Optimization of color removal from two types of anionic dyes by electrocoagulation/flotation in a batch agitated vessel

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ABSTRACT

The optimum conditions for the electrocoagulation/flotation of two types of anionic dyes (reactive Cibacron Red H-D dye and direct Sulphonil Yellow 5GL dye) have been investigated. The batch agitated vessel consisted of 45° pitched iron paddle anode and a horizontal iron disc cathode which was fixed at the bottom of the vessel. The performance of the vessel was expressed in terms of the percentage of color removal and power consumption calculations. Different parameters have been studied such as: electrolysis time, current density, NaCl concentration, initial dye concentration, initial solution pH, mixing speed (rpm), distance between electrodes, and different anode/cathode combinations. Results revealed that at optimum operating conditions using Fe/Fe electrode combination almost complete color removal of the two investigated dyes has been achieved. Economic studies reveal that removal of one kg of the reactive and direct dye requires 1.87 and 1.5 EGP, respectively. The treatment of real textile effluent at the optimum conditions using the present batch agitated vessel achieved 95.45% color removal and 44% COD reduction.

Keywords: Electrocoagulation/flotation; Color removal; Reactive Cibacron Red H-D dye; Direct Sulphonil Yellow 5GL dye; Batch agitated vessel; Iron electrode

1. Introduction

The textile and dyeing industry has drawn the attention of environmentalist worldwide because of its high resource consumption profile in terms of water, chemical energy, and release of highly colored wastewater. Dyes present in such wastewater are of particular environmental concern, since their presence in water is esthetically undesirable, even at very low concentrations. Furthermore, such dyes may undergo chemical as well as biological changes, produce dangerous by-products, consume dissolved oxygen from the stream, and destroy aquatic life because of their toxicity [1]. Thus, these waste must be treated prior to discharge in order to comply with the environmental protection laws for the receiving waters. Conventional methods for dealing with textile wastewater consist of various combinations of biological, chemical, and physical methods such as: ultrafiltration, adsorption, and chemical oxidation and reduction [2]. Because of the large variability of the composition of textile wastewater, most of these conventional methods are becoming inadequate and insufficient. Advanced oxidation processes such as

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H_2O_2/UV, O_3/UV, and O_3/H_2O_2 have been developed recently to treat contaminant of textile wastewater [3]. These methods are potential alternatives to degrade dyes into harmless species, however, further research is still needed for their wide applications to treat textile effluents. Electrocoagulation/flotation (ECF) is an attractive alternative for the treatment of textile dyes, especially the high conductivity of textile wastewater makes them amenable for such treatment. ECF is the direct passage of current through a sacrificial electrode to generate a coagulant and gas bubbles simultaneously into the medium [4]. ECF involves the interaction between two main processes, electrocoagulation (EC) and electroflotation (EF). The released coagulant from the anode would destabilize the pollutants in the medium and allow their aggregation into small flocs (EC), whereas the evolved gas bubbles at the cathode would enhance flocs growth and their further separation by flotation (EF). In addition, ECF has high removal efficiency and provides a reliable, simple, and economical way to treat waste without any need for chemicals and produces small amount of sludge [5]. EC has been applied successfully to treat lignin and phenol [6], kaolin-polluted wastewater [7], heavy metals [8–10], chemical mechanical polishing wastewater [11], oil emulsions [12], and laundry wastewater [13]. EC process has also been widely used to decolorize various structurally different dye-containing solutions such as disperse [14], reactive [15], acid [16], and basic dyes [17]. Other investigators developed an ECF process to remove color from wastewater where the gas bubbles can carry the pollutants to the top of the solution and also where it can be more easily concentrated and separated [18]. The objective of the present work is to optimize color removal from two different types of dyes-(reactive and direct)containing solution by ECF in a batch agitated vessel. The optimum conditions for the color removal of the two investigated dyes have been investigated in relation to the following parameters: electrolysis time, current density, initial dye concentration, electrolyte (NaCl) concentration, rpm, pH, distance between the electrodes, and different electrode combinations. In addition, the treatment of real textile effluent by the present batch agitated vessel was studied under optimum conditions.

2. ECF theory and mechanism

ECF is a complicated process involving many chemical and physical phenomena that use consumable electrodes to supply ions into the wastewater stream. It is generally accepted that the ECF process involves three successive stages [19,20]:

(1) Formation of coagulants by electrolytic oxidation of the sacrificial electrode.
(2) Destabilization of the dissolved contaminants, particulate suspension, and breaking of emulsions.
(3) Aggregation of the destabilized phases to form flocs and flotation of flocs by the evolved gas bubbles.

Iron upon oxidation, in an electrolytic system, produces iron hydroxide, $Fe(OH)_n$, where $n = 2$ or 3. Two mechanisms have been proposed for the production of $Fe(OH)_n$ [21,22].

