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Dye removal from textile wastewater using solar-powered electrocoagulation reactor

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Abstract. A wide range of methods is currently used to remove various pollutants from wastewater. The current focus of research and industries is the use of electrocoagulation for wastewater treatment as this technique can be run using solar energy which produces in-site coagulant able remove dissolved and suspended pollutants at a short time and low cost. Dyes are currently categorised as a universal surface water pollution problem since many industries produce dyes polluted wastewater such as the textile industry. The current investigation focus on the use of electrocoagulation to treat acid orange 2 dye polluted synthetic wastewater and study the impact of the experimental parameters. An electrocoagulation reactor was developed using Iron electrodes and the energy was provided to the reactor using a solar panel. It was found that 100% of the pollutant was removed using electrocoagulation reactor runs on solar power. The Neutral pH level is favourable to remove the dye from textile wastewater. Higher current density and smaller distance between electrodes provide higher removal efficiency of the dye. Generally, it could be said that the best removal of the dye was achieved at pH level at 7, the current density at 2 mA/cm^2, the spacing at 5 mm, and the treatment time at 40 minutes.

1. Introduction

The last century witnessed a defining moment in the history of the environment where the population growth and industrial revolution have led to an incomparable increase in waste production in which the planet earth is not yet ready to face [1-3]. Pigments and dyes are common water pollutants due to their wide use in many industries including textile and food industries [4, 5]. It has been estimated that 9 million tons of color polluted wastewater was generated in 2019-2020 in which 270 thousand tons were disposed to water bodies without treatment. For instance, more than 90 million cars were produced in 2017 leading to millions of tons of pigments' polluted water disposed in surface water from painting units [6]. The textile industry is another example which is considered as one of the main generators of colored wastewater even larger than that produced by car industries [7-9].

Scholars are currently focusing on the treatment of wastewater produced by the textile industry due to the chemical composition of the dyes (contain benzenes, heavy metals, and naphthalene) which have a significant impact on the ecosystem and, humans health. In terms of ecosystem, it was found that a high load of textile wastewater could rapidly deplete the dissolved oxygen and could kill the aquatic life. Items to human health, it was found that the textile wastewater discharged into the Noyyal River caused several health problems such as respiratory infections, and also found that the evaporated chemicals from the textile wastewater could cause damages to the functions of human organs and could sometimes result in death. Thus, the environmental protection agency issued a standard to control the quality of the textile wastewater and minimize its impact on the environment. The problem of water pollution has increased also because of climate change [10-18], which increased rainfall in some areas and droughts in other areas [19-22].

Though there are many methods for water or wastewater treatment [23-28], electrocoagulation is one of the most promising techniques used for water treatment due to its high efficiency and low cost [29, 30], and the fewer production of sludge [31] that minimizes the handling cost and the required landfills to get rid of the sludge [32-35]. However, sludge of water and wastewater treatment plants could be reused in many applications, such as construction materials [36-43]. For example, this technique was successfully used to remove heavy metals and other biological pollutants from the wastewater. Researchers used this technique to remove heavy metals, nitrate, biological pollutants, and phosphate from wastewater or water [44-47]. The technique was similarly adopted to remove organic contaminants from industrial wastewater. All the above-mentioned researchers agree that electrocoagulation provides high removal efficiency of 85% or above with low treatment cost comparing to other treatment technologies. Additionally, the electrocoagulation methods were attached to other methods, such as filtration and ultrasonic, to achieve high removal efficiency [48-51].

The electrocoagulation technique has been widely applied to the textile industry wastewater treatment. This technique was used to remove the chemical oxygen demand and the color from textile wastewater which more than 80% of both pollutants was successfully removed using iron electrodes, other scholars used the same technique with different electrodes namely aluminum, stainless steel, and iron to remove acid yellow 23 dye and chemical oxygen demand from textile wastewater confirming that using iron electrodes achieved higher removal efficiency compared to other electrodes. Many pollutants in textile wastewater such as 2-naphthoic acid dyes, turbidity, and red-nylosan dye were successfully removed using this technique. Yet, the current density of the electrocoagulation reactor plays a vital role in the performance efficiency of the reactor in which higher removal efficiency can be achieved using a higher current density. Another serious concern among researchers is the use of energy sources based on fossil fuels as such sources are considered as one of the main global warming problems due to the generation of greenhouse gases [11-13, 19]. It was highlighted that more than 85% of global energy generated from fossil fuels divided into about 25% produced from coal, and more than 20% produced from natural gases while the remaining fossil fuels energy is produced from oil. According to Bose [52], only 11% of the global energy is produced from nuclear plants and renewables including solar panels, and windmills. The fossil fuels energy production produced large quantities of harmful gases such as NOx and COx. Such gases could negatively impact the ecosystem such as global warming, and acidic rain which has a very serious long term-term impact.

