

# Chapter 16

## Effect of Current and Electrodes Area to Color Removal Efficiency and Energy Consumption by Electrocoagulation Process



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**Abstract** The objectives of these experiments were to investigate the effect of current and electrodes surface area on color removal efficiency and energy consumption. The result was showed that color removal efficiency was more than 95% for current apply 0.4–0.5 A, that pH increased with increasing time of electrolysis, then stabilize at close to 8–9. Amount of current density was indicate that increasing current was correspond to increase a removal efficiency that according to Faraday’s law. As for, the electrode surface area with constant current, the color removal efficiency is the trend to increase. During electrolysis, larger electrodes provide higher color removal efficiency than smaller electrodes. Also, the larger electrodes can also reduce the applied voltage of the system that cause of low operation cost. For effect of current per electrode area constant but difference current and electrode area, Color removal efficiency was difference where removal efficiency was depend on the current density. The conclusion was indicated that both of current and electrode area was effect to electrocoagulation process.

**Keywords** Wastewater · Treatment · Electrocoagulation · Electrode area · Current

### 16.1 Introduction

Dyes are one of the significant toxins in the textile industry, which influences the getting climate as well as emphatically influences the wellbeing of people and creatures because of a lot of wastewater (Huynh et al. 2016). The contaminants in the outflow are colloid-dal components and dissolved organic matters, which contain chiefly by-effects, the remaining dye, acid/alkalinity, additives chemicals, and cleaning solvents. Color is a significant impurity in the textile effluent and must be eliminated prior to releasing the gushing into the aqueous ecosystem (Naje et al. 2017).

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Electrocoagulation is an alternative technology for wastewater treatment (Francolins 2014) and relies upon the electrochemical dissolution of sacrificial metal electrodes (Chafi et al. 2011). Many studies have indicated the potentials of electrocoagulation in treating a variety of wastewater, such as dyes solution and textile wastewater (Abu Ghalwa and Saqer 2016; Chafi et al. 2011; El-Ashtoukhy and Amin 2010; Merzouk et al. 2009; Pajootan et al. 2012; Verma 2017), color food (Modirshahla et al. 2007), removal of pollutants from tannery (Benhadji et al. 2011; Jing-wei et al. 2007), wastewater from paint manufacturing (Akyol 2012), paper mill (Katal and Pahlavanzadeh 2011), dairy effluents (Tchamango et al. 2010, domestic wastewater (Omwene and Kobya 2018) and heavy metals (Al Aji et al. 2012). The EC technique is advantaged by its easiness, simple operation, less retention time, less or nonappearance of chemicals addition, fast sedimentation, less sludge creation, and ecological similarity when contrasted with customary techniques (Omwene and Kobya 2018).

EC operating conditions mostly depend on the current density, pH, Voltage, types of electrode, retention time, chemical constituents and concentrations containing wastewater (Mickova 2015). Generally, an increase in current causes the anode oxidation more readily, which increasing removal efficiency according to Faraday's law (Eq. 1) as described the relationship between current and the amount of anodic dissolution. Whereas the electrode surface area rarely mentions but has the advantage of a decreased time of coagulation (Ahangarnokolaei et al. 2018).

$$E = I \times T \times M / z \times F \quad (16.1)$$

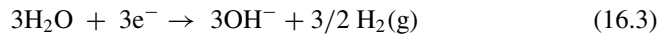
where, I is current (A), T is time of electrolysis (s), M is molecular mass of electrode (g/mol), z is number of electrons transferred, F is Faraday's constant (96,487 g/mol)

EC generally refers to the electrolytic generation of coagulating metal ions, which make colloidal particles larger so they can be filtered through from the water. The gas ( $H_2$ ) released at the cathode has no influence in the pollutant removal (Mickova 2015). For the most part, the EC process comprises six key processes: (i) movement to an oppositely charged electrode (electrophoresis) and aggregation due to charge neutralization;(ii) a precipitate with the pollutant forms a cation or hydroxyl ion ( $OH^-$ );(iii) to form a hydroxide, the metallic cation interacts with  $OH^-$  which has high adsorption properties that are therefore attached to the contaminant; (iv) the hydroxides, like structures, form larger lattices and sweep through the water (sweep coagulation);(v) pollutants oxidation to less toxic species;(vi) removal by electro flotation or sedimentation and bubble adhesion (Katal and Pahlavanzadeh 2011). According to the following reactions (Merzouk et al. 2009)

