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Study on Process of Denitrifying Phosphorus Removal with Single Sludge System

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This study investigated the effects of carbon-total nitrogen ratio (C/TN) and influent flow rate distribution ratio on nitrogen and phosphorus removal by a single-sludge system named anaerobic and aerobic flow end with anoxic activated sludge process. The results showed that C/TN was 10 and influent flow rate distribution ratio was 1:2:2:1, nitrogen removal and phosphorus uptaken are best. chemical oxygen demand can be reduced by 84 %, total nitrogen can be removed 81 %, phosphorus and ammonia nitrogen can be reduced by 86 and 84 %, respectively. Keep the C/P same, when C/TN rose from 10 to 20, total phosphorus removal decreased by 25 %, but total nitrogen removal rate increased. Denitrifying phosphorus accumulating organisms (DPAOs) uptaking phosphorus need nitrate or nitrite as electron acceptor, nitrogen decreased led to less electron acceptor. The less electron acceptor led to less phosphorus uptakes. As C/TN decreased from 10 to 5, phosphorus removal decreased too. Because keep the C/P same, C/TN decreased, P/TN decreased too. Remaining nitrate flow into anaerobic, anaerobic phosphorus release and phosphorus uptakes was inhibited. Changing the influent flow rate distribution ratio has little influence on nitrogen removal and phosphorus uptakes. It was indicated that anaerobic and aerobic flow end with anoxic activated sludge process can work well even under strong impact.

Keywords: Denitrifying phosphorus accumulating organisms, Denitrifying phosphorus removal, Carbon-total nitrogen ratio.

INTRODUCTION

Excessive nitrogen and phosphorus in water is the main reason of causing eutrophication in aquatic water system. Biological nitrogen and phosphorus removal from wastewater is very important for controlling or preventing eutrophication in water system. Traditional biological nitrogen and phosphorus removal process needs the right proportion of carbon, nitrogen and phosphorus[1-10]. However, carbon and nitrogen ratio, carbon and phosphorus ratio is usually lower in urban household wastewater, in traditional biological nitrogen and phosphorus removal process, the competition for orgainic carbon source between denitrfiers and phosphorus accumulating organisms lead to a lower nitrogen and phosphorus removal efficiency. Mixing of rich nitrogen wastewater with influent raw waste-water or providing an external carbon source in the anoxic tank is the way to treat lower carbon and nitrogen ratio and carbon and phosphorus ratio urban household wastewater [11-15]. But supplying carbon source or nitrogen source in this way is not easy to implement in engineering. In last decades, the denitrifying phosphorus removal process has been proposed as a feasible way to solve this problem[16-22]. Denitrifying phosphorus accumulating organisms[1,2,23-25] is the core of denitrifying phosphorus removal process. In conventional biological nitrogen and phosphorus removal systems, denitrification and phosphorus removal were separated. Denitrfiers and phosphorus accumulating organisms (PAOs) completed for carbon source, but in the denitrifying phosphorus removal process, denitrification and phosphorus removal was simultaneously in anoxic tank. In denitrifying phosphorus removal process, denitrifying phosphorus accumulating organisms are able to store phosphorus through sequential anaerobic-anoxic conditions. Organic carbon source, especially volatile fatty acids (VFAs), is taken up in anaerobic tank and stored as poly-β-hydroxyalkanoates (PHB) through the release of phosphorus and degradation of glycogen. A large amount of phosphorus is uptaken through oxidation of poly-β-hydroxyalkanoates when nitrate as an electron acceptor is supplied[26]. Compared with traditional biological denitrification and phosphorus removal process, denitrifying phosphorus removal process can save energy and organic carbon source and reduce sludge production[27]. It has been reported that nitrogen removal *via* nitrate as electron acceptor could reduce the demand for carbon source for denitrification by 40 %[28,29].

Some scholars[1,16,17,30] have used the properties of denitrifying phosphorus accumulating organisms to develop two-sludge denitrifying phosphorus removal process. In the two-sludge denitrifying phosphorus removal process, nitrifying bacterias and phosphorus accumulating organisms were run in different systems and separated with denitrifying bacterias. The two-sludge denitrifying phosphorus removal process is too complex, there are three settling tanks in the process that cover a large area. Anaerobic and aerobic flow end with anoxic activated sludge process is a newly denitrifying phosphorus removal process. The process is simple, without reflux nitrification, by setting the multi-stage anaerobic/aerobic/anoxic tank that allows microorganisms could stay in suitable environment as long as possible, which would increase nitrogen and phosphorus removal efficiency.

