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# Treatment of textile wastewaters by electrocoagulation employing Fe-Al composite electrode

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## ABSTRACT

In the present study, electrocoagulation process employing Fe-Al composite electrode was applied for treatment of different types of textile wastewaters. Effect of major operating parameters such as pH, reaction time, current density, voltage and inter-electrode distance were investigated for chemical oxygen demand (COD) and colour removal efficiency. The process was found promising and produced more than 90% COD and colour removal efficiency at optimised operating conditions of pH 8, reaction time 80 min, current density 20 $A/m^2$ with an inter-electrode distance of 3 cm. Robustness of the process was investigated on real and anaerobically pre-treated textile wastewater. For real textile effluents, the process produced approximately 99% colour removal efficiency, creating virtually colourless solution even at a lesser reaction time of 60 min. Electrocoagulation effectively detoxified the anaerobically pre-treated textile wastewater by eliminating 78% of aromatic amines within a reaction time of 180 min.

## 1. Introduction

Textile industry effluents are one of the major sources of environmental contamination and public well-beings, mostly in many urban regions. These effluents are severely polluted with the complex organic and inorganic chemicals which are used during various steps of textile processing. The unused constituents from each step are discharged as wastewater which possesses strong colour due to the presence of residual dyes, high organic and inorganic matters, turbidity, pH and toxic chemicals. Presence of a very small amount of residual dye in water is highly visible and consequently, affects the receiving environment not only aesthetically, but also disturbs the aquatic life by hindering the light penetration and oxygen transfer. The carcinogenic and mutagenic ability of various azo dyes and their precursors produces detrimental effects to the environment [1]. Therefore, to protect the environment, textile wastewater must be treated up to the safe discharge limits as recommended by legal bodies of different countries. Various physico-chemical, chemical and biological processes, as well as some of the new emerging techniques like sonochemical or advanced oxidation processes are practiced to treat the textile wastewater [2,3]. Each of them has some limitations and drawbacks in their application. Biological treatment by activated sludge offers appreciable efficiencies for COD removal, but does not effective for the elimination of the colour of the wastewater and often operational problems such as bulking of sludge appear. Coagulation/flocculation process has been found to be robust, cost effective, easy to operate and energy saving treatment options, but the coagulation process does not work well for all the types of textile dyes [4]. Advanced oxidation processes such as ultrasonication, ozonation, UV-radiation $H_2O_2$, and their combinations have a great interest, but the costs are still very high due to the high doses required and power consumption [5]. Adsorption and nanofiltration processes are not always enough to satisfy the discharge limits [6]. In addition, few electrochemical technologies such as electrochemical oxidation, electrochemical reduction, indirect electro-oxidation with strong oxidants, emerging photo-assisted electrochemical treatments and electrocoagulation have received considerable attention for treating dye wastewaters during last decade [7]. Electrocoagulation (EC) process has been successfully used for the treatment of textile wastewater being attractive for its versatility, safety, selectivity, amenability to automation, ease of control and environmental compatibility [8]. These processes are popular because of the ease of distribution and moderate requirement of chemicals [9,10]. It involves the generation of coagulant in situ by the dissolution of metal ions from the consumable anode with subsequent formation of hydroxide ions at the cathode [11,12]. In EC, contaminants are encroached up towards the surface of the EC cell by small bubbles of hydrogen gas produced from the cathode. Therefore, as an alternative of chemicals and microorganisms, electrons are the only working agents in electrochemical cell being responsible for facilitating wastewater treatment [13]. The most widely used electrode materials in electrocoagulation process are aluminum and iron. Many researchers reported appreciable treatment efficiency of electrocoagulation employing aluminum, iron and copper electrodes for

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different types of wastewater/textile wastewater [12,14–16]. However, the researches related to the use of composite electrode made of aluminum and iron both, for the treatment of textile wastewater are very terse [12].

To the best of our knowledge, no study has been reported to evaluate the effectiveness of composite electrode (Fe-Al) for the treatment of textile wastewater containing different category of textile dyes along with different chemical additives that are normally being used during different steps of textile processing. An electrocoagulation using the composite electrode (Fe-Al) was employed with the purpose of a simultaneous release of both iron and aluminum ions during electrolysis reaction and to assess its effect on the treatment efficiency. Therefore, the present study was focused on investigating, for the first time, the effectiveness of electrocoagulation process employing iron-aluminum composite electrode for the decolourisation and COD reduction of synthetic textile wastewater containing different classes of new generation dyes along with the various other chemicals. The study was focused on evaluating the effects of pH, inter-electrode distance, current intensity, reaction time, and applied voltage on decolourisation and COD reduction of synthetic textile wastewater.

## 2. Materials and methods

### 2.1. Synthetic textile wastewater

Synthetic textile wastewater was prepared as per the reported chemical constituents of real textile wastewater [4], with a total dye concentration of 200 mg/L along with various chemical additives such as starch, acetic acid, sucrose, sodium carbonate, sodium hydroxide, sulphuric acid, detergent, and sodium chloride, which are used during textile processing for various purposes. Three different categories of commercial dyes, namely, Reactive Black 5 (RB5), Congo Red (CR) and Disperse Blue 3 (DB3) were procured from Sigma-Aldrich, Germany and used in an equal ratio for the preparation of textile wastewater. The characteristic wavelength of simulated dye wastewater was determined by running a scan of the dye solution on a UV–vis spectrophotometer (Perkin-Elmeyer, Lambda 25), and the maximum absorbance wavelengths ($\lambda_{max}$) for RB5, CR and DB3 were found as 591, 502 and 638 nm, respectively. The colour content of the wastewater containing mixture of dyes was determined by taking the sum of the absorbencies measured at 591, 502 and 638 nm. The synthetic textile wastewater was possessing COD = 1970 ± 30 mg/L, pH = 9.5 ± 0.1, Abs (mixture) = Abs(591) + Abs(502) + Abs(638) = 2.4; electrical conductivity = 28 ± 2 mS/cm. The percentage decolourisation efficiency was determined using the following Eq. (1):

