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PERFORMANCE EVALUATION OF ON-SITE TREATMENT FACILITIES FOR WASTEWATER FROM HOUSEHOLDS, HOTELS AND RESTAURANTS

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ABSTRACT

In order to evaluate performance of on-site treatment facilities which can be provided for environment protection in coastal areas, effluent qualities and removal efficiencies were surveyed in actual treatment facilities for wastewater from households, hotels and restaurants. On-site treatment facilities in Japan are fundamentally built according to the structural standards. They have a pretreatment process (sedimentation separation tank, anaerobic filter or equalization tank with screens) followed by an aerobic process (contact aeration, activated sludge, etc.). Small-scale facilities for individual household wastewater showed good performance of BOD removal with their effluent BOD below 20mg l^{-1}. They also exhibited nitrogen removal efficiency when they were operated in mixed liquor recycle mode. The facilities applied to wastewater from hotels, restaurants and stores showed good performance when the influent oil (hexane extracts) concentration had been decreased below 30mg l^{-1} by using pretreatment. Nitrogen removal performance was high in the facilities which treated wastewater from a residential area or a condominium when they were operated in intermittent aeration mode. But resort condominiums of which influent BOD load was extremely low showed low performance of nitrogen removal even though they were operated in intermittent aeration mode because of the low BOD/N ratio in the influent. An equation was proposed to estimate the amount of methanol to be added in facilities in which the influent BOD/N ratio is low.

KEYWORDS

Domestic wastewater; intermittent aeration; nitrogen removal; on-site treatment; recycle operation; wastewater treatment in resort area.

INTRODUCTION

A large number of individual houses, condominiums and other buildings are using on-site type treatment facilities for their wastewater in Japan, in areas not provided with a public sewerage system including coastal resort areas. The on-site treatment facilities 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 sludges. They are called Johkasou systems which play an important role for measures to reduce water pollution caused by domestic wastewater in Japan

(Japan Education Center for Environmental Sanitation, 1994). Because even the smallest type of the facilities for 5p.e.-10p.e. contain an aerobic process, they are distinct from septic tanks and the BOD of the effluent of these facilities is expected to be less than 20mg l^{-1} in many cases. The number of Johkasou facilities in Japan is 7,996,748 in 1996 (The Ministry of Health and Welfare, 1997).

Recently on-site treatment facilities for domestic wastewater containing an aeration process have been reported (Gunn, 1994; Hanna *et al.*, 1995; Dharmappa and Khalife, 1997). Small-scale facilities for individual household wastewater treatment are called a small-scale gappei-shori Johkasou in Japan. A typical scheme of this type of facility is shown in Fig. 1. Plastic filter media were installed in the anaerobic filter tank and the contact aeration tank, while the sedimentation separation tank is similar to a septic tank without filter media. On the other hand, the process flow of the facilities larger than 51 p.e. is similar to that of a public sewerage system which consists of a contact aeration process or activated sludge process after primary treatment (The Building Center of Japan, 1990; Japan Education Center for Environmental Sanitation, 1994).

Although the on-site treatment facilities have been widely provided in Japan, the performance of treatment in a large number of actual facilities has not been reported, including their problems and the improvements on them. This paper reports firstly on the facilities of the individual household type, that is a small-scale gappei-shori Johkasou, concerning their good performance of BOD removal and improvements in nitrogen removal by the recycle operation. Secondly the facilities treating wastewater from restaurants, hotels and stores are examined. The influence of oil on the performance of BOD removal is discussed. Thirdly nitrogen removal performance in facilities larger than 201 p.e. operated in intermittent aeration mode are reported.

