Effect of Addition of Sea Water on Changes in Turbidity and Metal Content in Industrial Wastewater Treatment into Drinking Water using Electrocoagulation Process

Sutanto[1] and Rahmat[1]

[1]*Department of Electrical Engineering, State Polytechnic of Jakarta, Depok, Indonesia*

Keywords: Wastewater, sea water, electrocoagulation, turbidity, drinking water

Abstract: The treatment of industrial wastewater was studied by electrocoagulation process into drinking water. The wastewater 4.5 liters was drained off into the three cells of electrocoagulation process tank. The process was conducted at 12 Volt in voltage and observed of change of the turbidity and metal content in interval time of 10 minutes. Subsequently, the same procedure was carried out by adding sea water with varying volumes of 5,10 and 15 mL Based on the research results, the best processes are obtained 10 mL of sea water, 12 Volt of voltage and 100 minutes for processing time, where turbidity can be removed from 44.08 NTU to 4.85 NTU or equivalent 88.99 %, copper content from 3.55 to 0.93 mg/L or equivalent 80.97 % and iron content from 1.25 to 0.27 mg/L or equivalent 70,95 %.

1 INTRODUCTION

The wastewater is generally divided into two types, industrial and domestic wastewater. The content of pollutants in wastewater are organic and inorganic materials. These two types of waste water can be recycled into drinking water or clean water. According to the regulation of the Minister of Health of the Republic of Indonesia No. 492 / Menkes / Per / IV / 2010, the maximum content of each parameter in drinking water is as follows: are 5 NTU for turbidity, 0.3 mg/L for iron (Fe), 2 mg/L for copper (Cu), 0.01 mg/L for arsenic (As), 0.05 mg/L for chrome (Cr), 0,02 mg/L for aluminum (Al) and 0.003 mg/L for cadmium (Cd).

One of the methods that can be used to treat wastewater into clean or drinking water is the electrocoagulation process. The equipment needed to carry out the electrocoagulation process are as follows: direct current voltage source (DC), anode, cathode, process tank made from insulating material, voltage and current meter (Zaied et al,,2020) .

Aluminum or iron is a material that can be used as anode or cathode (Salem,2020). When the electrocagulation process is carried out, the anode will release metal ions to form a coagulant which absorbs all pollutants in the water. When aluminum is used as an anode, the coagulant formed is the compound $Al(OH)_3$. However, if the anode used is iron, the coagulant compound formed is $Fe(OH)_3$.

Wastewater from domestic or restaurants contains a lot of organic pollutants, so the electrical conductivity is very weak. If the electrical conductivity is very weak, the coagulant formed is very small. So that the time needed to remove pollutants is longer (Adegoke et al,2020).

Electrical conductivity can be increased by adding seawater into wastewater. The sea water has the ability to kill microorganisms and can also produce a strong electrolyte solution (Pishgar et al,2020).

Sea water added into wastewater will accelerate the removal of bacteria and pollutants in the wastewater, while the electrocoagulation process is being operated (Sefatjoo et al,2020).

The equation of the reaction in the electrocoagulation process using aluminum as anode is as follows (Rigueto et al, 2020):

anode (oxidation process):

$$2Al \rightarrow 2Al^{+3} + 6e^- \quad (1)$$

cathode (reduction process) :

$$6H_2O+6e^- \rightarrow 6OH^- +3H_2 \quad (2)$$

in overall :

$$2Al+6H_2O \rightarrow 2Al(OH)_3+3H_2 \quad (3)$$

Sutanto, . and Rahmat, .
Effect of Addition of Sea Water on Changes in Turbidity and Metal Content in Industrial Wastewater Treatment into Drinking Water using Electrocoagulation Process.
DOI: 10.5220/0010536000850092
In *Proceedings of the 9th Annual Southeast Asian International Seminar (ASAIS 2020)*, pages 85-92
ISBN: 978-989-758-518-0

In equation 3 shows that the final result of the chemical reaction from the electrocoagulation process is the coagulant compound $Al(OH)_3$. Coagulant $Al(OH)_3$ is a compound that has the characteristic of easily absorbing pollutants in the water.

