Sono-assisted treatment of textile wastewater: reactive black 5 dye a case study

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Abstract. The textile industry provides the global jobs market with a considerable number of jobs every year, and it supports the national economy of many countries, such as India, Turkey, Canada and many European countries. However, textile wastewater is very harmful to the environment and the ecosystem. The reports refer to the toxic effects of the textile industry on aquatic life, human, and also on the quality of water and soils. Also, the volumes of textile wastewater have dramatically increased over the last years because of the increase in the global demand for fabrics and clothes. Therefore, the need for efficient treatment became more urgent than ever before. The present work focuses on the use of the sonication process to enhance the electro-coagulation units’ (EC) ability to remove dyes from textile wastewater. Synthetic water containing 28 mg/L of reactive black 5 dye was treated firstly in the electro-coagulation for 1 hour at initial pH of 4, 5, 6, 7, and 8, and current density of 1, 2 and 3 mA/cm\textsuperscript{2}. Then, the wastewater was sonicated for 10 minutes before the electro-coagulation process. The results showed the lowest pH (4), and the highest current density (2 mA/cm\textsuperscript{2}) achieved the highest removal efficiency in the EC unit (82.14%), and the use of the sonication process before the EC unit increased the removal of the dye to 100%.

1. Introduction

The phenomenon of water pollution is increasing nowadays because of the increase in the generation of wastewater from different industrial sectors, agriculture, and the domestic use of water [1-3]. For example, the reports referred to a dramatic increase in the usage of freshwater over the last few decades due to the rise in the world population that recently reached 7 billion people [4-6], this increase in the world population is accompanied by the increase in the industrial and agricultural activities to meet the daily demands for the goods and food of this massive number of people [7, 8].

For example, the global statistics show the consumed amount of dyes is 700,000 tonnes per year, and the required volume of freshwater in the textile industry to produce 1000 g of fabric is 100 to 200 litres [9, 10]. This type of wastewater disposal to the rivers or lakes has potential severe effects on humans and aquatic life. For example, coloured wastewater limits the sunlight; consequently, many forms of aquatic life will disappear due to the lack of nutrients. Moreover, the dyes, especially azo dyes, in water undergo a series of reactions that lead to the production of carcinogenic agents, which cause serious health issues for humans [11, 12]. Moreover, these chemical reactions result in rapid consumption of the dissolved oxygen, and consequently, it leads to the mass death of fish, plants and other forms of life, which negatively influences the food chain [13, 14].

Hence, a broad range of treatments was used to remove dyes from the textile wastewater before the final disposal to the water bodies [12, 15], such as aerobic and anaerobic degradations, adsorptions, and filtrations [16-18]. Inappropriately, most conventional treatments are not effective in the removal of
dyes due to the complexity of textile wastewater, and also, some of the conventional treatments are too expensive to be used in developing countries. Therefore, the new trend in the researches is the use of a combination of methods to treat complex wastewaters, such as the combinations of filtration-electrocoagulation and ultrasonic-coagulation [19-21].

In this paper, the sono-electrocoagulation method will be used to remove a textile dye from water, which is the reactive black 5 dye, which was used as a model dye because of its wide use in the textile industry [10, 11].

2. Methodology

The reactive black 5 dye was purchased from Sigma Aldrich and used without further processing. The dye was dissolved in distilled water to produce a stock solution with initial concentrations of 100 mg/L, which was used to make diluted water samples with a concentration of 28 mg/L that were used in the experiments.

The experiments were conducted using an electro-coagulation unit, shown in Fig. 1. The unit is made from transparent plastic with a working volume of 1 litre and has 4 plates (electrodes). The electrodes are aluminium with an area of 500 cm². The dyed solution was circulated using a peristaltic water pump with a maximum capacity of 5 L/ hour. The electrolysis process was done using a rectifier (SP-3010). The sonication process was done using a 2.7 L ultrasonic bath (FB15051) with variable temperatures (up to 60 °C) and powers (up to 280W), and a constant frequency (37000 Hz). The experimental work was according to the literature [22-25].

The treatment was done in two phases; the first phase was conducted using the electro-coagulation unit separately. Water samples containing 28 mg/L of reactive black 5 dye were first treated in the electro-coagulation for 1 hour at an initial pH of 4, 5, 6, 7, and 8, with a current density of 1, 2 and 3 mA/cm². The removal efficiency was recorded after each run.

