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REMOVAL OF NUTRIENTS AND BOD FROM SOYBEAN FERMENTATION WASTEWATER IN A TEN-YEAR-OLD SEQUENCING BATCH REACTOR ACTIVATED SLUDGE PROCESS

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ABSTRACT

Surveys on the performance of nitrogen, phosphorus and BOD removal were carried out in a full-scale conventional, i.e. continuously aerated, sequencing batch reactor (SBR) activated sludge process which was constructed ten years ago, treating wastewater from a small factory producing soybean fermentation products. The old SBR plant, originally designed only for BOD removal, is operated with one cycle per day and aerated continuously for 19 hours per day from the start of working and wastewater inflow followed by sedimentation and decanting the next morning before work. In spite of continuous and a constant rate of aeration, DO increased rapidly immediately after the beginning of aeration, whereas it decreased down to less than 0.5 mg l^{-1} with the inflow of wastewater. DO increased again after work with little inflow of wastewater. The diurnal fluctuation of DO enhanced both nitrification and denitrification simultaneously in a single tank reactor with continuous aeration and resulted in high performance of nitrogen removal beyond expectation as well as BOD. The anaerobic condition and subsequent increase in DO also enhanced release and luxury uptake of phosphorus, i.e. biological removal of phosphorus. Increase in the strength of wastewater enhanced denitrification without deterioration of BOD removal. Phosphorus removal, however, was deteriorated by insufficient sludge production.

KEYWORDS

sequencing batch reactor; activated sludge; ten-years old full-scale plant; nitrogen removal; biological phosphorus removal

INTRODUCTION

Sequencing batch reactor (SBR) activated sludge process is known to have several advantages over conventional continuous flow systems (CFS) of activated sludge process (Okada and Sudo, 1986; Irvine et al., 1977; Silverstein and Schroeder, 1983). The batch reactor behaves as an ideal plug flow reactor and, therefore, any series of reactions in single sludge system which must be physically separated into different reactors in CFS can be carried out in a single tank. It is well known that nitrogen and/or phosphorus removal in addition to BOD are possible by a single SBR if operating conditions are properly modified to introduce anoxic and anaerobic reactions at the beginning of a cycle without any addition of separate reactors or recycling lines (Okada and Sudo, 1984, 1986; Alleman and Irvine, 1980; Hayakawa et al., 1982).

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Many SBR processes, however, have been constructed and in operation for more than ten years in Japan for small-scale wastewater treatment especially in agro-industries. Inevitably, most of them, except brand-new ones that incorporated anaerobic/aerobic reactions based on the above-mentioned findings, were designed and in operation only for BOD removal. It is generally accepted that many of these processes are well operated for this purpose, whereas some are troubled with sludge bulking by overloading with the increase in production.

In 1982, national standards for in-lake concentrations of phosphorus and nitrogen were legislated to control eutrophication of lakes and reservoirs (Kimura, 1983). And also, several lakes such as Lake Kasumigaura and Lake Biwa were designated by the Law Concerning Special Measures for Conservation of Lake Water Quality (July 1984) as the lakes where special planning is required to cope with artificial eutrophication. Local governments, therefore, which are responsible for the management of these lakes issued various regulations to satisfy the standards (Environmental Agency, 1986).

One of the most important measures is regulation of phosphorus and nitrogen concentrations in domestic and industrial effluents as shown in Table 1. The daily maximum concentration of total phosphorus and nitrogen in the effluent to the Lake Kasumigaura basin must be less than 3 mg P l^{-1} and 20 mg N l^{-1}, respectively for existing plants of agricultural industries which discharge more than 50 m^3 day^{-1} and less than 500 m^3 day^{-1}. More strict standards, i.e. 1.5 mg P l^{-1} and 15 mg N l^{-1}, are applied to all the plants put into operation after September 1983 (Ibaraki Prefectural Bureau of Environment, 1981).

It is necessary, therefore, for the conventional SBR processes to remove phosphorus and nitrogen in addition to BOD. Here in this study, a ten-years old SBR process originally designed and subsequently operated to remove BOD was surveyed to clarify the performance of these old processes on the removal of phosphorus and nitrogen and to demonstrate practical strategies to satisfy the new regulation.