The purpose of the research is to investigate the feasibility and reliability of the anaerobic and aerobic flow end with anoxic activated sludge process and providing theoretical guidance for practical application of the process in the future. Specific objectives of this research were: (i) to investigate the effect of C/TN on nutrients removal efficiency and find out the best of C/TN (ii) to investigate the effect of influent flow rate distribution ratio on nutrients removal efficiency and find out the best influent flow rate distribution ratio, and (iii) to investigate the nutrients removal efficiency of the process under optimal condition.

EXPERIMENTAL

Anaerobic and aerobic flow end with anoxic activated sludge process: As shown in Fig. 1, the activated sludge process is composed of five parts. From part one to part four is the same composition that each part contains one anaerobic tank, one aerobic tank and anoxic tank. The influent is continuously fed into anaerobic tank, influent flow rate is 10 L/h. Recycling sludge is fed into first anaerobic and aerobic tank. Recycling sludge ratio was 0.6. And the solids residence time (SRT) was maintained at 20 days. The dissolved oxygen in aerobic tank is kept in 1-1.5 mg/L. The total volume of the experiment tank is 160 L, the volume ratio of each part is 1:1.3:1.5:1.6. First part's volume was 30 L. In each part, the volume ratio of anaerobic tank, aerobic tank and anoxic tank is 1:5:3. The sludge concentration in first aerobic is 4000 mg/L, the last one is 2600 mg/L. There is no change in the total sludge volume in each aerobic. Denitrifying phosphorus accumulating organisms (DPAOs) was domesticated in advance. After domesticating, phosphorus can be reduced by 85-88 % continuously. In anaerobic tank, sludge used enough organic matter to composite poly-β-hydroxyalkanoates while releasing phosphorus. Ammonia nitrogen was oxidized into nitrates or nitrites in aerobic tank. Nitrates and phosphorus was removed in anoxic tank by denitrifying phosphorus accumulating organisms.

Wastewater source and composition: Experiment influent is laboratory simulation wastewater. Table-1 presents the characteristics of influent used for feeding. Wastewater was stored in three plastic buckets, the volume of each plastic bucket is 80 L. The temperature of feeding water was kept at 25-30 °C and the raw water pH is 6 to 9. To supply the additional organic matter, sodium acetate was added into running water which supplied an additional 300 mg/L chemical oxygen demand to the feed. Ammonium chloride and potassium dihydrogen phosphate were used to provide nitrogen and soluble reactive phosphate.

TABLE-1
CHARACTERISTICS OF THE INFLUENT

	Concentration (mg/L)
Chemical oxygen demand (COD)	262-364
NH_4^+-N	10-64
Total nitrogen (TN)	12.2-65.6
Total phosphate (TP)	6-9

Analytical techniques: Effulent samples were collected to measure the parameters *viz.*, total phosphate (TP), total nitrogen (TN), mixed-liquor suspended solids (MLSS), dissolved oxygen (DO), chemical oxygen demand (COD) and pH. For soluble constituents, samples were filtered by 0.5 µm syringe filter prior to testing. Total nitrogen was measured in accordance with potassium persiflage digestion-UV spectrophotometric method. Total phosphate was determined in using ammonium molybdate spectrophotometric method. chemical oxygen demand was measured by potassium dichromate method. pH was determined using a glass electrode pH meter. Dissolved oxygen concentration was measured using the dissolved oxygen meter.

RESULTS AND DISCUSSION

Effect of C/TN on nutrients removal efficiency: The experiments were conducted at three different carbon-total nitrogen ratios as shown in Table-2. Fig. 2 showed that the average chemical oxygen demand removal rates for all runs were above 84 % no matter how to change carbon-nitrogen ratios. However, total nitrogen and total phosphorus removal efficiency were dependent on carbon-total nitrogen ratios. As carbon-total nitrogen ratio increased from 10 to 20, total nitrogen removal efficiency can be reached 91 from 82 %, whereas total phosphorus removal efficiency decreased. The

