23. New Trends Of Advanced Wastewater Treatment

(biotechnology / membranes)

Presenter

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NEW TRENDS OF ADVANCED WASTEWATER TREATMENT
(biotechnology /membranes)

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ABSTRACT

The public sewerage system in Japan has developed rapidly in the past decade in terms of downsizing and advanced wastewater treatment. Many of the small-scale treatment plants use the oxidation ditch process owing to the easy maintenance of the facilities. The main methods of advanced treatment are the rapid filtration process and the biological nitrogen removal process with the addition of coagulant. This paper describes the submerged membrane bioreactor and the step feed multistage denitrification-nitrification process, both of which have attracted attention as new treatment technologies. Regarding the submerged membrane bioreactor, pilot-plant experiments were conducted for varying sewage influent flow. The experiments proved that up to three-fold variations in average daily flow can be normalized in the process by changing flux and water level of the bioreactor . As for the step feed multistage denitrification-nitrification process, the study was conducted using full-scale plant which has a combination of three-stage anoxic-oxic reactors over ten months. The study revealed that the nitrogen removal efficiency reached 89% on average.

KEYWORDS

Advanced Wastewater Treatment, Submerged Membrane Bioreactor, Organic and Nutrient Removal, Anoxic-Oxic Reactor, Step Feed, Activated Sludge

INTRODUCTION

Japan introduced the activated sludge process in 1930 as sewage treatment process. Thereafter, sewerage construction was conducted mainly on large cities. Large investment for sewerage construction, however, began in the late 1970s when the pollution of public water bodies caused by industrial wastewater and other contaminant sources became a serious social problem and when water quality conservation at public water bodies was added to the objectives of sewerage service. The percentage of sewered population at the end of fiscal year (FY) 1970 was only 16%. The percentage, however, increased to 30% at the end of FY 1980, 44% at the end of FY 1990, and 62% at the end of FY 2000 1), showing steady development in the last thirty years. The number of public sewage treatment plants (PSTPs) constructed by the end of FY 2000 stood at about 1,500. Advanced treatment of sewage is performed to prevent eutrophication in closed sea areas such as Tokyo Bay and at lakes and marshes, and also to conserve the quality of water supply sources. The percentage of sewered population served by advanced treatment stood at 8% at the end of FY 2000.

PUBLIC SEWAGE TREATMENT PLANT IN JAPAN

Figure 1 shows the number of PSTPs in operation by type of treatment process in each fiscal year. The total number of PSTPs in FY 1980 was 457, giving a sewered population of 30%. In that year, the conventional activated sludge process accounted for 65% of all processes. Since the conventional activated sludge process involves difficult maintenance, even though the process achieves high treatment efficiency per unit area, the districts serving sewerage before 1980 were rather limited to large cities where sewerage engineers were available.

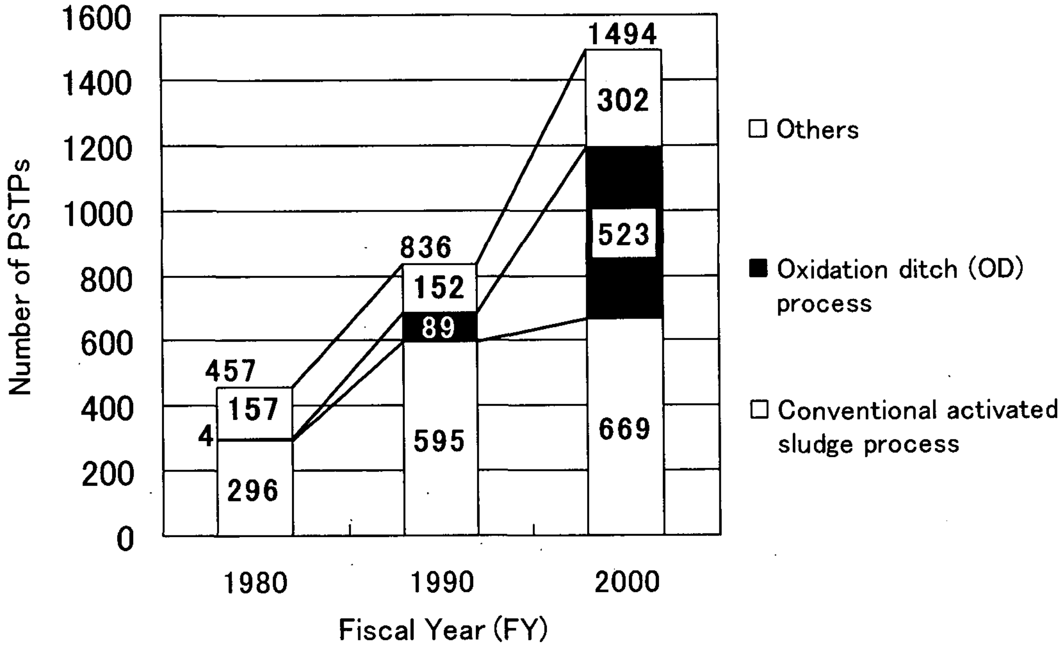
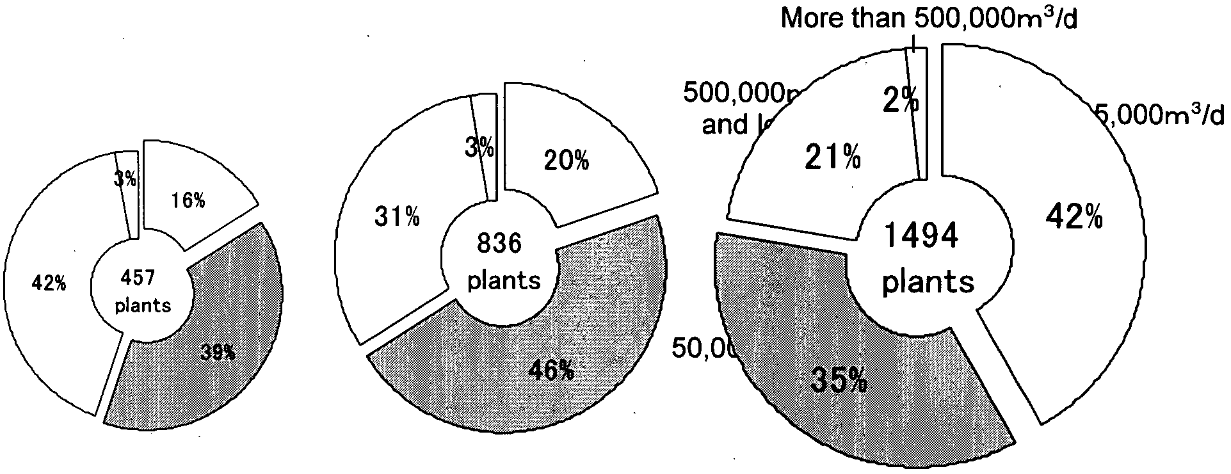


