Int. J. Electrochem. Sci., 15 **(2020)** 4481 – 4493, doi: 10.20964/2020.05.68

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Performance Assessment of a Combined System Using a Biological Aerated Filter and Electro-coagulation for Advanced Wastewater Treatment

Hyung-Soo Shin[1], *Woo-Yeol Kim*[2], *Dong-Jin Son*[1], *and Ki-Ho Hong*[3,*]

[1] Department of Advanced Technology Fusion, Konkuk University, Seoul, Republic of Korea
[2] Materials & Membranes Co., Ltd., Gangnung-si, Gangwon-do, Republic of Korea
[3] Department of Technology Fusion Engineering, Konkuk University, Seoul, Republic of Korea
[*]E-mail: khhong@konkuk.ac.kr

Received: 2 January 2020 / *Accepted:* 3 March 2020 / *Published:* 10 April 2020

In this study, a biological aerated filter (BAF), used for the preferred elimination of organic matter and ammonia nitrogen, was combined with an electro-coagulation process for guaranteed selective phosphorus removal. A synthetic feed was prepared and used to represent the concentrations of typical organics, nitrogen, and phosphorus in municipal wastewater in Korea. The performance of the combined system in the removal of organic matter, nitrogen, and phosphorus was assessed, and the internal behavior of major contaminants was also evaluated. Higher removal of organics with a concentration lower than 4 mg/L could be achieved under a retention time of 1 h or longer; however, the concentration of organic matter in the effluent increased significantly at shorter retention times, i.e., less than 1 h. When the retention time was further reduced from 1 to 0.5 h, a reduction in the nitrification efficiency was also observed because of an insufficient reaction time for the oxidation of ammonia nitrogen by microorganisms. As the electrolysis progressed, an additional removal of organics could be performed by up to 2 mg/L within 5 min. The phosphorus removal was performed by the BAF; however, the electrolysis process used copper electrodes. A phosphorus concentration of 0.1 mg/L or less could be guaranteed successfully using this combined method. Thus, the combination of the BAF and electro-coagulation procedure is an easy and reliable alternative for advanced wastewater treatment.

Keywords: Advanced wastewater treatment, Biological aerated filter, Electro-coagulation, Electrolysis

1. INTRODUCTION

In recent years, eutrophication has become a serious problem in aquatic ecosystems. Eutrophication can be caused by excessive algal growth through the discharge of untreated wastewater containing limiting nutrients, such as nitrogen and phosphorus, into aquatic ecosystems. It can lead to a degradation of water quality, as well as resources, by depleting the oxygen in streams or lakes, and consequently resulting in the depletion of life [1,2]. Therefore, nutrients, such as nitrogen and phosphorus must be removed from water bodies to prevent eutrophication, which has a serious adverse effect on the water resources.

Many treatment technologies for wastewater and the nutrients have been studied, and these methods can be largely classified into physical, chemical, and biological. They are used either individually or in combination. The biological nutrient removal (BNR) processes using suspended growth microbes are the most widely used [3]; however, they have many disadvantages, such as difficulties in operation and maintenance, and a need for large site areas [4]. Therefore, these days, various research studies are being carried out to secure efficient site areas for wastewater treatment plants (WWTPs).

Among various biological wastewater treatment processes, the biofilm processes using attached growth microbes, such as a biological aerated filter (BAF) have the advantage of being able to completely remove organic matter from wastewater even during a short operating time as microorganisms grow attached to the medium [5,6]. They can also easily reduce the contaminated load of the aquatic ecosystem by oxidizing the oxygen-consuming ammonia nitrogen from the wastewater into nitrate. Their modular installation, absence of a settling tank, and compactness of the biological reactor itself, are the main advantages of the BAF technology [7–9]. However, in the biofilm processes using attached growth microbes, the removal of phosphorus contained in the wastewater has a distinct limitation and requires a separate method.

The electrolysis process does not require an additional chemical unlike the other chemical methods for phosphorus removal and has the advantage of being able to quickly respond to changes in the concentration of influent wastewater [10–12]. The electrolysis process is also relatively simple, making it easier for even non-experts to operate. Generally, electrochemical removal of various pollutants in wastewater can be performed by electro-coagulation or electro-oxidation [13–17]. Suspended particles and matter containing organics and nitrogen in wastewater can be effectively removed by electro-coagulation, which separates the coagulated and flocculated contaminants with eluted ions from electrodes. Therefore, the electrolysis process using electro-coagulation can be a good candidate in selectively removing phosphorus.

For advanced wastewater treatment, in this study, the BAF with advantages, such as reliable performance and compactness was combined with the electro-coagulation process to guarantee a selective phosphorus removal. The treatment characteristics of organic matter, nitrogen, and phosphorus were evaluated in the combined system, and the internal behavior of major contaminants was also assessed.

