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Optimization of Rotation Speed, Disc Diameter, and Lighting Time in Batik Waste Treatment Using Rotary Algae Biofilm Reactor (RABR) with *Ulva* sp.

Sonya Hakim Raharjo[a*], Bekti Palupi[b], Rangga Yudha Syaifullah[a], Yohanes[a], Ratri Sekaringgalih[a], Nurul Hidayati[c]

[a]*Department of Chemical Engineering, Faculty of Engineering, Universitas Jember, Jember, East Java, 68121, Indonesia*

[b]*Research Center for Biobased Chemical Product, Jember, East Java, 68121, Indonesia*

[c]*Bioprocess Laboratory, Chemical Engineering, Universitas Jember, Jember, East Java, 68121, Indonesia*

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ABSTRACT*:* Batik, a cherished cultural heritage of Indonesia, requires ongoing protection and preservation. However, the batik production process generates liquid waste from various stages, including dyeing, washing, wax removal, and rinsing. Batik waste, if not treated properly, can harm the environment. Various studies have shown that effluent treatment using the *Rotary Algae Biofilm Reactor* (RABR) method is promising. This research focuses on improving the RABR design and optimal conditions for treating batik wastewater, as well as utilizing the synergy between batik production and *Ulva sp.* The variables used in this research are the Rotation Speed of 20, 30, and 40 rpm, the Lighting Time for 0, 6, and 12 hours, and the Disc Diameter size of 9, 11, and 13 cm. The parameters that analyzed are BOD, COD, and pH levels. Waste treatment optimization in this research uses the RSM with a combination of Design Expert 13 software. Based on the results, the most optimal batik wastewater treatment variable is when the Disc Diameter is 10.306 cm, the Rotation Speed is 20 rpm, and the Lighting Time is 7.805 hours. The BOD level decreased from 856.58 mg/L to 55.673 mg/L, the COD decreased from 631 mg/L to 25.538 mg/L, and the pH decreased from 11.99 to 10.406.

Keywords: batik waste; BOD; COD; RABR; *Ulva sp*.

1. Introduction

For centuries, batik has been a portion of Indonesian culture, and it has been recognized by UNESCO as a legacy for a long time (Fatimah et al., 2023). The great public interest in batik has caused the batik industry to experience an increase (Arofah et al., 2025; Siswanti et al., 2023). The development of the batik industry, which is commonly found in Indonesia, is a household-scale production (Fatiha & Irawanto, 2021; Subekti et al., 2020). One of the batik industry centers with household-scale production is located in Tegalsari Village, Ambulu District, Jember Regency. On the other hand, the water supply for the batik industry per year is equivalent to the provision of clean water for 2,500 households (Indrayani, 2018). The batik production process produces liquid waste that harm the environment (Virdiansyah & Nurkhamidah, 2024) because of dyes, which generally come from the colouring, washing, wax removal, and rinsing of batik cloth (Apriyani, 2018). Batik waste produces liquid waste with high Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), and pH (Indrayani, 2018). The initial levels contained in this batik liquid waste include BOD levels of 856.581 mg/L, COD levels of 631 mg/L, and pH levels of 11.99. The content of these waste levels is still not following the wastewater quality standards, because based on the Regulation of the Minister of Environment Number 5 of 2014 concerning textile wastewater quality standards, it states that for BOD parameters the highest levels allowed are 60 mg/L, COD levels of 150 mg/L, TSS of 50 mg/L, and pH 6.0-9.0 (Jannah & Muhimmatin, 2019).

Meanwhile, batik waste treatment is generally still performed in a very conventional way. One method involves sedimentation for 3-5 days. The sediment is discarded, while the water containing residual hazardous substances is directly drained into the public sewer without further treatment (Melfazen et al., 2022). Further than that, the sedimentation method has the disadvantage of requiring high installation and operational costs, and the separation process is less efficient (Munira et al., 2022). An approach for processing batik liquid waste that can help decompose organic compounds is the Rotary Algae Biofilm Reactor (RABR).

