환경영향평가 Vol. 27, No. 1(2018) pp.83~91 J. Environ. Impact Assess. 27(1): 83~91(2018) ISSN 1225-7184
https://doi.org/10.14249/eia.2018.27.1.83

Research Paper

Comparative Study on Biological Technology in Artificial Floating Island: Application of Media and Daphnia to Algal Biomass Control

Mei-Yan Jin* · Kwang-Hyeon Chang* · Tae-Hoon Kim* · Jong-Min Oh*
Department of Environmental Science and Engineering, Kyung Hee University*

인공부도의 생물학적 처리 기술 비교 연구: 인공부도의 조류의 저감 효과 개선을 위한 여재와 물벼룩 적용

Mei-Yan Jin* · 장광현* · 김태훈* · 오종민*
경희대학교 환경학 및 환경공학과*

요 약 : 호소의 경관성을 향상 시킬 수 있은 자연정화법인 인공식물섬을 설계하고 수질개선 효율을 향상 시키기 위하여 여재, 식생과 물벼룩을 혼용하는 방법을 개발하였다. 따라서 조류 제거 효율을 알아보기 위한 각 혼합시스템은 G-BD-여재와 물벼룩, G-OB-식물과 여재, G-BOD-여재 식물과 물벼룩, G-C-대조군으로 실험 및 평가하였다. 각 혼합시스템 현장적용성을 평가하기 위하여 chl-a, TN과 TP의 제거효율을 조사 하였고, 그 결과 G-BD의 평균제거 효율은 69.24%, 16.61%, -0.61%; G-OB는 평균 68.39%, 14.11%, 10.52%; G-BOD는 평균 78.30%, 6.69%, 25.09%; G-C는 평균 35.42%, -3.47%, -25.18%로 조사되었다. 결과에 따라 제안하면 여재, 식생과 동물플랑크톤을 혼용한 시스템이 조류제어방면에서 효율적으로 나타났다. 하지만 영양염류 제어관리에서는 식생과 여재를 혼합한 시스템이 가장 효율적이다.

주요어 : 생물조작, 여재, 미나리, 물벼룩, 부영양화

Abstract : Media (bio-stone), aquatic macrophytes (*Oenanthe javanica*) and herbivorous cladoceran (*Daphnia similoides*) have been used in artificial floating island (AFI) systems for water pollution control. Efficiency in chl-a concentration controlling of AFI was tested using different combinations of each device: G-BD-mixture bio-stone and *Daphnia similoides*, G-OB-mixture *Oenanthe javanica* and bio-stone,

First Author: Mei-Yan Jin, Department of Environmental Science and Engineering, Kyung Hee University, Yongin 1732, Korea, Tel:+82-31-201-3392, E-mail: jinmeiyan8709@163.com
Corresponding Author: Jong-Min Oh, Department of Environmental Science and Engineering, Kyung Hee University, Yongin 1732, Korea, Tel:+82-31-201-2461, E-mail: jmoh@khu.ac.kr
Co-Author: Kwang-Hyeon Chang, Department of Environmental Science and Engineering, Kyung Hee University, Yongin 1732, Korea, Tel:+82-31-201-3392, E-mail: chang38@khu.ac.kr
Tae-Hoon Kim, Department of Environmental Science and Engineering, Kyung Hee University, Yongin 1732, Korea, Tel:+82-31-201-2461, E-mail: thkim@samaneng.com
Received: 11 October, 2017. Revised: 24 November, 2017. Accepted: 6 February, 2018.

G-BOD-mixture bio-stone, *Oenanthe javanica* and *Daphnia similoides*, and the out-put water quality improvement was compared with G-C-control (no device was applied). We analyzed removal efficiency of chl-a concentration and nutrient concentrations in the artificially eutrophic water in the laboratory experimental facility. The results showed average removal rates of Chlorophyll a, TN and TP for different four groups: 69.24%, 16.61%, -0.61%; 68.39%, 14.11%, 10.52%; 78.30%, 6.69%, 25.09%; 35.42%, -3.47%, -25.18%, respectively. The results have suggested that the mixture of media, plants and zooplankton is the most efficient combination for Chlorophyll a control, while the mixture of macrophytes and bio-stone have better efficiency nutrient control.

