

Electrocoagulation for Southern Sarawak's Peat Water Treatment: Efficiency and Electrode Performance

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Abstract

The treatment of peat water poses challenges in places like Sarawak, Malaysia, due to its high turbidity, colour and organic contents. The causes of these water quality problems of peat water are the natural degradation of organic substances in peat soils to fulvic and humic materials, which resist treatment by traditional methods. Common treatment technologies are often ineffective for peat water sources and unsustainable, creating a need for new solutions. Hence, this work aims to investigate electrocoagulation as a sustainable and effective process for the treatment of peat water by using aluminium anodes at different current densities (4–20 A/m²). The study focuses on the trade-off between contaminant removal optimisation and electrode degradation reduction in electrocoagulation applications. The efficiency of turbidity, Total Suspended Solids (TSS), colour removal, and Faradaic efficiency, along with anode corrosion behaviour, are studied. The removal efficiencies were high (i.e., 98% for turbidity, 95% for TSS, and 96% for colour), while an excellent Faradaic efficiency of up to 27% was achieved. The corrosion rate increased with current density, rising from 0.00278 mm/y before electrocoagulation to 0.00511 mm/y at 20 A/m². The Tafel plots clearly showed that the electrochemical reactions had been changed after treatment. These results reveal a trade-off between treatment efficiency and electrode life, which is critical for better design of electrocoagulation treatment systems for sustainable water treatment applications. Overall, this study provides insights to promote electrocoagulation as a promising peat water treatment technology with indications for future research, such as electrode modifications, combined treatments and long-term operational stability for greater applicability and scaling-up of electrocoagulation.

1. Introduction

In Sarawak, Malaysia, the rural population along the coastal areas have peat water as their main source of domestic water owing to the lack of treated water [1]. Peat water has large amounts of natural organic matter, which is harmful when consumed without appropriate treatment [2]. Furthermore, Qadafi et al. [3] called for studies on cost-effective, value-added treatments for peat water. Thus, alternative treatment processes for these issues need to be explored. Electrocoagulation is considered a promising technology for water treatment, employing electrochemical processes to remove contaminants effectively and efficiently [4]. There are three distinct chemical processes that occur in an electrocoagulation treatment system, namely (i) the production of coagulants in situ, (ii) the destabilisation of contaminants, and (iii) the creation of flocs by electrocoagulation [5]. Hence, this paper focuses on the electrocoagulation treatment of peat water to overcome its challenges in Malaysia. The experiment examines the performance of the electrocoagulation method across different runs, namely, the removal efficiency and the faradaic efficiency of the process. In addition, the Tafel plot analysis is used to evaluate the corrosion properties of electrodes before and after EC treatment of peat water. As such, this work is a key contribution to the body of knowledge on electrocoagulation as an alternative method for peat water treatment in Sarawak. It is anticipated that the results obtained will enhance and optimise the performance of electrocoagulation for peat water at least in terms of efficiency.

2. Methodology

2.1 Peat Water Characterisation

Water samples were collected and treated in the laboratory for analysis of organic matter content, with special attention to colour, total suspended solids (TSS), and turbidity, as shown in Table 1. The analytical methods for peat water characterisation were based on standard methods as prescribed by previously reported research work by Abdul Rahman et al. [1], and thus, to guarantee coherence and comparability with former studies.

Table 1 Water quality parameters

Parameter	Method	Apparatus Model	Standard
Colour (Pt-CO)	Platinum-Cobalt Standard Method	Multiparameter portable colourimeter (Hach DR 900)	ASTM D5907
Total Suspended Solids, TSS (mg/L)	Absorptometric Method	Multiparameter portable colourimeter (Hach DR 900)	ASTM D5907
Turbidity (NTU)	Absorption Method	Multiparameter portable colourimeter (Hach DR 900)	ASTM D1889

2.2 Experimental Study

Peat water was treated by electrocoagulation in a batch mode in a lab-scale controlled set-up. 100 mL of peat water was added to the reactor for each experimental run, as shown in Fig. 1. The reactor was made of two flat parallel electrode plates (9 cm² effective area). These electrodes served as the anode and cathode and were arranged vertically with a spacing of 0.5cm between electrodes. Experiments were performed at a constant voltage of 5 V, with current densities of 4 A/m², 8 A/m², 12 A/m², 16 A/m², and 20A/m².