* Corresponding Author: +6285-786-847-156
Email address: sonyaraharjo@unej.ac.id

RABR is a type of photoconductor based on the design of the Rotating Biological Contactor, where microorganisms such as macroalgae grow on rotating disc-shaped media immersed in wastewater, creating a biofilm on the surface (Elystia et al., 2022). In the RABR system, macroalgae and bacteria work together in a mutual relationship. Bacteria use oxygen (O_2) to convert organic substances in wastewater into more stable compounds like NO^{3-}, CO_2, and PO_4^{3-}. Meanwhile, macroalgae use these products as raw materials for cell metabolism, driven by sunlight, which enables photosynthesis and oxygen production. This process helps reduce pollutant levels in wastewater. One macroalgae species used is *Ulva sp.*, a green macroalgae known for its efficient nutrient absorption and rapid growth. Besides its bioremediation capabilities, *Ulva sp.* also has antibacterial properties that can reduce health issues related to wastewater (Sode et al., 2013). This mutualism presents an innovative alternative technology for wastewater treatment (Jannah et al., 2023). The technology can remove organic matter with an efficiency of up to 95% (Suherman et al., 2020; Waqas et al., 2021). This study selected the RABR method for liquid waste processing due to its advantages, including simple operation, relatively low energy use, minimal sludge production, and easy maintenance. The following are some previous studies related to the use of the RABR method in Table 1.

Table 1. Previous Research Releated to RABR Method

Material	Method/Process	Operating Conditions	Results	Reference
Microalgae *Chlorella* sp.	Rotary Algae Biofilm Reactor (RABR)	Addition of 20 mL of kitchen waste MOL (VSS 3950 mg/L), 40 mL (VSS 4480 mg/L), and 60 mL (VSS 5170 mg/L) and contact time of 1, 3, and 5 days.	COD removal was 88.89%.	(Hamidah et al., 2023)
Microalgae *Chlorella* sp.	Rotary Algae Biofilm Reactor (RABR)	Rotation speed is 3 rpm, 5 rpm, and 7 rpm and contact time is 0, 1, 3, and 5 days.	BOD removal was 73.42% with an initial concentration of 737.4 to 196 mg/L and COD 70.64% with an initial concentration of 981 mg/L to 288 mg/L.	(Jannah et al., 2023)
Microalgae *Chlorella* sp.	Rotary Algae Biofilm Reactor (RABR)	Variation of RABR process speed (2, 4, and 6 rpm) and contact time (0, 1, 3, 5, 7 days).	The concentration of COD reduction was 210 mg/L with a reduction efficiency of 73.08%.	(Nurrahmadhani et al., 2020)
Microalgae *Chlorella* sp.	Rotary Algae Biofilm Reactor (RABR)	The variation of submerged disc depth was 40%, 60%, and 80% at 0, 1, 3, and 5 days of contact.	The COD removal efficiency was 81.58% with a concentration of 100 mg/l and an increase in TSS concentration of 522 mg/l.	(Mardhatillah et al., 2021)
Microalgae *Chlorella* sp.	Rotary Algae Biofilm Reactor (RABR)	Variation of disc surface roughness (type 1, type 2 and type 3) in Rotary Algae Biofilm Reactor process and contact time (0, 1, 3, 5 days)	Removing NH3 concentration of 3.26 mg/l and removal efficiency of 83.84%.	(Amelia. et al., 2021)
Microalgae *Chlorella* sp.	Rotary Algae Biofilm Reactor (RABR)	Variation of wastewater turnover period every 3 days, every 4 days and every 6 days for a total of 12 days	The COD removal efficiency of tofu liquid waste reached 90.24% with the final COD concentration of 64 mg/L.	(Elystia et al., 2024)
Microalgae *Chlorella* sp.	Rotary Algae Biofilm Reactor (RABR)	The treatment of tofu liquid waste concentration is 40%, 60%, 80%, and 100% and the duration of contact (0, 1, 3, and 5 days).	The highest COD and NH3 reductions were 75.88% and 80.45%, respectively.	(Elystia et al., 2023)

Based on previous research, this research objectives to optimize the Rotary Algae Biofilm Reactor (RABR) system using *Ulva* sp. in reducing Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and pH levels in batik industry wastewater. The main objective of this study is to examine the effect of variations in Rotation Speed,

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Diameter of the Rotating Disc, and Lighting Time using Sunlight Exposure on the performance of the RABR system.

2. Materials and Methods

2.1. Materials

The materials used were alkali iodide azide (NaN_3, NaOH, and NaI), sulfuric acid (H_2SO_4) 96%, starch indicator, potassium dichromate ($K_2Cr_2O_7$), manganese sulfate ($MnSO_4$) 1 N, and sodium thiosulfate ($Na_2S_2O_3$) 0.025 N, and COD reagent brand HANNA High Range 93754C-25. The macroalgae used was *Ulva* sp. or green algae that was obtained from Sanur Beach, Denpasar City, Bali Island.

2.2. Methods

The main bioreactor used in the processing of UMKM batik wastewater are RABR measuring 30 cm x 30 cm x 30 cm, glass tools, COD thermo-reactor brand VELP Scientifica F101A0127 ECO8, wastewater treatment photometer brand HANNA Instrument HI-83214, analytical balance, stand & clamp, and pH meter. The RABR Design image is shown in Figure 1.