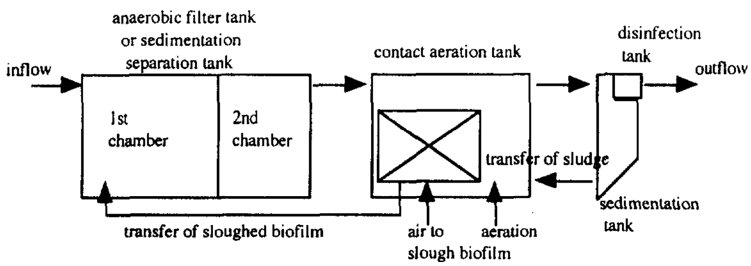

Figure 1. Typical scheme of small-scale gappei-shori Johkasou; individual household type.

METHODS

Ten facilities smaller than 10p.e. of small-scale gappei-shori Johkasous in Chiba City were surveyed once a month from August 1994 to May 1995 (Fujimura and Nakajima, 1998). The anaerobic filter - contact aeration process was used in 8 facilities and the sedimentation separation - contact aeration process was used in 2 facilities. In five facilities the mixed liquor in the contact aeration tank was attempted to be recycled into the anaerobic filter tank using the air lift pump for carrying sloughed biofilm of back washing. The effluent was sampled in the settling tank in the morning (9-12 am) in each facility and temperature, transparency, pH, biochemical oxygen demand (BOD), BOD with addition of N-allylthiourea to inhibit nitrification (ATU-BOD), chemical oxygen demand using $KMnO_4$ at 100°C (CODMn), suspended solids (SS), total nitrogen (T-N), dissolved total nitrogen (DTN); nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N) and total phosphorus (T-P) were measured. Nitrification BOD (N-BOD) and dissolved Kjeldahl nitrogen (DKN) were calculated by subtracting ATU-BOD from BOD and subtracting NO_2-N + NO_3-N from DTN, respectively. Dissolved oxygen (DO) in the contact aeration tank was also measured.

Forty-seven on-site wastewater treatment facilities larger than 11 p.e. and smaller than 200 p.e. were surveyed in Chiba Prefecture in 1997. The number of the facilities which treated wastewater from a restaurant, a hotel, a store, an amusement shop and a dormitory were 27, 14, 4, 1 and 1, respectively. The contact aeration process was used in 44 facilities while the activated sludge process was used in 3 facilities. As for the activated sludge process, 1 facility used the extended aeration process while 2 facilities used the sequence batch reactor process. The influent and the effluent of the facilities were sampled once in each facility and pH, BOD, CODMn, SS, hexane extracts (n-Hex), T-N and T-P were measured.

Thirty facilities which treated domestic wastewater from a residential area or a condominium larger than 201 p.e. were surveyed in Chiba Prefecture in 1989 and 1990 (Nakajima and Inamori, 1997). The number of the facilities which used the extended aeration process smaller than 500 p.e., the contact aeration process smaller than 500 p.e. and the extended aeration process larger than 501 p.e. were 10, 5 and 15, respectively. No facilities larger than 501 p.e. were using the contact aeration process. The water quality before and after the secondary treatment process was measured once in each facility. The measured items were pH, BOD, SS, alkalinity (acid consumption to pH 4.8), total Kjeldahl nitrogen (TKN), NO_2-N, NO_3-N and T-P. T-N was calculated as the sum of TKN, NO_2-N and NO_3-N. DO, pH and SV in the aeration tank or the contact aeration tank were also measured.

Seven facilities which treated domestic wastewater from a condominium in the Onjuku coastal resort area in Chiba Prefecture were surveyed in 1993 (Nakajima and Inamori, 1997). The scale of the facilities ranged from 233 p.e. to 596p.e. However the population of the condominiums was very small in practice compared with the plans. Therefore the influent BOD load was extremely low in the facilities. All the facilities used the contact aeration process except one using the extended aeration process. The water quality before and after the secondary treatment process was measured once in each facility. The measured items were pH, BOD, CODMn, SS, T-N, NO_2-N and NO_3-N. DO, ORP and pH in the aeration tank, the contact aeration tank and the equalization tank were also measured.

