Treatment of ballast water by complex process of advance filtration system

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Abstract

There have been several problems in treating shipboard sewage due to special environmental conditions of ship, such as limited space, rolling and pitching, change of temperature and so on. It was suggested that Sequence Batch Reactor (SBR) might be suitable process for overcome these problems in terms of small size, high capacity of treating wastewater and full automation. In this study a SBR process was employed for biological treatment of organic wastes in the shipboard sewage. This process was able to remove nitrogen and phosphorus as well as organic matter efficiently. More than 95% of chemical oxygen demand(COD) were removed. In addition, about 97% of total nitrogen (T-N) was reduced. The total phosphorus(T-P) reduction averaged 93%. A disturbance operation caused by the treatment of Methylene Blue Active Substances(MBAS) was not observed.

Keywords: shipboard sewage, Sequence Batch Reactor(SBR), nitrogen, phosphorus, Methylene Blue Active Substances(MBAS)

1. Introduction

Coastal pollution is becoming an increasingly serious problem and its damage continues to increase. Particularly, fish farms or fishing grounds are suffering from great damage, which can even create distortions in the ecosystem. In response to this problem, the International Maritime Organization (IMO), a UN special agency, has adopted MARPOL 73/78, a convention on maritime pollution. Annex IV to MARPOL 73/78, governing regulations on sewage from ships including toilets, came into force globally on September 27, 2003(adopted on November 2, 1973). The Convention provides that sewage discharged from ships of two hundred gross tons and above, or ships carrying ten or more people, should be treated according to international conventions (The Marine Environment Protection Committee of IMO, 2003 Conference data).

With the entry into force of this Convention, all ships are required to install and operate sewage treatment facilities in accordance with MARPOL 73/78. The treatment technologies applied to existing ships are a biological treatment facility using the activated sludge method and electrolysis, which is a physio-chemical treatment facility (John et al., 2002). All these methods can only eliminate organic matter and cannot get rid of nitrogen and phosphorus, which are marine pollutants causing red tides. Most of the ports in Korea are located in secluded areas and therefore, nitrogen and phosphorus discharged from ships at anchor cause eutrophication, which provides another cause of marine pollution and red tides (Obaja et al., 2003). Furthermore, other countries are implementing strict regulations on treating sewage and wastewater discharged from ships. Given this trend, it is urgent to develop advanced sewage treatment facilities for ships that can process nitrogen and phosphorus at the same time in order to meet these strict standards. Sequencing batch reactors (SBR) have been originally used for COD and phosphate removal from wastewaters (Tasli et al, 1997; Baozhen et al, 1998).

This thesis will evaluate the ship-discharged sewage and wastewater treatment capacity of the sequencing batch reactor, a biological treatment equipment using Bacillus sp, which is widely used at inland high-purity treatment facilities to get rid of nitrogen and phosphorus simultaneously.

2. Experiment Apparatus and Methods

2.1 Experiment apparatus

In this experiment, a 5 mm-thick, round-shaped reactor made of acryl was used as a reactor, with a 14L total capacity and a 12L effective capacity. The residual sludge after treatment was 5L and the outflow was 7L. The tube for inflow and outflow was made of silicon with a 5 mm-long diameter, and a peristaltic pump was used to adjust inflow and outflow finely and consistently To ensure smooth blending of the reactor within the mixing time, a mixing device was installed to mix at 50-70 rpm. The temperature in the reactor was maintained at 25±0.5 ^{o}C by using a constant temperature and humidity system. Fig. 1 shows the photos of the experimental apparatus and the diagram.