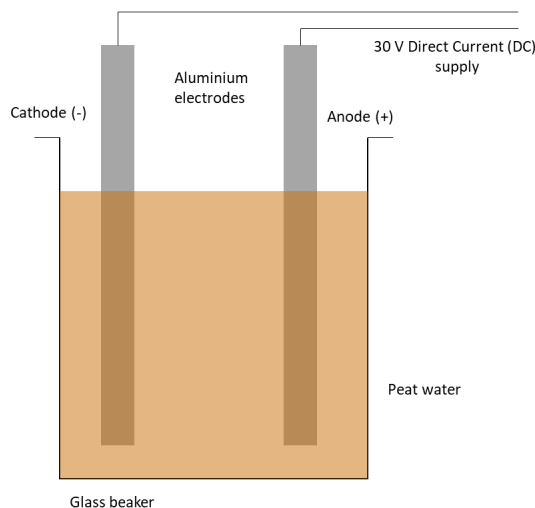


Fig. 1 Experimentation layout for electrocoagulation of peat water

Break point tests were performed for several durations (5, 10, 15, 20, 25 and 30 minutes) as batch operation was employed. The current intensity was recorded in each run and adjusted by the power source as needed to ensure uniformity. At the end of each treatment period, a sample of the treated peat water was taken, and its turbidity, TSS, and colour were determined immediately.

The changes in these peat water parameters are evaluated using the reduction efficiency (RE) of turbidity, TSS, and colour concentrations, calculated as in Eqn. (1) [6].

$$\text{Reduction Efficiency (RE)} = \frac{C_o - C_t}{C_o} \quad (1)$$

where C_t referred to the treated peat water in terms of the concentration of colour, concentration of TSS and concentration of turbidity, and C_o referred to the raw peat water.

Faradaic efficiency (FE) was determined to evaluate the efficiency of coagulant generation at the electrodes [7]. The faradaic efficiency for electrocoagulation treatment of peat water was calculated using the following formula:

$$\text{FE} = \frac{m_{\text{actual}}}{m_{\text{theoretical}}} \times 100\% \quad (2)$$

where FE represents faradaic efficiency, m_{actual} represents the actual mass of the electrode dissolution during treatment, and $m_{\text{theoretical}}$ is the theoretical mass of electrode dissolution determined by using Faraday's law of electrolysis [7]. Faraday's law was applied as follows:

$$m_{\text{theoretical}} = \frac{ItM}{zF} \quad (3)$$

here, I represent the current (A), t is the treatment time (s), M is the molar mass of the electrode material (g/mol), z is the number of electrons transferred, and F is Faraday's constant (96,485 C/mol).

2.3 Electrode Corrosion Study

The aluminium electrode corrosion behaviour was investigated by using a potentiodynamic technique. The experiment was conducted by using the ZIVE SM electrochemical workstation, operated through Smart Manager Software. A three-electrode system was employed, with the aluminium electrode as the working electrode, a platinum wire as the counter electrode, and an Ag/AgCl electrode as the reference electrode. Prior to experiments, the aluminium electrode was cleaned using acetone to remove contaminants and oxide layers, and the reference and counter electrodes were fabricated and connected in a three-electrode setup. The entire three-electrode system was soaked in 100 mL of peat water for electrode corrosion testing, as shown in Fig. 2.