Keywords : Biomanipulation, Bio-stone, Oenanthe javanica , Daphnia similoides, eutrophication

I. Introduction

From the latter half of the last century, there has been increasing concern regarding the elevated nutrient status and the eutrophication of rivers and lakes (Sierp et al. 2009). One of the most widespread examples of pollution is eutrophication due to inputs of large quantities of organic nutrients, particularly nitrogen and phosphorus to freshwater rivers, lakes, streams and reservoirs (Yang et al. 2008; Zhu et al. 2011). It is well known the main causes of water eutrophication are nitrogen in the form of nitrite or ammonia and phosphorus in the form of orthophosphate (Horne et al. 1994; Lijklema 1995; Cai et al. 1992). Nitrogen and phosphorus contained in wastewater accumulate incessantly in water body, and increase algal biomass excessively. Therefore, it is quite necessary to develop efficient treatments to mitigate and prevent eutrophication.

Ecological engineering for the removal of pollutants at low cost is an emerging field dedicated to the design and construction of sustainable ecosystems that provide a balance of natural and human values (Mitsch et al. 2002). Artificial Floating Island (AFI) technology (Watling 1975; Mallison et al. 2001; Sun et al. 2009; Hu et al. 2010; Hu et al. 2010; Li et al. 2010) is a surface soilless planting technology of modern agronomic and ecological engineering, and it has been proved to be cost-effective and feasible for water quality improvement in eutrophicated water bodies. Recently, AFI has been recognized as eco-technology all over the world and installed at various water bodies such as weirs, rivers, ponds and lakes (Ahn et al. 2004). To increase the efficiency of AFI, new designs and their application include not only various kinds of plant species but also trial of a huge variety of media.

In addition, biological control (Biomanipulation) of algal biomass is the method based on classical top-down control of algal biomass using herbivorous zooplankton. The key species in biological control is cladoceran genus, *Daphnia*, since it is major grazer on high variety of phytoplankton species. Thus, its intensive grazing can suppress algal growth efficiently in water body.

To control the algal biomass in the water body more efficiently, we combined these two techniques, AFI and biomanipulation, and tested its efficiency in nutrients removal and algal biomass suppression from the waste water. We tested the availability of bio-stone, new media material. We combined bio-stone, aquatic macrophytes (*Oenanthe javanica*) and herbivorous cladoceran (*Daphnia similoides*) in the AFI. We compared the algal biomass control efficiencies of the equipment among different combinations of media, macrophytes

Table 1. The primeval water quality of artificial eutrophic water in the two tests.

Parameters	The first test		The second test	
	Range	Value	Range	Value
Temp (°C)	24.50 ~ 25.10	24.80 ± 0.24	24.10 ~ 24.70	24.53 ± 0.29
pH	7.28 ~ 7.48	7.36 ± 0.09	7.79 ~ 8.15	7.97 ± 0.16
EC (μs/cm)	536.00 ~ 595.00	559.25 ± 25.47	537.00 ~ 554.00	546.50 ± 7.94
DO (mg/L)	6.17 ~ 6.59	6.38 ± 0.17	5.11 ~ 6.65	5.86 ± 0.76
TN (mg/L)	7.82 ~ 13.36	11.39 ± 2.45	12.08 ~ 12.67	12.39 ± 0.28
TP (mg/L)	4.70 ~ 5.80	5.08 ± 0.51	4.28 ~ 6.37	5.32 ± 0.93
Chl-a (μg/L)	15.85 ~ 18.25	17.01 ± 1.11	15.72 ~ 18.22	16.90 ± 1.29

and herbivore applied to AFI. We estimated their efficiency and suitability in application to eutrophic water bodies throughout the laboratory experiments.

II. Materials and methods

The experiments were carried out in laboratory. Before construction of AFI, the artificial eutrophic water was prepared with addition of algae (*Senedesmus*), which was cultured in the laboratory. The primeval water quality of artificial eutrophic water was showed in the Table 1. The bio-stone was used in the experiments, which was one kind of media with porosity (adsorptivity, filterability) (Kim et al. 2010). The water quantity used for the test was 800 L (the size of tank: Φ108 cm × 115 cm) (Figure 1).

