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SUSTAINABLE INNOVATION: THE DEVELOPMENT OF WASTEWATER TREATMENT SYSTEM AS A RESPONSE TO RIVER POLLUTION BY BATIK INDUSTRY OF MALANG

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ABSTRACT
This research developed a wastewater treatment system from the batik industry in Malang to reduce environmental impact. The prototype design system separates solids and liquids through a heating and vaporization process. Waste samples were taken from three locations: Kepanjen, Singosari, and Tumpang, which use natural and synthetic dyes. The results showed a significant decrease in water quality based on predetermined indicators, although some indicators such as BOD with a decrease from 1879 mg/L to 374.6 mg/L by 93.38% and COD with a decrease from 5330 mg/L to 374.6 mg/L by 92.97% still exceeded the standard limit of indicator values set. Additional optimization needs to be done to achieve the desired effectiveness and quality standards. However, these results also underscore the importance of continuous monitoring to ensure the long-term environmental sustainability of the proposed solutions. This is carried out to maintain the ecosystem and support an environmentally sustainable batik industry.

KEY WORDS
Water, batik, batik wastewater, wax, color.

The success of a country's economy today depends heavily on its ability to master the creative industries. The world will continuously undergo era changes, starting from the era of agriculture, industry, and information [1]. Currently the world is entering the fourth wave, also known as the creative era [2]. When the fourth era is driven by creativity and innovation, economic growth will increase. The cultural industry is included in the fourth wave era, which is often referred to as the creative industry era [3 Indonesian batik is a cultural treasure that can be a great capital to enter the fourth era of Indonesia [4]. Batik is a culture created by the creativity of the Indonesian people. There is no other country that can imitate or master batik because batik is the result of human ingenuity and is owned by the Indonesian people [5-6].

UNESCO has declared batik as the original culture of Indonesia because batik is one of the cultures passed down by our ancestors. Every city in Indonesia has unique batik characteristics, such as Malang [7]. Malang batik, also known as Malangan batik, shows the city's cultural and historical identity more than a cloth. Although Malangan batik is not as popular as batik in other parts of Java, its quality is not inferior to batik in other places [8]. The unique patterns of Malangan batik are influenced by the traditions and architecture of the ancient kingdom. The majority of Malangan batik enthusiasts are visitors from outside Malang and from overseas [9].

One of the negative impacts of the batik industry is batik waste, especially liquid waste. Most of the batik liquid waste comes from the coloring, washing, and candle removal processes [10]. Most of these wastes contain pollutants whose levels exceed the quality standards [11]. Wastes can pollute the environment if they are simply disposed of into the

environment without being processed first [12]. Reducing the negative impact on the environment and human survival now and in the future requires pollution control measures, such as the management of wastewater produced by the company [13].

The batik industry offers a variety of effluent treatment approaches to reduce the negative impact on the environment. One frequently used method is physical treatment, such as filtration and sedimentation, to separate solid particles from liquid waste [14]. In addition, chemical treatment using coagulants and flocculants can help precipitate harmful substances [15]. Sometimes, biological processes such as bioremediation can utilize microorganisms to break down chemical compounds that are difficult to degrade [16]. Incorporating such methods can improve treatment efficiency and ensure that the waste produced meets environmental standards before being disposed of or reused. A sustainable and holistic approach to batik waste treatment is essential to maintain the balance of the ecosystem and support an environmentally friendly industry.

Previous examples of batik effluent treatment solutions include various innovative and sustainable approaches. One such example is the use of filtration and sedimentation technology to separate solids from wastewater, which is effective in reducing the pollutant content before the effluent is discharged. In addition, coagulation and flocculation technologies have been applied to precipitate harmful chemicals, making the wastewater safer for the environment [17]. Bioremediation is also becoming a popular solution, where microorganisms are used to decompose poisonous chemical compounds in batik waste, accelerating the natural degradation process [18]. Not only this, some batik industries have adopted a wastewater recycling system, which allows treated water to be reused in the production process, thereby reducing the need for clean water [19]. These are examples of the various efforts that have been made to deal with batik waste.

One of the innovative methods in the treatment of batik wastewater is through an evaporation process, where the wastewater is heated until it turns into steam. This process aims to significantly reduce the volume of liquid waste, making it easier to handle and manage. The steam generated from this process can then be condensed back into cleaner water, which can be reused in the production process or safely disposed of. Processing batik waste steam not only helps to reduce the pollution load but also enables the recovery of reusable water, thus supporting efficiency and sustainability efforts in the batik industry. The method is one of the effective solutions for managing wastewater generated, especially in industries that want to reduce their environmental impact.

