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ORGANIC MATTER AND NITROGEN REMOVAL IN ROTARY DISK TYPE UF MEMBRANE BIOREACTOR FOR FERMENTATION WASTEWATER TREATMENT

Shuguang LU[1], Tsuyoshi IMAI[2], Masao UKITA[3], Masahiko SEKINE[4],
Masayuki FUKAGAWA[5] and Hiroshi NAKANISHI[6]

[1]Member of JSCE, M. Eng., Graduate Student, Dept. of Civil Eng., Yamaguchi University
(Ube, Yamaguchi 755-8611, Japan)
[2]Member of JSCE, Dr. Eng., Research Associate, Dept. of Civil Eng., Yamaguchi University
(Ube, Yamaguchi 755-8611, Japan)
[3]Member of JSCE, Dr. Eng., Professor, Dept. of Civil Eng., Yamaguchi University
(Ube, Yamaguchi 755-8611, Japan)
[4]Member of JSCE, Dr. Eng., Assistant Professor, Dept. of Civil Eng., Yamaguchi University
(Ube, Yamaguchi 755-8611, Japan)
[5]Member of JSCE, Dr. Eng., Professor, Dept. of Chemical and Biological Eng., Ube National College of Technology
(Ube, Yamaguchi 755-8555, Japan)
[6]Member of JSCE, Dr. Eng., Emeritus Professor, Yamaguchi University
(Ube, Yamaguchi 755-8611, Japan)

Various intermittent aeration modes were applied to treat fermentation wastewater by highly concentrated activated sludge process coupled with UF membrane. Organic removal did not decrease significantly compared with continuous aeration mode. Denitrification contributed most to T-N removal compared with T-N losses in sample and sludge synthesis, and the optimal operating condition (30-min. aeration on and 30-min. aeration off) was obtained for carbon and nitrogen removals. Fluctuation patterns of DO and ORP in a cycle were observed and the activity of sludge was assessed by INT- dehydrogenase activity. Based on SEM observation, the rod-type bacteria were predominant compared with filamentous bacteria at higher MLSS concentration.

Key Words: *membrane bioreactor, fermentation wastewater, intermittent aeration mode, highly concentrated activated sludge, nitrification, denitrification, sludge activity, ORP.*

1. INTRODUCTION

Nutrient removal becomes more and more important in wastewater treatment due to the more stringent effluent criteria[1]). Biological nitrification and denitrification are increasingly popular options in activated sludge processes because of the associated economic advantages. Recent development of ultrafiltration (UF) process has given rise to new techniques for wastewater treatment, such as membrane bioreactor that makes use of both biological treatment and ultrafiltration separation of suspended solids. Its advantages can be seen elsewhere[1)-6)]. The UF membrane process enables retention of high biomass concentration in the reactor, i.e. the process can be operated with quite long sludge retention time (SRT). Furthermore, reactions which are carried out by organisms having a very slow growth rate, such as nitrification, can also function well at high loading rate[7)].

In our previous study, a single-stage, single-sludge bioreactor in high concentration of activated sludge with rotary disk type UF membrane was used to treat high strength fermentation wastewater in continuous aeration condition[8)]. Almost 100% ammonia nitrogen was oxidized and high nitrification was obtained. However, denitrification was inhibited by the high DO concentration, and total nitrogen (T-N) removal efficiency was only around 11.6%. Therefore, in order to improve T-N removal, intermittent aeration mode

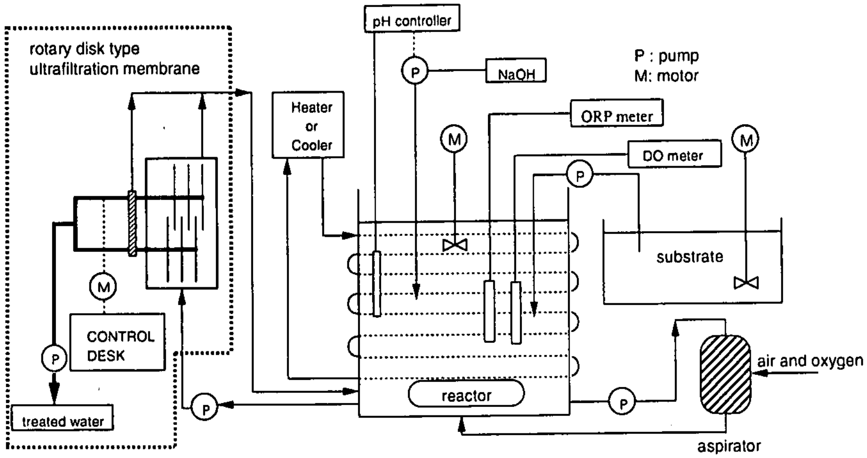

Fig.1 Schemetic diagram of experimental system.

of highly concentrated activated sludge bioreactor is selected because of its high biodegradability, slight pH variation in the reactor, cost saving and easy control7),9)-12).