2.1. Mechanism (1)

At the anode:

$$4Fe_{(s)} \rightarrow 4Fe^{2+}_{(aq)} + 8e^- \qquad (1)$$

$$4Fe^{2+}_{(aq)} + 10H_2O_{(l)} + O_{2(g)} \rightarrow 4Fe(OH)_{3(s)} + 8H^+_{(aq)} \qquad (2)$$

At the cathode:

$$8H^+_{(aq)} + 8e^- \rightarrow 4H_{2(g)} \qquad (3)$$

Overall:

$$4Fe_{(s)} + 10H_2O_{(l)} + O_{2(g)} \rightarrow 4Fe(OH)_{3(l)} + 4H_{2(g)} \qquad (4)$$
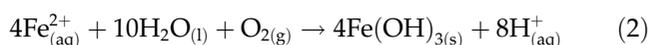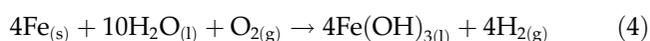
2.2. Mechanism (2)

At the anode:

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^- \qquad (5)$$

$$Fe^{2+}_{(aq)} + 2H_2O_{(aq)} \rightarrow Fe(OH)_{2(g)} \qquad (6)$$

At the cathode:

$$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 20H^-_{(aq)} \qquad (7)$$

Overall:

$$Fe_{(s)} + 2H_2O_{(l)} \rightarrow Fe(OH)_{2(s)} + H_{2(g)} \qquad (8)$$
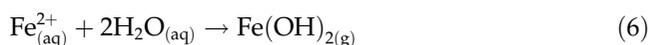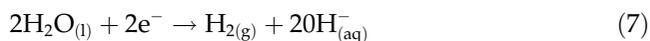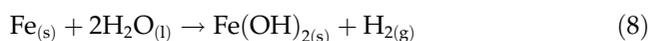
The $Fe(OH)_{n(s)}$ formed remains in the aqueous stream as a gelatinous suspension, which can remove the pollutants from wastewater either by complexation or by electrostatic attraction as shown in Fig. 1, followed by coagulation. Iron hydroxo complexes have pronounced tendencies to form polynuclear complexes
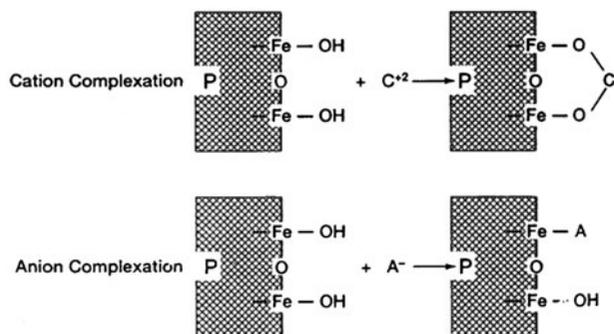
Fig. 1. Surface complexation mechanism on hydrous iron oxide.

[23]. During EC with iron various species are formed such as $Fe(OH)_4^-$, $Fe(H_2O)_3(OH)_3^0$, $Fe(H_2O)_6^{3+}$, $Fe(H_2O)_5(OH)^{2+}$, $Fe(H_2O)_4(OH)^{2+}$, $Fe_2(H_2O)_8(OH)_2^{4+}$, and $Fe(H_2O)_6(OH)_4^{4+}$.
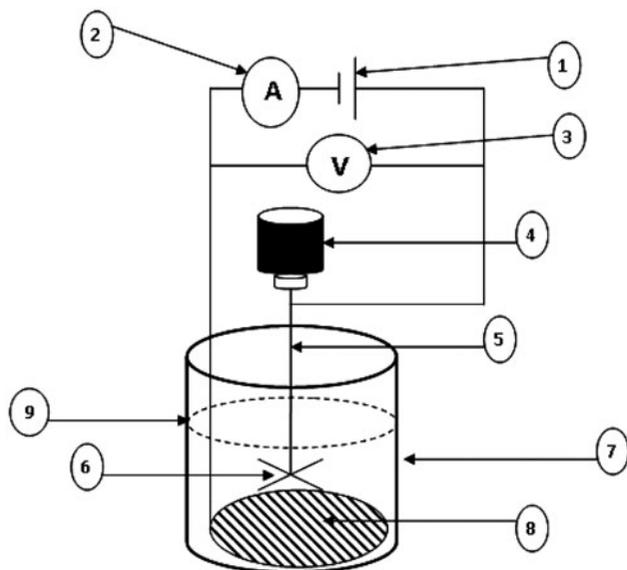
Fig. 2. Electrocoagulation cell and electrical circuit. (1) DC power supply (2) Multi-range ammeter (3) Voltmeter (4) DC digital electric motor (5) Insulated steel shaft (6) 45° pitched anode paddles (7) 2 liter cylindrical plexiglass container (8) Horizontal disc cathode (9) The solution level.

