Effect of Nitrogen Load and Water Temperature on Treatment Efficiency of Anoxic Reactor Using Submerged Bed Process

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Abstract

The effects of nitrogen load and water temperature on the treatment efficiency were studied using an anoxic reactor equipped with a lace-like contact media. Experiments were conducted under various nitrate nitrogen ($\text{NO}_3\text{-N}$) loads and water temperatures. Temperature coefficients (θ) of 1.046-1.064 were calculated. An equation expressing the relationship between $\text{NO}_x\text{-N}$ removal efficiency, the $\text{NO}_x\text{-N}$ load and water temperature was obtained. From the equation, the $\text{NO}_x\text{-N}$ load that allows a high $\text{NO}_x\text{-N}$ removal efficiency in the anoxic reactor can be estimated, and the value was greatly effected by water temperature. Denitrification rates of 2.4-4.5 $\text{mg-N/g-SS}\cdot\text{hr}$ under water temperature of 30°C were obtained.

Key words : denitrification, submerged bed process, nitrogen load, water temperature

INTRODUCTION

In order to reduce the pollutant level in daily sewage, the demand for high-efficiency treatment is increasing even in small-scale onsite household wastewater treatment systems. In the case of small scale waste water treatment facilities using a biological nitrogen removal process, a submerged bed process is effective considering the variations in the flow of influent waste water.

Biological nitrogen removal treatment is generally affected by factors such as the F/M ratio, the BOD/N ratio of the influent water, hydraulic retention time, water temperature and pH inside the reactor. We conducted an bench-scale experiment to examine the effects of nitrogen load and water temperature on the

nitrogen removal efficiency of an anoxic reactor using a submerged bed process, which removes the nitrified nitrogen through denitrification.

MATERIALS AND METHODS

Experimental apparatus A schematic presentation of the apparatus used in the experiment is shown in Fig.1. The anoxic reactor was an angular tank made of transparent vinyl chloride with an effective capacity of 1 l and an effective depth of 28 cm. The center of the reactor was divided into two compartments by a dividing wall. The two compartments were connected by a slot at the bottom. No stirrer was placed in the reactor. Water was circulated by a forced flow which ensured adequate contact with the contact medium.

Fig.1 Experimental apparatus. ①, tap water; ②, concentrated wastewater; ③, NaNO₃ solution; ④, thermostated water bath; ⑤, anoxic reactor; ⑥, contact media; ⑦, effluent.

Table 1 Experimental conditions

Run		1	2	3
Influent flow rate	(l/d)	16	8	4
HRT*	(hr)	1.5	3	6
Reactor volume	(l)	1	1	1
NO ₃ -N loading rate	(g-N/l/d)	0.24	0.12	0.06
Influent NO ₃ -N concentration	(mg/l)	15	15	15
Influent BOD concentration	(mg/l)	45	45	45

*hydraulic retention time

Table 2 Composition of wastewater

Glucose	1200mg/l
Glutamic acid	1200mg/l
NH ₄ Cl	1050mg/l
CaCl ₂ · 2H ₂ O	60mg/l
MgSO ₄ · 7H ₂ O	40mg/l
KCl	60mg/l
KH ₂ PO ₄	90mg/l
NaHPO ₄ · 12H ₂ O	230mg/l
FeCl ₃ · 6H ₂ O	10mg/l
NaHCO ₃	2000mg/l
BOD	2000mg/l
T-N	388mg/l
T-P	40mg/l

A frame consisting of stainless steel wire was placed in each compartment. Four lace-like contact media each measuring 25 cm were longitudinally placed on the frame to fill the compartments. The capacity of the filling portion was 0.85l.

The lace-like contact media consisted of fine vinylidene chloride thread knit in lace-like fashion (Commercial Name: Ring Lace) characterized by high physico-chemical stability¹⁾.

The reactor was placed in a thermostated water bath. Sodium nitrate solution (500 mg/l as NO₃-N) and synthetic waste water (BOD 2000 mg/l) were diluted with tap water to experimental conditions as shown in Table 1 using peristaltic pumps and supplied continuously to 6 to

the reactor. The synthetic waste water was prepared as in Table 2²⁾ and autoclaved before use. The tap water was flushed with nitrogen gas for approximately 8 hours to reduce the dissolved oxygen to 1 mg/l or low.

Experimental conditions Three anoxic reactor systems were used, each set at experimental conditions as in Table 1. The effects of water temperature at the experimental conditions shown in Table 1 were also examined by setting water temperatures at 10, 20 and 30°C.

At the beginning of the experiment, 1 g-SS of activated sludge obtained from the aeration tank of a domestic waste water treatment facility using conventional activated sludge process was seeded to the contact media in each of the reactor systems. Influent was supplied to each reactor at the conditions shown in Table 1 at the water temperature of 30°C for about two months. Following stabilization of effluent NO_x-N, the experiments were started.

The experiments were carried out at the water temperature of 30°C followed by 20°C and then by 10°C. On changing the water temperature, an interval of about 1 week was placed before the next experiment to allow the stabilization of effluent NO_x-N. After the end of the experiment at the water temperature of 30°C, attached biomass was removed from the contact media of each reactor to estimate SS, followed by reapplication. 1 g-SS of attached biomass was seeded to another reactor.