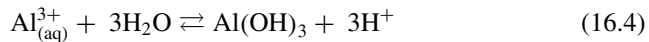
anode, sacrificial metal (Al):



cathode,  $H_2$  gas and  $OH^-$  is generated:



At low pH, aluminum anode generates the cationic monomeric species, for example,  $\text{Al}^{3+}$  and  $\text{Al}(\text{OH})^{2+}$ , which at proper pH values are transformed into  $\text{Al}(\text{OH})_3(\text{s})$  and finally polymerized to  $\text{Al}_n(\text{OH})_{3n}$  (Modirshahla et al. 2007):



In the EC, the predominantly formed amorphous  $\text{Al}(\text{OH})_3$  “sweep flocs” have large surface areas which are valuable for fast adsorption of soluble organic compounds and catching of colloidal particles. At last, these flocs are taken out effectively by sedimentation or flotation by  $\text{H}_2$  (El-Ashtouky and Amin 2010; Omwene and Koby 2018).

This article presents the results of the study of the laboratory scale on the removal of C.I. Acid Red 114 from water by electrocoagulation using aluminum electrodes. A detailed experimental has been done to notice the impacts of current and electrode surface areas on the efficiency of dye removal. Measurement of pH, operating time, and cell voltage for estimation of electrical energy consumption.

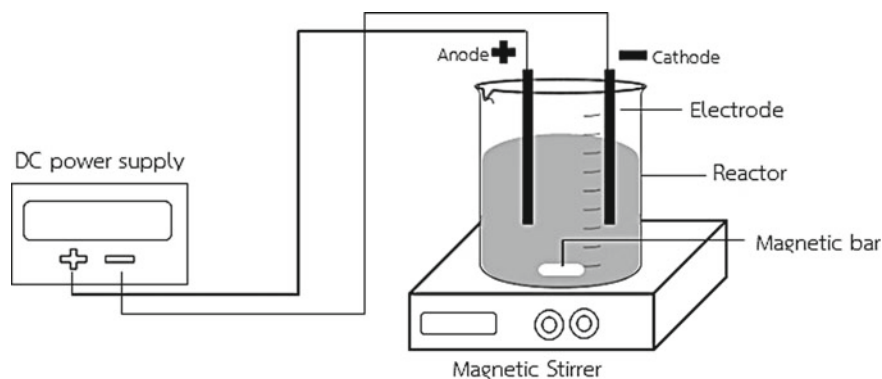
## 16.2 Experimental

### 16.2.1 Materials and Methods

The EC experiments were performed on Acid Red 114 (C37H28N4O10S3.2Na, C.I.:23635 MW: 830.8 g/mol,  $\lambda_{\text{max}}$ : 518 nm, sivasumpan Co.,Ltd.) solutions with a concentration of 400 mg/L. The batch reactor used 2 L polypropylene beaker. The aluminum electrodes with submerge surface areas range 4–100  $\text{cm}^2$  were used as anode and cathode with the distance of each electrodes was set 2 cm. the electrodes were submerged in HCl 15% for 30 min to remove impurities on the aluminum surface, then abraded with sandpaper and rinsed with distilled water, next and used suddenly. The DC power supply was GW Instek, GPS-3303. The experiments were performed at room temperature. The magnetic stirrer was set at 150 rpm. (see in Fig. 16.1.)

### 16.2.2 Experimental Procedures

The experiment was separated into 3 parts: (i) Effect of current, as testing current in range 0.05-0.5 A with fixed electrode surface area 40  $\text{cm}^2$ . (ii) Effect of electrode surface area, 4–100  $\text{cm}^2$  were the different surface area studied with testing current 50, 300, and 500 mA depend on limit maximum current used. (iii) Effect of



**Fig. 16.1** Experimental setup for batch electrocoagulation

**Table 16.1** Experimental scope

Experiment	Variation of parameters	Constant parameter
Effect of current	0.05, 0.1, 0.2, 0.3, 0.4, 0.5 A	$C_0 = 400$ mg/L, EA = 40 cm <sup>2</sup> , d = 2 cm, pH = 6
Effect of electrode surface area	4, 10, 20, 40, 60, 80, 100 cm <sup>2</sup> (0.2, 0.5, 1, 2, 3, 4, 5 cm)	$C_0 = 400$ mg/L, I = 0.05-0.5A, d = 2 cm, original pH value
Effect of current/surface area constant	5 mA/cm <sup>2</sup> (50 mA/10 cm <sup>2</sup> ) 5 mA/cm <sup>2</sup> (200 mA/40 cm <sup>2</sup> ) 5 mA/cm <sup>2</sup> (500 mA/100 cm <sup>2</sup> )	$C_0 = 400$ mg/L, I = 0.05-0.5A, d = 2 cm, original pH value

current density per electrode area was constant as 5 mA/cm<sup>2</sup> which corresponded as currents value 50, 200, and 500 mA with electrode surface areas 10, 40, and 100 cm<sup>2</sup>, respectively. (see in Table 16.1.)

