Effects of operational parameters on the removal of brilliant green dye from aqueous solutions by electrocoagulation

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Abstract This paper presents an experimental study on the removal of brilliant green dye from aqueous solutions in a batch stirred electrocoagulation (EC) reactor using iron electrodes. The main objectives of the experiments were to investigate the effects of the various operating parameters, such as current density, inter electrode distance, initial dye concentration, pH of the solution, EC duration and salt (NaCl) concentrations on the brilliant green dye removal efficiency from synthetic wastewater containing in batch EC process. The experimental results showed that 99.59% dye removal was observed for initial dye concentration of 100 mg/L with current density of 41.7 A/m², initial pH of 4.0 at the end of 30 min of operation. It was observed that, an increase in current density, time of operation and decrease in inter electrode distance improved the dye removal efficiency. Optimum pH for highest dye removal was 4.0–10.0. It was also observed that increase in salt (NaCl) concentration in the solution reduces the specific electrical energy consumption (SEEC).

1. Introduction

Textile, paints, pulp and paper, carpet and printing industries are well known as water intensive sectors as they generate considerable amount of wastewater, which contains strong color, suspended particles, non biodegradable materials, high chemical oxygen demand (COD) and hence causes severe water pollution. Also these effluents can contain chemicals that are toxic, carcinogenic, and mutagenic to various microbiological or animal species. Among various pollutants present in wastewater, the presence of synthetic dyes is of great concern because of their carcinogenic effects on human bodies. Dye containing effluents can obstruct light penetration in the water of lakes, rivers etc. thus inhibiting the biological processes based on photosynthesis. In order to get rid of this water contamination, a detailed study is necessary and hence, various research works have been carried out.

There are several methods available for removal of dyes from wastewater like adsorption over solid surface (Nandi et al., 2009), biosorption (Sharma and Nandi, 2013), membrane separation (Purkait et al., 2003), advanced oxidation...
(Jana et al., 2010), photo-degradation (Lodha et al., 2011), bioremediation (Abd El-Rahim et al., 2009), electrocoagulation (Golder et al., 2005), etc. All the methods have their own distinct advantages and disadvantages. Among these techniques, electrocoagulation (EC) has been found a promising technique in removal of arsenic (Balasubramanian et al., 2009), fluorine (Ghosh et al., 2008a), iron (Ghosh et al., 2008b) form water, removal of chromium (Vasudevan et al., 2011), removing of hardness of drinking water (Malakootian et al., 2010), etc. This is clearly a motivation for experimental investigation of dye removal from wastewater by EC process. EC process is also preferred due its simplicity, ambient operability, reliable and cost-effective, large volume handling ability, eco friendly, non-toxicity because of non-consumption of chemicals, and no eventual secondary pollutants to discard at acceptable physical and chemical conditions. It also requires comparatively less time for treatment.

EC technique uses a direct current (DC) power source between metal electrodes immersed in polluted water. The electrical current causes the dissolution of metal plates including iron or aluminum into wastewater. The metal ions generation takes place at the anode and hydrogen gas is released from the cathode. The metal ions, at an appropriate pH, forms a wide range of coagulated species and metal hydroxides that destabilize and aggregate the suspended particles or precipitate and adsorb dissolved contaminants (Chen, 2004). The hydrogen gas would also help to float the flocculated particles out of the water.

Brilliant green is very well known cationic dye used for various purposes e.g., biological stain, dermatological agent, veterinary medicine, an additive to poultry feed to inhibit propagation of mold, intestinal parasites and fungus (Zollinger, 1987). It is also extensively used in textile dying and paper printing (Gupta et al., 1992). It is estimated that around 30% of the applied dyes remain unixed and are discharged in the effluent (Lakshmi et al., 2009). Recently, very large number of scientific work has been published in the field of removal of dyes from wastewater by EC process but no work has been done to remove brilliant green dye by EC process.