2. EXPERIMENTAL

2.1 Combined System of BAF and Electro-coagulation Process

We used a bench-scale combined system of BAF, for preferred elimination of organic matter and ammonia nitrogen, and electrolysis process, for phosphorus removal, as illustrated schematically in Figure 1. The empty bed volume of the BAF made of plexiglass was 1.7 L. The cylindrical BAF was also packed with porous plastic balls (Bio balls, PERIHA Company), of which the packing depth was 1.4 m. This corresponds to 80% of the liquid depth of 1.7 m. The characteristics of the packing media in the BAF are presented in Table l.

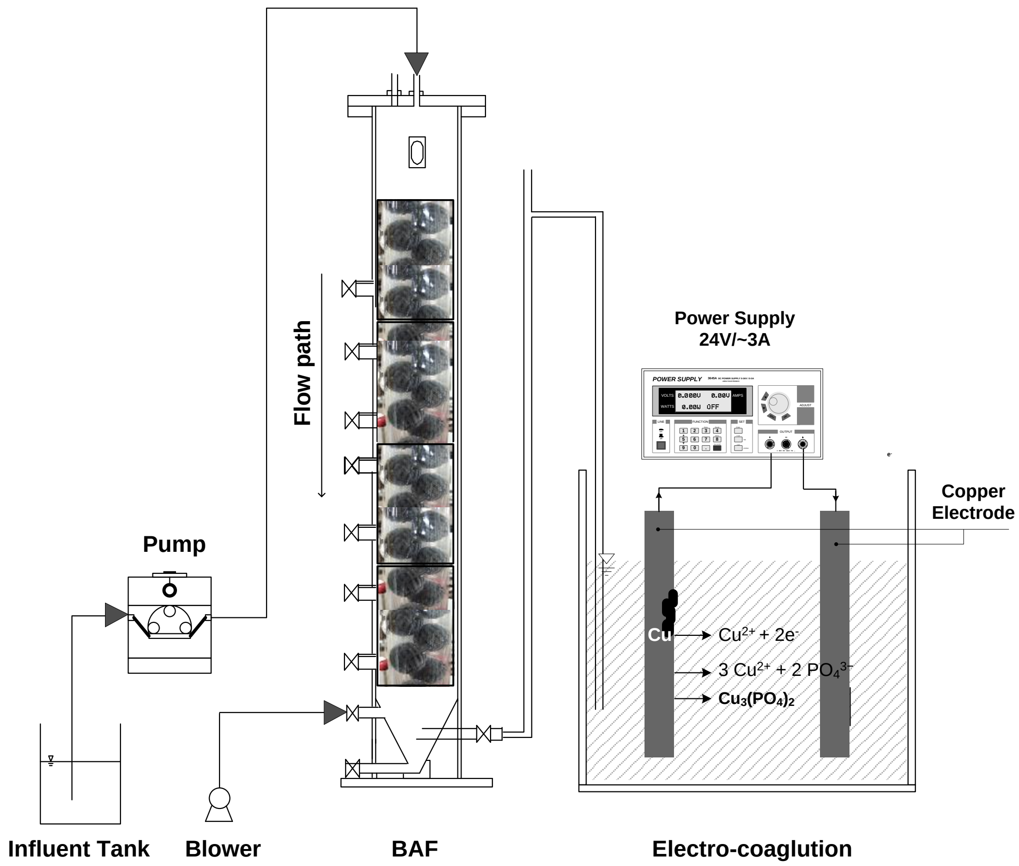

Figure 1. Schematic diagram of a BAF combined with electro-coagulation system for advanced wastewater treatment

Table 1. Physical Characteristics of the Packing Media in the BAF

Material	Plastic
Porosity (%)	94.5
Weight (g)	2.6
Volume (cm^3)	3
Average diameter (mm)	20
Specific gravity (g/cm^3)	0.86
Image	

To accommodate a counter current of inlet water/aeration and avoid short-circuiting, raw influent wastewater was introduced downwards into the BAF by using a peristaltic pump (Model No. 7553-75, Cole-Parmer Instrument Company). The hydraulic retention time (HRT) of the BAF was maintained in the range of 0.5–3 h. The BAF was inoculated with activated sludge at the beginning of the start-up process. The backwashing of the BAF was performed periodically using a combined air-water backwash system at an air/water flowrate of 251/170 $m^3/m^2\cdot h$ for 3 min.

The electro-coagulation process, which is one of the major components in the system, was also installed at the end of the BAF for the removal of phosphate and residual particle matters in the effluent after filtration by the BAF. The effluent from the BAF was subsequently directly introduced to the electro-coagulation process. The electro-coagulation process for phosphorus removal consisted of a 250 mL batch-type reactor and a pair of copper electrodes connected to a power supply, as shown in Figure 1.

The width and length of the electrodes were 7.5 and 170 mm, respectively, and each electrode was almost fully submerged in the batch-type reactor for electro-coagulation. The spacing between the anode and the cathode was also 7.5 mm, which was maintained by using a plastic joint. In general, conventional electrolysis processes have been operated under a variable range of voltage and a constant current. However, problems, such as the risk of accidental electrocution and high electric power consumption are encountered. Furthermore, contaminant concentration in the wastewater is not considered. Therefore, in this study, the electro-coagulation was performed for 2–20 min under a constant voltage of 24 V by using a DC Power Supply of 3645A (ARRAY ELECTRONIC), and a variable current with an upper limit of 10 A.

