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Ultrafiltration Technology for Batik SME Wastewater Treatment: Column-Based Materials with Zippers for Plant Irrigation Water Supply

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Abstract

Textile batik wastewater discharged into drains can contaminate groundwater and harm ecosystems and human health. This study focuses on reducing hazardous heavy metals in sewage through physical and chemical filtration. Heavy metals in the wastewater can poison aquatic organisms, disrupt food chains, and contaminate water sources. The goal is to analyze the heavy metal content, pH, and colour of batik wastewater to make it safe for plant irrigation. The filtration process uses silica sand, activated carbon, and zeolite for mechanical filtration and ion exchange. Ultrafiltration is added to remove fine particles, heavy metals, and organic matter more effectively while resisting fouling. These materials are placed in zipper bags for easy replacement and regeneration. The wastewater passes through a filtration column consisting of two tanks: Tank 1 for fresh wastewater and sedimentation, and Tank 2 for overflow from Tank 1. Tests were conducted for Cr, Cu, Pb, and Zn using AAS, pH with a universal pH meter, and colour through organoleptic analysis. Cr levels initially exceeded quality standards, while Cu, Pb, and Zn were within safe limits. After filtration, reductions of Cr, Cu, Pb, and Zn were 81%, 8%, 22%, and 85%, respectively. The pH decreased from 10–11 to 7–8, and water color improved from murky greenish-brown to clearer. The results demonstrate the potential of ultrafiltration in reducing heavy metals, stabilizing pH, and improving water clarity. Wastewater treated through this process meets safety standards and can be used for plant irrigation.

Keywords : filtration column, sedimentation, heavy metal, activated carbon, zippered pouch.

INTRODUCTION

The batik industry is an integral part of Indonesia's cultural heritage, experiencing significant growth each year. One of the centres of the batik industry is located in Kendal Regency, Central Java, which is known for producing batik using both stamped and handwritten techniques. The batik-making process generally involves several stages: preparation, patterning, waxing, dyeing, wax removal, and finishing (Zakaria et al., 2023). However, this industry also generates large amounts of wastewater, particularly during the dyeing stage. This wastewater poses a major challenge that requires attention to ensure environmental sustainability.

The batik industry generates 50–60 litres of wastewater per week from the dyeing process. The dyeing process uses two types of dyes: natural and synthetic, with a ratio of 40% and 60%, respectively. The natural dyes used come from materials such as secang wood, indigofera leaves, and jelawe seeds. Meanwhile, common synthetic dyes include remazol, indigosol, and naphthol. The wastewater produced by the batik industry contains hazardous chemicals and pathogenic microorganisms, which can have serious health and environmental impacts (Daud et al., 2022).

Batik dye wastewater typically has a dark colour, a strong odour, and significant volume. Improper disposal without adequate treatment can contaminate water bodies, damage aquatic ecosystems, and degrade the quality of water available for public use (Bashir et al., 2020). The synthetic dyes used in the batik production process can degrade into carcinogenic and toxic compounds (Kusumawati et al., 2021), contributing to increased pollution, especially heavy metals from the synthetic dyes, natural dyes, and mordants, which also cause pH levels to rise.

The pollutants in the wastewater, such as non-biodegradable organic compounds and heavy metals, are difficult to break down, leading to accumulation. This accumulation can have negative effects on environmental health and the survival of aquatic life (Handayani et al., 2018). Heavy metal waste is classified as hazardous and toxic waste (B3), which can pollute the environment and pose serious risks, such as poisoning to humans and other living organisms (Manisalidis et al., 2020).

Traditionally, batik wastewater is usually collected in a storage tank and allowed to seep into the ground without undergoing further treatment. However, proper wastewater treatment is essential to ensure that the discharged wastewater meets the required quality standards.

A simple wastewater treatment for batik SMEs can be carried out using tiered wastewater treatment ponds that rely on sedimentation processes. The wastewater is channelled through several ponds equipped with media such as sand, gravel, and activated carbon to filter large particles and reduce the dye content (Rahmadyanti & Audina, 2020).

This method is easy to implement as it does not require sophisticated equipment and has low operational costs, making it suitable for small-scale SMEs. Additionally, the treated water can be used for irrigation after undergoing adequate filtration.

To enhance treatment efficiency, one alternative technology is ultrafiltration. This technology is highly effective at filtering fine particles and small molecules (Han et al., 2021). Ultrafiltration does not require additional chemicals, making it more environmentally friendly and reducing the risk of further contamination.