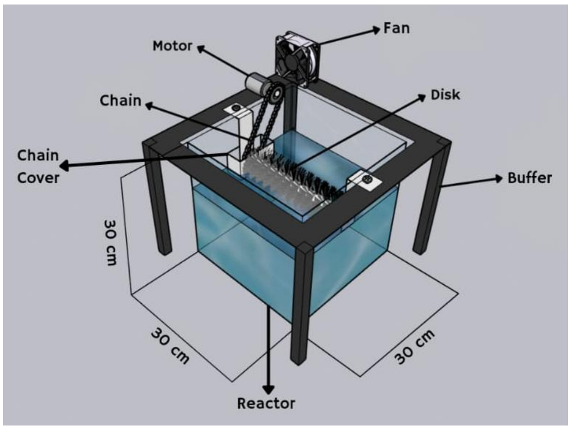

Figure 1. Rotary Algae Biofilm Reactor (RABR) Design

The independent variables used include the size of the Disc Diameter, Rotation Speed, and Lighting Time. Each RABR is given a Disc Rotation Speed variable of 20, 30, and 40 rpm. Other independent variables are the Lighting Time for 0, 6, and 12 hours where the reactor is placed in a location exposed to direct sunlight, and the variable size of the Disc Diameter used is 9, 11, and 13 cm. The control variables are the addition of the amount of *Ulva* sp. suspension in the RABR by 5% (300 g), the addition of urea as much as 0.5 g, and the addition of fine salt as much as 120 g. The dependent variables are Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and pH. Furthermore, the design variables for optimization are shown in Table 1. The dependent variables are Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and pH. Furthermore, the design variables for optimization are shown in Table 1. variables are Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and pH. Furthermore, the design variables for optimization are shown in Table 1.

This study was conducted in three primary stages. Initially, a preliminary analysis was performed on the raw batik wastewater to establish baseline characteristics. This involved measuring the initial Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and pH levels prior to treatment. For the second stage, the treatment process was initiated by introducing 12 L of batik wastewater and a specified mass of *Ulva* sp. into a Rotating Algal Bioreactor (RABR). Following the designated treatment period, samples of the processed effluent were collected. These final samples were then analyzed to determine the terminal pH, BOD, and COD concentrations to evaluate the efficacy of the RABR system.

Table 2. Research Design Varibles for Optimization

Var	Disc Diameter (D) (cm)	Rotation Speed (µ) (rpm)	Lighting Time (t) (hours)
P1	11	40	0
P2	11	30	6
P3	13	30	0
P4	9	30	12
P5	9	20	6
P6	11	40	12
P7	13	20	6
P8	9	30	0
P9	11	30	6
P10	11	30	6
P11	11	30	6
P12	9	40	6
P13	13	30	12
P14	11	30	6
P15	11	20	0
P16	11	20	12
P17	13	40	6

2.3. Analysis of Batik Liquid Waste

2.3.1. Analysis of pH

The pH testing procedure was carried out to determine the pH level of batik wastewater both before and after processing using RABR. The pH test was carried out periodically according to the variable Lighting Time used, namely 0, 6, and 12 hours. This test uses a digital pH meter.

2.3.2. Analysis of *Biological Oxygen Demand (BOD)*

This BOD level test is carried out with reference to SNI 6989.72:2009. The principle of BOD measurement is by measuring the initial dissolved oxygen content (DO_0) of the sample and measuring the dissolved oxygen content in samples that have been incubated for 5 days at a constant temperature (20˚C) (DO_5) (A. Ramadhani & Purnama, 2023). The calculation for finding the BOD level can be calculated using equations 1 and 2.

$$OT = \frac{\alpha \, x \, N \, x \, 8000}{V - n} \quad (1)$$

$$BOD = \frac{(X_0 - X_5) - (B_0 - B_5)(1 - P)}{P} \quad (2)$$

Remarks:
OT = disolved oxygen (mgO_2/L)
α = titrant volume (mL)
N = normality of solution (ek/L)
V = winkler bottle volume (mL)
n = solution added (mL)
X = disolved oxygen samples (mg O_2/L)
B = disolved oxygen blanko (mg O_2/L)
P = degree of dilution

2.3.4. Analysis of *Chemical Oxygen Demand* (COD)

Periodic testing of Chemical Oxygen Demand (COD) levels according to the variable Lighting Time used, namely 0, 6, and 12 hours. Measurement of COD levels using the spectrophotometric method refers to SNI 6989.2:2019 (*Cara Uji COD dengan Refluks Tertutup Secara Spektrofotometri*, 2019).