Figure 1. Treatment methods of PSTPs

Ten years later, in FY 1990, the number of treatment plants reached 836, an 83% increase, and the percentage of sewered population increased to 44%. The number of plants which adopted the conventional activated sludge process increased to 595, suggesting that sewerage construction was focused on urban districts. Also the oxidation ditch (OD) process, and involves easy maintenance and is suitable for small-scale plants, was constructed at 89 plants. In FY 2000, the total number of treatment plants increased to 1,494, and the percentage of sewered population increased to 62%. As for the sewage treatment processes in FY 2000, the conventional activated sludge process accounted for 45%, the OD process for 35%, and others 20%. Between 1991 to 2000, the OD process showed a significant increase, which suggests that the sewage treatment system proliferated rapidly in small and medium-sized towns and villages.



FY 1980 FY 1990 FY 2000

Figure 2. Design capacity of PSTPs

Figure 2 shows the number of PSTPs in FY 1980, FY 1990, and FY 2000, by design capacity. The number of plants having capacities of less than 5,000 m³/day was 73, 164, and 627 in FY 1980, FY 1990, and FY 2000, respectively. The number of plants having capacities of 5,000 m³/day up to 50,000 m³/day was 180, 388, and 531, respectively. Thus, the total number of plants having capacities of up to 50,000 m³/day was 253 (accounting for 55% of the total), 552 (66%), and 1,158 (77%), showing that the construction of small-scale treatment plants rapidly increased during the twenty years. As shown, significant features of Japanese sewage treatment system during the decade are the adoption of the OD process and the rapid downsizing of the treatment plants.