TABLE 1 Effluent Regulation for Nitrogen and Phosphorus from Agro-Industries in Lake Kasumigaura Basin (Daily Maximum Values as mg l^{-1})

	T-N		T-P	
DAILY DISCHARGE	existing	new	existing	new
FOOD INDUSTRIES				
20 - 50 m^3	25	20	4	2
50 - 500	20	15	3	1.5
> 500	15	10	2	1
LIVESTOCK INDUSTRIES				
20 - 50 m^3	50	25	5	3
50 - 500	40	15	5	2
> 500	30	10	3	1

SBR PROCESS AND CHEMICAL ANALYSIS

The SBR activated sludge process studied is an industrial wastewater treatment plant of a small fermentation factory located in the Lake Kasumigaura basin, Ibaraki, Japan. Traditional fermentation products of soybeans, i.e. soy sauce and "miso", are produced in this factory. The wastewater treatment plant in the factory was constructed in 1978 to remove organic pollutants. As mentioned above, it became necessary for this plant, however, to remove phosphorus and nitrogen to less than 3.0 mg l^{-1} and 20 mg l^{-1}, respectively by the new regulation which came into force in September 1983.

Fig. 1 shows schematic diagram of the plant. The influent to the plant is passed through an automatic screen and is stored in a reservoir with working volume of 8.5 m^3 and pH was regulated between 7.0 and 7.5. The effluent from

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the reservoir flows into a pumping pit and is pumped up to a reactor (working volume = 360 m^3). Most of the influent is discharged from the factory between 7:00 and 19:00. Submerged aerator is working continuously from 7:00 in the morning to 2:00 in the next morning followed by subsequent sedimentation from 2:00 to 6:00. The supernatant is discharged between 6:00 and 7:00. The cycle of operation, therefore, is 24 hours corresponding to the working schedule of the factory.

Flow rate and organic carbon, nitrogen and phosphorus concentrations of the influent were monitored from 8:00 to 19:00 with an interval of 1 hour. Performance of the sequencing batch operation was also monitored for a day of operation. Parameters determined were MLSS, dissolved oxygen concentration both at the surface and 1 m deep, dissolved organic carbon (DOC), orthophosphate (PO_4-P), total nitrogen (T-N), ammonium nitrogen (NH_4-N) and nitrate+nitrite nitrogen (NO_x-N)) in the filtrate of mixed liquor. These parameters were determined after "Standard Methods for the Examination of Water and Wastewater" (Am. Publ. Health Assoc., 1981) or "Methods for Chemical Analysis of Water and Wastes" (U.S. EPA, 1976). Glass fiber filters (Whatman GF/C) were used for the filtration of influent and mixed liquor.

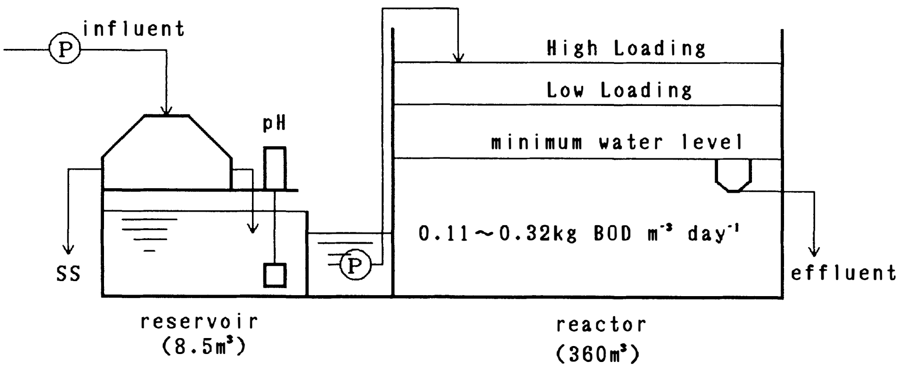

Fig. 1. Schematic diagram of the SBR plant surveyed

RESULTS AND DISCUSSION

Influent

Table 2 shows typical values in the daily volume of wastewater discharge, average concentrations of BOD, and BOD loading from various operations in the factory. The contribution of organic loading from soybean and rice processing wastewater, i.e. soaking and boiling, were remarkable and that of bottle washing wastewater was small. The plant was designed originally to treat daily average influent of 70 m^3 day^{-1}, 760 mg BOD l^{-1} and 53 kg BOD day^{-1}.