2.2 Preparation of Feed Water

A synthetic feed was prepared and used to represent typical concentrations of organics, nitrogen, and phosphorus of municipal wastewater in Korea, as presented in Table 2. The feed water was manufactured using glucose ($C_6H_{12}O_6$) for organics, ammonium chloride (NH_4Cl), and potassium phosphate (KH_2PO_4 and K_2HPO_4) to simulate the organic matter, nitrogen, and phosphorus concentrations in the wastewater, respectively. The average concentrations of the chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) in the synthetic feed were 195, 30.4, and 3.7 mg/L, respectively.

Table 2. Characteristics of synthetic wastewater

Parameter	min – max (average)
Temperature (℃)	25.0 – 25.2 (25.1)
pH	7.43 – 7.70 (7.56)
Alkalinity (mg as $CaCO_3$/L)	172 – 199 (190)
Total chemical oxygen demand (mg/L)	192 – 200 (195)
Ammonia nitrogen (mg/L)	29.9 – 30.9 (30.4)
Phosphate (mg/L)	3.65 – 3.8 (3.73)

2.3 Analytical Method

All analyses were conducted as per the procedures outlined in the American Public Health Association (APHA) Standard Methods [18].

3. RESULTS AND DISCUSSION

3.1 Biological Aerated Filter

The primary purpose of applying the BAF is to minimize the site area. To accomplish the same, the hydraulic retention time in the filter should be reduced as much as possible, while simultaneously satisfying the removal performance of the organics and nutrients. The optimal range for the retention time in general BNR processes using suspended growth microbes is approximately 6–8 h, whereas the retention time of a BAF is 2–4 h [19,20], which lessens the site area. For the derivation of the optimal retention time guaranteeing a high removal of organics and nitrogen in the filter, in this study, the BAF was operated for less than 3 h.

3.1.1 Removal of Organics

Microorganisms attached to the media in the BAF grow using the organic matter as a substrate and remove the same in the wastewater as follows;

$$3C_6H_{12}O_6 + 8O_2 + 2NH_3 \rightarrow 2C_5H_7NO_2 + 8CO_2 + 14H_2O \quad (1)$$

In general, the growth of heterotrophic bacteria for the elimination of organic matter in biological wastewater treatment processes requires adequate acclimation period, and it is difficult for the organics to be removed during a short retention time [21]. The organic matter in the effluent of BAF is directly affected by the retention time as shown in Figure 2.

In this study, a high removal rate of organics that have a concentration lower than 4 mg/L could be achieved under a retention time of 1 h or longer; however, the concentration of organic matter in the effluent increased significantly to 24 mg/L at retention times shorter than 0.5 h. Changes in the organic matter, based on the height of the filter were also not observed under a retention time of 3 h, and it was believed that the reason for this is the dilution effect of the wastewater entering the filter and the complete mixing by aeration. On the other hand, significant changes in the concentration of the organics in the filter under a retention time below 1 h were observed, which were believed to be due to the unstable distribution of the internal organic concentration, as microorganisms would provide a minimal retention time to remove the organic matter. Other studies had also shown 80% efficiency for organics removal over a hydraulic retention time of 1 h [22]. Therefore, it should be noted that a retention time of the BAF of at least 1 h would be needed for a higher removal of organics in the wastewater.

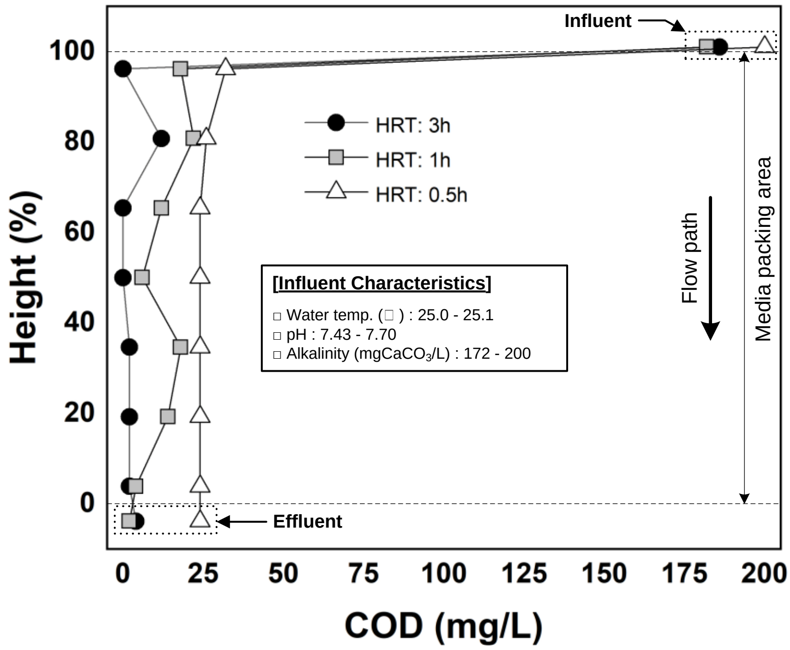

Figure 2. Profiles of COD concentration in the BAF

3.1.2 Nitrogen Removal

In the BAF, ammonia nitrogen in the wastewater can be oxidized to nitrate for the prevention of oxygen depletion in the discharged ecosystem, as shown in the following reaction.

