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NITROGEN REMOVAL EFFICIENCY OF AN A^2/O BIO-REACTOR TREATING DOMESTIC SEWAGE MIXED WITH LANDFILL LEACHATE AND FECAL SEWAGE

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ABSTRACT
A set of anaerobic-anoxic-aerobic (A^2/O) bio-reactor system was used to treat domestic sewage mixed with landfill leachate and fecal sewage in Datansha Sewage Treatment Plant in Guangzhou China. The experiment investigated the optimal mixing proportion of treating landfill leachate, fecal sewage mixed with domestic sewage synchronously and the optimal running conditions for the removal efficiency of nitrogen by an orthogonal array test. A confirmatory experiment was also carried out to verify the optimal parameters obtained by the orthogonal array test. The results showed that: the optimal volume ratio of landfill leachate, fecal sewage and urban wastewater in the A^2/O process was 1:3.75:1000. The average removal efficiency of NH_3-N, TN and COD can reach 96%, 61% and 85% respectively under the conditions of hydraulic retention time (HRT) of 11h, dissolved oxygen (DO) of 3 mg L^{-1} the mixed-liquid return ratio (r) of 200% and sludge return ratio (R) of 80%.

KEYWORDS: Anaerobic-Anoxic-Aerobic process (A^2/O); Landfill leachate; Fecal sewage; Domestic sewage; Orthogonal array test.

INTRODUCTION

Landfill leachate has generally been considered a high-concentration wastewater that is difficult to treat because of the high concentration of ammonia nitrogen and organic matters (Lema *et al*., 1988; Iza *et al*., 1992; Garcia *et al*., 1996; Zhou, 2007). Consequently, landfill leachate has been widely considered a significant pollutant to surface water and groundwater, and it is a significant factor in planning the location of landfills.

Fecal sewage, mainly from urban public toilets, is also a high-concentration organic wastewater, rich in nitrogen, phosphorus, potassium and other elements. If the fecal sewage is discharged untreated, it would cause water pollution, eutrophication and can lead to an infectious disease epidemic because fecal sewage contain a large number of pathogens.

The components of landfill leachate and fecal sewage can be removed by various physico–chemical and biological processes. The physico–chemical methods include coagulation–flocculation (Amokraneet *et al*., 1997; Urase *et al*., 1997; Zhou *et al.*, 2008), ammonium stripping (Diamadopoulos, 1994; Marttinen *et al*., 2002), membrane filtration (Linde and Jonsson, 1995; Ushikoshi *et al*., 2002; Jenkins *et al*., 2003; Li *et al.*, 2007) and activated carbon adsorption (Imai *et al*., 1995; Wasay *et al*., 1999). Biological treatments include anaerobic treatment such as up-flow anaerobic sludge blanket (UASB) (Kennedy and Lentz, 2000; Lin *et al*., 2000), aerobic treatment as a sequencing batch reactor (SBR) (Neczaj *et al*., 2005; Klimiuk and Kulikowska, 2006), and a membrane bioreactor (Ahn *et al*., 2002; Laitinen *et al*., 2006).

Among various technologies, it is attractive to use the anaerobic-anoxic-aerobic process (A^2/O) to treat the landfill leachate and fecal sewage mixed with relatively low-concentration domestic sewage in a domestic sewage treatment plant. The A^2/O process can remove nitrogen and phosphorus from wastewater simultaneously, and has high removal efficiency for organic pollutants. These characterisitics of the A^2/O process provide a new way to treat landfill leachate and fecal sewage. However, at the same time, there are some disadvantages. The high-concentrated landfill leachate and fecal sewage will effect the impulse load of nitrogen in the effluent and the concentration of NH_3-N and TN in the effluent. Therefore the quantities of landfill leachate and fecal sewage mixed with domestic sewage must be controlled within a certain range and the technical parameters of the A^2/O process need to be adjusted accordingly.

In this research, a A^2/O bio-reactor was used for the treatment of the mixed sewage, which comprised fecal sewage, landfill leachate and domestic sewage. The running mode based on the Datansha Sewage Treatment Plant in Guangzhou in China. This plant has accepted landfill leachate and fecal sewage for treatment for a long time. The objective was to evaluate the feasibility and optimal mixing proportion for treating fecal sewage, landfill leachate and domestic sewage simultaneously. The optimal condition of the nitrogen removal efficiency was also investigated by an orthogonal array test.

