

Hybrid Constructed Wetland Performance Using *Cyperus rotundus* for Batik Wastewater Treatment

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Abstract

Batik industry wastewater contains organic matter, suspended solids, phenolic compounds, and heavy metals that can pollute water bodies if left untreated. This study evaluated the Hybrid Constructed Wetland (HCW) with Vertical and Horizontal Subsurface Flow using *Cyperus rotundus* to treat batik wastewater at laboratory scale. Two Hydraulic Retention Times (HRT) of 4 and 8 days were compared, representing the first application of *C. rotundus* in a hybrid VSSF-HSSF configuration for batik wastewater treatment. Parameters analyzed included BOD, COD, TSS, TDS, phenol, total chromium, pH, and temperature. Initial characterization showed BOD, COD, TSS, phenol, and pH exceeded quality standards, while TDS and total chromium complied. HCW treatment showed the best overall performance at an HRT of 8 days for most parameters, with removal efficiencies of 83.73% (BOD), 91.36% (COD), 98.98% (TSS), 98.56% (total chromium), although phenol removal was marginally higher at 4 days (98.27% vs 96.30%), while TDS increased by 71.21% at 8 days. These results indicate that the HCW system with *C. rotundus* effectively improves batik wastewater quality and offers potential as a simple, eco-friendly treatment alternative, although BOD and COD concentrations remained above the applicable quality standards after treatment, and further optimization is needed to fully meet effluent standards.

Keywords: Batik Industry, *Cyperus rotundus*, Hybrid Constructed Wetland, Hydraulic Retention Time, Wastewater.

INTRODUCTION

Batik is a craft of high artistic value that has been part of Indonesian culture for centuries and was recognized by UNESCO in 2009 as a Masterpiece of the Oral and Intangible Heritage of Humanity. The batik industry uses large amounts of water in production, with resulting liquid waste reaching 80% of water used (Soeprijanto et al., 2023). Batik and textile wastewater from the dyeing process contains non-biodegradable synthetic compounds; only about 5% of dyeing compounds are utilized, while 95% are released as liquid waste. These stable chemical dyes are difficult to degrade and, at high concentrations, increase COD and BOD levels, causing environmental pollution (Sirait, 2018).

Constructed wetlands (CWs) are engineered systems using wetland vegetation, treatment media, and microbial communities to remove pollutants, and have been applied to various industrial effluents, including textile wastewater. CWs may be surface or subsurface-flow (horizontal or vertical), and hybrid CWs combine these configurations to integrate complementary treatment processes (Vymazal, 2014). For small-scale batik producers, wastewater treatment technologies that are simple to operate and relatively low-cost are important to support practical and sustainable wastewater management.

Usama et al., (2023) investigated control of surface water pollution from batik home industry wastewater in Wijirejo Village, Pandak Subdistrict, Bantul Regency, using an Advanced Oxidation Process Granular Activated Carbon (AOP-GAC), and found that BOD, COD, and phenol parameters exceeded quality standards. Rahmadyanti & Audina (2020) in Kampoeng Batik Jetis, Sidoarjo, applied a combination of Vertical Subsurface Flow (VSSF) and Horizontal Subsurface Flow

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(HSSF) Hybrid Constructed Wetland (HCWs) with *Canna indica* plants to batik wastewater.

The specific use of *C. rotundus* has been studied for other wastewater types. [Erwin \(2017\)](#) applied a subsurface flow CW system with *C. rotundus* to reduce phosphate and COD levels in laundry wastewater, concluding it showed potential as a phytoremediator. More recently, [Imron et al. \(2024\)](#) reported that *C. rotundus* in a batch constructed wetland treating aquaculture effluent achieved removal efficiencies of 70% for COD, 79% for BOD, and 90% for TSS, without adverse effects on plant growth. These findings indicate that *C. rotundus* can tolerate wastewater exposure and contribute to the removal of organic and suspended pollutants, supporting its consideration as wetland vegetation. However, its application for batik wastewater, particularly in a hybrid VSSF-HSSF configuration, has not yet been investigated. This study therefore investigates *C. rotundus* in an HCW combining VSSF and HSSF for batik wastewater treatment, aiming to characterize wastewater quality (BOD, COD, TDS, TSS, phenol, total chromium) and evaluate the system's effectiveness in reducing these pollutants.

