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Removal Characteristics of Algae for Drinking Water Treatment Plant Using Natural Coagulants

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Abstract

In domestic rivers, eutrophication has led to frequent algae outbreaks. In this regard, this study investigated the algae removal characteristics according to coagulant dosage, light irradiation and coagulation nuclei dose to remove algae for drinking water treatment plant. The test results according to the natural coagulant dosage showed that as the coagulant dosage increased, chlorophyll-a and turbidity decreased, and chlorophyll-a removal efficiency ranged from 79.1% to 86.9%, and turbidity removal efficiency ranged from 74.6% to 88.2%, respectively. According to the results of test on the algae removal efficiency by light irradiation, chlorophyll-a removal efficiency increased from 17.9% to 34.4% as light intensity increased from 2000 lux to 10000 lux, and with an increase of light irradiation, the floating speed of algae turned out to be faster. The test results according to coagulation nuclei dose found that turbidity removal efficiency was 82.8%, and chlorophyll-a removal efficiency was 92.0% at the kaolin dose of 20 mg/L, which suggests that even a small dose of coagulation nuclei can further improve chlorophyll-a and turbidity removal efficiency.

Keywords*: Natural coagulants, Algae, Drinking water treatment plant, Light irradiation, Coagulation nuclei*

1. Introduction

Algae generally inhabit rivers or lakes, which serve as the source of water supply for the water treatment plant. An increase in the population of algae can have an adverse effect on the water treatment plant operations. The water source with a lot of algae population can cause problems such as an increase in coagulant requirements in the coagulation process, membrane obstruction, clogging of sand filter and reduction of settleability [1,2]. In addition, algae cause taste-and-odor compounds and produce toxic substance, deteriorating the quality of the water source and are the causative agent of toxic disinfection byproducts. Cyanobacteria are photosynthetic bacteria which take a primitive form, and they become dominant species in the occurrence of algal blooms, which have a harmful influence on the ecosystem due to the water bloom and toxicity in a river system with high temperature, shallow depth and rich nutrients.

Due to the decrease in rive depth, increased residence time and reduced flow rate, floating algae increase rapidly in stagnant waters, and a big algae outbreak

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leads to taste-and-odor problems in tap water and toxins produced by blue-green algae in the water treatment process, causing concerns about damage to health [3].

In Korea, *Microcystis* are found in most river waters during the summer period. In the year when increased rainfall causes a large amount of rainfall runoff, water bloom caused by cyanobacteria occurs in lakes located in the upper stream, and cyanobacterial algal blooms occur almost every year in a eutrophic lake when flow rate is small and temperature is high [4]. According to the survey of Daecheong Lake, which was conducted by Kim et al. [5], cytobacteria were dominant species of the eutrophic lake, and *Microcystis* were dominant species in a severely eutrophic lake [5].

There have been frequent outbreaks of algae due to eutrophication in rivers of Korea, and many methods have been developed for removal of algae [1]. Korea has two physicochemical algae removal techniques such as a physical method for removing algae using clay and minerals as algicides and a coagulation & sedimentation technology including natural coagulants [6-7].

The cell membrane of algae is generally hydrophilic, and it is difficult to remove the highly hydrophilic substance with coagulants. Autotrophic phytoplankton produce organic matter in the process of photosynthesis, most of which is metabolic product and is mainly discharged in the form of extracellular organic matter (EOM) up to 60-70% of the carbon within the cell [7-8]. In case EOM emissions due to the algae increase during summer months and the target material of the coagulant covers the surface, the induced stabilization of the particles leads to an increase in the coagulant dosage. In addition, the reduction of carbon dioxide in water due to the photosynthesis of algae raises the pH and increases the solubility of the coagulant, thus inhibiting floc formation [7, 9].