This article presents the results of the laboratory scale studies on the removal of brilliant green dye from water using iron electrode by EC process. Detailed experimental investigation has been carried out to observe the effects of different operational parameters such as effect of current density (CD), initial dye concentration (C₀), pH, inter electrode distance (IED) and effect of salt concentration on the dye removal efficiency. Measurement of weight sludge generated per liter of wastewater and estimation of specific electrical energy consumption (SEEC) were carried out considering their significance in industrial application. All these parameters are very important in designing large scale plant for industrial application of EC. This fundamental study will be helpful for further application in designing an EC unit for the treatment of water containing brilliant green dye to keep their concentration within permissible limit.

2. Experimental

2.1. Materials and methods

Analytical grade brilliant green dye (C.I.: 42040, MW: 462.65, λmax: 626 nm), supplied by Merck, India was used in this study. Brilliant green molecule exists as cation in aqueous medium (Fig. 1). Dye solution was prepared by dissolving solid dye in distilled water. The conductivity of solutions was raised up and adjusted in different values by the addition of NaCl (Merck, India). Schematic of EC cell used in this study is shown in Fig. 2. Batch experiments were carried out using a 2 L capacity glass beaker with 1 L of dye solution at ambient temperature (298 ± 2 K). Mild steel plate of dimension 15 × 6 × 1 cm collected from the local market (Guna, M.P,
India) was used as an electrode. The gap between the anode and cathode was maintained by placing different wooden blocks of varying size from 1 to 3 cm. The entire electrode assembly was fitted on non-conducting wooden rod and hanged from the top of the glass beaker. During experiments, 6 cm height of electrode was dipped. So an effective surface area of the electrode was 72 cm² (0.0072 m²). The electrodes were connected to a DC power supply (Make: Aplab, India, Model: L3202) with galvanostatic operational options for controlling the constant current density by setting the constant current mode of operation. A magnetic stirrer (Make: Remi Instruments, India, Model: Q19A) was used for stirring purpose. The current density (CD) was calculated through the following equation as follows:

\[ CD = \frac{I}{2 \times S} \]  

(1)

where \( I \) is the current through the solutions (A) and \( S \) is the area of the electrode (m²). The conductivity of the solution was measured by using a Conductivity meter (Make: Lutron, India, Model: CD-4302). All the experiments were performed at pH 4 (Natural pH of 100 mg/L dye solution). The pH of the solutions was measured by pH meter (Make: Systronics Naroda, India, Model: MK 6) and adjusted by adding NaOH or HCl solutions. Concentrations of dye solutions were measured by UV–vis spectrophotometer (Make: Elico Instruments Ltd, India, Model: SL 159). After the experiment, the DC power source was switched off and the electrodes were dismantled. Before each run, the electrodes were abraded with sand-paper to remove scale and then cleaned with successive rinses of water and finally washed with acetone to remove any impurities on the mild steel electrode surface. After each experiment the used anode and cathode plates were interchanged for effective electrode utilization. Various parameters studied in this work were initial dye concentrations (varied from 50 to 200 mg/L), effect of current density (13.9–138.9 A/m²), effect of inter electrode distance (varied from 1 to 3 cm), effect of pH (varied from 1.5 to 10.0), salt concentration (0.1–1.0 g/L) and amount of solid waste generated. Details of experimental parameters studied are summarized in Table 1. The amount of solid sludge was measured by filtering the entire solution after experiment and drying it in hot air oven. During experiments samples were taken at 5 min interval and were filtered before analysis. All the experiments were repeated twice and the experimental error was around 3%. The dye removal efficiency (R) was calculated using the equation as follows

\[ R = \frac{C_0 - C_t}{C_0} \times 100 \]

(2)

where, \( C_0 \) is the initial dye concentration (mg/L),and \( C_t \) is the concentration (mg/L) of dye at any time \( t \) (min).

