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Decolourization of dye solutions by electrocoagulation: an investigation of the effect of operational parameters

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Abstract. This study investigates the influence of the current density on both removal of reactive black 5 dye (RB5) from water and energy consumption using aluminium-based electrocoagulation (EC) reactor. The influence of the current density was investigated by electrolysing coloured water samples containing 25 mg/l of RB5 for 60 min at three different current densities (1, 2, and 3 mA/cm2). While the initial pH, distance between electrodes, flow rate, and initial temperature of water were kept constant at 5, 4 mm, 1 L/h, and 20 ± 10C, respectively. The obtained results showed that both the removal of RB5 dye and energy consumption increased with the increase of the applied current density. For example, it has been found that the removal RB5 and the power consumption increased from about 95% to 99.5%, and the power consumption increased from 4.3 to 10.4 kWh/m3 as the current density increased from 1 to 3 mA/cm2, respectively.

1. Introduction

Water pollution is serious global problem due to the limited amount of water on planet of Earth, and due to the rapid growth in both global population and industrial activities, which in turn produce huge quantity of wastewater [2-6]. Though there is a wide range of industries that discharge huge quantities of wastewater into the surface water bodies, the textile industry is categorised as a major and serious source of water pollution as it produces large volumes of highly polluted wastewater [7, 8]. For instance, the relevant studies indicated that this industry consumes about 1-2 m3 of water per each 10 kg of textile products, and produce a similar amount of polluted wastewater [9]. Moreover, the textile effluent is categorised as serious and highly polluted wastewater due to its chemical composition, where this type of wastewater contains detergents, dyes, colour fixing agents, and organic matter [9, 10]. Furthermore, azo dyes could be decomposed in the receiving carcinogenic by-products that have long half-time life [8, 11, 12]. Discharging this highly polluted wastewater into the water bodies causes different pollution problems, for example it causes undesirable colours and odours [13]; minimises the penetration sun light that damages the aquatic life [14]; and minimises the concentration of the dissolved oxygen [11]. Thus, different treatment

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technologies have been used to treat the textile wastewater, such as aerobic and anaerobic degradation, oxidation, and filtration [12, 15, 16]. Unfortunately, many of the practiced methods were not efficient to remove the most dangerous pollutants such as the azo dyes [17, 18]. More badly, application of some of treatment methods to zo dyes containing wastewater results in the formation of carcinogenic compounds [19], for example, biological reduction of azo dyes under anaerobic conditions could form aromatic amines, which categorised as carcinogens [20].
Therefore, recent researches suggested different advanced treatment methods to treat the textile effluents, such as nano-filtration [1], and membrane bioreactor-ultrafiltration [21]. Amongst the recently practiced methods, electrocoagulation method (EC) received an increasing attention as an effective and affordable treatment method for textile and municipal wastewater due several merits. For instance, EC method does not required chemical additives, it requires relatively short treatment time, and it is easy to be operated, marinated, and integrated with other treatment methods. Additionally, EC method produces less sludge in comparison with traditional methods, which greatly enhances its cost-effectiveness because treatment and handling of solid wastes is a costly process [22-31].
In this context, the current study investigates the influence of applied current density on the performance of the EC method in terms of dye removal and energy consumption.

2. Aims and objectives
As it has been mentioned above, the current study investigates the influence of the applied current density on the performance of the EC method in terms of dye removal and energy consumption. It is noteworthy to mention that reactive black 5 dye (RB-5 dye) has been used, in the current study, as the model dye because it is widely used in the textile industry, and its degradation forms toxic compounds [32]. The molecular structure of RB-5 is shown in Figure (1).

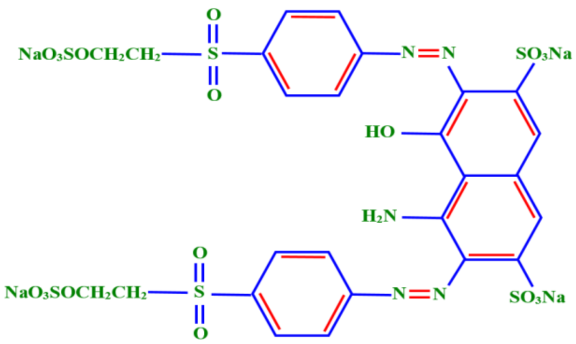

Figure 1. Molecular structure of RB-5 dye [1].