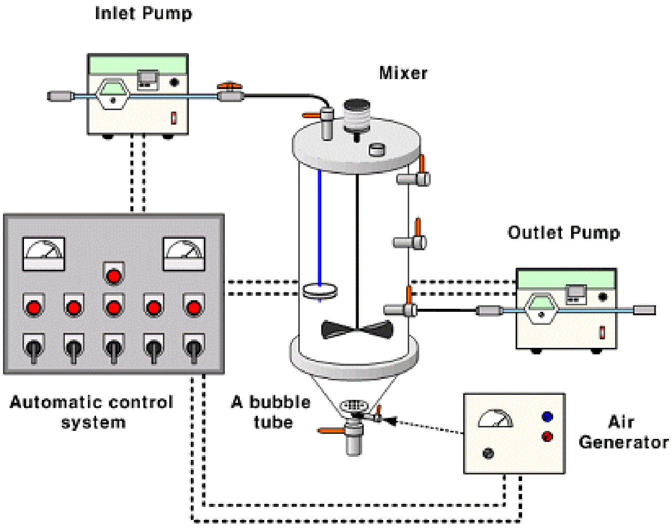

Figure 1. Schematic diagram of SBR reactor

2.2 Ship sewage and wastewater

For the convenience of the experiment, wastewater was artificially created, based on the characteristics of actual sewage and wastewater discharged from ships. Using glucose as a carbon source, COD was adjusted at 400mg/L, and the nitrogen density was fixed at 40㎎NH_3-N/L with NH_4Cl. Nitrogen was injected into the sample in the form of ammonium nitrogen, while the phosphorous density was maintained at 10㎎PO_4/L with K_2HPO_4. Table 1 shows the common characteristics of sewage and wastewater discharged from ships, and Table 2 shows parameter of the synthesized wastewater used for the experiment.

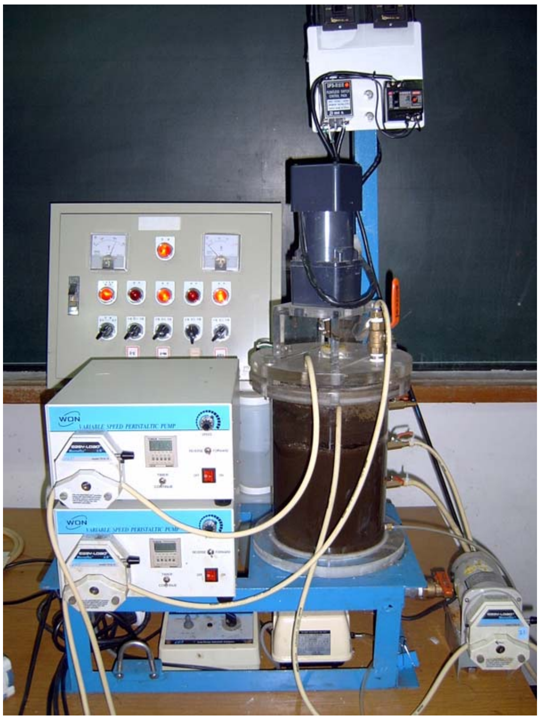

Figure 2. View of SBR reactor

Table 1. General characteristics of shipboard wastewater

Division	Concentration(㎎/L)	Mean(㎎/L)
CODcr	400-500	450
T-N	25-30	27.5
T-P	4-5	4.5
MBAS	10-20	15
Mineral oil (Diesel)	1.3-1.7	1.5
Animal Fat	1.4-1.6	1.5
Vegetable oil	1.4-1.6	1.5

Table 2. Composition of the synthetic shipboard wastewater used in SBR

Composition	Concentration(㎎/L)
CODcr	350-450
T-N	36-45
T-P	12-14
MBAS	11-12
Mineral oil(Diesel)	1.5
Animal Fat	1.5
Vegetable oil	1.5

2.3 Experimental conditions

Seeding sludge used in this study was sampled from the B3 (Best-Bio-Bacillus System) of the S Municipal Wastewater Treatment Plant in Ulsan and was planted in the reactor after a 15-day-adjustment period. This process has been designed to simulate the growth of Bacillus sp. shich is known to be very resistant to many adverse conditions (Sneath et al., 1986). Density of dissolved oxygen(DO) was adjusted according to the growth patterns of the Bacillus species, and aeration was decreased by four different stages according to aeration intensity of the diffuser, with the first level at 1.5-2㎎/L, the second level at 0.8-1.0㎎/L, the third level at 0.5-0.5㎎/L, and the fourth level at 0.3-0.5㎎/L. Reaction manipulation was done with 4 cycles a day and Table 3 shows the operating conditions. The treatment volume per cycle was 7L, and all operations were controlled by the time controller.

