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Phosphate Removal from Laundry Wastewater Using a Hybrid Biofilter–Phytoremediation System with Broken Roof Tile Media and *Chlorella* sp.

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ABSTRACT: Laundry wastewater is one of the primary sources of phosphate discharge into aquatic environments due to the extensive use of phosphate-based detergents. Excessive phosphate concentrations in aquatic environments can accelerate eutrophication, leading to excessive algal growth, depletion of dissolved oxygen, and ecological imbalance. Therefore, there is a need to develop an efficient, economical, and environmentally friendly treatment system. This study evaluated the performance of a hybrid biofilter-phytoremediation system using broken roof tiles as the biofilter medium and *Chlorella* sp. as the phytoremediation agent to reduce phosphate levels in laundry wastewater. The experiment consisted of three treatment groups: wastewater (control), a biofilter with microalgae (BF+MA), and a biofilter containing broken roof tile fragments combined with microalgae (BFg+MA). Wastewater quality was monitored through several sampling periods, and phosphate concentration was analyzed as the primary parameter. Supporting parameters, including pH, dissolved oxygen, ammonia, nitrate, total suspended solids, and temperature, were also evaluated. The data were analyzed using Welch's ANOVA to assess differences among treatments. When significant differences were found, the analysis was continued with the Games–Howell *post hoc* test at a 95% confidence level ($\alpha = 0.05$). The results showed that the hybrid system effectively reduced phosphate concentrations in laundry wastewater. Phosphate removal was attributed to adsorption by the broken roof tile media, microbial activity within the biofilm, and nutrient assimilation by *Chlorella* sp. Changes in supporting water quality parameters indicated favorable conditions for biological and physicochemical treatment processes. These findings suggest that the hybrid biofilter-phytoremediation system has significant potential as a sustainable and low-cost alternative for laundry wastewater treatment.

KEYWORDS: broken roof tile media, hybrid biofilter, laundry wastewater, phosphate removal, phytoremediation

INTRODUCTION

The rapid growth of the laundry business in urban areas has increased the volume of wastewater generated from washing activities. Laundry wastewater falls under the category of graywater, which contains various pollutants, such as surfactants, organic matter, suspended solids, and nutrients in the form of nitrogen and phosphate resulting from the use of detergents (Apriyani, 2017). Among these various parameters, phosphate is one of the most concerning pollutants because its presence can degrade water quality if discharged without adequate treatment (Zairinayati & Shatriadi, 2019).

Phosphate in laundry wastewater generally originates from sodium tripolyphosphate (STPP), which is used as a detergent builder (Setiawati & Ariani, 2022). The accumulation of phosphate in water bodies can trigger eutrophication, a condition of nutrient enrichment that causes excessive growth of algae and aquatic plants. Further impacts of this process include a decrease in dissolved oxygen concentrations, disruption of the aquatic ecosystem balance, and a decline in environmental quality (Schindler, 2021). Therefore, reducing phosphate concentrations in laundry wastewater is a critical aspect of sustainable wastewater management.

Various technologies have been developed to reduce phosphate levels in wastewater, including physical, chemical, and biological methods. However, chemical methods often entail high operating costs and produce secondary waste that requires further treatment. As a more environmentally friendly alternative, biofilters are widely used because they harness the activity of microorganisms growing on specific media to remove pollutants. The performance of biofilters can be enhanced by using broken roof tile media, which has a porous structure and the ability to adsorb phosphate. In addition, the application of phytoremediation using *Chlorella* sp. also has the potential to increase phosphate removal through nutrient assimilation mechanisms during microalgal biomass growth (Akhere & Chukwuka, 2023).

Although numerous studies on biofilters and phytoremediation have been reported, research integrating these two technologies using broken roof tile fragments and *Chlorella* sp. for laundry wastewater treatment remains relatively limited. The

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combination of these two processes has the potential to achieve more effective phosphate removal through the synergy between adsorption on the media, microbial activity within the biofilm, and nutrient uptake by microalgae. Therefore, this study aims to evaluate the effectiveness of a hybrid biofilter–phytoremediation system using broken roof tile media and *Chlorella* sp. in reducing phosphate concentrations in laundry wastewater.