TABLE 2 Daily Volume, BOD, and Daily BOD Loading of Wastewater discharged from Various Operations in the Factory.

Operation		Volume (m^3 day^{-1})	BOD (mg l^{-1})	BOD Loading (kg day^{-1})
Soybean	Washing	6.7	500	3.4
	Transfer	5.7	700	4.0
	Soaking	3.0	1,500	4.5
	Boiling	0.2	60,000	12.0
Rice	Washing	1.9	3,500	6.7
	Soaking	1.2	3,000	3.6
Washing Water		3.0	2,000	6.0
Bottle Washing		30.0	300	9.0
Miscellaneous		18.0	200	3.6

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It was found from our survey (4 times per year), however, that there is large variation in these values, i.e. daily volume, BOD, and BOD loading of the wastewater ranged from 49 to 89 m^3, 510 - 1,840 mg l^{-1} and 38 - 115 kg day^{-1}, respectively depending on the schedule of production in the factory. Actually, there were two typical types of schedule, i.e. regular production (low loading) and increased processing of soy beans once (1 day) per 7 to 10 days discharging higher strength of wastewater (high loading).

Fig. 2 shows daily variations of influent TOC values both in high and low loading. High strengths of wastewaters after washing, soaking or boiling of soy bean and rice were discharged in the morning. Washing wastewater and miscellaneous wastewater were discharged in the afternoon. After the work, only cooling water was discharged. TOC values were high between 10:00 and 12:00, i.e. from 1,300 mg l^{-1} to 1,700 mg l^{-1} in low loading and from 2,900 mg l^{-1} to 3,600 mg l^{-1} in high loading, whereas they decreased in the afternoon and were less than 70 mg l^{-1} after 19:00. A similar pattern of variation was noted both for BOD and COD(Mn) (not shown here).

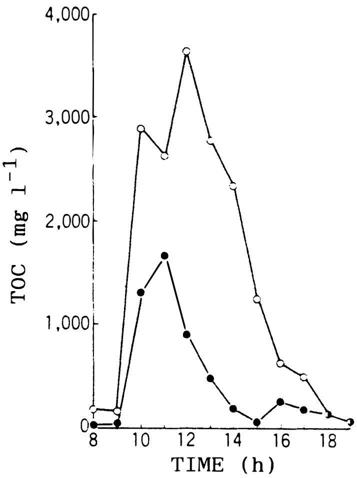

Fig. 2. Daily variations of influent TOC values.
(●:low loading, ○:high loading)

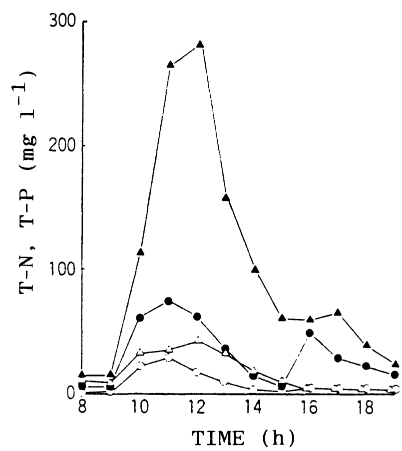

Fig. 3 Daily variations of influent T-N and T-P.
(●, ▲:low and high loading (T-N), ○, △:low and high loading (T-P))

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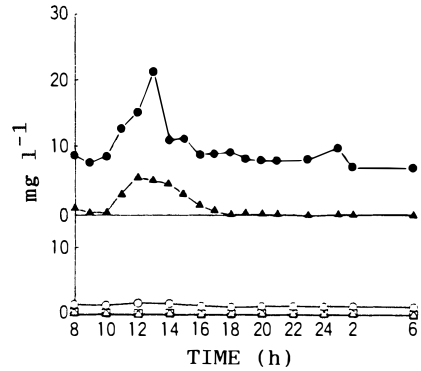

