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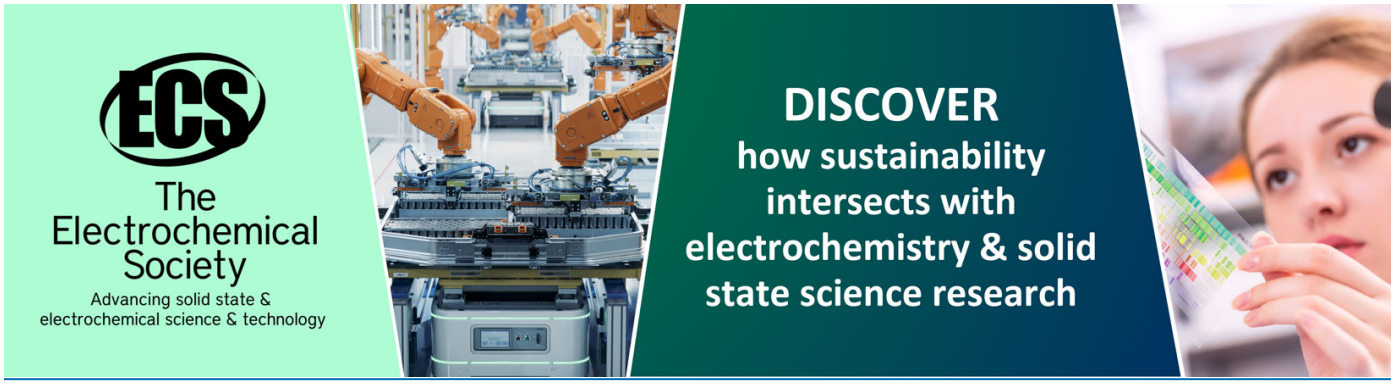

COD removal, decolorization, and energy consumption of electrocoagulation as a wastewater treatment process

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Abstract. The efficiency of color and COD removal in wastewater treatment is one of the essential factors. High color removal can encourage the reuse of wastewater as raw material in the recycled paper industry. Electrocoagulation (EC) process is effective pollutant removal in wastewater due to the adsorption, coagulation, and flotation. In this study, recycled paper industrial wastewater was used; this type of waste has a high content of disturbing pollutants, and treatment with electrocoagulation has not been widely carried out for this type of waste. EC treatment has a relatively high level of effectiveness to remove these pollutants; the influential factors studied include initial pH, applied current, supporting electrolyte, and processing time on a laboratory scale. The degradation of color, COD, and energy used was also evaluated. The best color removal was obtained as 100% at 80 minutes of process, and a COD concentration is 147 mg/L, and the energy used is 13.56 kWh/L.

1. Introduction

Even though it has entered the digital era, paper is still needed for offices, education, printing, industry, and other life activities. The size of an industry affects the amount of environmental pollution. The pulp and paper industry is one of the most prominent industry types globally, simultaneously the industry most associated with high water and energy use. Paper production in Indonesia reached 11 million metric tons in 2018, with total paper consumption reaching 8 million metric tons[1,2]. According to the raw material used, there are two kinds of paper manufacturing: virgin pulp paper and old recycled paper. In this study, we treated recycled paper industry wastewater.

Various studies have been carried out to reduce and eliminate various unwanted compounds in water due to pollution by paper wastewater, such as biological process, adsorption, membrane, ozonation. Biological processes do not adequately treat toxic and stubborn substrates. Chemical coagulation as the first treatment followed by biological treatment is quite effective in terms of pollutant removal, but the accumulation of chemical by-products after treatment is another problem.

Electrocoagulation (EC) is a continuous coagulation process using direct electric current through electrochemical events, namely an electrolyte decomposition process in which one of the electrodes is

aluminum (Al) or iron (Fe) [3–5]. There will be a reduction reaction process in the electrocoagulation process where metals will be reduced and deposited at the negative pole. At the same time, the positive electrode Fe will be oxidized $Fe(OH)_3$ function as coagulants. This coagulant will help floc formation from wastewater pollutants set aside in the form of deposits [5,6].