The ultrafiltration process involves several components, including a storage container for wastewater, either concentrated or rinse water. A pump is used to transport the wastewater to the ultrafiltration unit at a specific flow rate. The ultrafiltration unit separates harmful compounds, and a collection container stores the treated water, connected by a network of piping (Chew et al., 2018).

Ultrafiltration technology can treat wastewater by separating chemical processes, filtering colloids, and removing bacteria larger than the ultrafiltration filter pores (Hu & Wu, 2023), typically ranging from 0.01–0.02 microns. This technology has proven effective in handling wastewater from both natural and synthetic dyes in the batik industry. Applying ultrafiltration supports the creation of a more environmentally friendly and sustainable batik industry, while also reducing environmental impacts.

The use of ultrafiltration technology can be a potential solution for batik wastewater treatment. It ensures that the quality of treated wastewater meets the required standards before being discharged. Furthermore, the treated water can be safely used for irrigation without harming the environment. Therefore, ultrafiltration not only promotes environmental sustainability but also enhances compliance with wastewater quality standards.

METHODS

This study uses a series of tools divided based on the needs of the filtration process and cellulose membrane preparation. The filtration tools include a 15-litre bucket, rack, 4-inch diameter PVC pipe, valve, and material basket. The tools for cellulose membrane preparation include a beaker, measuring cup, magnetic stirrer, petridish, dropper, graduated pipette, pH indicator, glass funnel, oven, analytical balance, and filter paper.

The materials used in this study include the main material, which is Empty Palm Oil Bunches (TKKS) obtained from palm oil plantations owned by residents in Palembang. The wastewater used is sourced from the Linggo batik industry in Semarang. Chemicals used include distilled water, glacial acetic acid, sulfuric acid (98% v/v), acetic anhydride, N-methyl-2-pyrrolidone (NMP), Naphthol, and ZnO. Filtration media include activated carbon, zeolite, sand, and ultrafiltration membranes that have been prepared. These materials are used step by step according to the stages of the study, which involve membrane preparation and wastewater treatment.

Synthesis of Cellulose Acetate

The synthesis of cellulose acetate was carried out using cellulose from an empty bunch of fruit that had undergone an extraction process. The synthesis procedure consists of four main stages. The activation process was that 5 g of cellulose was dissolved in 150 mL of glacial acetic acid in a beaker. The solution was stirred using a magnetic stirrer at 1500 rpm and 38 °C for 3 hours. Acetylation process, the activated solution was then mixed with 45 mL of acetic anhydride and 1 mL of 98% sulfuric acid as a catalyst. The mixture was stirred with a magnetic stirrer at 1500 rpm and 25 °C for 2.5 hours. Hydrolysis process, to stop the acetylation process, 6 mL of distilled water and 15 mL of glacial acetic acid were added to the solution. The mixture was heated using a magnetic stirrer at 1500 rpm and 50 °C while stirring for 30 minutes. Sedimentation and purification process, the hydrolyzed solution was transferred into a 50 mL Falcon tube, and then processed using a centrifuge at 4000G and 25 °C for 10 minutes until the liquid and precipitate separated. The obtained precipitate was filtered using filter paper until the acetic acid odour disappeared. The cellulose acetate was obtained by drying the precipitate in an oven at 55 °C for 6 hours. The final product is cellulose acetate, ready for use.

Preparation of Cellulose Acetate Ultrafiltration Membrane

The ultrafiltration membrane was made using cellulose acetate (CA) synthesized at a 5%

concentration. The membrane fabrication process involved N-Methyl-2-pyrrolidone (NMP) as the solvent and ZnO as an additive. The membrane preparation steps are solution preparation: NMP was measured according to the concentration variations using a graduated pipette, and then placed into a closed beaker. Cellulose acetate and ZnO were measured using a spatula according to their respective concentration variations and then weighed using an analytical balance with the help of a watch glass. The cellulose acetate and ZnO were added to the beaker containing NMP, then stirred using a magnetic stirrer at 60 °C for 3 hours until the solution became homogeneous. For air bubble removal, the homogeneous solution was left to stand at room temperature for 1 hour to allow the air bubbles to dissipate. The homogeneous solution, consisting of the polymer, solvent, and additive, was slowly poured into a petri dish. The petri dish was then placed in an oven and dried at 55°C for 20 hours to evaporate the NMP solvent. The dried membrane was removed from the petri dish and prepared for further testing.