The cadmium removal efficiency from the electrocoagulation process carried out at a voltage of 20 volts is 90%. The initial content of Cadmium is 50 mg/L and a pH of 7 (Alameen,,2020).

In the electrocoagulation process of restaurant wastewater within 30 minutes, the results show that the efficiency of removal of dissolved oxygen (DO), color, chemical oxygen demand (COD), phosphorus pentoxide (P_2O_5), soluble reactive polyphosphate (PO_4^{3-}) and particulate phosphorus (PP) are 20.12%, -32.88%, 12.58%, 17.15%, 19.33%, 16.85% respectively (Temitope, 2020).

The results of the continuous process electrocoagulation research on iron pollutant removal showed that the removal efficiency of iron reached 99.9%. The process was carried out at a current density of 7.3 mA/cm^2, a processing time of 50 minutes and an initial concentration of iron 10 mg/L (Abdulhadi et al,2021).

The electrocoagulation process which is added with sodium chloride (NaCl) salt can accelerate the corrosion of aluminum electrodes, but can increase the electrical conductivity. So that the formation process of the $Al(OH)_3$ coagulant compound is increasing and can also accelerating the process of removing pollutants in wastewater

Research decoloration in wastewater using anode and cathode Al only able to remove the color reaches 95.50%, whereas when using the anode and the cathode Fe were able to remove the color can reach 97.24% (Ebba, 2021).

The results of a study on the electrocoagulation process in in brackish water and sea water showed that process can reduce silica content (Zhang et al, 2019). The silica content in brackish water is easier to remove than silica in seawater. The electrocoagulation process of brackish water containing 17 mg/L of silica dioxide can remove 60% of silica dioxide. Meanwhile, the electrocoagulation process of seawater containing 17 m/L of silica dioxide was only able to remove 40% of silica dioxide.

Salinity was removed electrochemically from saline water through electrocoagulation process (Raad et al, 2020). In saline water contain ions of Br^-, Cl^-, TDS, and SO_4^{2-}.

The study on the electrocoagulation process in brine which contain of lithium ions showed that more than 95% of lithium ions (1000 mg/L) could be recovered with a relatively low energy consumption of 0.064 kWh/g Li, under operating conditions of 76.9 mA/cm^2 of current density, 6.45 of pH, and reaction time of 150 minutes (Zhang et al, 2020). That the lithium recovery from brine by electrocoagulation was mainly attributed to the chemical precipitation of aluminum hydroxide coagulants.

Research on aluminum removal from biomass has been carried out using 7.1 mA/cm^2 current density, asymmetrical aluminum electrodes and 10 minutes electrolysis time (Hawari et al, 2020). The aluminum content in the harvested biomass which decreased by 52% compared to the conventional symmetrical electrocoagulation electrodes.

Research on cadmium removal in wastewater containing high concentrations of inorganic salts using electrocoagulation process. The results showed that cadmium can be removed up to 99.5% (Xu et al, 2019).

Research on the removal of ammonia and nitrite in seawater was carried out by electrocoagulation. The results showed that ammonia can be removed up to 95% (Song et al, 2020).

The study has been carried out on the effect of adding sodium salt on electrocoagulation wastewater treatment. The results of study shown that sodium salt is very influential on the corrosion of aluminum surface and found the aluminum metal in the sediment (Wellner et al, 2018)

The combination of electrocoagulation and osmosis processes can remove more than 90% phosphate, more than 80% carbonate and more than 40% dissolved organic pollutants (Azerrad et al, 2019).