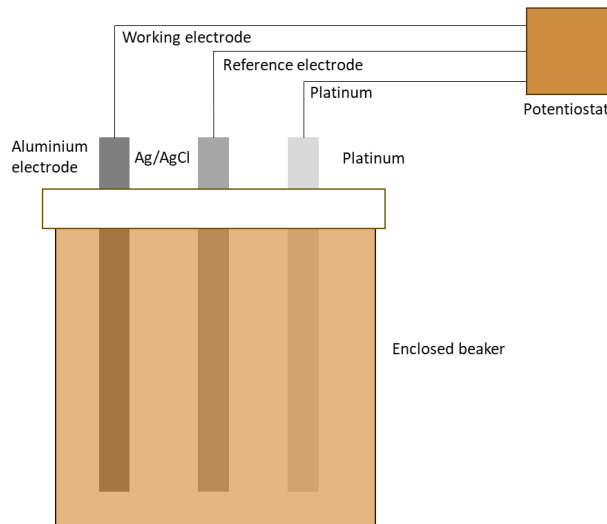


Fig. 2 Experimentation layout for three-phase electrode

The potentiodynamic polarisation scan was collected using the ZIVE SM system with a current window of 100 mA, a total scan time of 1:40 minutes, and a stability tolerance to ensure constant data acquisition. The current density and potential were measured using Smart Manager Software, and a Tafel plot was generated accordingly.

Corrosion current density (i_{corr}) and the corrosion potential (E_{corr}) from the Tafel plots were determined by identifying the linear portions of the curves in the cathodic and anodic segments [8]. These parameters were subsequently applied to Eqn. (4) in order to estimate the corrosion rate.

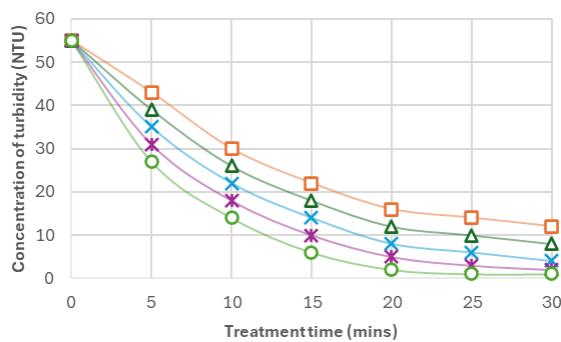
$$\text{Corrosion rate (mm/y)} = \frac{Ki_{corr}M}{n\rho} \quad (4)$$

Where K is a constant (3272 for units in mm/year), M is the molar mass of aluminium, n is the number of electrons transferred, and ρ is the density of aluminium. The experiment was repeated to ensure reproducibility and consistency of the results.

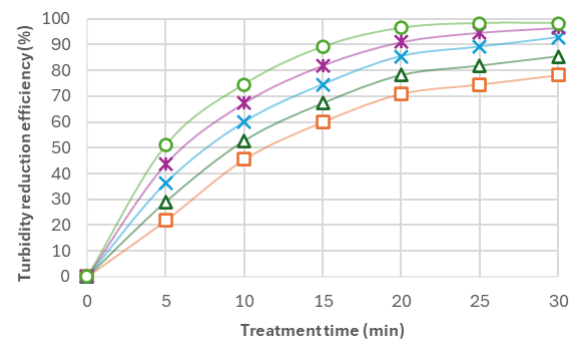
3. Results and Discussion

3.1 Effectiveness of Colour, Total Suspended Solids (TSS) and Turbidity Reduction

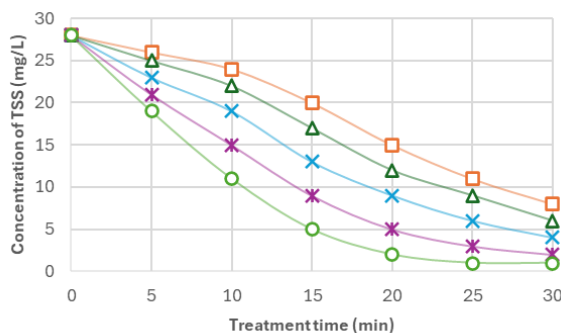
The results of the electrocoagulation experiments for peat water treatment are presented in terms of final treated concentration and reduction efficiency for, colour, total suspended solids (TSS), and turbidity, as shown in Fig. 3. The impact of varying electrocoagulation current densities (4 A/m², 8 A/m², 12 A/m², 16 A/m², and 20 A/m²) and treatment times (5 to 30 minutes) on these parameters was investigated. Current density and treatment time are two common factors affecting the effectiveness of an electrocoagulation treatment system, particularly for treating peat water.



