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Simultaneous nitrogen and phosphorus removal under low dissolved oxygen conditions

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Abstract: A full-scale test was operated by using low dissolved oxygen activated sludge process to enhance biological nitrogen and phosphorus removal. When the influent concentrations of COD_{Cr}, TN and TP varied in a range of 352.9 mg/L—1338.2 mg/L, 34.4 mg/L—96.3 mg/L, and 2.21 mg/L—24.0 mg/L, the average removal efficiencies were 94.9%, 86.7% and 93.0%, respectively. During the test period of two months, effluent meas of COD_{Cr}, BOD_5, NH_3-N, TN and TP were below 50 mg/L, 25 mg/L, 10 mg/L and 1.0 mg/L, respectively. The low dissolved oxygen activated sludge process has a simple flow sheet, fewer facilities and high N and P removal efficiency. It is very convenient to retrofit the conventional activated sludge process with the above process.

Key words: high concentration activated sludge; low dissolved oxygen process; nitrogen removal; phosphorus removal

Introduction

Nitrogen(N) and phosphorus(P) in municipal sewage, which mainly come from domestic wastewater and some industrial wastewater, will cause many harms and restrict the normal function of water environment after enter the water body. The problem of nitrogen an phosphorus pollution has been emphasized worldly since 80s(Pitman, 1983; Kang, 1992). In order to control the nutrient contaminant, Europe and USA have made very strict N and P discharge standard. The governments of these countries required that new municipal wastewater treatment plants must possess the functions of N and P removal. At the same time, they invested a great deal of money to reconstruct the existing municipal wastewater treatment plants so as to get the function of nitrogen and phosphorus removal.

In China, since most of the municipal wastewater treatment plants have no function of nitrogen and phosphorus removal, it is very necessary to search for feasible and economical technologies with nitrogen and phosphrus removal function to retrofit the existing wastewater treatment plants.

Although some processes, such as A^2/O process, Barnard process, Bardernpho process, UCT and VIP process, are effective for nitrogen and phosphorus removal, they have some shortages such as complicated flow sheet and facilities that restrict their application in retrofitting existing wastewater treatment plants are existed.

The low dissolved oxygen activated sludge nitrogen and phosphorus removal process is a process in low dissolved oxygen concentrations of between 0.5 mg/L and 1.0 mg/L in aeration tank to create aerobic, anoxic and anaerobic conditions. In aerobic condition, the organic pollutants are oxidized and biological P-uptake is achieved while ammonia as converted to nitrate, which will be subsequently removed through denitrification in anoxic condition. The School of Environmental Science and Engineering of Tongji University, Shanghai, China has been studying this topic since 1994. Based on bench scale study, the full scale test using low dissolved oxygen activated sludge nitrogen and phosphorus removal process was reconstructed to investigate the treatment efficiencies of N and P. General discussion on this study is presented in this paper.

1 Experimental

1.1 Full-scale study program

Full scale tests were operated at the Songjiang Municipal Wastewater Treatment Plant (MWTP), Shanghai for a period of 2 months. The influent of low dissolved oxygen aeration tank came from grit chamber (by passing primary settling tank), to get a high MLSS concentration (Liu, 1993). The original facilities were not modified. The flow sheet of low dissolve oxygen activate sludge nitrogen and phosphorus removal process is shown in Fig. 1.

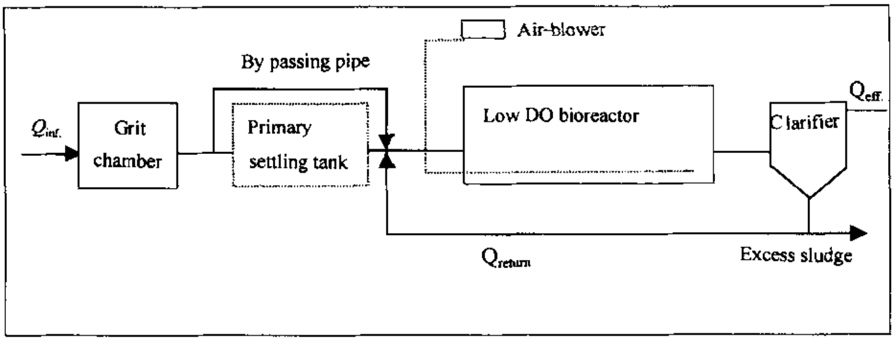

Fig. 1 The flow of the low dissolved oxygen process

1.2 Analytical method

The influent and effluent samples of the bioreactor were collected once 2 hours. The sample were analyzed in Lab daily. SS, VSS, COD_{Cr}, BOD_5 and NH_3-N were analyzed using standard methods. The other analytical methods are listed in Table 1.