Previous studies have found the effectiveness of EC in removing color and interfering compounds from paper mill waste. Wagle, D, et al. (2020) using iron as a sacrificial electrode was investigated at low current density (0.6–1.9 mA/cm^2). The experiment significantly affected color removal (>95%) and BOD_5 removal at 95 % [7]. EC process shows a reduction of COD and colors up to 95% and 67%. The result was achieved at pH = 7.15, CD = 20 mA/cm^2, electrode gap 2 cm in 20 min using iron electrode [8]. The EC was conducted using iron electrodes to remove color from wastewater under operational condition pH=3 and electrode distance=3 cm. The EC removed 89 % and 97 % of the initial COD and color from the dye solution, respectively [9]. At optimum conditions (pH=8.57 - 9, CD=91.5 - 96 mA/cm^2) 34.7% of COD and 92.32% of phenol removal was achieved by the EC process in 30 minutes [10].

This study tries to manage wastewater by treating wastewater to overcome environmental problems due to paper industry wastewater. Electrocoagulation technology is considered capable of cleaning paper industry wastewater to meet the required quality.

2. Methodology

2.1. Material

All chemicals and reagents such as sodium chloride (NaCl), potassium sulfate (K_2SO_4), ammonium chloride (NH_4Cl), and sulfuric acid (H_2SO_4) were purchased from Sigma Aldrich. All the solutions were prepared using distilled water. The wastewater sample used in this study is the result of the paper-making process from PT. XYZ then identified the characteristics of the wastewater before and after the treatment process using the electrocoagulation method.

2.2. Methods

The EC reactor was composed of a 1.1L glass reactor, a magnetic stirrer plate, iron (Fe) were used as the anode and cathode. Both electrodes were square 7 cm x 11 cm with a geometric area of 162.7 cm^2 each and an electrode gap of 3 cm. The experimental batch setup is shown in **Figure 1**.

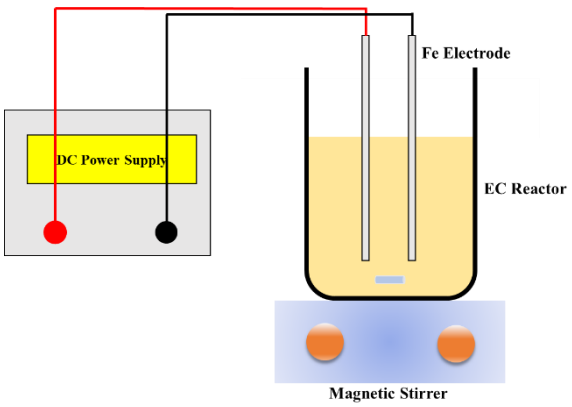

Figure 1. Schematic diagram of EC process.

The reactors were placed on a magnetic stirrer plate with a constant speed at 300 rpm. The DC power supply was then turned on and adjusted according to the desired power applied (0.5 – 1.5 A). 1 g/L electrolyte was prepared and added to the wastewater. After each electrolysis time (10, 20, 40, 60, and

80 min), the reactor was kept undisturbed to allow the flocs to settle for 30 minutes. Samples of the supernatant and sludge were then taken to perform COD and color tests.

COD test based on SNI-06-6989.2-2009 with closed reflux using a double-beam UV–vis spectrophotometer Shimadzu UV-1700, Japan. Color measurement refers to SNI 6989.80:2011 spectrophotometric color test with absorbance at a wavelength of 460 nm using a standard solution of Pt-Co.

Consumption energy calculated by C_{energy} = RT x U x I/V, where RT = reaction time of treatment (h), U = voltage (V), I = electrical current (A), V = volume of wastewater (L).

3. Results and discussion

3.1. Effect of initial pH

One of the main parameters in the electrocoagulation process is the pH of the solution. PH affects the conductivity of the solution, electrode dissolution, hydroxide speciation, and zeta potential of colloidal particles [3,11,12]. In general, the optimum pH for processing by electrocoagulation method is in the range of 5 – 9 depending on the type of electrode used, for the aluminum type electrode can work effectively at slightly alkaline pH. At the same time, iron can work without being limited in pH. The pH value in the electrocoagulation process has increased to become a constantly changing parameter[3,13–15].

