

The Potential of Ozone/UV System in The Treatment of Batik Wastewater in Indonesia

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ABSTRACT– The Batik dyeing method, producing famous fabric products recognized locally and internationally, requires lots of wax and dyes in the dyeing process. The wastewater containing high loads of organic pollutants requires proper treatment to prevent environmental damage. Among many technologies developed for wastewater treatment, combining ozonation and UV irradiation has been a promising method due to its effectiveness in degrading and reducing the organic pollutants in wastewater. In this study, Batik wastewater was treated using commercially available ozone generators and UV lamps in a combined ozone/UV system to confirm the effectiveness and to propose a simple and economically feasible method for Batik wastewater treatment. The color and the suspended solids in the wastewater were reduced significantly after 48-hour treatment using the setup in this study. A simple simulation of the investment and operational costs was also conducted.

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Introduction

The textile industry is one of the flagship industries in Indonesia, producing many kinds of products that are well-known even to the international community. Among the various textile products, one that stands out locally and internationally is the product produced using the Batik dyeing method because of its uniqueness and variety in patterns and its recognition by the global community as one of Indonesian cultural identities and heritages [1].

The traditional Batik dyeing method consists of several steps that are named Mola, Ngilowong, Nembok, Medel, Ngerok, Mbironi, Nyoga, and Ngilrod, as shown in Fig. 1.



Figure 1. The Steps in the Batik Dyeing Method

In the first step, the pattern is usually drawn on paper using a pencil before being traced to a white fabric that will be made into a Batik textile product. After that, a dipper called “canting” (Indonesian) will be used to apply melted wax on a section of the fabric according to the drawn pattern to prevent contact of dye material with the wax-covered sections during the dyeing process. During the dyeing process in step 4, the fabric is then dipped into a dye solution where the sections without wax coverage will be colored. The wax is later removed from the fabric by scraping using a metal plate and washing. Before the second dyeing process, another layer of wax is applied again to other sections of the pattern according to the design. Finally, the fabric that has been dyed thoroughly is dipped into boiling water to remove the wax completely.



Figure 2. Batik fabric crafted by Banyuwangi artisan

The handmade Batik fabric, such as the one shown in Fig. 2, requires a relatively long process that takes place for several days while the artisan collects enough fabric materials to continue to the next step.

As wax and dye are used in large quantities in the dyeing process, they also become the main components that will go into the wastewater after the Batik dyeing process. Batik wastewater is characterized by a high level of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and heavy metal content in the form of chromium ions (Cr^{6+}), as shown in the previous research data collected from Batik industries in Bogor City, Indonesia (Table 1) [2]. Since these values are much higher than the maximum limit set in the Indonesian environmental standards, proper treatment is a necessity before releasing the treated effluent into the environment to prevent pollution in water bodies and land.

Table 1. Characteristics of Batik Wastewater in Bogor City

Parameters	Concentration in wastewater (mg/L)	Environmental Standards (mg/L)
COD	52463	125
BOD	238	45
TSS	3679	40
Total Cr (Cr^{6+})	940.2	1.0

On the other hand, a proper wastewater treatment facility is a costly investment that usually can only be afforded by medium- to large-scale industries. According to an economic census conducted by the Indonesian Central Bureau of Statistics (BPS) in 2016 [3], the number of micro- and small-scale Batik industries reached around 2,609 units, far exceeding the medium-scale Batik industries, which were around 342 units. In fact, the pollution caused by Batik industries due to improper disposal of the effluents has been a major issue in Java Island, where most of the Batik industries are located.

