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CHARACTERIZATION OF HIGHLY CONCENTRATED ACTIVATED SLUDGE IN FERMENTATION WASTEWATER TREATMENT COUPLED WITH UF MEMBRANE

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., Associate Professor, 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., Associate 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., Professor, Dept. of Civil Eng., Osaka Institute of Technology
(Ohmiya 16-1, Asahiku, Osaka 535-8585, Japan)

Characterization of highly concentrated activated sludge in high strength fermentation wastewater treatment coupled with UF membrane is presented. High TOC and NH_4-N removal efficiencies were obtained by this process. Specific nitrification rate in continuous experiment was found to have the same trend as that in batch experiment, and specific denitrification rate in continuous experiment was much lower than that in batch experiment. Specific oxygen utilization rate and specific INT-dehydrogenase activity of sludge decreased slightly, however, the volumetric activities of both increased remarkably with the increase of MLVSS. The filamentous bacteria were predominant at lower MLSS and coccus-like or rod-type bacteria at higher MLSS.

Key Words : *membrane bioreactor, fermentation wastewater, highly concentrated activated sludge process, sludge activity, nitrification, denitrification.*

1. INTRODUCTION

One disadvantage of conventional wastewater treatment process is that the separation ability of secondary clarifier is dependent on the operation of the aerated reactor since this affects the settleability of the sludge. However, economic constraints limiting the size of the settling tank further limit the maximum biomass concentration in the reactor[1].

The use of synthetic membranes was started in industries in 1960s for desalination. Since then, the continuous development of membrane technology has expanded its fields of application. It also points out to a new direction in water and wastewater treatment for meeting stringent effluent criteria[2),3)].

Many studies have been carried out on the utilization of UF membrane for activated sludge separation in aerobic and anaerobic conditions[2),4)-13)]. It was found to enhance the COD removal capacity of the activated sludge reactor by enabling operation at high retained biomass concentration. Virus concentration resulting from gel layer on the membrane surface, too, was found to decrease greatly. This process can save cost because of the compactness, less land requirement and fewer operators[9),14)]. No excess sludge or lower sludge produced due to the lower F/M ratio save the cost further. The membrane fouling mechanisms also have been reported by some researchers[2),14)-16)]. According to them, promoting a high superficial velocity across the surface of the

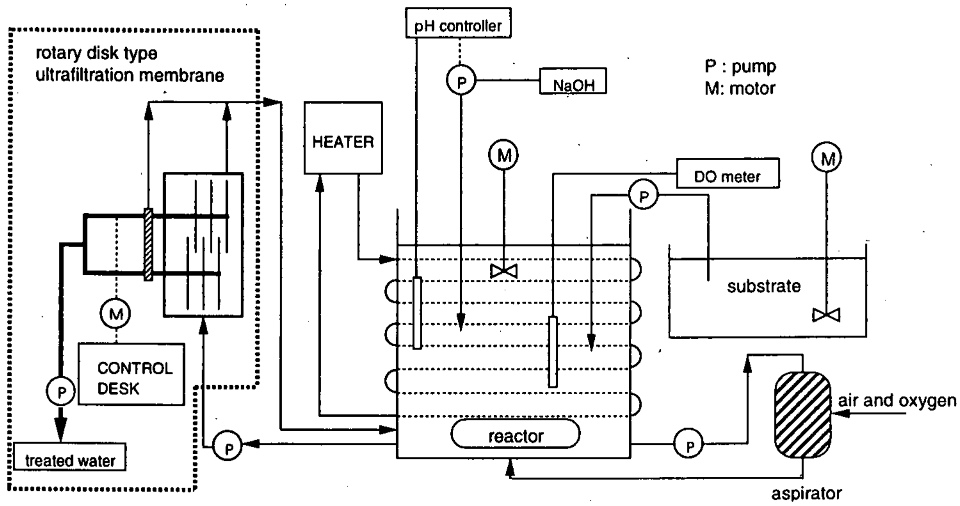

Fig.1 Schematic diagram of experimental system.

membrane or establishing turbulent mixing in the system can retard the fouling, minimize the problem of concentration polarization, and establish stable flux patterns.

The wastewater from a fermentation plant having about 100 fold as organic concentration (see **Table 1**) compared with domestic wastewater was used in this study. Being of high strength wastewater, high biomass concentration retained in the reactor would be ideal and suitable for its treatment. Due to high sulfate concentration in fermentation wastewater, anaerobic process would not be suitable because of high cost for desulfurization. Sulfide produced in anaerobic process might be a burden for further aerobic treatment. And in recirculation process between aerobic and anaerobic reactors for denitrification, sulfate accumulates gradually and inhibits anaerobic process[17]. Generally, aerobic process is mature for operation and can produce high quality of effluent. Therefore, aerobic process is employed in this study for fermentation wastewater treatment by means of membrane as a separator.

However, a need for comprehensive studies of the characteristics of highly concentrated activated sludge still remains. For example, the questions regarding to the activity of sludge in the reactor, the treatability of sludge for high strength wastewater, the change of sludge structure, and so on are still open. Whether the treatment performance is negatively affected with the increase of MLSS concentration is unknown as yet. Also it is still not clear whether the activated sludge remains sufficiently viable to ensure proper treatment with the increase of organic loading.

