Segmentation on Electrode Surface: Enhancement of Electroflotation on Laboratory of Wastewater Treatment

Siti Jumrah[1] and Rudy Syah Putra[1,2](✉)

[1] Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Islam Indonesia, Yogyakarta, Indonesia
19923012@students.uii.ac.id, rudy.syahputra@uii.ac.id
[2] Environmental Remediation Research Group, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Islam Indonesia, Yogyakarta, Indonesia

Abstract. Performance of the electroflotation process is strongly influenced by the size and number of the hydrogen and oxygen gas bubbles that form during the electrolysis of water. In this study, the analysis of the size distribution of gas bubbles by the segmentation of the electrode surface was evaluated. Further results as the optimum condition were then applied in the laboratory of wastewater treatment. Stainless Steel electrode was used as the cathode, and Titanium was used as an anode at a constant voltage of 20 V for 30 min process. The results showed that the average gas bubble size was found to vary in the range of 0.15–0.4 mm, which impacted the maximum collision between the gas bubbles and colloidal particles during the electroflotation process. In addition, the number of gas bubbles that formed has affected the performance of this process. The effectiveness of the electroflotation process was evaluated by decreasing the turbidity, total dissolved solid (TDS), Pb concentration, and light intensity. The initial conditions of chemical laboratory wastewater with a 20-times dilution showed that the turbidity, TDS, Pb concentration, and light intensity were 41.8 NTU, 680 mg/L, 1.291 mg/L, and 782 lx, respectively. The optimum results obtained by the electroflotation process under the same parameters were 0.22 NTU (99.47%), 534 mg/L (21.47%), 0.443 mg/L (65.59%), and increased light intensity by 1031 lx. Based on these results, it can be concluded that the electroflotation process has proven to reduce pollutants.

Keywords: Bubble size · Electroflotation · Laboratory wastewater · Segmentation

1 Introduction

Chemical laboratory of liquid waste is categorized as hazardous and toxic that contains organic, inorganic chemicals, and heavy metals [1]. According to the US Environmental Protection Agency (US EPA), the waste of chemical laboratories is classified as hazardous material with characteristics such as reactive, corrosive, flammable, toxic, and

S. Hadisaputra et al. (Eds.): NiTRIC 2022, AHCPS 4, pp. 30–39, 2023.
https://doi.org/10.2991/978-94-6463-130-2_5

pathogenic [2]. In general, the production of wastewater from the chemical laboratory is still a relatively small quantity, so it has not received more attention. However, in the long-term operation, it can have a negative impact on the environment, so it is necessary to manage the wastewater produced by the chemical laboratory.

Eletroflotation is a conventional method used in wastewater treatment that can separate the solid and liquid, involving the formation of gas bubbles during the electrolysis of water, as shown in Eq-1 and Eq-2 [3–5]. The gas bubbles bound to colloidal particles cause the particles to move upward to the surface [3]. Sodium dodecyl (SDS) as a surfactant with dissolved air flotation has been used to reduce the concentration of heavy metals such as chromium, cadmium, nickel, lead, and copper from the electroplating industry which decreased in the concentration of heavy metals by 97.39% [6]. The application of electroflotation with a current density of 14.18 Am-2, the addition of NaCl 0.5 gL-1, and using a flow rate of 0.33 m3h-1 for domestic wastewater treatment resulted decreasing the total solids, turbidity, oil, and fat, BOD, and total coliform were 97.53%, 93.91%, 99.98%, 91.55%, and 99.99%, respectively [7].

$$\text{Cathode: } 2\ H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2\ OH^-_{(aq)} \tag{1}$$

$$\text{Anode: } 2\ H_2O_{(l)} \rightarrow O_{2(g)} + 4\ H^+_{(aq)} + 4e^- \tag{2}$$

The electroflotation process is strongly influenced by the size of the gas bubbles formed. A smaller gas bubble size is more effective on the floating of suspended particles [8, 9]. Various methods have been used to measure the diameter of gas bubbles formed, such as the laser diffraction method [10], which requires high maintenance of operation costs. Measuring the bubble diameter using a digital camera with the aid of a magnifying glass has been evaluated manually [14]. The bubble size distribution, however, can only be classified using this method into three ranges: 0.5, 0.5, and > 0.5 mm. Additionally, the free program ImageJ, which has been a flaw in measuring the minute size of gas bubbles on the electrode surface, is used to confirm the bubble's size. Additionally, it can only work with 8-bit formats [15].