3. Material and methods

Fig. 2 shows the ECF cell and the electrical circuits used in the present work. The ECF cell consisted of two liters cylindrical plexiglass vessel. The anode was 45° pitched four iron blades paddle, each blade was 4 cm width and 0.9 cm height. The paddle shaft was insulated by epoxy resin and connected to a digital dc motor. The cathode was 14 cm diameter horizontal iron disc insulated by epoxy from its bottom and supported at the base of vessel. The electrical circuit consisted of 20 volt dc power supply, a multi-range ammeter connected in series in the cell, and a voltmeter connected in parallel to measure the cell potential. The study was conducted using two types of dyes namely Reactive Cibacron Red H-D (CRHD) and Direct Sulphonil Yellow 5GL (SY5GL). Fig. 3(a) and (b) shows their chemical structure, respectively.

A stock of 1,000 ppm of the dye solution was prepared using distilled water. The batch experiments were carried out by placing 2 liters of freshly prepared dye solution of known initial concentration in the vessel. The cell was conducted for a certain time and adjusted for a certain current density (CD). The ECF progress was followed by withdrawing a sample of 2 mls from the cell every 2 mins from the same location in the cell; the samples were analyzed using a spectrophotometer (Jena- Specord 40—Germany) to determine the dye concentration. The percentage of color removal was determined using the following equation:

$$R\,(\%) = \frac{C_0 - C}{C_0} \times 100 \tag{9}$$

where C_0 and C are initial dye concentration and concentration at any time t, respectively.

In studying the effect of different electrode combination, the blades of paddle anode were fabricated with different metals. While two opposite blades were made of Fe, the other two opposite blades were made from Al.
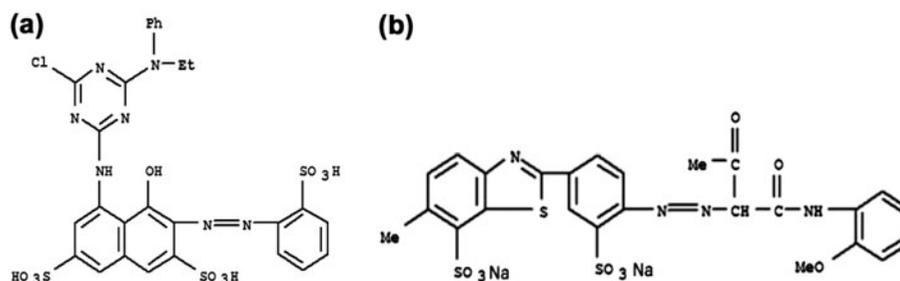
Fig. 3. Chemical structure of dyes (a): Reactive Cibacron Red H-D and (b): Direct Sulphonil Yellow 5GL.

4. Results and discussion

4.1. Effect of electrolysis time

Figs. 4 and 5 show the effect of electrolysis time on the percentage of color removal at different current densities for reactive CRHD and direct SY5GL dyes, respectively. It is well noted that as electrolysis time increases, percentage of color removal increases, until a plateau is reached at which the effect of electrolysis time on percentage of color removal is negligible. Based on these results, an optimum time of 10 and 12 mins were chosen for further experiments for reactive and direct dyes, respectively.

It is also well seen that direct dye removal steadily increases with time until a plateau is reached, whereas in case of reactive dye two rate regimes are observed, initial slow regime up to 4 min and moderately rapid regime until the plateau. That difference in kinetics of the two dyes reflects a difference in the mechanism of their removal by ECF.
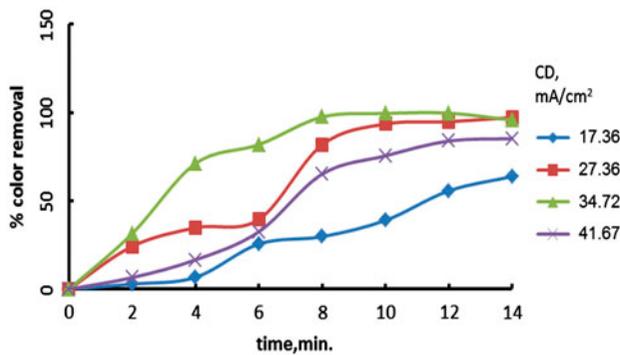
Fig. 4. Effect of electrolysis time on percentage of color removal of reactive CRHD ($C_o = 50$ ppm, NaCl concentration = 2 g/l, distance between electrodes = 2 cm, rpm = 54.3, and pH = 7).
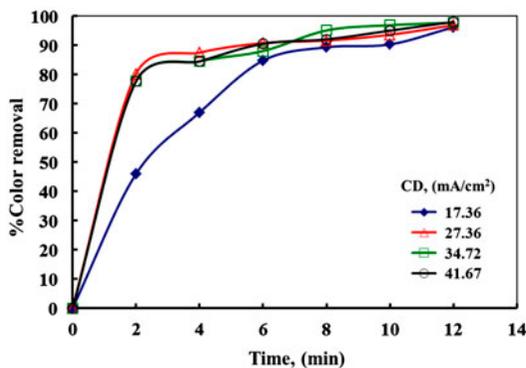
Fig. 5. Effect of electrolysis time on percentage of color removal of direct SY5GL ($C_o = 100$ ppm, NaCl concentration = 4 g/l, distance between electrodes = 2 cm, rpm = 50.3, and pH = 7).