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3. Methodology

3.1 EC unit

The influence of current density on the removal of RB-5 dye has been investigated by electrolysing dye containing synthetic water samples using aluminium-based EC unit, figure 2. The latter is consists of cylindrical Perspex container (25 cm in height and 10.5 cm in internal diameter), which is supplied with aluminium perforated discoid electrodes (10.4 cm in diameter and 0.1 cm in thickness), Fig. 2. These electrodes were stacked vertically within the cylindrical container with the plane of each electrode parallel and perpendicular to the direction of flow. Each electrode had the holes offset from the one above it to ensure that the water will flow in a convoluted path in order to increase mixing efficiency. A peristaltic pump (Watson Marlow, model: 504U) was used to circulate the water being treated through the EC unit, while the required current was supplied using a rectifier (HQ Power; Model: PS 3010).

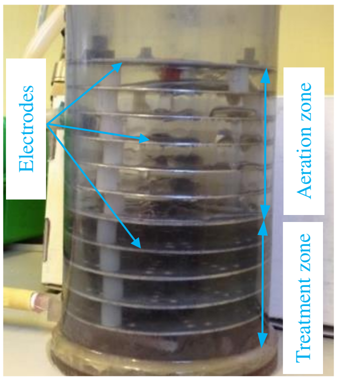

Figure 2. The EC unit.

3.2 Influence of current density on dye removal and energy consumption

Initially, synthetic stock solution, 100 mg/l, was prepared by dissolving the required amount of RB-5 dye in deionised water. Samples with less concentrations of dye, 25 mg/L, were diluted from this stock solution. Influence of current density on the removal of RB-5 dye has been investigated by subjecting diluted water samples to different current densities (1, 2, and 3 mA/cm2) for 60 min at flow rate of 1 L/h, inter-electrode distance of 4 mm, initial pH of 5, and ambient temperature of (20 ±10C).

5 mL water samples were periodically collected, each 5 min, from the EC unit to monitor the residual concentration of RB-5 dye. The collected samples were filtered at 0.45 μm filters (Whatman filters); the residual dye concentration in the filtrate was measured using a spectrophotometer (Hach Lange DR 2800). The removal efficiency (RE %) was determined using the following equation [33]:

$$RE\% = \frac{C_0 - C_t}{C_0} \times 100\% \quad (1)$$

Where C_0 and C_t represent the initial and the measured concentrations of RB5, in mg/L, respectively.
While the energy consumption (E), during the course of each set of experiments, was measured using the following formula [34]:

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$$E = \frac{I*V*T}{Vol.} \quad (2)$$

Where I is the current (A), V is the potential (V), t is the treatment time (H), and Vol. is the volume of treated water (m3).

4. Results and discussion

4.1. Influence of current density on dye removal

As it has been mentioned above, the influence of current density on the removal of RB-5 dye has been investigated by electrolysing coloured water samples (25 mg/L of RB-5 dye) for 60 min at three current densities (1, 2, and 3 mA/cm2).

The obtained results showed a direct proportion between the removal of the RB-5 dye and the magnitude of the applied current density. It can be seen from figure 3 that 30 min was enough to achieve 100% removal of RB-5 dye at current density of 3 mA/cm2, but 60 min was required at current density of 2 mA/cm2 to reach a removal percentage of 98.6%. %. This increase in removal efficiency with the increase of current density could be explained by the fact that the dissolved aluminium ions from the anode increases as the current density increase, which enhances RB-5 dye removal as a consequence [35].

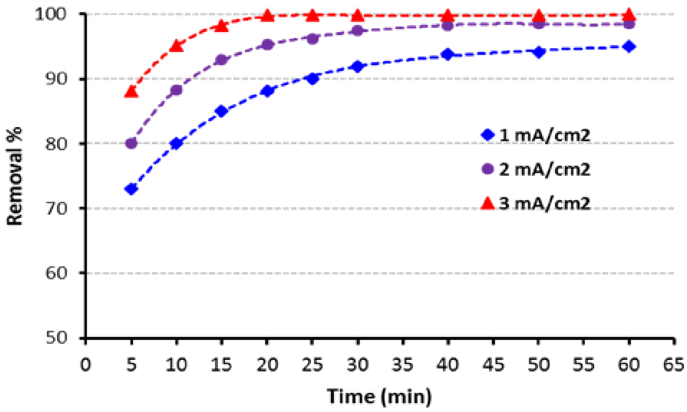

Figure 3. RB-5 dye removal at different current densities.