Therefore, this study has been carried out to investigate the treatability of fermentation wastewater with the concentrated activated sludge process coupled with rotary disk type UF membrane. The experiment conducted 130 days. Removal efficiencies of organic and nutrient matters, nitrification and denitrification were observed during the experimental period. The organic and nutrient biodegradability with the increase of MLVSS concentration was emphasized. The sludge activity and its characterizations were observed throughout the experiment. Furthermore, the mechanisms of organic and nutrient biodegradation by highly concentrated activated sludge were discussed.

2. MATERIALS AND METHODS

(1) Experimental Apparatus

The schematic diagram of lab-scale experimental apparatus used in this study is shown in **Fig.1**. The cylindrical bioreactor had a working volume of 30 liters. The activated sludge was retained by a rotary disk type UF membrane module (Hitachi Plant Engineering & Construction Co., Ltd.) with a volume of 10 liters. Membrane made of polysulfone with a cut-off 750,000 molecular weight and 0.3 m^2 of total surface area was used. This module consisted of two shafts each 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. Activated

Table 1 Compositions of fermentation 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
MLSS, mg/l	12040
MLVSS, mg/l	9900
pH	5.3

sludge was circulated between the reactor and membrane module by pump.

Adjustment of pH was made by addition of 1N-NaOH to keep pH in the range of 6.8-7.2. Temperature of mixed liquor was kept in the range of 28-33℃. The experiment was operated with continuous influent, and effluent was intermittently withdrawn under 1-minute on and 9-minute off operation by suction pump. The quantity of treated water was 15 l/day. Hydraulic retention time (HRT) of the system was 2.67 days.

(2) Fermentation Wastewater

The wastewater from a fermentation plant concentrated about 10 fold of the original state was used in this study. It was stored at 4℃ until usage. The compositions of the wastewater are summarized in **Table 1**. As shown in **Table 1**, TOC, COD_{Cr}, sulfate and total nitrogen concentrations are very high, and ammonia nitrogen is about 40% of total nitrogen. BOD_5/COD_{Cr} is about 0.67. This indicates that the organic matter in fermentation wastewater is relatively difficult to be degraded. Before being fed to the reactor, the wastewater was diluted with tap water to a desired TOC concentration.

(3) Analytical Method

Total organic carbon (TOC) concentration in liquid samples was determined by a Shimadzu model TOC-5000 analyzer. NO_2-N and NO_3-N concentrations were determined by ionic chromatography (UV-8000, Tosoh Co., Ltd.). T-N was determined by a T-N analyzer (GCT-16N, Sumitomo Chemical Co., Ltd. & GC-8APT, Shimadzu Co., Ltd.). Chemical oxygen demand (COD_{Cr}), NH_4-N, mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were determined according to Standard Methods[18]. DO was measured on-line using series 5700 oxygen probe connected to dissolved oxygen transmitter.

(4) Oxygen Utilization Rate (OUR)

The sample from the reactor was mixed with tap water to a concentration of suspended solids of about 2 g/l. A BOD bottle (300 ml) was filled completely with sample and was placed on the magnetic stirrer. A galvanic oxygen electrode was inserted and the top of the container was sealed with plastic film to prevent oxygen transfer from the atmosphere. Nitrification was inhibited by addition of 20 mg/l of allythiourea (ATU). Temperature was controlled at 30 ± 1℃. DO was recorded with a DO analyzer as a function of time for 30 minutes or until DO reached 0 mg/l. The specific OUR (mgO_2/gMLVSS/day) was calculated using the linear part of oxygen utilizing curve and dividing with the MLVSS concentration of the sample.

(5) INT-Dehydrogenase Activity (INT-DHA)

Besides OUR test, INT-dehydrogenase activity method was applied for determining the physiological activity of microorganisms in activated sludge. The basic technique involves the reduction of 2-(p-iodo-phenyl)-3-(p-nitrophenyl)-5-phenyl tetrazolium chloride (INT) to INT-formazan by active bacterial electron transport systems. INT solution (1.0 mM) was prepared using deionized, filter-sterilized water. The samples from the reactor were mixed with BOD_5 water to a concentration of suspended solids about 2.0 g/l. The BOD_5 water was prepared by distilled water, and contained the following basal nutrients (mg/l): K_2HPO_4, 21.75; KH_2PO_4, 8.5; $Na_2HPO_4 \cdot 12H_2O$, 44.6; NH_4Cl, 1.7; $MgSO_4 \cdot 7H_2O$, 22.5; $CaCl_2$, 27.5 and $FeCl_2 \cdot 6H_2O$, 0.25. Triplicate, 4 ml samples were amended with 1.0 ml of INT solution, incubated in the dark while mixing it intermittently at room temperature (20 ± 2℃) for 20 minutes. The reaction was terminated by adding 0.5 ml of 37% formalin. Prior to extraction, the treated samples were centrifuged at 2150G for 5 minutes and excess water removed. Pellets were extracted with 10 ml ethanol (99.5%) for 30 minutes in the dark at temperature 20 ± 2℃, after that the extracts were centrifuged and optical density of the supernatants was determined at 484 nm. INT-dehydrogenase activity was calculated in equivalent oxygen unit according to Logue *et al.*[19]

Table 2 Operational conditions of the lab-scale experiment.