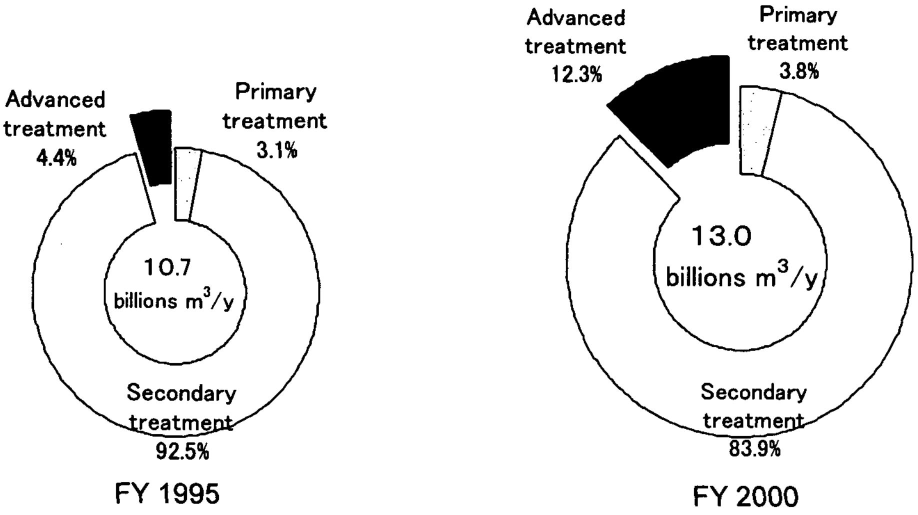


Figure 3. Annual treated wastewater by PSTPs

There are several types of advanced treatment process, such as the rapid filtration process which removes mainly organic matter and suspended solids, the biological nitrogen removal process with adding inorganic coagulant to remove nitrogen and phosphorus, and a method combining these processes. Figure 3 shows the annual treatment volumes of primary effluent, secondary effluent, and advanced effluent[2]. In FY 1995, 10.7 billion cubic meters of sewage was treated, of which 3.1% was primary effluent, 92.5% secondary effluent, and 4.4% advanced effluent of the total. In FY 2000, 13.0 billion cubic meters of sewage was treated, of which 3.8% was primary effluent, 83.9% secondary effluent, and 12.3% advanced effluent of the total. The number of plants using the advanced treatment process rapidly increased in Japan in these five years, reaching 178 plants in FY 2000. Of these 178 plants, 75 plants adopted the biological nitrogen removal process, including 16 plants which adopted the recycled nitrification-denitrification process, 3 plants the nitrification-denitrification using endogenous respiration process, 9 plants the anaerobic-anoxic oxic process, and 47 plants the anaerobic-oxic activated sludge process. 93 plants introduced the rapid filtration process. Nevertheless, the present rate of advanced treatment process applied in Japan is significantly lower than that of Western countries. Advanced treatment needs to be further promoted around rivers, lakes and bay areas, particularly at areas where water quality must be conserved.

MEMBRANE BIOREACTOR

Membrane bioreactor (MBR) applies membrane separation technology to activated sludge process for wastewater. A distinctive difference between activated sludge process and MBR is that the solid-liquid separation of activated sludge process basically utilizes gravity sedimentation, while MBR conducts solid-liquid separation by membrane in bioreactor. Compared with activated sludge process, MBR has the following advantages.

1) No secondary clarifier is needed.
2) Since the sludge concentration in MBR can be increased, the reactor volume can be reduced, nitrogen removal can be achieved by relatively small facility and no sludge thickener is necessary.
3) Solid-liquid separation is not hindered, such as by bulking.
4) Protozoa and infectious bacteria are likely to be removed.

Yamamoto[3)] reported that sludge retention time (SRT) can be extended so that biologically hard organics can be decomposed by microorganisms. With these advantages, membrane separation technology began to be used in the 1990s for night soil treatment, industrial wastewater treatment, combined septic tanks, and other uses.

Application to PSTP

In the public sewerage field, however, MBR process is still at the stage of extensive experiments using pilot plants. The reasons for delayed application in the field are high cost of membrane, high maintenance cost, and poor advantage of scale merits in commercial facilities. In addition to these drawbacks, the reason specific to public sewerage is namely the response of membrane to fluctuation of sewage influent. Public sewerage faces significant variations in sewage inflow during a day depending on human lifestyles. Furthermore, even separate sewer system may be influenced by storm water inflow. Therefore, it is important to know the degree to which MBR process can adjust to variations in sewage influent. The paper describes the results of pilot experiments on variations in influent.

Figure 4 shows the flow diagram of the pilot plant. To remove nitrogen, activated sludge reactor is divided into oxic tank and anoxic tank. The sludge is recycled from oxic tank to anoxic tank. To remove phosphorus, polyaluminum chloride (PAC) is added to oxic tank.