Electrocagulation process to completely eliminate 41 mg/L lead content in wastewater requires the following process conditions: electric current density of 0.3 A, pH 6, processing time of 13 minutes and energy of 0.77 watt-hours per gram of lead removal (Khan et al,2020)

Another alternative to kill or eliminate bacteria or other microorganisms contained in wastewater can be done by adding seawater into the wastewater which is being processed electrocoagulation. Because the content in seawater consists of 55% chloride salt, 31% sodium salt, 8% sulfate salt, 4% magnesium salt, 1% calcium salt, 1% potassium salt, and the remaining less than 1% is bicarbonate, bromide, boric acid, strontium, and fluoride salts. The composition of the chloride salt content which reaches 55% is very likely that sea water can be used as a disinfectant or sterilizer for wastewater, because it will form a compound hypochlorite (OCl^-) when combined with the electrocoagulation process. The hypochlorite compound (OCl^-) will act as a killing agent or oxidize microorganisms (Wellner et al,2018).

The electrocoagulation process that is carried out under strong acid conditions is the best choice, because chlorine (Cl_2) is the strongest oxidizing agent compared to HClO. Therefore, a higher pH value could theoretically increase the electrochemical oxidation of pollutants where HClO and ClO^- are not affected by gas desorption and can act as oxidizing agents (Anglada,2009). The following equation for the reaction is the evolutionary reaction of chlorine in the indirect oxidation process which is influenced by pH:

$$Cl \rightarrow 1/2\, Cl_2 + e^- \quad (4)$$

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (5)$$

$$HOCl \rightarrow ClO^- + H^+ \quad (6)$$

Increasing the concentration of Cl^- can increase removal or decrease the content of pollutants, but there is also an increase in the formation of chlorinated organic compounds which are quite toxic. High concentrations of electrolytes can increase the conductivity of the solution and reduce the demand for electrical voltage from the electrocoagulation cell. Thus it can be explained that the electrochemical oxidation process will be more economical or cheaper if the treated wastewater has a high level of salinity.

An important phenomenon that occurs in the electrocoagulation process is the formation of an oxidizing agent such as HOCl, OCl^-, ClO_2 and Cl_2. The oxidizing agent that is formed is to kill microorganisms The reaction mechanism can be explained as follows (Ghernaout et al,2020) :

$$2Cl^- \rightarrow Cl2 + 2e^- \quad (7)$$

$$Cl_2 + 2OH^- \rightarrow H_2O + OCl^- + Cl^- \quad (8)$$

$$Cl_2 + 4H_2O \rightarrow 2ClO_2 + 8e^- \quad (9)$$

2 METHOD

The research method that has been carried out consists of preparation of materials, preparation of equipment and implementation of research

2.1 Materials

Materials needed include seawater, industrial wastewater and aluminum HTC 16-35.

2.2 Equipments

The equipments needed include: electrocoagulation cells, waste water tanks, settling tanks, clean water storage tanks, electric power sources, electric voltage measuring devices, flow meters, turbidimeter and AAS (Atomic Absorption Spectrophotometer).

2.3 Implementation

2.3.1 Wastewater Quality Measurement

Several parameters are measured to determine the quality of wastewater, including: turbidity is measured by a turbidimeter, metal content is measured by AAS and the level of acidity is measured by a pH meter.

2.3.2 Constructing Research Equipments

The equipments used for research can be seen in Figure 1, consists of a voltage source, electrocoagulation process cells, waste water tanks, settling tanks, clean water tanks, electric current and voltage meters.