Figure 1 – Sampling Process in 3 Locations (Kepanjen, Tumpang, Singosari)

The research has high urgency as the batik industry, as an integral part of Indonesia's creative industry and cultural heritage, has significant environmental impacts, especially through the wastewater generated in its production process. The purpose of this research is to explore and develop innovative solutions in the treatment of batik waste, with an emphasis on methods that can reduce the negative impact on the environment. The research will assess various physical, chemical, and evaporation process approaches to find the most efficient method. Additionally, the research also aims to ensure that the waste produced

meets environmental standards before being disposed of or reused, thus supporting the creation of a more environmentally friendly and sustainable batik industry.

This research took waste samples from three main locations of the batik industry in Malang Regency, namely Kepanjen, Singosari and Tumpang. These locations were selected based on the intensity of batik industry activities and their potential impact on the surrounding river water quality.

The batik industries located in Kepanjen and Singosari use synthetic dyes and other chemicals in the process, while the batik industry located in Tumpang tends to use natural dyes in the production process, allowing a comparison of the quality between the use of natural and synthetic dyes which can be seen in Table 1.

Sampling was carried out by taking 1-liter samples of batik liquid waste from each location within the same period to maintain consistency of results. The time in question is the period after the removal of the coating candle at each location. After being taken, the sample is immediately tested in the laboratory to analyze water quality parameters such as pH (Hydrogen Potential), BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solid), ammonia (NH_3), and oil/grease.

In order to evaluate the impact of wastewater generated by the batik industry on water quality, this study uses several standard indicators commonly used in water quality measurement. The indicators include physical, chemical, and biological parameters that can provide a comprehensive picture of the level of water pollution that occurs, such as pH, BOD, COD, TSS, ammonia, and oil/grease [20]. The measurement standard used in this study is East Java Governor Regulation No. 72 Year 2013 on Wastewater Quality Book for Textile Industry, which sets the threshold for each parameter [21]. These restrictions are essential to ensure that the quality of wastewater generated by the industry does not damage aquatic ecosystems.

The pH value is a fundamental parameter in measuring the acidity or basicity of water [22]. Measurement of effluent pH is very important because it can affect various chemical and biological reactions in aquatic ecosystems. The ideal pH value for riverwater ecosystems ranges from 6.0 to 9.0. Sewage with extreme pH values, either too acidic or too basic, can potentially damage aquatic flora and fauna and reduce ecosystem stability [23].

Biological Oxygen Demand (BOD) is an indicator to measure oxygen demand by microorganisms in decomposing organic matter contained in wastewater [24]. This parameter is very significant in assessing the organic load in water from excessive coloring residues, chemicals, and other organic matter, which causes a decrease in dissolved oxygen levels and can negatively affect the survival of aquatic organisms [25]. The BOD value of wastewater should not exceed 60 mg/L. BOD measurement indicates the decomposition and microbiological activity in water, which is an important component in wastewater quality assessment [26].

Chemical Oxygen Demand (COD) is a chemical indicator that calculates the amount of oxygen required to oxidize organic substances in wastewater [27]. A high COD value indicates that chemicals used in the batik industry process, such as synthetic dyes, have contaminated the wastewater [28]. The allowable COD standard is 150 mg/L. This parameter is important in evaluating the chemical pollution load and identifying substances that are difficult to biodegrade, potentially causing prolonged pollution [29].

Total Suspended Solid (TSS) is the dry weight of insoluble particles suspended in water, which can be measured using filtration [30]. Such as fabric fibers, residues, and sludge produced during the batik production process. The high value of TSS can cause a decrease in water clarity, increase sedimentation at the bottom of the waters, and inhibit light penetration, which adversely affects the photosynthesis of aquatic organisms [31]. The allowable TSS standard in textile industry wastewater is 50 mg/L. These solid particles also have the potential to clog water flow, worsen the physical condition of the waters, and reduce the overall quality of the ecosystem.

Ammonia is a nitrogen compound that results from the decomposition of organic matter [32]. Ammonia in the batik industry can come from residual organic material in wastewater and residual chemicals used in the process of dyeing and washing fabrics [33]. High

ammonia content is harmful to the environment and human health [34]. One of the major problems caused by ammonia is eutrophication. The eutrophication occurs when a body of water experiences an excess of nutrients such as nitrogen and phosphorus [35]. As a result of this process, lakes or rivers can experience increased pollution of plankton, bacteria, and fungi. These conditions increase water quality degradation, unpleasant odors, and oxygen depletion. The resulting decrease in dissolved oxygen (DO) and release of toxins caused by the eutrophication process leads to disruption of the aquatic food chain [36]. Not only does this threaten the lives of aquatic organisms, but it also endangers human health through direct contact or consumption of polluted water. The ammonia content standard in wastewater is 8 mg/L.