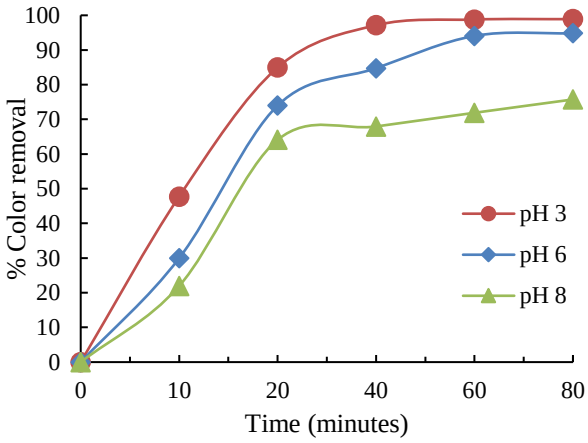

Figure 2. Effect of initial pH to color removal efficiency

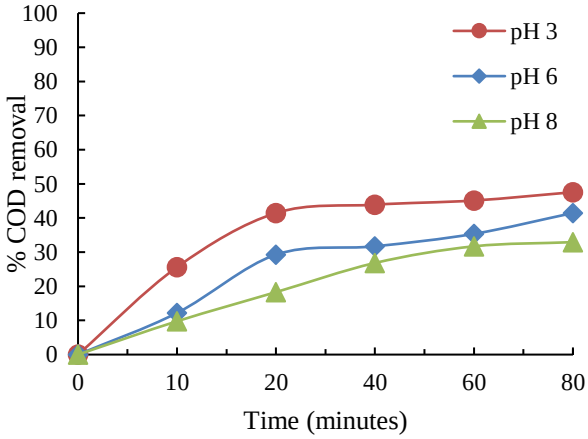

Figure 3. Effect of initial pH to COD removal efficiency

The maximum removal efficiencies of color and COD were 99% and 47%, respectively, as shown **in Figures 2 and 3** at initial pH was 3 and electrolysis time was 80 minutes. The electrocoagulation process involves two stages, destabilization and aggregation. The destabilization process runs in a relatively short time while the aggregation process runs more slowly. This can cause color removal in wastewater that takes place in a short time because the color has been removed in the destabilization process so that the color removal aggregation process is not so significant [6,15,16].

This test's decrease in COD value occurred due to a natural oxidation process at the anode followed by a coagulation and electroflotation process [6]. The coagulation process is supported by the formation of $Fe(OH)_3$, which functions as a coagulant that can bind pollutants contained in the soft drink industrial waste, which is then deposited. Besides that, an electroflotation process occurs due to H_2 and OH^- gases in the oxidation process at the anode. This gas removes pollutants that do not settle with $Fe(OH)_3$, while the OH^- formed helps raise the pH of wastewater [17].

3.2. Effect of applied current

The applied current in the electrocoagulation process is critical because it is the only operational parameter controlled directly. The applied current directly determines the coagulant dose and the number of bubbles produced as a stirrer in the electrocoagulation process and affects mass transfer at the electrode. The amount of metal dissolved or deposited depends on the amount of electricity passing through the electrolytic solution [3,6,18].

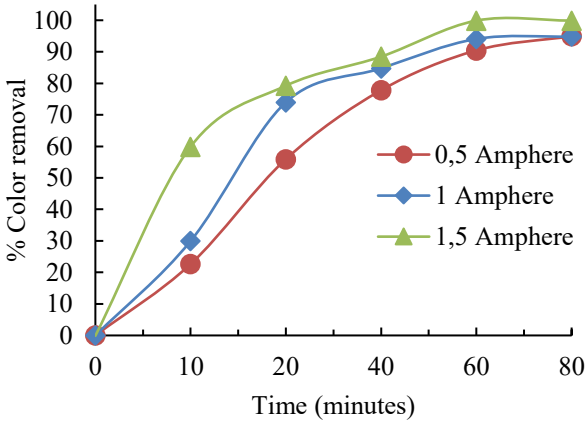

Figure 4. Effect of applied current on color removal efficiency.