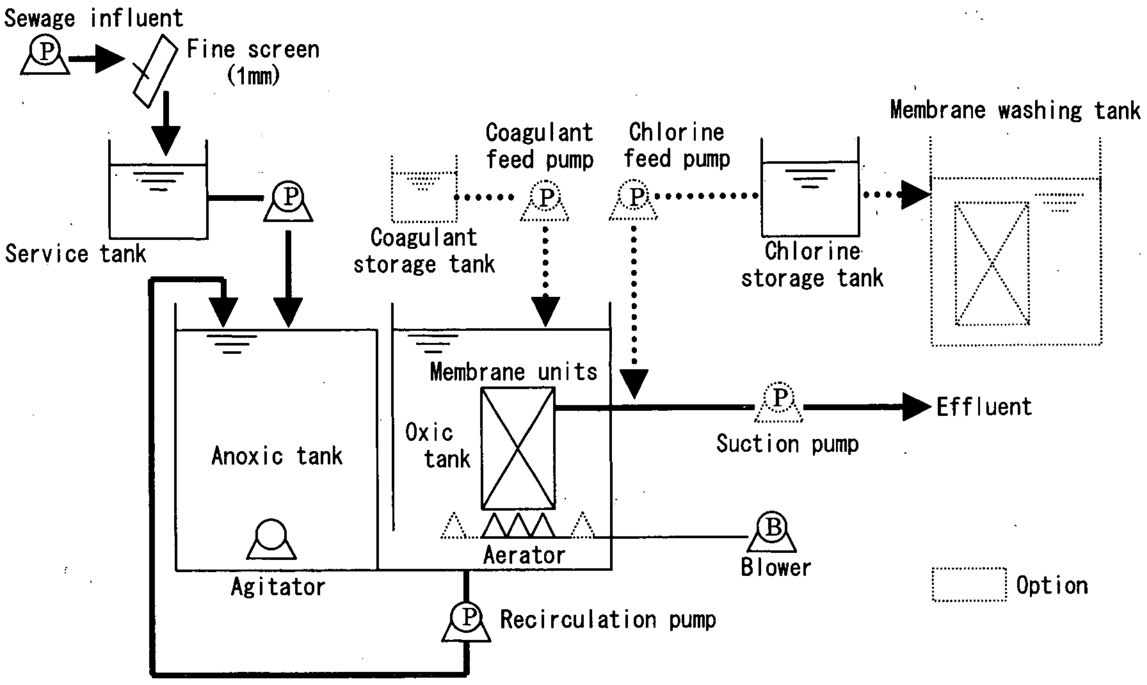


Figure 4. Flow diagram of the pilot plant

Six kinds of membrane were used in the experiment: three kinds of flat film, two kinds of hollow fiber, and one kind of ceramic membrane. The specifications of each membrane are given in Table 1.

Table 1. Membrane Specification

	A			B	C	D
	A−1	A−2	A−3			
Membrane	Flat film		Ceramic	Hollow fiber	Flat film	Hollow fiber
Pore size(μm)	0.4		0.1	0.1	0.4	0.4
Membrane surface area (m^2)	60	80	50.6	92	80	126
Filtration system	Gravity	Pump	Pump	Pump	Pump	Gravity /Pump

The operating conditions of the pilot plant are given below:

Sewage influent: Influent of primary clarifier coming from separate sewer system
Pattern of inflow: 4 patterns (Figure 5)
HRT at anoxic tank: 3 hours
HRT at oxic tank: 3 hours
Air to flow rate: 18 to 30 fold
Membrane flux: 0.4 to 0.8 $m^3/m^2 \cdot d$

Table 2. Water quality of influent sewage

	BOD (mg/l)	COD_{Mn} (mg/l)	TOC (mg/l)	SS (mg/l)	T-N (mg/l)	T-P (mg/l)	Coliform group number (number/ml)
Av.	172	111	103	217	37.8	5.9	3.3E+05
Max.	313	278	197	490	63.3	13.1	7.0E+05
Min.	92	52.5	35.5	72	23.3	2.74	3.0E+04