LITERATURE REVIEW

Batik Industrial Wastewater

Batik wastewater characteristics vary with textile type and chemicals used, typically containing high BOD, COD, and TSS, along with grease, wax, surfactants, and trace metals originating from dyes, especially azo dyes ([Zakaria et al., 2023](#)). Recent studies have also reported substantial organic and phenolic pollutant loads in batik wastewater, with COD concentrations reaching 4,256 mg/L, BOD 772 mg/L, and phenol 0.33-2.36 mg/L, highlighting the complexity of batik wastewater and the need for treatment ([Musawwa et al., 2026](#)). High concentrations of suspended solids also interfere with oxygen transfer, while heavy metals such as chromium may pose risks to aquatic ecosystem ([Zakaria et al., 2023](#)).

Hybrid Constructed Wetland

Constructed wetlands (CWs) are engineered systems that mimic natural wetland processes using vegetation, soil, and microorganisms. Based on flow direction, CWs are classified as horizontal-flow (HFCWs) or vertical-flow (VFCWs). These complementary strengths and limitations led to hybrid constructed wetlands (HCWs), which combine two or more configurations—commonly VFCW followed by HFCW—so that the VFCW promotes aerobic nitrification while the HFCW provides anaerobic conditions for denitrification and further pollutant removal ([Waly et al., 2022](#)). For batik wastewater specifically, [Rahmadyanti & Audina \(2020\)](#) applied a combination of VSSF and HSSF HCW planted with *Canna indica* in Kampoeng Batik Jetis, Sidoarjo, achieving removal efficiencies of up to 89.61% for COD (day 3), 98.74% for TSS (day 5), and 89.53% for FOG (day 3), demonstrating the viability of the hybrid VSSF-HSSF configuration for this type of wastewater.

Cyperus rotundus

Cyperus rotundus (nutgrass), typically regarded as a terrestrial weed, has shown notable tolerance to wastewater exposure. In a batch constructed wetland treating aquaculture effluent, it achieved removal efficiencies of 70% COD, 79% BOD, 90% TSS, 96% turbidity, 64% ammonia, 82% nitrate, 92% nitrite, and 48% phosphate, with no adverse effects on plant growth ([Imron et al., 2024](#)). It has also proven effective for parasite removal in domestic wastewater when planted in sand substrate ([Shingare et al., 2017](#)). Overall, *C. rotundus* shows strong potential for hybrid constructed wetland applications, though performance may vary with wastewater characteristics, substrate, plant density, HRT, and wetland configuration.

Hydraulic Retention Time (HRT)

Hydraulic Retention Time (HRT) the average time wastewater remains in a reactor, calculated as the reactor's effective volume divided by the flow rate determines the contact duration between wastewater and the filter media or microorganisms, directly influencing pollutant removal efficiency (Lamuel et al., 2022). A longer HRT generally allows more complete degradation, adsorption, and biological uptake of pollutants (Yeh & Wu, 2009), but an excessively long HRT can lead to substrate saturation and declining efficiency, as shown in a batik wastewater HCW study where COD and TSS removal dropped after several days of continuous loading, and where the optimum HRT varied by parameter across HRTs of 3, 5, and 7 days (Rahmadyanti & Audina, 2020). This study therefore selected HRTs of 4 and 8 days to compare shorter and longer retention periods and evaluate their effects on pollutant removal using *C. rotundus* in a hybrid VSSF-HSSF system.

RESEARCH METHODOLOGY

Wastewater Location and Source

The study was conducted at a household-scale batik industry in Wijirejo Village, Pandak Subdistrict, Bantul Regency, Special Region of Yogyakarta. Approximately 40 L of composite wastewater samples were collected from the equalization tank at 1:00 PM WIB for laboratory testing and Hybrid Constructed Wetland (HCW) experiments.