There are variety of overseas technologies for algae removal, which include an ozone treatment method, bottom dredging operations, nano-filtration technology, and algae removal techniques using ultrasound and plasma. Of these, the method by flocculation floatation is considered to be effective in terms of removing nutrients in water [7, 10]. Therefore this study investigated the algae removal characteristics using natural coagulants and light reaction of algae.

2. Experimental Materials and Methods

2.1. Experimental Content

For the specimen used in the experiment, raw water was collected in the Han River, and then algae were cultured with appropriate nutrients. In jar-test, a 1-liter container was filled with raw water containing algae, and then the specimen was collected from the bottom of the bottle after operations with a fast speed of 150 rpm for 2 minutes and slow speed of 30 rpm for 15 minutes [11](Figure 1). The natural coagulant used in the experiment was composed of natural raw materials, including a plant material such as a chestnut and a mineral material such as zeolite.

The experiment was conducted to investigate the changes in chlorophyll-a and turbidity according to natural coagulant dosage, algae removal efficiency according to light irradiation dose, and algae removal according to the dose of kaolin acting as coagulation nuclei [7].

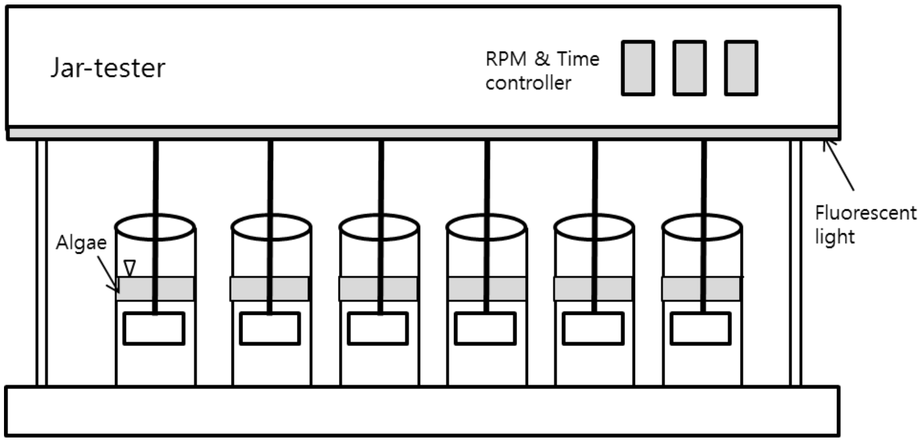

Figure 1. Jar-Tester used in this Experiment (light intensity: 2000-10000 lux)

2.2. Analytical Methods

Chlorophyll-a and alkalinity were analyzed using the standard analytical method (1998) [12], and turbidity and pH were measured by HACH 2100N and HANNA HI 2210, respectively. Light irradiation was investigated with a fluorescent light, and the quantity of light was measured using the MQ-306 (Apogee Instruments. Inc., Logan, UT). Particle size was analyzed with the CHEMTRAC (LaserTrac particle counter PC3400) and Malvern Mastersizer 2000E (Malvern Instrument Ltd., UK). For algae cultivation, $NaHCO_3$ 16.8 g, K_2HPO_4 0.5 g, $NaNO_3$ 2.5 g, K_2SO_4 1 g, NaCl 1 g, $MgSO_4$ $7H_2O$ 0.2 g, $CaCl_2 \cdot 2H_2O$ 0.04 g, $FeSO_4 \cdot 7H_2O$ 0.01 g, Na_2EDTA 0.08 g, H_3BO_3 0.03 mg, $MnSO_4 \cdot 7H_2O$ 0.025 mg, $ZnSO_4 \cdot 7H_2O$ 0.002 mg, $CuSO_4 \cdot 5H_2O$ 0.0079 mg and $Na_2MoO_4 \cdot 2H_2O$ 0.0021 mg were added to 1L of distilled water under conditions of temperature ranging from 25 to 30℃ and light intensity of 6000 lux [13].