4.2. Influence of current density on energy consumption

Though it has been found that increasing the current density positively influences the removal of BR-5 dye, the obtained results showed that increasing the current density negatively influenced the energy consumption, where Figure 4 shows that as current density increased from 1 to 3 mA/cm2, the power consumption increased from 4.3 to 10.4 kWh/m3, respectively.

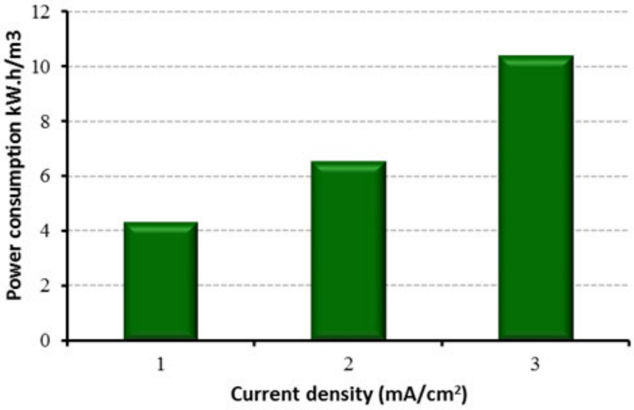

Figure 4. Power consumption at different current densities.

5. Conclusions

According to the outcomes of the current study, the removal of RB-5 dye can be effectively enhanced by increasing the generation rate of fresh coagulants from the metallic anode, which in turn could be enhanced by increasing the magnitude of the applied current density. However, the increase in the current density is beneficial to a certain limit as it increases the power consumption, which negatively influences the applicability of this method. Therefore, the magnitude of the applied current must be optimised to achieve the highest removal efficiency at a reasonable operational cost.

It is recommended to carry out further investigations about the influence of other operating parameters, such as water conductivity, ability of the EC method to remove dyes from water and wastewater. Additionally, the ability of the EC method to remove other pollutants from water and wastewater should be studied.

Finally, due the dramatic changes in climate [36-39] that greatly influencing the global water, the authors recommend to carry out future investigations about the development of new water treatment methods, such as integrating EC method with other methods.

References

[1] Y. K. Ong, F. Y. Li, S.-P. Sun, B.-W. Zhao, C.-Z. Liang, and T.-S. Chung, "Nanofiltration hollow fiber membranes for textile wastewater treatment: Lab-scale and pilot-scale studies," *Chemical Engineering Science,* vol. 114, pp. 51-57, 2014.

[2] K. S. Hashim, A. Shaw, R. Al Khaddar, M. Ortoneda Pedrola, and D. Phipps, "Defluoridation of drinking water using a new flow column-electrocoagulation reactor (FCER) - Experimental, statistical, and economic approach," *J Environ Manage,* vol. 197, pp. 80-88, Jul 15 2017.

[3] K. S. Hashim, A. Shaw, R. Al Khaddar, M. O. Pedrola, and D. Phipps, "Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor," *Journal of Environmental Management,* vol. 189, pp. 98-108, 2017.

[4] K. S. Hashim, A. Shaw, R. Al Khaddar, M. O. Pedrola, and D. Phipps, "Energy efficient electrocoagulation using a new flow column reactor to remove nitrate from drinking water - Experimental, statistical, and economic approach," *J Environ Manage,* vol. 196, pp. 224-233, Jul 01 2017.

[5] K. S. Hashim, N. H. Al-Saati, A. H. Hussein, and Z. N. Al-Saati, "An Investigation into The Level of Heavy Metals Leaching from Canal-Dreged Sediment: A Case Study Metals Leaching from Dreged Sediment," presented at the 1st International Conference on Materials Engineering & Science, Istanbul Aydın University (IAU), Turkey, 2018.

[6] N. H. Al-Saati *et al.*, "Statistical modelling of turbidity removal applied to non-toxic natural coagulants in water treatment: a case study," *Desalination and Water Treatment,* vol. 150, pp. 406-412, 2019.

[7] A. M. Lotito, M. De Sanctis, C. Di Iaconi, and G. Bergna, "Textile wastewater treatment: aerobic granular sludge vs activated sludge systems," *Water Res,* vol. 54, pp. 337-46, May 1 2014.

