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Cover Page Footnote

The researchers would like to extend special thanks to the Muhammadiyah University of Sukabumi for funding this research and to the water quality laboratory of the Centre for Freshwater Aquaculture Marine Ministry of Republic Indonesia and the chemistry laboratory of the Muhammadiyah University of Sukabumi for facilitating this research.

Simultaneous Combination of Electrocoagulation and Chemical Coagulation Methods for Medical Wastewater Treatment

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Abstract

Chemical coagulation, electrocoagulation, and combined electrocoagulation-chemical coagulation methods were used to reduce organic compound concentrations in medical wastewater. Some parameters in the methods were adjusted to optimize the process, including the applied current, distance between electrodes, number of electrodes, acid levels, coagulant type, and contact time. Chemical Oxygen Demand (COD) was used to indicate the total amount of organic compounds in the system. The results showed that the following conditions can be applied to achieve optimum results: 3 A of applied current, 4 pairs of electrodes, with 1 cm of distance between each electrode pair, a pH of 8, 1 g of polyaluminum chloride as the coagulant, and 3 hours of contact time. The optimum removal efficiency levels of total organic compound achieved via chemical coagulation, electrocoagulation, and the simultaneous combination of electrocoagulation-chemical coagulation methods were 41%, 62.51%, and 92.21%, respectively.

Abstrak

Kombinasi Simultan Elektrokoagulasi dan Koagulasi Kimia untuk Pengolahan Air Limbah Medis. Metode koagulasi kimia, elektrokoagulasi dan kombinasi elektrokoagulasi-koagulasi kimia telah digunakan untuk mengurangi konsentrasi senyawa organik pada limbah medis. Beberapa parameter dari setiap metode telah diberikan untuk mengoptimalkan proses, diantaranya adalah, kuat arus, jarak dan jumlah elektroda, tingkat keasaman, tipe koagulan dan waktu kontak. Hasil percobaan menunjukkan bahwa kondisi optimum dapat tercapai dengan kondisi berikut: kuat arus 3 ampere, 4 pasang elektroda, dengan 1 cm jarak antara elektroda, pH 8, 1 g polialuminium klorida sebagai koagulan, dan 3 jam waktu kontak. Efisiensi optimum penghilangan bahan organik berturut-turut untuk proses koagulasi kimia, elektrokoagulasi dan kombinasi elektrokoagulasi-koagulasi kimia berturut-turut adalah 41%, 62.51%, dan 92.21%.

Keywords: medical wastewater, chemical coagulation, electrocoagulation

Introduction

Medical wastewater consists of organic compounds, ammonia, solid suspensions, nitrate, and surfactant, with concentrations around 420–490 mg/L, 59.1–681 mg/L, 11.15–484 mg/L, 680 ppb, and 150.5 mg/L, respectively [1,2]. These contents are sources of water pollution that affect the aquatic environment when discharged without any treatment.

The methods most commonly applied for medical wastewater treatment are adsorption-coagulation, filtration, and anaerobic-aerobic bio-filter methods. Unfortunately, these

methods require a large area, produce a large amount of sludge, and require a time-consuming treatment process [3]. The electrocoagulation process is the preferred alternative treatment method for medical wastewater, mainly due to its low costs of operation and investment, as well as the ease with which it removes colloid pollutant particles. In this method, an electric current is applied to accelerate the movement of the colloid pollutant particles and to produce active coagulant species from anode reactions [4].

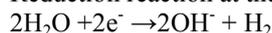
The electrocoagulation method is a continuous coagulation process using direct current through an electrochemical

process, which can generate decomposition, migration, adsorption, and coagulation on the electrode surface. Generally, the electrodes used in electrocoagulation are aluminum and iron [5]. The chemical reactions that occur on the surface of the aluminum electrodes are as follows:

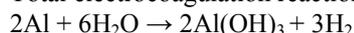
Oxidation reaction at the anode:



Reduction reaction at the cathode:



Total electrocoagulation reaction:



Aluminum hydroxide produced in the electrocoagulation process absorbs pollutant particles.

The aim of this research is to reduce the total amount of organic compounds in medical wastewater using a simultaneous combination of electrocoagulation and chemical coagulation, a method that is expected to facilitate the removal of organic compounds from medical wastewater.

Methods

The following pieces of equipment were used in this study: an electrocoagulation cell with an aluminum electrode (area: 80 cm²) and a DC source (model VOM 3020E). This cell was integrated with a sedimentation compartment, a UV-Vis spectrophotometer, a pH meter, and a turbidimeter. The electrocoagulation set-up is displayed in Figure 1.

