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Effect of broken roof tile adsorbent in constructed wetland for treatment of laundry waste pollutants

Indonesian title: Pengaruh adsorben pecahan genteng dalam constructed wetland untuk pengolahan polutan limbah laundry

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ABSTRACT

A Constructed Wetland (CW) is a modified wastewater treatment system that can be applied anywhere. The advantages of CW systems are low operational costs, naturally available constituent materials and provide aesthetic value as a wastewater treatment solution. The increasing number of laundry industries causes high concentrations of phosphate pollution in the environment. Shards of tile as an adsorbent may reduce the concentration of Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Chemical Oxygen Demand (COD), phosphate, Methylene Blue Active Surfactant (MBAS), and sulphate. The effect of adding tile fragments is supported by using Water Jasmine plants (Echinodorus palaefolius) and the diversity of microorganisms attached to the adsorbent. The results of this study showed a phosphate reduction efficiency of 99.96%. The presence of the bacterial genus Proteus sp. and Citrobacter sp. on the tile fragments adsorbent impacts phosphate reduction. Pollutant removal in CW systems occurs due to adsorption, sedimentation, filtration, biodegradation and precipitation.

Keywords: *Constructed Wetland; Laundry Wastewater; Broken Roof Tiles; Microorganisms; Proteus sp; Citrobacter sp.*

ABSTRAK

Constructed Wetland (CW) merupakan modifikasi sistem pengolahan limbah yang dapat diaplikasikan dimana saja. Keuntungan sistem CW yakni biaya operasional yang murah, material penyusun tersedia secara alami dan memberikan nilai estetika sebagai solusi pengolahan limbah. Semakin banyaknya industri laundry menyebabkan tingginya konsentrasi pencemaran fosfat pada lingkungan. Pecahan genteng sebagai adsorben dapat menurunkan konsentrasi Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Chemical Oxygen Demand (COD), fosfat, Methylene Blue Active Surfactant (MBAS), dan sulfat. Pengaruh penambahan pecahan genteng didukung dengan penggunaan tanaman Melati Air (Echinodorus palaefolius) dan keragaman mikroorganisme melekat pada adsorben. Hasil penelitian ini menunjukkan efisiensi penurunan fosfat sebesar 99,96%. Keberadaan bakteri genus Proteus sp. dan Citrobacter sp. pada adsorben pecahan genteng memberikan dampak terhadap penurunan fosfat. Penghilangan polutan pada sistem CW terjadi akibat proses adsorpsi, sedimentasi, filtrasi, biodegradasi dan presipitasi.

Kata kunci: *Constructed Wetland; Limbah Laundry; Pecahan Genteng; Mikroorganisme; Proteus sp.; Citrobacter sp.*

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INTRODUCTION

Globalization has led to an increase in the demand for clean water due to the rising population. The laundry industry has become one of the services favoured by many people. The numerous laundry industries increase the volume of wastewater. This wastewater enters water bodies and can cause various environmental problems. Ultimately, it will affect the need for clean water, which has become increasingly important to pay attention to.

Laundry uses detergent as a cleaning agent. Detergents have various constituent compositions, namely surfactants, as active ingredients that can reduce the surface tension of water and form a foam (Gupta & Sekhri, 2014). Builders are generally materials with phosphate as the main compound that can help improve dirt removal efficiency. Compound phosphates include sodium tripolyphosphate (STPP) and polyphosphate (Apriyani, 2017). It is reported that detergents have a degree of acidity (pH) of 11 (Kalak et al., 2021). High BOD, COD and TSS values in laundry wastewater that exceed quality standards (Abdelhakeem et al., 2016).

The quality standards for laundry wastewater are regulated in the Special Region of Yogyakarta Regional Regulation No. 7 of 2016 concerning Wastewater Quality Standards (Peraturan Daerah Daerah Istimewa Yogyakarta, 2016). According to Usman et al. (2022), phosphate concentrations greater than 0.025 mg/L can cause eutrophication (Usman et al., 2022). According to the Regulation of the Minister of Health of the Republic of Indonesia No. 32 of 2017 (Peraturan Menteri Kesehatan Republik Indonesia Nomor 32 Tahun 2017, 2017), the tolerance for sulphate presence in water is not allowed to exceed 400 mg/l.