The above review showed that textile wastewater is categorized as one of the main sources of environmental pollution in terms of high organic matters and intense color. Besides, the energy produced by fossil fuel sources also negatively impacts the environment and humans' health. Researchers agree that the electrocoagulation technique has achieved a satisfactory removal efficiency using iron electrodes comparing to other treatment technologies [20-22]. Therefore, the current research aims to use the electrocoagulation technique with Iron electrodes to remove acid orange 2 (AO2) dye from synthetic wastewater by using solar panels as an energy source to minimize the negative impacts on the environment.

2. Methodology

2.1. Materials

The University of Liverpool John Moores University supplied all materials used in this project including acid orange 2 (AO2) powder. The powder was used to formulate the synthetic wastewater by adding 200 mg of the powder to 1 liter of distilled water. The stock synthetic wastewater was stored in a fringe to maintain its properties and later was used to prepare samples of dye polluted wastewater of various concentrations ranged from 10 to 50 mg/L. The concentration of the dye in the wastewater was tested using Hach Lange, DR-2800 flowing the calibration and testing methods in the literature [4, 5].
The reactor of the electrocoagulation technique
According to Abdulhadi et al. [4], a rectangular electrocoagulation reactor is widely used among researchers in wastewater treatment. Thus, a rectangular unite in this study with inner dimensions of 10, 110, and 200 mm as shown in
Figure 1. Four Iron perorated plates with an area of 424 cm^2 as electrodes to treat the synthetic water. Similarly, all the parts of the electrocoagulation reactor were provided by the department of civil engineering at the university. Besides, the university provided Falcon, 21 Watts solar panels to supply the required energy to wastewater treatment. Researchers highlighted that Iron electrodes provide higher removal efficiency comparing to other treatment technologies.

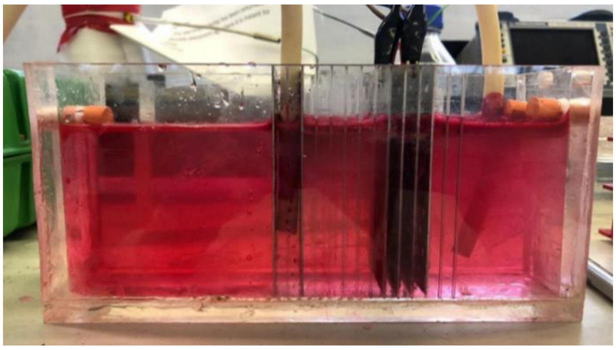

Figure 1. The electrocoagulation unite is employed in this research.

2.2. Experimental procedures

In each experimental run, 1000 milliliters of dye polluted synthetic wastewater with various concentrations were placed in the reactor for treatment. Using the peristaltic pump, the water was circulated in the reactor by pipe connects the outlet and the inlet. Researchers, [4, 53], highlighted that space between electrodes, pollutant concentrations, electrical current densities, pH level, and treatment duration have significant impacts on the removal efficiency. Thus, these parameters were selected as the experimental parameters in this study and were periodically recorded by collecting samples from the reactor at 5 minutes intervals. Then, Whatman filter paper number 2 was used to filter the sludge from the sample before the use of a spectrophotometer. The ranges of the parameters investigated in this research are shown in Table 1.

Table 1. Experimental parameters.

No.	Parameter	Ranges
1.	Initial dye concentrations	10 to 30 mg/L
2.	Initial pH level	4 to 9
3.	Electrical current densities	1 to 3 mA/cm^2
4.	Treatment time	5 to 40 min
5.	Space between electrodes	5 to 15 mm

3. Results

3.1. The effect of the pH level

The pH level of the wastewater affects the removal efficiency of the dye from the wastewater. The pH level impact on the removal of the dye has been investigated by treating samples for half an hour at pH level varied from 4 to 9 using 5 mm spacing, 2 mA/cm^2 electrical current, and 15mg/L initial dye concentration. It can be seen from Figure 2 that the neutral environment (pH level between 6 and 7) provides the best removal efficiency of the AO2 dye from the wastewater. This can be attributed to the influence of the properties of the coagulants where it was highlighted that Fe^2 is the favorable coagulants for AO2 dye treatment [4].