Table 3 Operating conditions for the SBR

Step	**Fill**		■		■		**Settle**	**Idle**	**Draw**	**Total (min)**
RUN	**10**	**40**	**60**	**50**	**40**	**60**	**80**	**10**	**10**	**360**

Aerobic : ▨ Anoxic : ■

2.4 Analysis methodology

In a normal condition where the analysis data was stabilized, test samples were taken from the influent and effluent for every five minutes during one cycle of 360 minutes, and they were analyzed for a total of 11 categories. The analysis methods used for individual categories in this study were based on the Standard Methods (1992). Specific analysis methods for each category are listed in Table 4. A phase contrast microscope was used to observe the changes in the microorganisms in the reactor

Table 4. Summary of analytical methods

Item	Analytical Method
pH	pH meter(Thermo Orion 720)
ORP	ORP meter(Thermo Orion 720)
TOC	TOC Analyzer(SHIMADSU 5000A)
NH_4^+-N	Indophenol Method
NO_3^--N	UV Spectrophotometric Method
NO_2^--N	NED, Colorimetric Method
T-N	UV Spectrophotometric Method
T-P	Automated Ascorbic Acid Reduction Method
DO	DO Meter (YSI Model 58)
MBAS	Metylene Blue Method

3. Results and discussion

3.1 Bacillus sp. microorganisms in the reactor

Microorganisms in the reactor were observed with a phase contrast microscope. When there are abundant microorganisms, Bacillus sp is observed in the form of a filament stuck on floc, while in an anoxic state, the filament shape gets cut off to form short rods or endospores.

Fig. 3 well illustrates the changes of Bacillus sp in the reactor. (a) is a precipitation period during which lack of nutrition retards growth. During this period, Bacillus sp forms endospores, and spherical and ellipsoidal spores are easily distinguished from other microorganisms when observed with a microscope, because they have high optical refraction. (b) is observed in a stage where an aerobic cycle shifts to an anoxic cycle in the form of thread-shaped long trichome attached onto organic floc. It was possible to examine the microorganisms in the reactor on a real-time basis by using a phase contrast microscope. In addition, *Bacillus* sp , which is a Gram(+) bacteria, turned violet, and Gram(-) bacteria was dyed red through Gram staining, which made it easy to distinguish among the microorganisms in the reactor(Choi et al, 2002).

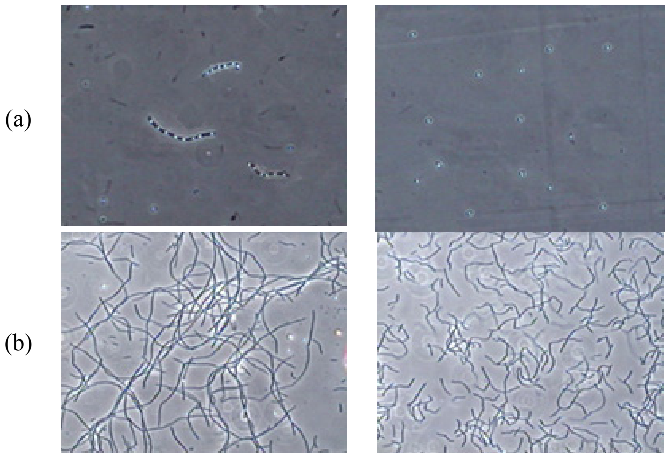

Fig. 3 Observation of *Bacillus* sp. on phase-contrast microscopy : (a) spores in settle(×300), (b) endospres in the anoxic(×300)

In the reaction set, *Bacillus* sp grew healthy and dominant. In order for *Bacillus* sp to stay dominant in the reactor, microbe activators, including Si, Ca and Mg which are critical elements to accelerate the decrease in aeration, the germination of *Bacillus* sp and cell division at an initial state were injected, and the injected amount was 5% of the raw water-loading rate in the aerobic state. Further, 5% of the raw water-loading rate was injected 15 days after seeding to increase the number of germs.