An integrated artificial floating bed system consisted of three subsystems, aquatic macrophytes (*Oenanthe javanica*) on the first floor (subsystemI), floating island with media (bio-stone) on the second floor (subsystem II) and net with herbivorous cladoceran (*Daphnia similoides*) on the third floor (subsystem III) was constructed (Figure 1). The bed dimension of System I was 40 cm (L) × 40 cm (W) × 15 cm (H) with a perforated bottom plate which had Φ2 cm aperture for supporting plants. The bed dimension of System II was 40 cm (L) × 40 cm (W) × 10 cm (H) with perforated acrylic plate which had Φ2 cm aperture. The bed dimensions of System III was covered with plastic net (40 cm × 40 cm × 40 cm, Φ1 mm). Four groups were devised with combination of bio-stone, *Oenanthe javanica* and *Daphnia similoides*. The groups consisted of G-BD-mixture Bio-stone

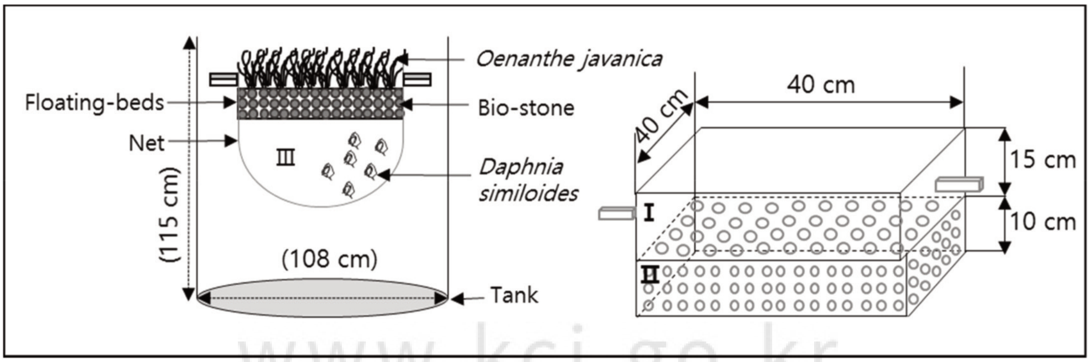

Figure 1. Schematic diagram of the integrated artificial floating island system.

and *Daphnia similoides*, G-OB-mixture *Oenanthe javanica* and Bio-stone, G-BOD-mixture Bio-stone, *Oenanthe javanica* and *Daphnia similoides*, and G-C-Control (no device was applied).

The experiment was repeated twice for each treatment, and each test was carried out for 8-day. The water samples were collected from 20 cm below the water surface at 4 O'clock on daily basis. The water column of experimental tank was gently mixed before the sampling. The collected water samples were kept at 4 °C until the analyzed. A portion of each sample was filtered (Whatman GF/C glass microfiber filters 47 mm Ø circles) and analyzed for ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N) and orthophosphate phosphorous (PO_4^{3-}-P) by ion chromatograph (Metrohm 792 Basic IC). Unfiltered samples were used for the measurements of total nitrogen (TN) by alkaline potassium persulfate digestion-UV spectrophotometry and total phosphorous (TP) by ammonium molybdate spectrophotometric method. Through the experiments, the Chlorophyll-a concentration was measured with Aquaflour (Tunner design).

III. Results and Discussion

As shown in Table 2, the experimental temperature was maintained about 25°C by using electronic thermostat (DH-1000AC1). The analysis of pH, there was not obvious changes in the four groups during the laboratory experiment, and they showed the similar changing ranges. The pH ranged from 7.3 to 8.3, the water was showed slightly alkaline. The electrical conductivity (EC) also showed relatively small changing range in the different four groups, but the changing ranges in G-C (control) and G-BOD (bio-stone, *Oenanthe javanica* and *Daphnia similoides*) were lower than G-OB (*Oenanthe javanica* and bio-stone) and G-BD (bio-stone and *Daphnia similoides*). The dissolved oxygen (DO) concentration was not obviously change in G-C and G-BD, another two groups were obviously decreased with the experimental time. At the second test, the DO concentration was decreased with the experimental time in all groups.

