Performance Evaluation of Nitrogen Removal Type On-site Treatment System for Domestic Wastewater

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Abstract

In this study, the performance of on-site treatment system for domestic wastewater (*Johkasou*) was evaluated. The qualities of effluent from actual nitrogen removal type *Johkasou* which has begun to become popular recently and removal efficiencies were examined. The nitrogen removal type *Johkasou* showed better performance for BOD and nitrogen removal than the conventional type *Johkasou*. Both BOD and total nitrogen (T-N) concentrations were 15 mg/L or less in 75–80% of effluent water samples investigated. The high performance of the treatments system was attributed to a mixed liquor recycle system for denitrification. The reduction of BOD concentration in the effluent water was also observed accompanied by the high efficiency of nitrogen removal. Recycling of treated water would result in improving reduction of not only NO₃-N but also dissolved Kjeldahl nitrogen (DKN) reduction, and the decrease in DKN led to a decrease in both N-BOD and BOD as well. The denitrification activity was declined when circulation ratio drop to 1 Q or less where Q is the influent flow quantity. The effluent T-N seemed to be controlled below 20 mg/L with the recycle ratio of 2 Q–15 Q. The average removal rates of T-N and total phosphorus (T-P) of the surveyed *Johkasous* were 67% and 58%, respectively.

Key words: Domestic wastewater, on-site treatment, nitrogen removal type *Johkasou*, N-BOD

INTRODUCTION

In Japan a large number of individual houses are using on-site treatment system for domestic wastewater in the areas not provided with a public sewerage system^{1)–4)}. The on-site treatment systems are designed, constructed, operated and maintained systematically according to the laws controlled by the Ministry of Construction and the Ministry of Health and Welfare, as well as collection and treatment of their sludge. They are called *Johkasou* which plays an important role to reduce water pollution caused by domestic wastewater in Japan. *Johkasou* consists of a

pretreatment process (anaerobic filter tank) followed by an aerobic process (contact aeration tank). The smallest type of the *Johkasou* for 5–10 population equivalents (p.e.) contains an aerobic process, which is distinctly different from septic tanks, and the BOD of the effluent after treatments of these systems is expected to be less than 20 mg/L in most of the cases¹⁾. *Johkasou* is a way to effectively treat domestic wastewater before it flows into the drainage of the residential area. However, the effluent from *Johkasou* has still been reported as one source of pollution in coastal areas such as lakes and bays^{5), 6)}.

Recently, *Johkasou* having the functions of removing nitrogen and phosphorus has been developed^{(7), (8)}. The *Johkasou* that can remove nitrogen or phosphorus is called "advanced treatment type". Nitrogen removal type *Johkasou* is widely used in Japan^{(5), (9)}, although phosphorus removal type one is not widespread because of high capital and operation costs. The nitrogen removal type *Johkasou* is equipped with an apparatus that circulates treated water to a conventional general system having an anaerobic tank and a contact aeration tank.

A typical scheme of nitrogen removal type *Johkasou* is represented in Fig. 1. The plastic filter media were installed in the anaerobic filter tank and the contact aeration tank, and the treated water was returned to anaerobic tank for circulation. There are three levels for the nitrogen removal type *Johkasou* due to the limitation of BOD and T-N concentrations in the final effluent. They are classified into 1) 20 mg-BOD/L and 20 mg-T-N/L, 2) 10 mg-BOD/L and 20 mg-T-N/L, and 3) 10 mg-BOD/L and 10 mg-T-N/L⁽⁴⁾. The structure of nitrogen removal type *Johkasou* has an ability to reduce BOD and T-N concentrations to less than the above three combinations for the discharge effluent. The research area of this study (Sakura City, Japan) is the watershed of Lake Inba-numa and removal of nutrients from domestic wastewater is required in this area. In this research area most of the nitrogen removal type *Johkasous* were 20 mg-BOD/L and 20 mg-T-N/L type.

Fig. 1 Typical scheme of small-scale nitrogen removal type *Johkasou*; individual household type.