The materials used in this research were sodium carbonate, aluminum sulfate, polyaluminum chloride (PAC), reagents for chemical oxygen demand (COD) analysis, and synthetic medical wastewater with the characteristics shown in Table 1.

A volume of 500 mL of synthetic medical wastewater was added to the electrocoagulation cell. The electrocoagulation process was conducted under various conditions,

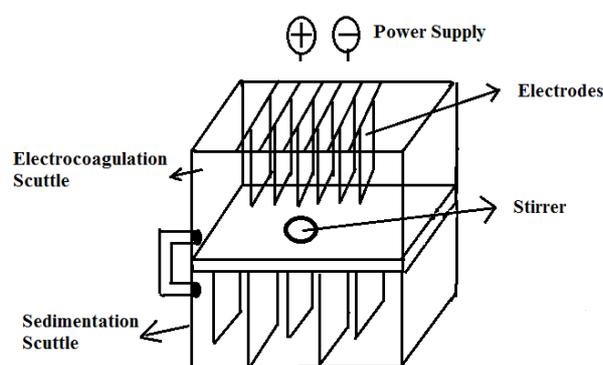


Figure 1. Electrocoagulation Set Up

Table 1. Characteristics of Synthetic Medical Wastewater

Parameter	Concentration
COD	954 ppm
Turbidity	44.3 NTU
TDS	273 ppm
pH	6.88

i.e. 0.1–5A of electric current, 1–4 cm distance between electrodes, 1–4 pairs of electrodes, a pH of 5–11, and an electrocoagulation time of 15–180 minutes with the following coagulants: sodium carbonate, aluminum sulfate, and PAC at dosages of 0.1 g, 0.5 g, and 1 g, respectively. Chemical coagulation, electrocoagulation, and the simultaneous combination of electrocoagulation-chemical coagulation were successfully carried out in this experiment.

The wastewater treated by each of these methods was separated from sludges and flocks in the sedimentation compartment. The total amount of organic compound in the water obtained from the sediment compartment was measured in terms of COD concentration by the spectrophotometric method at 600 nm wavelength. The turbidity of the water was measured by a turbidimeter.

Result and Discussion

Effects of electric current on the electrocoagulation process of medical wastewater. The effects of an electric current on the electrocoagulation process of medical wastewater are displayed in Figure 2. The COD removal efficiency rate at the range current of 0.1–3 A increased by 9.82%–20.72%. According to Faraday's Law, the amount of substance formed on each electrode is proportional to the electric current applied in the electrolysis process [6]. Therefore, an increase in electric current will result in a higher amount of generated Al³⁺. However, in this study, the applied electric current in the range of 4–5 A resulted in decreased COD removal efficiency. When the electric current was increased, the current density was also increased, which destabilized the reduction-oxidation reaction and resulted in an electrical short circuit due to decreased COD removal efficiency [7]. On the other hand, the turbidity removal efficiency rate remained stable at 90% for each electric current condition.

Effects of electrode distance and number of electrodes on the electrocoagulation process of medical wastewater. The distance between electrodes in the electrochemical cell affected the rate of particle diffusion under different concentrations. The distance between the electrodes resulted in slow particle movement [8], thus increasing the electrolyte resistance. Therefore, the electric current moved slowly in the solution, and small amounts of Al³⁺ and OH⁻ were formed. This process led

to the formation of a small amount of pollutant coagulation [9]. Figure 3(a) shows that COD removal efficiency at an electrode distance of 1–4 cm decreased from 28.29% to 20.61%. On the other hand, at an electrode distance of 1–3 cm, the turbidity removal efficiency was found to be 99%, and at an electrode distance of 4 cm, the turbidity efficiency decreased to 92.64%.

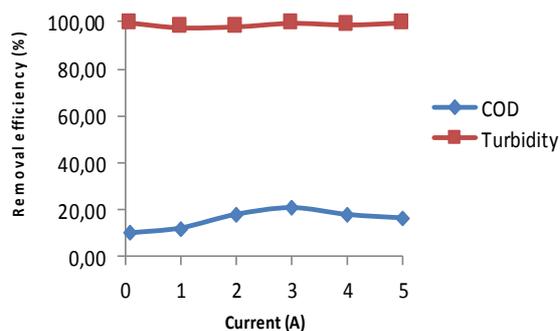


Figure 2. Effect of Electric Current on COD and Turbidity Removal Efficiency in the Electrocoagulation Process of Medical Wastewater (Time = 1 h, Distance between Electrodes = 1 cm, Total Number of Electrodes = 1 pair)

