Influence of current density and electrodes spacing on reactive red 120 dye removal from dyed water using electrocoagulation/electroflotation (EC/EF) process

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Abstract. The current study investigates the influence of the current density (CD) and electrodes gap (EG) on the removal of reactive red 120 dye (RR-120) from drinking water using electrocoagulation (EC) process. The influence of CD was studied by treating the dyed water at three different CDs (2, 4 and 6 mA/cm²). While the influence of EG was investigated at three EGs (5, 10, and 15 mm). The results obtained showed that increasing the CD enhanced the removal of the dye. However, increasing the EG significantly decreased the dye removal efficiency. It was found that dye removal increased from 87% to 98%, as the CD increased from 2 to 6 mA/cm², respectively. While increasing the EG from 5 to 15 mm decreased the dye removal from 96% to 80%, respectively.

1. Introduction
Reactive Red 120 dye (RR-120) is a component of azo dyes and it is widely used in textile industries [1, 2]. RR-120 is categorised as azo dye as it contains azo bond (−N=N−) in its molecular structure [3], figure 1. The textile industry released up to 60% of the entire dyestuff used in the tinting process into the environment, which causes serious problems due to their likely toxicity to both human and aquatic life [4, 5]. For example, discharging dyestuff into the water bodies creates unwanted water odours and colours; limits sun light penetration; and decreases the concentration of the dissolved oxygen [6]. Furthermore, the final results of degradation of azo dies, under certain conditions, could be carcinogenic oxygen [6]. A wide range of techniques therefore has been applied to remove dyes from water and wastewater, such as chemical oxidation, reverse osmosis and aerobic and anaerobic degradation [6, 7]. Unfortunately, some dyes have complex and stable molecular structures that make their removal by these tradition treatment methods very difficult [8]. Therefore, different traditional and advanced treatment methods have been used recently for removing these dyes, and other pollutants, from wastewater and drinking waters such as filtration, Nano-filtration, bioreactor-ultrafiltration and electrocoagulation [9-11]. The electrocoagulation (EC) has been suggested as an effective alternative process to the coagulation process in water and wastewater treatment over the last century because it tolerates many environmental and economic attractive advantages [12-15]. The EC process, in comparison with other water treatment processes, can be considered a cost effective process as it does not require any chemical additions and easy to operate [15, 16]. Additionally, its efficiency in treating different type of pollutants from drinking waters is well documented [17]. Furthermore, the EC method produces small volumes of sludge [18-21], the latter categorised as solid waste that required complex
and expensive handling and treatment procedures, which enhances the cost-effectiveness of the EC method. Finally, the performance of the EC method has been modelled to predict the removal of different pollutants under different operational conditions. For example, Hashim, Shaw [16] found that the relationship between the operating parameters and nitrate removal, using aluminium-based EC reactor, could be modelled with $R^2$ of 0.848, the latter is a statistical tool to evaluate the statistical relationship between two variables or events [22]. Additionally, Hashim, Khaddar [10] stated that the performance of aluminium-based EC units, in terms of phosphate removal, could be modelled with an $R^2$ of 0.882. It is noteworthy to highlight that these values of $R^2$ indicate good agreement between the predicted and measured removals [11, 22, 23].

2. Experimental

2.1. EC reactor

Mollah, Morkovsky [12] demonstrated that the design of the EC cells have not significantly changed during the last few decades. Generally, rectangular cells with plane rectangular electrodes are still the predominant design. Thus, the first stage of the current study was devoted to develop a new EC reactor. This new reactor consists of 1.0 L rectangular Perspex container, figure 2-A. The Perspex has been used as it is an inert and affordable material. The container is supplied with four rectangular perforated aluminium electrodes (total effective area of 280 cm$^2$). Each electrode has 35 hole each 5mm diameter drilled in lines of 3 and 4 holes to ensure each hole is offset from the one before. This configuration is

![Figure 1. The molecular structure of RR-120 dye.](image1)

![Figure 2. A) The EC reactor, B) Aluminium electrode.](image2)
to ensure that the water will flow in a convoluted path in order to increase solution mixing efficiency, figure 2-B. Aluminium has been used in the current study as it is an effective electrode materials [24]. This reactor was connected to both a bench top DC power supply (HQ Power; 0–30 V) and a peristaltic pump (Watson Marlow type, model: 504U) to supply the required electrical current and to circulate flow water through the reactor. The whole unit is shown in Figure 2.