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METHOD

This study aims to evaluate the ability of a hybrid *biofilter–phytoremediation* system using broken roof tile fragments and *Chlorella* sp. to reduce phosphate concentrations in laundry wastewater, as well as to examine the role of supporting parameters in the effectiveness of the phosphate removal process. The study was conducted at Universitas Kristen Duta Wacana, Yogyakarta, Indonesia. An experimental approach was used to compare the performance of several treatments in order to determine the contribution of each system component to the wastewater treatment process. The hybrid *biofilter–phytoremediation* system was chosen because it combines adsorption mechanisms on the media, microbial activity within the biofilm, and nutrient assimilation by microalgae, all of which have the potential to enhance phosphate removal efficiency.

The study was conducted using three treatment groups: influent (control), a biofilter combined with *Chlorella* sp. (BF+MA), and a biofilter with broken roof tile media combined with *Chlorella* sp. (BFg+MA). Laundry wastewater was used as the influent in the entire study. The biofilter reactor was constructed using gravel, medium-sized gravel/broken roof tiles, and large gravel, which served as both a biofilm growth substrate and an adsorption medium. Prior to system operation, an acclimatization process was carried out to support the formation of a stable biofilm on the biofilter media. Next, *Chlorella* sp. was inoculated into the phytoremediation unit and maintained throughout the study period to support the nutrient uptake process through biomass formation.

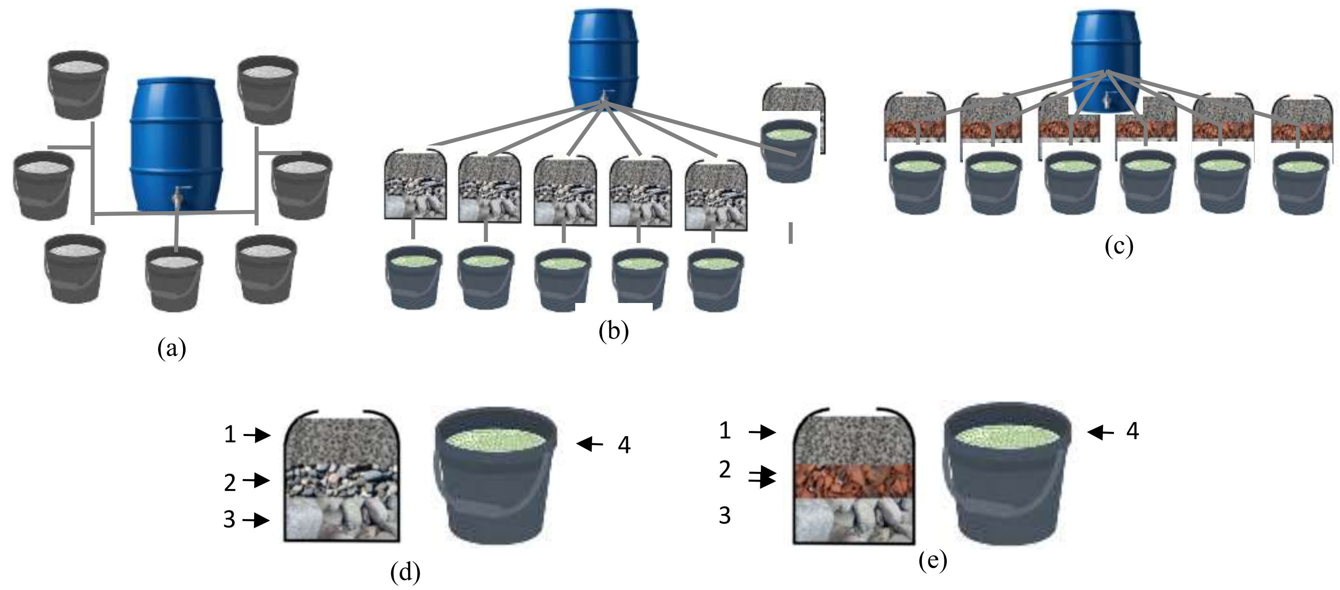

Figure 1. (a) Control Reactor Design, (b) Treatment 1 Reactor Design, (c) Treatment 2 Reactor Design, (d) Treatment 1 Reactor Setup, (e) Treatment 2 Reactor Setup

Reactor Composition Details:

1. Small gravel 0.5–1 cm (7.9 cm)
2. Medium gravel/broken roof tiles 1–1.5 cm (7.9 cm)
3. Large gravel 3 cm (7.9 cm)
4. *Chlorella* Sp. microalgae

System performance was evaluated through periodic sampling for each treatment. The primary parameter observed was phosphate, as it was the main target for removal in this study. In addition, several supporting parameters were also analyzed, including pH, *dissolved oxygen* (DO), ammonia, nitrate, *total suspended solids* (TSS), *total dissolved solids* (TDS), and temperature. These parameters were measured to evaluate the system's operational conditions and to elucidate the mechanisms influencing

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phosphate removal during the treatment process. The system's effectiveness was determined based on changes in parameter concentrations and the removal percentages achieved in each treatment.

The data obtained were analyzed using IBM SPSS Statistics software. Before hypothesis testing, the data were tested for normality and homogeneity to ensure that the statistical assumptions were met. Differences between treatments were analyzed using *a one-way analysis of variance* (ANOVA) at a 95% confidence level ($\alpha = 0.05$). If significant differences were found, the analysis continued using Tukey's HSD or Games–Howell post-hoc tests, depending on the results of the homogeneity of variances test, to identify differences among treatment groups.

RESULT

Table 1 presents the characteristics of laundry wastewater after treatment using a hybrid biofilter–phytoremediation system for each treatment condition. Phosphate was analyzed as the primary parameter for evaluating system performance, while pH, dissolved oxygen (DO), ammonia, nitrate, total suspended solids (TSS), total dissolved solids (TDS), and temperature were used as supporting parameters. In general, the measurement results show a decrease in phosphate concentration in the treated effluent compared to the influent, accompanied by changes in several supporting parameters. The results indicate that the applied treatment system had an effect on wastewater quality during the observation period.

Table 1. Characteristics of Laundry Waste After Processing

No	Parameter	Unit	Control/ Inlet	Treatment 1 (BF+MA)	Treatment 2 (BFg+MA)	Ef% Treatment 1 (BF+MA)	Ef% Treatment 2 (BFg+MA)
1.	DO	(mg/L)	0,00	4,48	4,36	-	-
2.	Temperature	(°C)	23,73	23,91	24,25	-	-
3.	pH	-	7,57	8,36	8,18	-	-
4.	TSS	(mg/L)	254,50	85,66	93,80	66,34	63,14
5.	TDS	(mg/L)	764,25	432,96	437,66	43,35	42,73
6.	COD	(mg/L)	874,79	147,73	153,35	83,11	82,47
7.	Phosphate	(mg/L)	5,79	0,30	0,17	94,75	97,09
8.	Nitrate	(mg/L)	49,59	11,09	14,21	77,62	71,34
9.	MBAS	(mg/L)	166,68	14,40	12,15	91,35	92,71
10.	Ammonia	(mg/L)	12,41	1,08	0,57	91,32	95,39

Phosphate Removal Performance

Based on Table 1, the phosphate concentration in the influent, which was 5.79 mg/L, decreased to 0.30 mg/L in the BF+MA treatment and to 0.17 mg/L in the BFg+MA treatment. These results indicate removal efficiencies of 94.75% and 97.09%, respectively, for each reactor. The higher removal efficiency in the BFg+MA treatment indicates that the addition of broken roof tile media contributes to increased phosphate removal in the hybrid biofilter–phytoremediation system. The phosphate concentration in the influent, which was 5.79 mg/L, decreased to 0.30 mg/L in the BF+MA treatment and to 0.17 mg/L in the BFg+MA treatment, with removal efficiencies of 94.75% and 97.09%, respectively.

Although the BFg+MA treatment showed higher efficiency in descriptive terms, the results of the Games–Howell test indicated that the difference between the two reactors was not statistically significant ($p > 0.05$). This suggests that both treatment systems have relatively equivalent capabilities in reducing phosphate, although the addition of broken roof tile media resulted in a

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slightly higher removal rate. The lack of a significant difference between BF+MA and BFg+MA may be due to the high removal efficiency already achieved by both reactors. When the phosphate concentration in both treatments reached very low levels (<0.5 mg/L), the absolute difference between treatments became small, making it difficult to detect a statistically significant difference (Asaad & Amer, 2024). In addition, data variability between replicates and the limited number of samples can also affect the sensitivity of statistical tests in detecting differences between treatments.