Ohba and Sakai developed a single-stage intermittent aeration system aiming to complete nitrification, promote denitrification to keep effluent pH neutral by intermittent aeration, and to equalize the flow to sedimentation tanks for sewage treatment plants of small communities11). High removal efficiencies of soluble nitrogen and COD were obtained with intermittent aeration in membrane separation activated sludge process with 3000 mg/l of MLSS concentration for artificial wastewater treatment similar to the quality of municipal sewage by Somiya et al10). In this study, various intermittent aeration modes (according to the control of aeration time and non-aeration time) were carried out to improve denitrification as well as organic removal of high strength fermentation wastewater by highly concentrated activated sludge process. The performances of different operating conditions were investigated. Emphasis was given on the evaluation of the effect of intermittent aeration mode on the allocation of total nitrogen, and the specific nitrification rate and denitrification rate were calculated according to nitrogen balance. Variations of DO and oxidation - reduction potential (ORP) in one cycle in the reactor at different intermittent aeration modes were observed. Finally, the activities of sludge were assessed by 2-(*p*-iodophenyl)-3-(*p*-nitrophenyl)-5-phenyl tetrazolium chloride (INT) - dehydrogenase activity, and the structure of sludge was observed by scanning electron microscope (SEM) throughout the experiment.

2. MATERIALS AND METHODS

(1) System Configuration

A schematic diagram of the lab-scale experimental apparatus employed in this study is shown in **Fig.1**. The unit consisted of a cylindrical bioreactor that had a working volume of 30 liters and a rotary disk type UF membrane separator with a volume of 10 liters. Membrane made of polysulfone with a cutoff 750,000 molecular weight and 0.30 m^2 of total surface area provided by Hitachi Plant Engineering & Construction Co., Ltd. was used in this study3). This module consisted of two shafts in which each was fitted with three disks of 210 mm in diameter. One set of disks was engaged with the adjoining set of disks on the other shaft.

1N-NaOH was added automatically to keep pH in the range of 6.8-7.2. Temperature of the liquid in the reactor was controlled to be in the range of 22-32℃. The experiment was conducted with continuous influent, and effluent was intermittently withdrawn under 1 minute on and 9 minutes off operation mode by a suction pump. At the disk peripheral velocity of 2.7 m/s, the system was able to maintain the flux of 0.41-0.47 m/d and the transmembrane pressure of 25-36 kPa for approximately two months. Then washing of membrane was performed in a long-term filtration, and sodium hypochlorite solution with a concentration of 100 $\mathrm{mgCl_2/l}$ was circulated through the UF membrane module for about 24 hours. After the washing, the flux of membrane recovered almost

Table 1 Compositions of wastewater.

Parameter	Concentration
TOC, mg/l	98600
COD_{Cr}, mg/l	247000
BOD_5, mg/l	164350
T-N, mg/l	35700
NH_4-N, mg/l	13600
$NO_{2,3}$-N, mg/l	negligible
SO_4^{2-}, mg/l	21400
pH	5.3

Table 2 Operational conditions.

phase	run1(days)	run2(days)	operation modes
1	20	20	continuous aeration
2	18	19	10 min on-10 min off
3	24	32	30 min on-30 min off
4	24	26	60 min on-30 min off

on: aeration on, off: aeration off

During aeration on, DO=1.5-3.0 mg/l

Table 3 Characteristics of influent.

parameters	run 1	run 2
TOC	1160-1600 (1360)	1950-2540 (2150)
COD_{Cr}	2180-4020 (3190)	4670-6430 (5445)
NH_4-N	235-350 (252)	390-540 (460)
T-N	370-560 (457)	490-750 (630)

unit: mg/l, Data in parenthesis is the average.

completely, and the transmembrane pressure recovered to about 95% of the first time.

(2) Influent

High concentration wastewater from a fermentation plant was used in this study. Its compositions are summarized in **Table 1**. It was stored at 4℃ until use. Before being fed to the reactor, it was diluted with tap water to a desired TOC concentration.

(3) Operating Conditions

Seeding sludge was taken from the municipal wastewater treatment plant in Ube City, Yamaguchi, Japan. The acclimatization of activated sludge was carried out with successive addition of fermentation wastewater by gradually increasing TOC concentration. Finally, the biomass acclimatization was achieved when steady removals of TOC, COD_{Cr}, NH_4-N (over 90%) were obtained, and MLSS, MLVSS concentrations in the reactor remained relatively unchanged. From then on, the experiment began as 0 day. The quantity of treated wastewater was 15 l/day. Hydraulic retention time (HRT) of the system was 2.67 days.

(4) Scanning Electron Microscope (SEM) and Microscopic Observation

The samples of activated sludge for microscopic observation were fixed in 0.1M phosphate buffer (pH=7.0) containing 2.5% glutaraldehyde for 24 hours and dehydrated with a graded series (50%, 70%, 80%, 90%, 95%, 99.5%) of ethanol solutions. Then ethanol was replaced with 2-methyl-2-propanol solution. The samples were subsequently dried overnight by JFD-300 freeze dryer (JEOL Co., Japan) and sputter-coated with gold by E-1020 ion sputter (Hitachi, Ltd. Tokyo Japan). SEM microphotographs were taken with Hitachi S-2300 scanning electron microscope.

(5) Analysis

Total organic carbon (TOC) concentration in liquid samples was determined by a Shimadzu model TOC-5000 analyzer. $NO_{2,3}$-N concentration was determined by ionic chromatography (UV-8000, Tosoh Co., Ltd.). T-N was measured by a T-N analyzer (GCT-16N, Sumitomo Chemical Co., Ltd. & GC-8APT, Shimadzu Co., Ltd.), whereas COD_{Cr}, NH_4-N, MLSS, MLVSS were determined according to Standard Methods[13]. DO, ORP, pH were measured on-line using probes. INT-dehydrogenase activity was determined according to Logue, *et al*[14].