RESULTS AND DISCUSSION

Effluent water qualities of small-scale gappei-shori Johkasous (smaller than 10 p.e.)

The distributions of the effluent BOD and T-N in the surveyed small-scale gappei-shori Johkasous which treated individual household wastewater are shown in Fig. 2. The frequency was highest in the class of less than 10 $mg \cdot l^{-1}$, 10-20mg $\cdot l^{-1}$, 10-20mg $\cdot l^{-1}$ and 3-4mg $\cdot l^{-1}$ for BOD, CODMn, T-N and T-P, respectively. Seventy percent of the BOD data were below 20$mg \cdot l^{-1}$.

Although the mixed liquor in the contact aeration tanks was attempted to be recycled into the anaerobic filter tanks in the five facilities, it was difficult 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. Sometimes the recycle operation had stopped because of clogging of the airlift pumps. The recycle ratio needed to be increased to more than 4Q in order to continue the recycle operation, except for one facility which had a notch type controller, in which the recycle ratio could be controlled below 4Q.

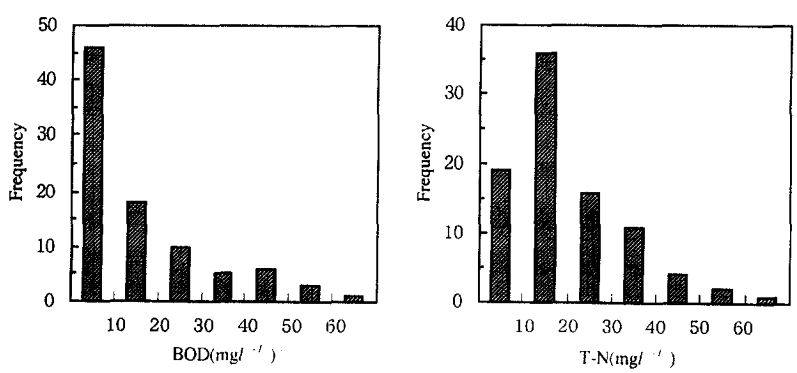

Figure 2. Distributions of the effluent BOD and T-N in the small-scale gappei-shori Johkasous.

The ranges and the averages of the effluent water qualities are shown in Table 1. The results were divided into the cases with or without the recycle operation. It was clear that BOD, N-BOD, T-N, NO_3-N and DKN decreased with the recycle operation. The marked decrease in T-N and NO_3-N suggested that the denitrification took place in the anaerobic filter tanks, reducing NO_3-N in the recycle liquor by using organic substances in the influent. BOD was more strongly correlated to N-BOD than ATU-BOD. N-BOD in Johkasou effluent is sometimes high because of the existence of residual NH_4-N and rather high SS which contain nitrifying bacteria. The decrease of DKN (that is nearly equal to NH_4-N) with the recycle operation seemed to cause the decrease of N-BOD and resulted in the decrease of BOD with the recycle operation.

Table 1. Effluent water qualities in the small-scale gappei-shori Johkasous

mg·l^{-1}

	Facilities No.1-5				Facilities No.6-10	
	with recycle operation n=22		without recycle operation n=28		without recycle operation n=40	
	min - max	average	min - max	average	min - max	average
BOD	2.7 - 41	12	2.3 - 51	17	2.7 - 127	21
ATU-BOD	0.9 - 33	7.3	1.2 - 25	5.2	1.6 - 41	8.8
N-BOD	0.5 - 29	4.5	0 - 46	11	0 - 86	13
COD_{Mn}	9.1 - 47	17	7.7 - 38	16	7.1 - 47	17
SS	1 - 36	9.0	0.5 - 44	11	2 - 63	14
T-N	2.9 - 27	10	8.6 - 74	32	7.1 - 40	20
NO_3-N	0.07 - 16	4.9	2.3 - 56	23	0.03 - 29	7.2
DKN	0 - 11	4.3	0 - 23	7.0	0 - 37	11
T-P	1.6 - 5.1	3.2	1.5 - 7.6	4.3	0.31 - 5.3	2.3

The relationship between the recycle ratio and T-N in the effluent is shown in Fig. 3. The increase of T-N at the recycle ratio around 20Q exhibited the decrease of denitrification activity caused by surplus DO entering from the contact aeration tank. The effluent T-N seemed to be controlled below 15mg·l^{-1} with the recycle ratio of 3Q-10Q. More reliable controllers to regulate the amount of the recycle liquor have been developed recently and have begun to be provided in the market.