2.2. Theory of electrocoagulation (EC) process

EC strongly depends on pH of the solution, concentrations and conductivity of the continuous phase. When iron electrode is connected by DC power source in an electrolytic system, it produces coagulant Fe(OH)ₙ, where \( n = 2 \) or 3. Two mechanisms for the production of the metal hydroxide have been proposed (Daneshvar et al., 2006):

Mechanism 1:

Anodic reactions: \( 4\text{Fe}(s) - 8e^- \rightarrow 4\text{Fe}^{2+}(aq) \)  

(3)

\( 4\text{Fe}^{2+}(aq) + 10\text{H}_2\text{O}(l) + \text{O}_2(g) \rightarrow 4\text{Fe(OH)}_2(s) + 8\text{H}^+(aq) \)  

(4)

Cathodic reaction: \( 8\text{H}^+(aq) + 8e^- \rightarrow 4\text{H}_2(g) \)  

(5)

Overall reaction: \( 4\text{Fe}(s) + 10\text{H}_2\text{O}(l) + \text{O}_2(g) \rightarrow 4\text{Fe(OH)}_2(s) + 4\text{H}_2(g) \)  

(6)

\( n\text{Fe(OH)}_2 \rightarrow \text{Fe}_n(\text{OH})_{2n}(s) \)  

(7)

Mechanism 2:

Anodic reactions: \( \text{Fe}(s) - 2e^- \rightarrow \text{Fe}^{2+}(aq) \)  

(8)

\( \text{Fe}^{2+}(aq) + 2\text{OH}^- (aq) \rightarrow \text{Fe(OH)}_2(s) \)  

(9)

Cathodic reaction: \( 2\text{H}_2\text{O}(aq) + 2e^- \rightarrow \text{2OH}^-(aq) + 4\text{H}_2(g) \)  

(10)

Overall reaction: \( \text{Fe}(s) + 2\text{H}_2\text{O}(l) = \text{Fe(OH)}_2(s) + \text{H}_2(g) \)  

(11)

\( n\text{Fe(OH)}_2 \rightarrow \text{Fe}_n(\text{OH})_{2n}(s) \)  

(12)

| Table 1 | Various experimental parameters studied during the EC of brilliant green dye by iron electrode. Time of experiments = 30 min, IED = inter electrode distance, CD = current density, \( C_0 \) = initial dye concentration. |
|---|---|---|
| Parameter studied | Parameter varied during experiment | Parameter kept constant during experiment |
| Effect of current density (CD) | 13.9, 20.8, 27.8, 34.7, 41.7, 69.4, 138.9 A/m² | \( C_0 = 100 \text{ mg/L}, \text{ CD} = 41.7 \text{ A/m²}, \) NaCl concentration = 0.2 g/L, IED = 1 cm, pH = 4 |
| Effect of initial dye concentration (\( C_0 \)) | 50, 100, 125, 150, 200 mg/L | CD = 41.7 A/m², NaCl concentration = 0.2 g/L, IED = 1 cm, pH = 4 |
| Effect of inter electrode distance (IED) | Each IED of 1, 1.5, 2.0, 2.5, 3.0 cm for every CD of 13.9, 27.8, 41.7 A/m² | \( C_0 = 100 \text{ mg/L}, \text{ NaCl concentration} = 0.2 \text{ g/L}, \) IED = 1 cm, pH = 4 |
| Effect of pH | 1.5, 3, 4, 5.5, 7, 8.5, 10 | \( C_0 = 100 \text{ mg/L}, \text{ CD} = 41.7 \text{ A/m²}, \) NaCl concentration = 0.2 g/L, IED = 1 cm, pH = 4 |
| Effect of solution conductivity and salt (NaCl concentration) | 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0 g/L | CD = 41.7 A/m², NaCl concentration = 0.2 g/L, IED = 1 cm, pH = 4 |
Chain oxidation reaction by NaCl

$$2\text{Cl}^- \rightarrow \text{Cl}_2 + 2e^- \quad \text{(13)}$$

$$\text{Cl}_2(g) + \text{H}_2\text{O} \rightarrow \text{HOCl} + \text{H}^+ + \text{Cl}^- \quad \text{(14)}$$

$$\text{Fe(OH)}_3 + \text{HOCl} + 2e^- \rightarrow \text{Fe(OH)}_4^- + \text{Cl}^- \quad \text{(15)}$$

The insoluble metal hydroxide of iron remains in the aqueous phase as a suspension, which removes the pollutants from wastewater by precipitation and adsorption mechanisms (Koby et al., 2003). NaCl increases the production rate of mono-nuclear and poly-nuclear aluminum hydroxide by chain reaction as described in Eqs. (13)-(15) and improves the pollutant removal (Koby et al., 2003).