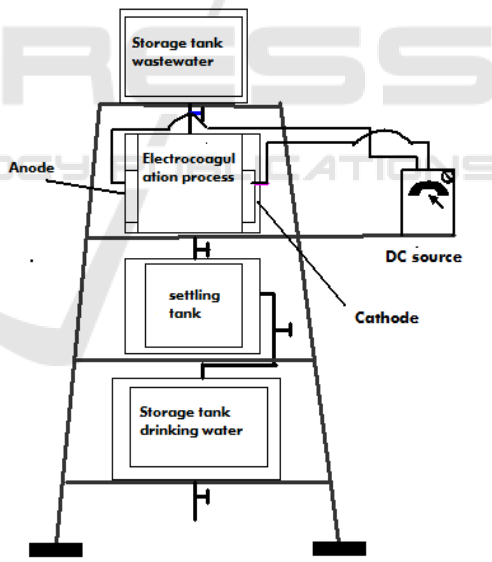

Figure 1: The series of research tools

2.3.3 Research Implementation

The wastewater 4.5 liters was drained off into the three cells of electrocoagulation process tank. The process was conducted at 12 Volt in voltage and observed of change of the turbidity and metal content in interval time of 10 minutes. Subsequently, the same procedure was carried out by adding sea water with varying volumes of 5, 10 and 15 mL. The turbidity is measured using the turbidimeter and metals content is measured using Atomic Absorption Spectrophotometer (AAS).

3 RESULT AND ANALYSIS

Laboratory test results of electronics industry wastewater parameters shown in table 1. According to table 1, it appears that the initial content of the metals in wastewater is 3.55 mg/L for copper, 0.78 mg/L for aluminum and 1.25 mg/L for iron. According to the regulation of the minister of health No.492/Menkes/Per/IV/2010, shown that all content of metals in wastewater has not met the requirements for drinking water standards.

Table 1: Results of measurements of electronics industry wastewater

Parameters	Measurement results
Copper (Cu)	3.55 mg/L
Aluminum (Al)	0.78 mg/L
Chrome (Cr)	not detected
Iron (Fe)	1.25 mg/L
pH	7.54
Turbidity	44.08 NTU

The results of research by impact of addition of sea water in wastewater treatment in electrocoagulation process presented in 3 views, namely: impact of addition of sea water to changes turbidity, impact of addition of sea water to changes copper content and impact of addition of sea water to changes iron content. Each research result, then can be seen in the sub-section discussion from 3.1 until 3.4.

3.1 Impact of Addition of Sea Water to Changes in Water Turbidity

The laboratory test results of water turbidity, shown in table 2. From table 2, can be seen that the addition of sea water in the electrocoagulation process is able to remove the turbidity in wastewater. The electrocoagulation process which is carried out without the addition of sea water, the turbidity level can be reduced from 44.08 NTU to 18.20 NTU or equal to 58.71% in 110 minutes for process time. If the process is carried out for up to 120 minutes, it will not be able to produce drinking water standard, because the turbidity of the water is 12.21 NTU or more than 5 NTU. Furthermore, the electrocoagulation process which was carried out for 120 minutes with the addition 5 mL of sea water had not yet obtained the water drinking standard. Because turbidity of water is 6.27 NTU. Meanwhile, the electrocoagulation process, which was carried out for 110 minutes with the addition of 10 mL of sea water, was able to produce water that has a drinking water standard with turbidity of 3.25 NTU or less than of 5 NTU. In this case the turbidity of water can be reduced from 44.08 to 3.25 or equal to 92.63 %.

When the electrocoagulation process is carried out using aluminum as an anode, an $Al(OH)_3$ coagulant will be formed. The $Al(OH)_3$ coagulant is an adsorbant that can absorb pollutants in water, so that the turbidity will be reduced in wastewater.

Table 2: Results of measurements of turbidity

Time (minute)	addition of sea water 0 mL	5mL	10 mL	15 mL
0	44.08	44.08	44.08	44.08
10	43.98	42.24	41.55	40.85
20	43.18	41.14	39.25	38.15
30	42.68	39.24	37.85	34.56
40	41.21	36.27	34.25	32.76
50	39.51	34.87	32.54	30.12
60	37.48	31.29	28.25	26.76
70	34.21	28.27	24.85	22.23
80	30.71	22.54	19.25	16.76
90	27.29	18.37	12.65	12.34
100	22.14	14.43	4.85	3.76
110	18.20	10.27	3.25	1.23
120	12.21	6.27	1.25	0.16