Experimental Design HCW

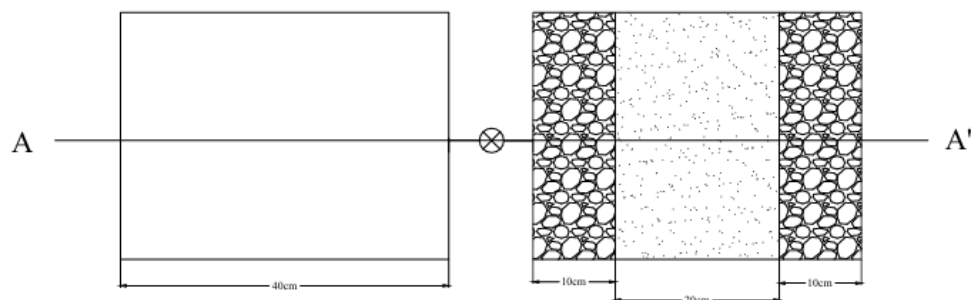


Figure 1. Top View of the Experimental Design

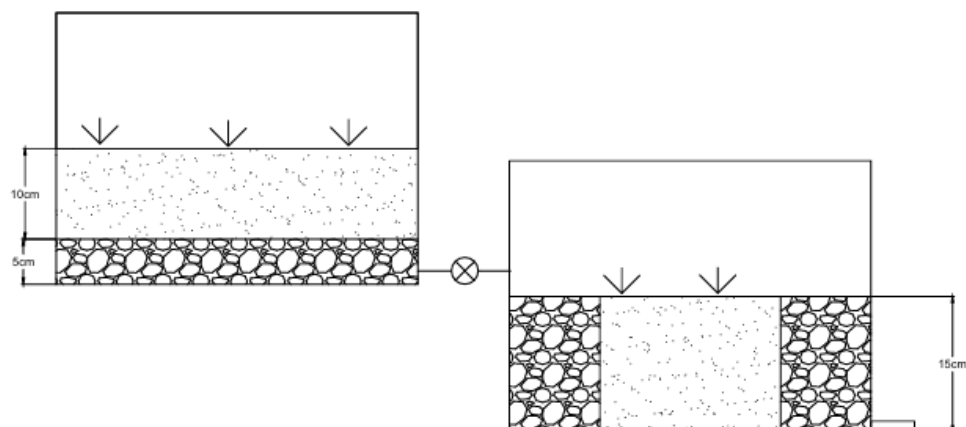


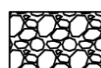
Figure 2. Section A-A'

Description :



= Sand 2-4 mm

= Gravel 20-30



mm

= *C. rotundus*



This laboratory-scale study used a Hybrid Constructed Wetland (HCW) system combining Vertical Subsurface Flow (VSSF) and Horizontal Subsurface Flow (HSSF) units in series (glass aquarium reactors, 40 x 30 x 30 cm, 5 L wastewater volume per reactor per batch cycle): see Figure 1 and 2. Reactors operated in batch mode without continuous flow, with 4- and 8-day HRTs representing the batch duration for each loading cycle. Media consisted of 10 cm of 2-4 mm volcanic sand as the filtration layer and 5 cm of 20-30 mm gravel as the drainage layer, planted with *C. rotundus* (6 clumps per reactor), selected for its fibrous root system supporting microbial growth and pollutant uptake.

The control reactor contained raw wastewater only, without gravel, sand, or plants, and was left undisturbed for the same period, distinguishing passive attenuation (e.g., settling) from the combined effect of media, microorganisms, and plant uptake in treated reactors. Before operation, plants were acclimatized for 18 days, starting with clean water (3 days) followed by gradual introduction of wastewater at 25%, 50%, 75%, and 100% concentrations to minimize stress. Two HRT variations were tested in triplicate with a control: 4 days (1-day VSSF, 3-day HSSF) and 8 days (2-day VSSF, 6-day HSSF). The 1:3 VSSF-to-HSSF allocation provided a shorter vertical-flow stage followed by a longer horizontal-flow stage within each batch. Each reactor received 5 L of wastewater per cycle and was left undisturbed until sampling. After acclimatization, wastewater samples served as influent, and reactors were operated per each HRT until effluent was obtained. Effluent was analyzed for BOD, COD, TSS, TDS, phenol, total chromium, pH, and temperature. Figure 3 showed the CW Experiment.



Figure 3. Constructed Wetland Experiment

Data Analysis

Data on the quality of wastewater before (inflow) and after treatment (effluent) using a Hybrid Constructed Wetland (HCW) system were analyzed using descriptively. Triplicate results were presented as mean $\pm$ standard deviation (SD), and removal efficiency was calculated for each parameter using the following equation.

$$\% \text{Removal Efficiency} = \frac{C_0 - C_1}{C_0} \times 100\%$$

Where :

C_0 = Wastewater concentration before treatment

C_1 = Wastewater concentration after treatment

Wastewater samples were analyzed for BOD, COD, TSS, TDS, phenol, total chromium, pH, and temperature using standard analytical methods based on Indonesian National Standards

(SNI), as summarized in Table 1. All laboratory analyses were conducted by the “Balai Besar Laboratorium Kesehatan Masyarakat Yogyakarta”.