In the batik industry, oil/grease in wastewater generally comes from the candles used in the coloring process [37]. Oftentimes, fully insoluble wax residues make their way into the waste stream, creating a thin film over the water's surface that stops oxygen from forming. These oils and greases are difficult to biodegrade, potentially causing long-term pollution[38]. The standard for oil and grease in wastewater is 3 mg/L, to minimize negative impacts on water quality and aquatic ecosystems.

The measurement results of wastewater samples from the three main locations, namely Kepanjen, Tumpang, and Singosari, are presented in Table 2, which includes the key parameters defined earlier. The obtained data provide a comprehensive picture of the variation in water quality at each site, while also showing significant differences in the level of pollution that occurs, according to the specific conditions of each region.

Table 1 – Waste Collection Results

No.	Indicator		Waste Sample		
			Kepanjen	Tumpang	Singosari
1	*pH*		9.1	8.1	8.5
2	BOD	mg/L	1879	768.5	865
3	*COD*	mg/L	5330	2290	3024
4	*TSS*	mg/L	1600	5.1	204
5	*NH3*	mg/L	1009	0.5751	203
6	*Oil and grease*	mg/L	3.0	<1.280	1.0

Overall, Kepanjen site showed significantly higher concentrations of BOD, COD, and TSS compared to Tumpang and Singosari, indicating high levels of organic and suspended solids pollution. Therefore, more intensive handling and management of effluents to minimize the impact of pollution on the surrounding aquatic environment is necessary.

METHODS OF RESEARCH

This research is a type of experimental research supported by laboratory testing. Field data were collected during the experiment, and the results were analyzed in the laboratory. The population in this study was conducted in the Malang area which produces batik cloth and the sample of this study was the Kepanjen, Tumpang, and Singosari areas. The data source used was obtained from the results of preliminary testing related to waste content and standard indicators set by the Governor Regulation of East Java Province No. 72 of 2013 concerning the Wastewater Quality Book for the Textile Industry.

Sampling of liquid waste from batik production is taken from the boiling furnace. Samples were taken directly from the industrial waste bin, known as “grab samples” [39]. The samples were put into cleaned polyethylene bottles and immediately tested in the laboratory to show the characteristics at the time of sampling. A sample amount of 1 liter was used to illustrate the sterilized characteristics and then directly tested at the laboratory of Jasa Tirta Malang City.

Measurement of physical and chemical parameters through experiments and laboratory measurements of pH, BOD, COD, TSS, NH_3, and oil/grease indicators. Indicator analysis was conducted at the Jasa Tirta Laboratory.