3.2 Impact of Addition of Sea Water to Changes in Copper Content

The laboratory test results of copper content, shown in table 3. From table 3, can be seen that the addition of sea water in the electrocoagulation process is able to remove the copper content in wastewater. The copper content can be reduced from 3.55 mg/L to 2.02 mg/L or equal to 43.10 % at 80 minutes for process time without adding sea water. If the electrocoagulation process is carried out for up to 120 minutes, it will produce the water that is as drinking water standard. Because the copper content in the water was 0.98 mg/L or less than 2 mg/L. In this case it is clearly shown that the copper content can be reduced from 3.55 mg/L to 0.98 mg/L or equal to 72.39%. Furthermore, the electrocoagulation process which was run for up to 70 minutes with the addition of 5 mL of sea water has been able to produce drinking water. Because copper content in the water was 1.85 mg/L or less than 2 mg/L or copper content can be reduced from 3.55 to 1.85 mg/L that was equivalent of 47.44 %. Meanwhile, the electrocoagulation process which was carried out for 60 minutes with the addition of 10 mL of sea water, was able to produce water that has a drinking water standard with copper content was 1.91 mg/L or less than of 2 mg/L. In this case the copper content in the water has been removed from 3.55 to 1.91 mg/L or equal to 45.74 %. Furthermore, the electrocoagulation process which was run for up to 50 minutes with the addition of 15 mL of sea water has been able to produce drinking water. Because copper content in the water was 1.98 mg/L (less than 2 mg/L) or copper content can be reduced from 3.55 to 1.98 mg/L that was equivalent of 43.75 %.

Table 3: Results of measurements of copper content

Time (minute)	addition of sea water 0 mL	5mL	10 mL	15 mL
0	3.55	3.55	3.55	3.55
10	3.50	3.48	3.28	3.00
20	3.42	3.32	3.02	2.67
30	3.21	3.08	2.82	2.45
40	3.01	2.83	2. 45	2.18
50	2.86	2.54	2.12	1.98
60	2.56	2.21	1.91	1.57
70	2.21	1.85	1.74	1.23
80	2.02	1.56	1.54	1.01
90	1.83	1.32	1.12	0.91
100	1.47	1.03	0.93	0.73
110	1.21	0.89	0.67	0.54
120	0.98	0.67	0.47	0.32

3.3 Impact of Addition of Sea Water to Changes in Iron Content

The laboratory test results of iron content, shown in table 4. From table 4, can be seen that the addition of sea water in the electrocoagulation process is able to remove the iron content in wastewater.

If the process is conducted without the addition of sea water, then to get water that is drinking water standard it takes a minimum of 120 minutes. In this case iron content can be removed from 1.25 to 0.21 mg/L or equivalent to 83.20 %. The maximum recommended iron content in drinking water is 0.3 mg/L (according to drinking water requirements).

If the process is conducted with the addition 5 mL of sea water, then to get water that is drinking water standard it takes a minimum of 100 minutes for process time. In this case iron content can be reduced from 1.25 to 0.26 mg/L (less than 0.3 mg/L) or equivalent to 78.51%. It appears that the time required for the process is 10 minutes faster than the process without adding sea water.

If the electrocoagulation process is carried out with the addition 10 mL of sea water, then to get water that is drinking water standard it takes a minimum of 100 minutes. In this case iron content can be reduced from 1.25 to 0.26 mg/L (less than 0.3 mg/L) or equivalent to 79.20 %. It appears that the time required for the process is 20 minutes faster than the process without adding sea water or 10 minutes faster than the process with adding 5 mL sea water.

If the electrocoagulation process is carried out with the addition 15 mL of sea water, then to get water that is drinking water standard it takes a minimum of 80 minutes. In this case iron content can be reduced from 1.25 to 0.22 mg/L (less than 0.3 mg/L) or equivalent to 82,40 %. It appears that the time required for the process is 40 minutes faster than the process without adding sea water or 20 minutes faster than the process with adding 10 mL of sea water.

