Electro-Purify: An Innovative Electrocoagulation System for Heavy Metal Removal from Krajood (Lepironia articulata L.) Dyeing Wastewater and Disaster-Affected Water

by

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Academic Year 2024 -2025

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Abstract

Heavy metal contamination in natural water sources is a critical environmental disaster that severely impacts ecosystems and human health. This issue is particularly prevalent in areas with industrial and manufacturing activities, such as Krajood (*Lepironia articulata* L.) dyeing, which utilizes chemicals containing lead (Pb) and sulfite (SO_3^{2-}). Without proper treatment, these pollutants accumulate in water sources, degrading ecosystems and posing health risks to local communities. The situation worsens during natural disasters such as floods and industrial spills, which can further spread heavy metal contamination into drinking water sources.

This research focuses on developing "Electro-Purify," a portable heavy metal treatment system utilizing Electrocoagulation (EC)—a technology that accelerates the coagulation and precipitation of metal contaminants using electrical currents. The system is designed to be compact, user-friendly, and operable via battery or solar power, ensuring practical deployment in disaster-affected and off-grid areas. The study evaluated the system's efficiency under different voltage conditions (10V, 15V, and 20V) using aluminum and copper electrodes to induce electrochemical reactions.

The results demonstrated that Electrocoagulation successfully removed up to 95% of Pb and 90% of SO_3^{2-}, while also reducing turbidity and chemical oxygen demand (COD) by over 80%, significantly improving water quality. The Electro-Purify system has strong potential for real-world applications in community-based wastewater management and disaster response efforts. Additionally, integrating automated control systems and real-time electrode maintenance alerts could further enhance its efficiency and long-term usability.

Keywords Electrocoagulation, Heavy Metals, Wastewater from Dyeing Process, Disaster Management, Environment

INTRODUCTION

Heavy metal contamination in natural water sources is a pressing global environmental challenge, particularly in regions with intensive industrial activities and chemical-dependent manufacturing processes. Sectors such as dyeing factories, textile industries, and jute production—a key local industry in Thailand—frequently discharge wastewater containing heavy metals like lead (Pb), chromium (Cr), and sulfites (SO_3^{2-}). Without proper treatment, these contaminants accumulate in aquatic ecosystems, posing severe risks to both the environment and public health.

According to the World Health Organization (WHO, 2021), prolonged exposure to heavy metals, especially lead and chromium, can severely affect the nervous system, kidneys, and increase the risk of cancer. These toxic elements persist in soil and water, eventually entering the food chain, where they pose long-term ecological and health hazards. The impact of heavy metal pollution is further exacerbated by natural disasters, which accelerate contamination through various mechanisms:

Floods: Mobilize heavy metal sediments from soil into rivers and lakes.

Industrial spills: Release large quantities of hazardous chemicals into water bodies.

Droughts: Reduce water availability, leading to increased concentration and toxicity of heavy metals.

Given the urgency of this issue, effective remediation strategies are essential to prevent health risks and environmental degradation in vulnerable areas. This research introduces "Electro-Purify"—a portable Heavy Metal Treatment System utilizing Electrocoagulation (EC). Designed for energy efficiency and adaptability, this system offers a sustainable, accessible solution for treating wastewater from jute dyeing processes and disaster-affected water sources. By mitigating heavy metal contamination, Electro-Purify aims to enhance water quality and support ecosystem resilience in high-risk areas.

Research Questions

1. How can a portable heavy metal treatment system be effectively designed to treat wastewater from the krajood dyeing process and disaster-affected water sources, ensuring practical usability in high-risk areas?

2. To what extent can Electrocoagulation (EC) efficiently remove heavy metals from krajood dyeing wastewater and disaster-contaminated water, and what factors influence its performance?

3. How feasible is the Electro-Purify system for real-world implementation in disaster-affected areas, and what design enhancements are required to improve its efficiency, adaptability, and long-term sustainability?

Research Hypothesis

1. A portable heavy metal treatment system can be effectively designed to treat wastewater from the krajood dyeing process and disaster-affected water sources, ensuring practical usability and adaptability in high-risk areas.

2. Electrocoagulation (EC) is an effective process for removing heavy metals from krajood dyeing wastewater and disaster-contaminated water, with its efficiency influenced by factors such as voltage, electrode material, and treatment duration.

3. The Electro-Purify system can be successfully implemented in disaster-affected areas, and design enhancements, such as energy efficiency, automation, and scalability, can further improve its long-term sustainability and operational effectiveness.