Table 1. Analytical Methods Used for Wastewater Quality Parameters

No	Parameter	Test Method	SNI Reference
1	BOD ₅	Winkler/Titrimetri	SNI 6989.72:2009
2	COD	Closed Reflux Spectrophotometric	SNI 6989.2:2019
3	TDS	Gravimetric	SNI 06-6989.27-2005
4	TSS	Gravimetric	SNI 6989.3:2019
5	Phenol	Spectrophotometric (aminoantipyrine)	SNI 06-6989.21-2004
6	Total Chromium	Atomic Absorption Spectrophotometric (AAS)	SNI 6989.17-2009
7	pH	Electrometric (pH meter)	SNI 06-6989.11-2004

FINDING AND DISCUSSION

Wastewater Quality

Table 2. Wastewater Quality

No	Parameter	Unit	Quality Standard*	Result
1	BOD ₅	mg/L	85	1,610
2	COD	mg/L	250	6,250
3	TDS	mg/L	2,000	198
4	TSS	mg/L	60	4,060
5	Phenol	mg/L	0,5	0.7669
6	Total Chromium	mg/L	1	0.6583
7	pH	-	6.0-9.0	9.6
8	Temperature	°C	± 3°C relative to ambient temperature	26.6°C

 more than quality standar

Table 2 showed that batik wastewater at the study site has high concentrations of organic matter and suspended solids: BOD (1,610 mg/L) and COD (6,250 mg/L) far exceed the standards of 85 and 250 mg/L. TSS, phenol, and pH also exceeded quality standards. While TDS and total chromium complied, indicating a high pollution potential if the wastewater is discharged untreated. The high BOD and COD values reflect the amount of organic matter-particularly wax and starch from the “pelorodan” (wax-removal) process. The low BOD/COD ratio typically found in batik wastewater (below 0.30) further indicates that this organic load is largely non-biodegradable (Handayani et al., 2025). The high TSS value (4,060 mg/L vs. the 60 mg/L standard) is consistent with the broader pattern reported for batik wastewater and likely stems from dye accumulation and wax removal, increasing turbidity and reducing light penetration. In contrast, the TDS concentration (198 mg/L) remained below the 2,000 mg/L standard, indicating that most solids were suspended rather than dissolved (Handayani et al., 2025).

Phenol (0.7669 mg/L) exceeded the 0.5 mg/L standard, likely originating from chemicals used in the dyeing process, and is of concern as it can inhibit microbial biodegradation. Total chromium (0.6583 mg/L) remained below the 1 mg/L standard but was relatively close to it, likely originating from chromium-containing dyes (e.g., egan soga, naphthol, indigosol) and mordants such as Cr(NO₂).

Effectiveness of Hybrid Constructed Wetland for Batik Wastewater Treatment at Laboratory Scale

Table 3. Performance Results of HCWs at 4-Day HRT

No	Parameter	unit	Test Result						Quality Standard
			Influent	HRT 4			Mean±SD	Control	
				1	2	3			
1	BOD	mg/L	1,610	358	348	338	348±10	1,995	85
2	COD	mg/L	6,250	1,240	1,190	1,175	1,202.67 ±34.03	3,850	250
3	TDS	mg/L	198	353	355	356	354.67 ±1.53	213	2,000
4	TSS	mg/L	4,060	57	54	54	55.00 ±1.73	193	60
5	Phenol	mg/L	0.7669	0.0168	0.0073	0.0158	0.0133±0.0052	0.044	0.5
6	Total Chromium	mg/L	0.6583	0.0647	<0.0095	0.2720	0.1154	0.169	1
7	pH	-	9.6	8.6	8.8	8.3	8.56±0.25	8.9	6.0-9.0
8	Temperature	°C	26.6	27.3	27.6	27	27.3±0.30	27.6	± 3 °C relative to ambient temperature

The HCW system reduced most pollutant parameters in batik wastewater, with removal effectiveness influenced by HRT. The 8-day HRT generally provided greater pollutant removal due to the longer contact time between wastewater, media, plant roots, and microorganisms, as shown in Table 3 and Table 4.