2.3.5. Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is used to determine the significance of the response analysis between variables from each treatment result of batik liquid waste samples, and to determine the model by Design Expert (Ramadhani et al., 2017). Variation table for Analysis of Variance (ANOVA) using Design Expert 13 software along with its response.

3. Results and Discussion

The characteristics of Batik Rezti waste were examined before waste treatment.

Table 3. Characterization of Rezti's Batik Waste

Parameters	Rezti's Batik Waste Content	Quality Standards of Textile Waste
BOD (mg/L)	856.58	60
COD (mg/L)	631	150
pH	11.99	6.0 – 9.0

The standard quality of this batik waste will be compared based on the Regulation of the Government of the Republic of Indonesia on Environment and Forestry. Table 2 shows the characteristics of waste before waste processing and the standard quality of textile industry waste. Table 3 shows the results of BOD, COD, and pH tests.

3.1. Effect of Disc Diameter, Rotation Speed, and Lighting Time on Biological Oxygen Demand (BOD) Reduction

The recommended BOD model response value is the Quadratic model, as determined by the results of the analysis of variance or Analysis of Variance (ANOVA) on the Design Expert 13 (Tablr 5). The results of the ANOVA statistical analysis indicate that the model is adequate with a p-value of less than 0.05. Each component of the model is tested using the results of the p-value. Variables with a p-value <0.05 are considered significant and have a significant influence on the model because the probability level of the research used is 5% (Stefany, 2023).

Table 4. Response data for *Biological Oxygen Demand* (BOD), *Chemical Oxygen Demand* (COD), and pH

Run	Variables			Response		
	D (cm)	µ (rpm)	t (hours)	BOD (mg/L)	COD (mg/ L)	pH
1	11	40	0	115.493	227	10.36
2	11	30	6	62.349	46	10.42
3	13	30	0	169.892	214	10.44
4	9	30	12	218.429	146	10.39
5	9	20	6	68.570	27	10.47
6	11	40	12	122.751	89	10.67
7	13	20	6	79.426	87	10.63
8	9	30	0	56.765	171	10.58
9	11	30	6	55.673	49	10.44
10	11	30	6	56.587	42	10.43
11	11	30	6	56.586	47	10.43
12	9	40	6	142.723	135	10.55
13	13	30	12	60.326	98	10.81
14	11	30	6	57.362	51	10.44
15	11	20	0	70.281	121	10.51
16	11	20	12	84.255	93	10.43
17	13	40	6	87.874	72	10.63

The response value of the experiment shows that the p-value> 0.05, where the p-value on the lack of fit given is 0.0643; therefore, this BOD response model is not accurate (Table 4). This shows that the model and accuracy of the analysis are correct and able to explain the problems in the analysis carried out. BOD levels decreased significantly, reaching 93.50% with an initial level of 856.5811966 mg/L to 55.673 mg/L. Based on Figure 2, it can be concluded that the larger the size of the Disc Diameter used, the more significant the decrease in BOD levels. The data shows that the BOD value at a Disc Diameter of 11 cm provides a specific decrease. This is also supported by other variables, namely, the greater the Rotation Speed used, the more significant the decrease in BOD levels. Figure 3 shows that BOD at a Disc Diameter of 11 cm and longer the Lighting, can provide a specific decrease in BOD. Figure 4 shows that the greater the Rotation Speed used and the longer the Lighting Time, the BOD levels will decrease.

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Table 5. ANOVA Result of BOD Value Response

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	35396,23	9	3932,91	186,40	< 0,0001	significant
A-Disk Diameter	982,49	1	982,49	46,57	0,0002	
B-Rotation Speed	3470,36	1	3470,36	164,48	< 0,0001	
C- Length of Sunlight Exposure	672,16	1	672,16	31,86	0,0008	
AB	1089,59	1	1089,59	51,64	0,0002	
AC	18391,43	1	18391,43	871,67	< 0,0001	
BC	11,28	1	11,28	0,5344	0,4885	
A^2	4449,64	1	4449,64	210,89	< 0,0001	
B^2	79,68	1	79,68	3,78	0,0931	
C^2	5497,33	1	5497,33	260,55	< 0,0001	
Residual	147,69	7	21,10			
Lack of Fit	119,38	3	39,79	5,62	0.0643	not significant
Pure Error	28,32	4	7,08			
Cor Total	35543,92	16				