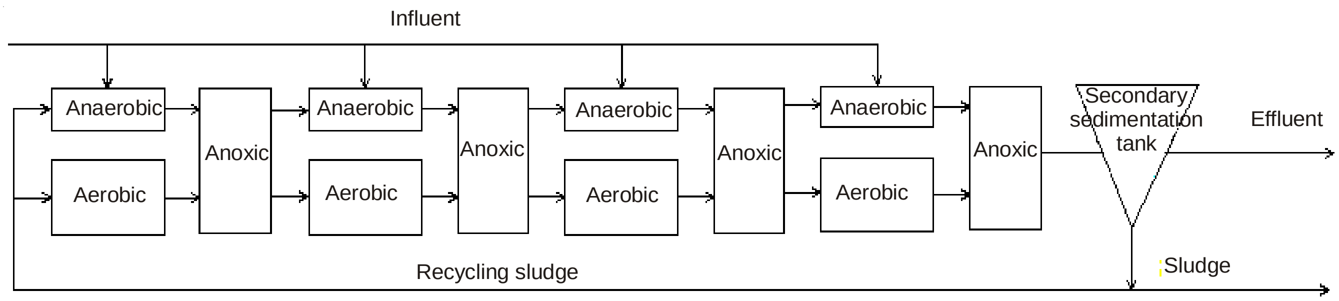

Fig. 1. Anaerobic and aerobic flow end with anoxic activated sludge process

removal efficiency decreased from 85 to 60 %. The higher carbon-total nitrogen ratio allowed lower nitrate load environment for denitrification and thus enhanced nitrogen removal. On the other hand, for phosphorus removal, the higher carbon-total nitrogen ratio resulted in less electron acceptor and that caused denitrification and phosphorus removal process worse[12]. As carbon-total nitrogen ratio decreased from 10 to 5, total nitrogen and total phosphorus removal efficiency decreased too. Total nitrogen removal efficiency decreased from 82 to 74 % and total phosphorus removal efficiency decreased from 85 to 55 %. Keep C/P was the same, decreasing carbon-nitrogen ratio means the increasing concentration of total nitrogen. Remaining nitrite flow into anaerobic, anaerobic phosphorus release and phosphorus uptakes was inhibited. According to investigate, the best carbon-total nitrogen ratio was found out. As C/TN kept at 10, concentration of chemical oxygen demand was kept at 300 and concentration of total nitrogen was kept at 30, the process removal efficiency is best for all runs.

TABLE-2
EXPERIMENT CONDITIONS FOR THE EFFECT OF C/TN ON NUTRIENTS REMOVAL EFFICIENCY

	Run 1#	Run 2#	Run 3#
Influent flow rate	240 L/d	240 L/d	240 L/d
Recycling sludge ratio	0.6	0.6	0.6
SRT	20 d	20 d	20 d
Influent flow rate distribution ratio	1:2:2:1	1:2:2:1	1:2:2:1
C/TN	300/60	300/30	300/15

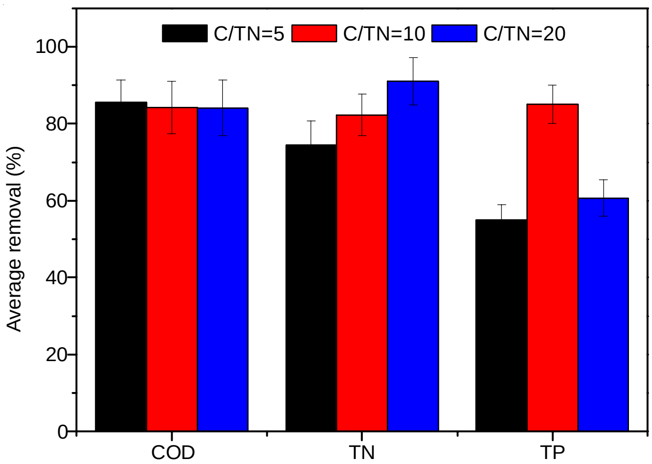

Fig. 2. Average removal efficiency of chemical oxygen demand, total nitrogen and total phosphate at different C/TN ratios. Seven samples were collected for 15 days of operation duration. Error bar represents standard deviation

Effect of influent flow rate distribution ratio on nutrients removal efficiency: The experiments were conducted at three different influent flow rate distribution ratios as shown in Table-3. Nutrients removal efficiency did not change too much as influent flow rate distribution ratio changed as shown in Fig. 3. As influent flow rate distribution ratio kept in 1:2:2:1, the process removal efficiency is best for all runs. Chemical oxygen demand, total nitrogen and total phosphorus can be reduced by 84, 82 and 85 %, respectively. As influent flow rate distribution ratio set as 1:2:3:4, the removal efficiency of chemical oxygen demand transforms to 77 % and total nitrogen removal efficiency decreased to 72 %, total phosphorus removal efficiency decreased to 71 %. Too much wastewater flowed into last part caused short hydraulic retention time, which inhibited nutrients removal efficiency. As influent flow rate distribution ratio set as 4:3:2:1, the total hydraulic retention time decreased which caused nutrients removal efficiency decreased. chemical oxygen demand can be reduced by 81 %, total nitrogen can be reduced by 76 %, total phosphorus can be reduced by 79 %. Therefore, the process can work well even under strong impact.