Various treatment technologies have been studied and developed to remove organic and inorganic contaminants in Batik wastewater, as shown in the review study conducted by Zakaria et al. [4]. These technologies include filtration methods such as membrane filtration using different membrane pore sizes (microfiltration, ultrafiltration, nanofiltration, reverse osmosis), chemical coagulation-flocculation method using chemical additives to create larger solid particles in water that are easier to remove, adsorption method that utilizes solid adsorbent affinity to pollutant molecules to attract them to its surface, advanced oxidation processes such as fenton reaction using combination of iron ions and hydroxyl radicals from hydrogen peroxide to create a strong oxidation reaction or ozonation that utilizes ozone as a strong oxidant to degrade organic pollutants in the wastewater, biological method using aerobic or anaerobic microorganisms that can degrade and consume organic pollutants converting them into sludge rich in biomass (aerobic) or into biogas (anaerobic), and electrical-assisted chemical processes that use plasma or electrical discharge as the energy source to induce chemical reactions that lead to pollutant degradation in wastewater.

Among the technologies mentioned above, advanced oxidation processes, i.e., the ozonation and ultraviolet (UV) irradiation methods, have the potential for small-scale application due to the availability of relatively small-size commercial equipment.

The application of ozone in water and wastewater treatment has been researched and developed for more than a century [5], and the commonly available ozone generators can be manufactured using a simple mechanism that utilizes electrical discharge to supply the energy necessary to produce a series of reactions that starts with the splitting of oxygen molecules into oxygen atoms and eventually converts a small amount of oxygen molecules into ozone molecules as shown in the study carried out by Sponholtz et al. [6].

UV irradiation methods have been researched and developed as water purification technology since 1801 [7], a much longer period compared to the ozonation method. The mechanism involves the degradation of organic matter including microorganisms, due to direct contact with UV light generated by UV lamps (UV photolysis), e.g., the research on the decomposition of antibiotics conducted by Yangcheng et al. [8], or the generation of hydroxyl radical, a strong oxidant that can degrade and mineralize organic matter (UV photocatalysis), e.g., the research on the degradation of perfluorooctanoic acid conducted by Estrellan et al. [9].

Some researchers have reported that the combination of ozonation and UV irradiation could improve the treatment efficiency and effectiveness of organic pollutants compared to a single method of ozonation or UV irradiation only due to the synergy effect of both methods that increase the number of strong oxidants produced. Jing and Cao have reported that COD removal in a wastewater treatment plant (WWTP) equipped with a biological aerating filter could be improved by 2.5 times up to 61% removal rate when integrated with UV/ozone pretreatment unit [10]. The research conducted by Dai et al. showed that a combined UV/ozone treatment system performed with much higher efficiency in removing poly-fluorinated alkyl substances compared to UV irradiation only [11]. The removal mechanism was mainly through the destruction of the pollutant molecules. This destruction mechanism is favorable in wastewater treatment compared to other chemical or physical methods that only transfer the pollutants into other media, requiring further treatment or disposal steps. One recent study conducted by Larasati et al. has reported that the combined UV/ozone treatment method could reduce BOD value and achieve partial decolorization in Batik wastewater [12]. However, the ozone generator and the UV lamp specification were unclear, and the setup of the UV/ozone system illustrated in the study showed inefficient UV irradiation due to lamp positioning on top of the reaction vessel. Ozone generation in wastewater with high organic pollutants will usually cause foaming in the liquid, which could prevent UV light from penetrating into the wastewater, causing reduced effectiveness of the UV photolysis mechanism.

This study highlighted the effectiveness of a combined ozone/UV treatment system in reducing organic pollutants in

wastewater, as shown by previous studies and conducted experimentations on Batik wastewater treatment using commercially available ozone generators and UV lamps. The purpose of this study was to propose a simple and economically feasible wastewater treatment method that can readily be implemented in micro- and small-scale Batik industries.

Materials and Methods

The ozone generator used in this study was Hanaco Ozonizer TSH-278 with ozone generation capacity of 400 mg/h and power consumption of 15 W. The UV lamp used was the immersion-type lamp with intensity of 35 W, wavelength at UVC range of around 250 nm, and length of 30 cm, commonly used for water sterilization in an aquarium with capacity ranging from 1000-2500 L. Batik wastewater was provided by the Batik artisan in Banyuwangi, East Java, Indonesia. The wastewater was directly used in the experimentation without any pretreatment.