4.2. Effect of current density

Fig. 6 depicts the effect of current density on percentage of color removal for reactive and direct dyes. It is obvious that an increase in current density from 17.36 to 34.72 mA/cm^2 yields an increase in percentage of color removal from 39 to 99.5% for reactive CRHD and from 96.2 to 98% for direct SY5GL. It is well known that as current density increases, the rate of metal dissolution increases and consequently more coagulants are produced in solution. In addition, as the current density increases, the H$_2$ gas evolution rate increases, which could adhere to the flocs and allow their flotation effectively.

Similar trends have been reported in literature [24,25].

It is also clear that the increase in percentage of color removal in case of direct dye with CD is relatively small compared to reactive dye. It may be concluded that a small release of Fe^{+n} ions in solution is sufficient to destabilize direct dye and its subsequent precipitation, whereas a certain concentration of Fe^{+n} ions must be released to affect ECF of reactive dye. Thus, the main controlling mechanism for the reactive dye seems to be its adsorption and sweep coagulation in the Fe(OH)$_n$ precipitate, whereas destabilization by charge neutralization is the main mechanism of direct dye removal. Beside the two above-mentioned main mechanisms, there are other secondary mechanisms for color removal during ECF, such as reduction of azo bond by the released Fe^{+2} and/or the partial oxidation of azo bond by evolved Cl$_2$ at the anode [26–28].

Fig. 7 depicts the effect of current density on power consumption. It is well noted that power consumption increases with current density in case of
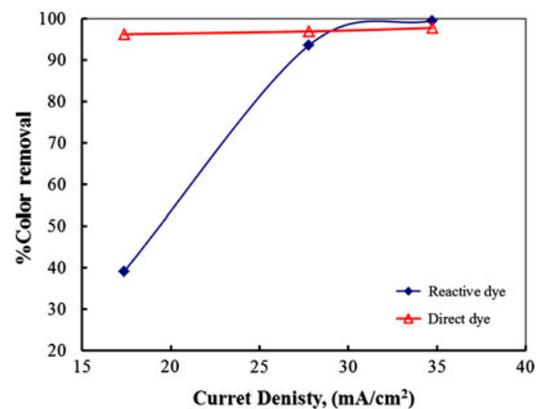
Fig. 6. Effect of current density on percentage of color removal. (Reactive CRHD dye, $Co = 50$ ppm, NaCl concentration = 2 g/l), and (direct SY5GL, $C_o = 100$ ppm, NaCl concentration = 4 g/l), in both cases distance between electrodes = 2 cm, rpm ≈ 50, and pH = 7.

Fig. 7. Effect of current density on power consumption. (Reactive CRHD, $C_o = 50$ ppm, NaCl concentration = 2 g/l) and (direct SY5GL, $C_o = 100$ ppm, NaCl concentration = 4 g/l) in both cases distance between electrodes = 2 cm, rpm $\approx$ 50, and pH = 7).
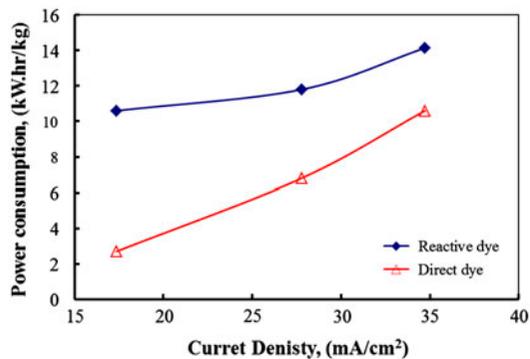
Fig. 9. Effect of NaCl concentration on power consumption. (Reactive CRHD, $C_o = 50$ ppm, CD = 34.72 mA/cm^2) and (direct SY5GL, $C_o = 100$ ppm, CD = 17.36 mA/cm^2), in both cases distance between electrodes = 2 cm, rpm $\approx$ 50, and pH = 7.

direct dye, and approximately constant in case of reactive dye. Based on power consumption values, optimum current densities of 17.36 and 34.72 mA/cm^2 were chosen for further experiments of direct and reactive dyes, respectively.