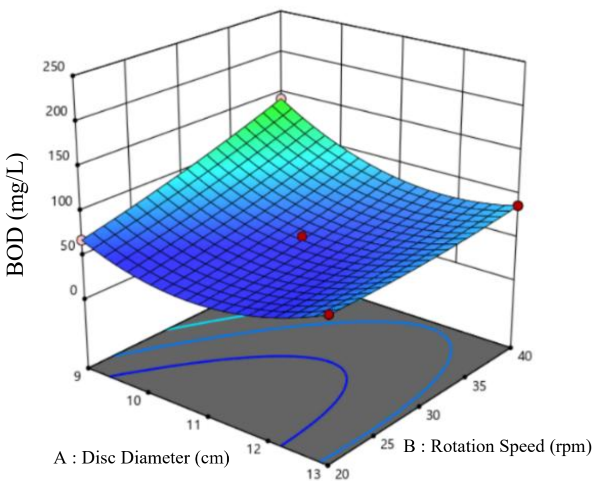

Figure 2. The Effect of Disc Diameter and Rotation Speed (rpm) on BOD Reduction (mg/L)The Effect of Disc Diameter (cm) and Rotation Speed (rpm) on BOD Reduction (mg/L)

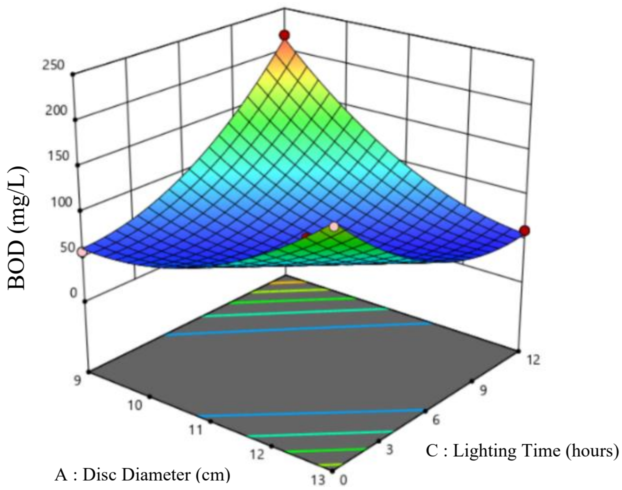

Figure 3. The Effect of Disc Diameter (cm) and Lighting Time (hours) on BOD Reduction (mg/L)

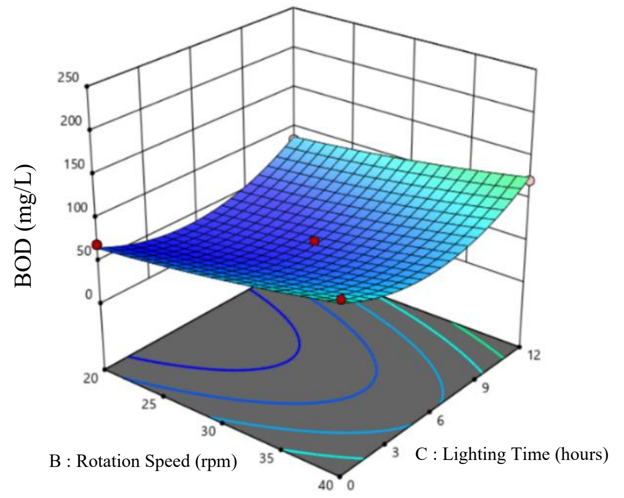

Figure 4. The Effect of Rotation Speed (rpm) and Lighting Time (hours) on the BOD Reduction (mg/L)

The decrease in BOD values seen in this study was due to the biodegradation of organic matter such as protein, carbohydrates, lipids, and oils by macroalgae and bacteria found in batik waste. Macroalgae and bacteria contribute significantly to nutrient cycling and pollution removal through biosynthesis and metabolic processes. Macroalgae and bacteria form a mutualistic relationship in waste media. Macroalgae produce oxygen (O_2) through photosynthesis, which is then consumed by bacteria. Therefore, the longer the process time, the better it is for removing pollutants. The decrease in value can also be caused by the degradation and decomposition of organic matter in the biofilm layer attached to the surface of the disc media, which is assisted by the aeration process (the process of adding air or oxygen to water, liquid, or substance), which reduces the concentration of pollutants (Mustofa & Febriyana, 2024).

3.2. Effect of Disc Diameter, Rotation Speed, and Lighting Time on the Chemical Oxygen Demand (COD) Reduction

Based on the analysis results, the COD value model uses the Quadratic model, as determined by the results of the analysis of variance or Analysis of Variance (ANOVA) on the Design Expert 13.