Application of Liquid Batik Waste Filtration Technology

In the ultrafiltration process, wastewater is first subjected to sedimentation to separate the liquid phase from the solids contained within. After sedimentation, the wastewater is introduced into the filtration system, which consists of several layers of filtration media: activated carbon, zeolite, silica sand, and ultrafiltration membrane. Each filtration media is placed in zipper bags to facilitate the replacement and regeneration of the filtration media. The filtered wastewater will be tested for heavy metal parameters, including Cr, Cu, Zn, and Pb. Wastewater that meets the testing standards can be reused, for example, for watering plants.

The ultrafiltration system, depicted in Figure 1, consists of a 15-litre capacity bucket mounted on a metal rack. The bucket is connected with a small pipe to direct wastewater through the various filtration layers. The filtered water is subsequently directed through a pipe for appropriate use.

The pH of the wastewater, before treatment, was alkaline. After being introduced into the filtration column, water samples were taken and placed into bottles to observe the pH change to determine the effectiveness of the filtration process in reducing the pH.

The colour change in the wastewater, before treatment, was greenish-brown and cloudy. After being introduced into the filtration column, water was sampled every 2 minutes and placed into bottles to observe any colour degradation over up to 10 minutes.

Figure 1. Wastewater Filtration Technology System for Batik Industry

Molecular sieve material is placed as a filter together with sand, activated carbon, and zeolite in the form of a bag using cloth, so that the flow of batik wastewater can pass through it as shown in Figure 2. This arrangement helps maintain porosity and ensures a stable arrangement in the filtration column.

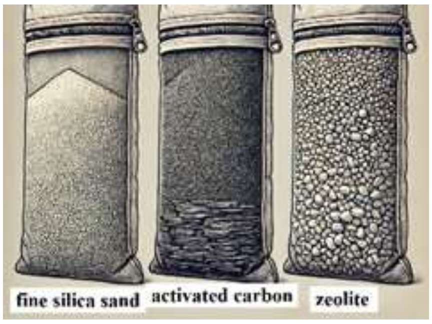

Figure 2. Materials Used in the Filtration Process Packed in Zippered Bags

Molecular sieve material is placed as a filter together with sand, activated carbon, and zeolite in the form of a bag using cloth, so that the flow of batik wastewater can pass through it as shown in Figure 2. This arrangement helps maintain porosity and ensures a stable arrangement in the filtration column.

The water that has passed through all the filtration layers exits the system as cleaner water, meeting the standards for specific uses, such as irrigation. This sequence ensures that each filtration layer functions optimally, and the ultrafiltration membrane is not quickly clogged by large particles that should have been captured by the previous media.

RESULTS AND DISCUSSION

Filtration Effectiveness in Reducing Heavy Metal Content

In the production process, batik artisans use both writing and stamping techniques. For dyeing, two types of colourants are used: natural and synthetic dyes, with a ratio of 40% and 60%, respectively. A byproduct of the dyeing process is wastewater, which primarily contains colourants from leftover dye, washing, and rinsing of the batik fabric. This wastewater still contains chemicals that can pollute the environment. Some of the chemical contents in batik wastewater are presented in Table 1. Wastewater with chemical concentrations exceeding the standard quality levels includes Cr and Pb. Although the concentration differences are not significant, the levels of these metals need to be reduced through filtration, while the levels of Cu and Zn are within safe limits.

Chromium is often used in certain synthetic dyes, particularly in reactive dyes or mordant-based dyes. The colour fixation process involving metal salts such as chromium sulfate can leave Cr residues in the wastewater. Testing the Cr concentration after filtration shows a significant decrease, with Cr levels in batik wastewater reduced by 81-86%. This reduction occurs due to adsorption through physical and chemical bonds on the porous surface. Two forms of Cr can be reduced: Cr(VI) and Cr(III). In acidic pH, Cr(VI) is more easily reduced than Cr(III) (Cong et al., 2023). Zeolite is more effective in reducing Cr(III) levels compared to Cr(VI), while silica sand is better at reducing Cr(III) levels than Cr(VI). The highest efficiency of coconut shell activated charcoal in reducing chromium (Cr) content in batik wastewater, achieved with a stirring speed of 90 rpm and 300 g of charcoal per 1 L of wastewater, reduced the initial Cr concentration from 0.8154 mg/L to 0.5329 mg/L, achieving a removal efficiency of 34.65% (Qisti & Rokhim, 2021). The reduction of heavy metals and colour is attributed to the presence of saponin and CMS, which effectively dissolve or bind heavy metal molecules such as Cr, achieving a removal efficiency of 95% in batik wastewater (Aryani et al., 2019).

