapid mechanical stirring.

stirring (fast mixing lasted 2 min with stirring intensity of 600 rpm) before PAC dosing was conducted to break floc into pieces. The average particle size of sludge floc in sludge water after rapid mechanical stirring was reduced to about 124.4 μm and the 2D fractal dimension of floc increased to 1.619 (Fig. 8). So, the loose structure of floc was broken, and the smaller and more dense floc was formed, which contributed to improve the collision probability, mutual penetration and precipitation effect. Fig. 9 shows phosphorus removal effect of coagulation after rapid mechanical stirring, it can be found that TP concentration in the coagulation supernatant fluid decreased significantly with the same PAC dosage. The TP concentration reduced from 14 to 11.6 mg/L, when PAC dosage increased from 100 to 200 mg/L, then TP reduced gradually. Given the quantity of sludge water was about 2% of influent of plant, TP in sludge water after coagulation will be diluted to 0.2–0.3 mg/L, when sludge water flowed into pump room and mixed with influent of plant, which will not impact the system dephosphorization effect. Considering processing cost and dephosphorization effect, the appropriate PAC dosage is 100–200 mg/L. So, the coagulation process can effectively alleviate impact of sludge water on the system phosphorus removal process, so as to guarantee the outflow stable up-to-first grade A standards.

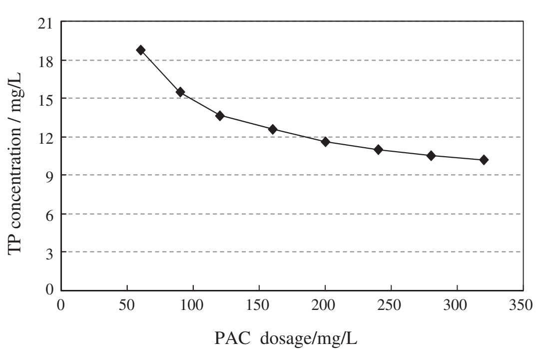


Fig. 9. Phosphorus removal effect of coagulation after rapid mechanical stirring.

4. Conclusions

(1) The sludge water of this WWTP contained high concentration SS and TP, and increased sharply the load of biochemical reaction tank when sludge water flowed into the front of process. The sludge water caused TP overloads for biochemical reaction tank and TP of effluent can not reach first grade A standards.

(2) Direct coagulation dephosphorization technology can reduce TP in sludge water to 16 mg/L, which can cushion the impact of sludge water on process operation. However, the large size and loose structure of floc influenced the effect of coagulation and the coagulant dosage was up to 250–300 mg/L, so the processing cost is high.

(3) Rapid mechanical stirring before adding PAC can break sludge floc into pieces, which contributed to coagulation phosphorus removal. The appropriate PAC dosage was from 100 to 200 mg/L after rapid mechanical stirring, and the TP concentration after coagulation was about 14–11.6 mg/L. The coagulation process can effectively alleviate impact of sludge water on the system phosphorus removal process, and guarantee the outflow stable up-to-first grade A standards.

Acknowledgements

This study was supported by the National Program of Water Pollution Control (Grant No. 2011ZX07302-

001), Science and Technology Innovation Project of Shaanxi Province (Grant No. 2011KTZB03-03-03) and Innovative Research Team of Shaanxi Province of China (Grant No. IRT 2013KCT-13).

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