Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

JEB
Journal of Environmental Biology

ISSN: 0254-8704
CODEN: JEBIDP

Water quality improvement by natural plant-mineral composites and field temperatures of a eutrophic lake in South Korea

Byung Jung-Hwan[1], Ha-Kyung Kim[1], Sun-Ki Mun[2] and Baik-Ho Kim[3]*

[1]Department of Environmental Science, Hanyang University, Seoul 133 791, South Korea
[2]MCE-Korea Co., Seongnam-si, Gyeonggi 463 712, South Korea
[3]Department of Life Science, Hanyang University, Seoul 133 791, South Korea
*Corresponding Author E-mail: tigerk@hanyang.ac.kr

Publication Info

Paper received:
23 September 2013

Revised received:
31 January 2014

Accepted:
14 February 2014

Abstract

To improve the water quality of Shingal Reservoir, a eutrophic lake in South Korea, field tests were performed to assess the influence of water temperature on water quality improvement (WQI) ability of domestic plant–mineral composites (PMCs). Interestingly, Cyanobacterium was found to be dominant even in low-temperature seasons, especially winter leading to more effective for diatom growth. Factors such as phytoplankton, biological oxygen demand (BOD) and phosphorous showed high WQI over 70% at 20°C, but declined to 40% at temperatures above 25°C. WQI for Cyanobacteria decreased with increasing water temperature, whereas for diatoms WQI was 90% regardless of water temperature. Additionally, bacterial density and total nitrogen showed very low WQI without water temperature. Collectively, the results indicate that high water temperature decreased WQI ability of a PMC to control phytoplankton (*Microcystis aeruginosa*) and increased their ability to control diatoms.

Key words

Allelochemicals, Field temperature, Phytoplankton, Plant-mineral composite, Water quality

Introduction

A variety of physical, chemical and biological technologies have been developed to improve the water quality of eutrophic water bodies (Yamamoto *et al.,* 2005; Sigee, 1999; Moslemi *et al.,* 2012). However, their effects are temporary, and their perforce repetitive treatment threatens to become a new factor disturbing ecosystems. This has led to an increasing demand for eco-friendly technologies with low eco-toxicity. Eco-friendly technologies that have been used so far to inhibit algal growth involve the use of either plant-derived allelochemicals, including tannins and other phenolic compounds (Pillinger *et al.*, 1994; Inderjit *et al.,* 1995) or minerals with properties of strong adhesion to particulate organic matter (POM) and dissolved organic matter (DOM) because of their densely distributed voids and positive ions (Cooke *et al.*, 2005; Na *et al.*, 1998; Kim, 2000; Kam *et al.,* 2003). However, to date, research combining two or more such natural materials with different properties has been rarely reported.

In an earlier study, in our laboratory, we have developed plant–mineral composites (PMCs) by extracting two or more natural materials with simple extraction process and mixing them at appropriate ratios, then conducting laboratory and field experiments to optimize their application and select PMC treatment concentrations, light intensity, water depth, algal species and toxins (Kim *et al.,* 2010; Kim *et al.,* 2011; Lee *et al.,* 2011; Kim *et al.,* 2013). However, these experiments were carried out under different aquatic conditions, so no clear explanation could be provided about the effects of PMC on water quality improvement in the same water body under different environments (i.e. water temperature).

In general, the efficacy of coagulants during water treatment is greatly influenced by environmental factors (Letterman *et al.,* 1999; Pernitsky and Edwald, 2006; Kim and Lawler, 2008; Kim *et al.,* 2008). It is, therefore, important to evaluate the changing behavior of coagulants by varying environmental gradients (i.e. temperature) in the same water

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body, rather than by varying the water body. As phytoplankton growth in an eutrophic lake rich in nutrients generally shows a highly positive correlation with increase in water temperature (Wade *et al.,* 2002), it is still unclear whether the reaction rate of phytoplankton with POM or DOM will increase after PMC treatment. Such a study is believed to be of vital importance for setting up optimal PMC treatment concentration and duration and to have an impact on ecological disturbance and economic feasibility.