3. Results and Discussion

3.1. Algae Removal According To Natural Coagulant Dosage

Figure 2 shows changes in chlorophyll-a and turbidity according to natural coagulant dosage. The algae in raw water was 60 μg/L, kaolin was injected at a dose of 30 mg/L, and light intensity ranged from 3700 to 5100 lux. The algae removal efficiency according to changes in natural coagulants was investigated in the experiment. According to the experimental results, chlorophyll-a and turbidity showed a tendency to decrease as the natural coagulant dosage increased, and the chlorophyll-a removal efficiency was 79.1-86.9%, and the turbidity removal efficiency was 74.6-88.2%, respectively.

Figure 3 shows changes in surface area of particles according to natural coagulant dosage. The total surface area of particles was reduced by about 65% at a dose of 20 mg/L, compared to that of the initial specimen, and the number of 2-5 μm increased the most, and the decrement of more than 5 μm was the least. At a dose of 100 mg/L, the removal efficiency was about 82%, and the decrement of more than 5 μm was greatest.

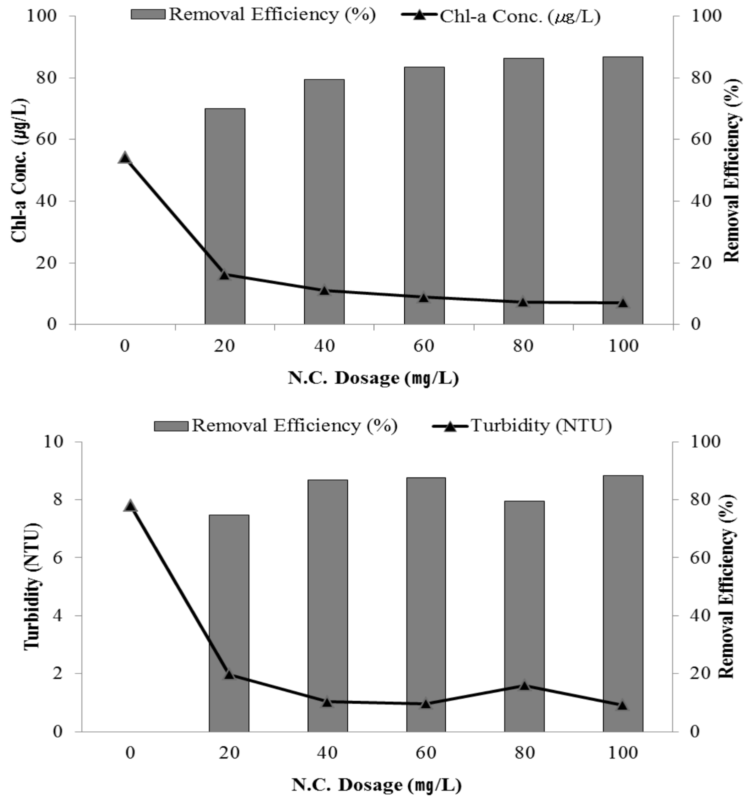

Figure 2. Changes in Chl-a and Turbidity according to Natural Coagulant (NC) Dosage

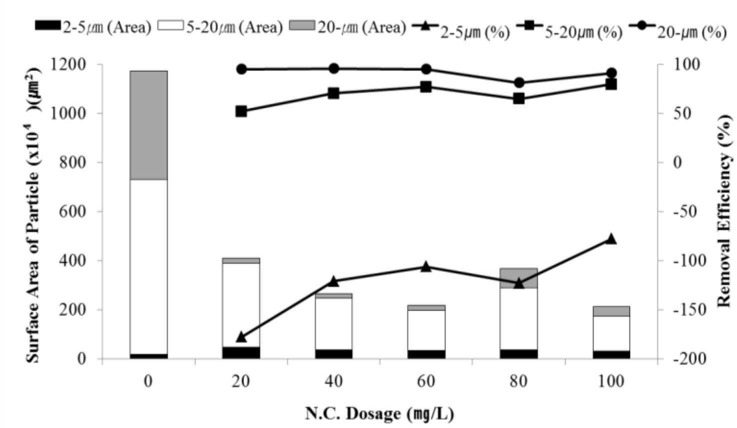

Figure 3. Changes in Surface Area of Particles according to Natural Coagulant (NC) Dosage