Sample analysis Treatment in each system was continued for approximately 10 days during which influent and effluent was sampled every two days for analysis.

Samples were analyzed for NO₂-N, NO₃-N, BOD, pH and alkalinity according to the Standard Methods for the Examination of Waste Water³⁾.

RESULTS AND DISCUSSION

Treatment results Based on the results of experiments, properties of the influent are

shown in Table 3 and those of the effluent are shown in Table 4. Values in the Tables are expressed as means (pH as median). Measurements were repeated 5 times in Experiment 1 and 2, 4 times in Experiment 3.

As shown in Table 4, the total concentration of NO₂-N and NO₃-N of the effluent (NO_x-N) became higher as the water temperature decreased, suggesting a profound influence of water temperature on denitrification efficiency. Even at the same water temperature, NO_x-N concentration of the effluent became higher as the NO₃-N load grew larger, suggesting a change of denitrification efficiency according to the condition of loading.

While the influent showed pH 7.2-7.6 and alkalinity 63-80 mg/l, the corresponding values in the effluent was 7.5-8.1 and 92-149 mg/l, indicating rises of both values during the process of treatment. The ratio calculated by dividing the increment of alkalinity by the amount of removed NO₃-N was 4.7-8.8.

Influent BOD was 36-59 mg/l and BOD / NO_x-N ratio 2.1-3.2. Influent BOD was relatively low in experiments at the water temperature of 10°C. The amount of hydrogen donor necessary for denitrification reaction (BOD/NO_x-N ratio) is generally reported to be more than 2.0⁴⁾, so that hydrogen donor was thought to be sufficient. Effluent BOD was 7-17 mg/l without any correlation with NO_x-N concentration. BOD removal rate was not influenced by the water temperature, 0.51-0.54 g/l·d in Run 1, 0.27-0.35 g/l·d in Run 2 and 0.10-0.15 g/l·d in Run 3.

Influence of water temperature NO_x-N loading rate, NO_x-N removal rate and NO_x-N removal efficiency are shown in Table 5. NO_x-N loading rate in Table 5 indicates NO₃-N loading rate. NO_x-N removal rate and NO_x-N removal efficiency were calculated from the NO_x-N loading rate and the amount of the effluent NO_x-N.

In order to evaluate the influence of water

Table 3 Flow rate and water quality of influent

Experiment	Water temperature (°C)	Run	NO ₃ -N (mg/l)	BOD (mg/l)	Alkalinity (mg/l)	pH	Influent flow rate (l/d)
1	30	1	16.4	45	75	7.5	14.7
		2	16.1	45	71	7.5	7.5
		3	15.4	37	80	7.6	3.9
2	20	1	17.8	50	63	7.4	15.6
		2	19.6	59	69	7.4	7.0
		3	16.5	53	68	7.6	4.1
3	10	1	17.5	44	64	7.2	16.0
		2	17.3	41	65	7.3	8.0
		3	17.3	36	70	7.4	4.1

Table 4 Water quality of effluent

Experiment	Water temperature (°C)	Run	NO ₂ -N (mg/l)	NO ₃ -N (mg/l)	BOD (mg/l)	Alkalinity (mg/l)	pH
1	30	1	1.6	2.9	8	133	8.1
		2	0.7	1.6	9	142	8.1
		3	0.1	0.6	11	149	8.1
2	20	1	4.1	6.2	15	104	7.7
		2	4.3	3.2	9	139	8.0
		3	1.8	1.2	17	139	8.1
3	10	1	5.3	9.0	12	92	7.5
		2	3.5	8.6	7	98	7.7
		3	2.5	9.3	11	99	7.8

Table 5 NOx-N removal efficiency

Water temperature (°C)	Run	NOx-N loading rate (g-N/l·d)	NOx-N removal rate (g-N/l·d)	NOx-N removal efficiency (%)
30	1	0.241	0.175	72.6
	2	0.121	0.104	85.9
	3	0.060	0.057	95.0
20	1	0.277	0.117	42.2
	2	0.137	0.085	62.0
	3	0.068	0.055	80.9
10	1	0.280	0.051	18.2
	2	0.138	0.042	30.4
	3	0.071	0.023	32.4

Fig.2 Relationship between water temperature and NOx-N removal rate. Symbols : ●, 0.24g-N/l·d; □, 0.12g-N/l·d; ■, 0.06g-N/l·d.

temperature on denitrification efficiency, the relationship between the NOx-N removal rate and water temperature was shown in Fig.2. Under each NOx-N loading condition, the NOx-N removal rate was apparently influenced by water temperature. Temperature coefficients (θ)⁵ were calculated to be 1.064 in Run 1, 1.046 in Run 2 and 1.046 in Run 3 as the slope of the lines shown in Fig.2. Since the influence of water temperature was stronger on treatment under NOx-N loading rate of 0.24 g/l·d than under NOx-N loading rate less than 0.12 g/l·d, this would indicate a difficulty in obtaining a high denitrification efficiency under high NOx-N loading rate at low water temperature.