The addition of sea water must be limited so that the quality of the water produced is maintained according to drinking water standard. However, turbidity and metal content are maintained so that the quality of the water produced is in accordance with drinking water standards. The volume of sea water recommended is 10 mL and the time for the processing is 100 minutes and 12 Volts in voltage. The water turbidity in this condition is 4.85 NTU, the copper content is 0.93 mg/L and the iron content is 0.27 mg/L.

The process of removing iron content in water can be accelerated by adding seawater. Because the added sea water can increase the electrical conductivity, so that the electric current that flowed is greater than the initial current. The increasing electric current can accelerate the formation rate of the $Al(OH)_3$ coagulant. The coagulant of $Al(OH)_3$ which functions as an absorbent compound and precipitates iron pollutants in the water.

Table 4: Results of measurements of iron content

Time (minute)	addition of sea water 0 mL	5mL	10 mL	15 mL
0	1.25	1.25	1.25	1.25
10	1.20	1.18	1.12	1.10
20	1.19	1.09	1.01	0.99
30	1.12	0.93	0.90	0.87
40	1.00	0.89	0.76	0.71
50	0.91	0.72	0.67	0.58
60	0.82	0.63	0.56	0.47
70	0.71	0.52	0.43	0.31
80	0.62	0.43	0.38	0.22
90	0.55	0. 37	0.31	0.19
100	0.41	0.32	0.27	0.12
110	0.31	0.26	0.18	0.09
120	0.21	0.18	0.07	0.01

3.4 Curves of Changes of Turbidity and Metal Content

Figure 2 is made from the data in table 2 which shows the relationship of the effect of changes in sea water addition to water turbidity.

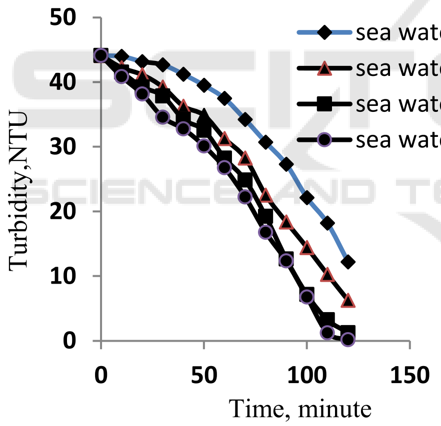

Figure 2: The relationship between changes of sea water additions to water turbidity

According to figure 2, it can be seen that the performance of the electrocoagulation process to remove turbidity increases when the sea water is added into the wastewater. If more and more sea water is added to the electrocoagulation process, the process of reducing water turbidity will be accelerated. The addition of sea water into wastewater will increase the electrical conductivity. The increasing electrical conductivity will accelerate the formation of the $Al(OH)_3$ coagulant. The Al $(OH)_3$ compound is a material that absorbs pollutants in water and precipitates it to the bottom of the process tank, so that the water is getting clearer.

Figure 3 is made from the data in table 3 which shows the relationship of the effect of changes in sea water addition to remove copper content in water. According to figure 3, it can be seen that the performance of the electrocoagulation process to remove copper content increases when the sea water is added into the wastewater. If more and more sea water is added to the electrocoagulation process, the process of reducing copper content in water will be accelerated. The addition of sea water to wastewater will increase the electrical conductivity. The increasing electrical conductivity will accelerate the formation of the $Al(OH)_3$ coagulant. The $Al(OH)_3$ compound is a material that absorbs copper content in water and precipitates it to the bottom of the process tank, so that the copper content in the water is getting lower.