Table 4 shows the jar-test results according to natural coagulant dosage. There was no significant change in pH despite an increase of natural coagulant dosage, but alkalinity tended to decrease gradually. The floating speed after coagulation was fastest (39 min) at the dosage of 20 mg/L, but it was slowest at the dosage of 100 mg/L. The number of particles showed a tendency to decrease gradually as the natural coagulant dosage increased.

Table 1. Jar-test Results according to N.C. Dosage

N.C. dosage (mg/L)	0	20	40	60	80	100
Light intensity (lux)	3800	4600	5100	4900	4500	3700
Chl-a conc. (μg/L)	54.1	16.2	11.1	8.9	7.4	7.1
Turbidity (NTU)	7.81	1.98	1.04	0.97	1.6	0.92
pH	6.97	6.83	6.87	6.83	6.86	6.92
Alkalinity (mg/L, $CaCO_3$)	94	84	84	80	78	72
Floating speed (min)	-	39	40	41	40	45
Number of particles ($\times 10^2$)	266	210	190	163	146	122

3.2 Algae Removal According To Light Irradiation

Figure 3 shows changes in chlorophyll-a concentration and turbidity according to light irradiation with the natural coagulants. As the irradiation dose increased, the chlorophyll-a treatment efficiency also increased, and the removal efficiencies were 17.9, 19.4, 25.4, 28.4 and 34.4% under light intensities of 2000, 4000, 6000, 8000 and 10000 lux, respectively. In the case of turbidity, an increase in light irradiation did not have a significant effect on the changes in turbidity, and the turbidity was found to be slightly increased from 5.2 to 6 NTU as the light intensities increased from 2000 to 10000 lux. Figure 5 shows changes in the surface area of particle according to light irradiation. Despite an increase in light irradiation, there was only a slight change in the total number of particles