3. RESULTS AND DISCUSSION

(1) Operational Performance

The bench-scale experiments were conducted with two operating conditions: run1 with an average TOC loading of 0.51 kgTOC/m^3/day at 30 ± 2℃ and run2 with 0.81 kgTOC/m^3/day at 24 ± 2℃. During the experiment, no sludge was wasted except samples. The volume of samples (50-100 ml/day) from the reactor was little compared with the volume of total activated sludge in the reactor and membrane module. The practical average sludge retention time (SRT) was between 400-800 days when sampling was considered. The operating conditions and the influent characteristics of experiment are shown in **Table 2** and **Table 3**, respectively.

a) Performance in Run1

The experiment of run1 lasted for 83 days. After 20 days of operation under continuous aeration in phase 1, intermittent aeration modes were applied to the system in order to provide anoxic condition for

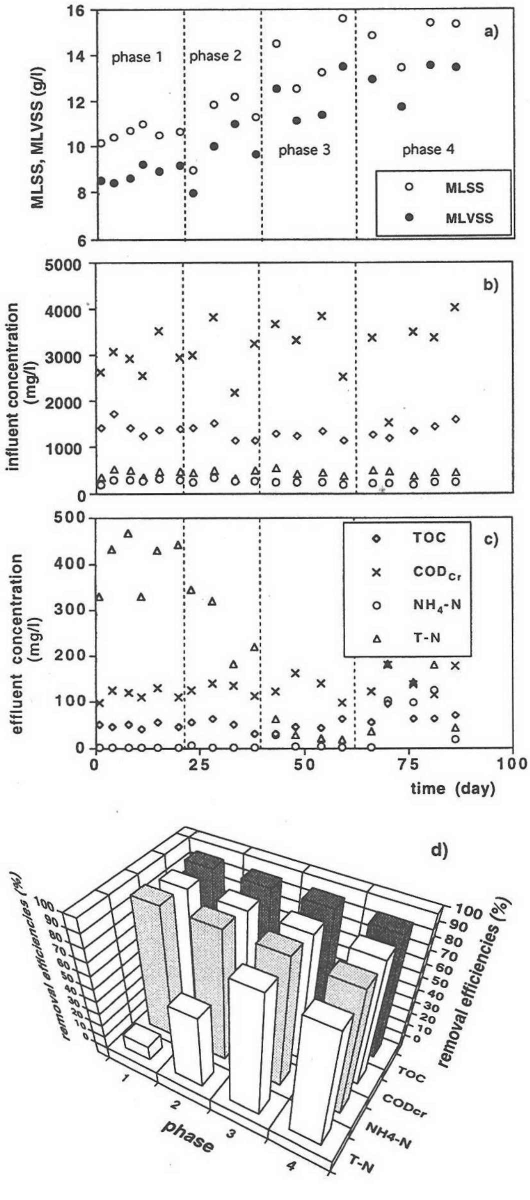

Fig.2 Performance of run1.

a) MLSS, MLVSS concentrations versus time

b) influent concentration versus time

c) effluent concentration versus time

d) removal efficiencies in phase 1-4

denitrification in phase 2-4. Phase 2 lasted for 18 days, and phases 3 and 4 lasted for 24 days. In the aeration period, oxygen was supplied to maintain DO of 1.5-2.5 mg/l. MLSS, MLVSS concentrations in the reactor, and the influent and effluent performances are shown in **Fig.2**. After introducing anoxic condition to the system, MLSS and MLVSS concentrations increased gradually from 10.6 g/l and 9.0 g/l at the beginning of phase 2 to 14.8 g/l and 12.9 g/l at the end of phase 4 corresponding to the change of sludge-mass-balance. At the 65th day in phase 4, pH controller broke and pH in the reactor increased to 10.5. Then HCl was added to the reactor and the effluent quality finally recovered on the 82nd day. The removal efficiencies of phase 1 to 4 at the end of each phase are also shown in **Fig.2** (data in recovering period was not used for calculation in phase 4). TOC and COD_{Cr} in the effluent were less than 96 mg/l and 180 mg/l in all phases with the removal efficiencies over 92% and 94%, respectively, even during recovering period in phase 4. NH_4-N was removed almost completely in phase 1-4 at general condition except during the high pH period in phase 4 which had a great influence on its removal and resulted in a high effluent NH_4-N concentration of 110 mg/l. This was because *Nitrosomonas* that oxidized NH_4-N to nitrite was inhibited at high pH condition. T-N removal efficiencies in phase 1-4 were 10%, 40%, 87% and 86%, respectively. The average $NO_{2,3}$-N concentrations in the effluent in phase 1,2 were 334 and 170 mg/l, respectively, and were not detected in phase 3 and 4 which indicated that all nitrified nitrogen was denitrified in phase 3 and 4.

b) Performance of Run2

The duration of run2 was 97 days with an average TOC loading of 0.81 $kgTOC/m^3/day$. Since the experiment was conducted in winter, the temperature of the liquid decreased to 24 ± 2℃. The experiment was conducted under continuous aeration condition after the change of TOC loading until a relative steady-state condition was obtained. The operation of phase 1-4 lasted for 20, 19, 32 and 26 days, respectively. DO was maintained at 2.0-3.0 mg/l in the aeration period. MLSS, MLVSS concentrations in the reactor, effluent quality and removal efficiencies at the end of each phase are shown in **Fig.3**. As in run1, MLSS and MLVSS increased gradually from 10.1 g/l and 8.5 g/l at the beginning of phase 2 to 14.6 g/l and 12.6 g/l at the end of phase 4. TOC and COD_{Cr} concentrations in the effluent were less than 130 mg/l and 300 mg/l, respectively, in all phases with both TOC and COD_{Cr} removal efficiencies over 94%. NH_4-N removal was almost complete with the NH_4-N concentration in the effluent less than 3.5 mg/l. T-N removal efficiencies in phase 1 to 4 at the end of each phase were 22%, 78%, 88% and 82%, respectively. The average $NO_{2,3}$-N concentrations in the effluent in phase 1-4 were 366, 71, 3.6 and 2.7 mg/l, respectively.