3.2 Changes in dissolved oxygen

Fig. 4 and 5 show the changes in DO and OPR in the reactor measured during 1 cycle time. Generally, DO density during the aeration time remained at 0.3-1.5㎎/L, and DO showed a tendency to increase gradually as aeration proceeded during 1 cycle time. A significant amount of organic matter's inflow at the beginning stage during the cycle time was removed, and thus the influent loading rate against the reactor's capacity relatively declined, lowering the oxygen uptake rate. At the mixing stage, aeration stopped to maintain an anoxic state within 10 minutes. ORP, a value of oxidation-reduction indicates signs of biochemical reactions. The result showed that as DO density grew according to the operating time, ORP also increased. ORP is a very sensitive parameter to follow-up the stages of a SBR system: the distinct phases of the cycle(aerobic and anoxic) can very well distinguished by means of the ORP profile (Obaja et al., 2003; Ra et al., 2000).

3.3 Evaluation of organic matter removal efficiency

Fig. 6 shows how dense CODcr and TOC in influent and effluent become as time goes by. In terms of changes in organic matter(CODcr, TOC), the density of CODcr and TOC in the influent was 370㎎/L and 240㎎/L, respectively, and 6.5㎎/L and 3㎎/L in the effluent, which represents a removal efficiency of more than 95%. The results satisfied the legal requirement for sewage released in the treatment process: in case of COD, 40㎎/L or less and for SS, 20㎎/L or less(Kim, etc, 2002).