In the present investigation, field tests were performed to assess the effect of *in situ* temperature on water quality treatment using a PMC in a eutrophic lake. Additionally, the test was conducted to compare the WQI using a PMC at a location where water temperature was declining, and compared the results with those of the previous studies which showed the conditions and water temperature at different locations.

Materials and Methods

The study station : The Shingal Reservoir is located in Yongin, Gyeonggi-do (South Korea), which is near the Gyeongbu Highway. This lake is shallow (maximum depth = 10 m), small (surface area = 5.3 km^2, Capacity=1.0 m^7), and is a major resource for agricultural water and recreation. In the river basin, increasing point pollution sources such as a golf course and factories and nonpoint pollution sources due to housing sites and urban development have been observed, and massive amounts of organic matter, including soil and nutritive substances, flow into the region during the rains. The Shingal and the Jikok streams meet at the entrance of upper region, which is connected to the outlet of a sewage treatment plant, causing water pollution and malodour. It has been reported that cyanobacterial blooms occur every year (Oh and Lee, 1997; Seo *et al.*, 2012).

For experiment, an experimental group (approximately 5000 t) was established near the shore to conduct a field application of the entire water body of the Shingal Reservoir located in Yongin, Gyeonggi-do. After choosing a location in which light was not limited, a fence made of Teflon material was installed to protect the water; our study included collecting information on the water level of the target area and regional characteristics. The fence was placed on the ground with a heavy pendulum hanging from the lower part of the fence to minimize the water traffic. Considering the tipping effect of turbidity materials and biotic factors due to wind, two locations from inside and outside the each fence were chosen and then used the average values of those locations.

Experimental design: Three field tests (8, 14 and 18°C) were conducted between October and November, 2012. After each test, the water-protecting fences were removed. For every test, PMC was processed to a final concentration of 0.5 mg l^{-1}, according to Lee *et al.* (2011). First, PMC formulated concentrate (10 g l^{-1}) was mixed with tap water to achieve a final concentration of 0.5 mg l^{-1}. The diluted PMC was sprayed uniformly over the experiment section (inside the fence), using a spray gun. After PMC processing, the coagulated suspended solids were collected to one side using an air blower or collecting net and were then gathered into a collection bag using an inhaler. The water separated from the collected material was returned to the reservoir. To compare the changes in water quality before and after PMC processing, the test was divided into the following time points: 3 days before processing, one day before processing, 6 hr after processing, and 24 hr after processing. After processing, the WQI ability of PMC was computed using the following formula: WQI (%) = (1-T/C) × 100, where C denotes the measured value before PMC treatment and T denotes the measured value after PMC treatment.

Water quality analysis : Environmental factors such as water temperature, pH, dissolved oxygen, electrical conductivity, turbidity, total nitrogen, total phosphorus, Chl-*a*, SS, BOD, COD, as well as biotic factors, namely phytoplankton and bacteria, were also examined. Environmental factors that were difficult to measure on site were sampled using a Van-Dorn water sampler and were then transported in an icebox to a laboratory for analysis. In each experiment, the water temperature, pH, dissolved oxygen, and turbidity were directly measured using a portable multi-parameter and the rest of the categories were measured in the laboratory after water sampling. The environmental factors were analyzed in accordance with the standard method (APHA, 2005). For chlorophyll (Chl-*a*), 500 ml site water sample was filtered using a GF/F filter, added 10 ml of 90% acetone, and then kept it in a cold bin for 24 hr. After incubation, water sample was centrifuged and supernatant was collected. Finally, Chl *a*, content in a multi-spectrum, was measured using a universal spectrophotometer.

The obtained suspended solids (SS) were dried at 100°C in a dry oven and a certain amount of the specimen was filtered using a GF/F filter and then weighed. The SS was dried again for 24 hr at 100°C in a dry oven and then weighed. Finally, we computed the difference in the measured weight for the SS. To determine biochemical oxygen demand (BOD), water was collected in BOD bottles according to the Winkler method and incubated the bottles in the dark at 20°C in an incubator for 5 days. Then, BOD was computed by comparing the current O_2 concentration to the O_2 concentration of the fixed specimen collected on the day of the water sampling. Chemical oxygen demand (COD) was measured using the alkaline potassium permanganate method (APHA, 2005). Total nitrogen (TN) was measured using cadmium reduction method and total phosphorus (TP) was measured using ascorbic acid method, after persulfate disintegration (APHA, 2005).