Research Objectives

1. To design and develop a portable heavy metal treatment system for wastewater from the krajood dyeing process and disaster-affected water sources, ensuring practical usability in high-risk areas.

2. To evaluate the efficiency of Electrocoagulation (EC) in removing heavy metals from krajood dyeing wastewater and disaster-contaminated water, considering key performance factors such as voltage, electrode material, and treatment duration.

3. To assess the feasibility of implementing the Electro-Purify system in real-world, high-risk, and disaster-affected environments, and to identify necessary improvements for enhanced efficiency, sustainability, and scalability.

Research Scope

This study was conducted in Phanang Tung Sub-district, Khuan Khanun District, Phatthalung Province, Thailand, focusing on five key locations along the water system impacted by krajood dyeing wastewater and natural hydrological processes. These locations represent different points of pollutant introduction, dispersion, and accumulation within the aquatic ecosystem:

Study area 1: Krajood Dyeing Community (Upstream) – Primary contamination source from dyeing wastewater. Location: 7°77'57.38"N, 100°12'14.16"E

Study area 2: Thale Noi Canal (Upstream) – Initial dispersion of pollutants into the natural water system. Location: 7°77'51.64"N, 100°12'22.05"E

Study area 3: Thale Noi Non-Hunting Area Office (Midstream) – Midpoint of water flow, where pollutants undergo dilution and accumulation. Location: 7°77'72.37"N, 100°12'33.42"E

Study area 4: Open Water, Thale Noi Non-Hunting Area (Midstream) – Open water zone where contaminants further spread. Location: 7°47'03.9"N, 100°08'43.8"E

Study area 5: Pak Khlong Nang Riam (Downstream) – Final outlet where contaminants impact broader ecosystems. Location: 7°77'75.68"N, 100°20'03.71"E

Research Methodology

1. Research Concept and Approach

This study follows an Experimental Research and Innovative Design Research approach, with three key objectives:

1. Assessing water quality before and after treatment.
2. Developing and testing the Electrocoagulation treatment system.
3. Evaluating system efficiency in real-world conditions.

2. Innovation Approach

1. Electrocoagulation (EC) as Core Technology – Uses electric current to remove heavy metals and contaminants.
2. Portable "Electro-Purify" System – Designed for decentralized water treatment in small-scale industries and disaster-affected areas.
3. Prototype Development Using Blender Software – The system is digitally modeled before assembly and testing.

Materials and Equipment

1. Water Quality Measurement Equipment

Used to assess chemical and physical properties of water samples before and after treatment:

1.1 Multifunctional Water Meter – Measures pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), and Salinity.

1.2 Dissolved Oxygen Test Kit (Vunique v-color 9780) – Determines Dissolved Oxygen (DO) levels.

1.3 Ammonium Test Kit (AQUA-VBC) – Measures ammonium ion (NH_4^+) concentration. Heavy Metals Test Kit – Detects Lead (Pb), Copper (Cu), Chromium (Cr), and Iron (Fe) concentrations.

1.4 Nitrite Test Kit NO_2 (AQUA-VBC) – Measures nitrite (NO_2^-), a common indicator of water contamination.

2. Equipment for the Electrocoagulation Treatment System

Materials used to construct and test the Electro-Purify portable heavy metal treatment system:

2.1 Aluminum and Copper Electrodes (11 × 4 cm).

2.2 Motorcycle Battery (MBLL LTZ5S 12V 5Ah) – Power source for the treatment system.

2.3 Flexible Tin-Coated Silicone Wires (4AWG - 24AWG) – Electrical wiring for system connections.

2.4 Copper Lugs (30A) – Used for securing electrode connections.

2.5 Plastic Water Container (20L) with Lid – Primary treatment chamber.

2.6Acrylic Sheets (5 mm Thick) – Used to divide compartments within the treatment system.

2.7 Electrical and Assembly Components – Includes screws, switches, and voltage regulators.

2.8 Solar Panel – Provides an alternative renewable energy source.

Research Method

Part 1: Water Sampling and Quality Analysis

1.1 Water Sampling (Three Collection Phases)

1. Baseline Measurement: Water collected on a non-dyeing day to establish pre-contamination quality.

2. Immediate Impact Assessment: Water collected one day after dyeing to evaluate direct contamination effects.

3. Long-Term Impact Assessment: Water collected three days after dyeing to assess prolonged pollutant retention.

1.2 Water Quality Analysis

Water samples are analyzed before and after treatment using specialized equipment. Data is recorded and compared across different time points.