Recently, active digital microscopy has been used to measure the size distribution of bubbles in various fields such as industry, medicine, plant observation, and education [11–13]. A DinoLite of digital microscope has been used to determine the size distribution of gas bubbles using image analysis of DinoCapture 2.0 software. The validation of this method was carried out by using ImageJ software based on the correlation coefficient (R2). However, in this method, the counting of gas bubbles on the electrode surface is only partially observed, so the total bubble distribution is not calculated accurately [14].

Using a DinoLite digital microscope, photographs of gas bubbles (namely hydrogen and oxygen) on the electrode surface were taken for this study. DinoCapture 2.0 program then measured the size diameter. The electrode surface was segmented in order to more precisely assess the size distribution of gas bubbles. These findings are then utilized to establish the ideal voltage for the electroflotation procedure employed in a chemical laboratory's wastewater treatment.

2 Materials and Methods

A. *Electroflotation Reactor*

The electroflotation reactor was made of glass with dimensions of 10 (length) × 10 (width) × 15 (height) cm with a volume of 1.0 L. Titanium electrode (Ø 4.5 cm, 0.3 cm thick) was assembled as anode, and stainless-steel net wire electrode 7.2 (length) × 5 (width) cm with a 20 mesh hole was assembled as the cathode. The two electrodes are installed facing each other with a distance of ±9.5 cm. Figure 1 demonstrates how the digital microscope (DinoLite AM4815ZT, Taiwan), computer, and DC power supply (Sanfix SP-305E, 30V/5A) were all linked to the electroflotation reactor.

B. *Voltage Optimization*

With 0.001 M NaCl as the electrolyte solution, DC constant voltages of 10, 20, and 30 V were used for 30 min to optimize the voltage on the electroflotation process. Using a digital microscope at a magnification of 15.9 times, images of hydrogen and oxygen bubbles were recorded after 20 min at a distance of around 5 cm from the reactor wall. As depicted in Fig. 2, the electrode surface's segmentation was used to capture the image of the gas bubbles. The DinoCapture 2.0 software calculated the size of the gas bubble. By counting the distribution of gas bubbles based on the segmentation on

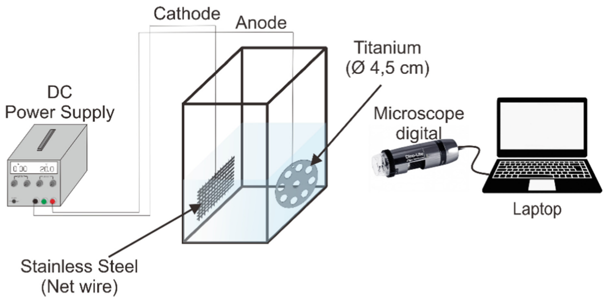

Fig. 1. Electroflotation process reactor was set-up and gas bubbles were captured by a DinoLite microscope.

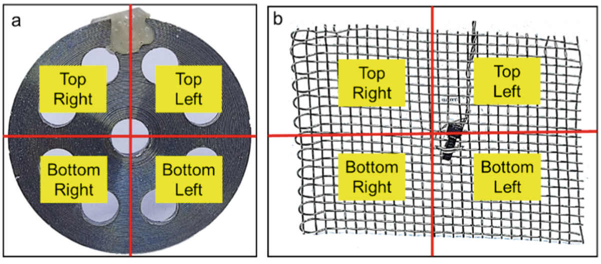

Fig. 2. Segmentation on the surface of the anode (a) and cathode (b) electrodes.

the electrode surface, the ideal voltage was identified. This optimum voltage was then further applied to wastewater treatment in the chemical laboratory by electroflotation with a 20 $\times$ dilution factor of 500 mL for 30 min.