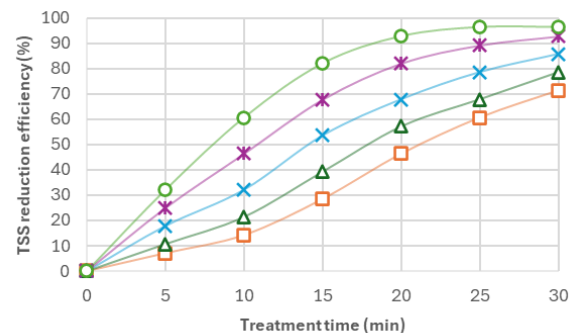
(a)



(b)



(c)



(d)

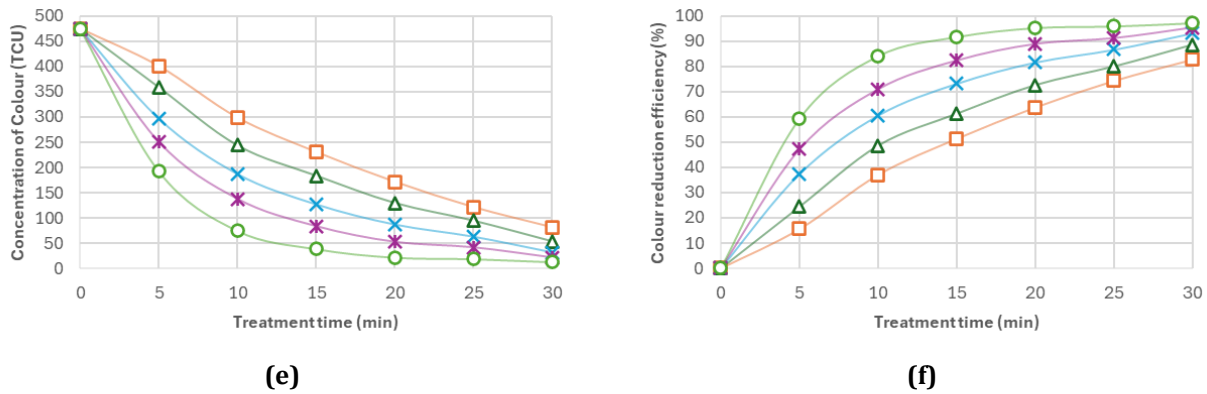


Fig. 3 Concentration and reduction efficiency of turbidity, TSS and colour – (a) Concentration of turbidity; (b) Turbidity reduction; (c) Concentration of TSS; (d) TSS reduction; (e) Concentration of colour; and (f) Colour reduction

The turbidity concentration decreased progressively with increasing treatment time, as shown in Fig. 3(a). For all current densities, turbidity reduction was most pronounced in the first 15 minutes, after which the rate of reduction slowed and stabilised by 25–30 minutes. Higher current densities, particularly at 20 A/m², exhibited the most significant removal efficiencies, achieving up to 98% turbidity removal efficiency by 30 minutes (see Fig. 3(b)). This demonstrates that higher current density increases coagulant production, thereby enhancing the destabilisation of colloidal particles and their subsequent removal [9]. Lower current densities, such as 4 A/m², showed a relatively slower reduction in turbidity concentration. This may be due to reduced coagulant production at lower current density.