Parameter	Tools Used	Measurement Frequency
pH	Multifunctional Water Meter	3 times
TDS (mg/L)	Multifunctional Water Meter	3 times
EC (µS/cm)	Multifunctional Water Meter	3 times
Salinity	Multifunctional Water Meter	3 times
DO (mg/L)	Dissolved Oxygen Test Kit	3 times
Heavy Metals (Pb, Cu, Cr, Fe)	Heavy Metals Test Kit	3 times
Nitrite (NO_2^-)	Nitrite Test Kit	3 times
Ammonium (NH_4^+)	Ammonium Test Kit	3 times

Part 2: Design, Development, and Testing of the Electrocoagulation System

2.1 Design of the Electro-Purify Heavy Metal Treatment System

A portable wastewater treatment prototype is digitally modeled using Blender before assembly. The system consists of:

- Main treatment chamber divided into two compartments for enhanced sedimentation.
- Aluminum and copper electrodes for ion release to remove heavy metals.
- 12V 5Ah battery as the primary power source.
- Inlet and outlet design to regulate water flow for efficient sedimentation.

2.2 System Assembly and Experiment Setup

1. Acrylic partitions are measured and cut to structure the treatment chamber.
2. Electrodes are installed and connected using silicone-coated wires and copper lugs.
3. Battery and electrical components are integrated to provide power.
4. The system is connected and prepared for testing.

2.3 Performance Testing of Electrocoagulation System

- Wastewater samples from the study sites are treated using the Electro-Purify system.
- Treatment process runs for 30 minutes at 13-15V.
- Pre- and post-treatment water samples are collected and analyzed for:
    (1) Heavy metal concentration (Pb, SO_3^{2-}).
    (2) pH, DO, TDS, and EC.

Part 3: Data Analysis

3.1 Statistical Methods for Data Analysis

1. Mean ($\bar{x}$) and Standard Deviation (SD) – Analyzes pre- and post-treatment water quality changes.

2. Paired Sample T-Test – Compares pre- and post-treatment heavy metal levels to evaluate treatment efficiency.

3. Correlation Analysis – Assesses relationships between key water quality parameters and heavy metal removal efficiency.

3.2 Discussion of Uncertainties and Errors

- Measurement Uncertainty: Potential device limitations affecting accuracy.
- Environmental Variability: Temperature and external factors influencing water quality.
- Replication Errors: Reduced by conducting multiple repeated tests (3-4 times per parameter).

Research Results

1. Water Quality Analysis Before and After Treatment

1.1 Water Quality Before Treatment

Table 1 presents the water quality parameters before treatment, measured at five locations within the study area.

Parameter	Study Area				
	1. Krajood Dyeing Community (Upstream)	2. Thale Noi Canal (Upstream)	3. Thale Noi Non-Hunting Area Office (Midstream)	4. Open Waters of Thale Noi (Midstream)	5. Pak Khlong Nang Riam (Downstream)
pH	7.518	7.518	7.97	7.65	6.41
TDS (mg/L)	122.2	122.2	56.66	28	73.33
EC (µS/cm)	198	198	118.33	57.66	158.66
DO (mg/L)	2.5	2.5	2.0	1.5	1.5
Turbidity (NTU)	47.3	53.6	88.3	86.7	67.3
Heavy Metals Pb (mg/L)	20	20	0	0	0
Sulfite SO_3^{2-} (mg/L)	80	80	10	10	10

From Table 1, wastewater samples collected from Positions 1 and 2 exhibited high contamination levels of lead (Pb) at 20 mg/L and sulfite (SO_3^{2-}) at 80 mg/L. In contrast, Positions 3, 4, and 5 showed significantly lower contamination levels, indicating that pollutants from upstream dyeing activities had diluted and dispersed further downstream. No additional heavy metal contamination was detected.

2. Effectiveness of Electrocoagulation in Wastewater Treatment

The study evaluated the efficiency of the Electro-Purify system in reducing lead (Pb), sulfite (SO_3^{2-}), COD (Chemical Oxygen Demand), and turbidity through electrocoagulation. Experiments were conducted under three voltage levels (10V, 15V, 20V) and three treatment durations (10, 20, and 30 minutes).