3 Results and Discussion

A. *Voltage Optimization*

Current density is important in the formation of gas bubbles in the electroflotation process. Current density directly affects the size and number of gas bubbles [14, 15]. In this study, the voltage was applied directly proportional to the current, as shown in Eq-3 and Eq-4.

$$V = I \cdot R \tag{3}$$

where V is the voltage (Volts), I is the current (Amperes), and R is the resistance (Ohms).

$$J = I/A \tag{4}$$

where J is the current density (A/m^2), I and A are the cross-sectional area of the electrode (m^2). The combination of Eq-3 and Eq-4 becomes equation Eq-5, which shows the relationship of the maximum voltage.

$$V = J/A \cdot R \tag{5}$$

Voltage has an impact on gas bubble size. During the electroflotation process, the gas bubbles that have formed on the electrode surface come into contact with the floc. The best clearance of contaminants is possible when smaller gas bubbles collide with suspended particles [16].

Figure 3 shows the image of oxygen bubbles on the segmentation of the anode surface and the number of gas bubbles at each voltage. In this study, the size of the bubble was distributed in five categories, namely a ($<$0.02), b (0.02–0.15), c (0.15–0.4), d (0.4–1), and e ($>$1) mm. Generally, the size of oxygen bubbles at the anode electrode was decreased by the increase of constant voltage. At a constant voltage of 10 V, the size of gas bubbles was collected in categories c, d, and e. While at a constant voltage of 20 V, the size of gas bubbles was collected in categories b, c, and d. The size of gas bubbles at a constant voltage of 30 V was collected in categories a, b, and c. Those results concluded that the higher the applied voltage, the increased number of oxygen bubbles with smaller sizes. The same results were also reported elsewhere [17, 18].

Figure 4 shows the image of hydrogen bubbles on the segmentation of the cathode surface and the number of gas bubbles at each voltage. In this study, the same results as an oxygen bubbles distribution were also evaluated. Generally, the size of hydrogen bubbles at the cathode electrode decreased with the increase of constant voltage. The size of hydrogen bubbles at the anode electrode was decreased by the increase of constant voltage. At a constant voltage of 10 V, the size of gas bubbles was collected in categories

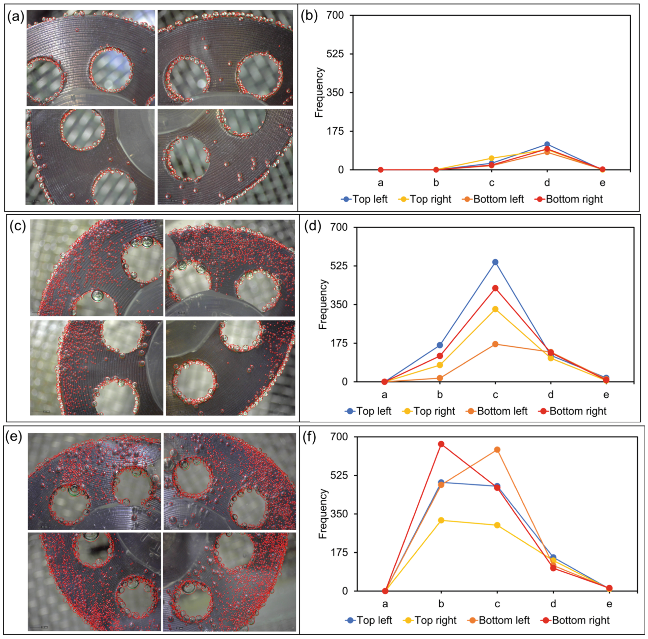

Fig. 3. Image of oxygen bubbles on segmentation of anode surface at a constant voltage of 10 V (a), 20 V (c), and 30 V (d). Size distribution of gas bubble (b, d, f) based on categories a (<0.02), b (0.02–0.15), c (0.15–0.4), d.

c, d, and e. While at a constant voltage of 20 V, the size of gas bubbles was collected in categories b, c, and d. The size of gas bubbles at a constant voltage of 30 V was collected in categories a, b, and c. Those results concluded that the higher the applied constant voltage, the increased number of hydrogen bubbles with smaller sizes.