The presence of phosphate in aquatic environments can cause various negative impacts. The abundance of phosphate in waters can lead to algal blooms. Phosphate is a compound containing the element Phosphorus (P), which plants can use as an essential nutrient in vegetative growth (Vásquez et al., 2023). Phosphorus can become increasingly difficult to remove because it settles or sediments at the bottom of the water, and then it will be released over time (X. Chen et al., 2022). An algal population explosion can lead to reduced dissolved oxygen that causes the death of microorganisms and other living things, thus destabilizing the aquatic ecosystem (Esharikha, S. & Rosariawari, F., 2023).

A Constructed Wetland (CW) is a modified wastewater treatment system that emphasizes physical processes, biochemistry, precipitation, and others (Rubi et al., 2024). CW utilizes aquatic plants that have root systems to provide a place for rhizosphere microorganisms. The rhizosphere microorganisms perform a series of organic matter degradation processes. CW systems are reported to provide phosphate removal efficiencies of up to 95.49% (Wahyudianto et al., 2019).

Aquatic plants can provide a good supply of dissolved oxygen in CW systems. Generally, aquatic plants have an intercellular network that will transfer oxygen through the roots. CW is a low-energy wastewater treatment using biotic and abiotic materials (Sutanto & Bawole, 2021; Daverey et al., 2019). Water jasmine plant (*Echinodorus palaefolius*) is a species that is widely used in various studies using CW systems. The ability of E. *palaefolius* to reduce phosphate is quite significant, at 99.5% (Perdana et al., 2018). This plant has very adaptive qualities, allowing it to survive in any environment and actively contribute to reducing the levels of pollutants present.

Using aquatic plants also adds aesthetic value to the wastewater treatment system (Sutanto & Bawole, 2021). This plant is proven to reduce phosphate consistently with its fibrous root system. This plant can also grow optimally in an environment with a pH of around 4.5-7 with a temperature of 25-35°C (Fitria & Dhokhikah, 2021; Lorensia & Rachmadiarti, 2024).

The CW system can be optimized by substituting adsorbent media, such as broken tile (Figure 1), which is expected to reduce the level of laundry wastewater pollutants.

Tile shards are reported to provide good adsorption and precipitation capabilities due to their mineral content, such as SiO_2, Al_2O_3, and Fe_2O_3 (Herawati et al., 2023; Momina et al., 2018). In addition, the large surface area can be an active side in binding/adsorption of phosphate and sulphate ions in laundry wastewater and has a larger fractional surface area than gravel in general (Awasthi et al., 2019; Fseha et al., 2024).

Figure 1.
Broken Rooftile
Source: Photo by the author, 2025

The research aims to see how optimal CW system treatment using roof tile fragments as adsorbents reduces phosphate. Preliminary tests were also conducted to identify the diversity of microorganisms found in the substituted adsorbent media layer in the CW system by observing bacterial morphology and testing their biochemical activities.

Method

Constructed Wetland (CW) Reactor Construction

The CW reactor was made using a bucket with a volume of 20L. The number of repetitions in each test group was determined by calculating Federer's formula (n-1) (t-1) ≥ 15 (Awasthi et al., 2019).

Table 1.
Research Treatment Data

Repetition	Treatment	
	K	**PG**
1	K1	PG1
2	K2	PG2
3	K3	PG3
4	K4	PG4
5	K5	PG5
6	K6	PG6

Source: Secondary Research Data, 2025

The reactor has four layers of media: paddy soil, small rocks, medium rocks/tile fragments, and large rocks, with a ratio of 1:3:2:3. This ratio is divided according to the bucket's height, which is 33 cm. Figure 2 provides an overview of the research design, and Figure 3 provides an overview of the media arrangement.