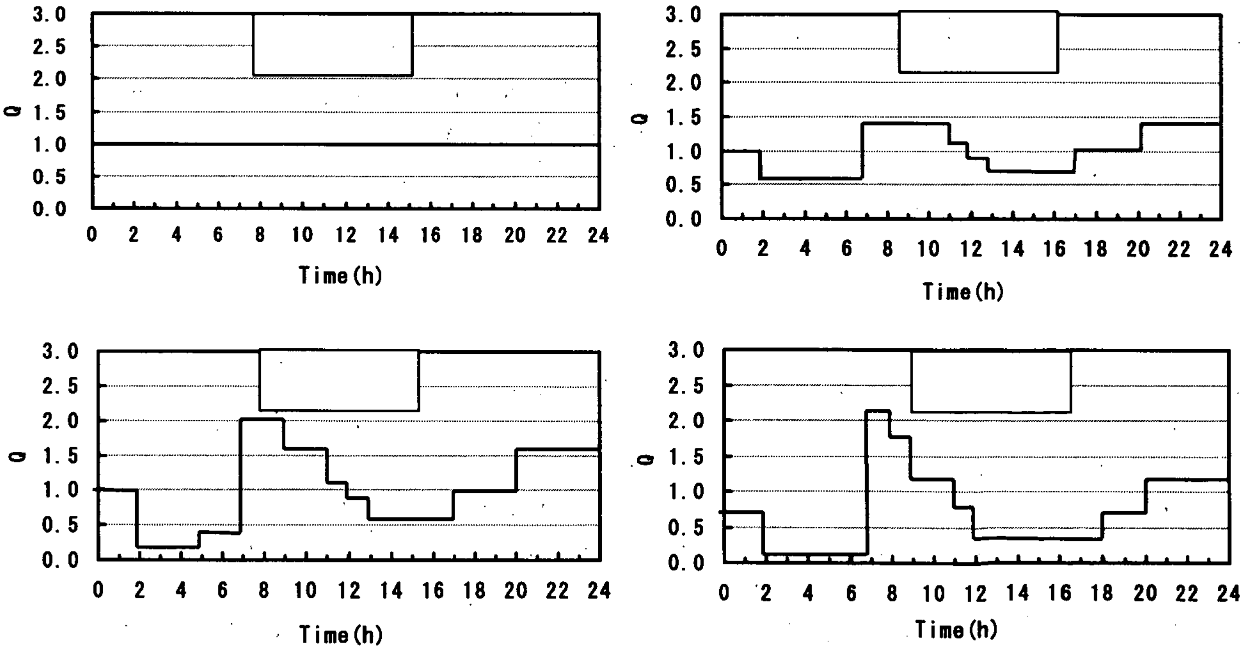


Figure 5. Influent flow diagram of the pilot plant

The inflow pattern RUN 1 fixed sewage influent flow for 24-hour. For RUN 2, sewage influent was set to 1.5 of average daily flow at peak time assuming inflow pattern at large treatment plant. For RUN 3, sewage influent was set to 2 times of average daily flow assuming medium-scale treatment plant. For RUN 4, sewage influent was set to 3 times of average daily flow assuming small-scale treatment plant. Generally, MBR process is considered to operate under the continuous filtration of fixed flow for preventing transmembrane pressure higher. Nevertheless, in the experiment the inflow was varied to study the response of membrane flux and the ease of maintenance.

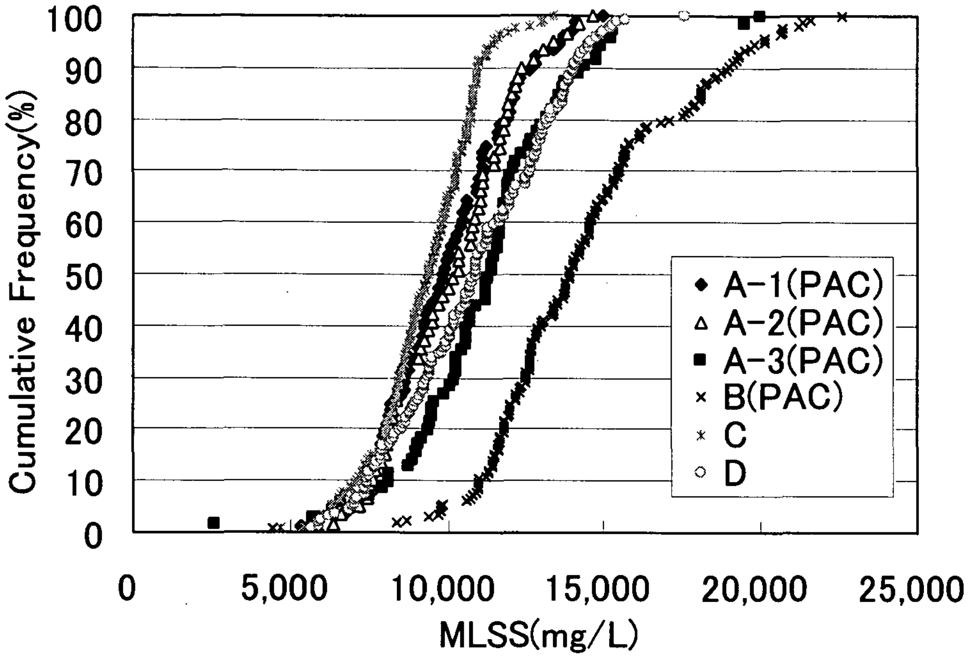


Figure 6. MLSS concentration in the experimental

Figure 6 shows the cumulative frequency of MLSS during the experiment. Data of Figure 6 include four plants (A-1, A-2, A-3, and B) in which PAC was added to remove phosphorus, and two plants (C and D) which were operated without PAC. During the experiment, MLSS concentration was varied from 5,000 mg/l to 20,000 mg/l, though the range was differed in each plant, and the flux expected was attained at all levels of MLSS concentration. However the higher the MLSS concentration is , the higher the viscosity of sludge is. Regarding the influence of high MLSS concentration, there was concern about agitation in the reactor and air diffusion efficiency. As a result, it was confirmed that practical operation should be conducted at MLSS concentration, of around 10,000 mg/l, assuming that SRT needed for nitrification is maintained.

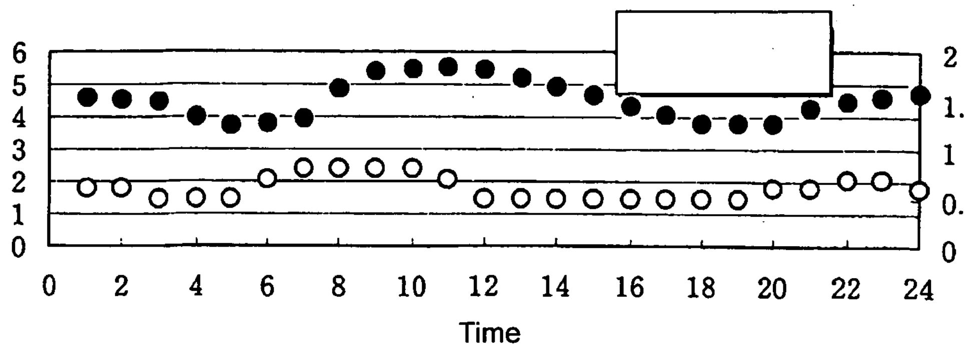


Figure 7. Variation of flux and water level in RUN4 (plant C)

In RUN 4 setting the largest variations of inflow in the experiment, it was confirmed that the variation can be normalized in the process by changing flux and water level of the reactor tank, as shown in Figure 7. Further investigation, however, is needed to confirm stable operation for responding the variation of inflow.