Precipitation: Dye + monomeric Fe $\rightarrow$ [Dye – monomeric Fe](s) \hspace{1cm} \text{(16)}

Adsorption: Dye + Fe\(_n\)(OH)\(_n\)(s) $\rightarrow$ [Sludge] \hspace{1cm} \text{(18)}

Adsorption: Dye + Fe\(_n\)(OH)\(_n\)(s) $\rightarrow$ [Sludge] \hspace{1cm} \text{(19)}

2.3. Specific electrical energy consumption and current efficiency

Current efficiency ($\varphi$) and specific electrical energy consumption (SEEC) are very important economical parameters in EC process like all other electrolytic processes. Different parameters such as applied current, voltage drop, inter electrode distance, and dissolved amount of contaminants affect the current efficiency. Lower current density would not be sufficient to achieve the desired separation; however, it lowers the possibility of the film-formation on the anode surface. Higher current density shows a better removal of dissolved contaminants. If the amount of dissolved contaminant is large then the removal process gets slowed down due to the accumulation of gelatinous aluminum hydroxide film on the anode even on the application of higher current density. As a result current efficiency falls down. Current efficiency ($\varphi$) for different operating conditions is calculated as (Ghosh et al., 2008a):

$$\varphi = \frac{\Delta M_{\text{experimental}}}{\Delta M_{\text{theoretical}}} \times 100 \quad \text{(20)}$$

This calculation is based on the comparison of experimental weight loss of iron electrodes $\Delta M_{\text{experimental}}$ during EC process with theoretical amount of iron dissolution $\Delta M_{\text{theoretical}}$ according to the Faraday’s law:

$$\Delta M_{\text{theoretical}} = \frac{M \cdot \varepsilon \cdot I \cdot t_{\text{EC}}}{n \cdot F} \quad \text{(21)}$$

where $M$ is the molecular weight of the iron (g/mol), $n$ is the number of electron moles, $F$ is the Faraday constant ($F = 96,487$ C/mol) and $t_{\text{EC}}$ is the time (s) of EC operation. Assuming Fe(OH)\(_2\)(s) is supposed to be the formed species, the number of electron moles in dissolution reaction is equal to 2. The specific electrical energy consumption (SEEC) is calculated as a function of iron electrodes weight consumption during EC in kW h/(kg Fe) (Ghosh et al., 2008a):

$$\text{SEEC} = \frac{n \times F \times U}{3600 \times M \times \varphi} \quad \text{(22)}$$

It is well known that the over potential caused by solution resistance has a significant effect on cell voltages ($U$) that depends on the distance ($d$) between the electrodes, surface area ($S$) of the cathode and specific conductivity of the solution ($\gamma$) and the current ($I$).