Table 1 Analytical methods for some wastewater quality parameter

Water quality indexes	Analytical methods
DO	YSL-model 58 dissolved oxygen meter
pH	PHS-3D model pH meter
NO_2^--N	α-naphthylamine hydrochloride colorimetric method
NO_3^--N	Calorimetric method
TKN	Sulfuric acid digestion, distillative titration method
PO_4^{3-}-P	Ammonium molybdate spectrometric method
TP	Perchloric acid digestion, ammonium molybdate spectrometric method

1.3 The operation parameters

The designed parameter of Songjiang MWTP, which did not have the function of nitrogen and phosphorus removal, are provided in Table 2.

Table 2 Designed parameters of Songjiang MWTP

Q, m^3/d	Volume of aeration tank, m^3	MLSS in aeration tank, mg/L	Volume load, $kgBOD_5/(m^3.d)$	Organic load, $kgBOD_5$/(kg MLSS. d)	DO, mg/L
270000	4500×2	2500	0.60	0.24	2—3

There are four parallel aeration tanks, which are divided into two groups. Every tank has an approximate volume of 2500 m^3(68×6×6m). The concentrations of MLSS in aeration tanks were increased through by passing primary settling tank. The DO concentrations of aeration tanks were monitored using YSL-model 58 DO meter every 2 hours at the end of aeration tanks and were controlled between 0.5 mg/L and 1.0 mg/L by adjusting the aeration strength. The operation parameters in the tests are listed in Table 3.

Table 3 Operation parameters in the test

Q, (m^3/d)	Volume of aeration tank, m^3	MLSS in aeration tank, mg/L	Volume load kg $BOD_5/(m^3.d)$	Organic load $kgBOD_5$/(kg MLSS. d)		
21000	4500×2	4931	0.721	0.146		
HRT in aeration tank, h	Sludge age, d	Recycle ration	T, ℃	MLVSS, mg/L	SVI, ml/g	DO mg/L
10.3	15	1.3	20—25	2916	79.7	0.5—1.0

2 Results and discussion

2.1 Results under low disolved oxygen conditions

2.1.1 Removal of COD_{Cr}

During a period of 2 months, the COD_{Cr} concentrations in 59 days were analyzed. The results are shown in Fig. 2.

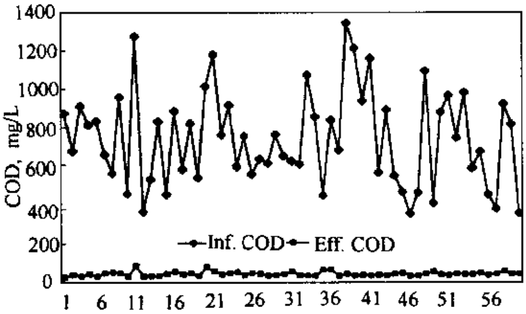

Fig. 2 Influent and effluent COD concentrations during the test period

Fig. 2 shows that the COD_{Cr} concentrations varied considerable from day to day. Influent COD_{Cr} to the aeration tanks was normally between 500 mg/L and 900 mg/L, with extreme values from 352.9 mg/L to 1338.2 mg/L, the influent mean was 797.3 mg/L during the investigation. The effluent concentrations ranged from 28.9 mg/L to 80.5 mg/L. The average effluent concentration and removal efficiency was 40.8 mg/L and 94.9%, respectively.

2.1.2 Removal of TN

TN concentrations in 50 days were analyzed. The results are shown in Fig. 3.

During the investigation, influent TN concentrations fluctuated in a range of 34.4 mg/L—96.3 mg/L and the average concentration was 64.2 mg/L. The effluent concentration ranged from 2.3 mg/L to 28.7 mg/L. The average effluent concentration and removal efficiency was 8.2 mg/L and 86.7%, respectively.

2.1.3 Removal of TP

TP samples in 51 days were collected. The test results are shown in Fig. 4.

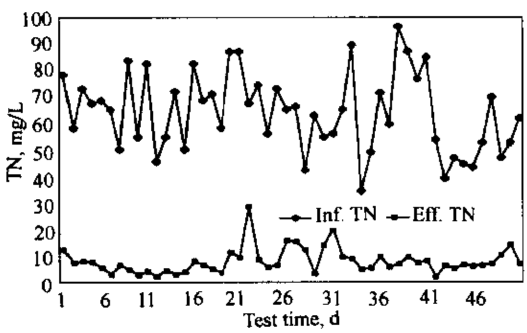

Fig. 3 Influent and effluent TN concentrations during the test period.