Large variation of flux should also be considered carefully because it causes the increase of transmembrane pressure rapidly and the increase of frequent washing of membrane, though the permissible variation differs with the characteristics of each membrane and with each system. For instance, plant B in RUN 4 was operated by applying flux changes (0.6 to 1.6 $m^3/m^2 \cdot d$) mainly and performed injection washing of sodium hypochlorite once a week. On the other hand, plants C and plant D, which mainly applied water level variation while minimizing flux changes, performed injection washing every two or three months.

The water quality of effluents was stable over the whole experimental period, achieving high removal rate of 99% for BOD, 91 to 93% for COD_{Mn}, and around 94% for TOC. Also for SS and coliform group number, most of the data were below the detection limit, thus obtaining very clean effluent.

Regarding biological nitrogen removal, T-N of effluents was less than 10 mg/l at recirculation rate of nitrified mixed liquor of 300%. For phosphorus removal, the simultaneous coagulation process adding PAC to the oxic tank gave less than 0.5 mg/l of T-P in effluents. For phosphorus, however, a plant stably achieved less than 0.5 mg/l of T-P in effluent even without adding PAC.

For practical application of MBR, the themes remaining to be solved are (i) the performance of membrane filtration during the period of low water temperature, (ii) reducing maintenance cost for washing and aeration power of membrane.

STEP FEED MULTISTAGE DENITRIFICATION-NITRIFICATION PROCESS

Figure 8[4] summarizes the target concentration of nitrogen in the effluent of treatment plants which operate advanced treatment. The target T-N concentration of 10 mg/l for effluent is adopted by many plants. Some of the plants, however, adopt 5 mg/l or lower concentrations in response to strict water quality targets for advanced effluent.

A treatment process that attains high nitrogen removal efficiency at low investment and maintenance cost is therefore required. The step feed multistage denitrification-nitrification process (SMDN process) is one process that satisfies the requirements.

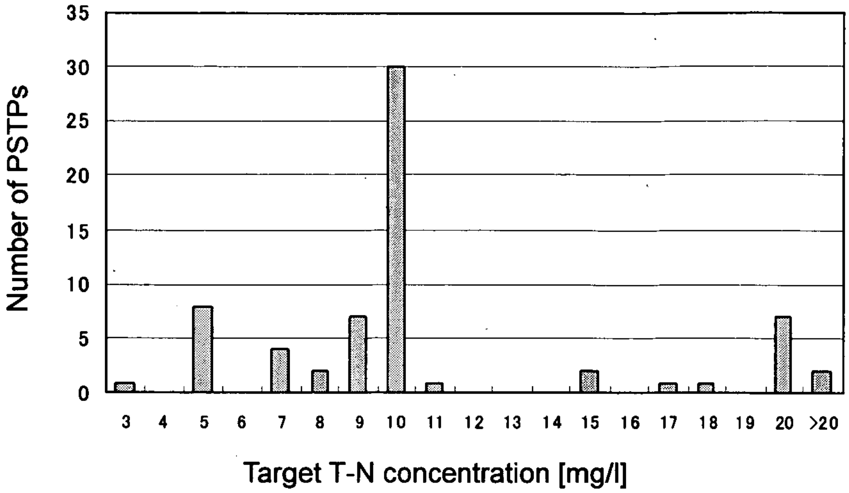


Figure 8.Target T-N concentration advanced effluent

A schematic diagram of the SMDN process is shown in Figure 9. It is characterized by (i) several stages of anoxic and oxic reactors in series, each reactor being completely mixed preferably, (ii) an uniform distribution of the influent wastewater to all the anoxic reactors, (iii) a reactor volume configuration which makes the mass of MLSS in each stage the same, and (iv) internal recycle of nitrified mixed liquor in each stage by airlift effect (if needed). By employing multistage of anoxic-oxic reactors, high nitrogen removal efficiency with smaller reactor volume can be achieved without mixed liquor recycle, as a feature of step feed processes.