3. Results and discussions

3.1. Effect of current density and time of electrolysis

In all electrochemical processes, current density and time of electrolysis are the two most important parameters for controlling the reaction rate within the reactor. Current density and electrolysis time ($t_{\text{EC}}$) determines the coagulant production rate and total production of coagulant (Fe\(^{2+}\) or Fe\(^{3+}\) ions). The variation in percentage removal of dye with contact time at different current densities of 13.9–138.9 A/m\(^2\) ($I = 0.1$–$1.0$ A) is presented in Fig. 3. It may be seen from the figure that dye removal rate increased with increase in current density. For current density of 69.4 and 138.9 A/m\(^2\), more than 90% dye removal was observed after 10 min of operation compared to dye removal of 73.6%, 64.6%, 51.8%, 41.8% and 35.9% for 41.7, 34.7, 27.8, 20.8 and 13.9 A/m\(^2\) current densities, respectively. However after 30 min of operation, more than 99% dye removal was observed for all current density above 41.7 A/m\(^2\). At the same time dye removal was 76–96% for current densities of 13.9–34.7 A/m\(^2\). So, the variation in current density has lesser effect on the final total dye removal, but the rate of dye removal was higher with high current density. It was due to fact that an increase in current density increased the rate of production of coagulant (Fe\(^{2+}\) or Fe\(^{3+}\) ions) on the anode. These increased the flocs generation rate and hence dye removal efficiency. In other words, higher current density will generate significant amount of flocs, which in turn will trap the dye molecules and enhance the dye removal efficiency. After 20–25 min of operation, the remaining concentration of dye in water was very low and hence rate of adsorption of dye in flocs decreased although the rate of flocs generation remains constant for constant current density. However for very low current densities (13.9 A/m\(^2\)), it was observed that 76% dye removal was achieved after 30 min of operation. This was due to the fact that, the total amount of produced flocs was not enough to remove all the dye molecules in the solution and it required more time to achieve higher dye removal efficiency.
3.2. Effect of initial dye concentration

To observe the effect of initial dye concentration on the dye removal efficiency by EC, experiments were carried out for five different dye concentrations (50, 100, 125, 150 and 200 mg/L) for 30 min with constant current density of 41.7 A/m². Fig. 4 shows the percentage removal of dyes for different initial dye concentrations. As the results indicated, the dye removal efficiency decreased with an increase in initial dye concentration. For example after 30 min of operation, dye removal decreases from 99.87% to 67.78% when dye concentration was increased from 50 to 200 mg/L. It was due to the fact that at constant current density and time, the same amount of iron hydroxide complexes was generated in all the dye solutions. Consequently, the same amount of flocs would be produced in the solutions. As a result, the flocs produced at high dye concentration were insufficient to adsorb all of the dye molecules of the solution. For low concentration of dyes, the number of iron hydroxide complexes was higher compared to the number of dye molecules. Hence 100% dye removal was obtained in quick time compared to higher concentration. Hence, it is quite clear that under the present operating conditions, the lower is the dye concentration better would be the removal efficiency. Kobya et al. (2003) reported similar results for the removal of reactive dye solutions by EC process.

3.3. Effect of inter electrode distance

The set up of electrode assembly is very important for required effective surface area of electrode and inter electrode distance. The variation in voltage drop (ηIR) is governed by following equation (Ghosh et al., 2008a):

\[ \eta_{IR} = I \times \frac{d}{S} \times k \]  \hspace{1cm} (23)

where \( I \) = current (A), \( d \) = distance between two electrode (m), \( S \) = active anode surface (m²), \( k \) = specific conductivity (10³ mS/m). Above equation infers that at constant anodic surface area and conductivity of the solution, voltage drop increases with the increase of inter electrode distance. Once distance between the electrodes increases, resistance between the two electrodes increases and hence, the electrical current decreases. So to achieve a certain current density, the voltage must be increased. With increasing electrode distance, less interaction of ions with hydroxide polymers is expected. In the present study, the effect of inter electrode distance was investigated between 1 and 3 cm as shown in Fig. 5. From the figure it is observed that, best efficiencies were obtained with weak distances. For example with inter electrode distance of 1 cm, dye removal efficiency was 99.59%, 89.98% and 76.14% for three different current density of 41.4, 27.8 and 13.9 A/m², respectively. On the other hand for inter electrode distance of 3 cm dye removal efficiency was 88.48%, 75.03% and 63.73% for three different current density of 41.4, 27.8 and 13.9 A/m², respectively. These results are in good agreement with those found in the study of Modirshahla et al. (2007).

Fig. 6 shows the effect of inter electrode distance on the SEEC. From the figure it was observed that, SEEC increased...
with an increase in the inter electrode distance and current density. This was due to the fact that when inter electrode distance increased, voltage across the electrode increased. Hence, the total power consumption and SEEC increased for obtaining the required current density increased.