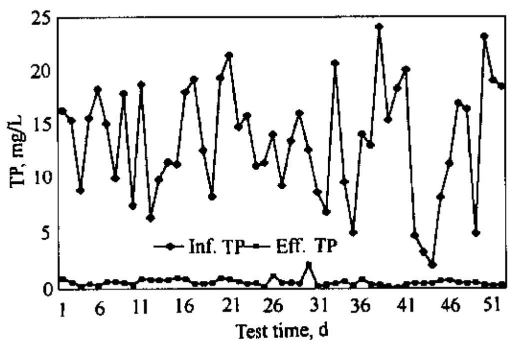

Fig. 4 Influent and effluent TP concentrations during the test period

The influent TP concentrations varied from 2.1 mg/L to 24.0 mg/L during the test and the mean was 11.8 mg/L. The average effluent concentration and removal efficiency was 0.87 mg/L and 93.0%, respectively.

2.1.4 Average removal of other water characteristics

During the investigation, all the following samples were collected and analyzed over 50 days. The average results of some water characteristics are summarized in Table 4.

All the above results showed that the removal efficiencies of COD_{Cr}, TN and TP are very high in low dissolved oxygen aeration process, although aeration reduced and volumetric loading increased by 20% of the designed value. The removal efficiencies of TKN, TN and

Table 4 The average results of some water characteristics

	BOD_5	NH_3-N	NO_3^--N	NO_2^--N	TKN	PO_4^{3-}-P
Inf., mg/L	330.5	21.5	1.36	0.12	66.2	1.94
Eff., mg/L	21.7	4.8	7.38	0.24	7.1	0.31
η, %	93.4	87.7			89.3	84.1

TP were 89.3%, 86.7% and 93%, respectively. It can be concluded that the denitrification of this process must be effective as a result of superior performance of TN removal. The effluent concentrations of TKN and TN were both less than 10 mg/L. TP concentration in the effluent was 0.87 mg/L on average. The average values of TN and TP were less that the discharge standard of China (GB8978-1996).

2.2 Compared with the results of other conditions

Because Songjiang MWTP had no function of nitrogen and phosphorus removal, TN and TP were not analyzed before we studied. The NH_3-N removal efficiencies in the corresponding April of 1990, 1996 and 1997, which are in the conditions of with primary settling tank under normal aeration, without primary settling tank under normal aeration, and without primary settling tank under low DO conditions respectively, are listed in Table 5.

Table 5 NH_3-N removal efficiencies under different conditions

Date	April 1990 With primary settling tank and normal aeration			April 1996 Without primary settling tank and normal aeration			April 1997 Without primary settling tank and low DO conditions		
	Inf., mg/L	Eff., mg/L	Removal, %	Inf., mg/L	Eff., mg/L	Removal %	Inf., mg/L	Eff., mg/L	Removal., %
1	19.7	9	54.3	20	3.8	81.0	28.6	11.2	60.8
2	11.9	11.2	5.9	27.6	7.3	73.6	20.4	6.3	69.1
3	14.8	13.2	10.8	30.5	9.1	70.2	25	6.1	75.6
4	28.9	14	51.6	25.6	13.6	46.9	23.9	7.1	70.3
5	22.5	15.3	32.0	38.4	10.5	72.7	17	3.4	80.0
6	17.9	13.5	24.6	31.6	12.8	59.5	20.3	2.9	85.7
7	15.3	15.6	-2.0	31.4	5.5	82.5	16.3	6	63.2
8	21.1	13.3	37.0	32.8	8.2	75.0	24	4.7	80.4
9	11.7	19.4	-65.8	34.4	11.1	67.7	26.4	2.8	89.4
10	25.9	14.5	44.0	31.8	9	71.7	23.8	3.7	84.5
11	19.2	13.7	28.6	22.6	6.3	72.1	24.3	1.7	93.0
12	17.9	12.7	29.1	18.4	5	72.8	19.9	2.6	86.9
13	16.8	14.5	13.7	24.1	5	79.3	18.6	2.5	86.6
14	17.8	14	21.3	15.7	4.8	69.4	21.5	2.5	88.4
15	18	14.9	17.2	32.9	3.4	89.7	22.7	7.6	66.5
16	16.8	13.2	21.4	27.4	11.2	59.1	31.7	6.5	79.5
17	24.6	16.3	33.7	30.4	4.4	85.5	23	4.3	81.3
18	19.1	15.7	17.8	27.9	2.6	90.7	30.1	1.97	93.5
19	19.1	15.5	18.8	16.9	2.1	87.6	32.4	8.7	73.1
20	22.1	17.1	22.6	22.5	3.9	82.7	29.6	7.6	74.3
21	21.5	15.1	29.8	18.3	4.7	74.3	27.5	10.8	60.7
22	15.4	13.9	9.7	30.1	5.2	82.7	25	7.8	68.8
23				23.9	8.5	64.4	20.3	4.2	79.3
24	16	16.1	-0.6	24.2	8.6	64.5	26.4	5.4	79.5
25	14.6	15	-2.7	31.1	11.6	62.7	21.3	13.9	34.7
26	19.2	14	27.1	26.1	7.3	72.0	26.9	3.4	87.4
27	13.9	14.3	-2.9	22.8	12.8	43.9	28.1	6.2	77.9
28	16.1	12.7	21.1	52.7	10	81.0	24	1.3	94.6
29	17.1	14.8	13.5	24.3	10.8	55.6	24.4	11.8	51.6
30	14	13.8	1.4	35.7	12.5	65.0	26.1	10.4	60.2
Average	18.2	14.4	17.7	28.7	8.0	74.3	25.2	6.0	78.5

