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Optimum operation conditions of nitrogen and phosphorus removal by a biofilm-activated-sludge system

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Abstract: In the biofilm and activated sludge combined system, denitrifying bacteria attached on the fibrous carriers in the anoxic tank, while the sludge containing nitrifying and phosphorus removal bacteria was only recirculated between the aerobic and anaerobic tanks. Therefore, the factors affected and restricted nitrification, denitrification and phosphorus removal in a traditional A/A/O process were resolved. This paper describes the optimum operation conditions for nitrogen and phosphorus removal using this system.

Keywords: nitrification; denitrification; phosphorus removal; biofilm; activated sludge

Introduction

In a traditional anaerobic-anoxic-aerobic (A/A/O) process, the activated sludge with nitrifying, denitrifying and phosphorus removal bacteria was recirculated among the anaerobic, anoxic and aerobic tanks. Because these bacteria required the different environments, the influence and inhibition were taken place to them during the recirculation. Some operation results from the wastewater treatment plants with A/A/O process showed that it is difficult to gain the high efficiencies of nitrogen and phosphorus removal at the same time(Feng, 1994; Shen, 1994). In order to gain high nitrification efficiency, the amount of sludge in the anaerobic and anoxic was limited(Yan, 1992). However, the release of phosphorus in the anaerobic tank or denitrification in the anoxic tank will be affected by the distribution of sludge and the organic substance between the anaerobic and anoxic tanks. Therefore, the removal efficiencies of total nitrogen(TN) or total phosphorous(TP) were limited in the process(Yeoman, 1988).

In a biofilm and activated sludge combined system, fibrous carriers were packed in the anoxic tank to facilitate attached growth of denitrifying bacteria while the sludge containing nitrifying and phosphorus removal bacteria was recirculated between the aerobic and anaerobic tanks. Therefore, nitrification, denitrification and phosphorus removal could be completed at their own optimum conditions respectively (Liu, 1996). The results during the test operation of some two years showed that the removal efficiencies of 99% NH_4^+-N, 85% TN, 95% TP and 95% COD were obtained in the system(Liu, 2000).

The aim of this experimental investigation is to find optimum operation conditions for nitrogen and phosphorus removal using the biofilm and activated sludge combined system. The experimental works have been carried out in the Netherlands and China respectively.

1 Materials and methods

The flow sheet of the biofilm and activated sludge combined system is shown in Fig.1. The effective volumes of the anoxic, aerobic and anaerobic tanks were 165L, 480L and 120L respectively. This was a laboratory scale experiment. The flow rate of influent in the system was 30—35 L/h.

NH_4-N, NO_3-N, NO_2-N and TP were analysed according to DIN 38406-E5-1(Dr Lange cuvette test LCK 303), DIN 38405-D9-2(LCK 339), DIN 38405-D10(LCK 341) and DIN 38405-D-11-4(LCK 350) or Chinese standard methods respectively. COD, organic nitrogen, MLSS, MLVSS and SS were determined according to the standard methods(APHA, 1990). The pH was measured with a pH meter. The dissolved

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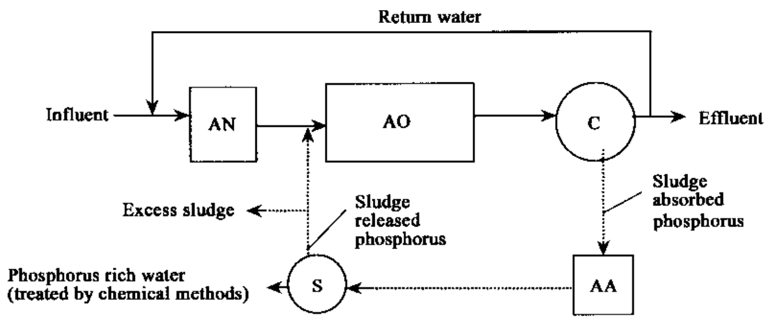

Fig.1 The biofilm-activated sludge system

AN is the anoxic tank; AO is the aerobic tank; C is the clarifier; AA is the anaerobic tank; S is the sludge thickener

oxygen(DO) concentration was measured with an oxygen meter.