Assimilation and removal of nutrients from water by floating island system are adsorptivity and filterability of media, bioremediation and

Table 2. The range and mean value (±standard deviation) of temperature, pH, DO, EC in the two tests.

Parameters	G-C (Control)		G-OB (*Oenanthe javanica* & Bio-stone)		G-BOD (Bio-stone & *Oenanthe javanica* & *Daphnia similoides*)		G-BD (Bio-stone & *Daphnia similoides*)	
	Range	Value	Range	Value	Range	Value	Range	Value
The first test								
Temp (°C)	24.60 ~ 25.10	24.80 ± 0.22	24.30 ~ 25.40	25.00 ± 0.39	24.70 ~ 25.40	24.90 ± 0.24	24.80 ~ 25.30	25.00 ± 0.18
pH	7.33 ~ 8.33	7.92 ± 0.28	7.48 ~ 8.14	7.90 ± 0.22	7.28 ~ 8.21	7.87 ± 0.27	7.34 ~ 8.29	7.91 ± 0.28
EC (μs/cm)	529.00 ~ 548.00	536.10 ± 7.10	522.00~ 558.00	534.30 ± 12.34	536.00 ~ 549.00	540.40 ± 5.53	539.00 ~ 595.00	550.10 ± 18.41
DO (mg/L)	6.05 ~ 6.65	6.46 ± 0.18	5.04 ~ 6.50	5.85 ± 0.44	5.04 ~ 6.60	5.66 ± 0.60	6.34 ~ 6.55	6.45 ± 0.08
The second test								
Temp (°C)	24.60 ~ 25.10	24.90 ± 0.21	24.70 ~ 25.10	24.90 ± 0.15	24.10 ~ 25.30	24.90 ± 0.24	24.60 ~ 25.40	25.00 ± 0.28
PH	7.81 ~ 8.15	7.97 ± 0.11	7.70 ~ 7.99	7.82 ± 0.12	7.68 ~ 7.88	7.81 ± 0.06	7.78 ~ 8.15	7.96 ± 0.12
EC (μs/cm)	537.00 ~ 552.00	546.00 ± 2.05	543.00 ~ 566.00	556.10 ± 7.95	552.00 ~ 575.00	564.90 ± 8.27	553.00 ~ 569.00	560.90 ± 5.51
DO (mg/L)	5.80 ~ 6.65	6.16 ± 0.27	4.42 ~ 5.33	4.71 ± 0.28	3.89 ~ 5.11	4.37 ± 0.41	5.52 ~ 6.36	6.10 ± 0.25

Table 3. Average removal rate of chlorophyll a, TP and TN in the artificial floating bed system.

	Chlorophyll a (%)	TP (%)	TN (%)
G-C (Control)	35.42	-25.18	-3.47
G-BD (Bio-stone & *Daphnia similoides*)	69.24	-0.61	16.61
G-OB (*Oenanthe javanica* & Bio-stone)	68.39	10.52	14.11
G-BOD (Bio-stone & *Oenanthe javanica* & *Daphnia similoides*)	78.30	25.09	6.69