Table 4. Performance Results of HCWs at 8-Day HRT

No	Parameter	Unit	Test Result						Quality standard
			Influent	HRT 8			Mean ±SD	Control	
				1	2	3			
1	BOD	mg/L	1,610	207	272	318	262.67 ±55.7	363	85
2	COD	mg/L	6,250	495	522	602	540 ±55.64	707.5	250
3	TDS	mg/L	198	339	338	340	339±1	238	2,000
4	TSS	mg/L	4,060	41	42	41	41.33 ±0.58	395	60
5	Phenol	mg/L	0.7669	0.0519	0.0267	0.0067	0.0284 ±0.0226	0.0658	0.5
6	Total Chromium	mg/L	0.6583	<0.0095	<0.0095	<0.0095	<0.0095	<0.0095	1
7	pH	-	9.6	8.5	8.9	8.8	8.73±0.21	9.1	6.0-9.0
8	Temperature	°C	26.6	26	25	26	25.6±0.58	26	± 3 °C relative to ambient temperature

Table 5. Effectiveness of the HCW Method

No	Parameter	Quality Standard	Unit	HRT 4			HRT 8		
				Concentration		Efficiency (%)*	Concentration		Efficiency (%)*
				Inlet	Outlet		Inlet	Outlet	
1	BOD	85	mg/L	1,610	348	78.39%	1,610	262	83.73%
2	COD	250	mg/L	6,250	1,202	80.77%	6,250	540	91.36%
3	TDS	2,000	mg/L	198	354.67	+79.12%	198	339	+71.21%
4	TSS	60	mg/L	4,060	55	98.65%	4,060	41	98.98%
5	Phenol	0.5	mg/L	0.7669	0.0133	98.27%	0.7669	0.0284	96.30%
6	Total	1	mg/L	0.658	0.1154	82.47%	0.6583	<0.0095	98.56%

Chromium

* for TDS the value represent a percentage increase in concentration rather than removal efficiency

■ more than quality standar

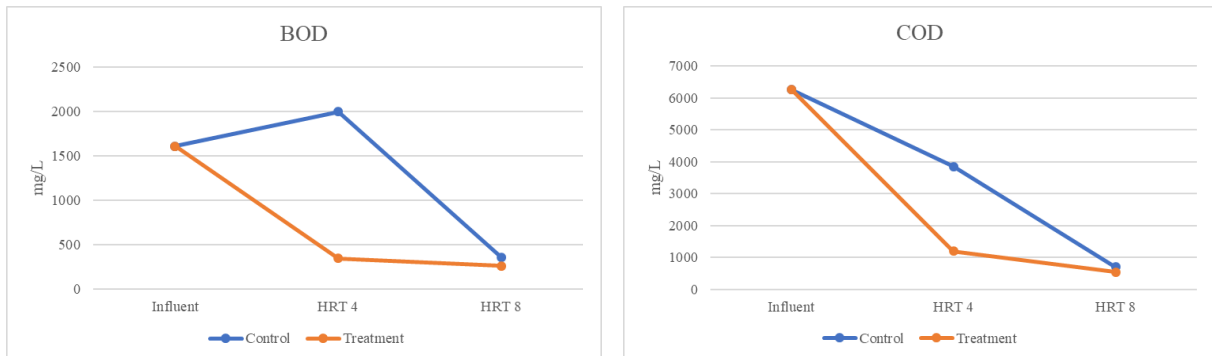


Figure 4. HCW Treatment Graph for BOD and COD Parameters

Table 5 and Figure 4 showed that BOD and COD decreased. BOD decreased from 1,610 mg/L to 348 mg/L (78.39%) at 4-day HRT and 262 mg/L (83.73%) at 8-day HRT, though both still exceeded the 85 mg/L standard due to the very high initial pollutant load. This reduction reflects biodegradation of organic matter by microorganisms in the wetland media and plant rhizosphere, consistent with prior hybrid CW research showing that most biodegradable materials are decomposed in the aerobic components of the system, with longer HRT further promoting degradation (Yeh & Wu, 2009).

Compared with the control (BOD: 1,995 mg/L at 4 days; 363 mg/L at 8 days), the HCW system achieved greater BOD removal, confirming the contribution of the wetland treatment components. The unusually high 4-day control value, which exceeded the influent concentration, likely reflects passive anaerobic decomposition of settled organic matter in the undisturbed reactor, so it should be interpreted cautiously rather than as a stable baseline.