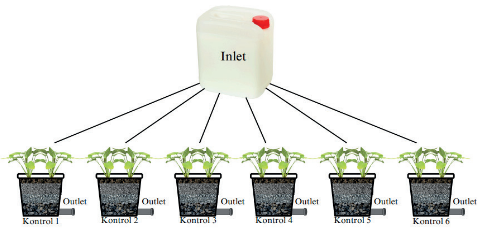

Figure 2.
Treatment design
Source: Image by the author, 2025

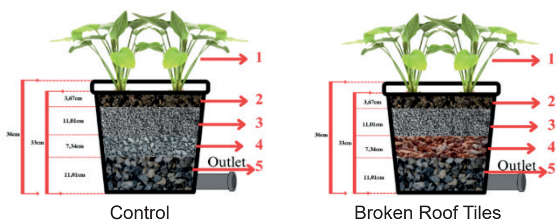

Figure 3.
Reactor layout
Source: Image by the author, 2025

Hydraulic Retention Time (HRT) and Debit (Q) Calculation.

HRT is the residence time of wastewater in the reactor (Rakasiswi et al., 2020). The HRT calculation formula is (Cruz-Salomón et al., 2018):

$$HRT = \frac{V}{Q}$$

Information:
HRT : Hydraulic Retention Time (Days)
V : Reactor volume (L)
Q : Debit/influent flow rate (L/hour)

Acclimatization of Constructed Wetland (CW) Reactor

Acclimatisation is the time required for the system to stabilise. CW system acclimatization is generally done for 7 days. The length of the acclimatization time is adjusted to the existing reactor arrangement.

Liquid Waste Sample Preparation

The laundry wastewater effluent used in this study came from a laundry service in Samirono, Yogyakarta Special Region. After the reactor reached steady state, the sampling period was carried out by measuring dissolved oxygen samples for 7 days (Nurfita et al., 2017).

Sample Sampling and Measurement

Samples were measured based on several water quality parameters such as, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), pH, temperature, Total Suspended Solid (TSS), Total Dissolved Solid (TDS), phosphate, and MBAS (Methylene Blue Active Surfactant, sulphate and bacterial identification (Gram staining and biochemical testing: motility, oxidase, catalase, indole, Methyl Red (MR), Voges-Proskauer (VP), citrate, nitrate reduction, and glucose fermentation.

Methods of Analyses

The independent T-test method was used in this study. This method was selected to see whether there was a significant difference between the average of each parameter in the control and treatment using broken roof tiles. The software application used in data analysis was IBM SPSS Statistics 25 Commuter License. The data to be analyzed included DO, Temperature, pH, TSS, TDS, COD, Phosphate, and MBAS parameters between the control reactor and the roof tile treatment.

RESULTS AND DISCUSSION

Characteristics of Laundry Wastewater After the Treatment Process

The wastewater treatment process in this study was conducted continuously over a three-day Hydraulic Retention Time (HRT) using the constructed wetland system. The treatment performance is presented as the average concentrations of selected physicochemical parameters, including Dissolved Oxygen (DO), temperature, pH, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), phosphate, Methylene Blue Active Surfactant (MBAS), and sulphate, as summarised in Table 2.

Table 2.
Average concentration of test parameters DO, temperature, pH, TSS, TDS, COD, phosphate, MBAS, and sulphate in the constructed wetland treatment system

No	Parameter	Unit	Inlet	Control	Roof tile	Quality Threshold
1.	DO	(mg/L)	0.88	1.02	1.06	-
2.	Temperature	(°C)	25.1	24.8	24.5	± °3C to air temperature*
3.	pH	-	6.96	6.51	6.30	6.0 – 9.0*
4.	TSS	(mg/L)	2079.75	122.96	120.79	10*
5.	TDS	(mg/L)	526.88	477.54	457.96	2000*
6.	COD	(mg/L)	653.08	342.05	357.53	150*
7.	Phosphate	(mg/L)	863.68	1555.47	0.34	-
8.	MBAS	(mg/L)	12.88	8.68	7.88	5*
9.	Sulphate	(mg/L)	116.5	36.47	48.92	-

Source: Research Result Data, 2025
Information:
*Regulation of the Special Region of Yogyakarta No. 7 of 2016 Concerning Wastewater Quality Thresholds

Physical Parameter Removal Efficiency

The processing value for the TSS parameter in the control and tile treatments is significantly different from the inlet. Based on statistical processing data, there is an insignificant difference between control and tile. Judging from the existing data, TSS removal is likely to be successful using natural stone and broken tile with efficiency values of 94.09% and 94.19%.