2. MATERIALS AND METHODS

2.1 Influent wastewater

The influent consisted of the effluent from the Datansa Sewage Treatment Plant grit chamber, landfill leachate from the Xingfeng Municipal Solid Waste Sanitary Landfill and fecal sewage from the Guangzhou Fecal Treatment plant. The quality of the three kinds of sewage are shown in Table 1.

Table 1. Water quality of domestic sewage, fecal sewage and landfill leachate (mg L^{-1})

	Domestic sewage	**Fecal sewage**	**Landfill leachate**
BOD_5	70-150	2000-6500	4000-12000
COD	100-300	5000-13000	8000-20000
NH_3-N	15-35	500-1500	1500-2300
TN	20-40	700-2500	2000-8000

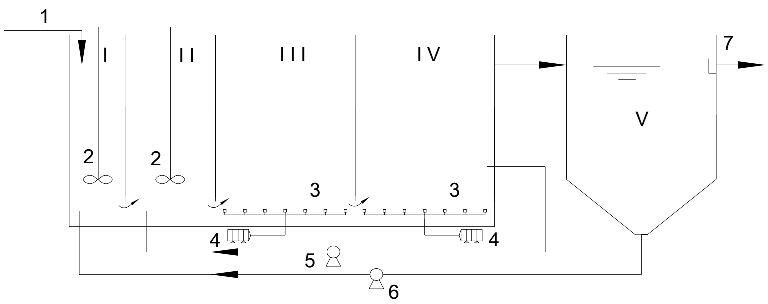
From Table 1, it was known that landfill leachate and the fecal sewage have a high concentration of organic compounds and nitrogen, which would result in an impulse loading to the operation of the A^2/O domestic sewage treatment system if the mixture was not operated properly.

2.2 Analytical methods

All the experiments were conducted in the Datansha Sewage Treatment Plant laboratory. The main items monitored were COD, NH_3-N and TN. All the physical, chemical or biological analysis were carried out in accordance with the Standard Methods recommended by US Environmental Protection Agency (APHA, 1998). In this study, the degree of confidence used was 95%, and all the experimental results represent the mean of at least five experiments.

2.3 Experimental system

The experimental system comprised of a regulating tank, three submersible pumps, an air compressor, the A^2/O bio-reactor and a settling tank. The flow process diagram is shown in Figure1. The A^2/O bio-reactor have four compartments made of steel-plate, with a total capacity of 3800 L. The first compartment was typically operated as an anaerobic zone, followed by second compartment containing an anoxic zone. The remaining two compartments with separate aeration control as aerobic zones. The volume ratio of anaerobic, anoxic and aerobic zone was 1:1.6:5. The settling tank was also made of steel-plate, with a volume of 900 L capacity. The effective depth of water was 1.1 m and on-line sensors to measure DO and temperature were installed in the system. Mixed-liquid return, sludge return and influent flow can be adjusted by the submersible pumps.



I.Anaerobic II.Anoxic III. Aerobic1 IV.Aerobic2 V.Settling tank
1.influent 2.stirrer 3.diffuser 4.air pressure 5.mixed-liquid return
6.sludge return 7.effluent

Figure 1. Schematic diagram of the A^2/O process

3. RESULTS AND DISCUSSION

3.1 Optimal mixing proportion for treating landfill leachate, fecal sewage and domestic sewage

Because the practical operation ratio of landfill leachate, fecal sewage and domestic sewage in Datansha Sewage Treatment Plant was near 0.2:1.0:400, the test assumed the volume ratio of domestic sewage was 400, and selected three volume ratios for landfill leachate and fecal sewage respectively. The volume ratios of 0.2, 0.4 and 0.6 were for landfill leachate and the volume ratios of 1.0, 1.5 and 2.0 were for fecal sewage. The test was designed to find the optimal ratio of landfill leachate, fecal sewage and domestic sewage, which can mix the largest proportions of landfill leachate and fecal sewage with domestic sewage while still achieving the Chinese first grade B effluent standard (COD<40 mg L^{-1}, NH_3-N< 8 mg L^{-1}, TN<20 mg L^{-1}). All the operating conditions were based on the Datansha Sewage Treatment Plant: the temperature was 24^{o}C, mixed-liquid return ratio was 200%, sludge return ratio was 80%, HRT was 9h, DO in the aerobic tank was 3 mg L^{-1}, MLSS was 3000 mg L^{-1} and SRT was 12 d. The average removal efficiency of NH_3-N, TN and COD at each ratio is shown in Table 2.