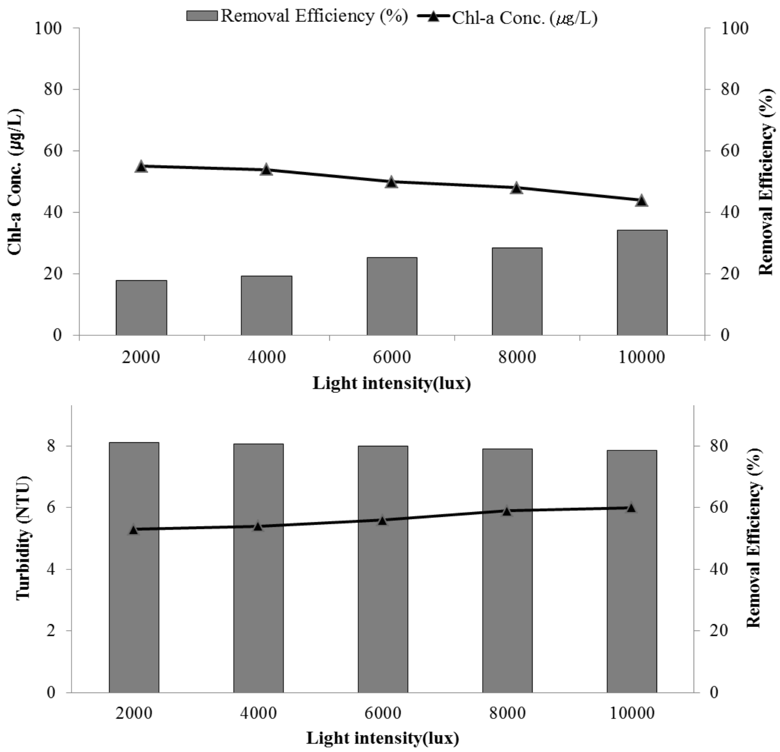

Figure 4. Changes in Chl-a and Turbidity According To Light Irradiation

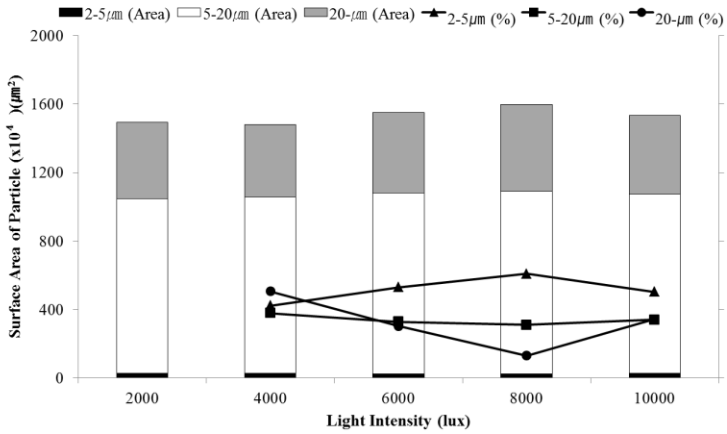

Figure 5. Changes in Surface Area of Particles According To Light Intensity

Table 2 show a summary of jar-test results according to light irradiation. As light irradiation increased, the floating speed increased, and the number of particles exhibited similar values.

Table 2. Jar-Test Results According To Light Irradiation

Light intensity (lux)	2,000	4,000	6,000	8,000	10,000
Chl-a conc. (μg/L)	55	54	50	48	44
Turbidity (NTU)	5.3	5.4	5.6	5.9	6
Floating speed (min)	72	54	44	39	38
Number of particles ($\times 10^2$)	14.91	14.91	15.79	16.25	15.68

3.3 Algae Removal According To Coagulation Nuclei Dose

Figure 6 shows changes in chlorophyll-a concentration and turbidity according to the dosage of kaolin used as cagulation nuclei. Without kaolin, the initial concentration was 15.3 μg/L, and as kaolin dosage increased, chlorophyll-a concentration decreased. In the case of kaolin 20 mg/L, chlorophyll-a concentration decreased to 92.0%, and chlorophyll-a concentration was reduced to 10 μg/L or less at the kaolin dosage of 80 mg/L. Figure 7 shows changes in the surface area of particle according to coagulation nuclei dose. As kaolin dose increased, the surface area of particle decreased, and it decreased up to about 35% at the natural coagulant dosage of 100 mg/L. The particle surface area by particle size showed a tendency to decrease.