The filtration process achieves the removal of suspended solids. Filtration can occur due to differences in the density of the media arrangement. The smaller the porosity of the substrate/adsorbent media, the easier it is to trap the SS present (Manios et al., 2003). Therefore, using broken roof tiles provides the same SS removal ability as natural rocks. The use of aquatic plants also greatly reduces TSS due to the root system that helps the filtration process (Abdelhakeem et al., 2016).

Chemical Parameter Removal Efficiency

This study's decrease in chemical parameters includes COD, MBAS and TDS. The control reactor and the broken tile treatment provided an insignificant decrease in COD against the inlet. COD removal efficiency in the control and fractional treatment was 47.63% and 45.26%, respectively. The broken tile treatment gave almost the same results as the control, then showed a less significant amount of MBAS removal in the treatment when compared to the inlet (Figure 4).

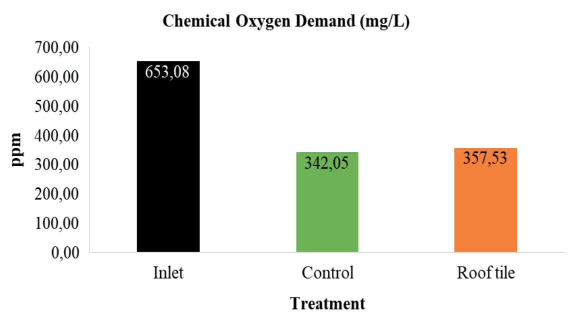

Figure 4.
COD Histogram Average Decline
Source: Research Result Data, 2025

The need for sufficient dissolved oxygen (DO) supports removing COD content (Table 2). Sufficient DO can increase the enzymatic activity of rhizosphere microorganisms in the plant root system in degrading organic matter, so that the wider degradation of organic matter will be higher. Plants can then utilize the degraded organic matter as a source of nutrients (Donde, 2017; Leonhard et al., 2024; Ratnawati et al., 2024).

MBAS is a test for the number of anionic surfactants in laundry wastewater. Anionic surfactants such as Linear Alkylbenzene Sulfonate (LAS) can react with methylene blue dye in MBAS testing (Dewi et al., 2024). Removal of surfactant levels can be achieved by the activity of rhizosphere microorganisms and biofilms that utilize complex forms of surfactants that will be broken down into simpler compounds, so that aquatic plants can uptake them (Oktaningtyas et al., 2024). MBAS removal can also be caused by the adsorption process, which is also influenced by temperature and pH. Too high a temperature can increase the solubility of surfactants, so the tendency to adsorb becomes weaker (Belhaj et al., 2020). Similarly, high pH can cause a removal in adsorption ability (Ersa et al., 2021). Therefore, the stability of temperature and pH in this study has a good impact on removing MBAS (Table 2).

TDS removal in laundry wastewater, such as soap residue, detergents, cleaning agents and other organic materials, can be optimally removed by adsorption. Tile adsorption is possible due to the presence of natural minerals such as aluminium oxide (Al_2O_3), silicon dioxide (SiO_2) and hematite (Fe_2O_3) (Herawati et al., 2023; Parab et al., 2025). This ion content can then bind to negative ions in laundry wastewater such as This study's decrease in chemical parameters includes COD, MBAS and TDS.

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Decreased or less efficient TDS removal can occur due to the concentrated concentration of wastewater (surfactants, phosphates and sulphates) and the depletion of the active side on the adsorbent surface. Therefore, it is necessary to modify the adsorbent by adding an acid solution such as HCl in order to open the surface pores (Belhaj et al., 2020; Bijang et al., 2024; Watiniasih et al., 2019).