Table 2. The average removal efficiency of NH_3-N, TN and COD at different ratios

Ratio of leachate: fecal swage: domestic sewage	NH_3-N			T-N			COD		
	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficie-ncy (%)	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal Efficie-ncy (%)	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficie-ncy (%)
0.2:1.0:400	23.8±0.8	0.6±0.2	97.5	26.4±1.0	9.6±0.5	63.6	125.6±14.5	21.6±1.6	82.8
0.4:1.0:400	26.2±1.2	3±0.7	88.6	29.5±1.0	11.4±0.7	61.4	134.7±16.3	26.4±4.1	80.4
0.6:1.0:400	28.9±1.6	5.4±0.4	81.2	31.3±1.7	14.2±0.7	54.6	142.2±22.9	31.5±1.9	77.8
0.2:1.5:400	26.2±1.7	1.6±0.5	94.0	28.6±1.7	12.3±1.6	57.0	148.2±20.7	23.5±1.6	84.1
0.4:1.5:400	29.9±1.6	4.1±0.8	86.3	32.4±1.4	15.7±0.7	51.6	160.9±14.1	29.8±3.5	81.5
0.6:1.5:400	31.5±1.3	7.6±1.5	76.0	34.5±1.4	16.7±0.9	51.6	170±15.5	34.9±4.8	79.5
0.2:2.0:400	28.1±0.7	3.8±0.5	86.6	30.9±0.7	13.3±0.5	57.0	171.8±19.4	28.6±2.9	83.3
0.4:2.0:400	31.5±1.9	7.1±0.8	77.3	34.9±1.5	16.7±0.6	52.1	180.7±7.1	34.3±2.9	81.0
0.6:2.0:400	33.9±1.3	9.7±1.2	71.3	37.2±1.2	19.6±1.1	47.3	193.5±16.3	39.8±4.4	79.4

*Note:23.8±0.8 means that: 23.8 is the average value and 0.8 is the standard errors; the removal efficiency based on the average value of influent and effluent. It is the same for the others.

The concentration of NH_3-N, TN and COD both in the influent and effluent increased as the landfill leachate and fecal sewage ratios increased. This shows that the higher concentration of organic compounds and nitrogen in the landfill leachate and fecal sewage produced adverse effects, especially for the landfill leachate. Most of the effluent values in Table 2 are below the required level for effluent. The exceptions were for influent ratios of 0.6:1.0:400, 0.6:1.5:400 and 0.4:2.0:400.

According to the principle of mixing landfill leachate, fecal sewage with domestic sewage as much as possible while meeting the effluent standard, the higher achievable ratio of landfill leachate, fecal sewage and domestic sewage was 0.4:1.5:400 (1:3.75:1000).

3.2 The influence of single factor on nitrogen removal

Based on the test above, the effects of the varying DO in the aerobic tank, the HRT, the mixed-liquid return ratio (r) and the sludge return ratio (R) on the efficiency of nitrogen removal was the next study. All the tests were based on the volume ratio of landfill leachate, fecal sewage and domestic sewage at 1:3.75:1000. Various Parameters of each test would maintained stable operation at least seven days before sampling detection.

3.2.1 The influence of DO on nitrogen removal

The effect of DO on the efficiency of nitrogen removal was investigated at 2 mg L^{-1}, 3 mg L^{-1} and 4 mg L^{-1} respectively under the experimental conditions as follows: temperature = 28 ^{o}C, r = 200%, R = 80%, HRT = 9 h. The average removal efficiency of NH_3-N and TN at each DO is shown in Table 3.

Table 3. The average removal efficiency of NH_3-N and TN at different DO concentrations

Value of DO	NH_3-N			T-N		
	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficiency (%)	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficiency (%)
DO=2mg·L^{-1}	33.5±1.7	3.8±0.3	88.8	36.5±1.6	18.1±0.7	50.3
DO=3mg·L^{-1}	31.1±1.7	0.2±0.0	99.3	34.5±1.5	14.9±0.5	56.7
DO=4mg·L^{-1}	28.2±0.7	0.1±0.0	99.6	29.5±1.1	18.3±1.2	38.1

Increasing the DO concentration to 3 mg L^{-1} in aerobic achieves much better nitrification, efficiency of NH_3-N and DO were in direct proportion to the changes. With the increase of DO from 2 to 3 mg L^{-1}, the removal efficiency of TN increased. But when the DO was further increased to 4 mg L^{-1}, the removal efficiency of TN decreased to 38.1%. The increased removal efficiency of TN was first due to the increasingly DO and then to the strengthened nitrification. This caused more NH_3-N to transform into nitrate, and more nitrate entered the anoxic tank by the mixed-liquid return pump. It was beneficial to denitrification of the system, so the removal of TN was increased. Nevertheless, when the DO increased to 4 mg L^{-1}, too much DO simultaneously entered the anoxic tank with the mixed-liquid return. This had a bad impact on the condition of anoxic tank, and the activity of denitrifying bacteria was also inhibited. So the DO in the aerobic tank must be controlled within an optimal range for high removal efficiency of TN.