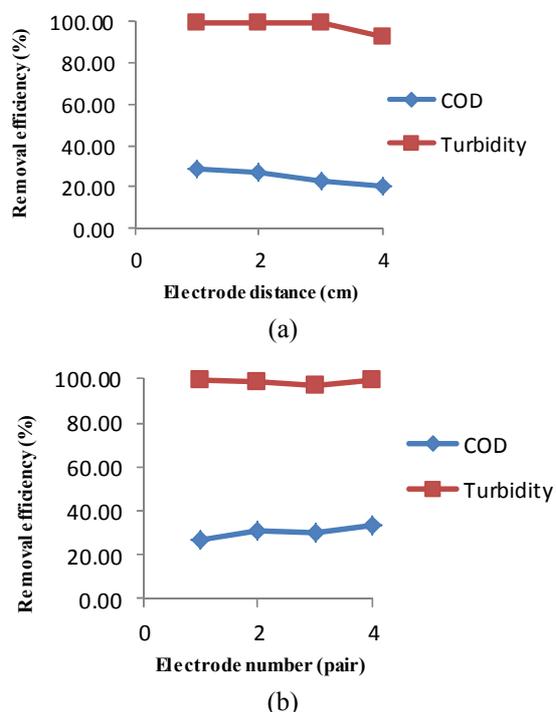


Figure 3. COD and Turbidity Removal Efficiency in the Electrocoagulation Process of Medical Waste Water; (a) Effect of Distance between Electrodes (Electrical Current = 3 A, Time = 1 hour, Total Number of Electrodes = 1 pair), (b) Effect of Number of Electrodes (Electrical Current = 3 A, time = 1 hour, Distance between Electrodes = 1 cm)

Furthermore, Figure 3(b) shows that the COD removal efficiency with 4 pairs of electrodes was 33.36%. The increasing number of electrodes resulted in the formation of more Al^{3+} and OH^- ions, which can lead to the formation of $\text{Al}(\text{OH})_3$ as a coagulant [10]. The results showed constant turbidity removal efficiency at each variation in electrode number. Therefore, in this study, the number of electrodes showed no influence on turbidity removal efficiency.

Effect of pH on the Electrocoagulation Process of Medical Wastewater Increased solution pH caused the formation of active $\text{Al}(\text{OH})_3$ species as a coagulant. Therefore, more active species were produced in the pH range of 6–8. At a pH lower than 6, Al^{3+} , $\text{Al}(\text{OH})_2^+$, and $\text{Al}(\text{OH})_2^+$ were formed, whereas at a pH greater than 6, the formation of $\text{Al}(\text{OH})_4^-$ and $\text{Al}(\text{OH})_5^{2-}$ were observed [11]. Figure 4 shows an optimum COD removal efficiency at a pH of 8. However, no significant effect of pH was observed on the turbidity of medical wastewater; acid and base conditions of wastewater both led to the removal efficiency of turbidity remaining stable at 90–100%.

Effect of Coagulant Type on the Electrocoagulation Process of Medical Wastewater. The COD removal efficiency levels of the electrocoagulation process with the addition of sodium carbonate (Figure 5a), PAC (Figure 5b), and aluminum sulphate (Figure 5c) were 37.90%, 65.84%, and 32.13%, respectively. Faster formation of flock was observed in PAC compared to sodium carbonate and aluminum sulphate, due to the aluminate active group that is effectively bonded to the colloidal particles, which is strengthened by polymers from polyelectrolyte groups to form a dense flock [12]. Furthermore, a fluctuation in removal efficiency levels was observed due to the different chemical characteristics of the coagulants. PAC formed large, rough flocks, causing high turbidity, whereas sodium carbonate and aluminum sulphate produced small, soft flocks, causing relatively low turbidity [13].

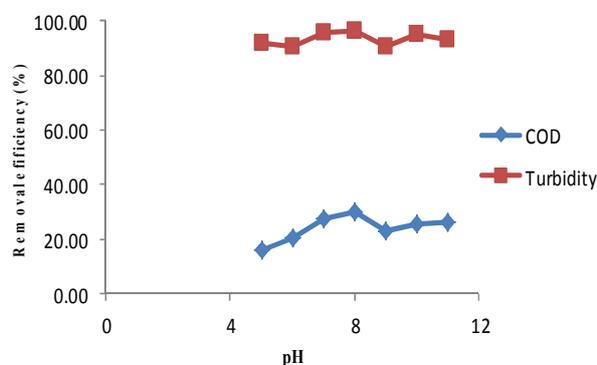


Figure 4. Effect of pH on COD and Turbidity Removal Efficiency in the Electrocoagulation Process of Medical Wastewater (Electrical Current = 3 A, Time = 1 hour, Distance between Electrodes = 1 cm, Total Number of Electrodes = 4 pairs)