Increasing the current density can shorten the electroflotation process by reducing the size of gas bubbles and producing more bubbles so that the bubble density formed is higher and produces more floc that can remove pollutants [18]. However, when the applied voltage exceeds the limit, the coalescence between the small-size of gas bubbles occurs that can move freely to form larger-size of gas bubbles. Therefore, it was difficult to collide with smaller particles and can reduce the efficiency of the process [17, 19]. Therefore, it can be concluded that the optimum constant voltage was 20 V in the electroflotation process.

B. *Effect of Voltage on the Number of Gas Bubbles*

The voltage directly affects the size of the gas bubble. Additionally, the voltage also affects the number of gas bubbles, as shown in Eq-6 [20].

$$Q_G = Q_H + Q_O \quad (6)$$

where QG is the total gases generating rate (L.sec-1), QH is the generating rate of hydrogen gas bubbles (L.sec^{-1}), and QO is the generating rates of oxygen gas bubbles

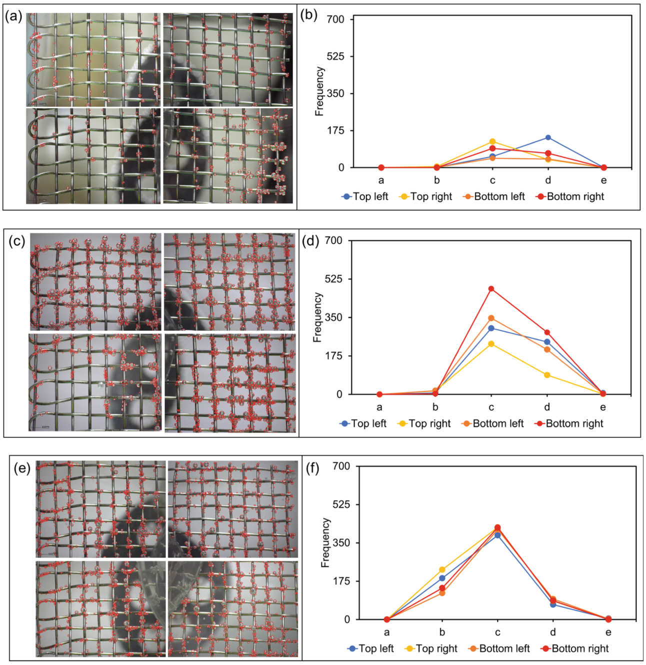

Fig. 4. Image of hydrogen bubbles on segmentation of anode surface at a constant voltage of 10 V (a), 20 V (c), and 30 V (d). Size distribution of gas bubble (b, d, f) based on categories a (<0.02), b (0.02–0.15), c (0.15–0.4), d (0.4–1), and e (>3) mm.

(L.sec-1) at the normal condition, which can be calculated according to Faraday's law as shown in Eq-7 and Eq-8 [20].

$$Q_H = \frac{I \cdot V_o}{Fn_H} \tag{7}$$

$$Q_O = \frac{I \cdot V_0}{Fn_o} \tag{8}$$

where V_0 is the volume of the gas under normal conditions (22.4 L.mol-1), F is the Faraday constant (96,500 $C.mol^{-1}$ of electrons), n_H is the number of electron transfer from H_2, and n_0 is the number of electrons transferred from O_2.