When using advanced treatment type *Johkasou* as a water purification counter-measure for lakes and bays, in order to ascertain the pollution load to the watershed from the *Johkasous* it is necessary to clarify the actual water quality of effluent from the *Johkasou* and to determine the pollutant load factor. In spite of the nitrogen removal type *Johkasou* ever being widely provided in Japan, the performance of treatment in a large number of actual facilities has not been reported yet, including problems and improvements on them. This paper reports small-scale nitrogen removal type *Johkasou* concerning their good performance of nitrogen removal and decline of BOD by utilizing the circulation system.

METHODS

Outline of the examined nitrogen removal type *Johkasous* Thirty-four nitrogen removal type *Johkasous* smaller than 10 p.e. in Sakura City (Chiba Prefecture) were surveyed from 1998 to 2004. From 1998 to 1999, each of seven facilities was examined once to six times, and from 2000 to 2004, duplicate investigations were conducted for each of twenty-seven facilities. In all facilities the mixed liquor in contact aeration tank was continuously recycled into the anaerobic filter tank using the air lift pump for removing nitrogen and carrying biofilm that sloughed off by backwashing. Recycling of mixed liquor is sustained with the aid of the maintenance by expert engineers three times a year for checking and confirming the normal operation of the equipment.

Sample collection and water analysis The effluent was sampled in the sedimentation tank just before disinfection in each facility, then temperature, transparency, and pH (HPH-110 pH meter, DKK Co., Ltd.) of the effluent were measured at each site. Dissolved oxygen (DO) (UC-12 DO meter, CENTRAL KAGAKU Co., Ltd.) in the contact aeration tank and the amount of mixed liquor recycled were measured as well. Samples were immediately transferred to laboratory and stored at below 10°C before use. Biochemical oxygen demand (BOD), BOD with addition of N-allylthiourea to inhibit nitrification (ATU-BOD), and chemical oxygen demand using

KMnO₄ at 100°C (COD_{Mn}) were quantified according to titration methods. The effluent for the measurement of suspended solids (SS) was filtrated by glass fiber filter (GS-25, ADVANTEC TOYO Co., Ltd.), then the filter was warmed at 110°C. And then, the sample was allowed to be cooled in desiccator and weighed. Nutrient concentrations in the effluent were also measured. Total nitrogen (T-N) and dissolved total nitrogen (DTN) were measured by a total nitrogen analyzer (TN-05, Mitsubishi Kasei Co., Ltd.). Particulate total nitrogen (PTN) was calculated by subtracting DTN from T-N. Total phosphorus (T-P) concentration was obtained based on molybdenum blue method. Nitrite-nitrogen (NO₂-N) and nitrate-nitrogen (NO₃-N) concentrations were measured by ion chromatograph (DX120, DIONEX Co., Ltd.) after filtrating the sample using a 5-mL syringe with PTFE syringe filter. Nitrification BOD (N-BOD) and dissolved Kjeldahl nitrogen (DKN) were calculated by subtracting ATU-BOD from BOD and subtracting NO₂-N + NO₃-N from DTN, respectively. Each measurement was conducted in accordance with JIS (Japan Industrial Standard) K 0102 (1998)¹⁰⁾.

RESULTS AND DISCUSSION

Effluent water qualities of nitrogen removal type *Johkasou* The frequency distributions of the effluent BOD and T-N concentrations in the surveyed nitrogen removal type *Johkasou*s which treated individual household wastewater are shown in Fig. 2. The frequency was highest in the class of less

than 5 mg/L and 5–10 mg/L for BOD and T-N, respectively, in the effluent water. Approximately 80% of BOD and 75% of T-N data for the final effluent water exhibit below 15 mg/L.

In the nitrogen removal type *Johkasou*, it was easy to regulate the amount of the recycled liquor by controlling the airlift pumps at the recycle ratio of 3Q–4Q where Q was the influent flow quantity. Therefore, the mixed liquor in the contact aeration tank was recycled to the anaerobic filter tank at most of the facilities with an appropriate recycle rate. In the conventional *Johkasou*, the recycling ratio was not stabilized because the control system for recycling mixed liquor was not equipped¹¹⁾.