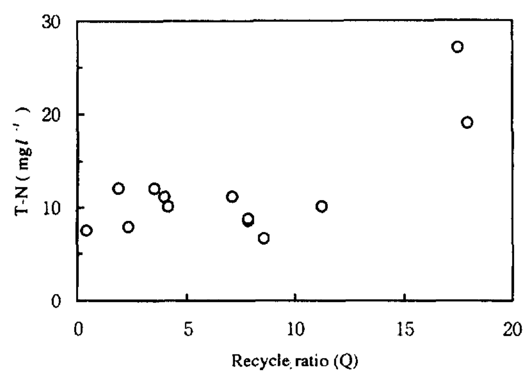

Figure 3. Relationship between the recycle ratio and the effluent T-N.

<u>Removal efficiencies in wastewater treatment facilities of hotels and restaurants</u>

A large number of wastewater treatment facilities between 11 p.e. and 200 p.e. are used for treatment of wastewater from restaurants, hotels and stores. This kind of wastewater contains a large amount of oil which is used in food processing or kitchens. Therefore removal of oil is important before biological treatment in these facilities.

More than 70% of the surveyed facilities treating wastewater from restaurants and stores were using a grease trap or a simple oil separator before the treatment facilities. About half of the facilities in the hotels were also using them. The water qualities of the influent are shown in Table 2. In the case of the facilities using the pretreatment for oil, the water qualities were measured after that. pH was below 6.0 in three facilities treating wastewater from Chinese restaurants. BOD, CODMn, SS and n-Hex in the influent had large variances and were high in restaurants and low in hotels. These 4 items were well correlated with each other. The average value of BOD was 285mg·l^{-1} and the BOD/CODMn ratio was 2.9 in the influent. In the restaurants serving beef steaks, barbecues and Chinese foods, BOD and n-Hex were especially high, while they were rather low in Japanese noodle or sushi restaurants. The variance of T-N and T-P in the effluent were small compared with BOD, CODMn, SS and n-Hex. T-N and T-P had no correlation with BOD.

Table 2. Water qualities of the influent and the effluent in the facilities for restaurants, hotels and stores

mg·l^{-1} except pH

	Influent		Effluent	
	min - max	average	min - max	average
pH	5.0 - 8.1	6.93	3.7 - 8.2	7.11
BOD	3 - 1600	285	1 - 120	29.0
CODMn	4 - 410	113	4 - 130	35.1
SS	2 - 2800	183	0 - 120	20.6
n-Hex	0 - 3800	154	0 - 13	1.7
T-N	4.3 - 94	31.0	3.5 - 60	24.1
T-P	0.30 - 18	5.83	0.07 - 15	4.99

The water qualities of the effluent are also shown in Table 2. The effluent BOD ranged from 1 mg·l^{-1} to 120 mg·l^{-1}, a large decrease from the influent BOD. Forty-four percent of the BOD data were below 10mg·l^{-1} and fifty-eight percent were below 20 mg ·l^{-1}. The effluent BOD was over 60 mg·l^{-1} in 9 facilities. In 6 of these facilities the influent BOD was over 300 mg·l^{-1}. The effluent BOD tended to be high in the facilities of which the influent BOD was high, especially in the restaurants. The average value of the effluent BOD was 29.0 mg·l^{-1} which is approximately one tenth of the influent average BOD. CODMn, SS and n-Hex in the effluent substantially decreased as well as BOD. They were also high in some restaurants of which the influent concentrations were high. The average BOD/CODMn ratio in the effluent was 0.96 showing good performance of BOD removal in the treatment process. T-N and T-P in the effluent did not substantially decrease from the influent concentrations compared with BOD, CODMn, SS and n-Hex.

