Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.23908

149 (2019) 52–57
May

An experimental study for removing algae particles using a metal mesh membrane

Changgyeong Park[a], Dain Yoon[b], Sung Hyuk Park[b], No-Suk Park[a,*]

[a]*Department of Civil Engineering and Engineering Research Institute, Gyeongsang National University, 501, Jinju-daero, Jinju 660-701, Republic of Korea, Tel. +82-55-772-1798; emails: nspark@gnu.ac.kr (N.-S. Park), pcg2990@gmail.com (C. Park)*
[b]*Department of Civil Engineering, Dong-A University, 550, Nakdong-daero, Busan, Republic of Korea, Tel. +82-51-200-7624; emails: 1770875@donga.ac.kr, (D. Yoon), shpark@dau.ac.kr (S.H. Park)*

Received 4 September 2018; Accepted 1 February 2019

ABSTRACT

This study evaluated the applicability of a metal wire-mesh as a filter to remove algae particles. The filtration experiments were performed with a single layer wire-mesh and a double layer wire-mesh. The removal efficiency was calculated by the total amount of suspended solids captured in the wire-mesh and it reached up to 97%. The single layer wire-mesh filtration experiments were carried out using four types of wire-mesh and the removal efficiencies were compared according to their pore sizes. The double layer wire-mesh filtration experiment was classified into eight cases and the experimental results showed the effective wire-mesh size for the algae removal. In addition, from scanning electron microscope photographs of the wire-meshes following the filtration experiments, the shape of the *Spirulina* sp. algae filtered on the wire-mesh was observed.

Keywords: Algae particles; Metal mesh membrane; Single layer wire-mesh; Double layer wire-mesh

1. Introduction

In Korea, recently there has been excessive algal growth in aquatic environments. This has caused deterioration of the biological environment in aquatic ecosystems due to an increase in turbidity, a reduction of dissolved oxygen, an increase of pH, and the formation of sediment by algal apoptosis, along with taste and odor issues in drinking water. In addition, the secretion of characteristic substances such as microcystin or geosmin can cause the secondary damage [1,2].

Algal blooms are influenced by a variety of environmental factors, including water temperature, sunlight, nutrients such as nitrogen and phosphorus, stratification, and water flow rates. Therefore, a number of ways to suppress the growth of algae or to remove the algae directly in the field have been proposed by far. The methods for directly removing existing algae can be divided into physical, chemical, biological, and complex methods [3–6]. As for the chemical methods, direct and indirect damages to secondary pollutants and the aquatic ecosystem have been reported. In the biological methods, the algae removal efficiency is influenced by temporal and spatial variations as well as seasonal and hydraulic influences. From the comparison of various methods, the amount of biomass after treatment and cost of equipment were found to be important for their application in the field [7]. In 2016, 19 projects related to algae problem have been developed and still in progress in three areas, which are green algae bloom prediction, green algae pre/post management and water purification plant management at national level in Korea [8]. The physical methods include sedimentation, filtration, centrifugation, and ultrasound. In addition, techniques have been proposed that can be applied prior to the occurrence of

* Corresponding author.

1944-3994/1944-3986 © 2019 Desalination Publications. All rights reserved.

algae, such as forced circulation, water amplification, artificial dilution, and algae barriers, to disrupt the stratification leading to algal overgrowth [9].