Run No.	Run period (day)	TOC conc.(inf.) (mg/l)	TOC loading (kgTOC/m³/d)	DO conc. (mg/l)
1	24	850	0.319	2.0-3.5
2	18	1000	0.475	2.0-3.5
3	25	1250	0.469	2.0-3.5
4	17	1500	0.563	1.5-2.5
5	46	1850	0.694	1.0-2.0

(6) Scanning Electron Microscopic and Microscopic Observation

The samples (4-6 ml) of activated sludge from the reactor for scanning electron microscopy (SEM) were fixed in 0.1M phosphate buffer (pH=7.0) containing 2.5% glutaraldehyde for twenty four hours, and dehydrated with a graded series (50%, 70%, 80%, 90%, 95%, 99.5%) of ethanol solutions at intervals of at least 30 minutes. Then ethanol was replaced with a 2-methyl-2-propanol solution. The samples were subsequently dried by JFD-300 freeze dryer (JEOL Co., Japan) overnight, and then sputter-coated with platinum. SEM microphotographs were taken with a Hitachi S-2300 scanning electron microscope. Microscopic photographs of activated sludge were taken with a Olympus SZ-PT stereomicroscope (Olympus Co., Japan).

3. RESULTS OF EXPERIMENT

The experiment was divided into five runs, in each run the steady-state condition was achieved, i.e. the steady removals of TOC and NH_4-N were obtained and roughly steady MLSS, MLVSS concentrations in the reactor were observed. No sludge was wasted from the reactor except sampling throughout the experiment. 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 was between 400-800 days when sampling was considered.

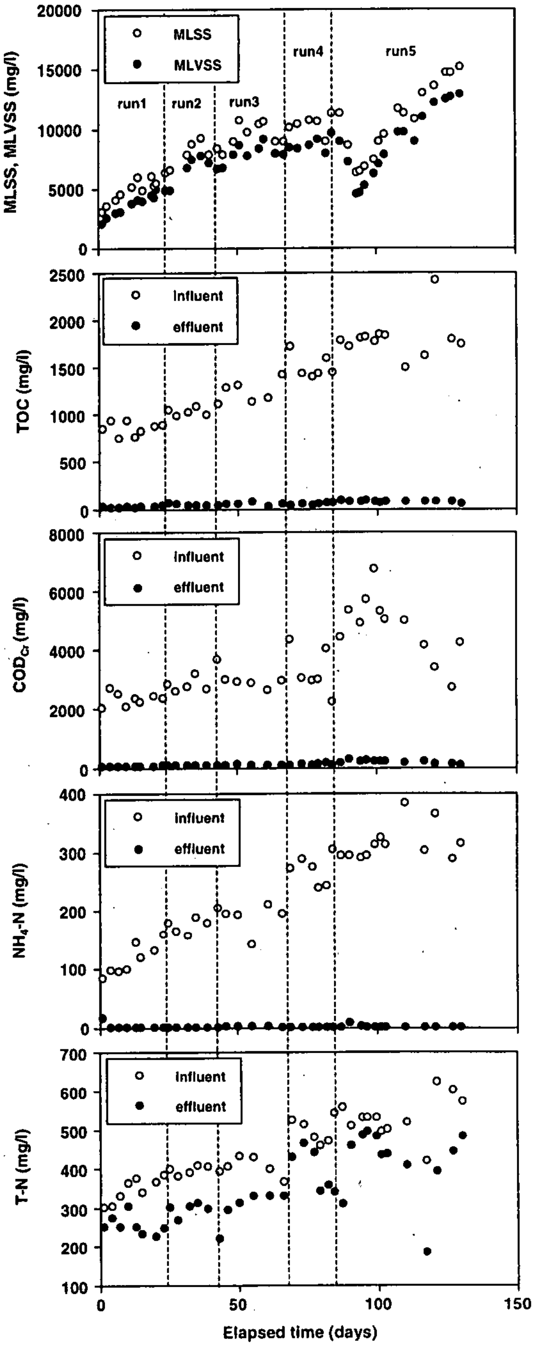

Fig.2 Variations of overall performances.

(1) Acclimatization of Activated Sludge

The concentrated activated sludge taken from the municipal wastewater treatment plant in Ube city, Yamaguchi, Japan was put in the reactor and used as seed for the lab-scale experiment. The experiment was carried out with successive additions of fermentation wastewater with gradually increasing influent TOC concentration until 500 mg/l. Finally, the biomass acclimatization was achieved when steady effluent quality was obtained at a steady-state condition after 20 days of operation.

(2) Continuous Aeration Operation

The operational conditions of the experiment at

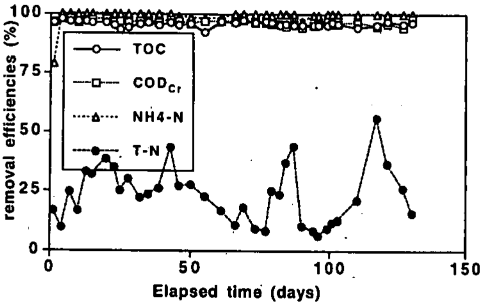

Fig.3 Time course of TOC, COD_{Cr}, NH_4-N and T-N removal efficiencies.

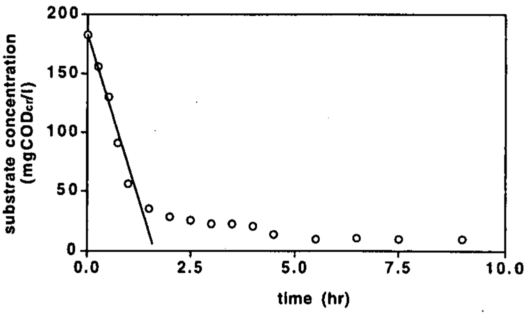

Fig.4 Substrate concentrations versus time for the soluble fraction.