COD decreased from 6,250 mg/L to 1,202 mg/L (80.77%) at 4-day HRT and 540 mg/L (91.36%) at 8-day HRT, still exceeding the 250 mg/L standard, suggesting that a longer HRT or supplementary treatment may be needed. COD removal generally proceeds through physical, chemical, and biological stages, and efficiency can decline over time as reduced oxygen supply to plant roots lowers aerobic microbial activity (Rahmadyanti & Audina, 2020). Similarly, COD concentrations in the control were 3,850 mg/L at 4 days and 707.5 mg/L at 8 days, which were higher than those of the HCW, indicating greater COD removal in the HCW system.

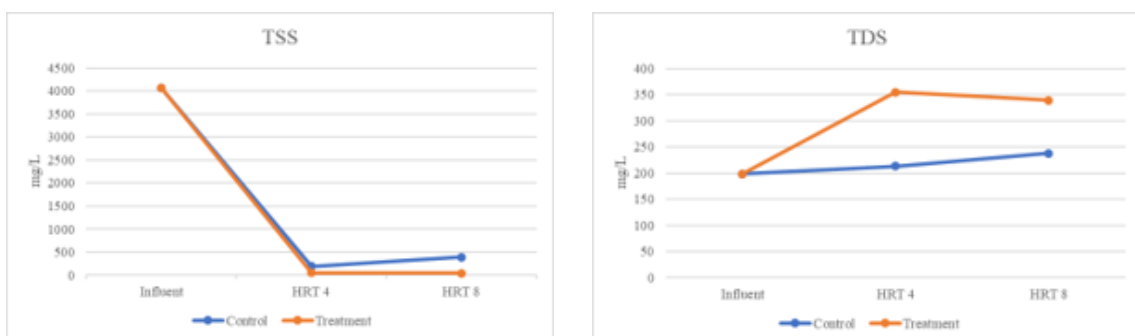


Figure 5. HCW Treatment Graph for TSS and TDS Parameters

Table 5 and Figure 5 showed the changed of TSS and TDS. TSS decreased sharply from 4,060 mg/L to 55 mg/L (98.65%) at 4-day HRT and 41 mg/L (98.98%) at 8-day HRT, meeting the 60 mg/L standard in both cases. This reflects effective filtration and sedimentation, aided by the fibrous root system's large surface area for capturing solids, though efficiency can decline once the media becomes saturated with contaminants (Rahmadyanti & Audina, 2020). The control showed higher TSS concentrations of 193 mg/L at 4 days and 395 mg/L at 8 days, indicating that filtration and sedimentation within the HCW contributed substantially to TSS removal. Meanwhile, TDS increased from 198 mg/L to 354.67 mg/L at 4-day HRT and 339 mg/L at 8-day HRT, corresponding to increases of 79.12% and 71.21%, respectively. This increase may be associated with biodegradation converting suspended organic matter into dissolved forms, as well as dissolution of minerals or organic compounds from the substrate. This is consistent with findings from a rain-garden constructed wetland study, particularly when the filter media has not been adequately conditioned before operation (Obeidat et al., 2026). In contrast, the control showed lower TDS concentrations of 213 mg/L and 238 mg/L, suggesting that the increase in TDS was more associated with processes occurring within the HCW media. The pH decreased from 9.6 in the influent to 8.56 and 8.73 after treatment at HRTs of 4 and 8 days, respectively. This decrease may be associated with biological processes and interactions between wastewater, wetland media, and plant-associated microorganisms during treatment.