For assessment of bacteria as a biotic factor, sampled water, was fixed with glutaraldehyde solution (final concentration, 1%), and transported it to a laboratory, where the number of

bacteria was counted using the 4', 6-diadimino-2-phenylindole (DAPI) staining method (Porter and Feig, 1980). For identification and measurement of phytoplankton coefficient, water samples were collected in 250 ml polyethylene gathering bottles, fixed using Lugol's solution (final concentration, 1%), and transported to the laboratory. The transported solution was allowed to settle for at least 12 h. For quantitative analysis, we placed 1 ml of the fixed specimens in a Sedgwick–Rafter Chamber and then counted them under an optical microscope at 100× magnification after allowing it to stabilize for at least 3 min. Phytoplankton were identified to the species level at 400–1000× magnification, and those that could not be identified were categorized as 'unidentified'.

Results and Discussion

After PMC treatment, environmental and biotic factors showed both increasing and decreasing patterns in the first, second, and third experiments (Fig. 1).

Addition of PMC induced a steep reduction of over 70% in turbidity, SS and Chl-*a* through the three experiments at different water temperatures, indicating that PMC treatment was not largely affected by temperature. It has been previously reported (Yoo and Yoon, 2004) that Si component is affected by change in temperature; when Si is added to a coagulant, the turbidity removal ratio increased and thus, even if floc was not formed normally, a relatively large floc formation could be induced by the addition of Si. On the other hand, after PMC processing, the total phosphorus level showed higher reduction when compared to the level of total nitrogen in the water body, which is equivalent to the results of the previous study (Kim *et al.,* 2011). These results might be largely attributable to the adsorption effect of Al as a PMC component (Galarneau and Gehr,1997; Chung and Yu, 2006). Phosphorus significantly contributed more to algal growth as compared to nitrogen, and thus, had to be removed from water body to improve water quality (Davis *et al.,* 2004; Hsieh *et al.*, 2007). Therefore, the results proved that PMC was extremely suitable for water quality improvement of eutrophic water bodies.