The data ranges for the effluent water qualities and their average values are shown in Table 1. The results were presented for nitrogen removal type *Johkasou* compared with conventional type without recycling¹⁾. In conventional type *Johkasou* the water with biofilm in the sedimentation tank can be circulated to the anaerobic filter tank by manual operation, but it cannot be circulated continuously¹¹⁾. It was obvious that the values of BOD, N-BOD, T-N, and DKN in effluent water for the nitrogen removal type *Johkasou* were lower than those of conventional *Johkasou*. The significant decrease in T-N suggested that the denitrification of NO₃-N could take place in the anaerobic filter tanks by recycling liquor containing NO₃-N. The organic matter in the influent could be used for the denitrification. The mechanism to remove nitrogen in nitrogen removal type

Fig. 2 Distributions of the effluent BOD and T-N in the nitrogen removal type *Johkasou*s.
Sample number of BOD: 75, T-N: 75

Table 1 Effluent water qualities in the nitrogen removal type *Johkasou* and conventional *Johkasou*

	Nitrogen removal type <i>Johkasou</i>		Conventional <i>Johkasou</i> without treated water recycle	
	n = 75		n = 68	
	min-max	average	min-max	average
BOD	0.9-55	10	2.3-127	19
ATU-BOD	0.6-48	5.9	1.2-41	7.3
N-BOD	0-50	4.5	0-86	12
CODMn	6.0-38	14	7.1-47	17
SS	1-59	8.4	0.5-63	13
T-N	4.0-33	12	7.1-74	25
NO ₃ -N	0.2-29	6.2	0.03-56	14
DKN	0-31	4.8	0-37	9.2
T-P	0.7-8.5	2.9	0.31-7.6	3.1

Johkasou was effective even at the actual facilities.

Decline of BOD in effluent water from nitrogen removal type *Johkasou* In the nitrogen removal type *Johkasou*, BOD in effluent water also remarkably decreased compared with the conventional *Johkasou* (Table 1). Fig. 3 shows the relationship between T-N and BOD in the effluent of nitrogen removal type *Johkasou*. As shown in Fig. 3, the majority of data plots for BOD and T-N were less than 15 mg/L. However, when BOD values exhibited above 15mg/L, the T-N values were somewhat proportional to the BOD values, suggesting that reduction of nitrogen could contribute to BOD removal in the nitrogen removal type *Johkasou*.

BOD consists of ATU-BOD and N-BOD. N-BOD is a BOD produced when ammonia nitrogen consumes oxygen in the presence of nitrifying bacteria in wastewater¹²⁾. It is often observed at high concentration in treated water in *Johkasou*¹¹⁾. N-BOD in treated domestic wastewater may also affect quality of river water into which wastewater is discharged^{13), 14)}.

As shown in Fig. 4, ATU-BOD and N-BOD in effluent from the nitrogen removal type *Johkasou* occupied about half of BOD, respectively. On the other hand, in conventional type *Johkasou*, the higher the concentration of BOD, the larger the proportion of N-BOD than ATU-BOD¹¹⁾. It

Fig. 3 Relationship between the effluent BOD and T-N in the nitrogen removal type *Johkasou*. Sample number of data: 72 Fig. 4 Relationship between the effluent BOD and ATU-BOD and N-BOD in the nitrogen removal type *Johkasou*. Sample number of data: 72

could be suggested that the BOD of effluent in the nitrogen removal type *Johkasou* was lower than the BOD of the conventional type *Johkasou* because the N-BOD of the nitrogen removal type *Johkasou* was low.

In this survey, DTN occupied most of the T-N of the effluent water (Fig. 5). DTN is generally composed of NO₃-N, NO₂-N, and DKN. DKN in nitrogen removal type *Johkasou* was approximately half of that in conventional *Johkasou* (Table 1). As shown in Fig. 6, NO₃-N occupied a large part of DTN

in effluent water at low concentration, and the DKN portion was very low in contrast. DKN consists of organic nitrogen and ammonia nitrogen. Based on our findings and treated water qualities in biological treatment of sewage water^{15, 16)}, it was inferred that more than 80% of the DKN of treated water in *Johkasou* investigated would be $\text{NH}_4\text{-N}$. The presence of ammonia nitrogen and nitrifying bacteria produces N-BOD¹²⁾. Therefore, it is inferred that N-BOD is decreased due to the decrease of $\text{NH}_4\text{-N}$. In

the nitrogen removal type *Johkasou*, the nitrification rate increases and DKN decreases under sufficient aeration. The decrease in DKN resulted in reductions of N-BOD and BOD as well. In a *Johkasou* where C-BOD (same as ATU-BOD) accounts for the majority of BOD in treated water, the decrease in N-BOD does not affect BOD¹⁷⁾, thereby recycling of treated water may not lead to a decrease in BOD. It is assumed that not only removal of organic matter but nitrogen removal can contribute to BOD removal in nitrogen removal type *Johkasou* investigated in the present study.