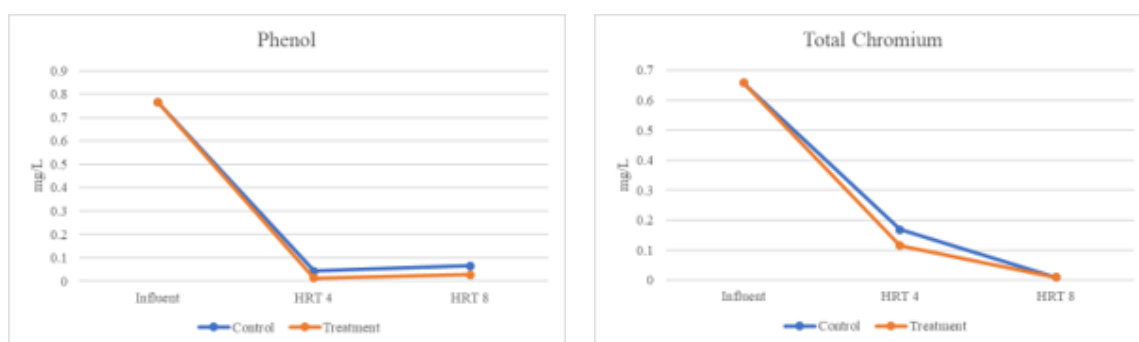


Figure 6. HCW Treatment Graph for Phenol and Total Chromium Parameters

Table 5 and Figure 6 showed that Phenol and Chromium concentrations decreased. Phenol decreased from 0.7669 mg/L to 0.0133 mg/L (98.27%) at 4-day HRT and 0.0284 mg/L (96.30%) at 8-day HRT, meeting the 0.5 mg/L standard, mainly through biodegradation and sorption rather than plant uptake or volatilization; plant roots primarily support microbial biofilm growth. This aligns with a pilot-scale study attributing about 95% of phenol removal to biofilm activity on plant roots and the porous bed, with the remainder from planktonic bacteria, occurring via both aerobic and anaerobic pathways (Kurzbaum, 2022). The control also reduced phenol to 0.044 mg/L at 4 days and 0.0658 mg/L at 8 days, but the HCW achieved lower concentrations at both HRTs. Total chromium decreased from 0.6583 mg/L to 0.1154 mg/L at 4-day HRT and below the detection limit (<0.0095 mg/L) at 8-day HRT, remaining below the 1 mg/L standard. This reduction may involve combined adsorption by the substrate, biosorption and uptake by plant roots, microbial interactions, and precipitation, consistent with mechanisms reported for chromium removal in constructed wetlands (Alemu et al., 2021). At 8 days, both the HCW and control showed total chromium below the detection limit (<0.0095 mg/L), indicating that chromium removal could not be attributed solely to the HCW components.

The results of this study can be compared with previous hybrid constructed wetland applications for batik wastewater treatment. Rahmadyanti and Audina (2020) applied a VSSF-HSSF system planted with *Canna indica* for batik wastewater treatment, whereas the present study applied *C. rotundus* to the same type of wastewater. This comparison demonstrates the application of the same hybrid flow configuration with different plant species and provides experimental evidence for the use of *C. rotundus* in a hybrid VSSF-HSSF system for batik wastewater treatment.

CONCLUSION AND FURTHER RESEARCH

Batik wastewater showed BOD, COD, TSS, phenol, and pH exceeding quality standards, while TDS and total chromium complied, indicating a high pollutant load. The HCW system using *C. rotundus* improved wastewater quality across all parameters, with the highest removal efficiencies at 8-day HRT for BOD (83.73%), COD (91.36%), TSS (98.98%), and total chromium (>98.56%), while phenol removal was slightly higher at 4 days (98.27%) than at 8 days (96.30%). TSS, phenol, and total chromium met applicable standards, whereas BOD and COD remained above standards after treatment. TDS increased at both HRTs, while pH decreased but stayed within range. These findings support using *C. rotundus* in a hybrid VSSF-HSSF system for batik wastewater treatment, indicating potential as a simple, low-cost pretreatment unit for household-scale batik industries. BOD and COD remained above standards, the HCW should be considered a pretreatment rather than standalone treatment system.

The experiment was conducted at a single site using one composite wastewater sample, one loading cycle, and only two batch durations (4 and 8 days), while the control was not replicated. The analysis was descriptive and did not include inferential statistical testing. In addition, the laboratory-scale design did not allow long-term evaluation of clogging or saturation, and plant biomass was not analyzed. Further studies should evaluate additional batch durations and planting densities, apply replicated controls and inferential statistical analysis, and assess long-term operation, polishing treatment, and pilot-scale performance.

