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The Effect of Hydraulic Retention Time (HRT) and Aeration Rate on the Removal of COD, TSS, and Color in Batik Wastewater Using a Sequencing Batch Reactor (SBR)

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Abstract

The batik industry produces liquid waste with high concentrations of organic compounds, synthetic dyes and suspended solids. Based on initial testing, the COD, TSS and Color content exceeds the quality standard limits. The Sequencing Batch Reactor method with a batch operation system is used to process liquid waste and reduce pollutant parameters. There is an adsorption medium with coconut shell activated carbon as a pre-treatment in the efficiency of color parameter removal. The purpose of this study was to analyze the effect of HRT and aeration rate to reduce polluted parameters in batik liquid waste. The HRT variations used were 18, 24, 32, and 38 hours with aeration rates of 7 and 14 L/minute. The results obtained from this study, the most optimal HRT in reducing pollutant TSS parameters is HRT 32 hours with a removal percentage of 71.43%. HRT 38 hours with COD and TSS parameters with a removal percentage of 92.12% and 78.57% and Color parameters 62,39%. The optimal aeration rate is 14 l/minute.

Keywords: *Batik Waste, Color, COD, Sequencing Batch Reactor, TSS*

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1. Introduction

The batik industry in Indonesia is part of the rapidly growing creative industry sector and involves various business scales, from household activities, small and

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medium enterprises to large corporations (Apriyani, 2018). The batik production process, particularly the dyeing stage, produces liquid waste with a significant content of organic and inorganic substances. Furthermore, batik waste also contains various synthetic materials that are easily dissolved and difficult to degrade naturally. Dye waste from the textile industry is generally organic and non-biodegradable, thus having a high potential to pollute the environment, especially aquatic ecosystems (A`yunina et al., 2022). The characteristics of textile waste are known to be complex because they contain various pollutants, including Biological Oxygen Demand (BOD), hazardous chemicals, dyes, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) (Rachmawati et al., 2022). If not properly treated, the presence of these pollutants can degrade water quality, disrupt aquatic biological activity, and have detrimental impacts on human health and the surrounding environment.

A widely used technology in industrial wastewater treatment is the Sequencing Batch Reactor (SBR), a biological treatment system that operates in a single reactor with sequential stages and can be operated under both aerobic and anaerobic conditions (Wirakusuma et al., 2023). The main advantage of SBR lies in its flexibility in regulating operating time and the volume of waste treated, allowing this method to adapt to varying waste characteristics from various industrial sectors. In principle, the SBR process involves five main stages: the fill phase, the reaction phase, the settle phase, the decant phase, and the idle phase (Indrayani & Rahmah, 2018).

SBR performance is strongly influenced by operational factors, particularly the Hydraulic Retention Time (HRT) and aeration rate, which play a crucial role in controlling the activity of microorganisms as the primary agents of degradation of organic pollutants and synthetic dyes. Selecting the appropriate combination of HRT and aeration rate will increase removal efficiency, while inappropriate conditions can degrade reactor performance. Thus, this study focused on analyzing the effectiveness of SBR technology in removing COD, TSS, and color parameters from batik wastewater, while also evaluating the effect of variations in HRT and aeration rate on removal efficiency. Furthermore, the research findings are expected to contribute to the development of more efficient, environmentally friendly, and sustainable batik wastewater treatment strategies.

2. Method

2. 1 Tools and materials

The instruments used in this study were an aerator, laboratory instruments, a pre-treatment tank reactor, a rectangular holding tank measuring 38 cm x 30 cm with a total wastewater volume of 40 liters, and a Sequencing Batch Reactor (SBR). The materials used were batik wastewater, coconut shell activated carbon, and batik waste. The parameters tested included COD, TSS, and color. As a preliminary study, initial testing was conducted to determine the characteristics of the batik waste and the seeding process, followed by acclimatization. The quality standard used is Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number

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P.16/MENLHK/SETJEN/KUM.1/4/2019. The results of the initial characteristic analysis of the batik waste can be seen in Table 1.