The second phase was done using both sonication and electro-coagulation; water samples were sonicated for 10.0 minutes before the electrolysis process, then treated in the electro-coagulation unit at the best conditions from phase 1.

The removal efficiency was calculated as follows [26, 27]:

\[
\text{Percentage of dye removal} = \left( \frac{\text{initial dye concentration} - \text{measured dye concentration}}{\text{initial dye concentration}} \right) \times 100
\]  

(1)

The concentration of dyes was spectrophotometrically measured using a Hach Lange device. Solids were separated from water samples, pre-measurement of concentration, using paper filters (0.45 µm) [28-30].
3. Results
The results of the first phase of this paper were obtained from the electro-coagulation experiments, as follows:

3.1. Effects of the pH
The pH is an important factor in the electro-coagulation process because it affects the sizes of the gas bubbles that affect the floatation of pollutants (the removal of pollutants) and also the chemical form of the aluminium coagulants depends on the pH of the solution [31-33]. Therefore, studying the effect of pH on the removal of pollutants is an important part of electro-coagulation studies.

In this paper, the effects of the initial pH on the reactive back 5 dye was studied at 4, 5, 6, 7, and 8. The results are shown in Fig. 2. The lowest residual concentration of the dye was noticed at acidic values of pH (4 and 5), while neutral and alkaline pH was not effective in the removal of the reactive dye. The explanation for the increase in the removal of the reactive dye at pH 4 and 5 is the aluminium coagulants has a high adsorption capacity for this kind of pollutants [10, 11]. The pH of 4 was used in this study for the next experiments.

![Figure 2. Effects of solution pH on dye removal.](image)

3.2. Effects of the current density
The current density is also an important factor in the electro-coagulation process because it affects the production of aluminium coagulants from the electrodes and also the production of hydrogen bubbles. Therefore, the current density seriously influences the removal of pollutants in the electro-coagulation unit [28]. Thus, the effects of this factor were studied in this paper at three currents (current density of 1, 2 and 3 mA/cm²).

The results are shown in Fig. 3. proved the current density strongly affects the removal of dye from water, the residual dye in the solution reduced from 5 mg/L to 1 and 0 mg/L when the current density increased from 1 to 3 mA/cm², respectively.
The effects of the current density are not always positive because it affects the power consumption strongly; when the current density increased from 1 to 3 mA/cm², the power consumption was increased by more than double the original value. Thus, 2 mA/cm² were used here to conduct the experiments because this value achieves good power consumption and removal of pollutants.

![Figure 3. Effects of current density on dye removal.](image)

It can be concluded from the results above the electro-coagulation unit can remove 82.14% of the dye when the pH, current density and treatment time were 4, 2 mA/cm², and 60 minutes, respectively.

The effects of the sonication process on the performance of the EC unit in terms of dye removal have been investigated by soncating the samples for 10 minutes using a 2.7 L ultrasonic bath (FB15051) at a power of 280a constant frequency of 37000 Hz before the EC process. The results are presented in Fig. 4. It was observed the sonication before the EC treatment increased the removal of the dye from 82.14 to 100% under the same operating conditions. Thus, it can be concluded that the sonication process is very effective in enhancing the performance of the EC unit. This improvement is because of the ability of the ultrasonic waves to remove the accumulated oxides and sedimentations from the surface of the anodes that accelerates the production of coagulants, which helps to remove the pollutants rapidly and efficiently from water [22-25].
4. Conclusion
The present study experimentally discussed the ability of ultrasonic waves to enhance the removal of dyes from solutions using electro-coagulation technology. Electro-coagulation is known for its ability to remove many pollutants, but the accumulation of contaminants on the electrodes and the passivation of the anodes minimise the efficiency of pollutants because of the limitation of the generation of coagulants. This defect in the EC method was the focus of the presented paper. The ultrasonic waves were used to remove the accumulated pollutants and oxidation layer from the electrodes.

The presented study results showed that the electro-coagulation method removes 82.14% of the dye when the pH is low, and the current density is high. However, to achieve 100% removal of the dye, ultrasonic waves were needed. The application of the ultrasonic waves for 10 minutes improved the removal of the dye from 82.14 to 100% under the same operating conditions of the EC method.

For future researches, the effects of the frequency and power of the ultrasonic waves on the performance of the EC method must be studied.

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