[8] P. A. Joshi and K. J. Mhatre, "Microbial efficiency to degrade Carbol fuchsin and Malachite green dyes," *Advances in Applied Science Research,* vol. 6, no. 12, pp. 85-88, 2015.

[9] H. Yin *et al.*, "Textile Wastewater Treatment for Water Reuse: A Case Study," *Processes,* vol. 7, no. 1, p. 34, 2019.

[10] V. S. Munagapati and D.-S. Kim, "Adsorption of anionic azo dye Congo Red from aqueous solution by Cationic Modified Orange Peel Powder," *Journal of Molecular Liquids,* vol. 220, pp. 540-548, 2016.

[11] P. I. Firmino, M. E. da Silva, F. J. Cervantes, and A. B. dos Santos, "Colour removal of dyes from synthetic and real textile wastewaters in one- and two-stage anaerobic systems," *Bioresour Technol,* vol. 101, no. 20, pp. 7773-9, Oct 2010.

[12] V. L. Gole and P. R. Gogate, "Degradation of brilliant green dye using combined treatment strategies based on different irradiations," *Separation and Purification Technology,* vol. 133, pp. 212-220, 2014.

[13] J. Fu *et al.*, "Degradation of Active Brilliant Red X-3B by a microwave discharge electrodeless lamp in the presence of activated carbon," *Environ Technol,* vol. 31, no. 7, pp. 771-9, Jun 2010.

[14] S. C. Santos and R. A. Boaventura, "Treatment of a simulated textile wastewater in a sequencing batch reactor (SBR) with addition of a low-cost adsorbent," *J Hazard Mater,* vol. 291, pp. 74-82, Jun 30 2015.

[15] D. K. Mahmoud, M. A. M. Salleh, W. A. W. A. Karim, A. Idris, and Z. Z. Abidin, "Batch adsorption of basic dye using acid treated kenaf fibre char: Equilibrium, kinetic and thermodynamic studies," *Chemical Engineering Journal,* vol. 181-182, pp. 449-457, 2012.

[16] D. Al-Jumeily, K. Hashim, R. Alkaddar, M. Al-Tufaily, and J. Lunn, "Sustainable and Environmental Friendly Ancient Reed Houses (Inspired by the Past to Motivate the Future)," in *2018 11th International Conference on Developments in eSystems Engineering (DeSE)*, 2018, pp. 214-219: IEEE.

[17] Y. Aşçı, E. A. Demirtas, C. F. Iscen, and A. S. Anagun, "A statistical experimental design to determine the azo dye decolorization and degradation by the heterogeneous fenton process," *Fresenius Environmental Bulletin,* vol. 24, no. 11a, pp. 3717-3726, 2015.

[18] H. Hayat, Q. Mahmood, A. Pervez, Z. A. Bhatti, and S. A. Baig, "Comparative decolorization of dyes in textile wastewater using biological and chemical treatment," *Separation and Purification Technology,* vol. 154, pp. 149-153, 2015.

[19] P. Aravind, V. Subramanyan, S. Ferro, and R. Gopalakrishnan, "Eco-friendly and facile integrated biological-cum-photo assisted electrooxidation process for degradation of textile wastewater," *Water Res,* vol. 93, pp. 230-41, Apr 15 2016.

[20] N. D. Lourenço, R. D. G. Franca, M. A. Moreira, F. N. Gil, C. A. Viegas, and H. M. Pinheiro, "Comparing aerobic granular sludge and flocculent sequencing batch reactor technologies for textile wastewater treatment," *Biochemical Engineering Journal,* vol. 104, pp. 57-63, 2015.

[21] D. De Jager, M. S. Sheldon, and W. Edwards, "Colour removal from textile wastewater using a pilot-scale dual-stage MBR and subsequent RO system," *Separation and Purification Technology,* vol. 135, pp. 135-144, 2014.

[22] S. Safari, M. Azadi Aghdam, and H. R. Kariminia, "Electrocoagulation for COD and diesel removal from oily wastewater," *International Journal of Environmental Science and Technology,* vol. 13, no. 1, pp. 231-242, 2015.

[23] S. Elabbas *et al.*, "Treatment of highly concentrated tannery wastewater using electrocoagulation: Influence of the quality of aluminium used for the electrode," *J Hazard Mater,* Jan 4 2016.