Time Effects on the Medical Wastewater Electrocoagulation Process. Figure 6 shows the effect of time on the electrocoagulation process on COD and turbidity removal efficiency. A COD removal efficiency of 92.21% was achieved after 3 hours of the electrocoagulation process. The time of electrocoagulation affected the amount of metal cations or coagulant released in the electrochemical cell. The number of metal cations was proportionally generated against time. The time of

electrocoagulation also increased the interaction of coagulants and pollutants, whereas at 0 to 45 minutes, the coagulation process caused an increase in turbidity.

Furthermore, at 45 to 180 minutes, the sedimentation process took place due to increased turbidity removal efficiency. A stirring process in electrocoagulation resulted in an irregular separation, which lead to fluctuations in turbidity removal efficiency [13].

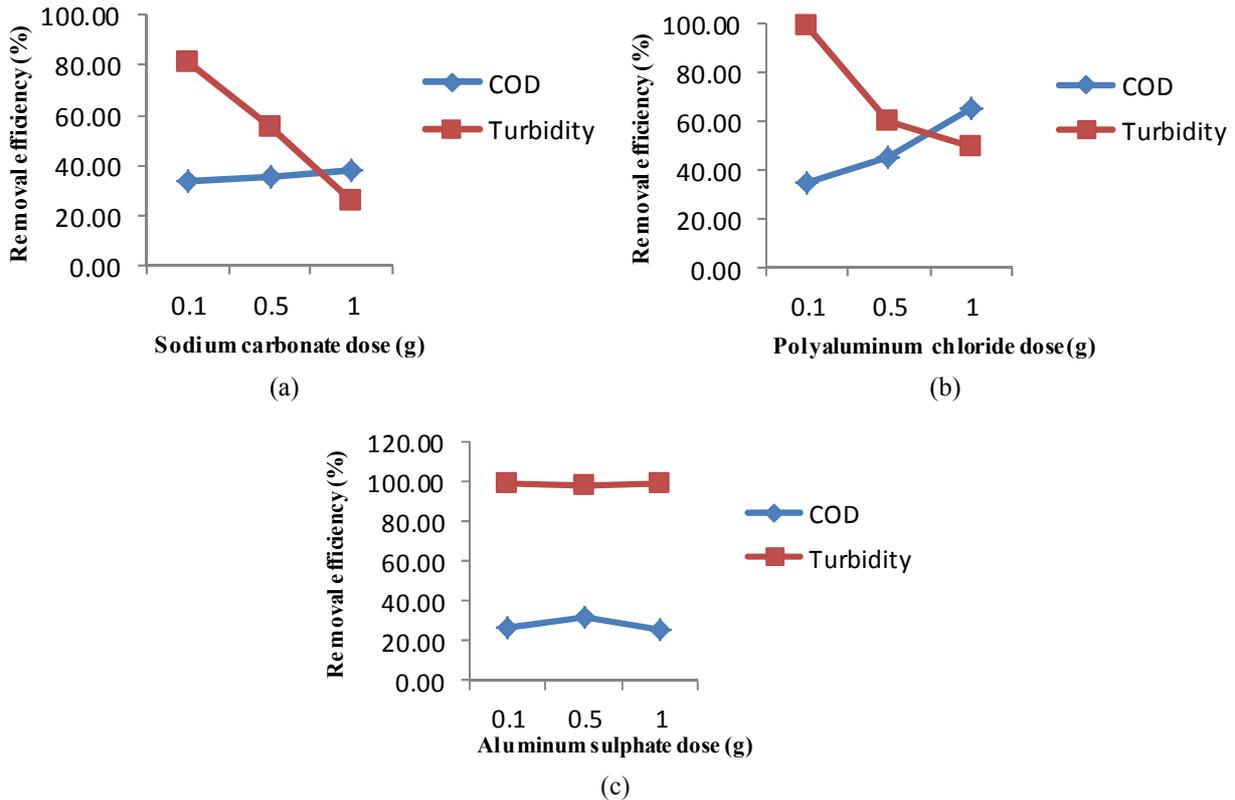


Figure 5. Effect of Coagulant Addition on COD and Turbidity Removal Efficiency of Medical Wastewater; (a) Sodium Carbonate, (b) Polyaluminum Chloride, (c) Aluminum Sulphate (Electrical current = 3 A, time = 1 hour, Distance between Electrodes = 1 cm, Total Number of Electrodes = 4 pairs, pH = 8)