phytoremediation approach. As shown in Figure 2A, the initial concentrations of TN in the two tests showed respectively: 11.92 mgL^{-1}, 12.58 mgL^{-1} in G-BD (bio-stone and *Daphnia similoides*); 12.44 mgL^{-1}, 12.23 mgL^{-1} in G-OB (*Oenanthe javanica* and bio-stone); 13.36 mgL^{-1}, 12.67 mgL^{-1} in G-BOD (bio-stone, *Oenanthe javanica* and *Daphnia similoides*); 7.82 mgL^{-1}, 12.08 mgL^{-1} in G-C (control). Average removal rates for TN were showed ranges of 16.61% in G-BD, 14.11% in G-OB, 6.67% in G-BOD, -3.47% in G-C (Table 3). The processes of nitrogen removal from eutrophic water may include nitrification/denitrification, plant uptake, microbial uptake, and volatilization (Tanner et al. 1999). As shown Figure 2D, NH_4^+-N concentrations of the two tests in the four groups ranged: 0.24 ~ 0.14 mgL^{-1} in G-BD, 0.67 ~ 0.18 mgL^{-1} in G-OB, 0.7 ~ 0.19 mgL^{-1} in G-BOD and 0.29 ~ 0.07 mgL^{-1} in G-C. NH_4^+-N concentrations in the two tests had similar trend between G-OB and G-BOD, and the same trend between G-BD and G-C. NO_2^--N concentrations of the two tests in the four groups ranged: 0.3 ~ 0.23 mgL^{-1} in G-OB, 0.3 ~ 0.19 mgL^{-1} in G-BD, 0.31 ~ 0.17 mgL^{-1} in G-BOD, 0.29 ~ 0.23 mgL^{-1} in G-C, as shown in Figure 2C. At the first test, all groups of NO_2^--N concentrations had the similar changing trend. Two groups were similar, one was between G-BD and G-C, another was among G-OBand G-BOD at the second test. As shown Figure 2B, NO_3^--N concentrations of the two tests in the four groups ranged: 9.3 ~ 6.6 mgL^{-1} in G-BD, 9.1 ~ 7.0 mgL^{-1} in G-OB, 8.3 ~ 7.0 mgL^{-1} in G-BOD, 9.2 ~ 6.8 mgL^{-1} in G-C. At the first test, three groups of NO_3^--N concentrations decreased except G-C, and both three groups of NO_3^--N concentrations increased except group G-BOD at the second test.

The initial concentrations of TP concentrations in the two tests showed respectively: 4.70 mgL^{-1}, 4.87 mgL^{-1} in G-BD (bio-stone and *Daphnia similoides*); 5.06 mgL^{-1}, 6.37 mgL^{-1} in G-OB (*Oenanthe javanica* and bio-stone); 5.80 mgL^{-1}, 5.76 mgL^{-1} in G-BOD (bio-stone, *Oenanthe javanica* and Daphnia similodes); 4.74 mgL^{-1}, 4.28 mgL^{-1} in G-C (control), as shown in Figure 2E. Average removal rate for TP in the two tests was shown for -0.61% in G-BD, 10.52% in G-OB, 25.09% in G-BOD, -25.18% in G-C (Table 3). From the Figure 2E, the TP concentrations were decreased obviously in two tests, and the reduced trend of three groups were similar except G-C at the second test. G-BOD revealed most clearly on the reduced trend of TP concentration in the two tests, but in the first test was mostly. As shown Figure 2F, PO_4^{3-}-P concentrations of the two tests in the four groups ranged: 3.3 ~ 2.7 mgL^{-1} in G-BD, 3.2 ~ 3.0 mgL^{-1} in G-OB, 3.2 ~ 2.8 mgL^{-1} in G-BOD, 3.4 ~ 3.1 mgL^{-1} in G-C.

The performance of TN concentration fluctuated up and down throughout the experiments due to the impacts of *Daphnia similoides*, bio-stone and *Oenanthe javanica* (Figure 2A). And the trend of TP concentrations was similar to TN (Figure 2E). The changes stemmed from integrated floating