Fig. 4. Profiles of TOC, nitrogen and phosphorus during a cycle of SBR operation in low loading
(●:TOC, ▲:T-P, ○:T-N, □:NH_4-N, △:NO_3-N)

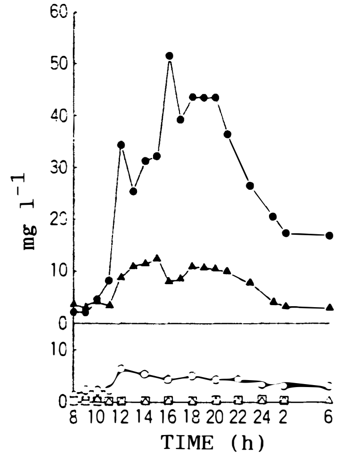

Fig. 5. Profiles of TOC, nitrogen and phosphorus during a cycle of SBR operation in high loading (see Fig. 4 for symbols).

Fig. 3 shows daily variations of influent T-N and T-P. Patterns of daily variation both in T-N and T-P were similar to that of TOC. It must be noted that NH_4-N ranged from 0 to 18 mg l^{-1} and NO_x-N ranged from 0 to 1.2 mg l^{-1}. Thus, most influent nitrogen was organic nitrogen.

Daily volumetric loading of TOC, T-N and T-P ranged from 0.09 to 0.21 kg TOC m^{-3} day^{-1}, from 0.007 to 0.02 kg T-N m^{-3} day^{-1} and from 0.002 to 0.003 kg T-P m^{-3} day^{-1}, respectively. The ratio of C:N:P in this wastewater indicates that no nutrient addition is necessary for biological treatment(Inamori et al., 1982).

Batch Reaction in the Reactor

Profiles of TOC (identical to DOC, dissolved organic carbon), T-N, NH_4-N, NO_x-N and T-P in the filtrate of mixed liquor in a cycle of operation both for low and high loading are shown in Figs. 4 and 5, respectively. In the low loading, TOC was only 9 mg l^{-1} in the morning (8:00). It increased by the inflow of wastewater and the maximum value was 22 mg l^{-1} at around 13:00. TOC decreased again after that and back to the level in the morning at 16:00.

T-P was 0.5 mg l^{-1} in the morning. It increased remarkably up to 5.9 mg l^{-1} during 10:00 to 12:00, whereas it decreased again back to the lowest level in the afternoon. The maximum value, 5.9 mg l^{-1}, was twice as high as the value, 2.6 mg l^{-1}, estimated from the influent phosphorus concentration

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assuming no reaction and simple dilution between 8:00 and 12:00. This difference should be attributed to the release of phosphorus from the activated sludge. A similar phenomenon is known both in SBR and CFS systems for biological phosphorus removal, whereas the increase in phosphorus concentration is observed only in anaerobic period of SBR cycle or anaerobic reactor in CFS into which no air was supplied. NO_x-N and NH_4-N were below detection limit throughout a cycle. T-N values were 1.3 mg l^{-1} or less.

TOC increased remarkably in the high loading. The maximum value was 51 mg l^{-1} at 16:00. Different from the low loading, TOC decreased gradually and was still 17 mg l^{-1} even at 2:00 a.m. the next day. Effluent TOC, however, was as low as that at the beginning of the cycle.

T-P increased rapidly in accordance with the increase in TOC. The maximum value was 12.5 mg l^{-1}. This is also far higher than the estimated value of 6.2 mg l^{-1} assuming simple dilution, indicating the release from the sludge. Gradual uptake of phosphorus continued until 2:00 when it returned to the initial value. Similar to the low loading, no NH_4-N nor NO_x-N was detected throughout a cycle and only T-N showed slight change during the cycle.

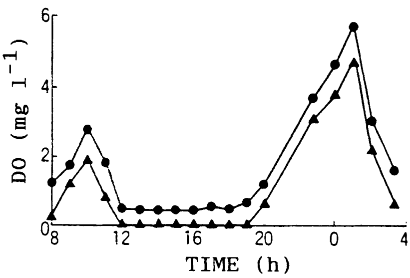

Fig. 6. Profiles of DO at the surface (●) and 1.0 m (▲) during a cycle of operation for low loading.