Of particular interest was the increase of MLSS

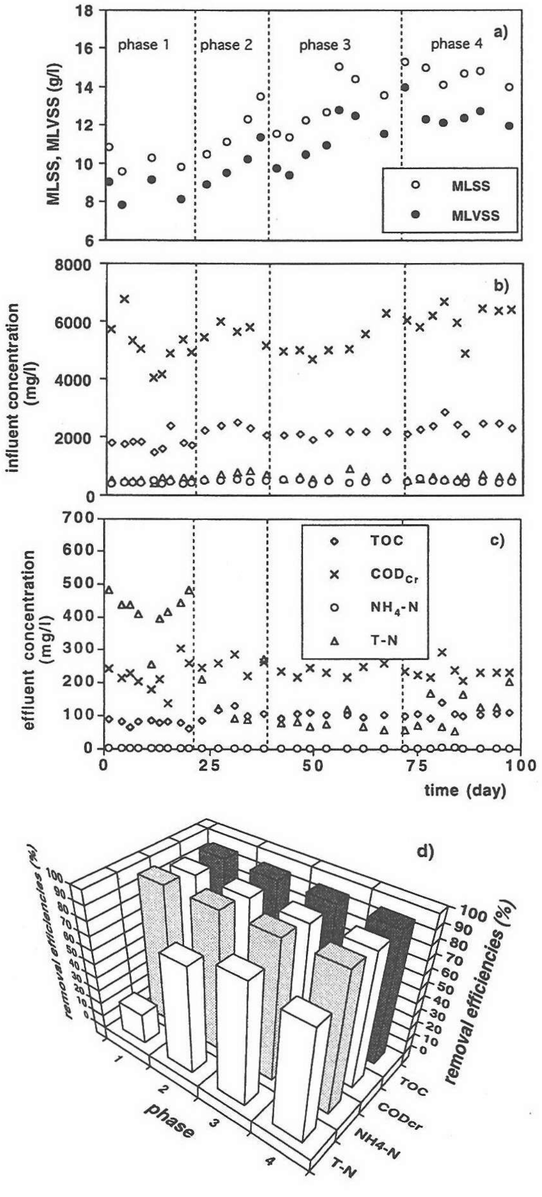

Fig.3 Performance of run2.

a) MLSS, MLVSS concentrations versus time

b) influent concentration versus time

c) effluent concentration versus time

d) removal efficiencies in phase 1-4

and MLVSS concentrations after introducing anoxic condition to the system in both run1 and run2. The increase of MLSS and MLVSS concentrations is related to the growth rate of biomass through the degradation of substrate, wasted sludge and decay of biomass. The decay rate of biomass is related not only to biomass concentration, but also to DO concentration in the reactor, and it is inhibited in the absence of DO. Therefore, after the incursion of anoxic operating condition to the system, the rate of biomass decay decreased as compared with that in continuous aeration condition. In addition, influent concentration of substrate increased slightly resulting in the increase of MLSS, MLVSS concentrations which was corresponding to the change of sludge-mass-balance. Although the average TOC loading in run2 was higher than that in run1, MLSS and MLVSS concentrations in run2 were not higher than those in run1. This was probably due to the lower biomass growth rate under slightly low temperature condition in run2 compared with that in run1.

(2) Nitrification and Denitrification

a) Allocation of Nitrogen

The influent of T-N can be allocated as following four parts:

Ⅰ. T-N loss in the effluent

This can be calculated by T-N concentration in the effluent.

Ⅱ. T-N deposited in sludge in the reactor

MLSS concentration increased gradually from phase 2 to 3 and nitrogen was synthesized in biomass. Here, the value of the total nitrogen content of sludge, 9.65%, was used for calculation[15].

Ⅲ. T-N waste in sample

In the whole experiment, no sludge was wasted except the samples. Samples included T-N in liquid as well as in solid phases. This part can be calculated according to Ⅰ and Ⅱ. Sample volume of 75 ml/day was used for estimation.

Ⅳ. T-N loss by denitrification

This can be calculated from T-N mass balance. Here, it must be noticed that disappeared N_2O was not taken into account and complete denitrification was assumed.

The results of allocation of nitrogen in run1 and run2 at phase 1-4 are listed in **Table 4**. T-N loss in sampling was very low, in an average of 1.3% in run1 and 1.0% in run2. T-N deposited in sludge from phase 2 to 3 during the increase of MLSS concentration were in the average of 4.1% in run1 and 2.4% in run2. The significant changes of T-N were found in the effluent and in denitrification. T-N losses by denitrification from phase 1 to 4 were 9.9%, 36.0%, 87.5%, and 85.8% in run1, and were 21.5%, 76.1%, 85.0% and 77.8% in run2, respectively. The high denitrification was characterized by lower T-N concentration in the effluent obtained in phase 3 of both runs.

Table 4 Allocation of nitrogen.