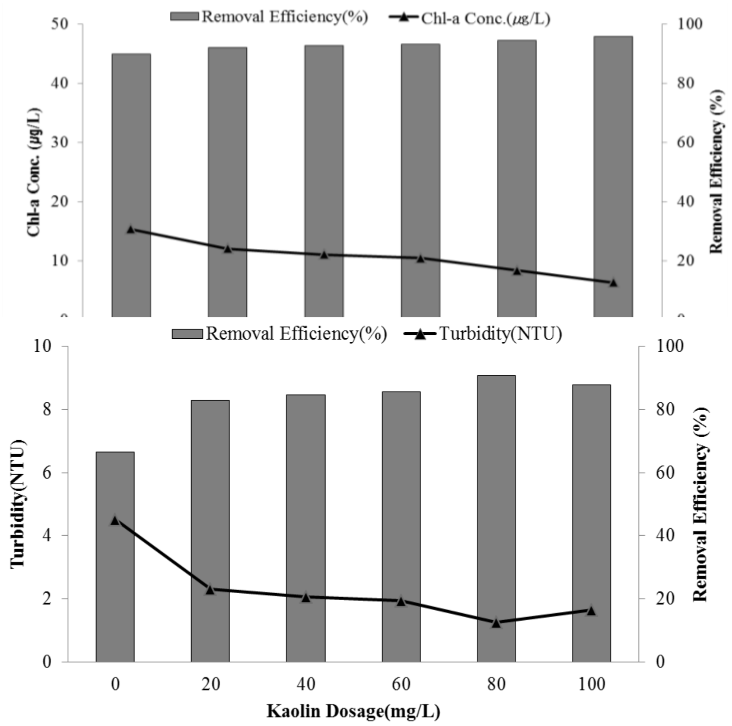

Figure 6. Changes in Chl-a and Turbidity According To Kaolin Dosage

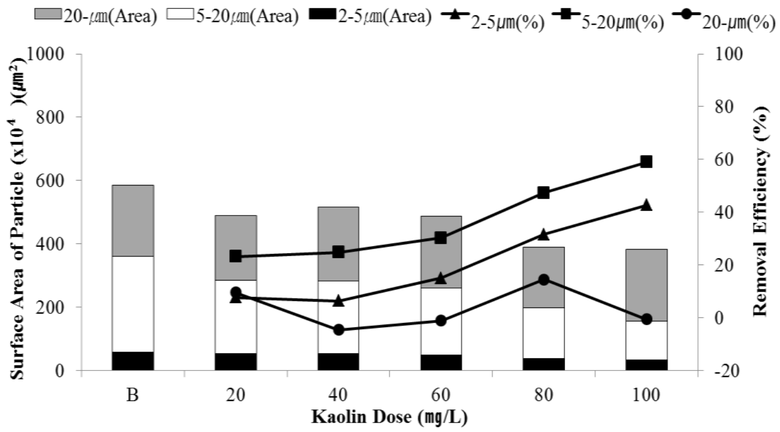

Figure 7. Changes in Surface Area of Particles According To Coagulation Nuclei Dose

Table 3 shows jar-test results according to coagulation nuclei dose. The pH range from 7.2 to 7.3, and alkalinity was lowest (60 mg/L) at the kaolin dose of 40 mg/L. The floating speed was found to be fastest (39 min) at the kaolin dose of 40 mg/L, and the number of particles showed a tendency to decrease gradually as the natural coagulant dosage increased.

Table 3. Jar-Test Results According To Coagulation Nuclei Dose

Kaolin conc. (mg/L)	0	20	40	60	80	100
Light intensity (lux)	6200	7500	7900	7900	7500	6200

Chl-a conc. (μg/L)	15.3	12	11	10.4	8.3	6.3
Turbidity (NTU)	4.5	2.3	2.06	1.94	1.25	1.64
pH	7.24	7.3	7.25	7.22	7.23	7.18
Alkalinity (mg/L, $CaCO_3$)	72	70	60	64	62	68
Floating speed (min)	77	42	39	42	47	54
Number of particles ($\times 10^2$)	215	188	190	173	137	114

4. Conclusion

Tests were conducted to investigate algae removal characteristics according to coagulant dosage, light irradiation and coagulation nuclei dose, and the results are as follows.

1) With regards to algae removal efficiency according to the natural coagulant dosage, as the coagulant dosage increased, chlorophyll-a and turbidity decreased, and the algae floating speed turned out to be fastest (39 min) at the coagulant dosage of 20 mg/L.

2) A look at the algae removal efficiency according to light irradiation revealed that chlorophyll-a removal efficiency increased from 17.9 to 34.3% as light intensity increased from 2000 to 10000 lux, and the floating speed of algae was found to be faster with an increase of light irradiation.

3) In the case of algae removal efficiency according to the dose of kaolin used as coagulation nuclei, chlorophyll-a removal efficiency was 92.0% at the kaolin dose of 20 mg/L, and turbidity removal efficiency was 82.8%, which suggests that even a small dose of nuclei can further improve chlorophyll-a and turbidity removal efficiency.

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