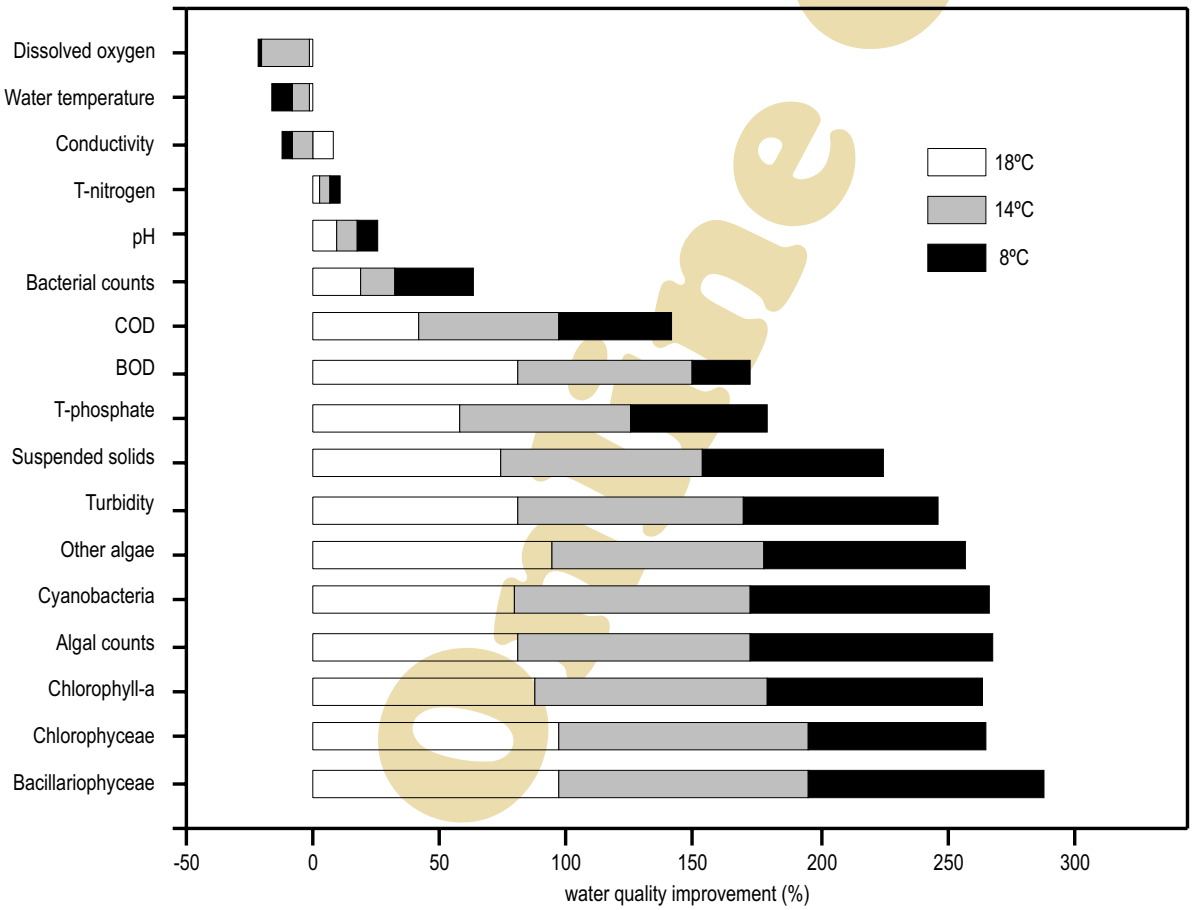

Fig. 1. Water quality improvement (%) by a plant-mineral composite (PMC) in field experiments at three different temperatures in a eutrophic lake, Lake Shingal, South Korea. Green and other algae were occupied below 1% of total concentration of phytoplankton

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The standing crop of bacteria affecting water was 18.4% in the first test, 13.4% in the second and 31.6% in the third. Phytoplankton accounted for 80.3% in the first test, 2.6% in the second and 94.7% in the third test. In terms of phytoplankton, at least 80% of high water improvement was observed in all experiments regardless of temperature, and this was similar to the findings of our previous study (Lee *et al.*, 2011). However, decrease in the bacterial standing crop was lower than decrease in phytoplankton level, which is in accordance with results from a previous study (Han *et al.,* 2012) showing minimal effects on bacteria compared to that on phytoplankton when a coagulant was processed. During experiment, cyanobacteria accounted for over 90% of the total standing crop, with *Microcystis aeruginosa* as the predominant species. The WQI effect increased with decrease in water temperature, 79.0% for the first test, 89.0% for the second and 94.4% for the third. In a similar study involving bird control using plant extracts, the density of *M. aeruginosa* decreased from 10^6 to 10^4 cells ml^{-1}. However, further research is needed to establish a relationship between density of *M. aeruginosa* and PMC concentration because it is uncertain whether this finding was merely due to bird density (concentration of organic matter) or due to low PMC concentration.

When considering the change of standing crop in terms of phytoplankton class and PMC treatment (Table 1), the first experiment showed the following composition: 97.5% diatoms; 97.2% green algae; 93.8% others (*Rhodomonas* + *Euglena*) and 79.0% cyanobacteria. The diatom density showed the most significant decrease, and in the second experiment, the order was as follows: 98.1% green algae; 97.1% diatoms; 89.0% cyanobacteria; 89.3% others. The green algae were most effectively decreased. However, in the third experiment, algal bloom showed highest values, as follows: 94.4% cyanobacteria; 93.0% diatoms; 79.9% others; 70.2% green algae. Eventually, regardless of water temperature, there was an over 70% decrease across all taxa, with diatoms the most effectively controlled. These results are different from those obtained in the previous study in which PMC was most effective for controlling cyanobacteria (Lee *et al.,* 2011). Further, research is therefore necessary to investigate whether our findings were merely due to differences in the features of the site and timing of the experiment.