[24] K. S. Hashim, A. Shaw, R. Alkhaddar, and M. O. Pedrola, "Controlling of Water Temperature during the Electrocoagulation Process Using an Innovative Flow Columns - Electrocoagulation Reactor," *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering,* vol. 9, no. 8, pp. 869-872, 2015.

[25] K. S. Hashim, A. Shaw, R. Alkhaddar, M. O. Pedrola, and D. Phipps, "Effect of the supporting electrolyte concentration on energy consumption and defluoridation of drinking water in the electrocoagulation (EC) method," in *The 2nd BUiD Doctoral Research Conference*, The British University in Dubai, 2016.

[26] A. Shaw, K. S. Hashim, R. Alkhaddar, M. O. Pedrola, and D. Phipps, "Influence of electrodes spacing on internal temperature of electrocoagulation (EC) cells during the removal (Fe II) from drinking water," in *The 3rd BUiD Annual Doctoral Research Conference*, The British University, Dubai, 2017.

[27] M. Abdulredha, R. Al Khaddar, D. Jordan, P. Kot, A. Abdulridha, and K. Hashim, "Estimating solid waste generation by hospitality industry during major festivals: A quantification model based on multiple regression," *Waste Manag,* vol. 77, pp. 388-400, Jul 2018.

[28] M. Abdulredha, A. Rafid, D. Jordan, and K. Hashim, "The development of a waste management system in Kerbala during major pilgrimage events: determination of solid waste composition," *Procedia Engineering,* vol. 196, pp. 779-784, 2017.

[29] A. W. Alattabi, C. Harris, R. Alkhaddar, A. Alzeyadi, and K. Hashim, "Treatment of Residential Complexes' Wastewater using Environmentally Friendly Technology," *Procedia Engineering,* vol. 196, pp. 792-799, 2017.

[30] A. W. Alattabi, C. B. Harris, R. M. Alkhaddar, K. S. Hashim, M. Ortoneda-Pedrola, and D. Phipps, "Improving sludge settleability by introducing an innovative, two-stage settling sequencing batch reactor," *Journal of Water Process Engineering,* vol. 20, pp. 207-216, 2017.

[31] I. A. Idowu *et al.*, "An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences," *Waste Management,* vol. 87, pp. 761-771, 2019.

[32] S. H. Chang *et al.*, "Treatment of Reactive Black 5 by combined electrocoagulation-granular activated carbon adsorption-microwave regeneration process," *J Hazard Mater,* vol. 175, no. 1-3, pp. 850-7, Mar 15 2010.

[33] K. S. Hashim *et al.*, "Removal of phosphate from River water using a new baffle plates electrochemical reactor," *MethodsX,* vol. 5, pp. 1413-1418, 2018.

[34] U. T. Un, A. S. Koparal, and U. B. Ogutveren, "Fluoride removal from water and wastewater with a bach cylindrical electrode using electrocoagulation," *Chemical Engineering Journal,* vol. 223, pp. 110-115, 2013.

[35] S. L. Zubaidi, J. Dooley, R. M. Alkhaddar, M. Abdellatif, H. Al-Bugharbee, and S. Ortega-Martorell, "A Novel approach for predicting monthly water demand by combining singular spectrum analysis with neural networks," *Journal of hydrology,* vol. 561, pp. 136-145, 2018.

[36] S. L. Zubaidi, S. K. Gharghan, J. Dooley, R. M. Alkhaddar, and M. Abdellatif, "Short-Term Urban Water Demand Prediction Considering Weather Factors," *Water Resources Management,* vol. 32, no. 14, pp. 4527-4542, 2018.

[37] S. L. Zubaidi, P. Kot, R. M. Alkhaddar, M. Abdellatif, and H. Al-Bugharbee, "Short-Term Water Demand Prediction in Residential Complexes: Case Study in Columbia City, USA," presented at the 11th International Conference on Developments in eSystems Engineering (DeSE), University of Cambridge, UK, 2018.

[38] S. L. Zubaidi, P. Kot, R. M. Alkhaddar, M. Abdellatif, and H. Al-Bugharbee, "Short-Term Water Demand Prediction in Residential Complexes: Case Study in Columbia City, USA," in *2018 11th International Conference on Developments in eSystems Engineering (DeSE)*, 2018, pp. 31-35: IEEE.