Table 3 The effluent concentrations in each run.

Run No.	TOC (mg/l)	COD_{Cr} (mg/l)	NH_4-N (mg/l)
1	22-40	54-94	0.19-0.31
2	40-68	93-99	0.24-0.38
3	36-85	91-125	0.29-3.41
4	45-72	112-179	0.33-1.26
5	62-88	103-241	0.26-9.75

different runs are summarized in **Table 2**.

Within 130 days of operation, continuous aeration was supplied to the system. TOC loading increased from 0.32 kgTOC/m^3/d to 0.70 kgTOC/m^3/d. MLSS concentration in the reactor increased from 3.10 g/l to 15.2 g/l. The variations of suspended solids concentrations in the reactor during various experimental stages are shown in **Fig.2**. At the beginning of the experiment, the solids concentration built up very slowly. In run 1, it needed about 12 days to reach steady-state condition. During run 2 and 3, they needed about 10 days and one week, respectively. Apparently, it was due to not so high TOC loading at the beginning of the experiment. On the 89th day in run 5, MLSS concentration accidentally decreased due to the loss of activated sludge by excessive foaming in the reactor. On the 93rd day, it decreased to 6.4 g/l, and then it increased gradually to 11.7 g/l until the 108th day.

The effluent quality remained good throughout the experiment. No suspended solids were detected in the effluent. Presumably, the UF membrane and the gel formed on the membrane surface were responsible for this advantage.

Variations of overall performances during the operation period are also shown in **Fig.2**. The removal efficiencies of TOC, COD_{Cr}, NH_4-N, T-N are shown in **Fig.3**. TOC, COD_{Cr}, NH_4-N, T-N removals were observed between 92-98%, 94-98%, 98-100%, 10-45%, respectively. In each run, high organic carbon removal was obtained and nitrification of ammonia nitrogen was successfully achieved. The effluent concentrations of TOC, COD_{Cr} and NH_4-N in each run are shown in **Table 3**. In all cases, T-N removal was lower than 45%. NO_3-N concentration was high in the effluent. Denitrification was inhibited by the high DO concentration in the reactor.

(3) Biodegradability of Soluble Organic Matter of the Fermentation Wastewater

For determining whether the treatability of refractory fermentation wastewater was improved by highly concentrated activated sludge, the ability of activated sludge for biodegradation of soluble organic matter of fermentation wastewater was assessed here. The soluble fraction of the sample was obtained by microfiltration of the sample using filter having pore size of 0.45 μm.

Batch culture test was used in this study to measure the biodegradability of the fermentation wastewater. The activated sludge from reactor was washed and diluted with BOD_5 water to get MLSS concentration of 3-4 g/l with a final volume of 300 ml. Then fermentation wastewater was added into the solution to an initial COD_{Cr} concentration of about 200 mg/l. The mixed liquor was kept in suspension by aeration through diffusers, which also provided the sludge with oxygen in a concentration of 4-6 mg/l. Temperature was kept at 30℃. Samples of 10 ml of mixed liquor were withdrawn with intervals of 15-120 minutes for 8-10 hours. The samples were immediately filtered and analyzed for COD_{Cr}. An example of the results obtained during the biodegradation of soluble fraction of the fermentation wastewater by activated sludge in batch culture test is shown in **Fig.4**.

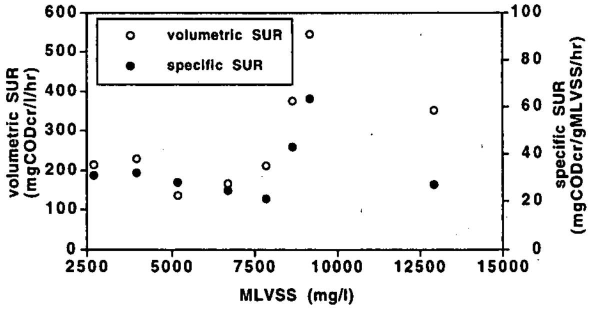

Fig.5 Substrate utilization rate for the soluble fraction with the MLVSS concentrations.

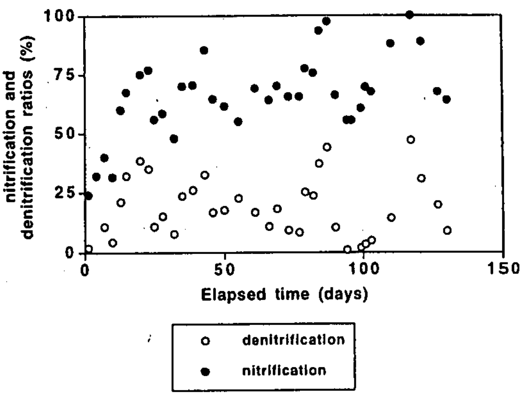

Fig.6 Time course of the ratios of nitrification and denitrification (based on total nitrogen in fermentation wastewater).

The rapid consumption of biodegradable organic matter lasted about 90 minutes, and the soluble COD_{Cr} concentration decreased from 183 mg/l to 35.8 mg/l (see **Fig.4**). Beyond this time, the soluble organic substrate concentration decreased slowly. About 80% of the soluble organic matter of fermentation wastewater was degraded quite well despite a low BOD_5/COD_{Cr} ratio (0.67). This indicated that sludge acclimatization was in good condition, and the ability of sludge for degrading organic matter in fermentation wastewater was improved. The specific substrate utilization rate (SUR) of biodegradable COD_{Cr} was calculated from the linear part of **Fig.4** as 30.9 $mgCOD_{Cr}$/gMLVSS/hr, and the volumetric SUR as 210 $mgCOD_{Cr}$/l/hr.