$$NH_4^+ + 1.83\ O_2 + 1.98\ HCO_3^- \rightarrow 0.021\ C_5H_7O_2N + 0.98\ NO_3^- + 1.041\ H_2O + 1.88\ H_2CO_3^- \qquad (2)$$

As shown in Figure 3, the nitrification efficiency in the BAF tended to decrease with a shorter hydraulic retention time. When the retention time decreased from 3 h to 1 h, the concentration of ammonia nitrogen in the effluent increased from 0.4 to 3.7 mg/L.

When the retention time was reduced from 1 h to 0.5 h, especially, the reduction in the nitrification efficiency was evident, which could be attributed to the insufficient reaction time for the oxidation of ammonia nitrogen by microorganisms [23–25], as was the case with the elimination of the organic matter.

In general, a hydraulic retention time of 1 h was required for complete biological ammonia oxidation in the wastewater treatment; the longer the retention time, the more stable the nitrification [26,27]. However, there was a serious problem in that the longer retention time would increase the site area of the treatment facility proportionally. The optimal retention time is that at which high organic matter removal efficiency is possible along with the nitrification reactions. In this study, both stable organic removal and nitrification could be successfully achieved under 1 h of hydraulic retention time.

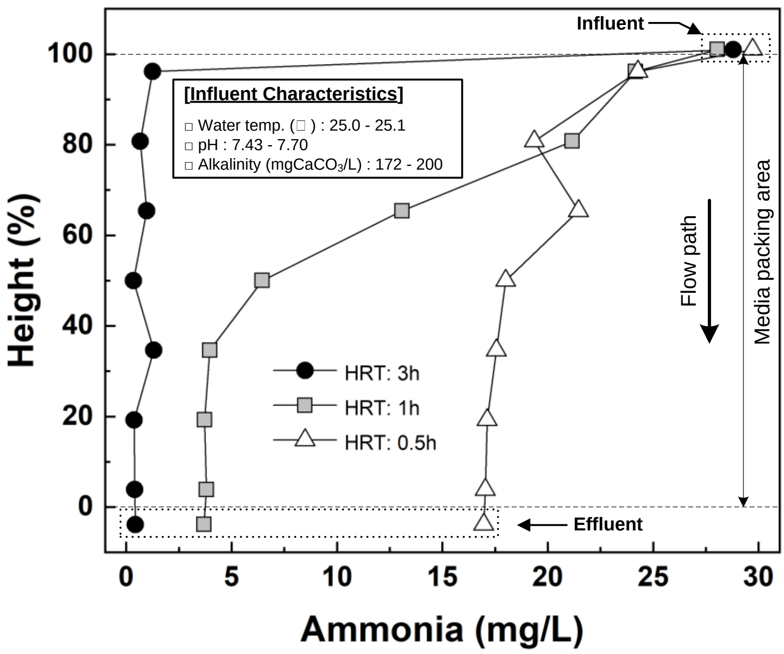

Figure 3. Profiles of ammonia nitrogen in the BAF

3.1.3 Phosphorus Removal

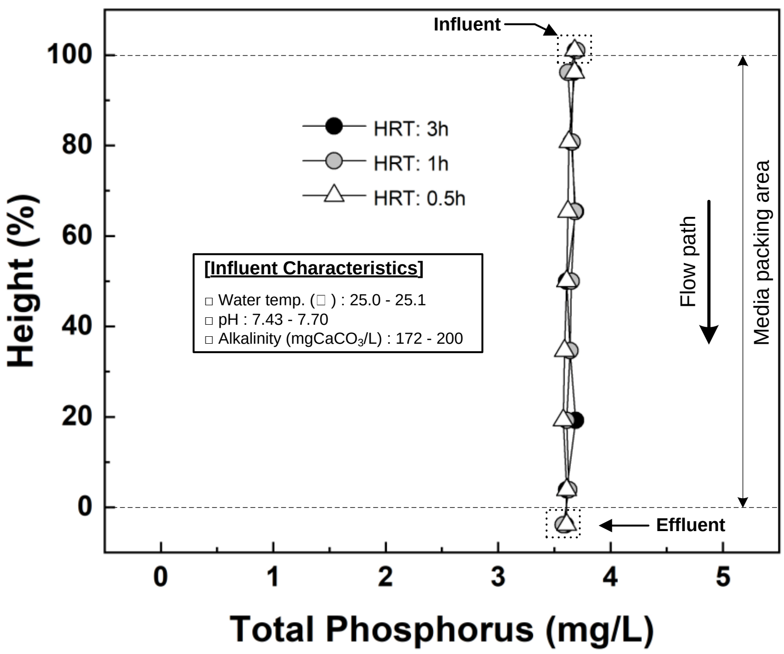

Figure 4. Profiles of phosphorus in the BAF

Phosphorus is one of the major nutrients that can cause eutrophication in water systems, such as rivers and reservoirs; it is a pollutant that must be removed [28]. In wastewater treatment, biological or chemical methods are commonly used for phosphorus removal. For biological phosphorus removal, excessively produced microorganisms should be periodically discharged through phosphorus release under anaerobic conditions and uptake under anaerobic conditions [29]. In general, in this study, phosphorus could not be removed by the BAF that performed the organic removal and nitrification, and only a fraction of the phosphorus content consumed by the microbial growth in the BAF was consumed. As illustrated in Figure 4, the phosphorus removal was also not shown in the operation of the BAF.

The elimination of phosphorus using biological methods is possible through the additional installation of an anaerobic reactor; however, it can be made easier by chemical treatment methods. The injection of chemicals, such as alum is one of the most used chemical methods. In this study, however, the electro-coagulation process guaranteeing a higher performance of phosphorus removal in a shorter operating time and with no consumption of chemicals was applied.