The average values of the removal efficiency of BOD, CODMn, SS, n-Hex, T-N and T-P were 83.6%, 62.1%, 72.2%, 94.2%, 27.3% and 21.4%, respectively. The removal of BOD, CODMn, SS and n-Hex were satisfactory in a large number of the facilities. On the contrary the performance of T-N and T-P removal was low because the nutrient removal process had not been introduced yet in most of the surveyed facilities. The removal efficiency of BOD was low or the effluent BOD was high in some facilities treating wastewater from restaurants and stores. The influent BOD and n-Hex were high in those facilities. Therefore it was likely that insufficient oil separation in the pretreatment caused overload of BOD which resulted in the low performance of the biological treatment.

The results indicated that the residual oil in the influent substantially affected BOD removal in the biological treatment process. The relationship between the influent n-Hex and the effluent BOD is shown in Fig. 4. In the figure the black circles show facilities which had high effluent BOD caused by high contamination of oil in the influent. They treated wastewater from restaurants (6 facilities) and stores (2 facilities). The two facilities indicated as squares were a Chinese restaurant and a supermarket, which seemed to have the effect of oil although the surveyed n-Hex concentrations were around 20 mg·l^{-1}. From Fig. 4, BOD removal was likely to have a risk of failing the performance if the influent n-Hex was over 30 mg·l^{-1}. Therefore the n-Hex concentration should be reduced to below 30 mg·l^{-1} before biological treatment in order to have a good performance of BOD removal.

Nitrogen removal by intermittent aeration in facilities larger than 201 p.e.

The water qualities before and after the secondary treatment of the 30 surveyed domestic wastewater treatment facilities larger than 201 p.e. are shown in Table 3. The effluent BOD was generally low and its average value was 5.3 mg·l^{-1}. Nineteen facilities were operated in intermittent aeration mode, with the number of the on-off cycle of aeration ranging from 1 to 6 times per day, and the total time of stopping aeration ranging from 2.5 to 17 hrs per day. The removal efficiencies of BOD, T-N and T-P are shown in

Table 4. Four facilities treating wastewater from condominiums in resort areas were eliminated there because their influent BOD concentrations were extremely low and differed from the other facilities.

Table 4 shows the higher removal of T-N and T-P in the facilities operated in intermittent aeration mode than the facilities operated in continuous aeration mode. The effluent NO_3-N was low and the marked decrease of alkalinity did not take place in the facilities which had a high efficiency of T-N removal. It is well known that alkalinity which decreases in nitrification is recovered by biological denitrification. It was clear that the nitrogen removal in the facilities operated in intermittent aeration mode was caused by biological denitrification which took place in the period when the aeration was stopped as discussed in Nakajima and Kaneko (1991). BOD removal did not differ between the facilities operated in continuous aeration mode and intermittent aeration mode.

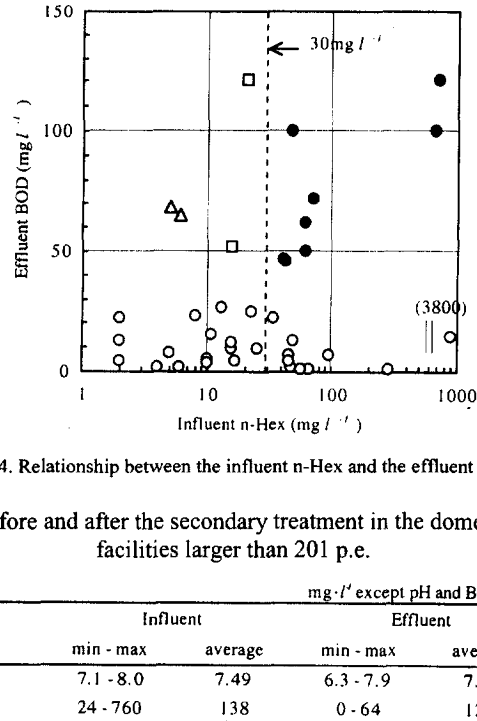

Figure 4. Relationship between the influent n-Hex and the effluent BOD.