### 16.3 Analytical Method

In each experiment, Dye wastewaters was sampling within 0-60 min. pH was measured immediately, pH analysis using Multi-Meter. (Hach, HQ40D Portable Multi Meter). Then the sample was filtered using by filter paper.(Whatman filter paper No. 42) Determination of color removal was using UV-vis spectrophotometer (Shimadzu UV-1900), using the wavelength that provided the maximum intensity ( $\lambda_{max} = 518$  nm). Experimentally, percentage of color removal efficiency during the treatment of dyes wastewater is determined by the expression (5):

$$\text{color removal (\%)} = [(Abs_0 - Abs_i)/Abs_0] \times 100 \quad (16.5)$$

where  $Abs_0$  and  $Abs_i$  are the average absorbance before electrolysis and after an electrolysis time, respectively, at the maximum visible wavelength of wastewater. Expense due to electrical energy ( $kWh/m^3$  dye solution) was determined using the following equation (Hashim et al. 2017):

$$E = I \times v \times t / Vol. \quad (16.6)$$

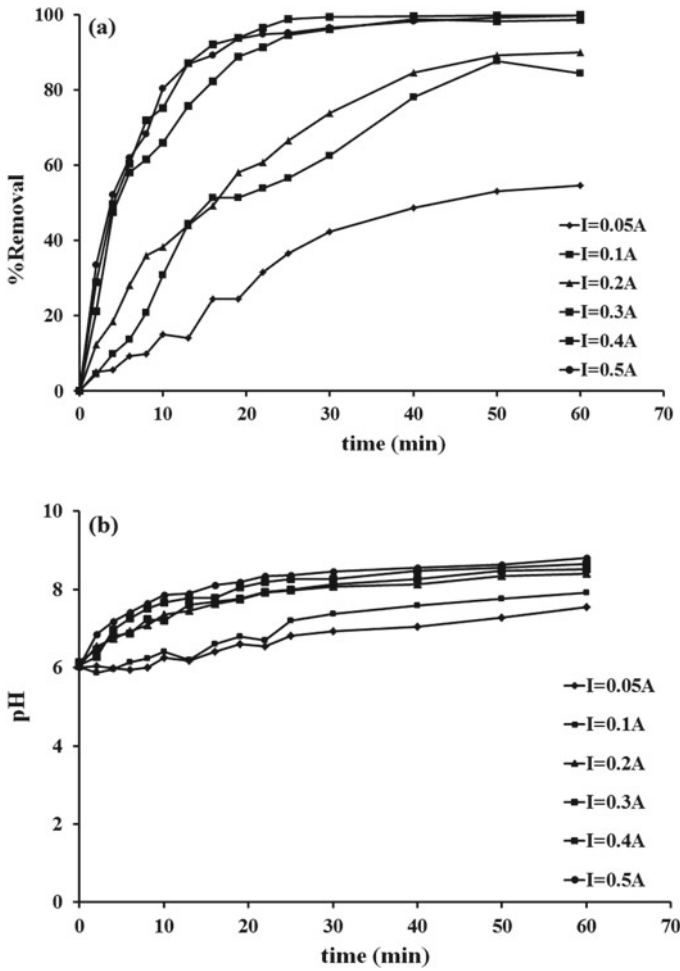
where  $E$  is the electrical energy consumption ( $kWh/m^3$ ),  $I$  is current (A),  $v$  is the cell voltage (V),  $t$  is time of electrolysis (hr) and  $Vol.$  is the volume of dye wastewater.