As the results of denitrification in a waste water treatment facility by using activated sludge process, the following equation was reported to indicate the relationship between denitrification rate (K : mg-N/g-ss·hr) and water temperature (T : °C)⁶.

$$K = 0.324 \cdot e^{0.0634 T} \dots\dots\dots(1)$$

The relationship between denitrification rate and water temperature in anoxic reactor by a submerged bed process using net-like contact media was reported as follows⁷ :

Fig.3 Relationship between NOx-N loading rate and NOx-N removal rate. Symbols : ●, 30°C; □, 20°C; ■, 10°C.

Fig.4 Relationship between NOx-N loading rate and NOx-N removal efficiency. —, 30°C ; ---, 20°C ; - · -, 10°C.

$$K = 1.98 \cdot e^{0.04 T} \dots\dots\dots(2)$$

Based on equations (1) and (2), a fall of denitrification rate by approximately 1/2-2/3 on a decrease of water temperature by 10°C is suggested. Anoxic reactor using lace-like contact media such as the reactor used in this study was therefore assumed to be influenced by water temperature to a similar degree.

Relationship between NOx-N loading rate and

NOx-N removal efficiency The relationship between the NOx-N load and NOx-N removal rate was shown in Fig.3. A strong correlation was observed between the NOx-N load and NOx-N removal rate. This relationship was greatly affected by water temperature.

To study the effect of NOx-N load and water temperature on NOx-N removal rate, the relationships between the NOx-N removal rate, the NOx-N load and water temperature were expressed by the following multiple regression equations:

$$\ln(Z) = 0.65 \cdot \ln(X) + 1.04 \cdot \ln(Y) - 4.42 \quad \dots\dots\dots(3)$$

$$Z = 0.012 \cdot X^{0.65} \cdot Y^{1.04} \dots\dots\dots(4)$$

where Z : NOx-N removal rate (g/l·d)

X : NOx-N loading rate (g/l·d)

Y : water temperature (°C)

When the NOx-N removal efficiency is designated r, $r = Z/X \cdot 100$. Substituting this equation into Equation (4) resulted in the following Equation:

$$r = 1.2 \cdot X^{-0.35} \cdot Y^{1.04} \dots\dots\dots(5)$$

By substituting X in Equation (5) with different values of NOx-N load, NOx-N removal efficiencies were calculated. The relationship between NOx-N loading rate and NOx-N removal efficiency at a given temperature is shown in Fig.4. The value is greatly affected by water temperature.

Denitrification rate After the end of the experiment at water temperature of 30°C, the weight of attached biomass was estimated in each reactor as shown in Table 6. At the water temperature of 30°C, denitrification rates were

2.4-4.5 mg-N/g-SS·hr.

Denitrification rate was reported to be 0.5-4.0 mg-N/g-SS·hr (at water temperature of 16.8-21.5°C)⁸⁾ and 0.03-15.3 mg-N/g-VSS·hr (20°C)²⁾ by using oxidation ditch processes, 1.20 mg-N/g-VSS·hr (20°C)⁹⁾ in a fluidized bed system using ceramic carriers of 0.5 mm in diameter and 0.03-5.0 mg-N/g-SS·hr (25°C) in a reactor using submerged bed process equipped with net-like contact media⁷⁾.

Since the results obtained in this denitrification experiment using submerged bed process equipped with lace-like contact media were comparable with those obtained by using anoxic reactor in other systems, the reactor using lace-like contact media is thought to be capable of growing the microorganism necessary for denitrification treatment.

CONCLUSION

NOx-N removal experiments using anoxic reactors equipped with lace-like contact media were conducted under various NOx-N loading conditions and water temperatures. The following results were obtained.

- (1) Temperature coefficients (θ) were calculated to be 1.046-1.064. The influence of water temperature was stronger on treatment under higher NOx-N loading rate than under lower NOx-N loading rate.
- (2) Equation expressing the relationships between the NOx-N removal rate, the NOx-N loading rate and water temperature was obtained. Transformation of this equation resulted in the equation which expresses the relationships between NOx-N removal efficiency, NOx-N loading rate and water temperature. The NOx-N loading rate in the anoxic reactor which permits a high NOx-N removal efficiency can be estimated from the equation. The value is greatly affected by water temperature.
- (3) Denitrification rate was 2.4-4.5 mg-N / g-SS ·hr at a water temperature of 30°C, increas-

Table 6 Biomass in anoxic tank and denitrification rate of each system at water temperature of 30°C

Run	Biomass concentration (mg-SS/l)	Denitrification rate	
		(g-N/l·d)	(mg-N/g-SS·hr)
1	1642	0.175	4.46
2	1359	0.104	3.19
3	999	0.057	2.38

ing in proportion to the rise of NO_x-N loading rate. Since the results obtained in this experiment were similar to those reported by using anoxic reactor of other systems, microorganisms are probably capable of growing sufficient for denitrification in the reactor equipped with lace-like contact media.

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(Submitted 1994.10.11)
(Accepted 1994.12.13)