4.3. Effect of NaCl

Fig. 8 shows the effect of NaCl concentration on the percentage of color removal. As NaCl concentration increases from 2 to 5 g/l, percentage of color removal increases from 35.6 to 90.62% and from 91.6 to 97.2% for reactive and direct dyes, respectively. Similar effects were reported by other authors [25,27]. The presence of NaCl is not only essential for enhancing the conductivity of solution but also is essential as an antipassive agent [24]. In addition, the evolved Cl$_2$ gas at the anode may contribute in partial oxidation of dye molecules [29].
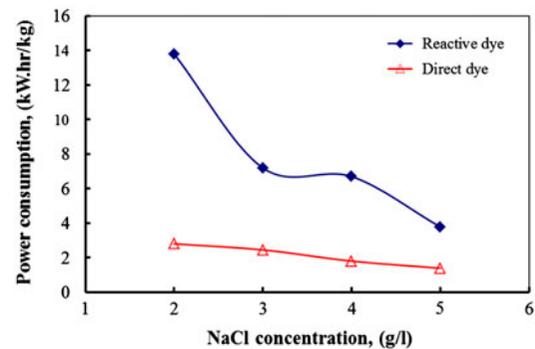
Fig. 9 shows the effect of NaCl concentration on power consumption for both dyes. It is well seen that as NaCl concentration increases, the power consumption decreases considerably. An optimum concentration of 5 and 4 g/l of NaCl was chosen for further experiments for reactive dye and direct dye, respectively. The similar results are obtained by other investigators [30–32].

4.4. Effect of rpm

Since paddles impellers are commonly employed in industrial flocculation units to provide the slow rotational speed which is sufficient to allow floc formation and growth. It would be of interest to study the effect of the paddle rotational speed on the percentage of color removal of dyes. Fig. 10 exhibits the effect of different rpm (0, 27, 54.3, 75.6) of the paddle on the percentage color removal. The percentage color

Fig. 8. Effect of NaCl concentration on percentage of color removal. (Reactive CRHD ($C_o = 50$ ppm, CD = 34.72 mA/cm^2) and (direct SY5GL, $C_o = 100$ ppm, CD = 17.36 mA/cm^2), in both cases distance between electrodes = 2 cm, rpm $\approx$ 50, and pH = 7.
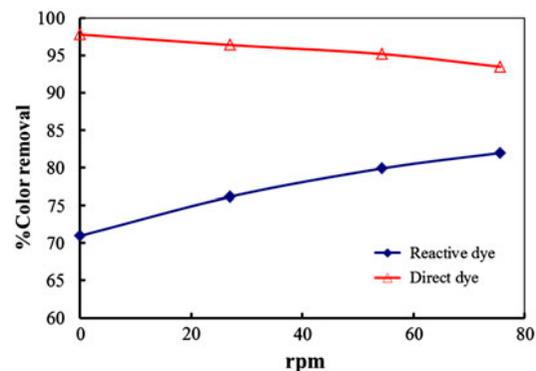
Fig. 10. Effect of rpm on percentage of color removal. (Reactive CRHD L, $C_o = 50$ ppm, CD = 34.72 mA/cm, NaCl concentration = 5 g/l) and (direct SY5GL, $C_o = 100$ ppm, CD = 17.36 mA/cm ^{2}, NaCl concentration = 4 g/l), in both cases distance between electrodes = 2 cm and pH = 7.
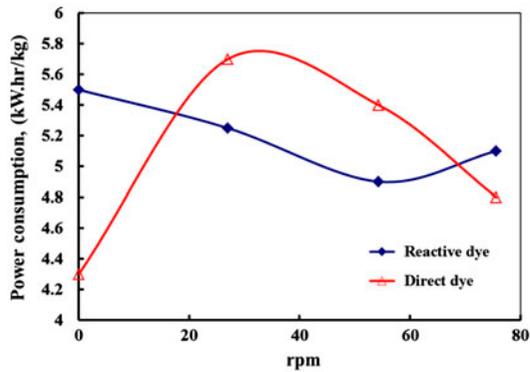
Fig. 11. Effect of rpm on power consumption. (Reactive CRHD, Co = 50 ppm, CD = 34.72 mA/cm, NaCl concentration = 5 g/l) and (direct SY5GL, C_o = 100 ppm, CD = 17.36 mA/cm^2, NaCl concentration = 4 g/l), in both cases distance between electrodes = 2 cm and pH = 7).
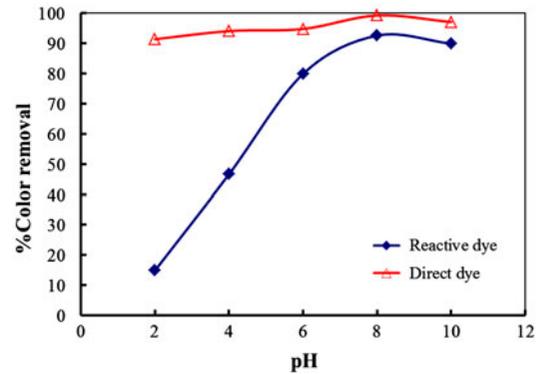
Fig. 12. Effect of pH on percentage of color removal. (Reactive CRHD, C_o = 50 ppm, CD = 34.72 mA/cm^2, NaCl concentration = 5 g/l, rpm = 50) and (direct SY5GL, C_o = 100 ppm, CD = 17.36 mA/cm^2, NaCl concentration = 4 g/l, rpm = 0), in both cases distance between electrodes = 2 cm.