## 16.4 Result and Discussion

### 16.4.1 Effect of Current

As a feature of water alkalinity, the current affects hydrolyzed metal species through pH evolution during the EC process (Hakizimana et al. 2017). Studies of differential current ( $I$ ) studies of 0.05-0.5 A with dye wastewater pH initial 6 was adjusted by adding NaOH 0.5 M. The aluminum electrode area was used  $40 \text{ cm}^2$ . The result was found that the efficiency of color removal increased with an increase in current as see in Fig. 16.2a. The current was increased from 0.1 to 0.3 A, the color removal increased from 31.6% to 91.4% was observed after 22 min of operation. At the same time color removal more than 90% for current 0.4-0.5A. However, after 30 min of operation, more than 95% color removal was observed for all current above 0.3 A. Figure 16.2b it may be seen from the figure that pH increased with increasing time of electrolysis, then stabilize at close to 8–9. For the same color removal efficiency more than 80%, in current 0.1, 0.2, 0.3, 0.4 and 0.5 A. the operation time was observed 50, 40, 16, 13 and 10 min respectively. As time increases, the pH was increased. The final pH range 8–9, at a current of 0.05-0.1 A. it has a similar pH and is less than at other currents, with the final pH 7.54–7.9. For current from 0.2–0.5 A, the final pH is 8.4–8.81. It can be concluded that when the current increases, the pH changes during system operation are higher resulting in the optimum pH was rapid. That means the current increased the time of electrolysis with optimum pH (4–9) was decreased. Because of pH between 4–9, the  $Al^{3+}$  and  $OH^-$  ions generated by the electrodes react to form various monomeric species such as  $Al(OH)^{2+}$ ,  $Al(OH)_2^+$ , and polymeric species such as  $Al_6(OH)_{15}^{3+}$ ,  $Al_7(OH)_{17}^{4+}$ ,  $Al_{13}(OH)_{34}^{5+}$  that finally transform into insoluble amorphous  $Al(OH)_{3(s)}$  through complex polymerization/precipitation kinetics (Merzouk et al. 2009).

Thus, the rate of ion output ( $Al^{3+}$ ) on the anode rises as the current density increases. These increase the output of flocs ( $Al(OH)_3$ ) in the solution and thus improve the efficiency of the removal of color. The fact that the dissolved coagulants ( $Al^{3+}$ ) increased as improved efficiency of color removal according to Faraday's law. On the other hand, the total amount of flocs produced at a very low current was not sufficient



**Fig. 16.2** Effect of current on the color removal efficiency with Al electrodes. Electrodes gap 2 cm. Initial pH 6 **a** color removal efficiency with different current **b** pH system

to remove all the dye molecules in the solution and more time was needed to achieve greater efficiency of color removal (Modirshahla et al. 2007; Nandi and Patel 2017). Moreover, The EC system design should consider the current and operation time which to reduce energy consumption.

### 16.4.2 Effect of Electrode Surface Areas

In order to investigate the effect of electrode surface areas on the efficiency of color removal, studies were carried out at different electrode surface areas of 4–100 cm<sup>2</sup> (width 0.2–5 cm) at fixed current min 0.05 A, current max 0.3 A (4–10 cm<sup>2</sup>) and 0.5 A (20–100 cm<sup>2</sup>) with original pH. Each experiment runs 60 min. According to Fig. 16.3a, demonstrate the removal efficiency of AR114 as a function of electrode surface areas. At EA 4 cm<sup>2</sup> (current 0.05 A) and original pH (4.09-4.28) the color removal efficiency was increased slowly. As for EA 10–100 cm<sup>2</sup> seems to tend was