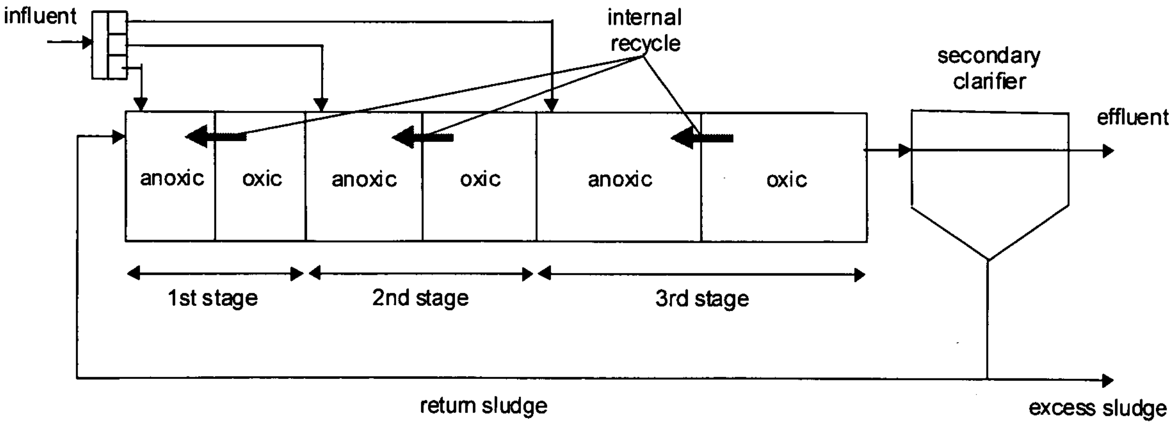


Figure 9. Schematic diagram of three stage SMDN process with internal recycle of nitrified mixed liquor.

With this process configuration, maximum nitrogen removal efficiency due to denitrification ($\eta_{DN,max}$) is decided by three parameters, the number of stages (N), sludge recycle ratio (r), and internal recycle ratio of the last stage (R_N), as shown in Eq.(1) which assumes complete nitrification and denitrification in oxic and anoxic reactors, respectively.

$$\eta_{DN,max} \doteq 1 - \frac{1}{N} \cdot \frac{1}{1+r+R_N} \qquad (1)$$

The $\eta_{DN,max}$ values of three and two stage SMDN process are 78% and 67%, respectively, under the condition of 0.5 of sludge recycle ratio and no internal recycle (Table 1). These correspond to the overall recycle ratios of 3.5 and 2.0, respectively, in a single stage anoxic-oxic process. The total reactor volume could be reduced by 22% and 17%, respectively, in comparison with a single stage process, assuming fixed ratio of anoxic to oxic reactor volume (V_{DN}/V_O ratio). As shown in Eq.(1), nitrogen removal can be improved by carrying out the internal recycle in the last stage.

Full-scale three/two stage SMDN process

Operating condition and average performance of Plant A and B during the survey period are summarised in Table 3. In both plants, nearly the designed values of wastewater were treated during the period, the total HRTs being 17.6hr and 9.3hr, respectively. A baffle wall with a channel at the bottom was installed between the reactors, thereby each reactor could be regarded as a separate compartment. One to four windows were opened on the baffle walls near the surface of the mixed liquor, and internal recycle was carried out by airlift from oxic reactors to the preceding anoxic reactors. Submerged mechanical aerator was installed in all the reactors, and DO was controlled at 2 mg/l in oxic reactors by changing the rotation rate of the aerators. PAC was added to the last oxic reactor at the rates of 4.3 and 2.0 g-Al/m^3-influent in Plant A and B, respectively, for chemical precipitation of phosphorus.

Table 3. Averaged operating condition and performance of Plant A and B.

	unit	Plant A		Plant B	
Survey period	-	Jun.99-Mar.00		Jun.99-Feb.00	
No. stages	-	3		2	
Total reactor volume	m^3	13,500		14,500	
V_{DN}/V_O ratio	-	1.0		0.67	
		designed	actual	designed	actual
Min. Temperature	°C	15.0	16.8	-	16.4
Flow rate	m^3/day	19,700	18,400	40,000	37,200
Sludge recycle ratio	-	0.5	0.5	0.5	0.5
HRT	hr	16.4	17.6	8.7	9.4
SRT	days	19	21	13	13
ASRT	days	9.7	10.6	7.7	7.9
MLSS (last stage)	mg/l	2,000	3,020	3,000	2,410
PAC dose	mg-Al/m^3	-	4.0	-	2.0
		influent	effluent	influent	effluent
SS	mg/l	185	1.5	84	2.1
BOD_5	mg/l	147	1.4	109	1.8
COD_{Mn}	mg/l	98	6.7	65	7.5
T-N	mgN/l	29.1	2.9	24.6	6.2
NH_4-N	mgN/l	19.4	0.1	14.7	0.2
NO_2-N	mgN/l	N.D.	0.1	0.1	N.D.
NO_3-N	mgN/l	N.D.	1.9	0.1	5.0
T-P	mgP/l	4.25	0.06	3.72	0.55
PO_4-P	mgP/l	1.93	0.02	1.38	0.35

The average influent and effluent T-N concentrations were 29 and 2.8 mgN/l for Plant A, and 23 and 5.8 mgN/l for Plant B, overall nitrogen removal efficiencies being 90.3% and 74.8% for Plant A and B, respectively. In Plant A, nitrification proceeded almost completely even in winter, the average effluent NH_4-N concentration was 0.1 mgN/l. In contrast, in Plant B, ammonium was remained in aerobic reactors temporary in winter, possibly due to the insufficient Aerobic SRT for nitrifiers' growth.

