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Novel anode made of iron scrap for a reduced-cost electrocoagulator

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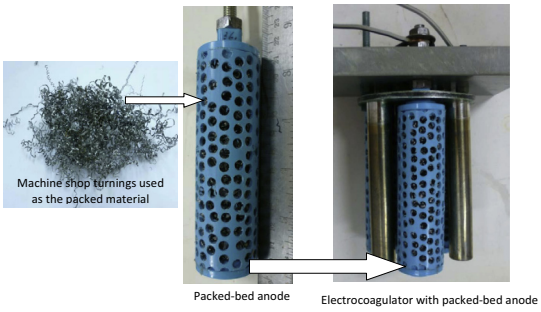
HIGHLIGHTS

- A novel anode was a PVC tube packed with machine shop turnings.
- Apparent density of the packed-bed was 493 kg/m^3.
- Reactive Blue 21 in the phthalocyanine class was used as the model compound.
- Optimal current and the electrocoagulation time was 0.9 A and 10 min.
- Energy was 0.39–0.50 kWh$_e$/m^3 for the color and COD removals of 98% and 93%.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper deals with the development of a reduced-cost electrode as a substitute for a plate or tubular electrode. A polyvinyl chloride (PVC) tube with an internal diameter of 28 mm was packed with machine shop turnings. The packed bed had an apparent density of 493 kg/m^3. The PVC tube had distributed 5 mm-holes on its surface to allow the transport of metal ions from the electrode to the bulk solution. Various electrical current and electrocoagulation times were investigated for achieving high color and Chemical Oxygen Demand (COD) removals. The required electrical current and electrocoagulation time for achieving a maximum color removal of 98% and a maximum COD removal of 93% were found to be 0.9 A and 10 min. The performances of the packed-bed anode electrocoagulator were compared with those of a conventional tubular iron anode electrocoagulator. It was found that the removal efficiencies of the packed-bed anode were higher than those of the tubular anode for the first 8 min. The higher removal performances of the packed-bed anode may be due to its higher surface area for the distribution of the electroactive species. However, at the optimal electrocoagulation time of 10 min, the energy consumption for the packed-bed anode (0.50 kWh/m^3) was higher than that of the tubular anode (0.38 kWh/m^3). The higher electrical energy consumption of the packed-bed electroagulator was expected to be due to the increased resistance associated with increased concentration overpotential (volt) for this anode.

1. Introduction

A major challenge for sustainable development is the treatment of wastewater from industrial processes and the reuse of the treated water so that the processes generate minimum wastes. There is an urgent need to develop more effective and inexpensive techniques for wastewater treatment. Among the evolving technologies, electrocoagulation is one that has received attention from

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the scientific community in the last decade [1,2]. The electrocoagulation process is widely accepted to produce less sludge than the conventional coagulation process [3]. From the point of view of sustainable development, electrocoagulation is environmentally friendly because the process does not produce secondary pollutants such as sulfate or chloride ions in the water [4]. In addition, the energy source for the process can be obtained from a solar photovoltaic panel that converts solar energy into direct current electricity [5,6]. Furthermore, it is also possible to reduce the energy consumption of the electrocoagulation system by harvesting the hydrogen produced during the treatment [7].

The textile industry produces considerable amounts of dye-containing wastewater during its dyeing and finishing operations. Dye-containing effluent is toxic to the environment since dyes are stable compounds that have low biodegradability and can be carcinogenic [8]. Many studies have reported that electrocoagulation has high efficiency in decolorization with the color removal ranging between 98% and 100% in most cases. A number of specific dyestuffs have been investigated, e.g. Orange II [9], Acid Orange 7 [10], Acid Yellow 23 [11,12], Reactive Yellow 84 [13], Acid Red 14 [14], Reactive Black 5 [15], Direct Red 23 [16], Acid Red 2 [17], Acid Green 50 [18], Crystal Violet [19], Acid Blue 29, Reactive Red 2, Acid Red 97, Reactive Blue 4 [20], Reactive Blue 140 [21], Reactive Blue 29 [22], Reactive Orange 84 [23] and real wastewater containing dyes [24–27]. In both batch and continuous flow reactors, the decolorization efficiency has been found to depend on the initial pH, the dye concentration, and the applied current density. Further, in batch mode, the efficiency has been found to depend on the electrolysis time, and in continuous flow reactors, on the flow rate [2].