2.1 Reduction of Heavy Metals (Pb and SO_3^{2-}) After Treatment

The results demonstrated that higher voltage levels (20V) and longer treatment durations (30 minutes) yielded the highest reduction in heavy metal concentrations.

Voltage	Time	Lead (Pb) Reduction (%)	Sulfite (SO_3^{2-}) Reduction (%)
10V	10 min	30	25
10V	30 min	50	40
15V	10 min	55	50
15V	30 min	75	70
20V	10 min	80	75
20V	30 min	95	90

From **Table 2**, the **Electro-Purify system effectively removed up to 95% of lead (Pb) and 90% of sulfite (SO_3^{2-}) when operated at 20V for 30 minutes**. Lower voltage levels and shorter treatment times resulted in **less effective heavy metal removal**.

2.2 Reduction of COD and Water Turbidity

The reduction in **COD and turbidity** after treatment was evaluated to assess the removal of organic contaminants and suspended particles.

Voltage	Time	COD Reduction (%)	Turbidity Reduction (%)
10V	10 min	30	28
10V	30 min	50	45
15V	10 min	65	55
15V	30 min	75	70
20V	10 min	85	80
20V	30 min	92	89

From **Table 3**, COD levels **decreased by more than 92%**, and **water turbidity was reduced by 89%** at **20V for 30 minutes**, confirming that **higher voltage and longer treatment times significantly improve organic matter removal and overall water clarity**.

Conclusions

The Electro-Purify system is an innovative, portable heavy metal treatment technology designed for easy deployment in high-risk areas, powered by either battery or solar energy. Utilizing aluminum and copper electrodes, which are both cost-effective and efficient, the system effectively removes heavy metal contaminants from wastewater.

Experimental results demonstrated that Electrocoagulation effectively reduced lead (Pb) by up to 95% and sulfite (SO_3^{2-}) by 90%, while Chemical Oxygen Demand (COD) and turbidity decreased by over 80%. These findings indicate that higher voltage levels (20V) and a 30-minute treatment duration yield the best removal efficiency.

Thus, the Electro-Purify system presents a practical solution for treating wastewater in small industries and disaster-affected areas. It plays a significant role in reducing heavy metal pollution before wastewater enters natural water bodies, particularly in sensitive ecosystems such as Thale Noi, Phatthalung Province, which requires urgent conservation efforts.

Discussion

Effectiveness of Electrocoagulation in Heavy Metal Removal

The results confirm that Electrocoagulation is highly efficient in treating heavy metal-contaminated wastewater, particularly for lead (Pb) and sulfite (SO_3^{2-}). These findings align with the study by Mollah et al. (2020), which reported that Electrocoagulation can remove over 90% of heavy metals when optimized.

The mechanism of Electrocoagulation involves electrodes (Al, Cu) undergoing electrochemical reactions, releasing Al^{3+} and Cu^{2+} ions, which interact with contaminants causing precipitation and separation from the water. Optimal voltage (20V) and duration (30 min) significantly enhance this process, ensuring maximum pollutant removal.

Impact of Voltage on Treatment Efficiency

- Lower voltage levels (10V and 15V) resulted in moderate removal efficiency.
- Higher voltage (20V) significantly improved coagulation, reducing Pb by 95% and SO_3^{2-} by 90%.
- Extended treatment duration (30 min) optimized pollutant precipitation and removal.

Reduction in COD and Turbidity

- COD decreased by over 80%, indicating a significant reduction in persistent organic pollutants.
- Water turbidity decreased by 89%, leading to clearer water, a key indicator of improved water quality.

These results reinforce the potential of Electro-Purify for deployment in disaster-affected areas, as it is portable and operates on renewable energy sources. However, long-term usability can be improved with automation, sensor integration, and solar power adaptation.

Challenges and Recommendations for System Enhancement

1. Electrode degradation – Regular maintenance required; replacement every two months is recommended.
2. Energy consumption – Integration of solar power would improve system sustainability.
3. pH monitoring – Continuous pH tracking is necessary to prevent ecological imbalances.
4. Comparison with chemical treatments – Electrocoagulation offers greater environmental safety and cost efficiency than conventional chemical treatments, making it a more sustainable alternative for industrial wastewater management.

Recommendations

1. Development of Electrocoagulation Technology for Practical Use

- Miniaturize the system for easier installation and maintenance.

- Implement full automation, including automatic on-off functionality and an Electrode Cleaning Alert System.

2. Implementation in Communities and Industries

- Deploy the Electro-Purify system in traditional krajood dyeing communities to reduce heavy metal discharge into local water sources.