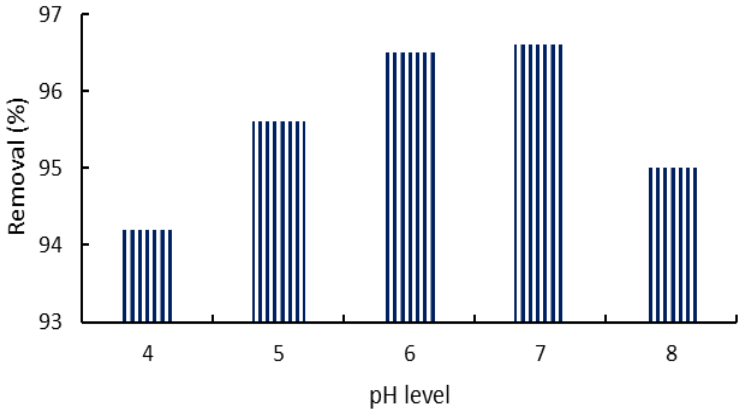

Figure 2. The pH impact on dye removal efficiency.

3.2. Effect of electrical current

According to the literature, [4, 8], the current has a significant impact on the treatment of the dye since it controls floc production and bubbles. Accordingly, the impact of the current on dye removal was analyzed using different densities that are 1, 2, and 3 mA/cm^2. The other parameters were kept to 7 pH level, 15mg L initial dye concentration, 5 mm spacing between electrodes, and treatment time ranged 5 to 30 minutes. Figure 3 shows that removal efficiency increases with an increase in the current density. At 15 minutes of treatment, the removal efficiency reached 99.5% using 3 mA/cm^2 while it was about 95% using 1 mA/cm^2 current density. This in agreement with other researchers' statements that higher current increases the production rate of coagulants and speeds up the treatment.

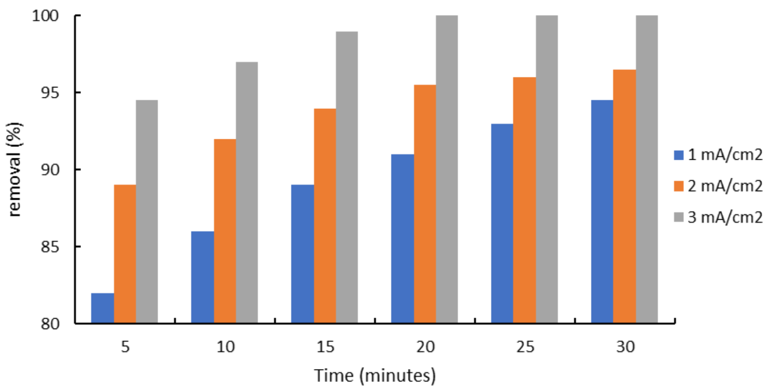

Figure 3. The influence of the electrical current on dye removal.

3.3. Effects of electrodes spacing

The electrodes spacing affects the removal of any pollutants using electrocoagulation. To understand the impact of the spacing, the electrodes were positioned at a distance varied from 5 to 15 mm while keeping the rest of the experimental parameters constant. The outcome presented in figure 4 showed that the closer the electrodes the better removal efficiency of the dye achieved. For instance, at 15 minutes treatment duration, it was noticed that the removal efficiency decreased from about 93% at a space of 5 mm to 86% at a space of 15 mm. According to the literature,[49, 54], larger spaces between electrodes rise current resistance which in turn minimizes the removal of the pollutant.

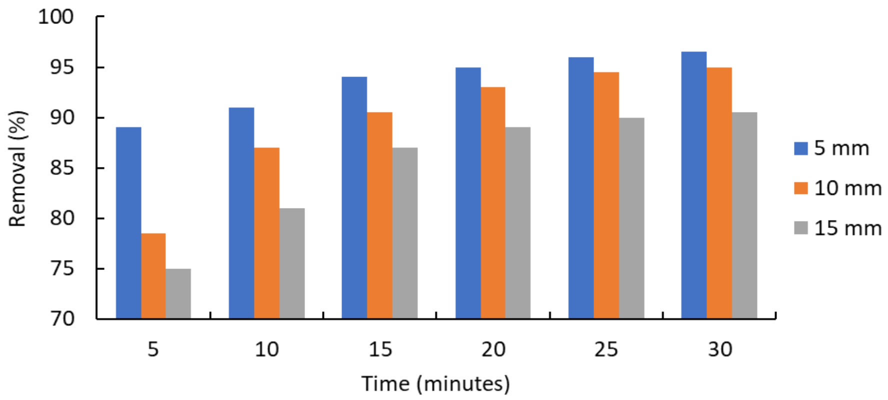

Figure 4. Impacts of electrodes spacing on dye removal.