3.2.2 The influence of HRT on nitrogen removal

The effect of HRT on the efficiency of nitrogen removal was investigated with hydraulic retention times of 7 h, 9 h and 11 h. The experimental conditions were: temperature = 28 ^{o}C, r = 200%, R = 80%, DO = 3 mg L^{-1}. Table 4 demonstrated the average of removal efficiency of NH_3-N and TN at each HRT, nitrification and denitrification were enhanced when the HRT was increased. In order to achieve better nitrogen removal efficiency, HRT should be controlled at a rate of more than 9 h.

Table 4. The average removal efficiency of NH_3-N and TN at different HRT

Value of HRT	NH_3-N			T-N		
	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficiency (%)	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficiency (%)
HRT=11h	31.8±1.7	0.6±0.1	98.1	35.8±2.9	13.3±1.1	62.8
HRT=9h	31.1±1.7	0.2±0.0	99.3	34.5±1.5	14.9±0.5	56.7
HRT=7h	33.8±2.2	5.6±0.7	83.5	38.4±3.0	20.3±1.5	47.0

3.2.3 The influence of r on nitrogen removal

The effect of r (the mixed-liquid return ratio) on the efficiency of nitrogen removal was investigated, with r = 100%, 200% and 300%. The experimental conditions were: temperature = 28 ^oC, HRT = 9 h, R = 80%, DO = 3 mg·L^{-1}. The average removal efficiency of NH_3-N and TN at each r is shown in Table 5.

Table 5. The average removal efficiency of NH_3-N and TN at different return ratios

Value of r	NH_3-N			T-N		
	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficiency (%)	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficiency (%)
r=100%	28.8±1.7	1.1±0.4	96.1	31.5±2.1	15.3±1.1	51.3
r=200%	31.1±1.7	0.2±0.0	99.3	34.5±1.5	14.9±0.5	56.7
r=300%	28.1±1.8	1.3±0.1	95.5	30.0±1.7	15.2±0.3	49.1

The efficient of NH_3-N removal was more than 95% for all three tested values of r. Table 5 shows the efficiency of TN removal, which was different to the removal efficiency of NH_3-N. When r was increased from 100% to 200%, the efficiency for TN removal increased from 51.3% to 56.7% but the removal efficiency decreased to about 49.1% when r = 300%. The function of the mixed-liquid return is to provide nitrate nitrogen for the anoxic tank as electron receptor in denitrification (Baeza *et al.*, 2003). When r is too low, it will lead to insufficient nitrate nitrogen in the anoxic tank and affect the removal efficiency of TN. When r is too high, the flow of recycle containing the same oxygen than the aerobic reactor. This excess of oxygen will damage the anoxic condition, thus the denitrification capacity of the system is decreased. The best efficiency of nitrogen removal was achieved at r = 200%.

3.2.4 The influence of R on nitrogen removal

The effect of R (the sludge return ratio) on the efficiency of nitrogen removal was investigated at 60%, 80% and 100%. The experimental conditions were: temperature = 28 ^oC, r = 200%, HRT = 9 h, DO = 3 mg L^{-1}. The average removal efficiency of NH_3-N and TN at each value of R is shown in Table 6.

Table 6. The average removal efficiency of NH_3-N and TN at different sludge return ratio

Value of R	NH_3-N			T-N		
	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficiency (%)	Influent (mg L^{-1})	Effluent (mg L^{-1})	Removal efficiency (%)
R=60%	29.6±2.4	0.9±0.2	96.9	33.6±3.7	16.5±1.2	50.7
R=80%	31.1±1.7	0.2±0.0	99.3	34.5±1.5	14.9±0.5	56.7
R=100%	29.9±3.3	0.2±0.0	99.4	33.5±2.9	13.2±0.8	60.5

Maintaining the quantity of active sludge in the system by continuous return ensures a high efficiency of nitrogen removal. Compared with enhancing the ratio of mixed-liquid return (r), increasing R was more beneficial for nitrogen removal (Gernaery *et al.*, 2003). It can be confirmed from Table 5 and Table 6 that the maximum of TN removal efficiency was 56.7% just considering r in Table 5 while the TN removal efficiency was 60.5% when R was 100%, which proved that increasing the R was more favorable to nitrogen removal.