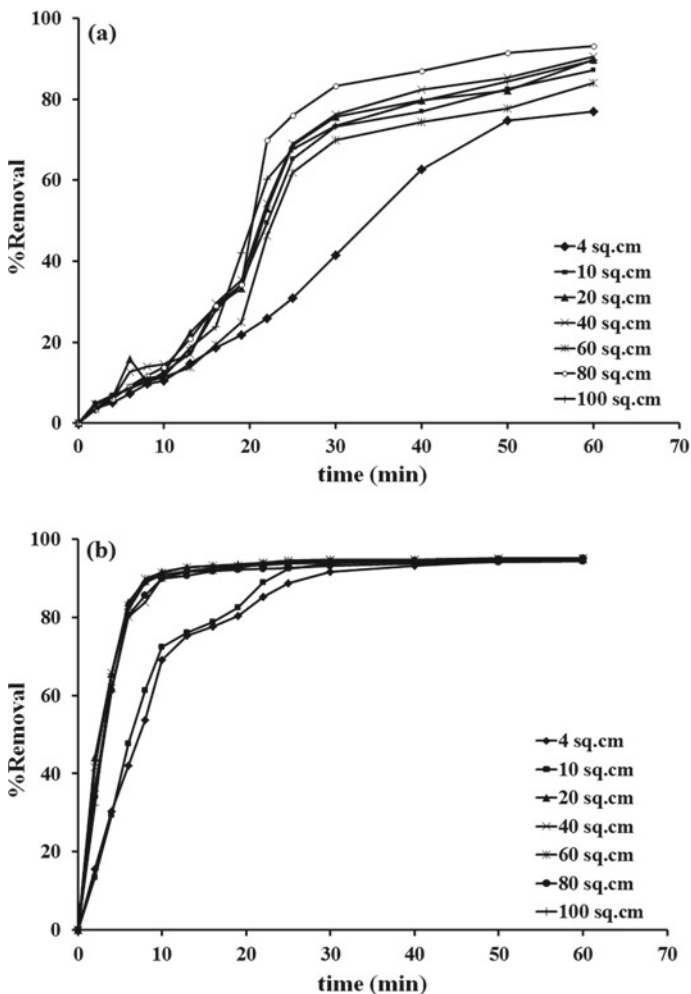


Fig. 16.3 Effect of electrode surface areas on the color removal efficiency with Al electrodes. Electrodes gap 2 cm. Initial pH 4–4.3 a I = 0.05 A, b I = 0.3–0.5 A

**Table 16.2** Effect of electrode area with constant current on the electrical energy consumption ( $I = 0.05$  and  $0.5$  A, Al electrodes, electrodes gap 2 cm and time of experiment 60 min)

Electrode surface area (cm <sup>2</sup> )	I = 0.05 A, T = 60 min		I = 0.5 A, T = 60 min	
	Volt	KW h/m <sup>3</sup>	Volt	KW h/m <sup>3</sup>
4	17.1	427.50	63.1 (0.3A)	15,775
10	13	325.00	63.1 (0.3A)	15,775
20	11.5	287.50	63	15,750
40	8.8	220.00	57.6	14,400
60	6.7	167.50	45.2	11,300
80	6.2	155.00	38	9,500
100	5.2	130.00	30.6	7,650

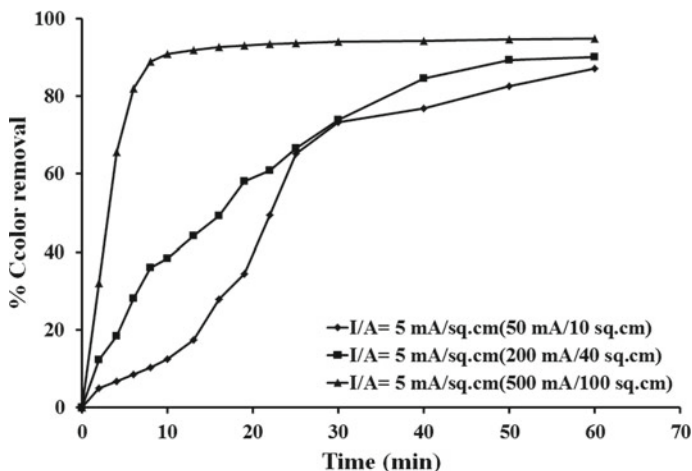
similar. The time of experiments in range 19–25 min the color removal was changing rapidly and during electrolysis, larger electrodes provide higher color removal efficiency than smaller electrodes according to the kinetics of electrode reaction (Walsh 1992). Then, at 60 min the removal efficiency increase of 77%, 87.2%, 89.8%, 90.5%, 84%, 93.1% and 89.6%, respectively and final pH was 6.68–7.57. While various EA with maximum current test 4–10 cm<sup>2</sup> (0.3 A) and 20–100 cm<sup>2</sup> (0.5 A), for EA 4–10 cm<sup>2</sup> the color removal efficiency increasing less than EA above 20 cm<sup>2</sup> but after 40 min the efficiency seems no difference which in the range 93.3–94.6%. In addition, EA 20–100 cm<sup>2</sup> in 10 min the treatment efficiency is more than 90%. At the end of the experiment was observed 95.2%, 95.2%, 94.7%, and 94.9% respectively as shown in Fig. 16.3b. As initial pH before run measured 4.16–4.3, after 60 min the pH was increasing of 8–8.84.

The result indicated that an increasing of electrode surface area with constant current, the color removal efficacy is the trend to increase. During electrolysis, larger electrodes provide higher color removal efficiency than smaller electrodes. Also, the larger electrodes can also reduce the applied voltage of the system while the current constant (see in Table 16.2).