The decrease in TSS concentration also followed a similar trend to the reduction in turbidity, as shown in Fig. 3(c) and Fig. 3(d). With increasing current density, the TSS removal rate increased, reaching a maximum of about 20 A/m² and removing more than 95% within 30 minutes. The better performance at higher current density can be attributed to the floc formation of metal hydroxide, which makes it more effective at capturing and settling suspended particles [8]. However, at lower current densities, the rate of floc formation was slow, and the amount of TSS removed was gradual [9]. The study has shown that electrocoagulation was successful in removing TSS while working at optimum current densities.

The colour concentration and its percentage reduction are shown in Fig. 3(e) and Fig. 3(f), respectively. Based on the trend, current density and treatment time affected the reduction of colour, with higher current density and treatment time yielding the best results. At a current density of 20 A/m², colour removal efficiency reached up to 96% within 30 minutes, whereas at a current density of 4 A/m², the colour concentration was reduced by no more than 75%. This can be explained by the higher generation of reactive species and coagulants at higher current densities, which help efficiently reduce the colour-causing organic compounds [10]. Moreover, increasing the electrical energy supplied at high current densities promotes the electrochemical degradation of organic compounds, thereby improving removal [11].

Overall, the efficiency of electrocoagulation treatment increases with increasing treatment time and current density. However, the trade-off between treatment efficacy and energy consumption should be closely examined, as higher current densities and longer treatment times increase operational costs [12]. The value of 20 A/m² revealed optimal performance across all variables, but intermediate current densities, such as 12 or 16 A/m², show a trade-off between efficiency and energy. All parameters were in equilibrium after 25 minutes, suggesting that prolonging the application time did not substantially increase efficiency and could therefore be considered a cut-off treatment time. Notably, several past studies show that long-term treatment does not significantly improve water quality, but it has led to energy waste [13], [14]. This indicates that the electrocoagulation process was highly effective in reducing the concentrations of colour, TSS, and turbidity in peat water.

3.2 Faradaic Efficiency Analysis

The Faradaic efficiency of the electrocoagulation process followed a clear pattern with treatment time and current density, as shown in Fig. 4. Faradaic efficiency is the percentage of electrical energy effectively used in creating coagulant species that remove contaminants [7]. Initially, Faradaic efficiency increased rapidly within 10 minutes at all current densities, reaching maximum values. This increasing trend is consistent with the ongoing production of metal hydroxides and other reactive species, which participate in destabilising and aggregating suspended particles, along with colour compounds, in peat water.

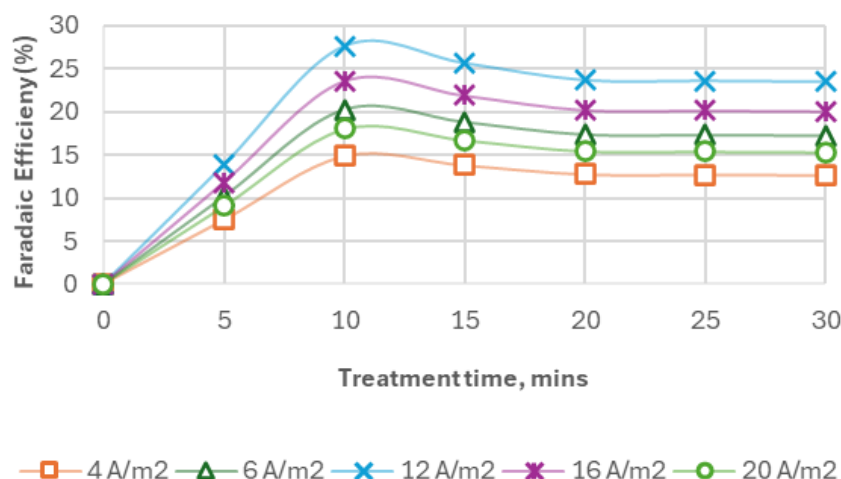


Fig. 4 Faradaic efficiency of peat water electrocoagulation for different current densities

Peak Faradaic efficiency values in the electrochemical experiments fluctuated with current density, with maximum efficiencies of 12 A/m² and 16 A/m² reaching about 27% after 10 minutes. The peak efficiencies are lower at lower current densities, such as 4 A/m², due to reduced generation of active species, and remain almost constant at higher current densities, such as 20 A/m², compared with those at intermediate current densities. Such lower efficiency for higher current densities is due to competing side reactions, such as oxygen evolution, where a smaller portion of the input electrical energy was effectively used for coagulation [15].