2 Results and discussion

2.1 Operation conditions of the anaerobic and aerobic tanks

2.1.1 The ratio of sludge

The nitrifying and phosphorus removal bacteria were recirculated between the aerobic and anaerobic tanks in the system. According to their characteristics, a condition with the sludge too much in the aerobic tank and the sludge very little in the anaerobic tank was beneficial to nitrification and absorption of phosphorus in the aerobic tank, but the release of phosphorus in the anaerobic tank was decreased, therefore, TP removal was decreased. Whereas, the nitrification efficiency was decreased.

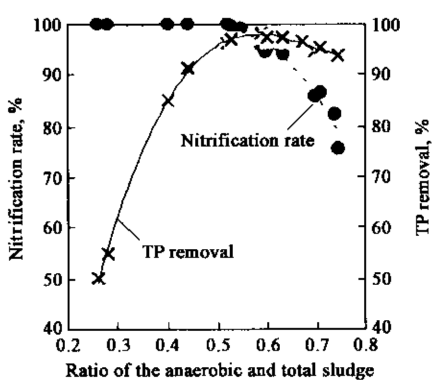

Fig.2 Influence of the ratio of the anaerobic and total sludge amount on nitrification and TP removal

The experimental result in Fig. 2 shows that the efficiencies of nitrification and phosphorus removal in the system are changed with the ratio of the amount of anaerobic sludge and total sludge (including the anaerobic and aerobic tanks). The high nitrification efficiency and low removal of phosphorus were gained at low ratio. The phosphorus removal was increased with an increasing of the ratio. When the ratio was about 0.5, the high efficiencies of nitrification and phosphorus removal were obtained at the same time. After the ratio was higher than 0.6, nitrification efficiency was evidently decreased.

2.1.2 The release of phosphorus

The experimental results of releasing phosphorus under the anaerobic condition are shown in Fig.3, 4 and 5 respectively. The anaerobic hydraulic retention time (HRT) is an important parameter in biological phosphorus removal and it relates to temperature. Spatzierer *et al*. (Spatzierer, 1985) studied phosphorus release under anaerobic conditions at 20℃ and 12℃. Their results showed that the release of phosphorus was 0.45 and 0.06 mg P/(g MLSS·h) respectively. Mamais and Jenkins(Mamais, 1992) stated that in a temperature range of 10—30℃ a 10℃ temperature drop resulted in a 1.5—1.7 fold decrease of the phosphorus removal. The optimum temperature for maximum enhanced biological phosphorus removal was between 28—33℃.

Fig.3 shows the experimental results of phosphorus release. In the experiment, the sludge from the clarifier was put in two bottles and operated at 20℃ and 5℃ respectively. For a maximum phosphorus release about 30h at 20℃ was needed. At 5℃ 95h were required to release the same amount of phosphorus. Therefore, the anaerobic HRT affects the amount of phosphorus released, and temperature affects the rate of phosphorus release.

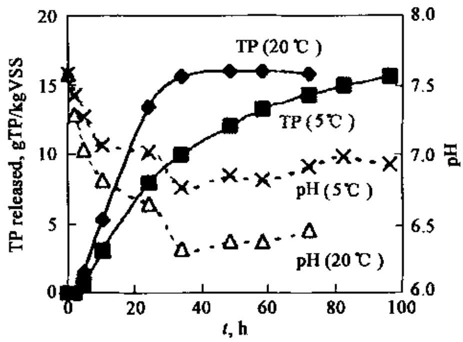

Fig.3 The influence of temperature and HRT on TP release

The release of phosphorus was also affected by the type of organic material in the anaerobic tank (Cong, 1997). In order to investigate the influence of the type of organic material on releasing phosphorus in the system, an experiment that NaAc, glucose and wastewater were put into the sludge from the clarifier, respectively, was carried out. The COD concentration in the sludge was about 100 mg/L after these materials were put into. The experimental result in Fig.4 shows that the rate of phosphorus release with NaAc was highest. However, in actual operation the organic material in wastewater was often used as carbon source for releasing phosphorus because of economical reason. In the biofilm and activated sludge combined system, raw wastewater enters the anoxic tank instead of anaerobic tank. Fig.5 shows an experiment result of releasing phosphorus under a condition of sludge with or without additional carbon source and its experimental conditions are presented in Table 1. According to the experimental result in Fig.5, the additional carbon source for releasing phosphorus in the anaerobic tank is not need in the system, because the sludge with high concentration from the clarifier can quickly form an anaerobic state and the organic material adsorbed in sludge can meet the need of releasing phosphorus.