- Encourage collaboration with environmental agencies to scale up and promote adoption of this sustainable wastewater treatment technology.

3. Recommendations for Future Studies

- Evaluate alternative electrode materials (e.g., iron (Fe) and titanium (Ti)) for improved efficiency and longevity.

- Expand Electrocoagulation testing to other industrial wastewaters (e.g., metal and food processing industries) to assess broader applicability.

Benefits of the Study

1. Reduces heavy metal contamination in wastewater, particularly in traditional krajood dyeing industries and disaster-affected areas.

2. Improves water quality by lowering COD and turbidity, benefiting both the environment and public health.

3. Offers a sustainable, cost-effective alternative to chemical treatments with minimal environmental impact.

4. Enhances disaster resilience, providing an off-grid, portable water treatment solution.

Supports global sustainability goals, particularly SDG 6 (Clean Water & Sanitation) and SDG 13 (Climate Action).

By integrating Electro-Purify into real-world applications, this research contributes to practical, scalable solutions for heavy metal pollution, fostering environmental protection and sustainable water management at local and global levels.

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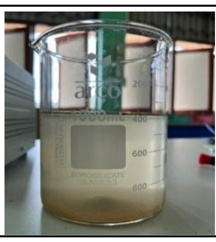
Appendix

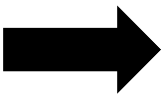
Consult an expert in heavy metal treatment system design,

Field sampling of water at the Krajood dyeing community,

Model design | Drilling electrode holes | Cutting electrodes | Electrode (Al)

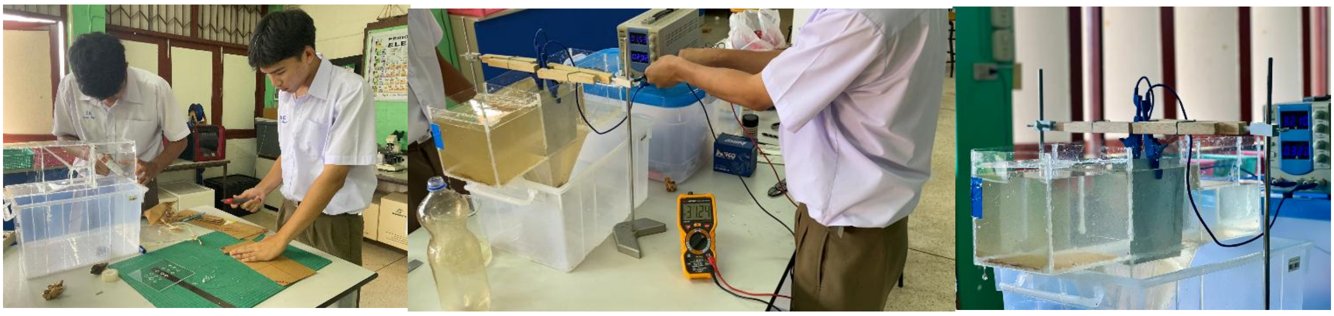
Electrical system testing for heavy metal removal in water samples.





Water sample before

Water sample after testing.



Electro-Purify Heavy Metal Treatment System in Wastewater from Traditional Lepironia Dyeing

Badges

I am an Engineer:

- This project is fundamentally an engineering endeavor. The students designed and developed a portable water treatment system (Electro-Purify) to address a real-world problem: heavy metal contamination.
- We experimented with different materials (aluminum and copper electrodes) and voltage conditions to optimize the system's performance.
- The project focuses on creating a practical, deployable solution, particularly for disaster-affected and off-grid areas, which aligns with engineering principles of problem-solving and design.
- This project has the potential to add to the knowledge of portable water treatment systems.

I make an Impact:

- The research directly addresses a critical local and global issue: water contamination.
- The Electro-Purify system has the potential to significantly improve water quality in communities affected by industrial pollution and natural disasters.
- By providing a portable and accessible water treatment solution, the project aims to have a tangible positive impact on public health and environmental sustainability.
- The research is directly designed to improve the quality of life for people in their local community.

I am a Data Scientist:

- The project involves the collection and analysis of quantitative data to evaluate the effectiveness of the Electro-Purify system.
- Students measured and analyzed parameters such as Pb and SO_3^{2-} removal rates, turbidity, and COD.
- We used this data to conclude the system's performance under different conditions.
- The research is based on measurable data that is used to evaluate the success of the project.