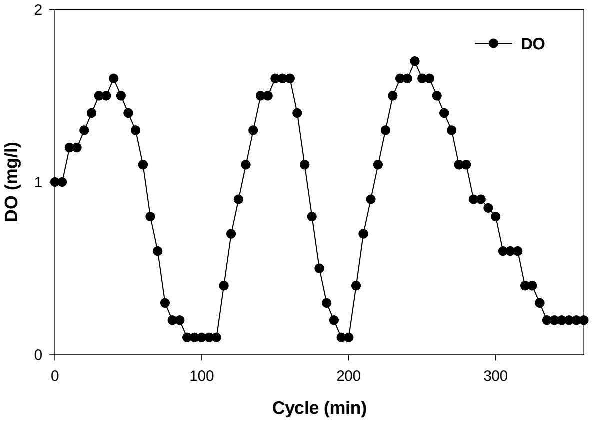

Figure 4. Variation of DO during one cycle in 6 hours

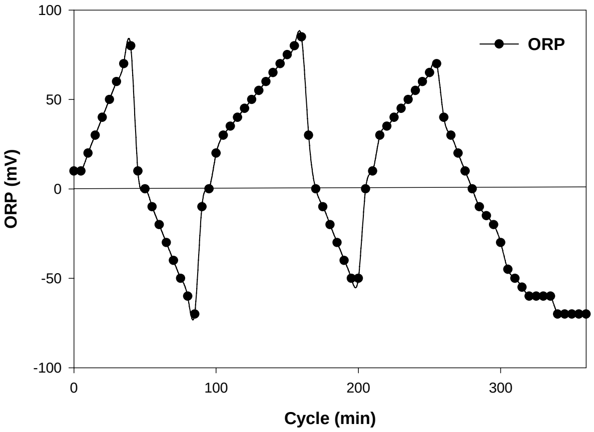

Figure 5. Variation of ORP during one cycle in 6 hours

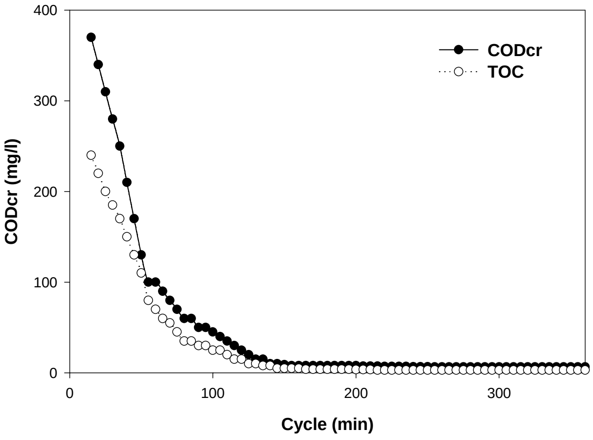

Figure 6. Variation of each concentration of CODcr and TOC

3.4 Evaluation of nitrogen and phosphorus removal efficiency

Fig. 7 and 8 show changes in the density of ammonia nitrogen and nitrate during one cycle (6 hours) of the SBR reactor. In the aerobic process within the reactor, ammonia nitrogen(NH_4-N) decreased from 40㎎/L to 4㎎/L while nitrate(NO_3^-) in the anaerobic process it increased to 0.5㎎/L to 2.7㎎/L. Nitrogen was removed as the aerobic and anaerobic processes repeated themselves.

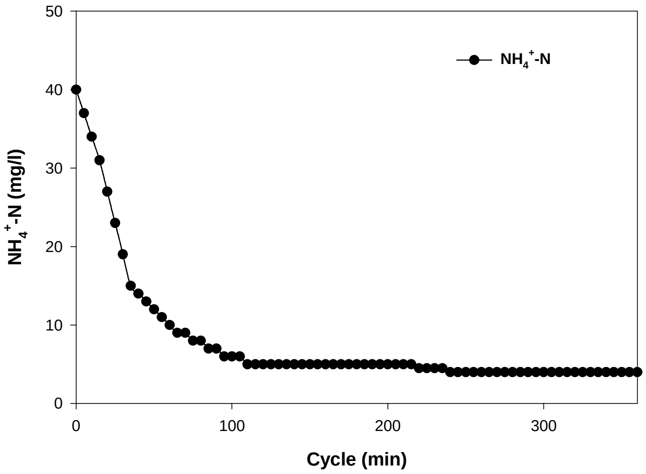

Figure 7. Variation of NH4+-N concentration in effluent with one cycle in 6 hours

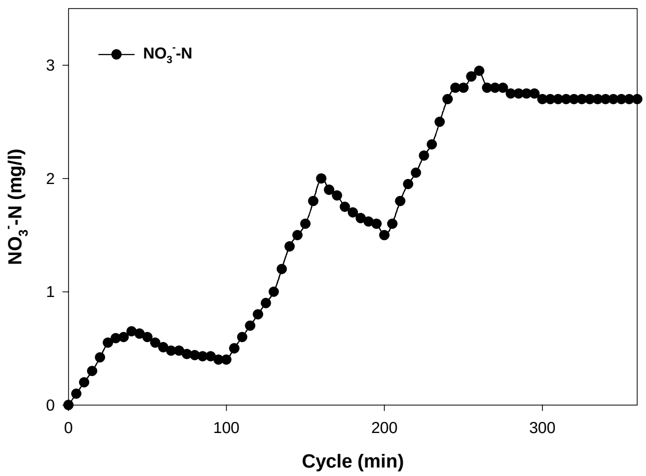

Figure 8. Variation of NO3--N concentration in effluent with one cycle in 6 hours

Given the characteristics of sewage from ships, toilet sewage is separated and thus, separate space and treatment equipment are necessary. Further, the density of nitrogen and phosphorus contained in the raw water is low, and thus, is not appropriate for biochemical treatment. IMO encourages all sewage from ships to be treated according to the regulations of each country before it is discharged from the ships. Currently, there are no specific criteria regulating discharge from ships in Korea. According to the Water Conservation Law(2003), however, the sewage discharge criteria is less than 40㎎/L in COD in a clean water zone, less than 30㎎/L in T-N and 4㎎/L in T-P. In this study, toilet sewage and kitchen sewage discharged from ships were combined for treatment in order to meet the international regulations. In the combined sewage, the total nitrogen was 30-40㎎/L, most of which was ammonia nitrogen, the main culprit of eutrophication of sea which therefore should be treated before it is discharged. The active nitrification of ammonia eliminated more than 90% of the total, and the discharge level of nitrate remained static at less than 5㎎/ℓ. It was confirmed that the SBR process used in this study can be used for organic matter treatment and nitrogen control.