Table 5 shows the removal efficiencies of NH_3-N were very low when there was primary settling tank under normal aeration. A high MLSS concentrations were obtained as the by passing pipe was built and a higher NH_3-N removal efficiencies were reached, but their was a weak function of TN and TP removal under aeration conditions. The highest NH_3-N removal efficiencies were obtained under lower dissolved oxygen condition compared with other two conditions and high removal efficiencies of TN and TP were obtained at the same time.

3 Discussion

Because of no primary settling in this process, a great deal of biomass and particulate organic compounds in wastewater directly entered bioreactor. Due to increasing of the total biomass guaranteed in the reactors, the carbon sources of nitrogen and phosphorus removal process were ensured and did not need to add separately.

A great deal of facultative bacteria, which had high reproductive capacity and had adopted themselves to the wastewater, entered biological reactor and enhanced the treatment capacity of the system and made the operation more stable. As a large amount of suspended solid entered the reactors and provided a good habitation for biomass and made the micro-organism species and quantity greatly increasing, all this enhanced the capacity of the system to resist shock loading and no suitable environment.

At the outer of the microbial floc in low dissolved oxygen bioreactor, the DO concentration was high and aerobic organism and nitrifiers were dominant. Towards the core of the floc, there were anoxic and anaerobic micro-environments due to the mass transfer resistance and gradual consumption of oxygen. The micro-environments were changeable due to microbial metabolism and agitation of aeration and ensured the simultaneous processes of nitrifying and dentitriying, P-uptake and P-release in low DO aeration reactor.

As a conclusion, the suggested parameter for low dissolved oxygen activated sludge nitrogen and phosphorus removal process is provided in Table 6.

Table 6 The suggested design parameters for low DO process

MLSS, g/L	5—7
Sludge recycle ratio	1—2
Volume organic loading, $kgBOD_5/(m^3.d)$	0.5—0.7
Sludge organic loading, $kgBOD_5/(kgMLSS.d)$	≤0.15
Sludge age, d	≥12
Dissolved oxygen, mg/L	0.5—1.0

4 Conclusion

Based on the test results, low dissolved oxygen activated sludge nitrogen and phosphorus removal process will be very suitable for treating the municipal wastewater those water characteristics are similar as that of Songjiang MWTP. When the influent concentrations of COD_{Cr}, TN and TP flucturated in a range of 352.9 mg/L—1338.2 mg/L, 34.4 mg/L—96.3 mg/L and 2.21 mg/L—24.0 mg/L, the average removal efficiencies reached 94.9%, 86.7% and 93.0% respectively. Effluent mens of COD_{Cr}, BOD_5, NH_3-N, TN and TP were below 50 mg/L, 25 mg/L, 10 mg/L, 10 mg/L and 1.0 mg/L respectively. The low DO process has a simple flow sheet and fewer facilities, only one recycle system, and high efficiency of N and P removal. It is very convenient to retrofit the conventional activated sludge process with low DO process. This process can be used to design new wastewater treatment plants, too.

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