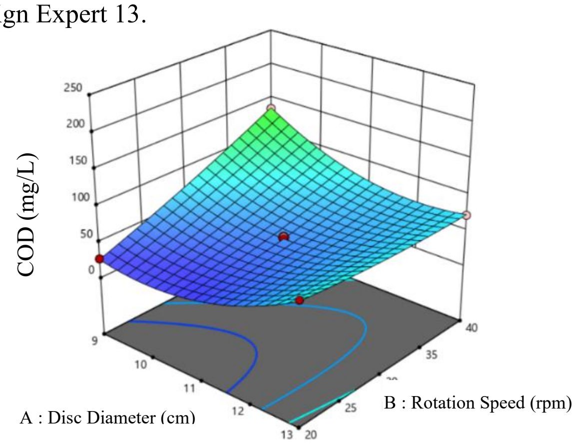

Figure 5. The Effect of Disc Diameter (cm) and Rotation Speed (rpm) on COD Reduction (mg/L)

The results of the ANOVA analysis on the COD response showed that the response value was significant. COD levels decreased significantly (Table 6), reaching 95.72% with an initial level of 631 mg/L to 27 mg/L.

Table 6. ANOVA Result of COD Value Response

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	58347,01	9	6483,00	336,78	< 0,0001	significant
A-Disk Diameter	8,00	1	32,00	0,4156	0,5397	
B-Rotation Speed	4753,13	1	4753,13	246,92	< 0,0001	
C- Length of Sunlight Exposure	11781,12	1	11781,12	612,01	< 0,0001	
AB	3782,25	1	3782,25	196,48	< 0,0001	
AC	2070,25	1	2070,25	107,55	< 0,0054	
BC	3025,00	1	3025,00	157,14	< 0,0001	
A²	3541,05	1	3541,05	183,95	< 0,0001	
B²	76,05	1	76,05	3,95	0,0872	
C²	27796,65	1	27796,65	1443,95	< 0,0001	
Residual	134,75	7	19,25			
Lack of Fit	88,75	3	29,58	2,57	0,1918	not significant
Pure Error	46,00	4	11,50			
Cor Total	58481,76	16	55718,94			

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Based on Figure 5, it can be concluded that the larger the Disc Diameter used, the more significant the decrease in COD levels. The data shows that the COD value at a Disc diameter of 11 cm provides a corresponding decrease. This is also supported by other variables, namely, the greater the Rotation Speed used, the more significant the COD levels. Figure 6 shows that the longer the Lighting and the larger the Disc Diameter, can provide the specific COD decrease. Figure 7 shows that the greater the Rotation Speed is used and the longer the Lighting is used, the COD levels will decrease.

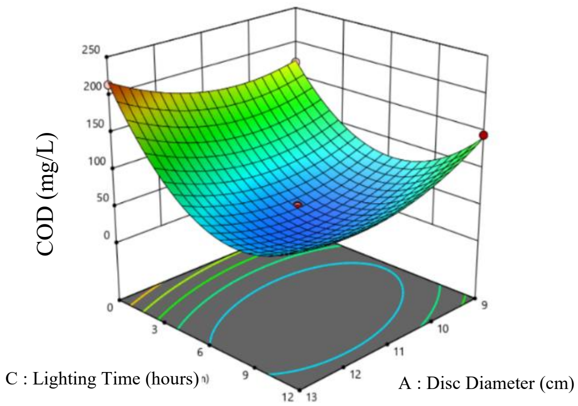

Figure 6. The Effect of Disc Diameter (cm) and Lighting Time (hours) on COD Reduction (mg/L)

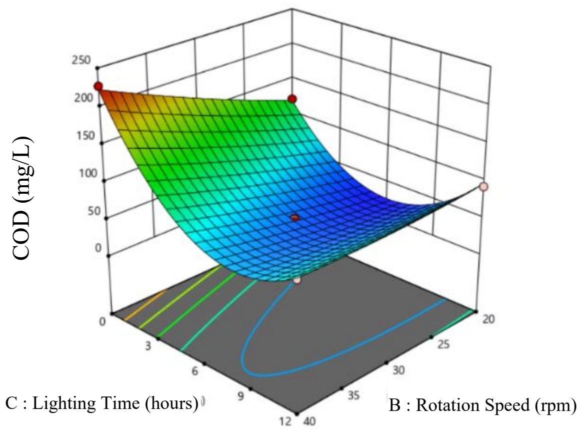

Figure 7. The Effect of Rotation Speed (rpm) and Lighting Time (hours) on COD Reduction (mg/L)

Significant amounts of oxygen are required to oxidize all organic and inorganic compounds in water, resulting in high COD values. The decrease in this number is related to the activity of bacteria in biofilms, such as oxidation, which decomposes organic content in liquid waste (Islamawati et al., 2018). The longer the contact period between waste, microorganisms, and air, the more oxygen (O_2) is available in the media, resulting in a thicker layer of microorganisms in the biofilm and lower concentrations of contaminants in the waste sample (Susilo et al., 2016).