![Figure 2](image.png)

**Figure 2.** EC setup: 1.influent tank (polluted water), 2. Peristaltic pump, 3. Power supply, 4. Electrical wires, 5. Electrodes, 6. EC reactor, 7. Magnetic stirrer, 8. Effluent tank (treated water)

### 2.2. Material and methods

According to the literature, the concentration of reactive dyes receiving rivers is normally ranging between 1.2 to 3 mg/L (average value, 25 days each year) or 5 and 10 mg/L (average value, 50 days each year), and could increase up to 300 mg/L in some cases at 1 or 2 days each year (the worst case) [25]. Thus, in the current study, samples with 20 mg/L (as the worst case of the 50 days average value) of RR-120 have been used to investigate the influence of the current density (CD) and electrodes gap (EG) on the decolourization process.

Initially, a stock solution, having 1000 mg/L of RR-120 dye, was prepared by dissolving 1000 mg of RR-120 in one litter of deionised water. Then, samples with less concentrations of RR-120 (20 mg/L) were diluted from this stock solution. The experimental work was initiated by treating the diluted samples at three different CDs (2, 4 and 6 mA/cm²) for 12 minutes, based on preliminary design experiment, at flow rate 100 ml/min, keeping the EG, initial pH, water conductivity, and initial water temperature constant at 5 mm, 8, 0.4 mS, and 20±1°C, respectively. The initial pH and the initial conductivity were controlled using HCl or NaOH, and NaCl, respectively. While, the influence of the EG was investigated by changing distance between electrodes from 5, to 10, and 15 mm keeping the CD at the optimum value that obtained from the previous step. The initial pH, water conductivity, and initial water temperature constant at 8, 0.4 ms, and 20±1°C, respectively.

The progress of decolourization process was monitored by collecting 5 mL samples at each 2 minutes for 12 minutes. The collected samples were filtered at 0.45 µm filter papers (Whatman filters)[26], the filtrate was analysed using a spectrophotometer (Hach Lange DR 2800) at 512 nm. All chemicals were supplied by Sigma Aldrich and used as supplied.

Dye removal efficiency (RE %) was determined as follows:

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RE\% = \frac{C_0 - C}{C_0} \times 100\%
\]

Where \(C_0\) and \(C\) are the influent and effluent concentrations of RR-120 dye, in mg/L, respectively.
3. Results and discussion

3.1. Influence of CD
This part of the study was conducted to study the influence of CD (2, 4 and 6 mA/cm$^2$) on the removal of RR-120 dye from drinking water using EC process. The results obtained showed that the removal of RR-120 dye from the synthetic water samples increases with the increase of the applied current density, figure 4. For example, it has been found that the removal efficiency, after 8 minutes of treatment, has increased from 80% to 88% and 96% as the CD increased from 2 to 4, and 6 mA/cm$^2$, respectively. This could be explained by the fact that increasing the CD increases the dissolving rate of aluminium ions from the anode, which enhances the dye removal [27, 28]. However, increasing the applied CD results in an increase in power consumption, thus CD of 4 mA/cm$^2$ will be used to carry out the rest of experiments.

![Figure 4. The removal efficiency of RR-120 dye at different CDs.](image)

3.2. Influence of EG
In order to explore the influence of the gap between electrodes on the removal of RR-120 dye, coloured water samples were treated at three different EGs (5, 10, and 15 mm), keeping the CD, initial pH, water conductivity, and initial water temperature constant at 4 mA/cm$^2$, 5 mm, 8, 0.4 ms, and 20±1°C, respectively.

The results obtained indicated that the wider the EG was, the lower the removal efficiency was, figure 5. For instance, after 12 min of electrolysis, the dye removal decreased from 96%, to 89%, and 80% as the electrode distance increased from 5 to 10, and 15mm, respectively. This behaviour could be attributed to the fact that increasing the gap between electrodes results in decreasing the required attraction force for flocs formation, and thus reduces the dye removal. In addition, as the electrodes gap increase, the produced gas bubbles will raise fast toward the surface of the polluted solution then reduces the mixing effect required to attract the different ions and form the adsorbent as a consequence [26].
Figure 5. The removal efficiency of RR-120 dye at different EGs.

4. Conclusion
The outcomes of the current study indicated that the removal of RR-120 dye, using aluminium-based electrocoagulation method, is positively influenced by the increase of current density and negatively by the gap between electrodes. Therefore, to enhance the performance of EC units, in terms of dye removal from water or wastewater, it is recommended to keep the gap between electrodes as short as possible, and increase the applied current density to the level that does not influence the cost-effectiveness of the treatment method. Moreover, the obtained coefficient of correlation ($R^2$) for the relationship between the operational variables and the responses is more than 0.97 for all operation conditions. These statistical values indicate a very good relationship between the predicted and measured removals and can be used for modelling the performance of the EC method[29].

Finally, due to the recent development in sensing technology [30], the authors recommend the application of this technology in the development of smart EC units. For example, sensors could be used to control the applied current density according to the concentration of the targeted pollutants.

5. References
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