3.3 The influence of changing multiple factors on nitrogen removal

3.3.1 Design and results of an orthogonal array test

Through the experiments above, the influence of HRT, DO, r and R on nitrogen removal in A^2/O process was isolated and obtained. However, the operating system actually was affected by all the factors simultaneously. Consequently, the optimal combination of multiple factors for the system should be investigated by using an orthogonal array test. The optimization experiments were designed according to the Taguchi fractional design method (Taguchi, 1987). This method considers only the important combined effects of factors in the experimental plan. In this test, the four factors to be considered were HRT, DO, r and R. The optimization criteria were the maximum removal efficiency of COD, NH_3-N and TN. A $L_9(3^4)$ orthogonal array was used in this experimental design (Pililip,1989; Mason *et al.*, 2003), Table 7 summarizes the test levels employed for the selected factors.

Table 7. Factors in orthogonal array experimental design

Level	Factor			
	A-HRT (h)	B-DO (mg L^{-1})	C-r (%)	D-R (%)
1	11	2	100	60
2	9	3	200	80
3	7	4	300	100

In order to obtain conditions close to the steady state operation for the test, the plant maintaining the same operating parameters at least seven days before each sampling event. Six times experiments were conducted continuously at each condition, the values of the three indexes were measured in each experiment and the average values of the three indexes in the six experiments were calculated and filled into the right side of the table. Calculate the data of per column for each horizontal: k_1, k_2, k_3 , the average value K_1, K_2, K_3 and the range of every column. The analysis and result of the orthogonal experiment are shown in Table 8.

Table 8 shows that the removal efficiency for NH_3-N and TN obtained ranged from 71.7% to 98.3% and from 32.3% to 61.8% respectively, while the removal efficiency of COD was from 65.6% to 83.8%.The optimum is the combination of the tested factor levels that produces the largest values of the percentage removal of NH_3-N, TN, and COD. Based on this principle the influential sequence of the four factors for the three criteria was ABDC and the optimal formulation was A1B2C2D2. The optimal values of factors were HRT = 11 h, DO = 3 mg L^{-1}, r = 200% and R = 80%.

3.3.2 Confirmatory experiment under near optimal conditions

A confirmatory experiment was carried out to verify the optimal parameters obtained from the orthogonal array test. The experimental results are summarized in Figure 2 after operation for 45 days.