With treatment times exceeding 10 minutes, the Faradaic efficiency of electrocoagulation gradually decreased and then levelled off across all current densities. Faradaic efficiency may be affected by various parameters, including current density, ion diffusion to and from the electrode surfaces, and electrolyte concentration [16]. This type of behaviour indicates that the rate at which useful coagulants were produced was offset by the lack of reactive species during contaminant removal and by side reactions [15]. Furthermore, the stabilisation period suggests that the process had achieved equilibrium (stable) conditions, in which removal mechanisms are less affected by the provision of freshly formed coagulants [10]. Chow & Pham [17] also reported that higher current density increases the Faradaic efficiency of the treatment, while a longer treatment period decreases the overall efficiency.

3.3 Electrode Corrosion Behaviour and Rate

The results shown in Fig 5 describe the electrochemical performance of the aluminium electrode, before and after electrocoagulation treatment at different current densities (4 A/m², 8 A/m², 12 A/m², 16 A/m² and 20 A/m²) for peat water. The curves reveal variations in electrode response with increasing current density, which determines polarisation and the tendency for corrosion, thereby directly affecting treatment efficiency and equipment life. Furthermore, these findings help study the relationship among current density, removal efficiency, and lifespan of the following electrodes in an electrocoagulation system.

The Tafel plots show noticeable variation in the electrochemical responses of the aluminium electrodes. Fig. 5(a) shows the electrode response in peat water prior to electrocoagulation treatment, with broad anodic and cathodic curves. On the other hand, Tafel curves after electrocoagulation treatment at different current densities in 4 A/m² (see Fig. 5(b)), 8 A/m² (see Fig. 5(c)), 12 A/m² (see Fig. 5(d)), 16 A/m² (see Fig. 5(e)) and 20 A/m² (see Fig. 5(f)) shows the change of current effect on cathodic kinetics in which elucidate the mechanism. Prior to electrocoagulation, the aluminium electrodes maintained rather consistent profiles, and these changed significantly following electrocoagulation with pronounced alterations, especially at higher current densities, indicating increased anodic activity and enhanced oxidation. After post-treatment, some electrodes exhibit varying degrees of polarisation shift, indicating that the corrosion potential (E_{corr}) and corrosion current density (I_{corr}) have changed. With increasing current density, both the anodic and cathodic branches tended to have steeper slopes, which may be due to the higher current density driving electrochemical reactions through enhanced passivation or changes in the electrode's oxide layer properties [7].

Corrosion rates of aluminium electrodes before and after the electrocoagulation treatment are also quantitatively compared in Fig. 6. Then, the corrosion rate before electrocoagulation is about 0.00230 mm/y for peat water treatment. With the increase in current density, the corrosion rate is accelerated to 0.00278 mm/y (4 A/m²), 0.00351 mm/y (6 A/m²), 0.00381 mm/y (12 A/m²), 0.00469 mm/y (16 A/m²) and 0.00511 mm/y (20 A/m²). Corrosion rates rise gradually with the increasing current density, reaching 0.00511 mm/y at 20 A/m². This phenomenon indicates that at higher current densities, aluminium dissolution becomes more pronounced

due to elevated anodic activity during electrocoagulation [9]. The higher dissolution can be explained by the increased concentration of reactive aluminium ions at the higher currents required for coagulation [11]. Nevertheless, the percentage increase in corrosion rates is low, indicating that at high current densities, aluminium retains some corrosion resistance.