Figure 3. Ozone generator (left) and UV lamp (right)

For the experimental setup (Fig. 4), two ozone generators and one UV lamp were used. The UV lamp was set diagonally at the bottom of the experimentation tank and was immersed completely in the 5 L wastewater. Ozone generators were connected to air stones that were immersed completely at both opposite corners, separated by the diagonally positioned UV lamp. The setup positioning was to ensure a complete mixing condition in the tank and the maximum contact of ozone and UV light.

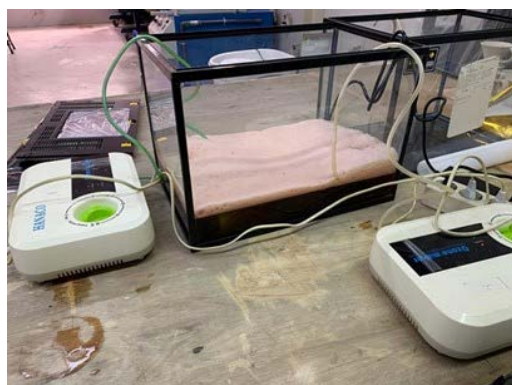


Figure 4. The experimentation setup

Samples were collected using a pipette at certain time intervals throughout the 3-day experimentation time. The color change of samples during the experimentation was observed and compared visually.

A simple cost estimation of an upscaled process to accommodate the actual wastewater quantity produced by the artisans in Banyuwangi was also carried out based on the experimental results and the price of commercially available products.

Results and Discussion

The samples collected in sample tubes throughout the 3-day experimentation were arranged in tube racks as shown in Fig. 5. The samples could be roughly grouped into numbers 1-4 for day-1 samples, number 5-8 for day-2 samples, and number 10-12 for day-3 samples.

Sample number 1 was the untreated Batik wastewater. The wastewater was dark reddish brown in color and murky, mainly due to wax and brown dye existing in it. No sedimentation or phase separation was observed throughout the experiment time, meaning that the wastewater contained a significant quantity of suspended solids that reduced the transparency of the liquid and was difficult to separate by settling only.

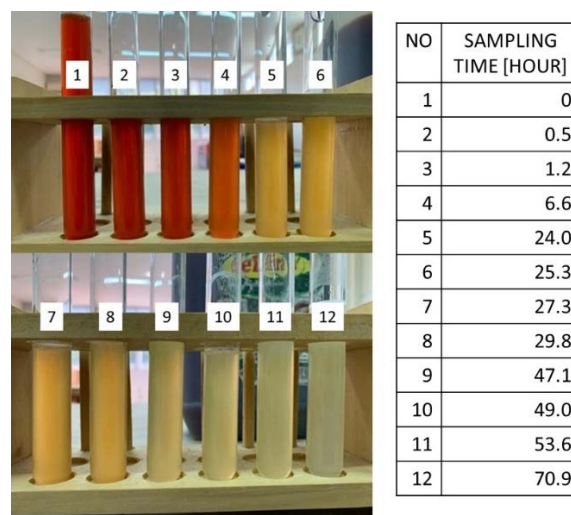


Figure 5. The collected samples and the sampling time

With ozonation and UV irradiation, the color of samples could be reduced significantly. 6.6 hours into the treatment, the color has been reduced to a light reddish brown and started to show some transparency. After 24-hour treatment, the sample changed into a murky yellowish liquid. The color reduction continued further with the treatment time, and the samples collected on day-3 showed a much lighter yellowish color. The murkiness of the liquid did not disappear during the 72-hour experiment. The color change could be attributed to the degradation of the dye complex chemical structure that usually consists of azo group ($-N=N-$), which is the main contributor to the dye color and polyaromatic rings. Fig.6 shows the chemical structure of Remazol synthetic dye (Reactive Red 2 Azo), which is commonly used in Batik dyeing nowadays [13].