REFERENCES

- Alemu, A., Gabbiye, N., & Lemma, B. (2021). Evaluation of tannery wastewater treatment by integrating vesicular basalt with local plant species in a constructed wetland system. *Frontiers in Environmental Science*, 9, 721014. <https://doi.org/10.3389/fenvs.2021.721014>
- Erwin, E. (2017). Efektifitas constructed wetlands tipe subsurface flow system dengan menggunakan tanaman *Cyperus rotundus* untuk menurunkan kadar fosfat dan COD pada limbah cair laundry. *Jurnal Kesehatan Masyarakat*, 5(1), 1–6. <https://doi.org/10.14710/jkm.v5i1.15794>
- Handayani, W., Suwarno, D., & Widianarko, B. (2025). The potential of adsorption technology for batik wastewater treatment: A review. *Journal of Natural Resources and Environmental Management*, 15(5), 864–876. <https://doi.org/10.29244/jpsl.15.5.864>
- Imron, M. F., Hestianingsi, W. O. A., Putranto, T. W. C., Citrasari, N., Abdullah, S. R. S., Hasan, H. A., & Kurniawan, S. B. (2024). Effect of the number of *Cyperus rotundus* and medium height on the performance of batch-constructed wetland in treating aquaculture effluent. *Chemosphere*, 353, 141595. <https://doi.org/10.1016/j.chemosphere.2024.141595>
- Kurzbaum, E. (2022). The partial contribution of constructed wetland components in the removal of phenol: A mini review. *Water*, 14(4), 626. <https://doi.org/10.3390/w14040626>
- Lamuel, R. P., Utomo, B., & Qomariyah, S. (2022). Evaluasi layanan instalasi pengolahan air limbah (IPAL) Pucangsawit di Jebres, Surakarta. *Jurnal Matriks Teknik Sipil*, 10(1), 32–38. <https://doi.org/10.20961/mateksi.v10i1.55280>

- Musawwa, M. M., Sarkawi, M., Arrunillah, D., Sazawa, K., & Mohan, G. (2026). Review of traditional batik wastewater treatment in Indonesia to address environmental and health hazards and support sustainable practices of micro, small, and medium enterprises. *Discover Environment*, 4(1), 18. <https://doi.org/10.1007/s44274-025-00466-6>
- Obeidat, N., Al-Salaymeh, A., Awwad, A. A., Bresciani, R., Shehadeh, A., AlBtoosh, J., Rizzo, A., Sarti, C., & Masi, F. (2026). Performance of a rain-garden-based constructed wetland for decentralized graywater treatment. *Water*, 18(4), 514. <https://doi.org/10.3390/w18040514>
- Rahmadyanti, E., & Audina, O. (2020). The performance of hybrid constructed wetland system for treating the batik wastewater. *Journal of Ecological Engineering*, 21(3), 94–103. <https://doi.org/10.12911/22998993/118292>
- Shingare, R. P., Nanekar, S. V., Thawale, P. R., Karthik, R., & Juwarkar, A. (2017). Comparative study on removal of enteric pathogens from domestic wastewater using *Typha latifolia* and *Cyperus rotundus* along with different substrates. *International Journal of Phytoremediation*, 19(10), 899–908. <https://doi.org/10.1080/15226514.2017.1303809>
- Sirait, M. (2018). Cleaner production options for reducing industrial waste: The case of batik industry in Malang, East Java-Indonesia. *IOP Conference Series: Earth and Environmental Science*, 106(1), 012069. <https://doi.org/10.1088/1755-1315/106/1/012069>
- Soeprijanto, S., Anara, S. A., & Azis, A. R. (2023). Batik industry wastewater treatment using constructed wetland in Sidoarjo Regency. In *Seminar Nasional Teknik Kimia "Keuangan"* (pp. I13-1–I13-6). <https://jurnal.upnyk.ac.id/index.php/keuangan/article/view/10326>
- Usama, I. S. I., Yudono, A. R. A., & Asrifah, R. D. (2023). Metode AOP–GAC dalam penanganan limbah cair batik di Kalurahan Wijirejo, Kepanewon Pandak, Kabupaten Bantul, Daerah Istimewa Yogyakarta. *Prosiding Seminar Nasional Teknik Lingkungan Kebumihan SATU BUMI*, 4(1), 235–240. <https://doi.org/10.31315/psb.v4i1.8836>
- Vymazal, J. (2014). Constructed wetlands for treatment of industrial wastewaters: A review. *Ecological Engineering*, 73, 724–751. <https://doi.org/10.1016/j.ecoleng.2014.09.034>
- Waly, M. M., Ahmed, T., Abunada, Z., & Mickovski, S. B. (2022). Constructed wetland for sustainable and low-cost wastewater treatment: Review article. *Land*, 11, 1388. <https://doi.org/10.3390/land11091388>
- Yeh, T. Y., & Wu, C. H. (2009). Pollutant removal within hybrid constructed wetland systems in tropical regions. *Water Science and Technology*, 59(2), 233–240. <https://doi.org/10.2166/wst.2009.846>
- Zakaria, N., Rohani, R., Hanna, W., Wan, M., Purwadi, R., Sumampouw, G. A., & Indarto, A. (2023). Batik effluent treatment and decolorization—A review. *Water*, 15(7), 1339. <https://doi.org/10.3390/w15071339>