The relationship between the recycle ratio and T-N in the effluent water In the process of removing nitrogen from wastewater, the recycling rate of nitrifying solution affects a great influence on the process¹⁸⁾. In the nitrogen removal type *Johkasou*, the recycling rate is adjusted between 3Q and 4Q three times a year but in fact it often fluctuates. This is because pipes for recycling and weirs for adjusting the recycling amount tend to be plugged due to the growth of microorganisms in 3 to 4 months. Clogging of the weir for adjusting the recycling amount may also cause an increase in the recycling ratio. The relationship between the recycle ratio and T-N in the effluent is shown in Fig. 7. The number of samples exhibiting high T-N concentration was increased with the recycle

Fig. 5 Relationship between the effluent T-N and DTN in the nitrogen removal type *Johkasou*.
Sample number of data: 75

Fig. 6 Relationship between the effluent DTN and $\text{NO}_3\text{-N}$ and DKN in the nitrogen removal type *Johkasou*.
Sample number of data: 75

Fig. 7 Relationship between the recycle ratio and the effluent T-N in the nitrogen removal type *Johkasou*.

ratio of around 1Q or less. The effluent T-N seemed to be largely controlled below 20 mg/L with the recycle ratio of 2Q or more. In this survey, the T-N in the effluent was low even if the circulation ratio was 15Q or more, but this is not always the case. According to the previous surveyed results¹⁾, the T-N in the outflow water increased when the recycling rate reached 15Q or more. If the recycle ratio is too high, oxygen is brought into the anaerobic filter tank and denitrification will be inhibited. It does not seem to be preferable that the recycling rate becomes 15Q or more for nitrogen removal. Maintaining the normal recycling rate is a key point to keep clean effluent from on-site nitrogen removal type *Johkasou*.

Nitrogen and phosphorus removal efficiency in effluent water

In the survey from 2003

to 2004, we sampled the water for 28 times in total at the first chamber of the anaerobic filter tank (raw water) in addition to the effluent water at 14 *Johkasous*. The samples were taken between the floating scum and sediment in the first chamber. Fig. 8 shows the average values of nitrogen and phosphorus concentrations of 28 samples for raw water and effluent water.

The average concentrations of T-N, DKN and T-P in the raw water were 39 mg/L, 13 mg/L and 6.5 mg/L, respectively, and these concentrations were declined by 67%, 70% and 58% in the nitrogen removal type *Johkasou*. As shown in Table 1, T-N and DKN of effluent water in conventional type *Johkasou* do not seem to be removed so much. The removal rate for T-N and DKN was higher than that of conventional type

Fig. 8 The average of T-N, DTN, PTN, DKN, NO₃-N, and T-P of 28 samples of raw water and effluent water. Data values are the means of 28 samples, and error bars indicate the standard deviations.

Johkasou, whereas T-P was not changed considerably (Table 1), because the nitrogen removal type *Johkasou* does not have any function to remove phosphorus. In coastal areas, it is desirable to use a *Johkasou* with phosphorus removal function in addition to nitrogen removal functionality.

CONCLUSIONS

Nitrogen removal type *Johkasou* showed good performance for BOD and T-N removal with their effluent BOD and T-N below 15 mg/L, which accounted for 75–80% of the surveyed data. BOD, N-BOD, T-N and DKN values of the final effluent treated with the nitrogen removal type *Johkasou* were indeed lower than those of conventional *Johkasou*. It was suggested that the denitrification occurred in the anaerobic filter tanks, which was attributed to the reduced $\text{NO}_3\text{-N}$ in the recycle liquor by utilizing organic substances in the influent. It was also estimated that recycling of treated water led to not only decreases of $\text{NO}_3\text{-N}$ but also decreases of DKN that contributed to decreases of both N-BOD and BOD. The effluent T-N seemed to be controlled below 20 mg/L in most cases with the recycle ratio of 2Q–15Q. The removal rate for T-N and DKN from raw water was higher than that of conventional type *Johkasou*, whereas T-P was not changed considerably.

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