In this study, we propose the application of metal wire-mesh to remove algae particles. Although there are few applications of metal wire-mesh to water treatment and algae removal, there are some cases in wastewater treatment and industrial applications, and its advantages have been recognized in membrane backwash water treatment [10,11]. Park et al. [12] showed an application case of metal wire-mesh for treating the backwash water from a low-pressure membrane and excellent ability to remove suspended solids (SS) were was shown. Metal filters can be roughly classified into four types according to their production types: powder, fiber, wire-mesh, and foam. A metal fiber has a structure in which fibers of 5–30 μm in diameter are randomly arranged without any direction, and a gas or liquid is filtered through the zig-zag path. A metal mesh is woven into a certain shape, and the mesh differs in size based on the characteristics of the weaving methods. A metal powder is manufactured by a molding and sintering process in the desired form after the metal powder is classified into a predetermined particle size. At this time, the size of the particles that can be filtered is determined by the size of the metal powder, and the material is mainly made of stainless steel and bronze powder, thus offering excellent corrosion resistance [11]. The primary objective of this study is to investigate the feasibility of metal wire-mesh filters for removing algae particles through jar-test and filtration experiments.

2. Methods

2.1. Preparation of algae and coagulation experiments

A pretreatment is necessary to apply the wire-mesh as the main process when filtering algae. On algal coagulation, Chekli et al. [13] compared $TiCl_4$, $FeCl_3$, and polytitanium chloride (PTC) coagulants and confirmed that $TiCl_4$ was most effective. Therefore, $TiCl_4$ was used for the coagulation pretreatment process. The algae used in our experiment was *Spirulina* sp. It is a kind of cyanophyta, characterized by a short, thin, spiral cord shape with a short axis of 8–10 μm and a long axis of 60–120 μm. It was cultured in a laboratory and diluted in distilled water for experiments.

Since the coagulation of algae differs depending on the amount of coagulant, a jar test was conducted to determine the optimum dose. In the jar test, the cultivated algae was diluted in distilled water, and six jars were filled with 2 L each. In each of the jars filled with algae diluent, 0.5, 1, 1.5, 2, 2.5, and 3 mL of $TiCl_4$ (0.25, 0.5, 0.75, 1, 1.25, and 1.5 mL L^{-1}) coagulant were injected by reference to the study of Chekli et al. [14], respectively. After injection, the jar tester was rapidly stirred at 100 rpm for 20 s. Then, 70 rpm for 7 min and 30 s, 7 min 30 s at 40 rpm, and finally 25 rpm for 7 min and 30 s. After agitation, the jars were allowed to settle down for 30 min. When sedimentation was complete, the turbidity was measured by taking the supernatant from each jar. It was measured in NTU using a LUTRON TU-2016 turbidity meter. Table 1 shows the turbidity measured according to the amount of coagulant. The turbidity of the raw water was 33.3 NTU, and flocculation and precipitation were best observed in No. 3 case. The turbidity of the No. 3 (refer to Table 1) after jar test was measured as the lowest, 2.6 NTU. Chekli's study used the dose from 1.0 to 10.0 mL L^{-1}, but we observed that 0.75 mL L^{-1} was the best condition for our experiment. Thus, No. 3 test conditions were used for the following experiments.

In filtration experiments, the removal efficiency of the wire-mesh was analyzed based on the suspended solid (SS). SS of a solution of algae sample was determined by filtering solution of water through a pre-weighed filter of a specified pore size, then weighing the filter again after the drying process that removes water in the filter [15].

2.2. Single layer wire-mesh filtration experiments

The wire-mesh used for the filtration is made of Cr and Ni, and has a pore size of 5, 10, 15, and 30 μm. The wire-mesh is in a form in which the horizontal lines are arranged so as to be in contact with one another, and two or more lines are crossed or intersected. The single layer wire-mesh experiments were carried out using four meshes with different pore sizes. First, the wire-mesh was cleaned to remove contaminants. While washing, it was placed in ethanol, ultrasonically washed for 1 h, dried at room temperature for 24 h, and then dried in a dryer at 100°C for 2 h. The dried wire-mesh was cooled in a sulfuric acid desiccator. The cooled wire-mesh was weighed using an electronic scale. A 30 mL solution of algae was filtered through a washed and dried wire-mesh using a filtration device, and the filtrate was suction filtered again with a paper filter. We used Whatman glass microfiber filter which has 47 mm diameter and 1.2 μm pore size with GF/C grade. The filtrated wire-mesh and paper filter were dried in a dryer at 105°C