Run No.	phase	TN in effluent gN/day	TN deposited in sludge gN/day	TN in sample gN/day	TN loss by denitrification gN/day	TN in influent gN/day
1	1	6.07 (88.74%)	0 (0%)	0.09 (1.35%)	0.68 (9.91%)	6.84 (100%)
	2	4.01 (58.63%)	0.28 (4.10%)	0.09 (1.26%)	2.46 (36.02%)	6.84 (100%)
	3	0.49 (7.12%)	0.28 (4.07%)	0.09 (1.31%)	6.02 (87.50%)	6.88 (100%)
	4	0.6 (8.71%)	0.28 (4.06%)	0.1 (1.45%)	5.91 (85.78%)	6.89 (100%)
2	1	6.27 (77.37%)	0 (0%)	0.09 (1.11%)	1.74 (21.52%)	8.1 (100%)
	2	2.36 (21.03%)	0.24 (2.14%)	0.09 (0.76%)	8.55 (76.08%)	11.24 (100%)
	3	1.17 (11.70%)	0.24 (2.40%)	0.09 (0.86%)	8.5 (85.04%)	10.0 (100%)
	4	1.73 (18.57%)	0.24 (2.57%)	0.1 (1.06%)	7.27 (77.81%)	9.34 (100%)

( ) are allocation percentages of total nitrogen

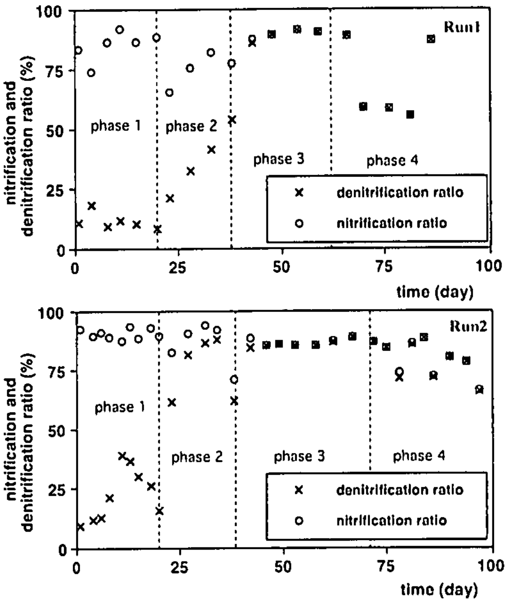

Fig.4 The ratios of nitrification and denitrification in run1 and run2.

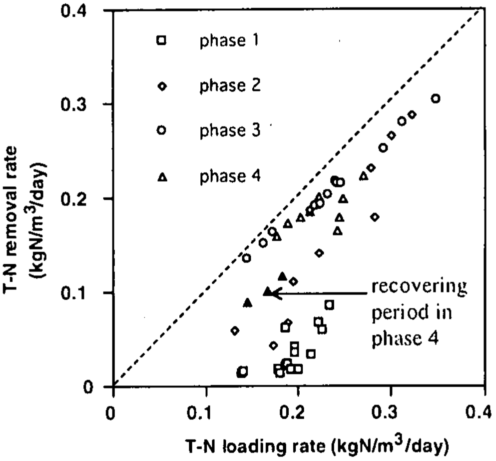

Fig.5 T-N removal rates in phase 1-4 of run1 and run2 versus T-N loading rates.

b) Nitrification and Denitrification Ratios

During nitrification, organic nitrogen and NH_4-N were partly nitrified to $NO_{2,3}$-N. Whilst, during denitrification, $NO_{2,3}$-N was denitrified to nitrogen gas. Here, nitrification and denitrification ratios based on total nitrogen were calculated according to the allocation of nitrogen, T-N, NH_4-N and $NO_{2,3}$-N concentrations in the influent and effluent. The results are shown in **Fig.4**. In phase 2 of both runs, nitrification ratio had a slight decrease which might be due to the sudden incursion of anoxic condition. Later, however, it gradually increased and recovered to the original level in phases 3 and 4 compared with that in phase 1. However, denitrification ratio increased remarkably in phase 2 to about 50% in run1 and to about 80% in run2. In phases 3 and 4 of both runs, denitrification ratio increased and its value was almost the same to nitrification ratio, which indicated that all nitrified nitrogen was denitrified and denitrification was limited by nitrification. During the recovering period from the failure of pH control in phase 4 of run1, nitrification and denitrification were significantly influenced and both decreased to 58%. This was also demonstrated by other researchers that nitrification was inhibited under high pH condition[16),17)].

c) Influence of T-N Loading on T-N Removal in Different Phases

T-N loading rate varied between 0.13～0.21 kgN/m³/day in run1 and 0.18 ～ 0.35 kgN/m³/day in run2 at the average of 0.17 kgN/m³/day and 0.23 kgN/m³/day, respectively. T-N removal rates in the whole experimental period versus T-N loading rates is shown in **Fig.5**. During continuous aeration period in phase 1, T-N removal rate was quite lower, and the maximum T-N removal rate was lower than 0.1 kgN/m³/day. After incursion of anoxic operation, T-N removal rate increased proportionally to the T-N loading rate, and T-N removal rate in phase 3 was the nearest one to the T-N loading rate comparing with those in phases 2 and 4. During the recovering period in phase 4 due to the failure of pH control, T-N removal rate decreased significantly and deviated from the linear part remarkably. **Fig.5** also indicated that T-N removal capacity did not reach its limit even at 0.35 kgN/m³/day (in phase 3) of T-N loading rate under this experimental condition. This probably contributed to the high concentration of activated sludge in UF membrane bioreactor and most nitrifiers having slow growth rate held by UF membrane compared with conventional activated sludge process.