Inorganic Parameter Removal Efficiency

Phosphate removal using the broken tile treatment and the control gave significantly different results. The broken tile treatment reduced phosphate to 0.34 mg/L with a removal efficiency of 99.96%. Meanwhile, the control reactor did not reduce phosphate. Thus, the broken tile media showed the best ability. A decrease followed the decrease in phosphate in sulphate parameters. The decrease in sulphate in the control reactor was 36.47 mg/L; in the roof tile reactor, there was a 48.92 mg/L decrease. The sulphate removal efficiency in the control reactor and the roof tile fraction treatment was 68.70% and 58.01%, respectively.

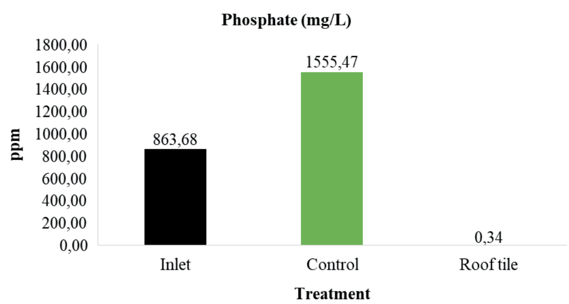

Figure 5.
Phosphate Histogram Average Decline
Source: Research Result Data, 2025

Phosphorus is present in the form of phosphate compounds in laundry wastewater. Several phosphate removal processes occur in this study, such as precipitation, rhizosphere microbial activity, absorption by aquatic plants, and adsorption by adsorbents. Precipitation occurs due to the bonding between positive ions on the surface of the tile adsorbent with negative ions of phosphate, thus forming an insoluble complex (Owodunni et al., 2023). The use of plants provides a root system that provides a process of degradation of pollutants by root microorganisms as well as a filtration medium (Fitria & Dhokhikah, 2021; Herlina et al., 2020).

Then, supported by adsorbent media that provide adsorption capabilities, due to the presence of minerals Al_2O_3, SiO_2, and Fe_2O_3, can react with negative ions on phosphate (Adnan & Ismayana, 2022). The control treatment did not remove phosphate, possibly due to the lack of gravel surface area and natural mineral content compared to broken roof tiles (Fseha et al., 2024).

Sulphate removal in the CW system can be achieved by obtaining a sufficient carbon source for sulphate-reducing bacteria (SRB). The decreased surfactant content of the inlet treatment can be assumed to occur due to the SRB activity (Chen et al., 2016). The adsorption ability is reduced due to the depletion of the active side of the adsorbent. Other ions in the effluent, such as chloride, nitrate, fluoride, and carbonate, can be present (Manna et al., 2022).

Morphological Identification of Bacteria

Microorganisms in the broken tile and gravel adsorbent layers were identified through a series of biochemical tests. The second layer from the bottom of the reactor was selected to see the differences in microorganisms on the gravel and broken tile adsorbents. Biofilm samples were taken from one of the reactors from both treatments. The sample was put into sterile distilled water and then diluted to find separate bacterial growth (Jufri, 2020).

Bacteria that grow dominantly in the entire dilution series are purified through the streak plate method. The streak plate results are then used to identify bacterial morphology through Gram staining.

Figure 6.
Gram Staining Control Bacteria

Figure 7.
Target Rooftile Bacteria

Source: Photo by the author, 2025

Bacterial gram staining was observed with a microscope with a magnification of 400x, and the results were A gram-negative (-) bacillus-shaped, a control gram-negative (-) bacillus-shaped, and a gram-negative (-) bacillus-shaped. Therefore, it can be assumed from the results of gram painting that there are potential gram-negative bacteria that utilize organic matter in wastewater. Biochemical identification was carried out to find the suspected genus of bacteria in the control and tile treatments.

Identification of Biochemical Activities of Bacteria

Biochemical testing is carried out to determine the mechanism and ability of certain types of bacteria to utilize nutrients in growth media, so that it can provide good results through changes in colour, visual, bacterial growth and others (Table 3).