In the present investigation, the extent of WQI using PMC treatment and different water temperatures were examined (Fig. 2). For BOD, the range of WQI was 24–79%, showing that it was greatly influenced by water temperature. In the third experiment, WQI was lowest when water temperature was lowest (7°C), but was highest when water temperature was highest in the first experiment. Correlation between water temperature and BOD was very high (r^2 = 0.996, P <0.05). COD (WQI, 38–55%), TN (2.6–4.7%) and TP (53–68%) were not significantly influenced by changes in water temperature. Compared to the previous study,

Table 1 : Water quality improvement (%) ability of plant-mineral composites (PMCs) on phytoplankton communities in field experiments at three different temperatures in a eutrophic lake, Lake Shingal, South Korea. Green and other algae were occupied below 1% of total concentration of phytoplankton

Phytoplankton	Water quality improvement (%)		
	1st Experiment	2nd Experiment	3rd Experiment
Cyanobacteria			
Microcystis aeruginosa	80.8	93.4	95.6
Microcystis spp.	77.1	91.1	94.9
Bacillariophyceae			
Melosira varians	81.3	94.7	100.0
Nitzschia palea	97.8	97.2	92.9
Chlorophyceae			
Chlamydomonas globosa	91.1	97.1	
Coelastrum microporum	96.1	98.6	85.7
Coelastrum reticulatum	100.0	100.0	
Oocystis borgei	100.0	100.0	
Pandorina morum		100.0	
Pediastrum duplex var. *gracilimum*	100.0	100.0	
Pediastrum duplex var. *reticulatum*	100.0	100.0	100.0
Pediastrum simplex var. *stumii*			
Pediastrum tetras	93.8	66.7	66.7
Scenedesmus aculeolatus	100.0		
Scenedesmus obtusus	57.3		14.3
Scenedesmus quadricauda		100.0	
Scenedesmus quadricauda var. *insingnis*	100.0		100.0
Others			
Cryptomonas ovata	93.9	83.9	63.3
Trachelomonas sp.	87.5	100.0	

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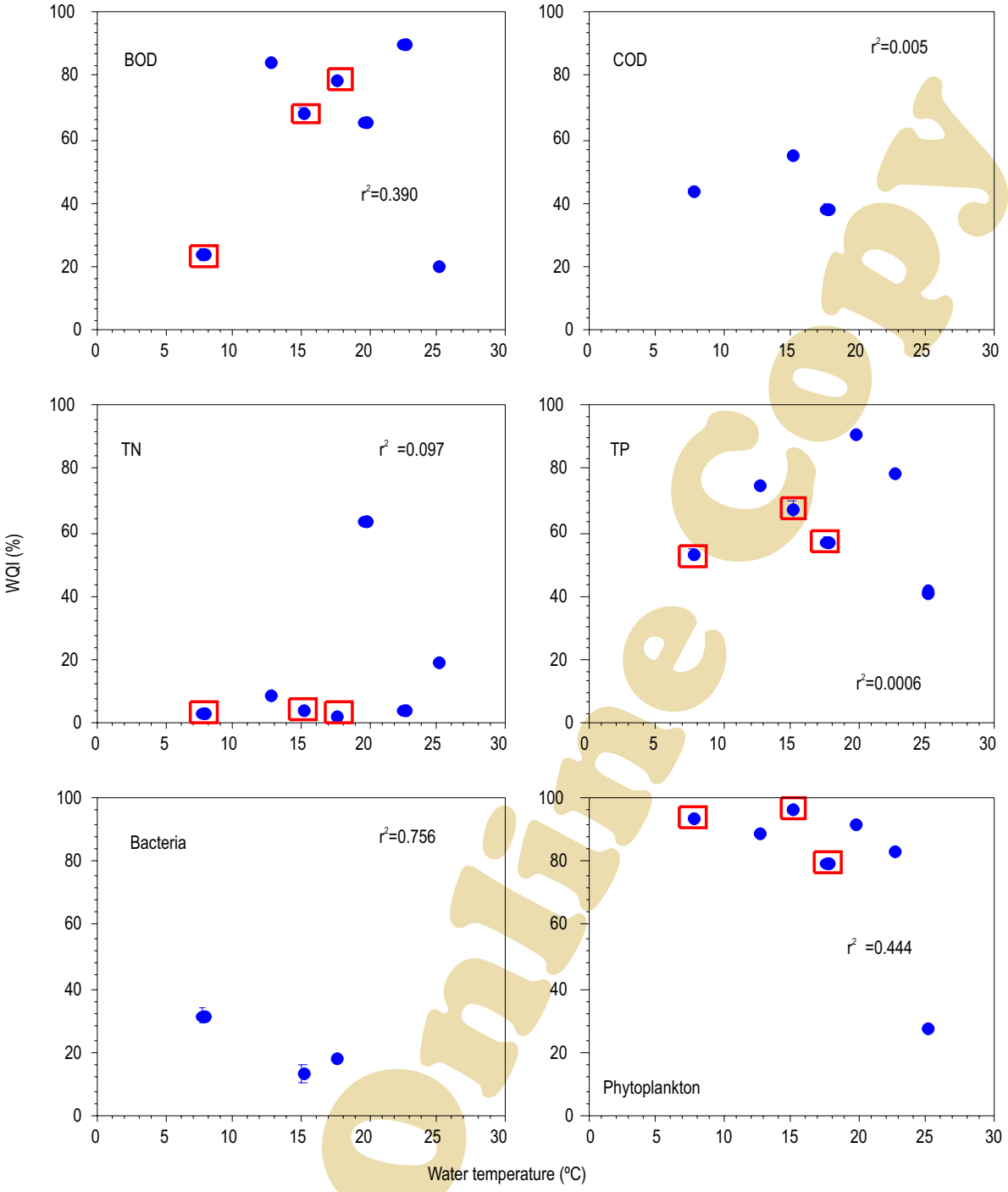