A series of batch culture tests were conducted and the results of the specific and volumetric SUR for biodegradable COD_{Cr} versus MLVSS concentration are shown in **Fig.5**. From the results, it was observed that the specific SUR did not decrease with the increase of MLVSS concentration. It varied between 20-65 $mgCOD_{Cr}$/gMLVSS/hr. When MLVSS concentration was between 8-10 g/l, the specific SUR increased 1-2 times compared with others, which indicated that the sludge ability for degrading organic matter was quite well during this range. The volumetric SUR varied between 140-550 $mgCOD_{Cr}$/l/hr. Although specific SUR decreased significantly at 12.9 gMLVSS/l, the volumetric SUR could keep still higher level because of high MLVSS concentration retained in the reactor.

(4) Nitrification and Denitrification

For examining the actual nitrification and denitrification ratios of fermentation wastewater by highly concentrated activated sludge, nitrification and denitrification ratios were calculated according to nitrogen balance and the results are shown in **Fig.6**. The experiment was operated with no sludge wastage from the reactor except samples. Because the volume of sample (50-100 ml/day) from the reactor was insignificant as compared with the volume of the reactor, it was not considered in calculation of nitrogen balance. With the increase of MLSS concentration in the reactor, part of nitrogen was synthesized into the biomass. Suwa *et al.*[20] reported that the total nitrogen content of sludge was between 8.74-10.17%, at the average of 9.65% when treating synthetic wastewater by activated sludge process with cross-flow filtration. This value was used for estimation of nitrogen balance calculation. From the beginning to the 14th day, the nitrification increased from 24% to 70% and then it varied between 60% and 100%, with an average value of 70%. The retention of activated sludge by UF membrane and the high DO concentration were responsible for high nitrification. Denitrification was around 20% throughout the experiment.

To investigate the nitrification and denitrification abilities of activated sludge, a series of batch culture tests were conducted to confirm the maximum specific nitrification rate (SNR) and the maximum specific denitrification rate (SDNR) of activated sludge in the reactor. To determine the maximum SNR, the sample of activated sludge from the reactor was washed and diluted by BOD_5 water to get 3-4 g/l of suspended solids concentration. The mixed liquor was kept in suspension by aeration through diffuser, which also provided the sludge with oxygen in a concentration of 4-6 mg/l. Fermentation wastewater, as ammonia nitrogen source, was added to achieve an initial concentration of 25 mgN/l of the mixed liquor.

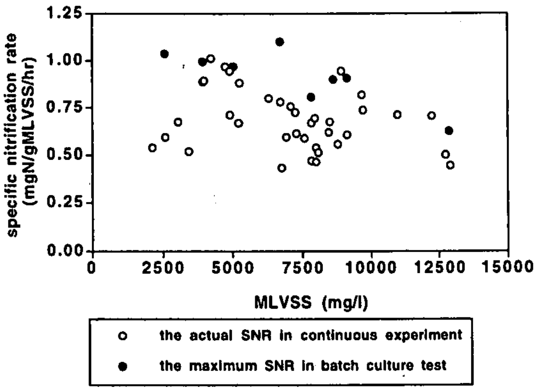

Fig.7 Specific nitrification rates with MLVSS concentration.

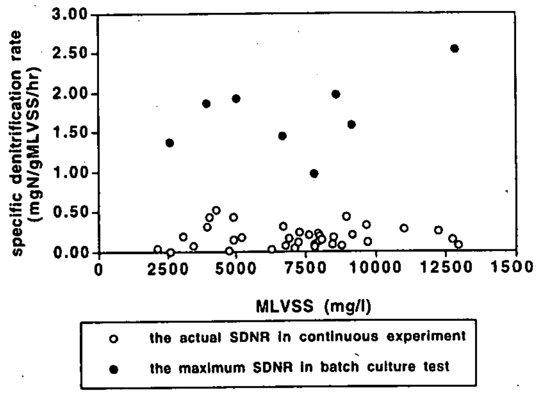

Fig.8 Specific denitrification with MLVSS concentration.

Temperature was controlled at 30℃. Samples of 10 ml of mixed liquor were withdrawn with intervals of 15-30 minutes for 4-5 hours and analyzed for nitrate plus nitrite. The maximum SNR was calculated from the slope of the resulting nitrate plus nitrite production curve.

The maximum SDNR was determined by the use of completely mixed, air closed glass bottle. The sample of activated sludge from the reactor was washed and diluted with BOD_5 water to get 3-4 g/l of suspended solids concentration. CH_3COONa and KNO_3 as carbon and nitrogen sources with the C:N=5:1 were added to achieve an initial concentration of 25 mgN/l of mixed liquor. Temperature was controlled at 30℃. Samples of 10 ml of mixed liquor were withdrawn with intervals of 15-30 minutes for 4-5 hours. Samples were withdrawn under nitrogen gas addition in order to avoid oxygen intrusion into the bottle. The samples were analyzed for nitrate plus nitrite. The maximum SDNR was calculated from the slope of the resulting nitrate plus nitrite utilization curve. The actual SNR and SDNR in continuous experiment were also calculated according to nitrogen balance. The comparisons of two results are shown in **Fig.7** and **Fig.8**.