### 16.4.3 Effect of Current Density and Electrode Area When Current/Electrode Area Constant (CA)

Electrocoagulation process is often designed as a function of current density as the proportion current over the electrode surface (Hakizimana et al. 2017). Current density is an important factor because it determines the production rate of coagulation, bubble formation rate and hence of flocs (Naje et al. 2017). Experimental studies were carried out at fixed current density per electrode area at 5 mA/cm<sup>2</sup>, which corresponded as currents value 50, 200 and 500 mA with electrode surface areas 10, 40 and 100 cm<sup>2</sup> respectively. It can be indicated from Fig. 16.4, at fixed





**Fig. 16.4** Effect of current density on the color removal efficiency with Al electrodes. Electrodes gap 2 cm, Initial pH 4–4.3,  $I/A = 5 \text{ mA/cm}^2$

current density as various currents system was different when currents increased from 50 to 500 mA with the area of  $10 \text{ cm}^2$  and  $100 \text{ cm}^2$  after 10 min, the color removal efficiency increased from 12.5% to 90.9%. Although the same value of current density per electrode area ratio, it seems that currents are an important factor affecting efficiency. Other studies the current density with constant electrodes area; CA of 5–20  $\text{mA/cm}^2$  observed an increase in dye removal efficiency up to 98.7% with an increasing CA (Abu Ghalwa and Saqer 2016). Another study, using CA in range 100–1200  $\text{mA/cm}^2$ , the dye removal increased from 65% to 92% (acid black 52) and 97% (acid yellow 220) with an increasing CA of 10–40  $\text{mA/cm}^2$ , but increasing CA up to 1200  $\text{mA/cm}^2$  no real difference (Pajootan et al. 2012). For CA was varied between 20.8–62.5  $\text{mA/cm}^2$ . An increase in CA from 20.83 to 62.5  $\text{mA/cm}^2$  the color removal efficiency increased 78–93% when CA higher than 31.25  $\text{mA/cm}^2$  became a small difference curve (Merzouk et al. 2009). As a result, the CA corresponded to the currents value (I), which influent to electrocoagulation efficiency. When increased CA with electrodes area was constant, the current value was increasing. In other words, seems to currents the most influential to the EC system.

### 16.4.4 Electrical Energy Consumption

Energy consumption regarding potential (Cell voltage; Volt), current (I; Amp), time of electrolysis and volume of dye solution that is calculated by Eq. 5. Table 16.2 represents the variation of electrical energy consumption with various electrodes areas (4–100  $\text{cm}^2$ ), current 0.05, 0.3, and 0.5 A at the time of experiment 60 min. According to observation, the cell voltage decreases by increasing the electrode

surface area due to constant current. When the electrode area increased from 4 to 100 cm<sup>2</sup> ( $I = 0.05\text{A}$ ), cell voltage lower from 17.1 to 5.2 volts the electric energy consumption decreasing 427.5 to 130 KW hr/m<sup>3</sup>. As for current 0.3–0.5 A the cell voltage decreased 63.1 to 30.6 volts, with the energy consumption 15,755–7650 KW hr/m<sup>3</sup>.

In other words, at smaller electrode surface areas indeed to more potential to stabilize the current, it can be said the larger electrodes area has the least amount of energy consumption (Ahangarnokolaei et al. et al. 2018). Consequently, the electrocoagulation process design should be consider electrode surface areas.

## 16.5 Conclusion

Effect of current and electrodes surface area on color removal efficiency towards energy consumption with EC process using Al electrodes in the sacrificial anode and cathode with Acid red 114 dye solution. The result influent of current showed, the more color removal efficiency direct by increasing current. At the highest current 0.4–0.5 A, the color removal efficiency increases rapidly with a short time. As for the lower current 0.05–0.3 A, it required more time to achieve higher color removal efficiency and pH stabilize close 8–9. For the effect of electrodes area, it can be seen an increase in the electrodes surface areas was to increase the efficiency of color removal. Increase of current density per electrode area was correspond to increase removal efficiency The color removal efficiency indicate to depend on the current, not current density per electrode area. As for the effect of electrodes area, the smaller electrode surface areas need more voltage to stabilize the current. Consequently, the larger electrodes area uses less voltage towards reducing the amount of energy consumption. The results were concluded that both of current density and electrode area effect to electrocoagulation process. For future study will experiment to limit of electrode area in another material such iron electrode.

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