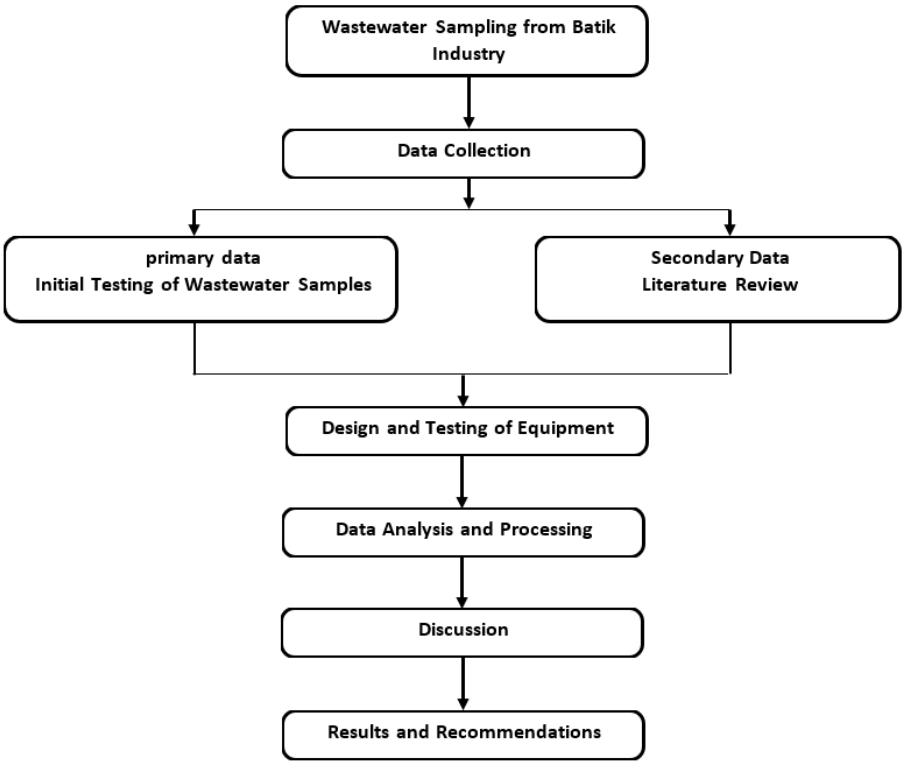

Figure 2 – Research Flow

Table 2 – Analysis Method on Indicators

No.	Indicator	Unit	Analysis Method
1	*pH*		SNI 6989.11:2019
2	BOD	mg/L	SM APHA 23rd Ed., 5210 B-2017
3	*COD*	mg/L	SNI 6989.2:2019 (Spektrofotometri)
4	*TSS*	mg/L	SM APHA 23rd Ed., 2540 D,2017
5	NH_3	mg/L	SM APHA 23rd Ed., 4500-NH3 F-2017 (phenat)
6	*Oil/Grease*	mg/L	SM APHA 23rd Ed., 5520 B-2017

The principles and procedures for testing the levels of batik wastewater in this study aim to assess the feasibility limit of the waste before it is released into the environment around the research object.

The waste treatment system used in this study is based on the concept that the liquid waste of the batik industry can be separated into solids and liquids through a process of evaporation and heating. The system is designed to optimize energy efficiency by utilizing the heat generated during the washing and wax coating removal processes. The waste treatment device design consists of three main components, as follows.

The heating furnace is made of brick material and serves as the main heat source for the system. It is designed to ensure even heat distribution, allowing the evaporation process to take place optimally. The generated heat is used to convert waste liquid into water vapor and wash batik cloth at the same time, thus improving energy efficiency.

The separating system consists of several parts, including a wastewater inlet, a water vapor outlet, and an evaporated solids reservoir. Waste batik liquid, which contains solids such as wax layers, is introduced into the system through the inlet. When the heat from the furnace causes the water to evaporate, the solids are left behind in the sump. They can be retrieved through specially designed holes for easy cleaning and waste collection.

The water vapors formed during the evaporation process are discharged through special channels, which can then be condensed back into cleaner water. This process not only separates solid waste and liquid waste but also reduces the amount of water discharged as waste, thus lowering the potential for pollution.

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Figure 3 – Main Part of Batik Waste Processing Equipment

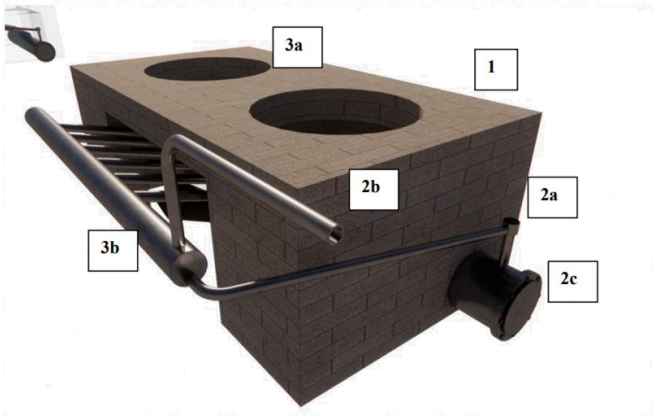

Figure 4 – Tool Model and Notation of Elements

Description: 1. The furnace is made of masonry; 2a. The hole where the batik liquid waste is inserted; 2b. The hole where water vapor exits; 2c. The shelter and lid remove solids from water evaporation; 3a. Furnace Pit to process washing and coloring; 3b. The fire as a heater evaporates water while washing and releasing the candle.

RESULTS AND DISCUSSION

The wastewater generated from batik production contains a lot of organic and inorganic materials that can pollute the environment if discharged directly into the water. Based on environmental regulations, batik waste is not allowed to be discharged into rivers, sewers, or similar channels. The waste must be treated first until it meets environmental quality standards. The negative impacts of batik liquid waste include damaging river biota if it is directly discharged into the surrounding river flow, disturbing health, or causing skin diseases because if it seeps into the well and then the water is consumed, it will cause cancer [40]. Dyes in batik waste include liquid substances that take a long time to degrade in nature. Therefore, testing is needed to sort or process liquid waste from batik production so as not to pollute the environment.