Table 1
Turbidity change by coagulant dose

Jar test number	Turbidity of raw water (standard deviation) (NTU)	$TiCl_4$ dose (mL)	Turbidity after coagulation (standard deviation) (NTU)
No. 1	33.3 (1.98)	0.5	42.3 (1.9)
No. 2		1.0	19.8 (2.3)
No. 3		1.5	2.6 (0.4)
No. 4		2.0	21.1 (1.5)
No. 5		2.5	14.0 (0.6)
No. 6		3.0	12.6 (0.5)

for 2 h and allowed to cool in a sulfuric acid desiccator. The cool wire-mesh and filter paper were carefully weighed, and the algae particle removal ability was evaluated [12]. All experiments were conducted in duplicate.

2.3. Double layer wire-mesh filtration experiments

Two wire-meshes with different pore sizes were layered to check whether it increases the algae removal efficiency. The double layer wire-mesh used in the experiment was arranged such that the upper layer wire-mesh had a pore size of either 15 or 30 μm. The relatively large pore size filters were placed on the top to prevent the filtration from stopping quickly by surface fouling. A wire-mesh with pore size of 5, 10, 15, or 30 μm was used as the lower layer. The arrangement condition of double layers is summarized in Table 3. For each of the eight cases, the solution containing algae was filtered through the double layer wire-mesh and the filtrate was suction filtered through the paper filter, then the wire-mesh and filter paper were dried and allowed to cool. The wire-mesh particle removal efficiency was evaluated by measuring the weight of the dried and cooled wire-mesh and the paper filter.

2.4. Scanning electron microscope photography

Scanning electron microscope (SEM) photographs were taken in order to observe the shape of the algae present on the cross section of the wire-mesh. Each specimen is scanned with an electron beam with a diameter of 10 μm or less, and the part that emits electrons consists of the detector part of the electrons coming from the specimen, the part shown on the screen such as the amplifier and the scanning coil [16]. The shapes of the wire-mesh and algae were examined by SEM before and after the filtration experiments (JSM-6700F, JEOL, Tokyo, Japan)

3. Results and discussion

3.1. Single layer wire-mesh filtration experiments

Fig. 1 shows the result of filtration performance by the removal efficiencies based on the SS analysis. In this figure, the columns define average removal efficiency and error bars do each standard deviation. Removal efficiencies ranged from 44.2% to 93.9%. The efficiency of the single wire-mesh with pore size 5 μm was 93.2% ± 1.0%, the highest found here. The efficiency of the wire-mesh with pore size of 10, 15, and 30 μm were 66.1% ± 2.1%, 49.1% ± 7.0%, and 58.0% ± 6.8%, respectively. The slope of the regression model equation is negative value (−20.73) and determination coefficient is close to 0.7 (Table 2), we found that the smaller the pore size, the higher the removal efficiency. Since the standard deviation range of 15 and 30 μm cases overlaps, the difference was considered to be insignificant.

The average removal efficiency of wire-mesh of pore size 5 μm was the highest at 93.2% ± 1.0%, but the filtration rate was observed lower than other pore size wire-meshes. That is, a mesh with a small pore size can have high removal efficiency, but the clogging on the surface of wire-mesh proceeds quickly.