of removal increases from 70.97 to 81.98 with the increase in rpm from 0 to 75.6 for reactive dye. The same results have been obtained by Daneshvar [33] for azo dye decolorization, whereas the percentage of color removal decreases from 97.8 to 93.5 with the increase in rpm from 0 to 75.6 in case of direct dye. The same trend has been obtained by other authors [34].

The dissimilar behavior of the two dyes can be attributed to the difference in chemical structure and molecular weight. Direct dye has lower molecular weight than reactive dye as indicated previously. Thus as rpm increases, direct dye molecule can easily re-dissolved back into the solution, in contrast to reactive dye.

According to Fig. 11, which shows the effect of rpm of the paddle anode on power consumption an optimum rpm of 54.3 and 0 was selected for further experiments for reactive CRHD and direct SY5GL dyes, respectively.

4.5. Effect of initial pH

Fig. 12 shows the effect of pH on percentage color of removal for reactive CRHD and direct SY5GL. It is well noted that maximum percentage of color removal is at pH 8 for the reactive CRHD dye. It is also well remarkable that the pH has a negligible effect on percentage of color removal of direct dye. The slight dependence of percentage of color removal on pH in case of direct dye compared to reactive dye may be ascribed to that of the main mechanism of removal of direct dye is by charge neutralization and precipitation as a result of the release of Fe^n into the bulk of solution. Whereas, the main mechanism of removal

of reactive dye is by adsorption on the $Fe(OH)_n$ precipitate. Accordingly, the percentage removal of reactive dye is maximum at pH of minimum solubility of $Fe(OH)_n$ which corresponding to pH = 7–8 [35]. The pH of the dye solution (natural pH) was chosen as an optimum value of pH and no pH adjustment was done before runs.

Daneshvar et al. [36] also found that the maximum percentage of color removal of Acid Red 14 by EC was observed at pH in the range 6–9.

4.6. Effect of initial dye concentration

Fig. 13 depicts the effect of initial dye concentration on percentage of color removal. It is observed that percentage of color removal decreases from 96.5 to 48% and from 97 to 85% for reactive and for direct dye, respectively, corresponding to the
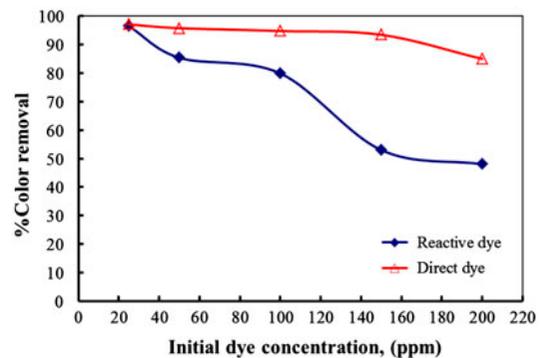
Fig. 13. Effect of initial dye concentration on percentage of color removal. (Reactive CRHD, CD = 34.72 mA/cm^2, NaCl conc. = 5 g/l, rpm = 50), and (direct SY5GL, CD = 17.36 mA/cm^2, NaCl conc. = 4 g/l, rpm = 0), in both cases distance between electrodes = 2 cm and pH = 7.

initial dye concentration changes from 25 to 200 ppm. It is well known that as the dye concentration increases, at fixed current density, the adsorption capacity of the Fe $(OH)_n$ consumed rapidly and as result percentage removal of dye decreases. The same trend was obtained with other authors in many studies on the decolorization of textile dye wastewater by batch and continuous EC processes [24,25,32].

4.7. Effect of distance between the electrodes

Fig. 14 shows the effect of the electrode distance on percentage of color removal. It is well clear that as the electrode distance increases from 1 to 4 cm, percentage of color removal decreases from 96.85 to 94.11% and from 97.24 to 88.8% for reactive CRHD and direct SY5GL dyes, respectively. Previous studies [24,25] indicated that the distance between electrodes has positive effect on percentage of color removal up to certain distance, beyond which percentage of color removal decreases with time. The absence of the positive effect of distance in the present study may be attributed to the different cell design.