TABLE-3
EXPERIMENT CONDITIONS FOR THE EFFECT OF INFLUENT FLOW RATE DISTRIBUTION RATIO ON NUTRIENTS REMOVAL EFFICIENCY

	Run 1#	Run 2#	Run 3#
Influent flow rate	240L/d	240L/d	240L/d
Recycling sludge ratio	0.6	0.6	0.6
SRT	20d	20d	20d
C/TN	300/30	300/30	300/30
Influent flow rate distribution ratio	1:2:2:1	1:2:3:4	4:3:2:1

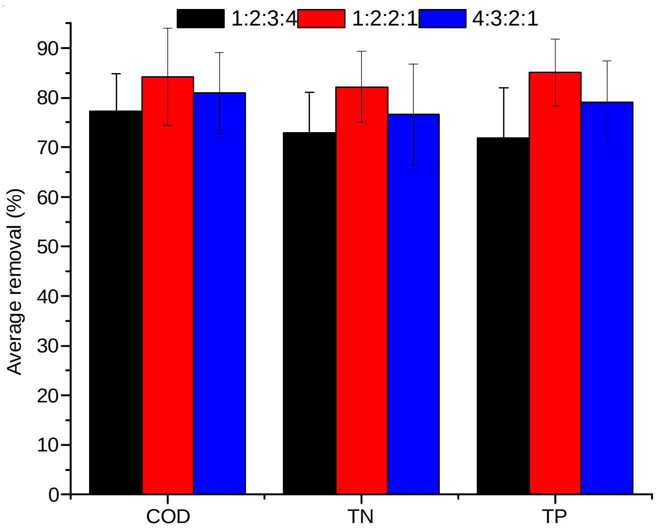

Fig. 3. Average removal efficiency of chemical oxygen demand,total nitrogen and total phosphate at different influent flow rate distribution ratios. Seven samples were collected for 15 days of operation duration. Error bar represents standard deviation

Nutrients removal efficiency of the process under optimal condition: As influent flow rate distribution ratio set as 1:2:2:1, C/TN ratio set as 10(300/30), the removal efficiency of the process for nutrients is best for all runs. Under optimal condition, chemical oxygen demand ,total nitrogen , ammonia nitrogen and total phosphorus removal efficiency are shown in Fig. 4. The chemical oxygen demand concentration of influent was about 300 mg/L, effluent chemical oxygen demand concentration of second part (effluent of anoxic) was about 49.9 mg/L (average concentration, the same as below), effluent chemical oxygen demand concentration of third part was 49.2 mg/L and effluent chemical oxygen demand concentration of last part was 48 mg/L. Chemical oxygen demand can be reduced by 84 % (average removal, the same as below) and the removal efficiency of chemical oxygen demand did not increase too much as reactor part added. However, ammonia nitrogen, total nitrogen and total phosphorus removal efficiency were dependent on reactor parts. In second reactor part, the removal efficiency of ammonia nitrogen was only 57 %, in third one,