3.3. Effect of Disc Diameter, Rotation Speed, and Lighting Time on pH Value Response

Based on the analysis results, the pH value response model uses the Quadratic model, as determined by the results of the analysis of variance on the Design Expert-13 (Table 7).

The ANOVA results on the pH response showed that the response value was significant. The pH level decreased by 13.60%, but it still did not follow the quality standard, namely with an initial level of 11.99 to 10.36. Based on Figure 8, it can be concluded that the larger the Disc Diameter is used, the lower the pH level. The data shows that the pH value at a Disc Diameter of 11 cm decreased. This is also supported by another, namely the Rotation Speed at 30 rpm, which can reduce the pH level. Figure 9 shows that the longer the use of Lighting and the larger the Disc Diameter can reduce the pH, although it is still less specific. Figure 10 concludes that the higher the Rotation Speed used and the longer the use of Lighting, the lower the pH level.

According to (Siswandari et al., 2016), maximum pH that can be discharged into the environment is 6-9. The pH of the liquid media affects the solubility of the metals in it. As a result, if the water contains significant levels of metals such as Pb, the pH will decrease. The results of the study showed that the pH level was still high at 10.36. The pH value is directly related to the carbon dioxide (CO_2) value and increasing CO_2 levels in wastewater result in a decrease in the pH value. This is triggered by the separation of electrons during the bicarbonate reaction. Increasing pH reduces the solubility of metals ranging from carbonate ions to hydroxides and also forms particle bonds in aquatic bodies (Fatiha & Irawanto, 2021). Diameter and Lighting Time have a stronger influence on the decrease in pH, especially at larger diameters, because macroalgae will actively attach to the disc media where oxygen transfer occurs, encouraging the development of macroalgae and biochemical activity with the help of sunlight which can encourage a decrease in pH. Based on (Gao, 2021), a way to control pH stability in algae is by cultivating algae. There are many methods or approaches to cultivating algae, such as pretreatment through aeration, manipulating biomass density to achieve stable carbonate chemistry, and adding CO_2. One recommendation from these three methods is to control pH in solid cultures of both microalgae and macroalgae, where high CO_2 levels above 10,000 ppm or pure CO_2 are injected into the culture to examine the physiological response to carbonate chemistry, as solid cultures usually cause significant variations in pH.

Table 7. ANOVA Resulto f pH Value Response

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0,2305	9	0,0256	222,71	< 0,0001	significant
A-Disk Diameter	0,0338	1	0,0338	293,91	< 0,0001	
B-Rotation Speed	0,0036	1	0,0036	31,41	0,0008	
C- Length of Sunlight Exposure	0,0210	1	0,0210	182,72	< 0,0001	
AB	0,0016	1	0,0016	13,91	0,0074	
AC	0,0784	1	0,0784	681,74	< 0,0001	
BC	0,0380	1	0,0380	330,65	< 0,0001	
A²	0,0423	1	0,0423	367,97	< 0,0001	
B²	0,0060	1	0,0060	52,18	0,0002	
C²	0,0022	1	0,0022	19,95	0,0033	
Residual	0,0008	7	0,0001			
Lack of Fit	0,0005	3	0,0002	2,50	0,1985	not significant
Pure Error	0,0003	4	0,0001			
Cor Total	0,2313	16				