3.2 Electro-coagulation Process

3.2.1 Removal of Organics

In the electrolysis process using copper electrodes, the representative removal mechanism of the organics can generally be explained by the following reactions [30, 31]:

$$2\ Cl^- \rightarrow Cl_2\ (\text{dissolved}) + 2\ e^- \quad [\text{at anode}] \tag{3}$$

$$2\ H_2O + 2\ e^- \rightarrow 2\ OH^- + H_2 \quad [\text{at cathode}] \tag{4}$$

(between the electrodes)

$$Cl_2 + H_2O \rightarrow HOCl + Cl^- + H^+ \tag{5}$$

$$HOCl \rightarrow OCl^- + H^+ \tag{6}$$

$$\text{Organics} + OCl^- \rightarrow \text{intermediates} \rightarrow CO_2 + Cl^- + H_2O \tag{7}$$

As the electrolysis progressed, the concentration of the chemical oxygen demand representing the organics gradually decreased as shown in Figure 5, and this result showed that the electrolysis of organic matter could be carried out successfully in the electro-coagulation process using copper electrodes. The COD concentration of synthetic wastewater simulating the properties of municipal wastewater was removed linearly by electrolysis, and the rate of COD reduction was 1.8 mg/L·min. As the electrolysis time increases, the more COD could remove [31, 32, 33]. However, a BAF combined with electro-coagulation system could reduce retention time effectively.

The COD concentration in the effluent of the BAF was 8 mg/L, and up to an additional 2 mg/L could be removed within 5 min. Although an effective removal of organics could not be performed by the electro-coagulation process alone, the system associated with the BAF showed that additional organics removal could be achieved within a shorter electrolysis time of 5 min.

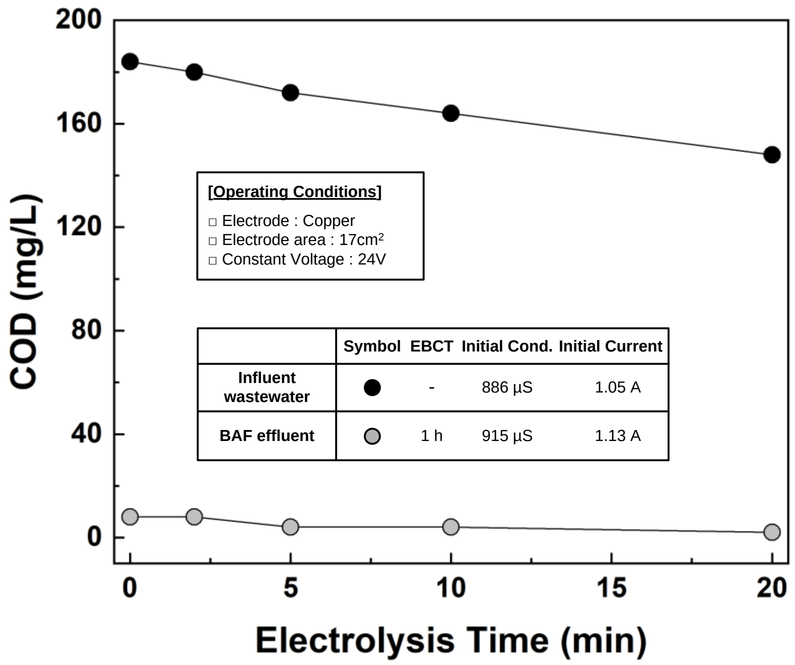

Figure 5. Characteristics of COD removal during electro-coagulation

3.2.2 Nitrogen Removal

The BAF, installed at the front of the electro-coagulation process, was responsible for oxidizing ammonia nitrogen to nitrate. This reduced the risk of depletion of the dissolved oxygen in the aquatic ecosystem owing to the release of ammonia nitrogen from the effluent through the wastewater treatment; however, the risk of eutrophication because of the nitrate remained. The additional nitrogen content during the electrolysis process could be converted into nitrogen gas, and the nitrate could be reduced to ammonia as follows [33, 34]:

$$2NH_3^{+} + 3HOCl \rightarrow N_2 + 3H_2O + 3H^{+} + 3Cl^{-} \quad (8)$$

$$NH_4^{+} + 3OH^{-} \rightarrow 0.5N_2 + 3H_2O + 3e^{-} \quad (9)$$

$$NO_3^{-} + 6H_2O + 8e^{-} \rightarrow NH_3 + 9OH^{-} \quad (10)$$

As shown in Figure 6, the concentrations of ammonia and nitrous nitrogen in the electro-coagulation process for BAF effluent were reduced slightly during the electrolysis. However, the total nitrogen concentration in the electro-coagulation process when raw wastewater was treated was lower than when BAF effluent was treated. This was thought to be partly since the nitrate was reduced to ammonia nitrogen, as indicated by the reaction formula presented earlier [34, 35, 36].

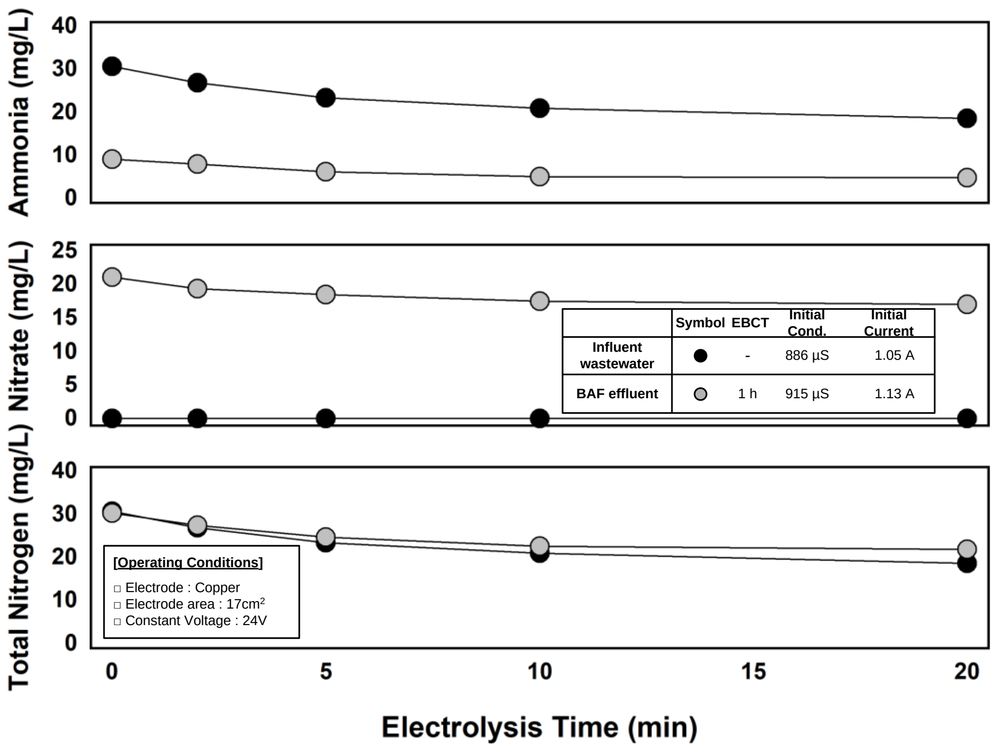

Figure 6. Characteristics of nitrogen removal in the influent and BAF effluent during the electro-coagulation

3.2.3 Phosphorus Removal

Unlike the biological phosphorus removal, the electro-coagulation process can quickly remove phosphorus from wastewater [37, 38]. The system using the copper electrodes can also performed removal of phosphorus by copper metal ions eluted from the anode as follows [39];

$$3\ Cu^{2+} + 2\ PO_4^{3-} \rightarrow Cu_3(PO_4)_2 \quad \text{(at anode)} \qquad (11)$$

As shown in Figure 7, the phosphorus removal through the electro-coagulation reaction was performed for a short operation time, i.e., within 5 min, regardless of the type of inflow water. The characteristics of phosphorus removal in the electro-coagulation process were different from those of conventional chemical methods that use coagulant agents, such as alum. In general, the phosphorus removal by a conventional chemical method can be achieved by forming a flock with metal salts through a procedure comprising 5 min of rapid coagulation and 30 min of continuous coagulation.