On the other hand, in removing phosphorus, night soil discharged from ships and kitchen sewage were mixed to resolve this problem as ship-discharged sewage contains a low level of phosphorus. This process, using release by microorganisms and surplus uptake via the removal mechanism of phosphorus, was highly effective for removing phosphorus. Barker and Dold (1996) observed the P uptake under anoxic conditions. Fig.9 shows changes in the phosphorus after the experiment. Around 50% of the phosphorus was removed in the first anoxic treatment process, followed by additional removal in the second process. As a result, a total of 93% was eliminated during the reaction process.

Fig. 10 indicates treatment efficiency of each item in the reactor for analysis. COD removal efficiency was 98.5% and for ammonia nitrogen, it was 95%. Total nitrogen removal efficiency was 95%, while it was 93% for phosphorus. Bacillus sp.-using SBR produced stable treatment efficiency rates for wastewater from ships.

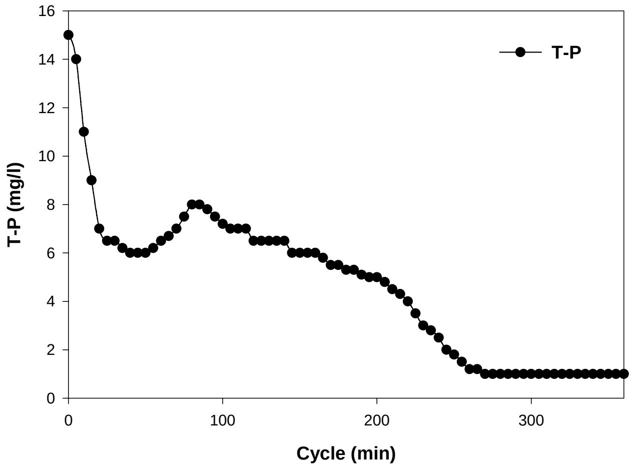

Figure 9. Variation of T-P concentration in effluent during a 8 cycle

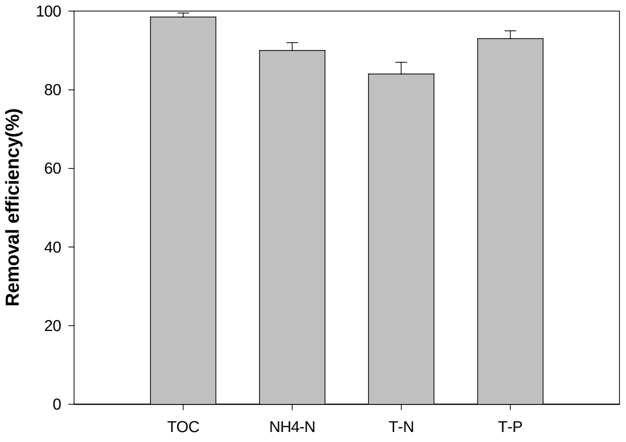

Figure 10. Removal efficiency of TOC, NH4-N, T-N and T-P in the SBR system

3.5 Changes in sludge volume

In the SBR reactor, the density of MLSS(mixed liquor suspended solids) which initially stood at 4,500㎎/L, gradually stabilized at 3,500-4,000㎎/L, according to the density of the influent. As the density of microorganisms stabilized with its natural ability to adjust it, a returning process is not necessary in the SBR treatment process, unlike other activated sludge-based processes, and the SBR process is easy to install and operate.

Fig. 11 shows changes in the volume of SV30 as an indicator of biological changes. Total microorganism volume consistently declined at an early stage of the operation and stabilized at a certain point. The reason for this initial decrease in SV30, is assumed to be the increase in microorganisms that disappear or die during the adjusting period, according to changes in the operation conditions. The difference in SV30 was not so large, according to different TOC values, because the adjusting period for microorganisms according to the changing cycles was 2-3 days, which implies that microorganisms in the SBR reactor have strong loading resistance and excellent resilience.