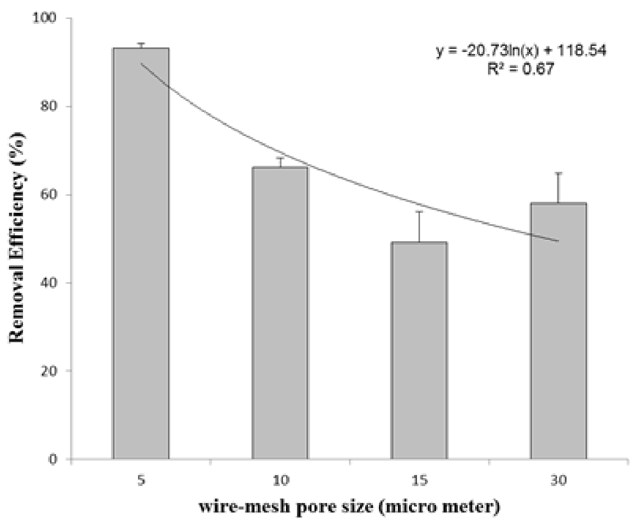


Fig. 1. Single layer wire-mesh removal efficiencies.

Table 2
Filtration experiment results using a single layer wire-mesh

Wire-mesh (pore size)	Average removal efficiency (%)	Standard deviation	Regression model; $y = \beta + \alpha \ln(x)$		
			β	α	R^2
Wire-mesh (5 μm)	93.2	1.0	118.54	−20.73	0.67
Wire-mesh (10 μm)	66.1	2.1			
Wire-mesh (15 μm)	49.1	7.0			
Wire-mesh (30 μm)	58.0	6.8			

3.2. Double layer wire-mesh filtration experiments

Table 3 shows eight configuration cases of double layer of wire-meshes. Because of clogging on the surface of wire-mesh with smaller pore sizes which was shown in the single layer experiments, 15 and 30 μm meshes were placed on the upper side, and the other four types of meshes were placed on lower side. Fig. 2 shows results of SS removal efficiencies. Investigating from the average removal efficiency, case 5 and case 1 had high removal efficiencies, 97.4% ± 3.2% and 95.8% ± 3.2%, respectively. The difference between two cases seems insignificant due to the overlapping of standard deviations. The wire-mesh with pore size of 5 μm, which had the highest removal efficiency of 95.2% ± 3.2% in the single layer wire-mesh filtration experiment, was included in case 1 and case 5 of the double layer wire-mesh filtration experiment. As expected, the double layer resulted in higher efficiency of 87.2% ± 3.9% and 87.6% ± 4.4% than the single layer of 66.6% ± 4.2% in average. It means that the removal of algae particles could be increased more than 20% by adding one layer of wire-mesh. This seems to be due to the enhanced

Table 3
Filtration experimental configurations using a double layer wire-mesh

Configuration	Pore size of upper wire-mesh	Pore size of lower wire-mesh
Case 1		5 μm
Case 2	15 μm	10 μm
Case 3		15 μm
Case 4		30 μm
Case 5		5 μm
Case 6	30 μm	10 μm
Case 7		15 μm
Case 8		30 μm

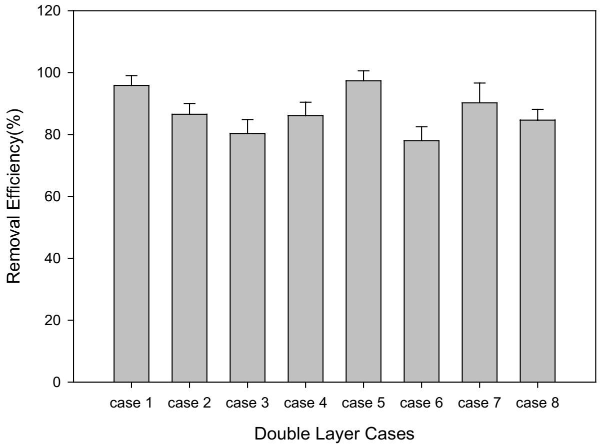
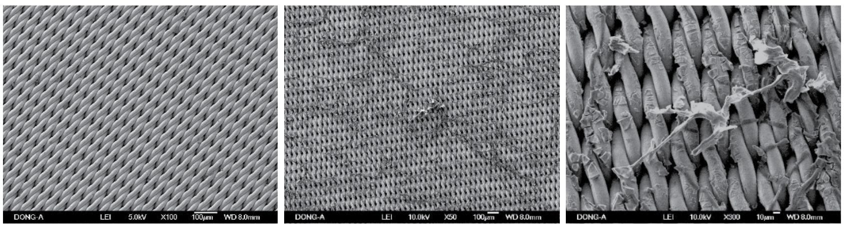