Fig. 2 : Relationship between water temperature and water quality improvement by a plant-mineral composite in Lake Shingal, South Korea. Except for the three quadrats in each figure, all data were used with permission of Kim *et al.* (2011)

WQI was strongly influenced by water temperature fluctuations; however, when the water temperature decreased below 10°C, the WQI also decreased. When water temperature increased above 25ºC, the WQI also decreased, implying that the effect of PMC was limited to a certain range (10–23°C). Although TN did not show any significant influence, WQI increased at

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temperatures above 20°C, whereas TP and phytoplankton, regardless of the condition of nutrition and other environmental conditions, showed high WQI (over 80%) below 25°C. In terms of biotic factors, bacteria showed relatively low water quality improvement at 13–32%, but showed a highly negative correlation with water temperature, confirming that it was not greatly influenced by changes in water temperature.

In addition, although the experimental sites were different, the experiment involved various water temperatures (Lee *et al.,* 2011). After addition of blue-green algae *M. aeruginosa* at each water temperature (10°C, 20°C and 30°C), and after adding the same concentration of PMC at 10°C and 20°C, the chlorophyll content was 74%, whereas at 30°C, the content was 50.1%. The mineral ingredients in PMC (loess and elvan) increased in cohesiveness as water temperature increased (Gao and Yue, 2005), but when the pH level increased above 7, more coagulant was required, which was rather uneconomical (Letterman *et al.,* 1999; Lim and Kim, 2009). Although water temperature of all the three experiments was below 20°C, these were not considered huge influences to the cohesiveness because the local water remained close to pH 7. Eventually, because the increase in water temperature requires an increase in the concentration of PMC injection, this method becomes inappropriate in terms of ecotoxicology and safety. Furthermore, it is considered to be inefficient when the field water temperature is higher during summer.

In conclusion, for PMC, high water temperature decreased the effectiveness of cyanobacterial bloom (*Microcystis aeruginosa*) control and increased the effectiveness of diatom control. Additional field tests on PMC treatment concentration and methods in relation to water temperature, when cyanobacterial bloom occurred during warm seasons, are warranted.

Acknowledgment

This work was supported by the research fund of Hanyang University (HY-2012- 731).

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