It is of interest to note that with the increase of MLVSS concentration, the maximum SNR slightly decreased, whereas, the maximum SDNR slightly increased in batch culture tests. The actual SNR had the same trend with the maximum SNR in batch culture test. Because MLVSS concentration gradually increased with the increase of T-N loading from 0.13 to 0.20 kgN/m^3/day, the actual SNR was about 50% of the maximum SNR in batch culture test due to lower T-N loading at the beginning. The ability of nitrification of sludge did not function completely. At the low MLVSS concentration in run 5, T-N loading did not decrease and remained high at 0.20 kgN/m^3/day and the actual SNR was near the maximum SNR under batch culture test. At high MLVSS concentration (over 10 g/l), the actual SNR was close to the maximum SNR. On the contrary, the actual SDNR was remarkably lower (lower than 0.5 mgN/gMLVSS/hr) in this study.

The phenomenon above was considered to be caused by the following reasons. With the increase of MLVSS concentration, the viscosity of liquor in the reactor increased rapidly. Bailey *et al.*[13] reported that at 10.7 g/l solids concentration, the viscosity was nearly double that of water. At the same time, the oxygen transfer coefficient decreased because MLVSS concentration increased, as Muller *et al.*[12] demonstrated that this coefficient as a fraction of that tap water was 0.98 at 3 gMLSS/l and decreased to 0.5 at 16 gMLSS/l. Although pure oxygen was used during high MLVSS concentration, oxygen transfer efficiency decreased with the increase of MLVSS concentration and nitrifier in the reactor was in difficulty to acquire enough oxygen to maintain the activity. Therefore, the maximum SNR slightly decreased with the increase of MLVSS concentration, while in opposite, the maximum SDNR was enhanced under high MLVSS concentration. However, the actual SDNR was much lower in the continuous aeration experiment and not found remarkable change with the increase of MLVSS concentration. Because the experiment was operated in continuous aeration condition, denitrification was inhibited and resulted in low actual SDNR and low denitrification ratios with the average of 20% throughout the experiment.

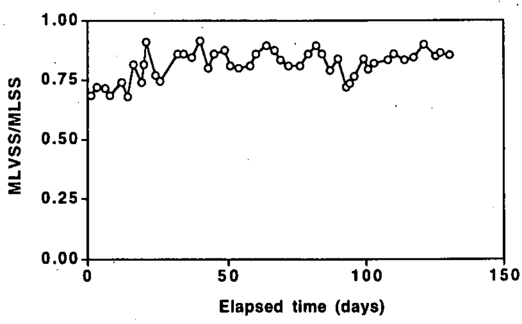

Fig.9 Time course of MLVSS/MLSS.

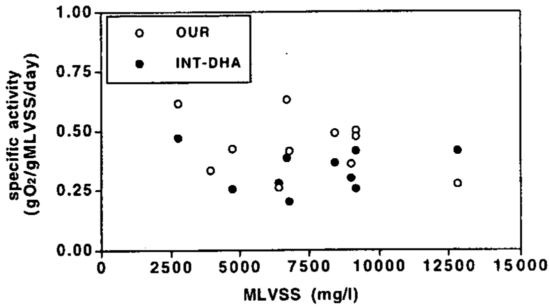

Fig.10 Specific activities of sludge with MLVSS concentration.

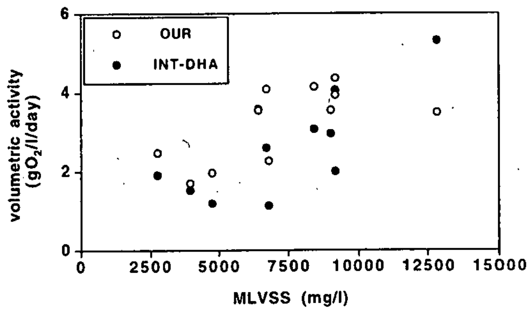

Fig.11 Volumetric activities of sludge with MLVSS concentration.

With the increase of MLVSS concentration in the reactor, different patterns were observed between the specific SUR and SDNR. When MLVSS concentration exceeded 10 g/l, the specific SUR in batch culture test decreased. On the other hand, the maximum SDNR in batch culture test still increased. This indicated high potentiality of denitrification under high MLVSS concentration. However, the specific nitrification rate and specific denitrification rate in batch culture tests were about 0.62 mgN/gMLVSS/hr and 2.5 mgN/gMLVSS/hr respectively at 12.9 gMLVSS/l. It also indicated that nitrification would be the limiting stage if anoxic condition was provided in this process.

(5) Characterization of Activated Sludge

In this study, MLSS and MLVSS concentrations increased from 3.1 g/l to 11.4 g/l, 2.1 g/l to 9.7 g/l, respectively, during the first 88 days. Then they decreased due to the loss of activated sludge from the reactor. After that, MLSS, MLVSS concentrations increased gradually from 6.4 g/l to 15.2 g/l, 4.6 g/l to 12.9 g/l, respectively, until the end of experiment. MLVSS/MLSS with the elapsed time is shown in **Fig.9**. After one month of the experiment, MLVSS/MLSS increased from 0.68 to 0.80 and then varied between 0.8-0.9 except for the period of sludge loss, in which MLVSS/MLSS decreased to 0.7. High MLVSS/MLSS ratio obtained in this study indicated that nonvolatile compounds hardly accumulated in the reactor during the whole experiment. This was probably caused by the lower inorganic materials contained in fermentation wastewater used in this study with 14.5% of ash. Hence, inorganic compounds did not disrupt treatment and membrane performances when sludge was completely retained in the experiment for fermentation wastewater treatment.