Table 3. Water qualities before and after the secondary treatment in the domestic wastewater treatment facilities larger than 201 p.e.

mg·l^{-1} except pH and BOD/T-N

	Influent		Effluent	
	min - max	average	min - max	average
pH	7.1 - 8.0	7.49	6.3 - 7.9	7.09
SS	24 - 760	138	0 - 64	12.3
BOD	28 - 440	134	0 - 28	5.3
Alkalinity	43 - 240	139	6 - 160	62.9
NO_2-N	0 - 4.2	0.364	0 - 0.87	0.128
NO_3-N	0 - 11	1.88	0.16 - 28	9.60
TKN	8.7 - 49	25.1	0 - 15	3.24
T-N	8.9 - 50	27.4	2.6 - 28	13.0
T-P	1.3 - 7.9	3.82	0.60 - 3.5	2.05
BOD/T-N	1.7 - 10.5	4.9	0 - 1.9	0.5

Table 4. Removal efficiencies of BOD, T-N and T-P in the domestic wastewater treatment facilities

	Continuous aeration mode			Intermittent aeration mode		
	average	S.D.	number	average	S.D.	number
BOD	94.2%	6.9%	10	94.7%	6.2%	16
T-N	39.8%	33.8%	10	62.3%	23.7%	16
T-P	33.8%	19.4%	10	49.7%	20.8%	16

Difficulty of nitrogen removal in the case of low Influent load

The facilities of 4 resort condominiums in the 30 surveyed facilities had low SV (average: 18%) and high DO (average: 7.9 $mg \cdot l^{-1}$) in their aeration tanks. They were apparently over-aerated. Although they were operated in intermittent aeration mode, the T-N removal efficiencies were low (average: 5.5%). The low T-N removal seemed to be caused by the low influent load. Therefore seven facilities of resort condominiums were surveyed in addition.

It was found that the ratio of the actual annual population using the condominiums to the designed population ranged from 3.7 to 12.4% (average:7.7%), while the ratio of the actual amount of water consumption to the designed consumption ranged from 5.2 to 9.7% (average: 8.0%) in the surveyed condominiums. The influent BOD entering the aeration tanks ranged from 29$mg \cdot l^{-1}$ to 140 $mg \cdot l^{-1}$ and its average was 69.4 $mg \cdot l^{-1}$. Because the designed influent BOD was 200 $mg \cdot l^{-1}$, the actual BOD load was less than 5% of the designed BOD load. The influent BOD/COD_{Mn} ratio ranged from 0.8 to 2.1 (average: 1.5) and BOD/T-N ratio ranged from 1.1 to 3.0 (average. 1.9). These low ratios seemed to be caused by mixing of wastewater with aeration in the equalization tanks. As NO_2-N and NO_3-N were detected in the equalization tanks, it was suggested that nitrification was taking place there.

The average T-N removal efficiency in the seven facilities was 25.0%. Because the (NO_2-N +NO_3-N)/T-N ratio was high in the effluent, the process of nitrification was enough and the poor process of denitrification resulted in the low performance of T-N removal. The reason for the poor progress of denitrification seemed to be the lack of BOD which is necessary for denitrification and was degraded in the equalization tanks. The lack of BOD should also make it difficult to get anaerobic conditions in the aeration tanks in the period of stopping aeration.