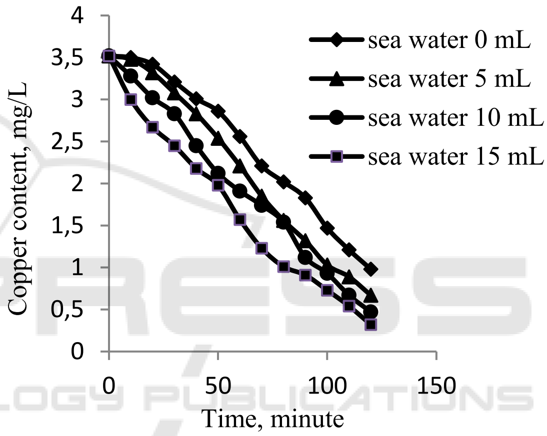

Figure 3: The relationship between changes of sea water additions to copper content

Figure 4 is made from the data in table 4 which shows the relationship of the effect of changes in sea water addition to remove iron content in the water. According to figure 4, it can be seen that the performance of the electrocoagulation process to remove iron content increases when the sea water is added into the wastewater. If more and more sea water is added to the electrocoagulation process, the process of reducing iron content in water will be accelerated. The addition of sea water into wastewater will increase the electrical conductivity. The increasing electrical conductivity will accelerate the formation of the $Al(OH)_3$ coagulant. The Al $(OH)_3$ compound is a material that absorbs iron content in water and precipitates it to the bottom of the process tank, so that the iron content in the water is getting lower.

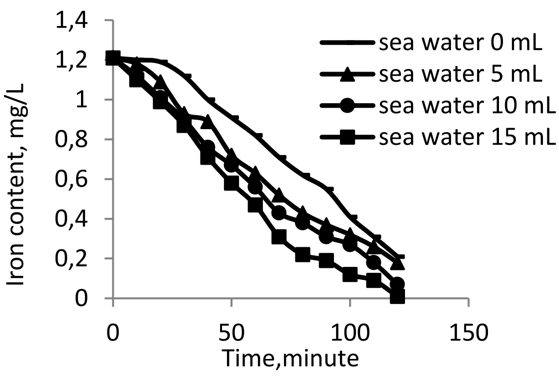

Figure 4: The relationship between changes of sea water additions to iron content

4 CONCLUSION

Sea water added to wastewater which is being processed electrocoagulation can remove turbidity, copper and iron content. The recommended variable values to operate the electrocoagulation process are 12 V for voltage, 10 mL for seawater requirements and 100 minutes for processing time. Efficiency removal of turbidity is 88.99 %, copper content is 80.97% and iron content is 70.95 % repectively.

ACKNOWLEDGEMENTS

The Authors would like to thank the head of research and community unit, Jakarta State Polytechnic for financial support, so that the authors are able to complete this research. Thank a lot also to Afiliation-Laboratory FMIPA University of Indonesia UI for giving laboratory equipment support.

REFERENCES

Abdulhadi, B., Kot, P., Hashim, K., Shaw, A., Muradov, M. and Khaddar, R.A., 2021. Continuous-flow Electrocoagulation (EC) Process for Iron Removal from Water: Experimental, Statistical and Economic Study, *Science of The Total Environment.*

Adegoke, A.T, Abayomi and Temitayo, E.,2020. A Preliminary Study on The Treatment of Restaurant Wastewater Using Electrocoagulation Technique, *Journal of Degraded and Mining Lands Management.*

Alameen, M. and Majeed, N., 2020. Removal of Cadmium from Industrial Wastewater using Electrocoagulation Process, *Chemical, Petroleum and Environmental Engineering.*

Anglada, A., Urtiaga, A. and Ortiz, I., 2009. Contributions of Electrochemical Oxidation to Waste-water Treatment: Fundamentals and Review of Applications, *Society of Chemical Industry.*

Azerrad, S. P., Isaacs, M. and Dosoretz, C. G., 2019. Integrated Treatment of Reverse Osmosis Brines Coupling Electrocoagulation with Advanced Oxidation Processes, *Chemical Engineering Journal.*

Ebba, M., 2021. Application of Electrocoagulation for the Removal of Color from Institutional Wastewater: Analysis with Response Surface Methodology, *Journal of Environmental Treatment Techniques.*

Ghernaout, D. and Elboughdiri, N., 2020. Electrocoagulation Process in the Context of Disinfection Mechanism**,** *Scientific Research.*

Hawari, A.H., Alkhatib, A.M., Das, P., Thaher, M. and Benamor, A.,2020. Effect of the Induced Dielectrophoretic Force on Harvesting of Marine Microalgae (*Tetraselmis* sp.) in Electrocoagulation, *Journal of Environmental Management*.