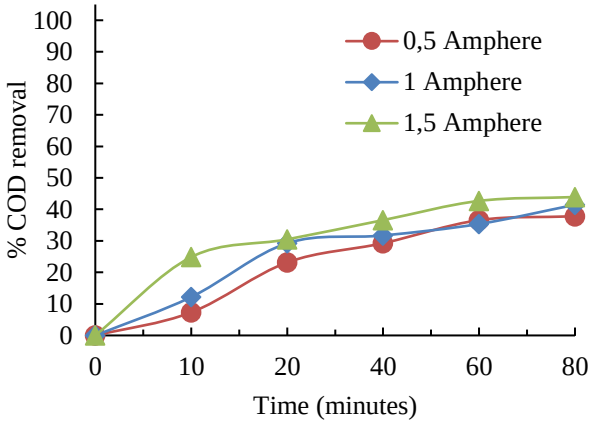

Figure 5. Effect of applied current on COD removal efficiency.

The high and low applied current used affects the processing capability. Depending on the type of waste and the electrodes used, the processing capacity will increase when the applied current increases. Still, the electrode will saturate faster when the applied current is too large, so the treatment process is no longer efficient[18–20].

3.3. Effect of supporting electrolyte

The electrolyte is a current-conducting medium in which the current flows according to the properties of a substance. The supporting electrolyte consists of anions and cations in the water to be treated or added to obtain sufficient conductivity in the medium [21]. The supporting electrolyte can cause several effects, (1) the rate of metal destruction, (2) a decrease in the ohmic value and voltage and energy consumption, and (3) the phenomenon of the electrode surface that occurs between pollutant substances and metal hydroxides [3,6].

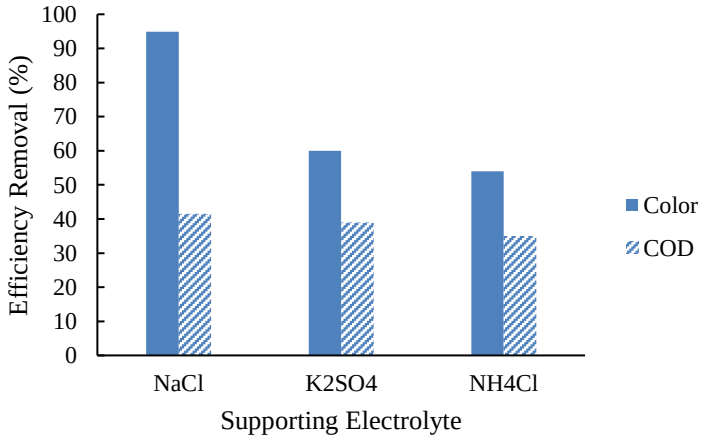

Figure 6. Effect of supporting electrolyte to color and COD removal efficiency.

In this study, the electrocoagulation performances were compared, experiments were performed, the color and COD removal performances were given in **Figure 6**. Almost complete decolorization was achieved with NaCl electrolytes in 80 minutes. Chlorine gas and hypochlorite ion from NaCl increase the removal efficiency because they are oxidizing solid agent form in the bulk solution [22–24].

3.4. Effect of reaction time

Reaction time affects the efficiency of pollutant removal. The high contact time increases the pollutant removal achieved due to more metal coagulants and flocs in the solution. However, the efficiency of EC over a specific time frame can decrease the rate of pollutant removal because the floc formed on the electrodes can hinder the oxidation process and electron transfer [8,16,25]. The optimization of EC time is necessary. The pollutant removal rate is affected by electrolysis time to avoid loss of energy and resources [3,6].

3.5. Energy consumption

The consumption energy in the EC method, could be calculated by C_{energy} = RT x U x I/V, where RT = reaction time of treatment (h), U = voltage (V), I = electrical current (A), V = volume of wastewater (L) [6]. Energy consumption from EC process for removal 47% COD, 99% color with initial pH = 3 at 80 minutes was 13,56 kWh/L. Higher values of C_{energy} were observed at high levels of reaction time and applied current, which affected the value current density[7].

4. Conclusion

The performance of EC using iron as an electrode was investigated. The experimental factors showed that initial pH, reaction time, applied current, and electrolyte significantly affected color and COD removal. Color removal >99% when initial pH was 3 with applied current 1 A, and when pH = 6, applied current must be increased to 1.5 A to reach the same result. The highest COD removal was carried out when the initial pH was 3, with efficient removal of 47% after 80 minutes of electrolysis with an energy consumption of 13.56 kWh/L.

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