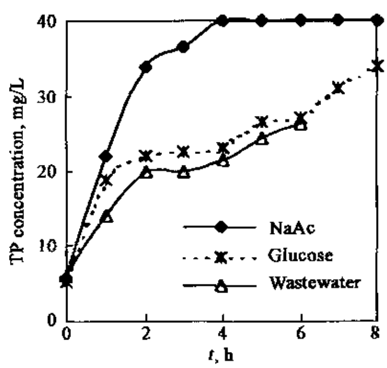

Fig.4 The influence of the type of organic material on TP release

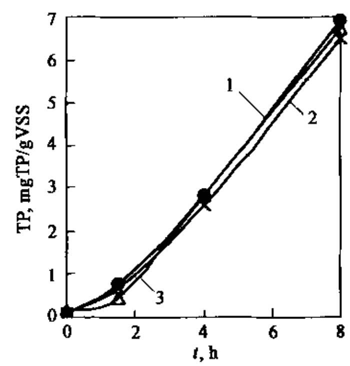

Fig.5 The TP release under anaerobic condition

Table 1 The experimental conditions for releasing phosphorus

Parameter	1	2	3
Sludge, L	2.2	2.2	2.2
Additional carbon source	No	200 mg(glucose)	0.2L(wastewater)
MLVSS, g/L	11.976	11.976	10.887
NOx-N, mg/L	6.05	6.05	5.5
TP, mg/L	1.02	1.02	1.98
COD, mg/L	102	305	120
Temperature, ℃	20	20	20

Spatzierer *et al*. (Spatzierer, 1985) have reported that if the nitrate concentration in the effluent rises above 3 mg/L the phosphorus removal efficiency decreases to 30%, due to the incorporation into organic matter removal. The presence of nitrate inhibits phosphorus release by competition between denitrifying bacteria and polyphosphate accumulating bacteria for acetic acid and other volatile fatty acids. Alternatively, in case of the presence of denitrifying phosphorus removing bacteria, a reduction of phosphorus release by nitrate is due to the conversion of acetic acid in the TCA cycle and subsequent oxidation of the produced $NADH_2$ and $FADH_2$ with nitrate(Kuba, 1994).

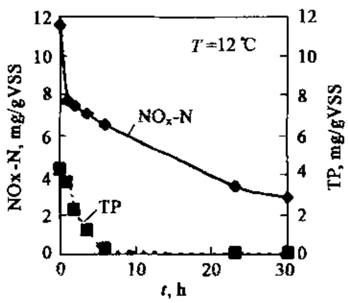

Fig.6 The influence of oxidized nitrogen on phosphorus release

The influence of nitrate on phosphorus release in the experimental system is very weak because of the high sludge concentration in the anaerobic tank of the system. In order to investigate the influence of high nitrate concentration on releasing phosphorus, amount of KNO_3 was put into the anaerobic sludge. The experimental result is shown in Fig. 6. According to Fig. 6, the high concentration of oxidized nitrogen (NOx-N) in the anaerobic sludge inhibits the phosphorus release and results in absorption to phosphorus. Therefore, the amount of oxidized nitrogen entered the anaerobic tank must be reduced as little as possible in actual operation.

When the sludge contains a little of oxidized nitrogen, denitrification is carried out first in the anaerobic tank. The release of phosphorus takes place after oxidized nitrogen is completely removed from the sludge. The time for denitrification in the anaerobic tank relates to the amount of oxidized nitrogen in the sludge. The test results in Fig. 7 show the time for full denitrification is increased with an increasing of the amount of oxidized nitrogen in sludge. In order to ensure release of phosphorus, the anaerobic HRT must be increased with an increasing of the amount of oxidized nitrogen.