Despite some promising laboratory results and several published articles in the field, the commercial success of this technology is rather limited at this stage for several reasons. First, the interdependence between the electrochemical operating parameters and the pollutant makes the effectiveness of the electrocoagulation process difficult to validate [28]. Second, passivation of electrode surfaces, which is the accumulation of an inhibiting layer on the electrode surfaces, can also impede the electrocoagulation process in a continuous mode of operation [28–30] because electrode passivation leads to a higher resistance for anodic dissolution and thus to a higher cell potential [29]. Another main obstacle to the commercial success of the electrocoagulation technology has been suggested to be high material costs [31], since in this technique aluminum and/or iron are employed as sacrificial anodes. Metal plates with various geometries have been employed as the sacrificial anodes [32]. The production of metal plates is known to be a high energy-consuming process. Therefore, one area of research that is critically needed is the development of low-cost electrodes. Only a few studies have focused on the design of low-cost electrodes [31,33]. In the study by Wei et al. [31], low-cost steel wool was employed as cathode. The steel wool cathode not only reduced the cost of electrodes, but also provided a larger electrode surface area than iron plates. In the study by Un and Aytac [33], wrapped iron wire netting was used as an anode in a packed bed electrochemical reactor. This unique anode was found to effectively remove color and to reduce COD in real textile wastewater.

In this paper, a new design of anode made of low-cost iron scrap is proposed. The color removal and COD reduction efficiencies of this iron scrap anode have been investigated and compared with the efficiencies of a typical iron anode using a bench-scale batch reactor for treatment of a synthetic wastewater containing Reactive Blue 21 dye. The efficiencies were compared under a range of conditions of current density and electrocoagulation time.

2. Materials and methods

2.1. Synthetic wastewater

A blue reactive dye (Reactive Blue 21) supplied by a textile industry in Thailand was used to prepare synthetic wastewater by dissolving 500 mg/L of dye into tap water, and then adjusting the pH with NaOH to 8.3 ± 0.1 and the conductivity with NaCl to 2 mS/cm. Reactive Blue 21 belongs to the phthalocyanine class, and its chemical structure is given in the Supplementary material. An initial concentration of 500 mg/L was selected because it provided a COD value of the same order of magnitude as that of actual wastewater from a textile factory [34]. The values of pH and conductivity were selected to represent the most extreme pH and conductivity conditions for electrocoagulation of the real textile wastewater, namely high pH and low conductivity.

2.2. Reactor configurations

The proposed new batch packed-bed electrocoagulator consists of three scrap iron anodes and four cathodes. Each anode is a PVC tube packed with machine-shop turnings (Fig. 1). The PVC tube has an internal diameter of 28 mm, a length of 105 mm and a thickness of 3 mm. The packed-bed anode has an apparent density of 493 kg/m^3. Each PVC tube has 5 mm-holes distributed on its surface. The holes allow the transport of metal ions from the anode to the bulk solution. Each cathode is a stainless steel tube with an internal diameter of 16.7 mm, a length of 120 mm and a thickness of 1.2 mm. The arrangement of the packed-bed anode and the cathode on a top flange is shown in Fig. 2. Details of the electrode configurations and the arrangement are provided in the Supplementary material. The electrode set is contained in a 1.0-L

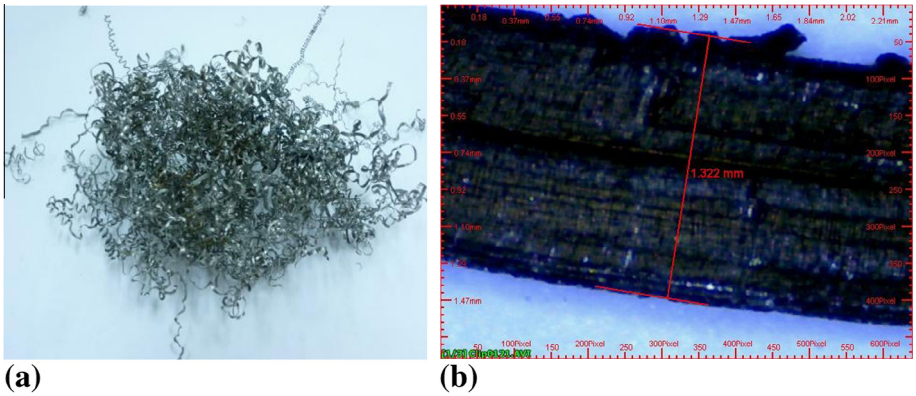

Fig. 1. Machine shop turnings used as the packed material in this study (a) a bundle (b) a magnified piece.