Fig. 6 shows profiles of DO at the surface (0.1 m) and at the depth of 1.0 m in the SBR reactor during a cycle of operation for low loading. In the beginning of the operation when aeration started and wastewater inflow began, DO increased rapidly up to 2 to 3 mg l^{-1}. This is because plenty of air was introduced into the reactor irrespective of the amount of wastewater inflow and concentration of organic substances in the reactor. The small amount of wastewater inflow at the beginning, which was diluted by a large volume of treated water remaining in the reactor at the end of the previous cycle, could not increase TOC values until 10:00 (see Fig. 5). However, DO decreased rapidly after 10:00 by the inflow of wastewater with high strength. DO could not be detected in 1.0 m and was less than 0.5 mg l^{-1} even at the surface of the reactor. The same condition of DO was noted until the end of wastewater inflow. DO increased again after the end of wastewater inflow up to 5 mg l^{-1}.

It is clear from daily profiles of DO in the reactor that both anaerobic and aerobic conditions were repeated in the reactor. The rate of aeration was kept constant throughout a cycle, whereas the supply of DO was too small to keep aerobic condition during the inflow of wastewater and resulted in anaerobic condition for most parts of the reactor. In contrast, the supply was in excess before and after the inflow of wastewater when little organic substances remained and resulted in aerobic condition.

Budgets of phosphorus and nitrogen are summarized in Table 3. Figures in the table are percentages of mass flow out of reactor by the corresponding process such as effluent discharge, sludge production/removal and denitrification (for nitrogen) to that of inflow shown in parentheses. The sludge production/removal includes the mass flow of nutrients both stored and/or used for the growth of sludge and finally removed through excess sludge removal. It must be noted that excess sludge removal was not daily but once or twice per month.

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The amount of phosphorus flowing out through sludge production/removal was estimated from the phosphorus budget, i.e. (input) - (output) through daily influent and effluent, respectively. Then the rate of sludge production/removal was estimated from the phosphorus output through sludge and phosphorus content in the sludge. The amount of nitrogen flowing out through sludge production/removal was estimated by nitrogen content of the sludge. Denitrification was estimated from nitrogen budget, i.e. (influent) - (effluent) - (sludge production/removal).

Nitrogen and phosphorus contents in the sludge were 4.9 and 1.8 %, respectively and little differences were noted between low and high loading. The estimated rate of sludge production/removal from phosphorus budget and phosphorus content were 0.088 and 0.11 kg m^{-3} d^{-1} for low and high loading, respectively. The rate of sludge production observed during a consecutive low loading for 10 days was 0.089 kg m^{-3} d^{-1} showing good agreement with the estimated one. The rate for high loading was small irrespective of high organic loading by three times.

TABLE 3 Nitrogen and Phosphorus Budgets (Percentages for the Influent)

	NITROGEN			PHOSPHORUS	
loading	effluent	sludge	denitrification	effluent	sludge
low %	11	64	25	11	89
(loading)		(2.4 kg day^{-1})		(0.64 kg day^{-1})	
high %	10	26	64	29	71
(loading)		(7.4 kg day^{-1})		(1.00 kg day^{-1})	

Fairly large percentages of nitrogen were removed by denitrification irrespective of continuous aeration and absence of oxidized form of nitrogen. Taking the fact that T-N, and also NO_x-N and NH_4-N were low throughout a cycle irrespective of the inflow of high concentration of nitrogen into consideration, it seemed likely that nitrogen was oxidized and, at the same time, it was removed by denitrification making use of organic carbon flowing into the reactor as hydrogen donor. The denitrification and excess sludge removal resulted in the high percentages of nitrogen removal, i.e. 89 % in low loading and 90 % in high loading, although it was not expected when the plant was designed.

As mentioned above, the luxury uptake of phosphorus enhanced phosphorus removal. The percent removal for phosphorus calculated from the difference between influent and effluent was as high as 89 % and 71 % both in low and high loading, respectively. The difference may be attributed to insufficient sludge production during high loading. It must be noted that percent of TOC and BOD removal was more than 96 % both for high and low loading. Especially, BOD in effluent was less than 10 mg l^{-1}.