The impact of constant voltage on the total number of gas bubbles at the electrode surface is depicted in Fig. 5. The number of hydrogen and oxygen gas bubbles that developed on the electrode surface increased with the applied voltage. These findings are consistent with those of another study [17]. At constant voltages of 10, 20, and 30 V, the total number of hydrogen gas bubbles on the cathode electrode was 607, 2228, and 2661, whereas the total number of oxygen gas bubbles on the anode electrode was 513, 2380, and 4408, respectively. Generally, it can be concluded that the highest number of gas bubbles was formed at a constant voltage of 20 V for the electroflotation process, in which a more uniform size of gas bubbles was produced (0.15–0.4 mm) on an electrode surface.

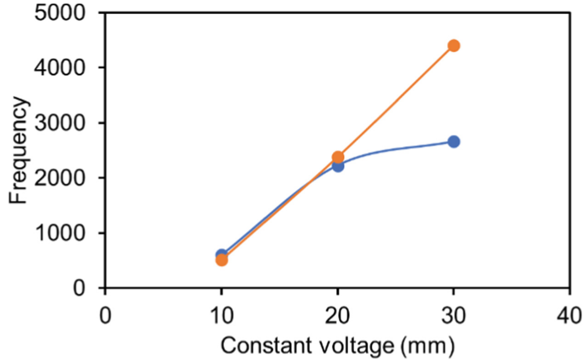

Fig. 5. Effect of voltage on the total number of gas bubbles on the electrode surface

Table 1. Quality of Wastewater Before and After Treatment with Electroflotation Process.

Parameter	Initial	Electroflotation	Removal efficiency (%)
COD (mg.L^{-1})	1742	1645	5.57
Logam Pb (mg.L^{-1})	1.29	0.44	65.69
TDS (mg.L^{-1})	680	534	21.47
Turbidity (NTU)	41.87	0.22	99.47
Light intensity (Lux)	782	1031	24.15
Absorbance	0.386	0.237	38.47

C. *Application of Electroflotation on the Wastewater Treatment*

The effectiveness of the electroflotation process is measured based on the decrease of chemical oxygen demand (COD), heavy metal concentration (Pb), total dissolved solids (TDS), turbidity, and the increase of light transmittance which shows the clarity of the water. Table 1 shows the qualities of treated wastewater before and after the electroflotation process.

Removal efficiency (%) $= \left[\frac{(C_i - C_t)}{C_i} \times 100\%\right]$ where C_i is value before, and C_t is value after the electroflotation process. Absorbance is measured by spectrophotometer at the wavelength of 557 nm.

COD is a measurement of the oxygen equivalent required by organic matter in water samples that is susceptible to oxidation by chemical oxidants [21]. The higher the COD content, the more pollution in the water. The electroflotation process reduced the COD and Pb concentrations, respectively, by 5.57% and 65.60%. In this regard, the electrolysis of water produces H^+ and OH^- ions, as shown in Eqs. 1 and 2. The presence of OH^- ions derived alkaline properties in water so that the Pb^{2+} ions precipitated as $Pb(OH)_2$ [22].