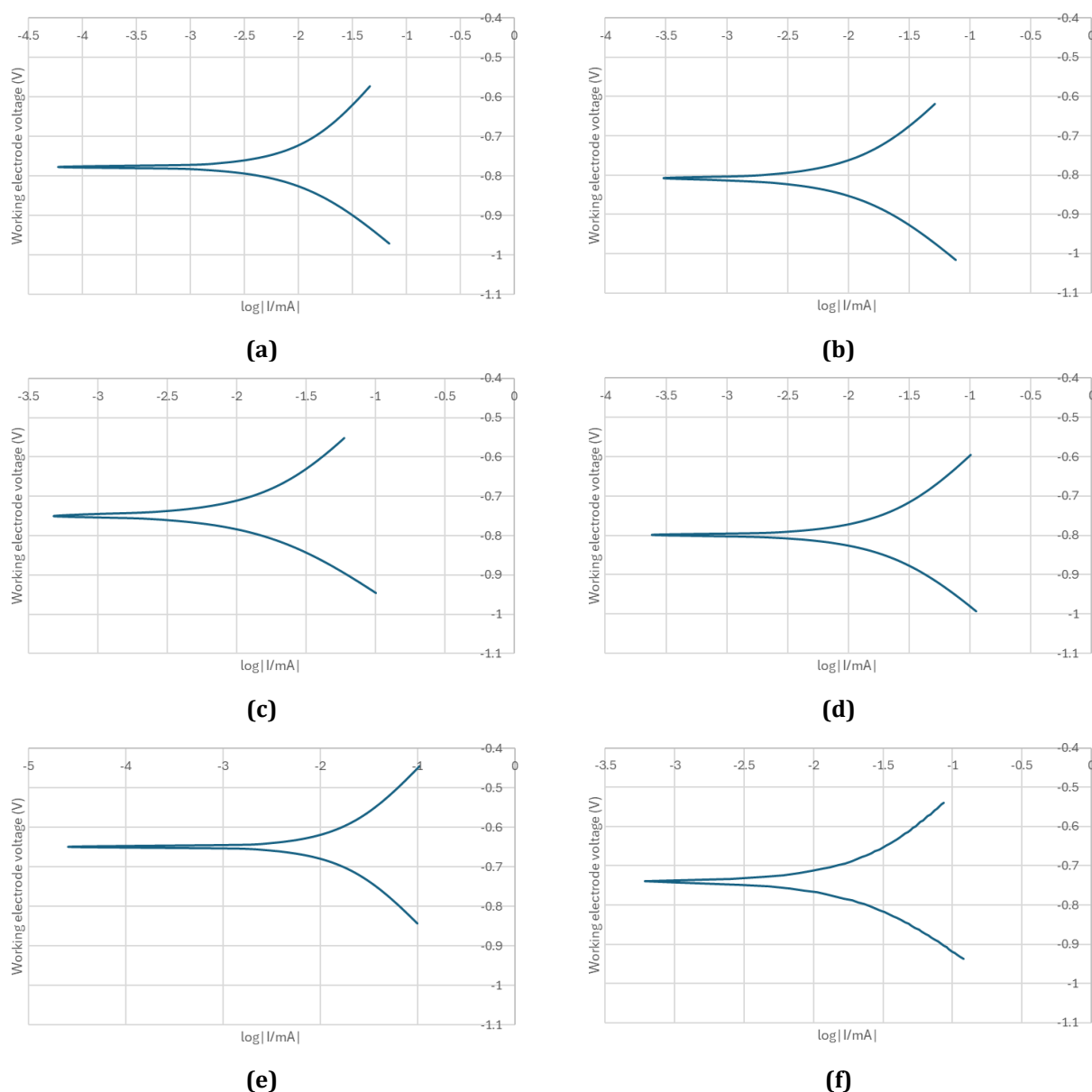


Fig. 5 Tafel plot for aluminium electrode before and after electrocoagulation of peat water – (a) Electrode before electrocoagulation; (b) Electrode after electrocoagulation 4 A/m²; (c) Electrode after electrocoagulation 8 A/m²; (d) Electrode after electrocoagulation 12 A/m²; (e) Electrode after electrocoagulation 16 A/m²; and (f) Electrode after electrocoagulation 20 A/m²