Table 1. Concentration of Heavy Metal Levels in Wastewater Before and After Filtration

Metal Content in Effluent	location tank	Conc mg/L	Conc mg/L	Efficiency	Quality Standard
Cr	1	0.31	0.06	81%	0.1
	2	0.21	0.03	86%	
Cu	1	0.37	0.02	95%	0.5
	2	0.33	0.02	93%	
Pb	1	0.47	0.07	85%	0.1
	2	0.39	0.02	95%	
Zn	1	0.27	0.21	22%	1.0
	2	0.26	0.19	27%	

On the other hand, Cu(II) compounds are used in certain synthetic dyes, particularly those based on metals, which contain copper as a dye component. Cu can also originate from equipment or other additives used during the dyeing process. There is a slight reduction in Cu levels after filtration at both sites, indicating that the filtration process partially succeeded in reducing copper concentrations by 93-95%. Cu metal ions are easily adsorbed by activated carbon through electrostatic and van der Waals interactions. The ion exchange mechanism of Cu also involves zeolite, while silica sand has little effect. By utilizing ultrafiltration hybrid matrix hollow fibre membranes impregnated with ZnO nanoparticles, Cu(II) removal efficiency exceeded 92% at a specific permeate flux (Liu et al., 2023). A polymer-anchored co-deposition technique featuring positively charged hollow fibre nanofiltration membranes with a bridged network structure demonstrated outstanding efficiency in removing heavy metal ions Cu2+ (94,1%) at high concentrations of 4000 mg/L (Tang et al., 2022).

Lead (Pb) can be present if dyes or additives used in the batik process contain lead-based compounds. Some inexpensive and environmentally unfriendly textile dyes may contain Pb to improve colour fastness. Pb concentration decreases by 85-95% with the filtration arrangement of the three filtration materials, both physical and chemical. Pb can be captured through ion exchange mechanisms from zeolite, as it has a high affinity for Pb^{2+} ions. The presence of activated carbon helps reduce this metal ion, as it is easily absorbed through electrostatic and van der Waals interactions (Neolaka et al., 2023). In contrast, silica sand has low adsorption capacity for heavy metals but functions as a pre-filtration stage.

Zinc (Zn) is commonly found in chemicals such as mordants (colour fixers) or other additives used in batik production. The use of solutions or colour enhancers can also contribute to Zn in the wastewater. The reduction of Zn is more significant with zeolite, while activated carbon does not adsorb it as effectively as Cu and Pb, and iron sand does not significantly aid in reduction through adsorption. The reduction in Zn levels reaches 22-27%.

Activated carbon and zeolite play a role in reducing the metal content in batik wastewater, while silica sand is used as a filter for larger contaminants. At the bottom is ultrafiltration, a physical separation mechanism based on molecular size or relative molecular weight, as well as surface interactions. The reduction of Cr, Cu, Pb, and Zn, particularly for metal ions in solution, can proceed effectively because the size of the ions is larger than the pore size of the ultrafiltration membrane. With high separation capability, ultrafiltration can remove various types of contaminants simultaneously, but it requires maintenance to prevent fouling (Zhang et al., 2023).

It is important to note that exposure to sunlight, particularly UV rays, can help break down organic compounds and some complex metal compounds through photochemical processes. This suggests that chromium in the form of Cr(VI), which is more toxic, can be reduced to Cr(III), which is more stable and less toxic, with the aid of sunlight and organic materials in the wastewater. Sunlight exposure can increase the temperature of the wastewater, stimulating the growth of microorganisms that can convert heavy metals into less soluble or more stable forms. When the absorption capacity of activated carbon and zeolite reaches their maximum limit, the absorption of copper (Cu) becomes incomplete.