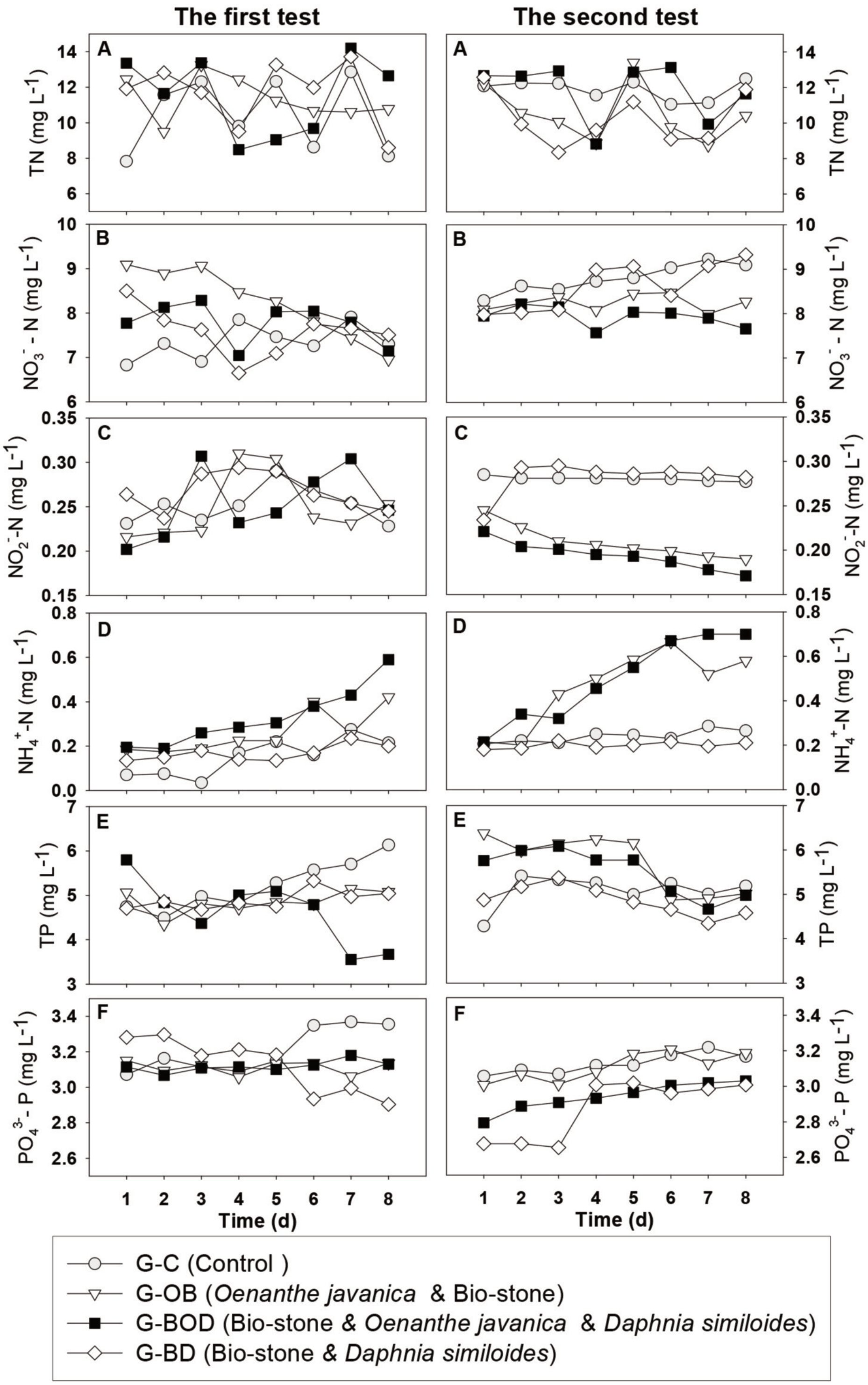

Figure 2. Time courses of total nitrogen (TN), ammonia nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N), total phosphorous (TP) and orthophosphate phosphorous (PO_4^{3-}-P) concentration of different floating-bed systems in the two tests.

island system with *Daphnia*, aquatic macrophytes and bio-stone. There was a marked drop in chl-a concentration due to the direct grazing of *D. similoides* on algae. Therewith, nutrient concentration was decreased. But nutrient regenerated by *Daphnia* and they returned N to the environment at a much higher rate than P, nutrients recycling theory predicts that the phytoplankton community should become more uniform and strong P limited system in the presence of low N : P ratio (Sterner 1990). It has been suggested that grazers such as *Daphnia*, result in the elevated phytoplankton C : P and N : P ratios. Consistent with this prediction, the removal rate of TN was lower than TP but rates did not change in the control. Nutrient was consumed by the growth process of plants, and microorganisms on aquatic macrophytes' roots can absorb and assimilate a part of nutrient (Schmidt et al. 2002). However, particles attached on the roots, and stems and leaves made Suspended Solid (SS) and nutrient concentrations increase when they are released to the water. Besides, there was a marked removal efficiency in nutrient by using bio-stone. Bio-stone decreased nutrient concentrations with its porosity (adsorptivity, filterability) (Kim et al. 2010).