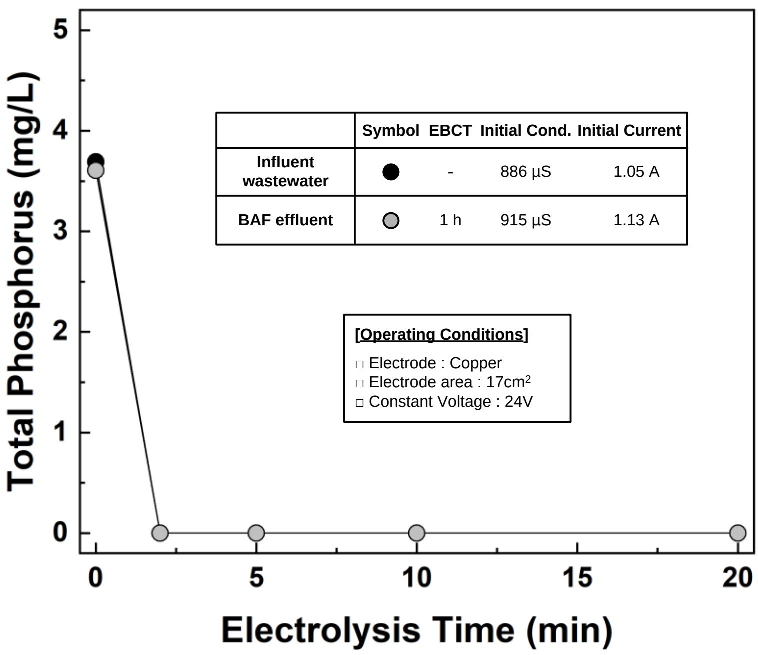

Figure 7. Characteristics of phosphorus removal in influent and BAF effluent during electrocoagulation

In electro-coagulation, however, a very short period of 5 min was adequate to form and remove the phosphates. In addition, a phosphorus concentration of 0.1 mg/L or less could be successfully guaranteed. Therefore, it could be seen that an easier operation and a smaller site requirement for the installation of wastewater treatment facility could be expected by the application of the electro-coagulation procedure.

4. CONCLUSIONS

In this study, a BAF for the preferred elimination of organic matter and ammonia nitrogen was combined with an electro-coagulation process for guaranteed selective phosphorus removal. The performance of the combined system for the removal of organic matter, nitrogen, and phosphorus was assessed, and the internal behavior of major contaminants was also evaluated.

The concentration of organics and ammonia nitrogen in the effluent was lower than 4 and 3.8 mg/L, respectively, with a hydraulic retention time of 1 h. The organic removal efficiency was similar to that observed with a hydraulic retention time of 1 h, whereas the nitrogen concentration in the effluent could be reduced to less than 0.4 mg/L, as the retention time was extended to 3 h. A shorter retention time of less than 0.5 h was applied in this study, because an increased area requirement for the installation of WWTPs would be caused by longer retention times. However, poor performance of the system was observed owing to insufficient time for the microorganisms to use the substrates. Therefore, it appeared that the optimal retention time for the simultaneous removal of organics and nitrogen was 1 h.

The electro-coagulation process was also applied to the rear of the filter because it was impossible to remove phosphorus from only the BAF. The electrolysis was able to remove phosphorus with a content of less than 0.2 mg/L at a very short retention time of less than 5 min, and additional organics removal could be also achieved through the application of the electrolysis process. Thus, a combination of the BAF and the electro-coagulation procedure is an easy and reliable alternative for advanced wastewater treatment.

.