Table 3 – Waste Retrieval Results

No.	Indicator		Kepanjen		Standard	Reduction (%)
			Before	After		
1	*pH*		9.1	7.1	6.0 – 9.0	21.98
2	BOD	mg/L	1879	124.4	60	93.38
3	*COD*	mg/L	5330	374.6	150	92.97
4	*TSS*	mg/L	1600	27.3	50	98.29
5	NH_3	mg/L	1009	0.1435	8	99.99
6	*Oil anda grease*	mg/L	3.0	2.5	3	16.67

The test results show that several indicators of waste content levels have decreased close to the maximum limit specified in the East Java Governor Regulation No. 72 of 2013.

Before the treatment, the waste pH reached 9.1, which indicates alkaline conditions and exceeds the recommended water quality limit of 6.0-9.0. After the treatment process, the pH decreased to 7.1, which is within the range of environmental standards. This decrease in pH by 21.98% showed the effectiveness of the vapor separation method in reducing excessive alkali levels.

The initial BOD value was recorded at 1,879 mg/L, which significantly exceeded the set threshold of 60 mg/L. After the treatment process, the BOD value dropped to 124.4 mg/L, with a percentage reduction of 93.38%. Although there has been a significant decrease, the final BOD value is still above the permitted standard. This indicates that the treatment method needs to be further optimized to achieve standards that are in line with environmental requirements.

The preliminary COD was recorded at 5330 mg/L, indicating a high organic matter content in the wastewater at the Kepanjen site compared to Tumpang and Singosari. With these results, the variation of COD values in textile effluents seems to be influenced by the type of textile produced as well as the procedures used in the production process [41]. After the treatment of the Kepanjen wastewater sample, the COD value was significantly reduced to 374.6 mg/L, with a reduction efficiency of 92.97%. Despite this, the final COD value still exceeds the set standard limit of 150 mg/L, indicating that although the vapor separation method is effective in reducing chemical contamination, the addition of advanced treatment technologies may be required to produce wastewater that is completely safe for aquatic ecosystems.

The concentration of TSS in the initial effluent reached 1600 mg/L, indicating the high amount of suspended particles in the water, such as cloth fibers and residues from the batik production process. After the treatment, the TSS decreased drastically to 27.3 mg/L, with a reduction efficiency of 98.29%, far below the permissible limit of 50 mg/L. This reduction shows the high effectiveness of the steam separation method in removing suspended solid particles.

The ammonia content in the wastewater before treatment was recorded at 1009 mg/L, far exceeding the quality standard limit of 8 mg/L. In high concentrations, ammonia is very dangerous for aquatic organisms. After the treatment, the ammonia content decreased drastically to 0.1435 mg/L, with the percentage reduction reaching 99.99%. This remarkable effectiveness shows that the steam separation method is highly efficient in reducing nitrogen content in the form of ammonia, resulting in wastewater that is much safer to release into the environment without harming aquatic biota.

The content of total oil and grease found in the initial wastewater was 3.0 mg/L, slightly exceeding the permissible limit of 3 mg/L. After the treatment, this content decreased to 2.5 mg/L, with a percentage decrease of 16.67%. While the final value is under the allowed limit, the relatively small decrease compared to the other parameters indicates that the oil and grease removal process requires additional treatment.

Based on the guidelines of the East Java governor's regulation no. 72 of 2013, the test results of the liquid waste treatment process using the prototype that has been designed still have shortcomings. This is shown in the BOD value of 124.4 mg/L which is still greater than 60 mg/L and the COD value of 374.6 mg/L which exceeds the maximum limit of 150 mg/L. However, this prototype can reduce TSS levels by 98.29% and ammonia by 99.99%, so the results of this waste discharge process hardly cause sediment and eutrophication.

CONCLUSION

Based on the results of the experimental research, it was found that there was a significant reduction in the effluent quality limit levels after testing using the designed prototype. Although this treatment is effective in reducing the main indicators, there are still some indicators such as BOD and COD that do not meet the environmental standards set by local regulations. The technical explanation for the non-conformity of the indicator results is due to the imperfection of the prototype tool, so it is necessary to improve the tool to provide additional treatment in the waste treatment process such as the addition of filtration after the

wastewater condensation process and by safety and security standards for prototype users to avoid work accidents during the waste treatment process. The results of the batik waste treatment process in the form of solids require further scientific studies related to processing in the reuse of these wastes.

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