$$\text{Decolourisation efficiency (\%)} = [(A_b - A_t)/A_b] \times 100 \qquad (1)$$

where $A_b$ and $A_t$ are the absorbencies of the solution before treatment and after treatment of the textile wastewater, respectively. Tap water was used as a reference.

### 2.2. Experimental setup

The experimental setup is shown in Fig. 1. A container (electrochemical cell) made of brass was used as the cathode having a diameter of 75 mm, depth of 80 mm, and 1.5 mm thickness with an effective volume of 350 mL. A 300 mL of solution was placed for electrocoagulation at a time. Brass made electrochemical cell was used as the cathode to increase the surface area and facilitate the electrochemical process. Moreover, in this condition, electrocoagulation was highly enhanced since the bubbles mainly originated from the cathode were distributed thoroughly and extensively from the bottom and walls of the electrochemical cell [12]. The electrochemical cell was subjected to the magnetic stirrer at constant stirring speed (120 rpm) to provide proper mixing of the solution throughout. The prepared composite electrodes (Fe-Al) with dimensions of 60 mm × 30 mm × 2 mm were applied as the anodes simultaneously which were placed at the center of the cell with a certain distance from each other. A 50 mm of the anodes were submerged in wastewater providing an effective submerged surface area of 0.0033 $m^2$. The electrodes were connected to a digital dc power supply (Topward 6306D; 30 V).

### 2.3. Analytical procedures and chemicals

Colour measurement of the reactor effluents treating textile wastewater was carried out after filtration of supernatant through Whatman 42 filter paper. Subsequently, the absorbance of the sample was measured using a UV–vis spectrophotometer (Perkin-Elmeyer, Lambda 25). COD was analysed as per the closed reflux colourimetric method after digestion of the samples in a COD reactor (Model DRB 200, HACH, USA), and then absorbance measurement was carried out by COD spectrophotometer (Model DR 2800, HACH, USA) at 600 nm 1.0 M $H_2SO_4$ and 1.0 M NaOH were used to adjust the desired pH. High Performance Liquid Chromatography (HPLC) was used for the analysis of aromatic amines from anaerobically pre-treated and electrochemically treated textile wastewater. Aromatic amines were also quantified colourimetrically as per the method suggested by Oren et al. [17]. For the HPLC analysis of aromatic amines, an aliquot of respective wastewater were centrifuged at 4000 rpm for 15 min. The supernatants were transferred into a petri-dish which subsequently kept into the freeze dryer (Christ, ALPHA 1–2 LD plus) for the evaporation to its dryness. The residues were dissolved in methanol. Samples were filtered through a 0.22 μm nylon filter paper and eluted isocratically using a C18 column. The mobile phase used was a mixture of filtered methanol (HPLC grade) and Millipore water in 7:3 (v/v) ratio with a flow of 0.7 mL/min.

## 3. Results and discussion

### 3.1. Effect of initial pH

In wastewater treatment using electrocoagulation, pH plays a very important role in determining treatment efficiency. Therefore, experiments were designed to determine the optimum pH of synthetic textile wastewater that allowed for maximum decolourisation and COD reduction. The effect of pH on the treatment efficiency was examined by altering the initial pH from 2 to 11 and keeping all other parameters (Fe-Al, current density = 15 A/$m^2$ and reaction time = 60 min) constant. Decolourisation and COD reduction efficiency increased with increasing pH up to pH 8 and then decreased afterward. Results showed that at pH 8, up to 79% COD, and 86% colour removal efficiencies were achieved (Fig. 2). A small increase in the overall pH was noted in the acidic solutions (pH 2–6). In the electrochemical process, an increase in the overall pH may be linked to the increase of the bulk concentrations of hydroxide ion formed in the solution due to the reduction of water at the cathode.

During electrocoagulation, composite electrode (Fe-Al) produces iron and aluminium hydroxides which start coagulating the impurities present in the solution. It can also be observed from Fig. 2 that decolourisation and COD reduction followed the same trend and the efficiency of electrocoagulation was low either at low pH or at high pH. This behavior may be attributed to the amphoteric nature of aluminum hydroxide which does not precipitate at very low pH and starts dissolving at increasing pHs [18]. At low pH, cationic monomeric species $Al^{3+}$ and $Al(OH)_2{}^{+}$ prevail. When pH is between 4 and 9, various monomeric species such as $Al(OH)_2{}^{+}$, $Al(OH)_2{}^{2+}$, and polymeric species such as $Al_6(OH)_{15}{}^{3+}$, $Al_7(OH)_{17}{}^{4+}$, $Al_{13}(OH)_{34}{}^{5+}$ transform into insoluble amorphous $Al(OH)_3(s)$ flocs through complex polymerization and/or precipitation mechanism. When pH is higher than 8, the monomeric $Al(OH)_4{}^{-}$ concentration increases, decreasing the significance of insoluble amorphous $Al(OH)_3(s)$ flocs [19]. In contrast, the