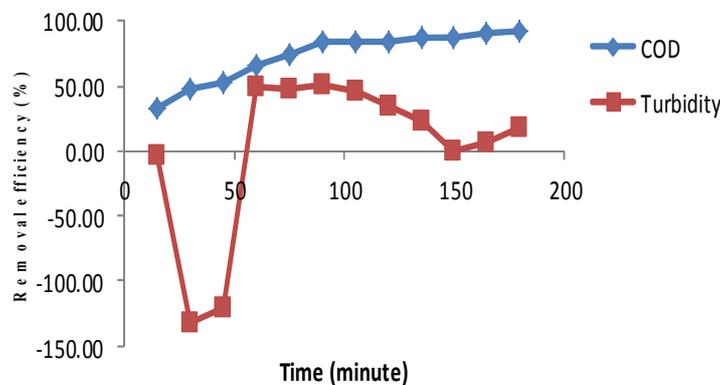


Figure 6. Effect of Time in Electrocoagulation to COD and Turbidity Removal Efficiency of Medical Wastewater (Electrical current = 3 A, Distance between Electrodes = 1 cm, Total Number of Electrodes = 4 pairs, pH = 8, Type of Coagulant = PAC 1 g)

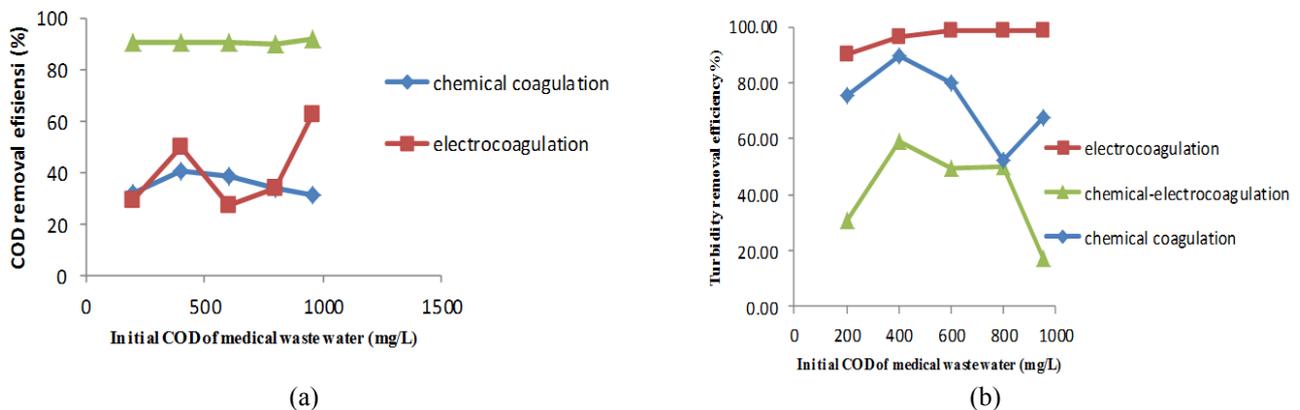


Figure 7. Effects of Chemical Coagulation, Electrocoagulation, and Combined Electrocoagulation-chemical Coagulation on Diverse Initial COD Concentrations in Medical Wastewater; (a) Comparison of COD Removal Efficiency, (b) Comparison of Turbidity Removal Efficiency (Electrical current = 3 A, Distance between Electrodes = 1 cm, Total Number of Electrodes = 4 pairs, pH = 8, Type of Coagulant = PAC 1 g)

Conclusions

The optimum conditions of COD removal efficiency of medical wastewater by electrocoagulation method were 3 A of applied current, 1 cm of distance between electrodes, 4 pairs of electrodes, a pH of 8, 1 g of coagulant, and 3 hours of contact time. The simultaneous combination of electrocoagulation-chemical coagulation processes applied to medical wastewater showed the best results on COD removal efficiency, achieving a removal efficiency rate of 92.21%, which was superior to rates achieved with the chemical coagulation or electrocoagulation process alone. On the other hand, the turbidity was lower compared to both processes. Electrocoagulation process result the turbidity removing efficiency is lower than separate process. It's mean the turbidity of waste water is higher and so that the coagulation or flocculation is better. This phenomenon correspond with a higher of reduction COD efficiency (Figure 7a).

Acknowledgements

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