d) Specific Nitrification and Denitrification Rates

Generally, organic nitrogen is converted to ammonia nitrogen by ammonification. During nitrification, ammonia nitrogen is nitrified to $NO_{2,3}$-N. Whilst, during denitrification, $NO_{2,3}$-N is denitrified to nitrogen gas. Based on total nitrogen mass balance, the specific nitrification rate (SNR) and specific denitrification rate (SDNR) were calculated according to the following equations:

$$r_{DN} = \frac{(TN_1 - TN_2) \cdot Q - r_{MLSS} \cdot V \cdot 9.65\%}{V \cdot MLVSS \cdot 24} \qquad (1)$$

$$r_N = r_{DN} + \frac{\left[(NO_x\text{-}N)_2 - (NO_x\text{-}N)_1\right] \cdot Q}{V \cdot MLVSS \cdot 24} \qquad (2)$$

where,

r_{DN}: the average specific denitrification rate (gN/kgVSS/hr)

r_N: the average specific nitrification rate (gN/kgVSS/hr)

TN_1: T-N concentration in influent (mg/l)

TN_2: T-N concentration in effluent (mg/l)

$(NOx\text{-}N)_1$: $NO_{2,3}$-N concentration in influent (mg/l)

$(NOx\text{-}N)_2$: $NO_{2,3}$-N concentration in effluent (mg/l)

Q: volume of treated water per day (15 l/day)

V: reactor volume, cylindrical bioreactor (30 l) + membrane separator (10 l)

r_{MLSS}: the average increasing rate of MLSS in the reactor from phase 2 to 3 (run1: 73 mg/l/day, run2: 61 mg/l/day)

MLVSS: MLVSS concentration in the reactor (g/l)

9.65%: total nitrogen content of sludge[15)]

The average SNR and SDNR in phase 1-4 of both runs are shown in **Table 5**. In both runs, SNR were between 0.51 ~ 1.02 gN/kgVSS/hr, and SDNR were between 0.27 ~ 0.91 gN/kgVSS/hr except in phase 1 in which SDNR were much lower than 0.09 gN/kgVSS/hr in run1 and 0.22 gN/kgVSS/hr in run2. SNR did not vary greatly from phase 1 to phase 4. However, SDNR increased significantly after the incursion of anoxic condition. In phase 2, SDNR increased to the half of SNR in run1 and about 90% of SNR in run2. In phases 3 and 4, SDNR were almost the same to SNR and this indicated that nitrification was a limiting step which was in agreement with the results of Chiemchaisri, *et al*[7)]. On the other hand, the simultaneous nitrification and denitrification could be obtained in phases 3 and 4 by intermittent aeration mode.

Table 5 The average specific nitrification and denitrification rates.

phase		SNR (gN/kgVSS/hr)	SDNR (gN/kgVSS/hr)
Run1	1	0.69	0.09
	2	0.56	0.27
	3	0.53	0.53
	4	0.51	0.51
Run2	1	0.88	0.22
	2	1.02	0.91
	3	0.81	0.81
	4	0.62	0.61

The experiment demonstrated that the incursion of anoxic operating condition to the system indeed improved the nitrogen removal, and the organic carbon removal was not adversely influenced. High nitrogen removal (over 80%) was obtained in phases 3 and 4. However, the longer aeration operation in phase 4 (60 min. aeration on - 30 min. aeration off) would consume larger oxygen and increase operating cost. The optimal operating condition in phase 3 (30 min. aeration on - 30 min. aeration off) was obtained in this study due to the high efficiency of simultaneous carbon and nitrogen removals. The lower nitrogen removal in phase 2 might be due to the sudden change of operating condition from continuous aeration mode, and the experiment in phase 2 did not last enough longer. However, because of the rapid change between aerobic and anoxic operating conditions, aeration pump on and off modes changed quickly which probably resulted in bad condition for pump maintenance. Therefore, 30 min. aeration on - 30 min. aeration off can be concluded to be the optimal operating condition in this study for fermentation wastewater treatment by highly concentrated activated sludge process with membrane as a separator.

(3) Characteristics of Operating Environment and Activated Sludge in the Reactor

The investigations of DO and ORP variations in the reactor, activities of sludge and SEM observations were investigated in run2.

a) Variations of DO and ORP (all ORP data is with reference to Ag/AgCl)

In phase 1 of run2, DO was maintained at 1.5 ~ 2.5 mg/l. ORP in this phase was between +100 ~ +140 mV. In phase 2-4, anoxic condition was introduced to