To maintain high activity of sludge in the reactor is most important for wastewater treatment. Oxygen utilization rate (OUR) and INT-dehydrogenase activity (INT-DHA) were used to assess the activities of highly concentrated activated sludge throughout the experiment because of their simplicity and exactness. Plots of MLVSS concentration with specific activities and volumetric activities of sludge are shown in **Fig.10** and **Fig.11**, respectively. The specific OUR and INT-DHA of sludge slightly decreased with the increase of MLVSS concentration. However, the volumetric activities of both OUR and INT-DHA increased greatly. Although no sludge was wasted from the reactor except sampling throughout the experiment, inhibitors or toxic materials did not accumulate in the reactor. Fewer heavy metal ions or toxic materials contained in fermentation wastewater might be responsible for the results. On the other hand, the high removal efficiencies of TOC and NH_4-N also indicated that the activity of sludge remained quite well throughout the experiment. Considering the above results, it can be inferred that the fermentation wastewater is suitable for treatment by highly concentrated activated sludge membrane bioreactor process.

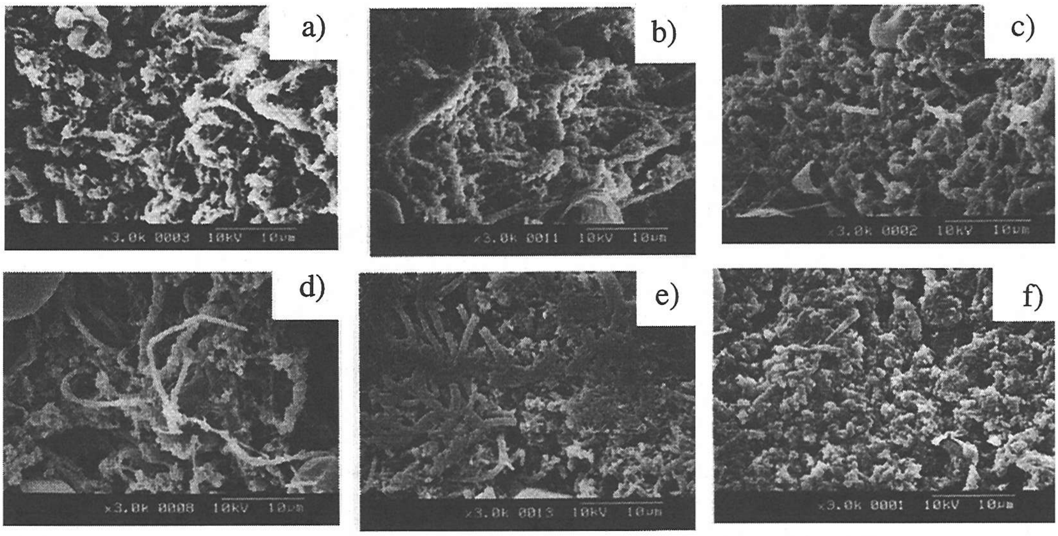

Fig.12 SEM microscopic photographs of sludges.
a): the 2nd day, MLSS=3500 mg/l b): the 60th day, MLSS=10700 mg/l c): the 87th day, MLSS=11400 mg/l
d): the 93rd day, MLSS=6400 mg/l e): the 117th day, MLSS=13000 mg/l f): the 130th day, MLSS=15200 mg/l

(6) SEM Observation of Activated Sludge

The activated sludges in the reactor were observed throughout the experiment based on SEM observation. The photographs are shown in **Fig.12**. At the beginning, the flocs of activated sludge seed were broken by recirculation of sludge and rotation of disk type membrane. There were many fragments of flocs in the reactor. When the MLSS concentration increased to 10.7 g/l on the 60th day, the filamentous bacteria were predominant and the fragments of flocs were degraded completely. On the 87th day with the MLSS concentration of 11.4 g/l, the coccus-like or rod-type bacteria gradually appeared. After that MLSS concentration in the reactor decreased due to the excessive foaming and decreased to 6.4 g/l on the 93rd day. During this period, filamentous bacteria occurred again. And then, with the gradual increase of MLSS concentration, filamentous bacteria gradually disappeared. On the 130th day, the coccus-like or rod-type bacteria were predominant and the filamentous bacteria disappeared completely at the 15.2 gMLSS/l.

4. DISCUSSION

High biomass concentration can improve the reaction rate and high MLSS concentration in the reactor is desirable for high strength wastewater treatment. Combining UF membrane as a separator is a suitable process that can maintain high MLSS concentration in the reactor. During the 130 days experiment, the MLSS concentration increased from 3.1 g/l to 15.2 g/l in this study.

Another advantage is the lower sludge production resulting from the lower sludge loading. During 130 days experiment, no sludge was wasted except sampling. The sludge loadings versus the time curve is shown in **Fig.13**. The average sludge loading was 0.05 gTOC/gMLSS/day at every steady-state conditions.