Table 1. Initial Waste Characteristics

No	Parameter	Unit	Mark	Quality Standards
1.	COD	mg/l	1120	150
2.	TSS	mg/l	456	50
3.	Color	Pt-Co	869.7	200

2. 2 Research Procedures

The following is a research procedure regarding the previous research process and the main research, namely the operation of the sequencing batch reactor, as follows:

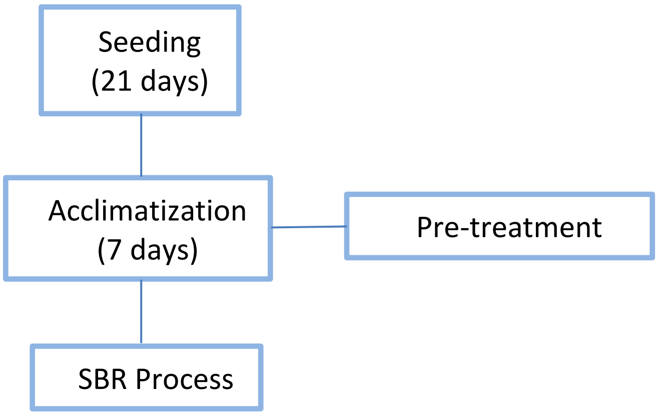

Figure 1: How Research Works

2. 3 Seeding and Acclimatization

Seeding is carried out at the stage as an initial step to grow microorganisms until a biofilm is formed which is characterized by a layer of black mucus on the reactor wall, carried out in batches with an even oxygen supply and a temperature of 28–31°C, where the MLSS value increases from 570 mg/l until the 6th day to 3160 mg/l until the 21st day, indicating consistent growth and approaching optimal standards (Hendrasarie & Febriana, 2022), so that the microorganisms are ready to enter the acclimatization stage. Furthermore, acclimatization is carried out in the SBR reactor with a gradual increase in waste concentration of 30%, 60%, up to 90% so that microorganisms can adapt to organic and toxic compounds (Ayuningtyas, 2020) and its success is shown by significant COD removal, indicating the resilience and effectiveness of microorganisms in degrading organic matter at high concentrations (Maria, 2019). So that this stage is an important basis for optimal reactor performance in research-scale waste treatment.

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2. 4 Pre-Treatment Stage

The pretreatment process of batik waste using the adsorption method with activated carbon media from coconut shells was able to reduce the COD concentration by 792 mg/L, TSS by 398 mg/L, and color from 667.9 Pt-Co to 452.2 Pt-Co with a removal efficiency of 32.3%. This stage plays a crucial role because the high color intensity in batik waste has the potential to disrupt the activity of microorganisms in subsequent biological processes. Intense color can inhibit light penetration into the media and is toxic to microorganisms, especially if it contains azo compounds that are difficult to degrade biologically. By reducing the color, COD, and TSS content in the initial stage, the pollutant load entering the Sequencing Batch Reactor (SBR) reactor is lower, so that the organic degradation process in the biological stage is expected to proceed more optimally and stably (Hendrasarie & Yadaturrahmah, 2021).

3. Result and Discussion

After the acclimatization process is completed with significant COD removal, the next stage is to operate the Sequencing Batch Reactor (SBR) by introducing 100% of the waste using HRT of 18 hours, 24 hours, 32 hours and 38 hours with an aeration rate of 7 l/minute and 14 l/minute. The following is the COD, TSS and Color removal efficiency produced during the SBR operation process in Table 2 as follows:

Table 2. Results of % Removal of SBR Reactor Operation Process

Running	Reactor	Aeration rate	HRT	% Removal COD		% Removal TSS		% Removal Color	
				inlet	outlet	inlet	outlet	inlet	outlet
1	1	7 L/minute	18	792	9,09	398	69,85	635,8	18,59
	2		24		39,19		74,87		45,93
	3		32		56,57		84,92		54,66
	4		38		84,24		87,44		62,39
	5	14 L/minute	18		36,36		67,34		13,95
	6		24		47,88		72,36		30,47
	7		32		65,25		89,98		40,26
	8		38		92,12		92,46		48,00

3.1 The Effect of HRT Variations and Aeration Rate on COD Removal

The following is the COD parameter removal efficiency for each HRT and the aeration rate produced during SBR operation is as follows:

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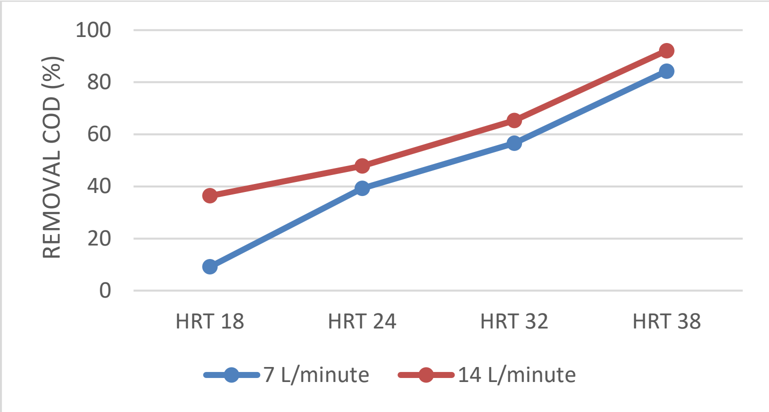

Figure 2. Relationship between % COD Removal and HRT Variation and Aeration Rate

Based on Figure 2, the highest COD removal efficiency reached 92.46% at a 38-hour HRT with an aeration rate of 14 L/minute, while the lowest efficiency was 67.34% at an 18-hour HRT with an aeration rate of 14 L/minute. The increase in efficiency with increasing HRT and aeration rate is due to longer aerobic reaction and stabilization times, allowing microorganisms to optimally degrade organic compounds. The degradation process even occurs since the filling stage when organic material concentrations are still high. However, at too long an HRT (38 hours), an endogenous phase occurs, namely a condition where food supply is reduced, the accumulation of biomass and metabolites disrupts the activity of microorganisms, so that removal efficiency decreases. Under anoxic conditions, COD removal occurs through denitrification with nitrate as an electron acceptor, while under oxic conditions, oxygen is more effective because organic compounds have been previously broken down (Raman et al., 2022). This study shows that COD removal reached 16.12% with the best HRT of 38 hours and an aeration rate of 14 L/minute, and has achieved the standard quality requirements for small industrial wastewater according to the Minister of Environment and Forestry Regulation No. P.16/2019 of 150 mg/L.

3.2 The Effect of HRT Variations and Aeration Rate on TSS Removal

The following is the TSS parameter removal efficiency for each HRT and the aeration rate produced during SBR operation can be seen in Figure 4 below.

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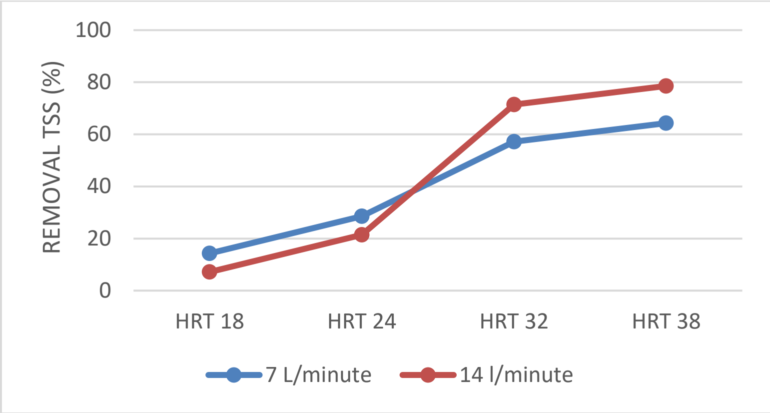

Figure 3. Relationship between % TSS Removal and HRT Variation and Aeration Rate

Based on Figure 3, TSS removal efficiency increases with increasing HRT, with the highest efficiency being 78.57% at a 38-hour HRT with an aeration rate of 14 L/min. However, under these conditions, there is also a loss of effectiveness due to some suspended solids being carried away during effluent discharge due to accumulation around the tap. At a 32-hour HRT, the efficiency has met the quality standard, namely 71.43% at 7 L/min aeration and 64.29% at 14 L/min aeration. Therefore, it can be said that the longer residence time provides sufficient opportunity for microorganisms to degrade organic matter while forming stable flocs. In general, TSS removal in SBR occurs through the degradation of organic matter by microorganisms and the settling of activated sludge flocs during the sedimentation phase. A longer HRT improves the settling process, while adequate aeration maintains oxygen supply and sludge stability. On the other hand, excessive aeration causes turbulence which inhibits sedimentation so that solids remain suspended in the effluent (Bieby Voijant et.al 2025).