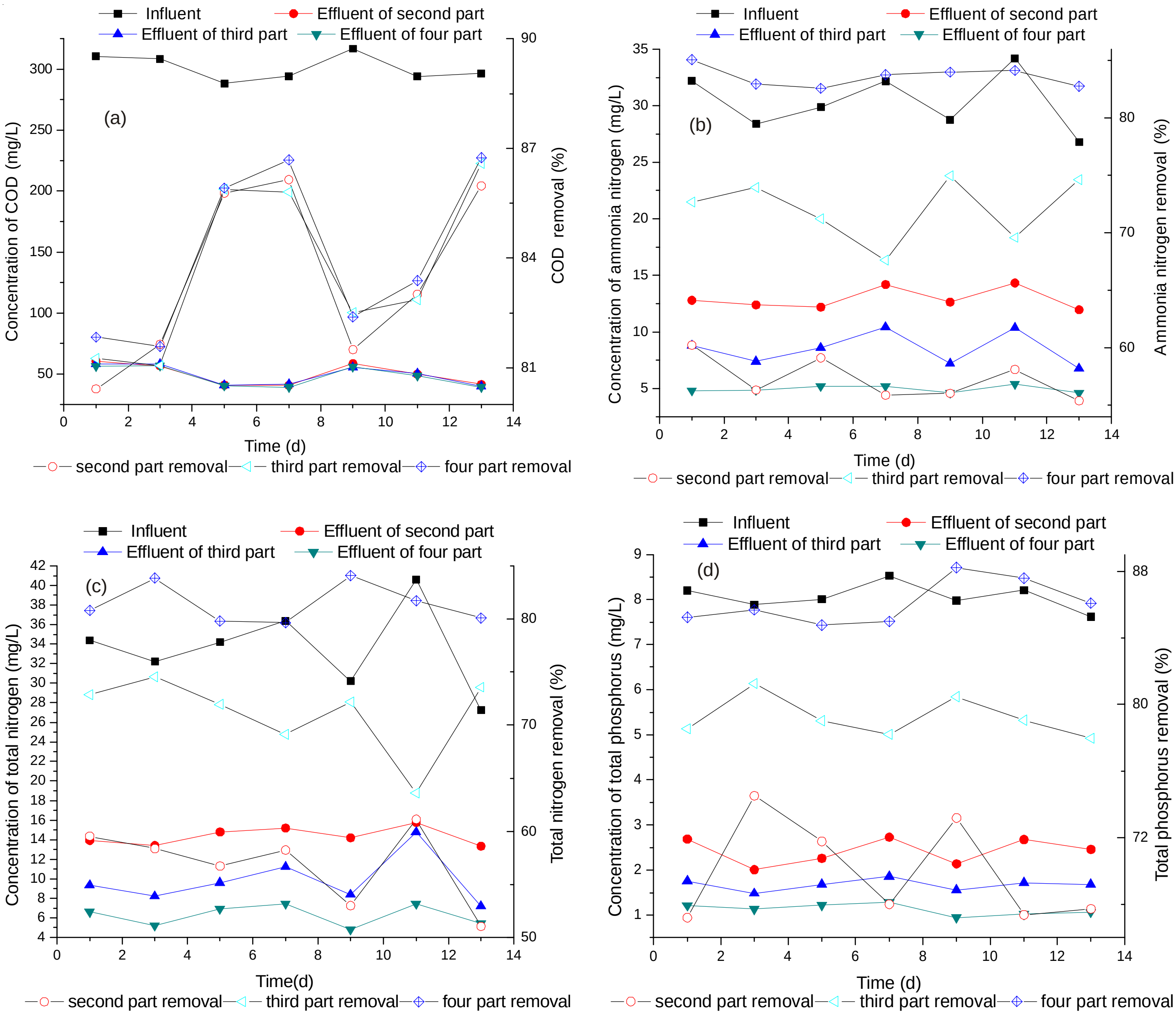

Fig. 4. Nutrients removal efficiency of the process under optimal condition: (a) Chemical oxygen demand; (b) ammonia nitrogen; (c) total nitrogen; (d) total phosphorus

ammonia nitrogen can be reduced by 72 % and in the last part, the ammonia nitrogen concentration of effluent was 4.9 mg/L, ammonia nitrogen can be reduced by 84 % at last. Concentration of dissolved oxygen was only 1-1.5 mg/L in aerobic tank caused ammonia nitrogen removal efficiency was not high. If the concentration of dissolved oxygen in aerobic tank was increased, ammonia nitrogen removal efficiency would be higher, but total nitrogen and total phosphorus removal efficiency decreased. Due to the dissolved oxygen concentration of effluent from aerobic tank would be higher too, as the effluent flowed into anoxic tank, denitrification and phosphorus removal would be inhibited. Total nitrogen concentration was about 33.6 mg/L in feed water, effluent concentration of last reactor part was about 6.5 mg/L. The total nitrogen removal efficiency of second part was about 57 %, third part was about 71 %. And finally, total nitrogen can be reduced by 81 %. The removal rate of total phosphorus could reach the average of 70 %(2nd), 79 %(3rd) and 86 % (4th), respectively. With the increase of the reaction order, water flow was also growing, hydraulic retention time would be shorter. The nutrients removal efficiency would decline as reaction order increased. But water flow would dilute the pollutants concentration, due to that nutrients removal efficiency increased as the reaction part increased.

Conclusions

This research focused on denitrification and phosphorus removal by anaerobic and aerobic flow end with anoxic activated sludge process. Major findings are as follows:

• Denitrification and phosphorus removal by anaerobic and aerobic flow end with anoxic activated sludge process can be used to treat low carbon-nitrogen ratio wastewater.

• Keep C/P the same, changing the C/TN ratio has great influence on denitrification and phosphorus removal by anaerobic and aerobic flow end with anoxic activated sludge process. But nutrients removal efficiency did not change too much as influent flow rate distribution ratio changed. In other word, the process could work well even under strong impact.

• As C/TN was10, influent flow rate distribution ratio set as 1:2:2:1, the process removal efficiency for nutrients is best. chemical oxygen demand can be reduced by 84 %, total nitrogen can be removed 81 %, phosphorus and ammonia nitrogen can be reduced by 86 and 84 %, respectively.

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