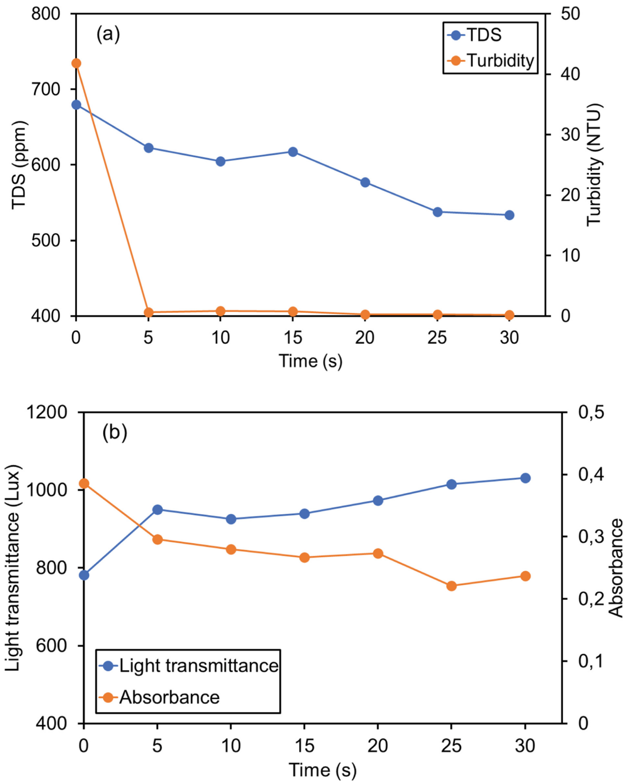

Fig. 6. Effect of electroflotation time on the TDS and turbidity (a), and light transmittance and UV-Vis absorbance (b).

Figure 6a shows the effect of electroflotation time on the decrease of TDS and turbidity. TDS is a measurement of dissolved substances in water with a diameter of $<10^{-6}$ mm the colloidal particles with a diameter of 10^{-6}–10^{-3} mm cannot be filtered by 0.45 microns of porous filter paper [23]. The initial condition of the effluent after 20× dilution factor showed that the TDS content and turbidity of 680 mg.L^{-1} and 41.87 NTU, respectively. The electroflotation process for 30 min reduced the TDS and turbidity by 21.47% and 99.47%, respectively. This occurs due to the formation of particles that become hydrophobic and combine with gas bubbles and float forward the surface while the hydrophilic particles are suspended in water. These results showed that the longer the electroflotation process, the lower the TDS and turbidity value.

Figure 6b shows the effect of time on light transmittance in water after the electroflotation process. The clarity of the water was evaluated based on light scattered by the colloidal particles in the water, which is known as the Tyndall effect. The greater the content of colloidal particles, the higher the light-scattered properties. When the transmittance of light in wastewater is lower than in freshwater, it was indicated by lower measurements of light intensity [24]. Figure 7 shows the clarity of wastewater after treatment with electroflotation. Light transmittance of wastewater with a 20× dilution

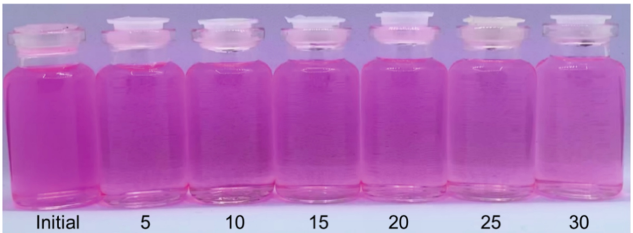

Fig. 7. The clarity of wastewater after the electroflotation process with the interval time of 5 min

factor was 782 lx (Abs. 0.386). After 30 min of the electroflotation process, the light intensity increased by 1031 lx (Abs. 0.237). In this study, the light intensity of distilled water was used as a reference which is 1293 lx. These results have concluded that the electroflotation process was able to decrease the treatment parameter of wastewater.

4 Conclusion

The optimum of constant voltage has an essential effect on the electroflotation process. Under the segmentation measurement of the size distribution of hydrogen and oxygen gas bubbles on the electrode surface, it was concluded that the constant voltage of 20 V produces a more even distribution of the number of gas bubbles on the cathode and anode surfaces. In this regard, the effectiveness of the electroflotation process can reduce the value of TDS, turbidity, COD, and Pb concentration by 21.47%, 99.47%, 5.57%, and 65.69% and increase light intensity by 24.15%, respectively. Further study is still needed on the effect of time on the formation of gas bubbles.

Acknowledgement. The authors, acknowledge grants from Universitas Islam Indonesia through Collaborative Research (contrat no. 3686/Rek/10/DSDM/XI/2020).