Fig. 2. Double layer wire-mesh removal efficiencies.

effect of internal filtration by clogged SS between two layers. Unlike the single layer test results, it was not possible to clearly see the tendency of the efficiency to decrease even if the pore size increased in the double layer experiment. It is considered that this is due to the characteristic of the double layer which performs the filtering function both on the surface of wire-mesh and inside of two meshes, unlike the single layer which is mostly filtered by the surface.

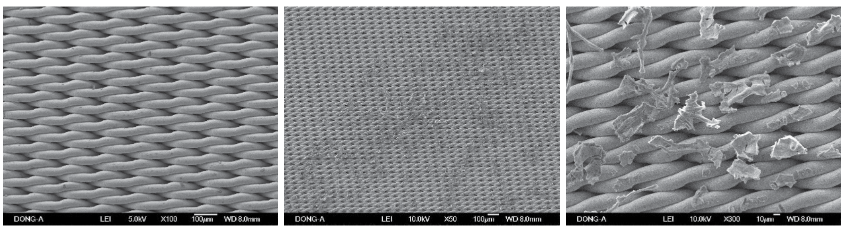
3.3. Scanning electron microscope photography results

The algae solution after coagulation using $TiCl_4$ was filtered through the wire-mesh as mentioned above, and the surface of each wire-mesh was photographed by SEM. The filtered shape *Spirulina* sp. algae was observed in the photographs. Figs. 3(a), 4(a), 5(a), and 6(a) show SEM images of a clean wire-mesh before filtration experiments. Also, the horizontal lines of the wires of mesh are arranged so as to be in contact with one another, and the weaving method is such that two or more lines are crossed or intersected. This method of weaving a wire-mesh is called a twilled Dutch weave, and it is primarily used for filtration purposes, and (b) and (c) were images of the algae on the wire-meshes subjected to the filtration experiment at 50× and 300× magnifications. In the images taken at 50× magnifications, the amount of algae filtered by 5 μm wire-mesh seems to be larger than that of 10 μm wire-mesh, 15 μm wire-mesh, and 30 μm wire-mesh. This was the same results as the single layer wire-mesh experiment. The comparison of the amount of algae in 10 μm wire-mesh, 15 μm wire-mesh and 30 μm wire-mesh was not visually comparable because the SEM images were a portion of the enlarged wire-mesh. The SEM images of 300× magnifications showed the shape of the broken algae on the wire-mesh. The reason for this was to be that the algae was broken due to the heat during the drying process of the filtration experiment to measure the suspended solid.



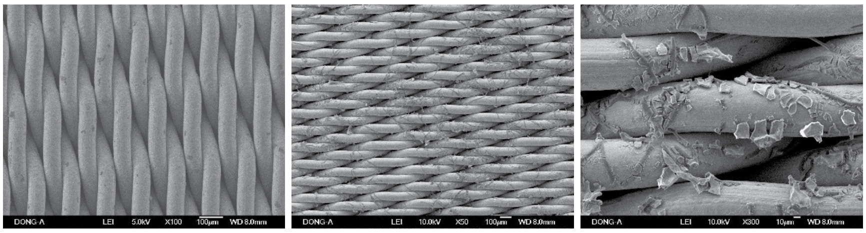
(a) (b) (c)

Fig. 3. Structure of wire-mesh with pore size 5 μm: (a) SEM image of clean wire-mesh (100×), (b) SEM image of filtration wire-mesh (50×), and (c) SEM image of filtration wire-mesh (300×).