3.3 The Effect of HRT Variations and Aeration Rate on Color Removal

The following is the efficiency of the Color parameter removal for each HRT and the aeration rate produced during SBR operation can be seen in Figure 4 below.

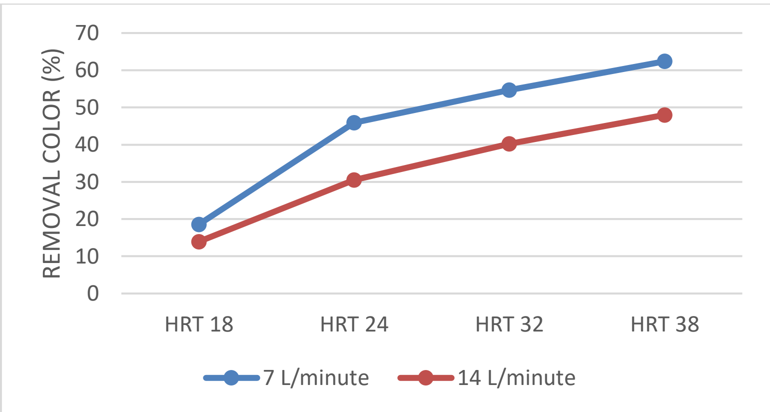

Figure 4. Relationship between % Color Removal and HRT Variation and Aeration Rate

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The color removal efficiency increased with the addition of HRT and aeration rate. At an aeration rate of 7 L/min, the efficiency rose from 18.69% (HRT 18 hours) to 62.39% (HRT 38 hours), while at 14 L/min, it increased from 13.95% to 48.00%. The best result was achieved at an HRT of 38 hours with an aeration rate of 14 L/min, resulting in a final color concentration of 62.39 Pt-Co. This improvement in efficiency indicates that the longer the hydraulic retention time, the more colored organic compounds are degraded, while a higher oxygen supply accelerates the biological oxidation process by microorganisms. This can be attributed to several factors, including a retention time that is too short, preventing microorganisms from having sufficient time to degrade complex compounds that form the dye substances (Indrayani & Rahmah, 2018). This is in line with research by (Hendrasarie et al., 2022) This finding aligns with the study by Wijayanti et al. (2019), which explained that sufficient oxygen availability can enhance bacterial metabolism in decomposing colored organic compounds. Therefore, the condition of 38 hours HRT and 14 L/min aeration rate can be considered the most effective for reducing batik wastewater color to meet the quality standards. The following are the results of batik wastewater that has been processed using biological processing, namely by using a Sequencing Batch Reactor, as follows:

Figure 5. Initial Waste (right), Processing Results (left)

4. Conclusion

The results showed that removal efficiency increased with increasing HRT and aeration rate. For COD, the highest efficiency reached 92.12% at 38-hour HRT with an aeration rate of 14 L/min, although at too long a residence time an endogenous phase occurred which reduced the performance of microorganisms. TSS removal also increased with the highest efficiency of 78.57% under the same conditions, but some solids were still carried away during effluent discharge due to accumulation around the tap. At 32-hour HRT, TSS efficiency met the quality standard with a value of 71.43% at 7 L/min aeration and 64.29% at 14 L/min aeration. Meanwhile, color removal showed an

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increase in efficiency from 18,59% at 18-hour HRT to 62,39% at 38-hour HRT with an aeration rate of 14 L/min. This increase in efficiency indicates that longer residence time and sufficient oxygen availability improve the activity of microorganisms in degrading organic compounds and dyes, so that HRT conditions of 38 hours and an aeration rate of 14 L/minute can be considered the most effective in processing batik liquid waste.

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