The decrease in percentage of color removal with the increase in the electrode distance may be explained by fact that, as the distance between electrode increases, the cell resistance increases which leads to increase in the cell voltage according to ohm's law. The increase in cell voltage can increase electrode potential to a limit that allow O_2 evolution at the anode which results in the decrease of current efficiency of the cell, and decrease the amount of Fe ions released to solution, which in return decreases the rate of ECF of the dye [37]. Fig. 15 shows the effect of the electrode distance on power consumption. It is obvious that as electrode distance increases, power

Fig. 15. Effect of distance between the electrodes on power consumption. (Reactive CRHD, $C_o = 100$ ppm, CD = 34.72 mA/cm, NaCl conc. = 5 g/l, rpm = 50) and (direct SY5GL, $C_o = 100$ ppm, CD = 17.36 mA/cm^2, NaCl conc. = 4 g/l, rpm = 0), in both cases pH = 7.

consumption increases for reactive CRHD and direct SY5GL dyes, respectively, therefore 1 cm distance was chosen as optimum electrode distance for both dyes.

4.8. Effect of different electrode combinations

Since Al and Fe are the most commonly used anodes in EC cells, the effect of their different combinations on percentage of color removal and power consumption was investigated to determine the most economic and effective electrodes combination. Different anode/cathode combinations used in the present study are: Fe/Fe, Al,Fe/Fe, Al,Fe/Al, and Al/Al.

Fig. 16 shows the effect of different electrode combinations on the percentage of color removal of reactive and direct dyes. It is well obvious that the highest percentage of color removal is obtained for Fe/Fe combination, whereas the least percentage of color removal is obtained for Al, Fe/Fe combination

Fig. 14. Effect of distance between the electrodes on percentage of color removal. (Reactive CRHD, $C_o = 100$ ppm, CD = 34.72 mA/cm^2, NaCl conc. = 5 g/l, rpm = 50) and direct SY5GL, ($C_o = 100$ ppm, CD = 17.36 mA/cm^2, NaCl conc. = 4 g/l, rpm = 0), in both cases pH = 7.
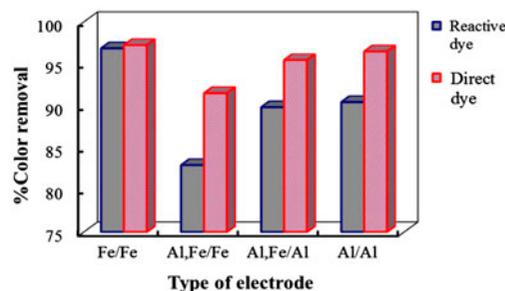
Fig. 16. Effect of different electrode combinations on percentage of color removal. (Reactive CRHD, $C_o = 100$ ppm, CD = 34.72 mA/cm, NaCl concentration = 5 g/l, rpm = 50) and (direct SY5GL, $C_o = 100$ ppm, CD = 17.36 mA/cm^2, NaCl concentration = 4 g/l, rpm = 0), in both cases distance between electrodes = 1 cm and pH = 7.
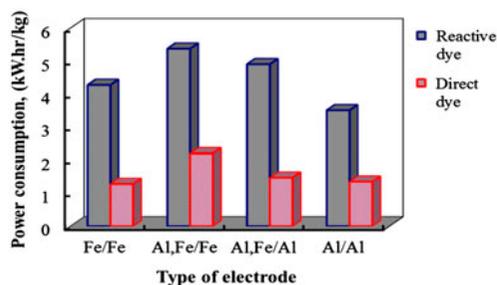
Fig. 17. Effect of different electrodes combination on power consumption of reactive CRHD, (C_o = 100 ppm, CD = 34.72 mA/cm, NaCl concentration = 5 g/l, rpm = 50) and direct SY5GL, (C_o = 100 ppm, CD = 27.36 mA/cm^2, NaCl concentration = 4 g/l, rpm = 0), in both cases pH = 7.

for both types of dyes investigated. The high efficiency of Fe/Fe combination may be explained by the high adsorption capacity of Fe^{+n} ions compared to Al^{+3} ions [33]. This trend is in agreement with many investigators [38]. On the other hand, it seems that the interaction of Al and Fe electrodes results in a reduction of the net amount of ions released for a fixed current density due to the difference in their oxidation potential and their susceptibility to passivation. This effect is very obvious at low Al-contribution, that is Al, Fe/Fe combination; however, with the increase in Al contribution, this effect is decreased. It is worth mentioning that both Fe/Fe and Al/Al electrode combination give the maximum color removal of direct dye. These results indicate that direct dye is destabilized effectively whether Al^{+3} or Fe^{+n} ions are released into solution.

Phalakornkule [39] has shown that the order of performance of different electrode combinations toward decolorization of reactive dye is Fe > combined Fe–Al > Al. The difference in their results with the present work may be due to the difference in their cell design. Fig. 17 depicts the effect of different electrode combinations on power consumption. It is well seen that comparable values of least power consumption are obtained by either Fe/Fe electrodes or Al/Al electrode, while the highest power consumption values are related to Al, Fe/Fe or Al, Fe/Al.

5. Economic study

Another comparative study between the different types of dyes has been investigated in relation to the amount of metals dissolved per kg of dye removed and evaluated by using Faraday's law and the power consumption.