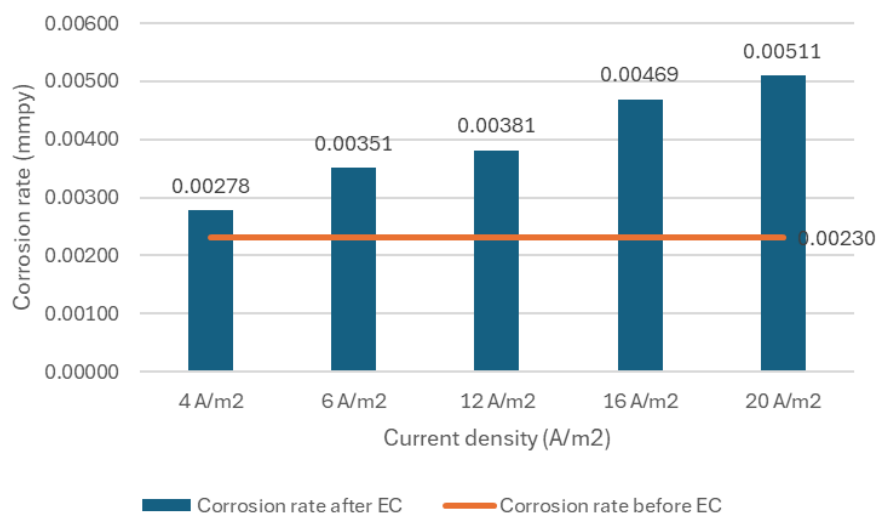


Fig. 6 Corrosion rate before and after electrocoagulation for peat water

4. Conclusion

This study conclusively demonstrates the applicability of electrocoagulation as an alternative treatment technology for peat water, fulfilling all the objectives and requirements of the research. The performance of electrocoagulation was stable and high, with optimal current densities of 12–16 A/m² yielding colour, TSS, and turbidity removal efficiencies of up to 98%, 95%, and 96%, respectively. Faradaic efficiency reached up to 27%, demonstrating efficient production of the coagulant and its applicability for long-term pollutant removal. Apart from removal performance, the research work generated useful information on electrode behaviour, indicating that corrosion rates continually increased with current density, reaching 0.00511 mm/y at 20 A/m², according to Tafel plot evaluation. Crucially, this work contributes to the development of electrocoagulation as a robust and sustainable solution for peat water remediation, providing a practical alternative to current conventional methods, which are ineffective at treating peat-related contaminants. Further studies could be based on these results to inform electrode modifications, hybrid pretreatment designs, and long-term performance stability, thereby improving the operability and scalability of electrocoagulation systems. These initiatives would establish electrocoagulation's role in sustainable water technologies and ensure that technological solutions reach people living in peatland areas.

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Conflict of Interest

This manuscript has not been published elsewhere, and it is not under consideration by other journals. The review has been read, and all authors have approved its submission; the authors have no conflicts of interest regarding this manuscript.

Author Contribution

The authors confirm contribution to the paper as follows: **Study conception and design:** N. Abdul Rahman, A. Albania Linus, C. Jose Jol, K. M. Chieng and A. S. L. Parabi; **Data collection:** Abdul Rahman, A. Albania Linus, C. Jose Jol, K. M. Chieng, A. S. L. Parabi, N. S. Shamsol, S. B. John and E. F. Kushairy; **Analysis and interpretation of results:** Abdul Rahman, A. Albania Linus, C. Jose Jol, K. M. Chieng, A. S. L. Parabi, N. S. Shamsol, S. B. John and E. F. Kushairy;; **Draft manuscript preparation:** N. Abdul Rahman, A. Albania Linus, C. Jose Jol, K. M. Chieng, A. S. L. Parabi, N. S. Shamsol, S. B. John, E. F. Kushairy, A. A. Jitai and D. F. A. Abang Abdul Hamid. All authors reviewed the results and approved the final version of the manuscript.

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