In this study, T-N loading gradually increased from 0.13 kgN/m^3/d in run 1 to 0.20 kgN/m^3/d in run 5. Almost all NH_4-N was nitrified to nitrate. NO_3-N concentration in effluent was between 150-500 mg/l and no NO_2-N was detected. About 20% denitrification occurred only. Denitrification was inhibited by the high DO concentration in the reactor. Moreover, during the period of MLSS concentration increase, parts of T-N were synthesized by biomass and this decreased denitrification. The average specific denitrification rate of 1.7 mgN/gMLVSS/hr in batch culture tests throughout the experiment demonstrated that the enzyme synthesis of denitrifier for denitrification reaction could be stimulated if the anoxic condition was applied to the system.

During the decrease of MLSS concentration in run

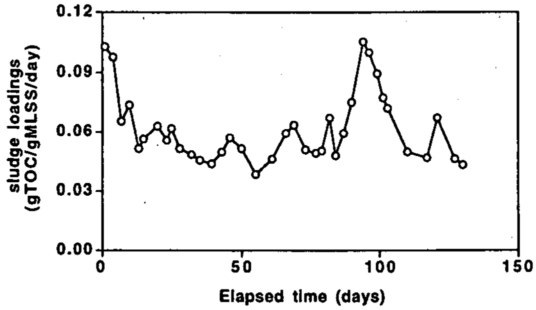

Fig.13 Time course of activated sludge loadings.

5 on the 89th day, the treated water constantly showed a good quality in spite of no change of TOC load except that T-N removal decreased to 10%. Specific activities of OUR and INT-DHA had no significant change. However, the volumetric activities of both decreased due to the decrease of MLVSS concentration.

In a conventional activated sludge process, the biomass in the reactor was composed in firm and compact flocs with the size ranging from 100 to 1000μm. Generally, the conventional reactor contains *amoebae*, *pseudomonas*, filamentous organisms, *flagellates*, *ciliates* and sometimes *rotifers*, *nematodes* and mosquito larvae in which a food linkage is established. On the contrary, the reactor coupled with UF membrane did not find larger predators. It contained filament type bacteria and coccus-like or rod-type bacteria (1-5 μm) only. This phenomenon was also observed by other researchers[12),13)]. During the decrease of MLSS concentration on the 89th day, the filamentous bacteria occurred again. Therefore, two factors affected the sludge structure: one was the circulation of sludge and rotation of disk type UF membrane, and the other was the MLSS concentration in reactor. Due to the circulation of sludge and rotation of disk type UF membrane, large flocs could not form and sludge settling was difficult. At the MLSS concentration lower than 11 g/l, the filamentous bacteria were predominant. At the MLSS concentration between 11-13 g/l, the filamentous bacteria and the coccus-like or rod-type bacteria occurred simultaneously. At the MLSS concentration higher than 13 g/l, the coccus-like or rod-type bacteria were prevailing in the reactor. However, the removal of organic materials was not adversely affected by the absence of larger microorganisms. The coccus-like or rod-type bacteria in the reactor performed very well for removal of organic materials and this was also demonstrated by other researchers[12),13)].

5. CONCLUSIONS

The following conclusions can be drawn from the results of this study:

1. The study demonstrated that highly concentrated activated sludge process coupled with rotary disk type UF membrane can be used for the treatment of high strength fermentation wastewater. The maximum MLSS and MLVSS concentrations obtained in this study were 15.2 g/l and 13.0 g/l, respectively.
2. Biodegradation of the soluble organic matter in fermentation wastewater was improved by this process. The specific substrate utilization rates (SUR) varied between 20-65 mgCOD$_{Cr}$/gMLVSS/hr, and the maximum specific SUR was obtained under the MLVSS concentration between 8-10 g/l.
3. The maximum specific nitrification rate (SNR) in batch culture test slightly decreased and the maximum specific denitrification rate (SDNR) in batch culture test slightly increased with the increase of MLVSS concentration in the reactor. The actual SNR calculated in continuous aeration experiment had the same trend with the maximum SNR in batch culture test, and the actual SDNR was much lower than the maximum. The denitrification was largely inhibited by the high DO concentration in the reactor. However, the enzyme synthesis of denitrifier for denitrification reaction could be stimulated if anoxic condition was applied to the system.
4. Nonvolatile compounds hardly accumulated in the reactor during the whole experiment. The specific activities of sludge slightly decreased with the increase of MLVSS concentration, however, the volumetric activities increased significantly.
5. Two factors were observed to affect the sludge structure, one was the circulation of sludge and rotation of disk type UF membrane, and the other was the MLSS concentration in the reactor. At the MLSS concentration lower than 11 g/l, the filamentous bacteria were predominant, and coccus-like or rod-type bacteria were prevailing at MLSS concentration higher than 13 g/l.

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回転平膜を用いた膜分離高濃度活性汚泥法における汚泥の特性に関する研究

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により高濃度発酵廃液の連続処理運転を行い，高濃度活性汚泥の特性に関して検討を加えた．実験結果より有機物及びアンモニア性窒素に関しては高い除去能が得られた．また，反応槽内で高DO濃度が維持されたため，連続運転結果から得られた比硝化速度と回分実験から得られた最大比硝化速度はほぼ同じ傾向を示したが，連続運転結果から得られた比脱窒速度は回分実験から得られた最大比脱窒速度よりもかなり低かった．反応槽内の汚泥濃度の増加とともに、単位汚泥当たりの比酸素消費速度と脱水素酵素活性はわずかながら減少したが，反応槽全体の各活性は飛躍的に増加した。低汚泥濃度域では糸状菌が優占種となり，高汚泥濃度域では球菌及び桿菌が優占種となり，菌相に変化が認められた．