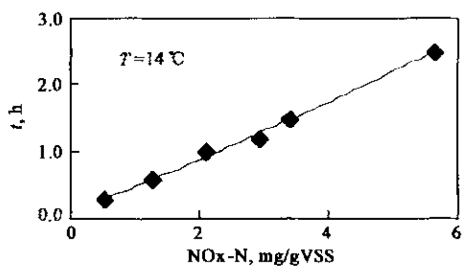

Fig.7 Time for denitrification in anaerobic tank as a function of oxidized nitrogen concentration

2.2 Optimum loading rate for nitrogen removal

The loading rate is one of important parameters to design and operate in a process for wastewater treatment. The experimental results of nitrification or denitrification with different ammonia or oxidized nitrogen concentrations in the aerobic or anoxic tanks are shown in Figs.8 and 9 respectively. According to Fig.8, the nitrification rate of 99.9% can be gained under these conditions that temperature is higher than 10℃ and the loading rate is lower than 0.07 gNH_4-N/(g VSS·d).

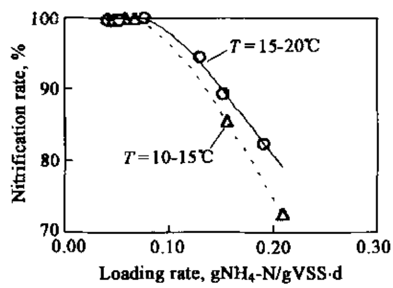

Fig.8 The influence of NH_4-N loading rate and temperature on nitrification in the aerobic tank

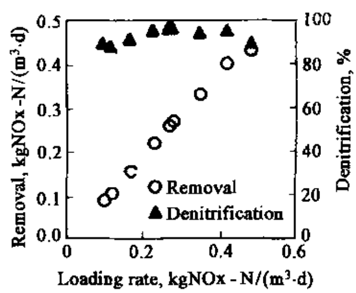

Fig. 9 Denitrification as a function of oxidized nitrogen loading rate in the anoxic tank

The loading rate of oxidized nitrogen including nitrate and nitrite is one of the factors that affect the denitrification rate. In the test system, fibrous carriers were packed in the anoxic tank to facilitate attached growth of denitrifying bacteria. Therefore, the loading rate was expressed in volume loading rate. The experimental results in Fig.9 showed that the removal rate of oxidized nitrogen was increased with an increasing of its loading rate, and denitrification efficiency was higher than 90% during the experimental operation.

2.3 Effect of HRT on nitrogen removal

The experimental results in Fig. 8 showed that the nitrification efficiency in the aerobic tank was affected by ammonia nitrogen loading rate. In order to reach high nitrification efficiency, the loading rate of ammonia nitrogen must be controlled. The HRT of the aerobic tank was affected by the loading rate and mainly decided by NH_4-N concentration. The data in Fig.10 illustrate the relationship between HRT of the aerobic tank and NH_4-N concentration in the effluent of the test system under the condition of NH_4-N concentration in influent 80—120 mg/L. According to Fig. 10, the NH_4-N concentration in the effluent was decreased with an increasing of HRT, and lower than 10 mg/L at HRT of 12 hours in the aerobic tank.

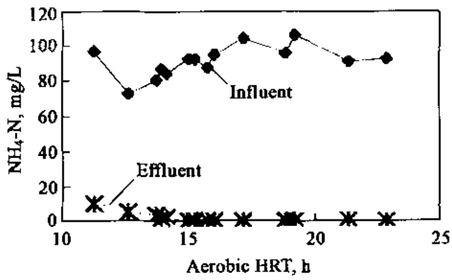

Fig.10 The influence of HRT in the aerobic tank on NH_4-N removal

3 Conclusion

According to the results of this experimental study, the optimum conditions of the biofilm and activated sludge combined system are as follows: (1) In order to obtain the high efficiencies of nitrification and phosphorus removal at the same time, the ratio of the amount of anaerobic sludge and total sludge should be about 0.5. (2) The additional carbon source for release of phosphorus in the anaerobic tank is not need in the system, because the organic material absorbed in sludge can meet the need of releasing phosphorus. (3) Anaerobic HRT is determined on the basis of denitrification time and releasing phosphorus time in the anaerobic tank. Aerobic HRT is decided by ammonia nitrogen concentration in the influent and the effluent. (4) The nitrification rate of 99.9% can be obtained when the loading rate is lower than 0.07 gNH_4-N/(gVSS·d) in the aerobic tank. The loading rate of oxidized nitrogen in the anoxic tank is lower than 0.6 kg NOx-N/(m^3·d).

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