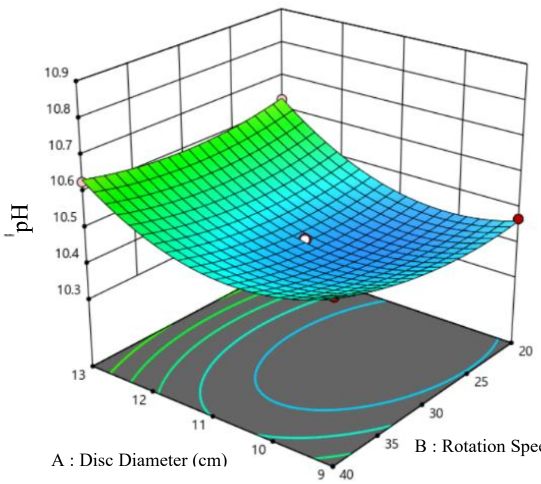

Figure 8. Effect of Disc Diameter (cm) and Rotation Speed (rpm) on pH Reduction

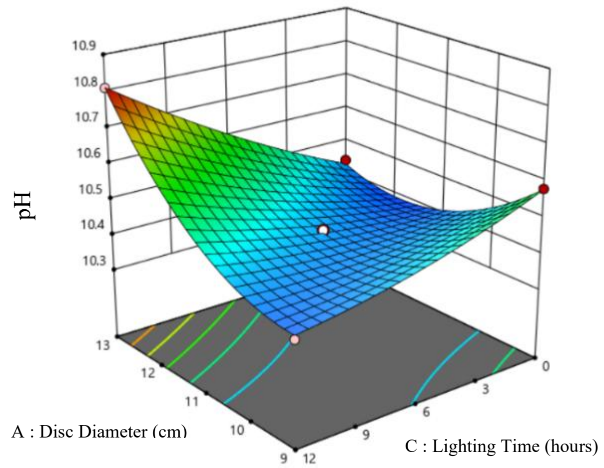

Figure 9. Effect of Disc Diameter (cm) and Lighting Time (hours) on pH Reduction

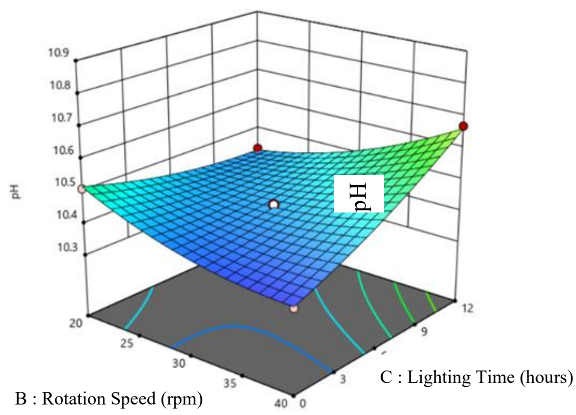

Figure 10. Effect of Rotation Speed (rpm) and Lighting Time (hours) on pH Reduction

Table 8. Comparison with Previous Research

Methods	Algae	BOD	COD	pH	Ref
Composite in situ treatment system	*Caulerpa lentillifera*	-	68.61%	-	(Ye et al., 2024)
Bioremediation	*Klebsormidium flaccidum*	93%	74%	-	(Novak et al., 2024)
Algal-mediated green synthesis NPs	*Ulva fasciata Delile*	88.50%	88.80%	-	(Fouda et al., 2022)
Photobioreactor	*Ulva lactuca*	-	94.10%	-	(Mhatre-Naik et al., 2021)
Column treatment plant	*Chlorella* sp	51.20%	53.10%	-	(Deviram et al., 2011)
RABR	*Ulva* sp.	93.50%	95.72%	13.60%	(This research)

3.4. RABR Design Optimization Results

The optimal condition analysis using Design Expert 13. The top solution achieved the following results: a Disc Diameter (D) of 10,306 cm, a Rotation Speed (μ) of 20,000 rpm, a Lighting Time (t) of 7.805 hours, a BOD level of 55.673 mg/L, a COD level of 25.538 mg/L, and a pH of 10. In sum, the comparison this research and previous research results is presented by Table 8. RABR process with *Ulva* sp. significantly reduce COD, BOD, and pH.

4. Conclusions

Based on the research, it was concluded that the variables of Disc Diameter, Rotation Speed, and Lighting Time significantly affect the effectiveness of batik wastewater treatment using the RABR method. The optimization results show that this system is capable of reducing BOD and COD to meet environmental quality standards, although the pH value of the treated effluent still does not meet the standards. These findings emphasize the importance of adjusting operational variables to improve RABR performance, while also highlighting the need for further development to address pH challenges in the batik wastewater treatment process. The challenges in future research, it is expected to conduct pre-treatment to increase the solubility of CO_2 in its distribution within the culture medium of microalgae and macroalgae towards pH stability.

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Statement

During the preparation of this work the authors used deepL translator in order to improve English language and proofread the text. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Sonya Hakim Raharjo: Writing – review & editing, Writing – original draft, Validation. **Bekti Palupi:** Funding acquisition, Project administration, Supervision. **Rangga Yudha Syaifullah:** Formal analysis, Investigation. **Yohanes, Yohanes:** Formal analysis, Investigation, Visualization. **Ratri Sekaringgalih:** Validation. **Nurul Hidayati:** Resources

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data may be shared upon request

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