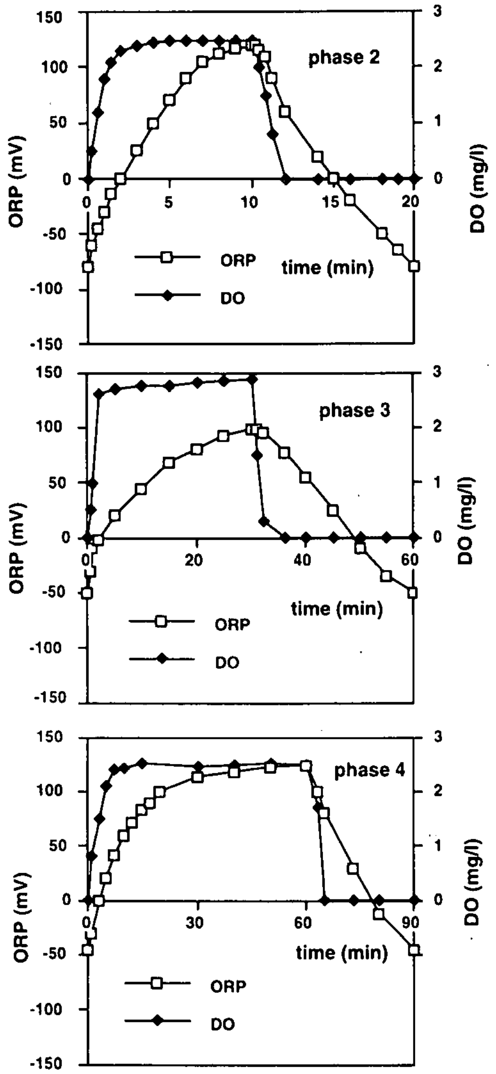

Fig.6 Fluctuation patterns of DO and ORP in one cycle in phase 2-4.

the reactor. Fluctuation patterns of DO and ORP in one cycle in phase 2-4 are represented in **Fig.6**.

In phase 2, the maximum DO in the reactor was about 2.5 mg/l. After the stop of aeration pump, DO decreased quickly from 2.5 to 0 mg/l within about 2 minutes. ORP varied between -80 ~ +120 mV. It increased during aeration condition and decreased significantly during non-aeration condition in one cycle.

In phase 3, the maximum DO in the reactor was at 2.8 mg/l. ORP varied between -50 ~ +100 mV. The patterns of DO and ORP were almost the same to those in phase 2.

In phase 4, the time under aeration condition was increased to 60 minutes. The maximum DO in the reactor was 2.5 mg/l. ORP varied between -45~+120 mV. After the start-up of aeration, ORP increased gradually during the first 20 minutes, then it increased slowly until the aeration was stopped.

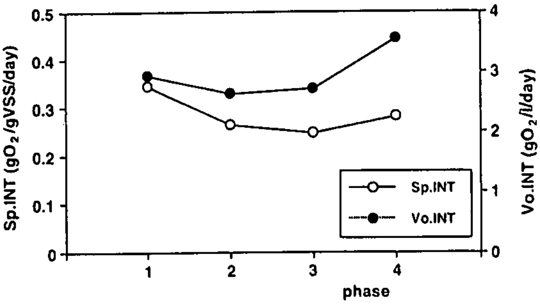

Fig.7 Activities of sludge in phase 1-4.

Although the patterns of DO and ORP in one cycle in phase 2 and 3 were almost the same, T-N removals were significantly different. The lower T-N removal in phase 2 was probably because of the following two reasons: First, phase 2 was followed by phase 1 with continuous aeration mode and the denitrifier might not fit to the sudden change of environment, and the experimental period in phase 2 was probably too short. Second, a little lag-time might exist in denitrification.

In our studies, ORP varied between -80 ~ +120 mV during phase 2-4. It was in accordance to the results of Yuyama, *et al*[18] who reported that ORP was desirable to change from not less than -100 mV to more than +100 mV in a cycle in batch-activated sludge process for the removal of nitrogen. Koch and Oldham[19] also suggested that ORP could be used as a unique and effective means in monitoring and controlling nitrate removal process.

b) Activity of Sludge in the Reactor

Due to high SRT (400-800 days) in this process and incursion of anoxic operating condition, the activity of sludge in the reactor is utmost important. The activity of highly concentrated activated sludge in phase 1-4 was assessed by INT- dehydrogenase activity[14),20)], and the plot of activities in phase 1-4 is shown in **Fig.7**.

The average specific activities in phase 1-4 were 0.34, 0.26, 0.25 and 0.28 gO_2/gVSS/day, respectively. After introducing anoxic operating condition into the system, the specific activity decreased. This might be due to the sudden change of environment, or the increase of MLVSS concentration in the reactor as the previous research has shown that the specific activity of sludge would decrease slightly with the increase of MLVSS concentration in continuous aeration condition in highly concentrated activated sludge bioreactor system[8]. In phase 4, the activity had a slight increase and this was probably because of the time increase of aerobic condition with reference to anoxic condition. On the other hand, the volumetric activities of phase 1-4 were 2.93, 2.64, 2.72 and 3.56 gO_2/l/day, respectively, and the volumetric activities in phases 2 and 3 did not decrease greatly compared with that in phase 1. The maximum volumetric activity was obtained in phase 4. Accordingly, it can be concluded that the whole activity of sludge in the reactor was not influenced significantly after the incursion of anoxic operation and high concentration of activated sludge might be responsible for the high ability of shock adsorption.

Although the fermentation wastewater included high SO_4^{2-} concentration, the effluent quality was not adversely influenced. This was probably because no complete anaerobic condition occurred in the reactor. During the intermittent aeration operation, the minimum ORP was not lower than -80 mV, and the environment in the reactor changed between aerobic-anoxic condition. Hence, no hydrogen sulfide was produced in the reactor, and the process was not inhibited[21].