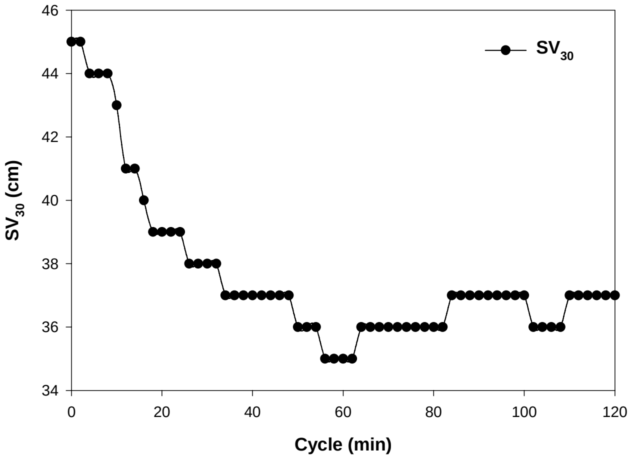

Figure 11. Variation of SV30 during the test period

3.6 Treatment of surfactants

A surfactant is discharged in the process of bathing and washing dishes and clothes and it is difficult to use the microorganism treatment for it. Recently, the biodegradability of surfactants has largely improved as the key ingredient has changed from Alkylbenzene Sulfonates(ABS) to Linear Alkylbenzene Sulfonate(LAS). The density of surfactants (LAS) was represented by the density of MBAS (Methylene Blue Active Substances), according to the Standard Methods (1992). When the activated sludge equipment was at its optimal operation without loading, the LAS removal rate stood at 95%-99%, and more than 95% of MBAS was eliminated (Klein and McGauhey, 1965). Normally, the density of MBAS discharged from washing dishes and clothes is 30-40㎎/L, but that of wastewater from ships is 10-20㎎/L, as it is diluted with other wastewater. In this experiment, the MBAS density of the raw water was adjusted to 12-15㎎/L. As shown in Figure 11, the volume of MBAS changed during one cycle time. Around 50% was treated during the first aerobic treatment and after anaerobic treatment, only 1㎎/L was found left in the effluent, which means more than 93% of MBAS was treated. As Fig. 12 indicates, there was nearly no impediment to the microorganism treatment of MBAS and the treatment rate remained stable. The maximum wastewater release of anionic surfactant is 3㎎/L or less in clean water zones and 5㎎/L in other zones (Sung, Lee, 2000). No other last treatment was necessary, as all effluent requirements were met.

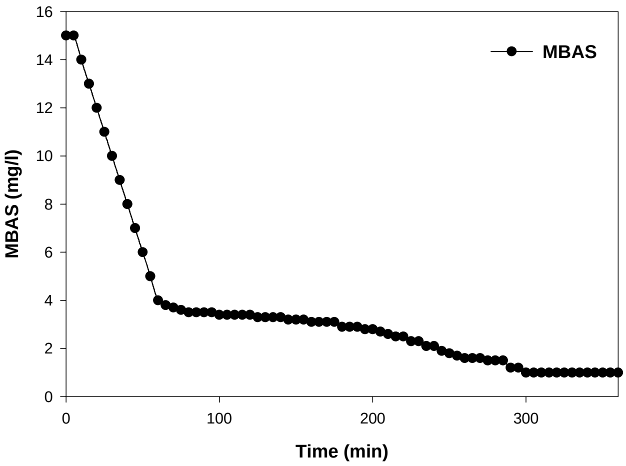

Figure 12. Variation of MBAS concentration in effluent during a cycle

4. Conclusion

The following is the summary of the results gained from the evaluation of the treatment capacity when using SBR with Bacillus sp for inland sewage and wastewater treatment. In the reactor, the average efficiency rate of organic matter removal was around 98%. As the volatility of treatment efficiency according to C/N changes was small, thus the treatment process showed a high level of adaptability of organic matter to shocks from BOD changes. In the anaerobic stage, it was proven to be able to eliminate nitrogen and phosphorus simultaneously without an external carbon source. The surfactant treatment rate was found to be higher than 93% in the treatment equipment, and it did not work as a factor to block the treatment of microorganisms. In the experiment on artificial water created based on the characteristics of wastewater discharged from ships, the organic matter removal rate was 98.5% and 84% and 93% for nitrogen and phosphorus, respectively, which satisfies the water quality control requirements for effluent.

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