References

1. R. S. Putra, G. A.Trahadinata, A. Latif and M. Solehudin, Wastewater Treatment of Chemical Laboratory Using Assisted-Phytoremediation (EAPR)," in *International Conference on Chemistry, Chemical Process and Engineering (IC3PE)-2017*, AIP Conference Proceedings 1823, 020077 (2018)
2. Environmental Protection Agency. Resource Conservation and Recovery Act (RCRA). https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-overview. Accessed Oct. 23, 2019.
3. X. Chen, G. Chen, and P.L. Yue, Environ. Sci. Technol. **36**, 778-783 (2002).
4. R. Alam and J.Q. Shang, J. Water Process Eng. **12**, 78-88 (2016).
5. M.S.K.A. Sarkar, "Electroflotation: Its Application to Water Treatment and Mineral Processing", Thesis, The University Of Newcastle (2012).
6. G. Pooja, P.S. Kumar, G. Prasannamedha, S. Varjani, and D.V.N. Vo, J. Environ. Manage. **295**, 113147 (2021).

7. J.A. Palomino-Romero, G.R. Salazar-Banda, and M.O. Maria, Sep. Sci. Technol. **48**, 192-198 (2013).
8. M.S.K.A. Sarkar, G.M. Evans, and S.W. Donne, Miner. Eng. **23**, 1058–1065 (2010).
9. M.S.K.A. Sarkar, P.M. Machniewski, and G.M. Evans, Chem. Process Eng., **34**, 327-336 (2013).
10. S.G. Da Cruz, A.J.B. Dutra, and M.B.M. Monte, J. Environ. Chem. Eng. **4**, 3681-3687 (2016).
11. U. Rubins, J. Zaharans, I. Ļihačova, and J. Spigulis, Latv. J. Phys. Tech. Sci. **51**, 65-70 (2014).
12. Y. Hiroshima, A. Maawy, S. Sato, T. Murakami, F. Uehara, S. Miwa, S. Yano, M. Momiyama, T. Chishima, K. Tanaka, M. Bouvet, I. Endo, and R.M. Hoffman, J. Surg. Res. **187**, 510-517 (2014).
13. M. Kholil and R. Rulaningtyas, Indonesian Applied Physics Letters, **1**, 7-12 (2020).
14. R. S. Putra, M. Sarkawi, F. Faikha and L. Fitmoko, “Analysis of Bubbles Size Produced in Electroflotation Using Graphite and Stainless Steel Electrode with DinoCapture 2.0,” in *International Conference on Health, Instrumentation & Measurement, and Natural Sciences (InHeNce)-2021, IEEE 21136099* (2022)
15. B. Tadesse, B. Albijanic, F. Makuei, and R. Browner, Miner. Process. Extr. Metall. Rev. **40**, 108-122 (2019).
16. L. Ben Mansour, S. Chalbi, and I. Kesentini, Indian J. Chem. Technol. **14**, 253-257 (2007).
17. C. Jiménez, B. Talavera, C. Sáez, P. Cañizares, and M.A. Rodrigo, J. Chem. Technol. Biotechnol. **85**, 1368-1373 (2010).
18. R. Issaoui, I. Ksentini, M. Kotti, and L. Ben Mansour, J. Water Chem. Technol. **39**, 166-170 (2017).
19. D. Tao, Sep. Sci. Technol. **39**, 741-760 (2005).
20. Alam, R. *Fundamentals of Electro-Flotation and Electrophoresis and Applications in Oil Sand Tailings Management*. The University of Western Ontario, 2015.
21. S.K. Jain and V.P. Singh, Dev. Water Sci., **51**, 743-786 (2003).
22. I. De Oliveira Da Mota, J.A. De Castro, R. De Góes Casqueira, and A.G. De Oliveira Junior, J. Mater. Res. Technol. **4**, 109-113 (2015).
23. C.S. Rao, *Environmental Pollution Control Engineering*, Revised Second (New Age International (P) Ltd., New Delhi, 2007.
24. R. S. Putra and N. H. Airun, “The effect of particle size and dosage on the performance of papaya seeds (carica papaya) as biocoagulant on wastewater treatment of batik industry,” In *IOP Conf. Ser.: Mater. Sci. Eng.* 1087, 012045 (2020).