The result of this survey suggests that both nitrogen and phosphorus removal will be possible, in addition to BOD, even in traditional SBR processes with continuous aeration. This would be due to an insufficient rate of aeration and fluctuation of organic strength and flow rate of influent to give anaerobic and aerobic conditions in a cycle of batch operation. The rate and schedule of aeration in a cycle of SBR operation, therefore, must be determined and/or controlled, taking not only by the daily mean loading but also by the diurnal fluctuation of strength and flow rate of wastewater for a given plant into consideration.

CONCLUSION

Surveys on the performance of nitrogen, phosphorus and BOD removal were carried out in a full-scale conventional, i.e. continuously aerated, sequencing batch reactor (SBR) activated sludge process. The plant was designed and constructed ten years ago to remove BOD in wastewater discharged from a small

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factory producing soybean fermentation products. The old SBR plant is operated with one cycle per day and aerated continuously for 19 hours per day from the start of working and wastewater inflow, followed by sedimentation and decanting the next morning before work. Specific conclusions derived from this study are as follows.

1) In spite of continuous and a constant rate of aeration, DO increased rapidly immediately after the beginning of aeration, whereas it decreased down to less than 0.5 mg l^{-1} with the inflow of wastewater. DO increased again after work with little inflow of wastewater.

2) The diurnal fluctuation of DO enhanced both nitrification and denitrification simultaneously in a single tank reactor with continuous aeration and resulted in high performance of nitrogen removal beyond expectation as well as BOD.

3) The anaerobic condition and subsequent aerobic condition by the increase in DO also enhanced release and luxury uptake of phosphorus, i.e. so-called biological removal of phosphorus was observed. Increase in the strength of wastewater for one day enhanced denitrification without deterioration of BOD removal. Phosphorus removal, however, was deteriorated by insufficient sludge production.

REFERENCES

Alleman, J. E. and Irvine, R. L. (1980) Storage-induced denitrification using sequencing batch reactor operation. Water Research, 14, 1483-1488.

Am. Publ. Health Assoc. (1981) Standard methods for the examination of water and wastewater. 15th Ed.

Environmental Agency (1986) Quality of Environment in Japan, pp.305.

Hayakawa, N., Inami, S., Kusunoki, T., Tsuji, J. and Hamamoto, Y. (1982) Wastewater treatment by a sequencing batch reactor activated sludge process with continuous inflow ---a full scale plant study---. (in Japanese) Yosui to Haisui, 24 28-38.

Ibaraki Prefectural Bureau of Environment (1981) Water Pollution Control Plans for Lake Kasumigaura, Report of Water Quality Control Board in Ibaraki Prefecture.

Inamori, Y., Terazono, K., Kodama, K., Sudo, R. (1982) An experimental study on two-stage biological treatment of wastewater from a food industry. (in Japanese) Yosui to Haisui, 24, 47-53.

Irvine, R. L., Fox, T. P. and Richter, R. O. (1977) Investigation of fill and batch periods of sequencing batch biological reactors. Water Research, 11, 713-717.

Kimura, Y. (1983) Environmental standards of nitrogen and phosphorus in lakes. (in Japanese) Kogai to Taisaku, 19, 716-721.

Okada, M. and Sudo, R. (1986) Performance of sequencing batch reactor activated sludge processes for simultaneous removal of nitrogen, phosphorus and BOD as applied to small community sewage treatment. Water Science and Technology, 18(7/8), 363-370.

Okada, M., Sudo, R. and Terazono, K. (1984) Simultaneous removal of nitrogen and phosphorus by SBR activated sludge process. (in Japanese) Chemical Engineering Symposium Series, 4, 46-51.

Silverstein, J. and Schroeder, E. D. (1983) Performance of SBR activated sludge processes with nitrification/denitrification. Journal of Water Pollution Control Federation, 55, 377-384.

U. S. EPA (1976) Method for Chemical Analysis of Water and Wastes. EPA-625/6-74-003a, 168-172.

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