3.4. Treatment time

The production of the coagulant is affected by the treatment time [53]. Therefore, the impact of the treatment time was analyzed by adopting several treatment durations ranged from 5 to 40 minutes while keeping other parameters constant. As illustrated in figure 5, higher treatment duration achieves higher removal efficiency for the AO2 dye. For example, the removal efficiency increased from about 89% after 5 minutes of treatment to more than 97% after 30 minutes of treatment. Yet, it can be seen from figure 5 that the removal efficiency almost constant from the treatment duration of 25 minutes and above. These results were in line with the results in the literature that focused on the application of the Ec method for the removal of different pollutants [29, 31, 50].

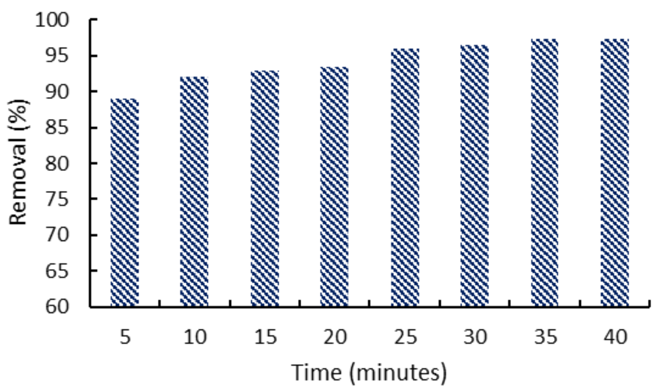

Figure 5. Treatment time impact on dye removal.

3.5. Initial dye concentration

Pollutant concentration significantly influences its overall removal efficiency. In this research, the impact of the initial dye concentration was analyzed by adopting several concentrations (10 to 30 mg/L) and keeping the pH level at 7, the current density at 2 mA/cm^2, the spacing at 5 mm, and the treatment time at 40 minutes. Figure 6 showed that higher dye concentration extended the treatment duration. For example, only 10 minutes were required to remove 92% of the dye when the initial concentration was 10 mg/L while only 40% was removed after 40 minutes of treatment when the initial concentration was 30mg/L.

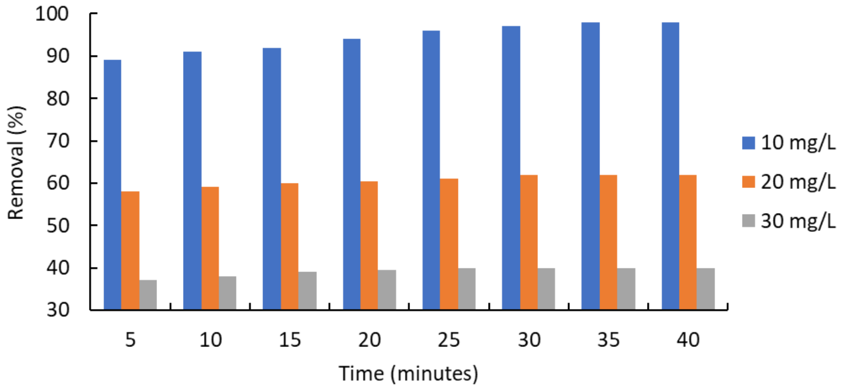

Figure 6. Initial dye concentration impact on its removal.

Recent researches focused on the use of sensing technology to control/monitor the experiments [55-58]; therefore it is highly recommended here to use this technology in the electrocoagulation unit to achieve the best removal of phosphate.

4. Conclusion

The removal of the acid orange 2 dye from the textile industry wastewater was investigated in the research using Iron electrodes as well as the impact of electrical current, pH level, the spacing between electrodes, treatment time, and initial concentration of the dye on the removal efficiency. The results showed that iron electrodes are suitable to remove the dye from wastewater. Neutral pH level, higher electrical density, longer treatment duration, and smaller distance between electrodes can provide high removal efficiency of the acid orange 2 dye. Besides, the solar energy source can be sued to operate the electrocoagulation reactor effectively.

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