The relationship between the influent BOD/T-N and the T-N removal efficiency of the 37 facilities, the sum of 30 domestic wastewater treatment facilities larger than 201 p.e. and the 7 facilities of the resort condominiums, is plotted in Fig. 5. Some facilities had 70-90% T-N removal in the case of BOD/T-N ratio larger than 3. On the contrary no facilities had over 70% of T-N removal in the case of the ratio below 3. The dotted line in Fig. 5 shows the maximum T-N removal efficiency according to the influent BOD/T-N ratio. The line linearly decreased if the BOD/T-N ratio was below 4. The maximum T-N removal was 70% at BOD/T-N = 3, 50% at BOD/T-N = 2 and 30% at BOD/T-N = 1. Hence the dotted line was approximately as follows.

$$R_{N,Max} = 20 \times (BOD/T\text{-}N) + 10 \qquad (1)$$

where $R_{N,Max}$ means the maximum T-N removal (%).

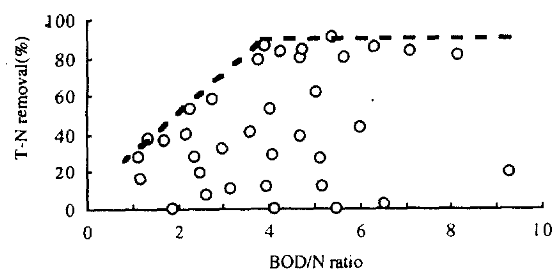

Figure 5. Relationship between the influent BOD/T-N ratio and T-N removal in the 37 facilities.

Equation 1 suggested the amount of the lack of BOD for biological denitrification. The amount of BOD necessary to be added in the case of low influent BOD/T-N ratio will be calculated by using Eqn. 1. For example, in order to get R_N(%) of T-N removal in the facilities of which the water quantity is Q ($m^3 \cdot d^{-1}$) the amount of methanol M ($g \cdot d^{-1}$) to be added will be written as follows by assuming 1.3g of methanol is equal to 1 g of BOD.

$$M = \{(R_N - 10) \times T\text{-}N/20 - BOD\} \times 1.3Q \quad (2)$$

where BOD/T-N < 4. Mixing wastewater in the equalization tank without aeration as well as using part of the equalization tank or aeration tank if they are divided into several parts will be useful to improve T-N removal efficiency in facilities of low influent load. Moreover Eqn. 2 can be applied if the addition of methanol is needed.

SUMMARY AND CONCLUSIONS

The small-scale gappei-shori Johkasous showed good performance of BOD removal with their effluent BOD below 20 $mg \cdot l^{-1}$ in 70% of the surveyed data. BOD, N-BOD, T-N, NO_3-N and DKN decreased with the recycle operation. It suggested that the denitrification took place in the anaerobic filter tanks reducing NO_3-N in the recycle liquor by using organic substances in the influent. The effluent T-N seemed to be controlled below 15 $mg \cdot l^{-1}$ with the recycle ratio of 3Q- 10Q.

The BOD removal performance in the facilities treating wastewater from restaurants and hotels was largely influenced by the influent n-Hex (oil) concentration. It was likely to have a risk of failing the performance if the influent n-Hex was over 30 $mg \cdot l^{-1}$. The n-Hex concentration should be reduced to below 30 $mg \cdot l^{-1}$ by using pretreatment before biological treatment in order to have a good performance of BOD removal.

In the facilities treating domestic wastewater larger than 201 p.e., the removal of T-N and T-P were apparently higher in the facilities operated in intermittent aeration mode than the facilities operated in continuous aeration mode. The higher removal of T-N was caused by biological denitrification which took place in the period when the aeration was stopped.

The performance of T-N removal was low in the facilities of which influent BOD was extremely low, like the surveyed resort condominiums, even though they were operated in intermittent aeration mode. The maximum TN removal linearly decreased if the influent BOD/T-N ratio was below 4. An equation to estimate the amount of methanol to be added in facilities with low influent BOD was proposed.

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