Considering these two economic parameters, it has been found that it requires 1.87 and 1.5 using Fe

Table 1
Optimum conditions based on maximum percentage of color removal and minimum power consumption for the two types of dyes

Parameter	Reactive CRHD	Direct SY5GL
Electrolysis time (min)	10	12
Initial dye concentration (ppm)	100	100
Percentage of color removal	96.85	97.24
Current (Amp)	1	0.5
NaCl (g/l)	5	4
rpm	50	0
pH	7	7
Distance between electrodes (cm)	1	1
Type of electrodes combination	Fe/Fe	Fe/Fe
Amount of electrode dissolved per kg of dye removed (g)	0.16	0.194
Cost of dissolved electrode (EGP/kg dye removed)	0.72	0.873
Cost of electricity (EGP/kg dye removed)	1	0.63
Total operating cost/kg dye removed (cost of dissolved electrode + cost of electricity)	1.87	1.5

anode to remove 1 kg of reactive CRHD and direct SY5GL, respectively, at the optimum conditions. Table 1 summarized the optimum conditions of ECF using the present cell for the two investigated dyes and their calculated operating cost.

6. Case study: real effluent

The performance of the present cell was further investigated by using real textile effluent which was obtained from Misr-Al-Amrya for spinning and weaving company, Alexandria, Egypt. The effluent was withdrawn from the drainage of cold batch dyeing process without dilution or mixing with other effluents from processing stages.

The main composition of the real textile effluent is given in Table 2.

Table 2
Composition of real textile effluent

Constituents	Concentration (g/l)
Levofix navy Blue E-BNA green	39
Levofix brown E-green	17
Nova green/nova red S2B	5.5
Soda ash	50
Urea	50
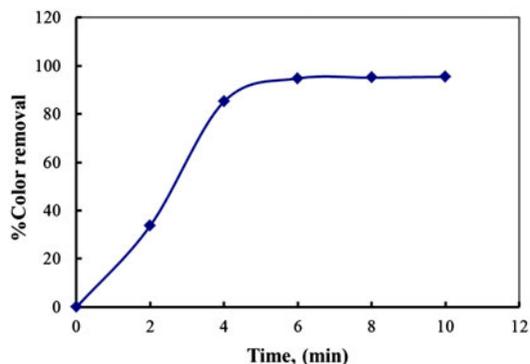
Fig. 18. Percentage of color removal versus time for EC of real textile effluent (CD = 34.72 mA/cm^2, NaCl conc. = 5 g/l, rpm = 50, distances between electrodes = 1 cm and pH = 7).

ECF of the real effluent which is diluted 500 times in the presence of 5 g/l NaCl at 34.72 mA/cm^2 showed 95.45% removal of color and 44% of COD reduction in 6 min. Fig. 18 shows the percentage of color removal of dye against electrolysis time. It is well remarkable that the presence of dyeing auxiliaries (urea and soda ash) has a negligible effect on the kinetics of dye removal.

7. Conclusions

The present work has investigated the optimum parameters for the removal of color from two types of anionic dyes (reactive and direct) in a batch agitated vessel from synthetic wastewater by ECF. The performance of the present batch agitated vessel was expressed in terms of percentage color removal and power consumptions calculations. Different parameters have been studied such as: electrolysis time, current density, NaCl concentration, initial dye concentration, initial solution pH, rpm, distance between electrodes, and different electrode combinations.

The following conclusions have been withdrawn for the ECF of the two types of dyes:

(1) The study of the effect of current density and electrolyte (NaCl) concentration on the percentage of color removal for the two types of dyes showed that the percentage of color removal increases as both current density and NaCl concentration increase.

(2) Increasing both initial dye concentration and distance between electrodes were proven to decrease the percentage of color removal significantly with other operating conditions remaining constant.

(3) The pH of the investigated dye solution is within the range of pH corresponding to the maximum

color removal and no need for pH adjustment before ECF treatment unit.

(4) It has been found that the rpm has a different effect on percentage of color removal of each dye, that is in case of reactive dye as rpm increases, percentage of color removal increases. Whereas in case of direct dye as rpm increases, percentage of color removal decreases gradually.

(5) Fe/Fe is the optimum electrode combination for the two investigated dyes.

(6) Power consumption (PC) is a very important economical parameter in ECF. The results showed that as the current density and distance between electrodes increases PC increases, whereas as NaCl concentration increases, PC decreases.

(7) Direct operating cost evaluation of the present EC cell, revealed that the removal of 1 kg of reactive CRHD and direct SY5GL at the optimum conditions requires 1.87 and 1.5 EGP, respectively.

(8) Treatment of real textile effluent by the present batch agitated vessel showed promising results in terms of color removal. It has been found that under optimum conditions 95.45% of color removal and 44% of COD reduction have been achieved.

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