3.4. Effect of pH

The literature reports that pH plays a key role on the performance of EC (Ghosh et al., 2008a; Daneshvar et al., 2006). It will determine the ionic characteristic of the metal hydroxides and dye molecules in solution and hence it will have a significant influence on the dye removal mechanism. In order to investigate the effect of the pH of the solution on dye removal experiments were performed by adjusting the initial pH in the interval from 1.5 to 10. Fig. 7 shows the variation of initial pH and final pH observed during experiments. From the figure it was observed that, the pH of the medium increases during the reactive phase and then stabilizes at a pH in the range of 6.5–10.5 depending on the initial pH. During experiments it was observed that, the pH of the medium increases during the reactive phase, then stabilizes at pH close to 8–10.5 depending on the initial pH. Similar observations were also reported by other investigators (Yavuz et al., 2011) and this variation depends on the type of electrode and initial pH. This increase in pH can be explained by the occurrence of water electrolysis resulting in hydrogen evolution and production of OH\(^{-}\) ions. The relative stability of pH afterward could be probably due to the formation of the insoluble Fe(OH)\(_3\) flocs and the rest metal hydroxides.

The percentage of dye removal at different pH is shown in Fig. 7 for the initial dye concentration of 100 mg/L for two different times of 15 and 30 min. It can be seen that the initial pH has a significant effect on the dye removal efficiency. At very low pH, minimum removal efficiency of 30% and 50% was observed after 15 and 30 min of experiments. However at higher pH range of 4.5–8.5, there was maximum of 99% dye removal was observed. Beyond 8.5 there was no change in removal efficiency. Higher efficiencies were recorded in 4.5–8.5 pH range which is close to the optimal pH for iron hydroxide solid formation (Daneshvar et al., 2006). As, the initial pH value of brilliant green dye solution was around 4.5. Hence, there is no need for the addition of chemicals to change the initial pH values.

3.5. Effect of solution conductivity and salt concentration

Table salt (NaCl) is usually employed to increase the conductivity of the wastewater to be treated by EC. Increase in salt concentration, increases the ion concentration in the solution and hence reduces the resistance between the electrodes. Increase in salt concentration decreases the cell voltage at constant current density and reduces the power consumption in electrolytic cells.

Also, at higher anode potential, other reactions may occur at the anode, such as direct oxidation of organic compounds or H\(_2\)O (Ge et al., 2004). The effect of wastewater conductivity on dye removal and specific electrical energy consumption, various experiments were performed using NaCl as the electrolyte in the range of 0.1–1.0 g/L at current density of 41.7 A/m\(^2\). Table 2 summarizes the variations of, applied voltage and percentage dye removal at constant current density for different salt concentrations. From the table it may be observed that, with an increase in salt concentration from 0.1 to 1.0 g/L, drastic improvement in solution conductivity (from 0.38 to 1.94 ms) was observed. This improvement resulted in the reduction of cell voltage from 21.5 to 3.9 V and hence decreases in SEEC (from 17.15 to 3.11 kW h/kg Fe). At the same time percentage of dye removal increased slightly. In other words, raising the conductivity of dye solutions has no considerable effect on the dye removal efficiency but has great effect in decreasing power consumption. However it is also to be considered that addition of any salt to improve solution conductivity and decrease SEEC also leads to addition of impurity in wastewater.

![Figure 7](image_url) Effects of initial pH on dye removal efficiency. NaCl concentration: 0.2 g/L.

<table>
<thead>
<tr>
<th>Salt (NaCl) Concentration (mg/L)</th>
<th>Conductivity (mS/m)</th>
<th>Voltage drop (Volt)</th>
<th>Dye removal (%)</th>
<th>SEEC (kW h/kg Fe)</th>
<th>Sludge generated (kg/kg dye removed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.38</td>
<td>21.5</td>
<td>97.27</td>
<td>17.15</td>
<td>1.74</td>
</tr>
<tr>
<td>0.2</td>
<td>0.56</td>
<td>15.8</td>
<td>99.59</td>
<td>12.60</td>
<td>1.82</td>
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<tr>
<td>0.3</td>
<td>0.71</td>
<td>11.5</td>
<td>99.67</td>
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<tr>
<td>0.4</td>
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<td>0.6</td>
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</tr>
<tr>
<td>1</td>
<td>1.94</td>
<td>3.9</td>
<td>100</td>
<td>3.11</td>
<td>2.76</td>
</tr>
</tbody>
</table>