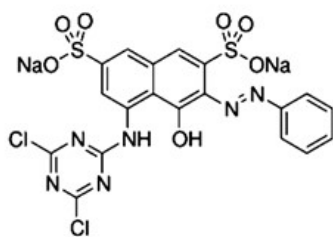


Figure 6. Example of Remazol dye

Shen et al. have studied the degradation mechanism of Remazol dye in an ultrasonic-assisted ozone oxidation process [14]. The degradation could follow several pathways, resulting in many reaction intermediates consisting of bicyclic and monocyclic aromatic compounds with hydroxyl or carbonyl functional groups that eventually decompose mainly into carbon dioxide (CO₂) and water (H₂O) with enough contact time. Without the azo functional group, the remaining chemical compounds could not interact with the visible light spectrum; thus, the decolorization of the liquid occurred.

After treatment, the collected samples were left for several days without any disturbance, and the results showed that samples collected after 6.6 hours had improved transparency, and some solid sediments were observed at the bottom of the sampling tubes. Samples no.9-12 also showed some flocs floating on the liquid surfaces (Fig. 7).



Figure 7. The collected samples, after several days, settling

These results showed that the ozone/UV system using commercially available equipment can degrade Batik dye in wastewater, thus removing the color significantly. The separation of the suspended solids into sediment layer and flocs for day-3 samples also confirmed the pollutant degradation mechanism as the treatment produced lighter oil molecules that floated to the surface of the liquid. From visual observation of samples no.9 to 12, around 48 hours of treatment time was sufficient to produce wastewater with enough clarity and an improved solid separation characteristic.

The high TSS observed during the experiment in the form of murkiness of the liquid could reduce the effectiveness of UV irradiation, as shown in many previous studies, such as the one conducted by Bell et al. [15]. Therefore, it is possible that the removal of TSS in Batik wastewater prior to treatment

with an ozone/UV system could improve the treatment efficiency and reduce the treatment time required.

According to the interview results with the Batik artisans at Banyuwangi, the quantity of wastewater produced is around 1 m³ per month for each artisan. If the treatment time for 5 L wastewater using 800 mg/h ozone generators and 35 W UV lamp is 48 hours according to the experiment results, then ozone generators with a total output capacity of 160 g/h and 35 W UV lamp will be necessary to treat the 1 m³ of wastewater produced by one artisan monthly. Since the treatment time was estimated to be 48 hours, this facility should be able to treat the wastewater produced by a maximum of 15 artisans if operated continuously.

Currently, the commercially available ozone generator has ozone output ranging from 10 mg/h up to 40 g/h with pricing ranging between Rp.200,000 up to Rp.700,000 per g/h of ozone produced. One of the potential products capable of producing 40 g/h of ozone with a power consumption of 400 W is being sold at a price of Rp.25,000,000. On the other hand, the price of a 35 W UV lamp used in this study was Rp.340,000. An investment of around Rp.100,340,000 to purchase four units of 40 g/h ozone generator and one unit of 35 W UV lamp can already support the wastewater treatment of a small-scale Batik industry consisting of 15 Batik artisans. The operational cost of the facility is mainly the electricity cost. The total power consumption required by the equipment will be 1.635 W, or equivalent to 39.24 kWh/day. The monthly electricity cost of the equipment will be around Rp.1,765,800 at the rate of Rp.1,500/kWh.

Conclusion

The combined ozone/UV system in this study could improve the quality of Batik wastewater by reducing the color and increasing the transparency of the liquid. Pretreatment of Batik wastewater by filtration or chemical coagulation is recommended due to the high suspended solid content that could reduce the ozone/UV treatment effectiveness and efficiency. A quantitative study can be conducted to compare the effectiveness of the ozone/UV system with and without pretreatment and to determine the optimal treatment time based on the environmental standards for industrial effluent in Indonesia. The cost to set up a treatment facility for the small-scale Batik industry could be a costly investment that can be supported by the local government while the operating cost is covered by the collective of artisans according to their wastewater disposal quantity.

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