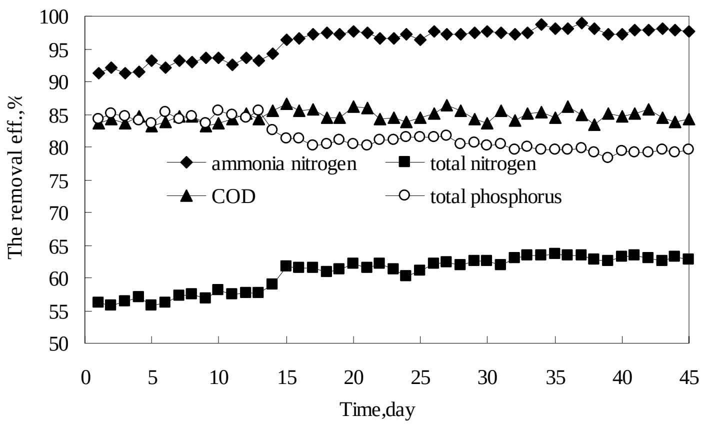


Figure 2. The removal efficiency of NH3-N, TN, COD and TP of the system

The average efficiency of NH_3-N, TN, COD and TP removal was 96%, 61%, 85% and 81% respectively. The system has high nitrogen and phosphorus removal and good removal efficiency for organic compounds. The removal efficiency for COD was over 82% during all the experiments, showing that COD removal was only slightly affected by variation of any factors. The removal efficiency of NH_3-N and TN increased at the beginning and was stable after 15 days, maintaining the high removal efficiencies of 96% and 61% respectively, but TP removal efficiency gradually declined from 85% to 78%. Research has found that two main reasons for this phenomenon. One is the contrasting requirement for the sludge retention time (SRT). The best SRT for nitrification is usually more than 20 days but for the removal of phosphorus it is 5-8 days, which means it is hard to accomplish high level of P and N in same system concurrently. Another reason was the competition between poly-phosphate bacteria and denitrifying bacteria for the organic carbon sources. When more organic compounds were synthesized by poly-phosphate bacteria and stored as PHB, the phosphorus absorption in the aerobic tank was strengthened. The phosphorus removal efficiency would improve but the denitrification would be reduced because of the lack of an organic carbon source. On the contrary, if the ability of poly-phosphate bacteria to compete for carbon was weaker than that of the denitrifying bacteria, denitrification would be enhanced and the dephosphorization would be restricted. However, in this experiment the TP concentration of the effluent remained below 0.5 mg L^{-1} while the system had a high nitrogen removal rate, which implied that the A^2/O bio-reactor could achieve concurrently high removal efficiencies for both nitrogen and phosphorus at the optimal condition.

Table 8. The analysis and result of the orthogonal experiment

	Factor				COD removal efficiency (%)	NH_3-N removal efficiency (%)	TN removal efficiency (%)
	A	B	C	D			
	Column						
	1	2	3	4			
1	1(11)	1(2)	1(100)	1(60)	78.4	90.8	51.9
2	1	2	2	2	83.8	98.3	61.8
3	1	3	3	3	82.4	99.1	53.1
4	2(9)	1	2(200)	3	72.9	84.8	44.4
5	2	2(3)	3	1	75.1	89.8	47.2
6	2	3	1	2(80)	74.4	91.7	42.1
7	3(7)	1	3(300)	2	65.6	71.7	35.9
8	3	2	1	3(100)	67.4	77.7	37.8
9	3	3(4)	2	1	68.8	76.5	32.3
The analysis of the COD removal efficiency							
factor	k_1	k_2	k_3	K_1	K_2	K_3	R
A	244.6	222.4	201.8	81.5	74.1	67.3	14.3
B	216.9	226.3	225.6	72.3	75.4	75.2	3.1
C	220.2	225.5	223.1	73.4	75.2	74.4	1.8
D	222.3	223.8	222.7	74.1	74.6	74.2	0.5
The analysis of the TN removal efficiency							
factor	k_1	k_2	k_3	K_1	K_2	K_3	R
A	166.8	133.7	106.0	55.6	44.6	35.3	20.3
B	132.2	146.8	127.5	44.1	48.9	42.5	6.4
C	131.8	138.5	136.2	43.9	46.2	45.4	2.2
D	131.4	139.8	135.3	43.8	46.6	45.1	2.8
The analysis of the NH_3-N removal efficiency							
factor	k_1	k_2	k_3	K_1	K_2	K_3	R
A	288.2	266.3	225.9	96.1	88.8	75.3	20.8
B	247.3	265.8	267.3	82.4	88.6	89.1	6.7
C	260.2	259.6	260.6	86.7	86.5	86.9	0.3
D	257.1	261.7	261.6	85.7	87.2	87.2	1.5

4. CONCLUSIONS

An A^2/O bio-reactor was used for the treatment of mixed sewage, that was made of landfill leachate, fecal sewage and domestic sewage. The objective was to evaluate the optimal mixing proportions and the optimal condition for nitrogen removal efficiency by an orthogonal array test. The following conclusions were obtained.

The landfill leachate and fecal sewage, with high concentrations of organic compounds and nitrogen, bring various disadvantages to the domestic sewage treatment plant, especially the impulse load. They can be mixed with domestic sewage within certain proportions. The results showed that the optimal ratio of landfill leachate, fecal and domestic sewage was 1:3.75:1000. The average effluent concentrations of COD, NH_3-N and TN could be maintained below the permissible limit for Chinese first grade B effluent standard (COD < 40 mg L^{-1}, NH_3-N < 8 mg L^{-1}, TN < 20 mg L^{-1}).

The orthogonal array test was designed and used to investigate the optimal combination of four factors. HRT was the most major factor. The optimal conditions for the system were HRT = 11 h, DO = 3 mg L^{-1}, r = 200% and R = 80%.

A confirmatory experiment was carried out using the optimal formulation. This combination of parameter values enabled the system to achieve good removal efficiency for nitrogen, phosphorus and organic compounds. The average removal efficiencies of NH_3-N, TN, COD and TP were 96%, 61%, 85% and 81% respectively.

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