Nitrogen removal efficiency due to denitrification ($\eta_{DN,actual}$) was calculated by Eq.(2),

$$\eta_{DN,actual} = 1 - \frac{N_{total,out} - N_{org,out}}{N_{total,in} - N_{org,out} - N_{total,waste}} \qquad (2)$$

where $N_{total,in}$ and $N_{total,out}$ are the amount of influent and effluent total nitrogen, respectively, $N_{org,out}$ is the amount of effluent organic nitrogen, and $N_{total,waste}$ is the amount of total nitrogen removed by excess sludge. This modified efficiency is based on the amount of effluent inorganic nitrogen divided by the amount of nitrogen to be nitrified, and this permits a direct comparison with the $\eta_{DN,max}$ value expressed by Eq.(1). For Plant A, the average $\eta_{DN,actual}$ value was 88% (Figure 10(a)), obviously higher than the $\eta_{DN,max}$ value expected by the three stage SMDN process without internal recycle (78%). Using the $\eta_{DN,actual}$ value and Eq.(1), actual internal recycle ratio of the third stage (R_N) was estimated to be in a range of 1.0 to 2.0. For Plant B, the $\eta_{DN,actual}$ value was calculated to be 74% on average (Figure 10(b)), also higher than the $\eta_{DN,max}$ value without taking internal recycle into account (67%). While the data fluctuated more than that of Plant A, an expected R_N value was 1.1 on average.

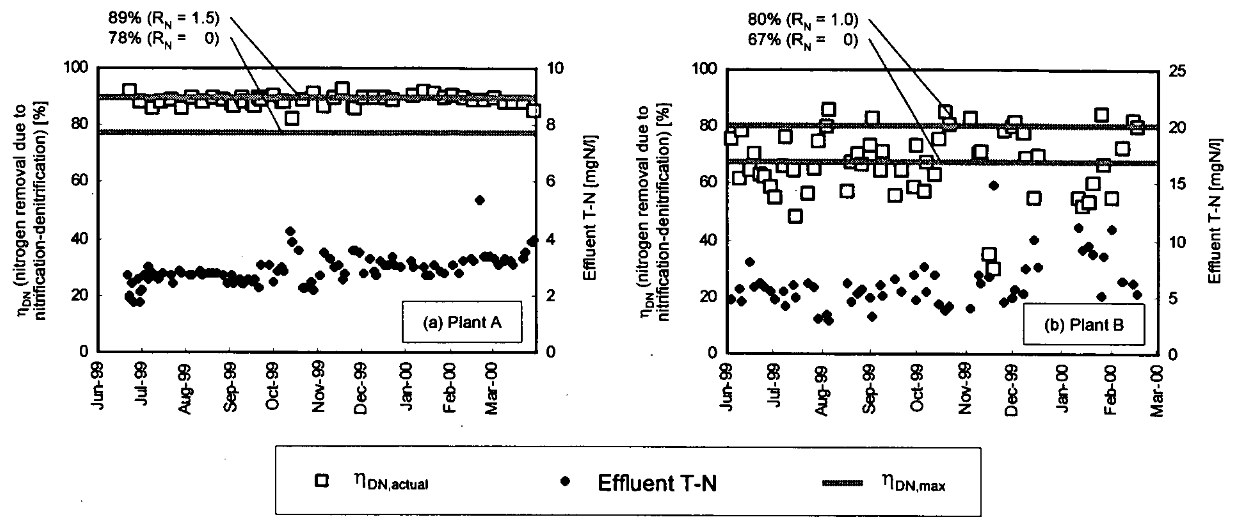


Figure 10. Nitrogen removal efficiency due to denitrification in Plant A and B.

CONCLUSION

The percentage of public sewered population in Japan stood at 62% at the end of FY 2000, and public sewerage was mainly served in densely populated districts. The percentage of wastewater treatment population as the sum of agricultural village wastewater treatment and combined septic tanks, which are promoted at less densely populated districts, and public sewerage is 71%. Since sewerage construction will proceed in less densely populated districts, the cost of construction, operation and maintenance of wastewater treatment plants must be reduced, and maintenance must be simplified. In addition, advanced treatment is required for preventing eutrophication in closed water bodies and for conserving the quality of water supply sources. The MBR and the step feed multistage denitrification-nitrification process, which are described in this paper, are expected to be applied in practice to meet such requirements.

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