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Decolorization and COD reduction of paper industrial effluent using electro-coagulation

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ABSTRACT

Electro-coagulation is an effective technique for treatment of pulp and paper industrial effluent. The influence of electrolysis time, applied charge density, electrolyte pH and supporting electrolyte on electro-coagulation efficiency for the treatment of pulp and paper industrial effluent has been attempted in the present investigation. It has been observed from the present experimental results that the effluent can be effectively treated using electro-coagulation. The maximum color removal efficiencies were recorded as 92% and 84% for mild steel and aluminum electrode respectively. The maximum COD reduction has been recorded as 95% and 89%. Experiments were also carried out coupling electro-coagulation with sequential batch reactor (SBR) to improve the efficiency of biochemical treatment by increasing the biodegradability index through electro-coagulation. The electro-coagulation was modeled using various adsorption isotherms and observed that the Langmuir and Radke–Prausnitz isotherm models predictions match satisfactorily with the experimental observations.

1. Introduction

Pulp and paper industry is one of the major water-intensive chemical process industries. They are significant contributors of pollutant to the environment in the form of black liquor. The effluent from pulp and paper industry contains high organic matter, suspended solids, strong color, Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The strong blackish color is mainly attributed to the complex compounds derived from polymerization between lignin-degraded products and tannin during various pulping/bleaching operations. Conventionally, the pulp and paper effluent is treated by physical adsorption, chemical oxidation and biochemical methods. The low biodegradability index (less than 0.4) of pulp and paper effluent clearly shows that this kind of effluent cannot be treated effectively through biochemical method. On the other hand, the chemical methods generate considerable amount of sludge which itself needs further treatment. The drawbacks associated with the conventional techniques forced the industries/researchers for effective treatment method for complete degradation of pollutants [1,2].

In recent years, there has been increasing interest in the use of electrochemical techniques such as electro-coagulation, electro-floatation, electro-oxidation, etc., for the treatment of paper industrial effluent. Among these methods, electro-coagulation emerges as one of the promising techniques due to its unique feature such as complete degradation of pollutants, less sludge generation and easy in operation. Electro-coagulation is a complex and interdependent process where the generation of coagulants takes place in situ by dissolving sacrificial anode. Aluminum or mild steel is mostly used as sacrificial electrode. The mechanism of electro-coagulation can be summarized as follows. When a potential is charged through an external power source, the sacrificial electrodes undergo oxidation as given below:For aluminum electrode:

$$Al_s \rightarrow Al^{3+}_{aq} + 3\ e^- \tag{1}$$

For mild steel electrode:

$$Fe_s \rightarrow Fe^{3+}_{aq} + 3\,e^- \tag{2}$$

The gas generated at the cathode helps to float the flocculated particles, i.e.

$$3\ H_2O_l + 3\,e^- \rightarrow \frac{3}{2}H_{2g} + 3\,OH^-_{aq} \tag{3}$$

The ionic species react to form flocks, i.e., $Fe(OH)_2$ and $Al(OH)_3$ as given below,For aluminum anode

$$Al^{3+}_{aq} + 3\ H_2O_l \rightarrow Al(OH)_{3,s} + 3\,H^+_{aq} \tag{4}$$

For mild steel anode

$$Fe^{3+}_{aq} + 2\,OH^- \rightarrow Fe(OH)_{3,s} \tag{5}$$

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The flock $Al(OH)_3$)/($Fe(OH)_3$ incarcerates the organic molecules present in the solution by precipitation and/or adsorption mechanism. Successful electro-coagulation treatment of various industrial effluents has been reported by earlier researchers [3,4]. Ugurlu et al. [5] reported more than 70% COD and lignin removal from pulp and paper effluent through electro-coagulation. Mahesh et al. [6] experimented the treatment of pulp and paper mill effluent by electro-coagulation and reported an overall COD removal of 91% with complete color removal. Ben Mansour et al. [7] studied the treatment of paper industrial effluent by coagulation followed electro-floatation and reported more than 95% removal of suspended solids. Though there has been good amount of literature available on electrochemical treatment of pulp and paper effluent, the work related to improvement of biodegradability and isotherm modeling of electro-coagulation process is very scarce. The objective of the present study is to treat the pulp and paper effluent through electro-coagulation. The mechanism of electro-coagulation and the effect of individual parameters on the efficiency of electro-coagulation process have been critically examined. Further it is attempted to model the electro-coagulation process using adsorption isotherms. The effect of electro-coagulation on the biodegradability index of the effluent has also been critically examined.