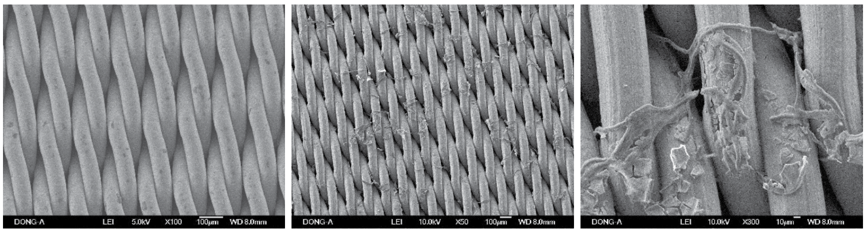
(a) (b) (c)

Fig. 4. Structure of wire-mesh with pore size 10 μm: (a) SEM image of clean wire-mesh (100×), (b) SEM image of filtration wire-mesh (50×), and (c) SEM image of filtration wire-mesh (300×).



(a) (b) (c)

Fig. 5. Structure of wire-mesh with pore size 15 μm: (a) SEM image of clean wire-mesh (100×), (b) SEM image of filtration wire-mesh (50×), and (c) SEM image of filtration wire-mesh (300×).



(a) (b) (c)

Fig. 6. Structure of wire-mesh with pore size 30 μm: (a) SEM image of clean wire-mesh (100×), (b) SEM image of filtration wire-mesh (50×), and (c) SEM image of filtration wire-mesh (300×).

4. Conclusions

In this study, the single and double layer wire-mesh filtration experiments were carried out after pretreatment using $TiCl_4$ as a coagulant for cultured algae to investigate the algae removal performance. From the experimental results, the following conclusions were drawn.

First, as a result of the single layer wire-mesh filtration experiments using four types of wire-mesh with pore sizes 5, 10, 15, and 30 μm after pretreatment to coagulate the algae, removal efficiency ranged from 44.2% to 93.9%. It is investigated that the relatively small wire-mesh has higher removal efficiency, and the removal efficiency of pore size 5 μm was the highest at 93.2% in average, but the filtration rate was slower than that of the wire-mesh with larger pore size. That is, a small pore size mesh can have high filtration removal efficiency in a short period of time, but because of the fast clogging and low filtration rate, applicability to the field needs to be re-evaluated.

Second, the double layer resulted in 20% higher efficiency than the single layer in average. It seems to be due to the enhanced effect of internal filtration by clogged SS between two layers. There was no significant tendency of the efficiency decrease according to pore size increase in the double layer experiment. This seems to be due to the nature of the bilayer, which filters the suspended solids from the surface of the wire mesh and the interior of the mesh above and below, unlike a single layer which mostly filters the suspended material by the surface.

Third, SEM photographs were taken in order to confirm the details of the algae filtered out by the wire-mesh. The shape of the wire-mesh before and after filtration was investigated through the enlarged SEM images. In addition, the shape of the algae was observed in the specimen of the wire-mesh subjected to the filtration experiment. The algae were evenly filtered through the wire-mesh in a wide range. The high magnification SEM photograph showed the appearance of broken algae on the wire-mesh. It is considered that the algae are damaged due to the drying process of the filtration experiment.

As a result of above experiments, it was found that metal wire-mesh could be used as an effective filter for algae removal. Although wire meshes are not yet widely used in water treatment process, we investigated the possibility through this study. Considering the toughness of the metal wire-mesh, the filtration rate can be improved by increasing the backwashing flow rate or speed, although the slowing down of the filtration rate may be an obstacle.

Acknowledgment

This work was supported by the SMEs Partnership Project for strengthening tech-competitiveness funded by Korea Small and Medium Business Administration in 2016 (Grant No. S2317919).

References

[1] H. Olem, G. Flock, The Lake and Reservoir Restoration Guidance Manual, 2nd Ed., U.S Environmental Protection Agency, Washington DC, USA, 1990.