Based on the tabulated results of biochemical testing (Table 3), it was found that the results of biochemical testing of CA and G isolates gave the same results, and isolate G gave differences in the citrate test results. Suspected bacteria can be identified and analyzed through the determination key in Bergey's Manual of Determinative Bacteriology, Ninth Edition. The suspected genus of control treatments A and G tentatively leads to *Proteus* sp., and in the CB treatment, *Citrobacter* sp.

Table 3.
Tabulation of Biochemical Test Results

	Motil	Oxidase	Catalase	MR	VP	Citrate	Indole	Nitrate Reduction	Glucose Fermentation
CA	+	-	-	+	+	-	+	+	+
CB	+	-	-	+	+	+	+	+	+
G	+	-	-	+	+	-	+	+	+

Source: Research Result Data, 2025
Information:
KA: Control A, KB: Control B, G: Rooftile

The genus *Proteus* sp. is a bacterium commonly found in industrial wastewater. Biochemical testing gave similar results to some previous studies, namely gram-negative, giving positive results in catalase, motility, glucose fermentation, MR, indole and citrate tests, then negative results in oxidase testing (Al-Kubaisi & Al-Deri, 2022; Drzewiecka, 2016). Based on Bergey's Manual of Determinative Bacteriology, Ninth Edition (Holt et al., 1994), *the Proteus* genus has bacillus-shaped characteristics with a 0.4 - 0.8μm x 1-3μm long diameter. These bacteria can live in areas with facultative anaerobic properties, an optimal temperature of 37°C, and have flagella. Bacteria of this genus are also commonly found in wastewater.

The suspected genus of bacteria in the three isolates belongs to the Enterobacteriaceae family. Bacteria of this family are reported to live in facultative anaerobic areas with a temperature resistance of 25-37°C. Similar biochemical testing results were also found in previous studies, namely oxidase, indole and negative VP then MR, catalase, citrate, nitrate, and positive glucose fermentation (Chen et al., 2018).

The suspected genus of bacteria in the three isolates belongs to the Enterobacteriaceae family. This family of bacteria can live in facultative anaerobic areas with a temperature resistance of 25-37°C (Morales-López et al., 2019). The existence of the two existing bacterial genera can be an assumption that the genus *Proteus* sp. and *Citrobacter* sp. are suspected bacteria that have the potential to utilize organic matter in wastewater. Bacteria genus *Proteus* sp. and *Citrobacter* sp. may be able to utilize carbon sources in laundry wastewater. The content of surfactants in laundry wastewater can be an obstacle to bacterial growth. However, the Enterobacteriaceae family bacteria are tolerant and adaptive to environmental conditions with toxic substances (Vaishnavi & Osborne, 2024).

Due to the diversity of bacterial strains, some differences in results, such as false positives/negatives in the assay, may be possible. However, biochemical testing is a conventional method that can give biased results (false positives/false negatives). Therefore, more in-depth bacterial identification testing is needed to target the species level, such as 16S rRNA Gene Sequencing, specific PCR, or Next-Generation Sequencing (NGS).

CONCLUSION

Based on the research that has been done, the use of broken roof tiles might provide a high phosphate removal efficiency of 99.961% (very significant compared to the control). Thus, the use of broken roof tiles successfully reduced phosphate efficiently. Through a series of isolation processes, characterization of gram bacterial properties and biochemical activity testing, it was found that the suspected bacteria in the control adsorbent media A (gravel diameter 1-1.5 cm) and broken roof tiles were the genus *Proteus* sp., and the control adsorbent media B (diameter 1-1.5 cm) were the genus *Citrobacter* sp.

This study has several recommendations, such as more thorough physical cleaning of the adsorbent media to avoid re-dissolution. Then, variation in the thickness of the adsorbent media can be done to increase the adsorption capacity. Further identification of suspected bacteria types at the species level is done through several advanced tests, such as NGS or PCR. The input from this research is expected to provide an update on further research.

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