Daphnia had a significant grazing impact on phytoplankton biomass, and induced lower chl-a in the treated systems. At the same time, bio-stone have good efficiency for decreasing chl-a concentrations with its porosity (adsorptivity). Moreover, aquatic macrophytes over the water surface provides a barrier against light penetration into the water column, and deficiency in nutrients due to the competition with hydrophytes, thereby inhibiting algae growth. Chl-a concentrations of the two tests in the four groups ranged: 18.2 ~ 5.3 ugL^{-1} in G-BD (bio-stone and *Daphnia similoides*), 18.4 ~ 3.8 ugL^{-1} in G-OB (*Oenanthe javanica* and bio-stone), 16.3 ~ 2.4 ugL^{-1} in G-BOD (bio-stone, *Oenanthe javanica* and *Daphnia similoides*), 17.6 ~ 9.7 ugL^{-1} in G-C (control), as shown in Figure 3. Average removal rate for chl-a in the two tests was shown for 69.24% in G-BD, 68.39% in G-OB, 78.30% in G-BOD, 35.42% in G-C (Table 3). All of the groups except group control showed an obviously reducing pattern of chl-a in two tests.

IV. Conclusions

The main purpose of the present study was

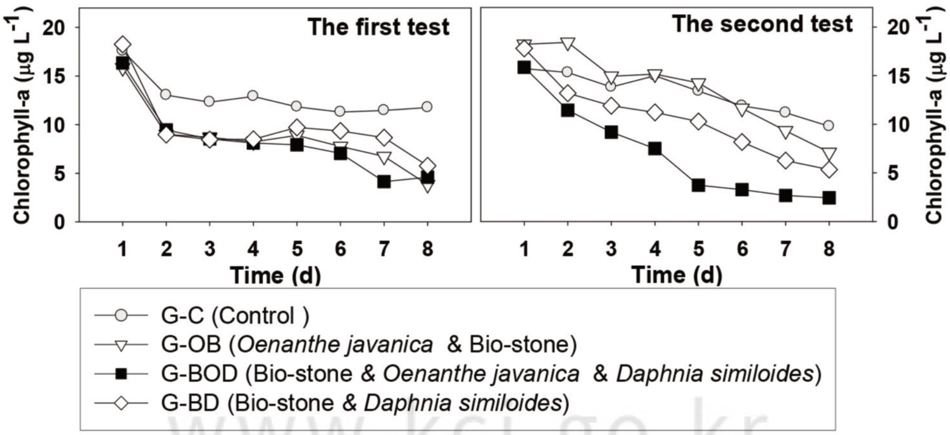

Figure 3. Time courses of Chlorophyll-a concentration of different floating-bed systems in the two tests.

application of different floating-bed systems with bio-stone, Oenanthe javanic and *Daphnia similoides*, estimate their efficiencies in nutrients and chl-a removal from the water body. The results showed good efficiency on algae control in different artificial floating beds system, but the removal rates of nutrient were not efficient as we expected. This low efficiency seems to be due to the nutrient recycling through the *Daphnia* grazing and excretion, which is often happening in the artificial floating bed with application of biomanipulation. The removal efficiency of chl-a concentration was different according to different combination of bio-stone, herbivore and macrophyte. The most efficient removal of chl-a occurs at the different artificial floating beds system treatment followed by G-BOD (bio-stone, *Oenanthe javanica* and *Daphnia similoides*) > G-OB (*Oenanthe javanica* and bio-stone) > G-BD (bio-stone and *Daphnia similoides*) > G-C (control). In spite of this, with the experimental duration of floating island system, the removal rates of algae were more than 65% in all groups except group C, but the group including all devices (with *D. similoides*) was better in algal biomass control. From the results, mixture of *Oenanthe javanica* and bio-stone had better efficiency than other combination in nutrient control. Therefore, the present study had suggested that the combination of various devices should be considered depending on the eutrophication characteristics of target water body for the efficient application.

Acknowledgment

This subject was supported by "Development of algae management using stream structures in the stream" (code 17CCTI-B063263-06) funded by MOIT (Ministry of Land, Infrastructure and Transport).

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