[2] G.D. Cooke, E.B. Welch, S.A. Peterson, S.A. Nichols, Restoration and Management of Lakes and Reservoirs, 3rd Ed., CRC Press Taylor & Francis Group, New York, 2005.

[3] J.K. Shin, H.S. Yi, S.A. Jeong, S.J. Hwang, Construction of environmental friendly special-purpose ship for the removal of blue-green algae, J. Korean Soc. Limnol., 42 (2009) 404–406.

[4] J.K. Shin, H. Kim, S.W. Kim, S.A. Chong, B.C. Moon, S. Lee, J.W. Choi, A practical new technology of removing algal bloom: k-water GATe water combine, Korean J. Ecol. Environ., 47 (2014) 214–218.

[5] KMOE, Improvement of Algal Management Strategy through Algal Expert Forum, Korean Ministry of Environment (KMOE), Republic of Korea, 2013.

[6] M.Y. Song, M.S. Jeon, H.D. Lee, B.S. Jeong, A Study on the Traveling Route and Control Method of Eutrophication Sources in Han River Basin, Gyeonggi Research Institute, Republic of Korea, 2015.
[7] K.D. Byeon, G.Y. Kim, I. Lee, S. Lee, J. Park, T. Hwang, J.C. Joo, Investigation and evaluation of algae removal technologies applied in domestic river and lakes, J. Korean Soc. Environ. Eng., 38 (2016) 387–394.
[8] J.K. Kim, D.G. Kang, W. Yeo, H.H. Kim, Trends in algae removal technology and eco-friendly algae control technology, J. Water Treat., Korean Soc. Water Sci. Technol., 25 (2017) 91–109.
[9] H.R. Islami, Y. Filizadeh, Use of barley straw to control nuisance freshwater algae, J. Am. Water Works Assoc., 103 (2011) 111–118.
[10] S.J. Park, D.G. Lee, J.H. Kim, G.B. Cho, H.S. Kim, Y.I. Jeong, Filtration characteristics of metal foam filters for DPF combined with electrostatic precipitation mechanism, Trans. Korean Soc. Automot. Eng., 15 (2007) 151–158.
[11] I.C. Kim, K.H. Lee, J.Y. Park, J.Y. Kwon, B.R. Jeong, K.O. Kwon, S.S. Kim, M.J. Choi, Development of High Strength Metallic Microfiltration and Ultrafiltration Hollow Fiber Membrane and Module, Korea Research Institute of Chemical Technology, Ministry of Environment, Republic of Korea, 2009.
[12] N.S. Park, S. Yoon, Y.T. Moon, S.J. Lee, S. Park, Experimental study on feasibility test for removing particles in air scouring membrane backwash water with metal membrane, J. Korean Soc. Water Wastewater, 29 (2015) 251–259.
[13] L. Chekli, C. Eripret, S.H. Park, S.A.A. Tabatabai, O. Vronska, B. Tamburic, J.H. Kim, H.K. Shon, Coagulation performance and floc characteristics of polytitanium tetrachloride (PTC) compared with titanium tetrachloride ($TiCl_4$) and ferric chloride ($FeCl_3$) in algal turbid water, Sep. Purif. Technol., 175 (2017) 99–106.
[14] L. Chekli, E. Corjon, G. Naidu, B. Tamburic, S.H. Park, H.K. Shon, Performance of titanium salts compared to conventional $FeCl_3$ for the removal of algal organic matter (AOM) in synthetic seawater: Coagulation performance, organic fraction removal and floc characteristics, J. Environ. Manage., 201 (2017) 28–36.
[15] J.P. Michaud, A Citizen's Guide to Understanding and Monitoring Lakes and Streams, Department of Ecology, State of Washington, 1991.
[16] S.K. Jeong, J.B. Chun, Principle and application of scanning electron microscope (Part II), J. Korean Soc. Ind. Eng. Chem., 13 (2010) 51–60.