Khan, S.U., Mahtab, M.S.and Izharul Haq Farooqi, I.H., 2020. Enhanced Lead (II) Removal with Low Energy Consumption in an Electrocoagulation Column Employing Concentric Electrodes: Process Optimisation by RSM Using CCD, *International Journal of Environmental Analytical Chemistry.*

Pishgar, Z., Samimi, A., Kalhori, D.M. and Shokrollahzadeh, S.,2020. Comparative Study on The Harvesting of Marine Chlorella Vulgaris Microalgae from a Dilute Slurry Using Autoflocculation-Sedimentation and Electrocoagulation-Flotation Methods*, International Journal of Environmental Research.*

Raad, A. A. A., Hanafiah, M. M, Naje, A. S., Ajeel, M.A., 2020. Optimized parameters of the electrocoagulation process using a novel reactor with rotating anode for saline treatment, *Environmental Pollution.*

Rigueto,C.V.T., Nazari,M.T., Souza,C.F.D, Cadore,J.S., Brião, V.B. and Jeferson Steffanello Piccin, J.S, 2020. Alternative Techniques for Caffeine Removal from Wastewater: an Overview of Opportunities and Challenges, *Journal of Water Process Engineering*

Salem, M. A., 2020. Removal of Cadmium from Industrial Wastewater Using Electrocoagulation Process, *Journal of Engineering.*

Sefatjoo, P.,Moghaddam,M.R.A.and Mehrabadi,A.R., 2020. Evaluating Electrocoagulation Pretreatment Prior to Reverse Osmosis System for Simultaneous Scaling and Colloidal Fouling Mitigation: Application of RSM in Performance and Cost Optimization, *Journal of Water Process Engineering*

Song, J., Yin, Y., Li, Y.,Gao, Y. and Liu,Y.,2020. in-Situ Membrane Fouling control by Electrooxidation and Microbial Community in Membrane electro-bioreactor Treating Aquaculture Seawater, *Bioresource Technology.*

Wellner, D. B., Couperthwaite, S. J. and Millar, G.J.,2018. Influence of Operating Parameters During Electrocoagulation of Sodium Chloride and Sodium

Bicarbonate Solutions Using Aluminium Electrodes, *Journal of Water Process Engineering.*
Xu, L., Wu, D., Liu, W., Xu, X., Cao, G., 2019. Comparative Performance of Green Rusts Generated in Fe^0–Electrocoagulation for Cd^{2+} Removal from High Salinity Wastewater: Mechanisms and Optimization, *Journal of Environmental Management.*
Zaied, B.K, Rashid, M., Nasrullah,,M..Zularisam, A.W.,Pant,D.and Singh, L., 2020. A Comprehensive Review on Contaminants Removal from Pharmaceutical Wastewater by Electrocoagulation Process, *Science of The Total Environment.*
Zhang, X.,Lu, M., Idrus, M.A.M., Crombie,C.,Veeriah and Jegatheesan,V., 2019. Performance of Precipitation and Electrocoagulation as Pretreatment of Silica Removal in Brackish Water and Seawater, *Process Safety and Environmental Protection.*
Zhang,Y., Xu, R., Sun, W. , Wang, L. and Tang, H., 2020. Li Extraction from Model Brine via Electrocoagulation: Processing, kinetics, and Mechanism, *Separation and Purification Technology.*

.

.