References

1. C.C. Tanner, J.P.S. Sukias, T.R. Headley, C.R. Yates, R. Stott, *Ecol. Eng*., 42 (2012) 112–123.
2. V.H. Smith, D.W. Schindler, Trends *Ecol. Evol*., 24 (2009) 201–207.
3. E. Loupasaki, E. Diamadopoulos, *J. Chem. Technol. Biotechnol*., 88 (2013) 190–204.
4. A. Luciano, P. Viotti, G. Mancini, V. Torretta, *J. Environ. Manage*., 113 (2012) 51–60.
5. C. Tao, T. Peng, C. Feng, N. Chen, Q. Hu, C. Hao, *Bioresour. Technol*., 218 (2016) 307–317.
6. B.K. Pramanik, S. Fatihah, Z. Shahrom, E. Ahmed, *J. Eng. Sci. Technol*., 7 (2012) 428–446.
7. L.M. Despland, T. Vancov, M. Aragno, M.W. Clark, *Sci. Total Environ*., 433 (2012) 383–389.
8. H.A. Hasan, S.R.S. Abdullah, S.K. Kamarudin, N.T. Kofli, *Desalination*, 275 (2011) 50–61.
9. S. Han, Q. Yue, M. Yue, B. Gao, Y. Zhao, W. Cheng, *Bioresour. Technol*., 100 (2009) 1149–1155.
10. D.-J. Son, W.-Y. Kim, C.-Y. Yun, D. Chang, D.-G. Kim, S.-O. Chang, J.-H. Kim, Y. Sunwoo, Y.-S. Bae, K.-H. Hong, *Int. J. Electrochem. Sci*., 9 (2014).
11. R. Daghrir, P. Drogui, J. François Blais, G. Mercier, *J. Environ. Eng. (United States)*, 138 (2012) 1146–1156.
12. N. Tran, P. Drogui, J.F. Blais, G. Mercier, *Sep. Purif. Technol*., 95 (2012) 16–25.
13. E.E. Gerek, S. Yılmaz, A.S. Koparal, N. Gerek, *J. Water Process Eng*., 30 (2019).
14. E. Isarain-Chávez, C. De La Rosa, L.A. Godínez, E. Brillas, J.M. Peralta-Hernández, *J. Electroanal. Chem*., 713 (2014) 62–69.
15. S. Kara, E. Gürbulak, M. Eyvaz, E. Yüksel, *Desalin. Water Treat*., 51 (2013) 5421–5429.
16. V. Orescanin, R. Kollar, K. Nad, I.L. Mikelic, S.F. Gustek, *J. Environ. Sci. Heal. - Part A Toxic/Hazardous Subst. Environ. Eng*., 48 (2013) 1543–1547.
17. S. Sundarapandiyan, R. Chandrasekar, B. Ramanaiah, S. Krishnan, P. Saravanan, *J. Hazard. Mater*., 180 (2010) 197–203.
18. APHA, AWWA and WEF, Standard Methods for the Examination of Water and Wastewater, 22nd ed., APHA, Washington, D. C. (2012)
19. H.D. Ryu, J.S. Kim, M.K. Kang, S.I. Lee, *Sep. Purif. Technol*., 136 (2014) 199–206.
20. G. Ji, J. Tong, Y. Tan, *Bioresour. Technol*., 102 (2011) 550–557.
21. J.N. Lester, J.W. Birkett, Microbiology and Chemistry for Environmental Scientists and Engineers, 2nd ed., E & FN SPON, London and New York (1999)
22. Y. Feng, Y. Yu, L. Qiu, J. Zhang, L. Gao, *J. Ind. Eng. Chem.*, 18 (2012) 1051-1057.
23. Y. Feng, Y. Yu, Q. Duan, J. Tan, C. Zhao, *Desalination*, 263 (2010) 146–150.
24. Y.X. Liu, T.O. Yang, D.X. Yuan, X.Y. Wu, *Desalination*, 254 (2010) 149–153.
25. L. Qiu, S. Zhang, G. Wang, M. Du, *Bioresour. Technol*., 101 (2010) 7245–7251.
26. T. Bao, T. Chen, N. Ezzatahmadi, S.I. Rathnayake, D. Chen, M.L. Wille, R. Frost, *Environ. Technol. (United Kingdom)*, 38 (2017) 827–834.
27. T. Bao, T.H. Chen, C. Qing, J. Jin Xie, R.L. Frost, *Desalin. Water Treat*., 57 (2016) 1790–1803.
28. WEF, Nutrient Removal, WEF Manual of Practice No.34, WEF Press, Alexandria, Virginia (2011)
29. G. Tchobanoglous, H.D. Stensel, R. Tsuchihashi, F. Burton, Wastewater Engineering: Treatmnet and Resource Recovery, 5th ed., McGraw-Hill, Inc., New York (2014)
30. J. Ding, L. Wei, H. Huang, Q. Zhao, W. Hou, F.T. Kabutey, Y. Yuana, D.D. Dionysiou, *J. Hazard. Mater*., 351 (2018) 90-97.
31. H. Rubí-Juárez, C. Barrera-Díaz, I. Linares-Hernández, C. Fall, B. Bilyeu, *Int. J. Electrochem. Sci*, 10 (2015)6754-6767

32. A.L. Torres-Sanchez, S.J. Lopez-Cervera, C. de la Rosa, M. Maldonado-Vega, M. Maldonado-Santoyo, J.M. Peralta-Hernández, *Int. J. Electrochem. Sci*, 9 (2014) 6103-6112.
33. K.L. Huang, K.C. Wei, M.H. Chen, C.Y. Ma, *Int. J. Electrochem. Sci*, 13 (2018) 11418-11431
34. Y. Zhang, Y. Zhao, Z. Chen, L. Wang, P. Wu, F. Wang, *Electrochim. Acta*, 291 (2018) 151-160.
35. C. Sun, F. Li, H. An, Z. Li, A. M. Bond, J. Zhang, *Electrochim. Acta*, 335 (2018) 475-482
36. F. Yao, Q. Yang, Y. Zhong, X. Shu, F. Chen, J. Sun, Y. Ma, Z. Fu, D. Wang, X. Li, *Water Res.*, 157 (2019) 191-200.
37. D.D. Nguyen, H.H. Ngo, W. Guo, T.T. Nguyen, S.W. Chang, A. Jang, Y.S. Yoon, *Sci. Total Environ.*, 563-564 (2016) 549-556.
38. K.S. Hashima, R.A. Khaddara, N. Jasim, A. Shawa, D. Phippsa, P. Kota, M. O. Pedrola, A.W. Alattabia, M. Abdulredha, R. Alawsh, *Sep. Purif. Technol*., 210 (2019) 135–44.
39. W.-Y. Kim, D.-J. Son, C.-Y. Yun, D.-G. Kim, D. Chang, Y. Sunwoo, and K.-H. Hong, *Int. J. Electrochem. Sci*, 8 (2017) 124-132.