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3.6. Solid sludge material

The amount of sludge produced during electro treatment is of industrial relevance. It points to the problem of solid waste generation and disposal associated with the process. Sludge contains large amount organics that may be carcinogenic. It also contains metals, which may have originated from the use of metal electrodes. So, investigation on the quantity of sludge generation during EC was carried out. ‘Sacrificial electrodes’ get dissolved during EC and require regular replacement. Oxide film formed on the electrodes leads to loss of efficiency of the cell. Sludge formation per kilogram of dye removed from the solution during EC with varying salt concentration is summarized in Table 2. From the table it was observed that total sludge generated was varied from 1.74 to 2.76 kg/kg of dye removed when NaCl dose was varied from 0.1 to 1.0 g/L.

3.7. Absorbance spectra of samples

Fig. 8 shows the evolution of the UV–vis spectra of the dye solution (containing 0.2 g/L NaCl, 100 mg/L of dye) during the different steps of treatment (Inter electrode distance 1.0 cm, CD 41.7 A/m²). It can be seen that the absorbance in the visible region was partially reduced after the electrochemical experiment and completely removed later by applying UV light. It is clear that the intensity of characteristic band (626 nm) of brilliant green was found to reduce gradually during the experiment and disappeared totally after 20 min. It can be seen that by EC almost complete dye removal from water was possible.

3.8. Comparison with the literature

The most important point about the removal of brilliant green dye by electrocoagulation using iron electrode is its dye removal capacity in terms of adsorption capacity (mg dye removed/g of aluminum or mg dye removed/g of Fe(OH)₂/Fe(OH)₃ produced). Based on the data reported in Table 2 for 0.2 g/L dose of NaCl, (99.59% dye removal with initial dye concentration of 100 mg/L and experimental metal loss of 0.12 g), the calculated values of adsorption capacity 829.92 mg dye/g of iron or 516.39 mg dye removed/g of Fe(OH)₂ or 434.35 mg dye removed/g of Fe(OH)₃ are produced. Table 3 presents a comparison of the maximum brilliant green dye removal capacity (adsorption capacities) of various sorbents reported in the literature with the present work. The comparison shows that for brilliant green dye removal iron hydroxides have higher adsorption capacity than many of the other reported adsorbents in the literature. The easy availability of aluminum and DC power source is one of the additional advantages, reflecting a promising future for EC in brilliant green dye removal from aqueous solutions.

4. Conclusions

In the present work removal of brilliant green dye from synthetic aqueous solutions by EC with mild steel electrode has been reported. Effects of various parameters; viz., current density, EC time, initial dye concentration, initial pH, distance between electrodes, and dose of salt concentration in the solution on dye removal efficiency have been studied. The results of brilliant green with iron electrode showed that the removal efficiency was enhanced from 76% to 99.59% with the increase in current density from 13.9 to 138.9 A/m². It was found that the electrolysis time of 30 min was enough for the removal of more than 99% dye from 100 mg/L of dye solution with IED of 1 cm and current density of 41.7 A/m². The dye was removed efficiently in the normal pH values of the solution of 4.0. Dye

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Maximum adsorption capacity (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid treated almond peel</td>
<td>30</td>
</tr>
<tr>
<td>NaOH treated saw dust</td>
<td>58.5</td>
</tr>
<tr>
<td>Kaolin</td>
<td>65.42</td>
</tr>
<tr>
<td>Red clay</td>
<td>125</td>
</tr>
<tr>
<td>Fe electrode (Iron hydroxide produced)</td>
<td>516.39 mg dye removed/g of Fe(OH)₂ produced or 434.35 mg dye removed/g of Fe(OH)₃ produced</td>
</tr>
</tbody>
</table>
removal efficiency was decreased when the initial dye concentrations were more than 100 mg/L. High conductivity of solution was in favor of low SEEC and hence low operating cost.

References


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