2. Materials and methods

Three types of experiments were carried out in the present investigation: electro-coagulation, sequential batch reactor, integrated process combining electro-coagulation followed by sequential batch reactor. For electro-coagulation, experiments were carried out in a batch electrochemical reactor of 250 ml capacity having aluminum/mild steel was used as anodes and stainless steel as cathode. The active surface area of the electrode was 16 cm^2. The anode–cathode distance was kept constant at 1.5 cm. The electrodes were cleaned with 15% hydrochloric acid followed by distilled water prior to each experiment. The anode was weighed before and after the each experiment to estimate the electrode consumption. All the experiments were carried out under potentiostatic conditions. The samples were collected at regular intervals of time and analyzed for pollutant degradation. The effluent used in this study was collected from nearby pulp and paper industry and its characteristics are shown in Table 1.

For sequential batch reactor experiments, a laboratory scale SBR having capacity of 1000 ml was used in the present investigation. Proper aeration was provided by air pump with sintered sand diffusers at the bottom of reactor. The required activated sludge was collected from the local municipal sewage treatment plant. The sludge was aerated for 1–2 days at room temperature before inoculating the reactors and subjected for culturing with the effluent. For integrated process, the effluent was treated by electro-coagulation and then subjected for SBR treatment. The pollutant degradations were estimated by dichromate method for COD/BOD estimation using standard procedure [8].

Table 1
Characteristics of pulp and paper effluent.

Characteristics	Value
pH	7.8
Color	Black
COD ($mg\,l^{-1}$)	32,000
BOD ($mg\,l^{-1}$)	8225
BOD/COD	0.26
Suspended solids ($mg\,l^{-1}$)	2200
Dissolved solids ($mg\,l^{-1}$)	5800
Total solids ($mg\,l^{-1}$)	8000

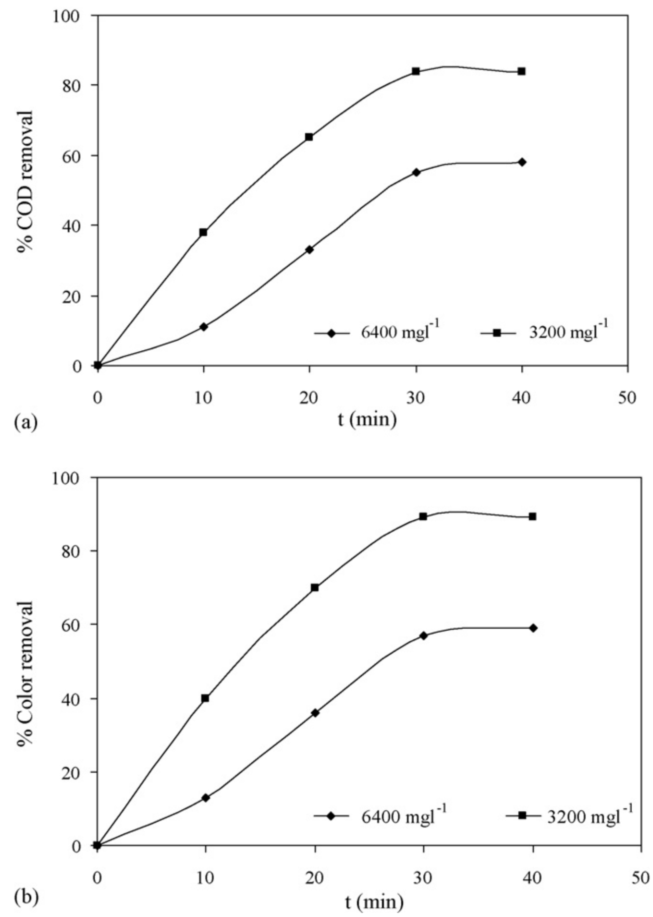

Fig. 1. Variation of (a) percentage COD removal, (b) percentage color removal with electrolysis time; anode: mild steel, pH: 7, current density: 10 mA cm^{-2}; NaCl: 400 $mg\,l^{-1}$.

3. Results and discussion

Experiments were carried out covering wide range in operating conditions and the observations are presented in the form of tables and figures. Fig. 1a shows the variation of percentage COD removal with process time. It can be noticed from the figure that the percentage COD removal increases with electrolysis time. This is obvious that the $Fe(OH)_3$ flocks are generated in situ once the charge is applied and the generated flocks adsorb the organic molecules present in the effluent resulting reduction in percentage COD with electrolysis time. Notice that more than 50% of COD has been reduced within 15 min of electrolysis. It can be further ascertained that the percentage COD removal decreased with increase in the initial effluent concentration. The percentage COD removal decreased from 91% to 53% when the initial effluent concentration was increased from 3200 $mg\,l^{-1}$ to 6400 $mg\,l^{-1}$. This can be explained that the ratio of hydroxo cationic complexes to the initial effluent concentration decreased with influent concentration. The COD removal is more in the case of mild steel anode than the aluminum anode for the same operating conditions. Similar observations have been recorded for the percentage color removal (Fig. 1b).

3.1. Effect of initial pH

In electro-coagulation, the electrolyte pH plays an important role on the performance of the process [9]. Experiments were carried out at various pH in order to verify the effect of electrolyte