On the other hand, the fermentation wastewater contained lower inorganic materials. Inorganic compounds did not disrupt treatment performance when sludge was almost completely retained in the reactor. pH of the liquid in the reactor was maintained between 6.8-7.2, therefore no NH_3 was produced to inhibit biomass even through the fermentation wastewater included high NH_4-N concentration[21]. Also, the high removal efficiencies of TOC and NH_4-N during the entire experiment indicated that inhibitors or toxic materials did not accumulate in the reactor due to fewer heavy metal ions or toxic materials contained in the fermentation wastewater.

Due to high concentration of activated sludge in the reactor, the biodegradability of organic materials was improved[8]. The metabolic products of sludge in liquid such as protein (170 mg/l) and polysaccharide (30 mg/l) remained high compared with those (protein, 24 mg/l; polysaccharide, 12 mg/l) in conventional activated sludge process. However, they did not accumulate unlimitedly and maintained almost the same during the experiment.

c) SEM Observations of Activated Sludge

The activated sludge was observed based on SEM observations. There were no significant differences with those in our former studies[8] that the filamentous bacteria were predominant at lower MLSS concentration and the coccus-like or rod-type bacteria were prevailing at higher MLSS concentration (over 10 gMLSS/l). The comparisons of SEM photographs of sludges in different conditions are shown in **Fig.8**. The rod-type bacteria were predominant compared with filamentous bacteria. This also indicated that the type of bacteria did not significantly change when anoxic condition was introduced to the system.

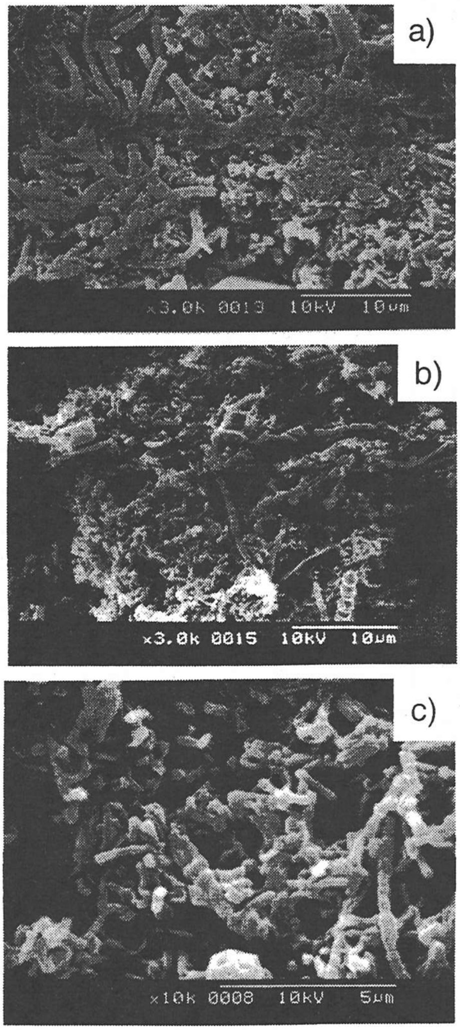

Fig.8 The SEM photographs of sludge in different conditions.
a). in continuous aeration condition in former study[8], MLSS=13 g/l, × 3000
b). in intermittent aeration condition in this study in phase 3 of run 2, MLSS=12 g/l, × 3000
c). in intermittent aeration condition in this study in phase 3 of run 2, MLSS=12 g/l, × 10000

4. CONCLUSIONS

The following conclusions can be drawn from the results of this experiment.

(1) Various intermittent aeration modes can be applied to treat fermentation wastewater by highly concentrated activated sludge UF membrane bioreactor process. Organic removal did not significantly decrease when anoxic condition was introduced to the system, however, T-N removal increased remarkably.

(2) Denitrification in anoxic condition contributed most for T-N removal compared with T-N losses in samples and biomass synthesis. T-N removal capacity did not reach its limit even at 0.35 kgN/m^3/day of T-N loading. The optimal operating condition, i.e. 30 min. aeration on and 30 min. aeration off, was obtained in this study.

(3) Fluctuation patterns of DO and ORP in one cycle were effective indices for regulation of operation. ORP was desirable to change from not less than -100 mV to more than +100 mV in one cycle in intermittent aeration mode for nitrogen removal.

(4) Introducing anoxic operating condition to the system, the specific INT-dehydrogenase activity of sludge decreased. However, the volumetric activity did not decrease significantly.

(5) Based on SEM observations, there were no significant differences of sludge structure with those in continuous aeration mode. The type of bacteria did not change significantly when anoxic operating condition was introduced to the system. The rod-type bacteria were predominant compared with filamentous bacteria at higher MLSS concentration.

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回転平膜を用いた高濃度活性汚泥法による発酵廃液処理における有機物及び窒素除去に関する研究

呂 樹光・今井 剛・浮田正夫・関根雅彦・深川勝之・中西 弘

回転平膜を用いた高濃度活性汚泥法による発酵廃液の処理において，様々な間欠曝気条件を設定して実験を行い，有機物及び窒素除去に関して検討した．有機物除去に関して，連続曝気を行った場合と比較して間欠曝気による影響はほとんど認められなかった．T-Nの除去量は，脱窒によるものがほとんどであり，サンプリング及び菌体合成によるものは少なかった．DO及びORPの変動パターンを測定し，これらが運転指標として有効であること，さらに，INT脱水素酵素活性による菌体活性を測定し，間欠曝気による活性低下がほとんどないことを確認した．SEMによる菌体観察の結果，高MLSS域において桿菌が糸状菌に比較して優占種となっていた．本プロセスにおける最適間欠曝気条件は，30分曝気-30分無曝気と推定された．