According to the Ministry of Environment Regulation No. 5/2014 on Effluent Quality Standards, the Cr content in batik SMEs exceeds the quality standard, from 0.31 mg/L, while the standard should be 0.1 mg/L. Therefore, with the use of the filtration system, all tested heavy metals are reduced and meet the quality standards. This means the treated water can be safely discharged into water bodies and used for irrigation.

pH Decrease

The results of wastewater testing through physical and chemical filtration media showed varying effectiveness in reducing heavy metal concentrations. Filtration treatment was proven to be effective in reducing Cr and Pb levels but less optimal for Cu and Zn, indicating that the filtration system used is not fully suitable for all types of heavy metals.

The pH decreases in both filtration tanks also showed significant results. In tank 1, the initial pH of around 10.14 decreased to 7.67 after filtration, while in tank 2, the initial pH of 11.37 dropped to 8.14. This decrease indicates the effectiveness of the filtration process in reducing the alkalinity of the wastewater. Among the three-filtration media used (activated carbon, silica sand, and zeolite), zeolite showed the best ability to lower pH from an alkaline level (pH 11) to near neutral (pH 7). This is due to zeolite's ion-exchange properties, where its porous structure allows the exchange of ions such as H^+ and OH^-. In alkaline solutions, zeolite can reduce the concentration of OH^- ions through ion exchange, thus lowering pH. When used in its activated form, zeolite is also effective in adsorbing heavy metals in addition to controlling pH.

On the other hand, the ultrafiltration process is not only effective in filtering solid particles but also helps lower pH through precipitation and the removal of hydroxide ions that cause high alkalinity. The hydrophilic cellulose acetate membrane is suitable for reducing moderate pH (8–9) and can retain certain ions, including OH^-, through physical filtration. However, to address very high pH, ultrafiltration should ideally be combined with pretreatment, such as initial pH adjustment using chemicals or adsorbents. Unlike ion-exchange media like zeolite, the pH reduction in ultrafiltration is more of a physical filtration of ions in solution.

The reduction in pH to this level shows that the filtration process successfully reduced alkalinity-causing ions, such as OH^-, which contribute to increased pH (Athaya et al., 2021). The tolerance limit of pH for irrigation water ranges from 6.0 to 9.0, with the average pH value for wastewater samples from the discharge point and irrigation area recorded at 7.64 (Chaoua et al., 2019). The ultrafiltration-treated water meets these standards and can safely be used for agricultural irrigation and plant watering without significant risks. This is supported by the fact that when the optimal amount of activated carbon is utilized for treatment, the pH value adjusts to 7.10 (Oladimeji et al., 2023)

Colour Change of Waste Liquid

The filtration process carried out showed significant results in clarifying the colour of waste, especially batik waste. Observations in both filtration tanks showed changes in the color of wastewater which was initially cloudy greenish brownish to increasingly clear over time.

In the early stages of filtration, namely in the first 2 minutes, the filtered water still had a thick colour due to the high concentration of particles and dissolved substances that had not been completely filtered. However, in the next 2 minutes, the filtered water began to show a brighter colour change than before. In the third 2 minutes, the wastewater produced appeared cloudy white, and in the fourth 2 minutes, the colour of the filtered water became clearer, indicating the success of ultrafiltration in separating most of the dyes from batik waste.

In the final experiment, the wastewater produced appeared clear, indicating that the ultrafiltration technology used was able to effectively clarify batik wastewater as shown in Figure 3. Ultrafiltration works by utilizing sufficient pressure to force water through a semi-permeable membrane. This process filters out small particles, while larger contaminants are retained on the membrane surface so that the dyes can be removed effectively. The Brackish Water Reverse Osmosis membranes achieved an 87% colour removal efficiency (Cinperi et al., 2019).

Figure 3. Results of Color Clarification in the Filtration Process

CONCLUSION

The treatment of batik wastewater to reduce heavy metal content, which can be harmful to the environment if discharged directly into groundwater, can be achieved using filtration technology. Wastewater from the collection tank can be treated through a filter consisting of silica sand, activated carbon, zeolite, and ultrafiltration membranes, with each material demonstrating removal efficiencies for heavy metals of 81%, 8%, 85%, and 22%, respectively. This process also adjusts the acidity (pH) of the water, which initially has an alkaline pH (10-11), to neutral levels within the pH range of 7-8, following the required standard of pH 6-9. Additionally, the initially turbid, greenish-brown water colour transformed into clearer water after treatment. Thus, water quality parameters, including heavy metal content, pH, and water clarity, meet the standards for potential reuse, such as for irrigation.

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