The trend toward higher efficiency values in the BFg+MA mixture indicates that the broken roof tile media continues to contribute to the phosphate removal process. Broken roof tile media has the potential to enhance removal through adsorption and ion exchange mechanisms because it contains minerals such as Ca^{2+} and Mg^{2+} (Moșiu et al., 2026); these ions can interact with phosphate ions (Lie et al., 2025). In addition, calcium ions released from the medium have the potential to form insoluble calcium phosphate compounds, causing phosphate to precipitate and separate from the liquid phase (Cory & Kling, 2018). The formation of calcium phosphate compounds through the precipitation process allows the phosphate content in wastewater to decrease (Agarwala & Mulky, 2023).

$$3Ca^{2+} + 2PO_4^{3-} \rightarrow Ca_3(PO_4)_2$$

In addition to these physicochemical mechanisms, *Chlorella* sp. also plays a role in utilizing phosphate as a nutrient for biomass growth (Chicaiza et al., 2020). Therefore, the high phosphate removal in both treatments is believed to be the result of a synergy between biofilm activity in the biofilter, nutrient assimilation by microalgae, and adsorption and precipitation occurring on the broken roof tile media. Although the contribution of the broken roof tile media has not been shown to be statistically significantly different from that of BF+MA, the trend toward increased efficiency from 94.75% to 97.09% indicates the potential of this media to enhance the stability and performance of the treatment system in the long term.

Supporting Water Quality Parameters

The improvement in water quality was also demonstrated by changes in supporting parameters following the treatment process. The DO value increased from 0.00 mg/L to 4.48 mg/L (BF+MA) and 4.36 mg/L (BFg+MA), indicating that the photosynthetic activity *of Chlorella* sp. was proceeding well (Permatasari et al., 2018). The pH value remained within the quality standard range (6–9), while ammonia and nitrate levels decreased by 95.39% and 77.62%, respectively; the ammonia and nitrate parameters are interrelated in the treatment system, with the results for ammonia and nitrate shown in **Table 1.** This indicates the presence of a nitrogen cycle within the treatment system (Pashaei et al., 2022). Additionally, COD, TSS, TDS, and MBAS also showed significant reductions. The improvement in these parameters indicates that the hybrid *biofilter–phytoremediation* system is not only effective in removing phosphate but is also capable of improving the overall quality of the wastewater, thereby supporting the sustainability of biological and physicochemical processes within the reactor.

DISCUSSION

The results of the study show that *the biofilter–phytoremediation* hybrid system was able to reduce phosphate concentrations from 5.79 mg/L to 0.30 mg/L in the BF+MA treatment and to 0.17 mg/L in the BFg+MA treatment, with removal efficiencies of 94.75% and 97.09%, respectively. These high removal efficiencies indicate that the combination of a biofilter and *Chlorella* sp. is effective in reducing phosphate in laundry wastewater. These findings are consistent with various previous studies reporting that microalgae can utilize phosphorus as a nutrient for biomass growth (Metin & Altınbaş, 2024), while biofilters provide an environment that supports microbial activity and treatment process stability (Ighalo et al., 2022). The increase in DO levels in both treatments also indicates that photosynthetic activity is proceeding well, thereby supporting the biological processes occurring within the system (Metsoviti et al., 2019).

Although both treatments demonstrated high removal efficiency, BFg+MA resulted in a lower final phosphate concentration compared to BF+MA. These results indicate that broken roof tile media has the potential to enhance system performance through additional mechanisms such as adsorption, ion exchange, and phosphate precipitation. Clay-based materials are known to contain minerals such as calcium and magnesium that can interact with dissolved phosphate ions, thereby reducing their concentration in water (Agarwala & Mulky, 2023). However, the results of the Games–Howell test showed that the difference between BF+MA and BFg+MA was not statistically significant. This suggests that most of the phosphate removal was likely achieved through biological activity within the system, while the contribution of the broken roof tile media appears to be more of a descriptive improvement in efficiency rather than a statistically significant increase.

This study contributes to the development of a simple, economical, and environmentally friendly laundry wastewater treatment technology. Unlike previous studies, which generally evaluated biofilters or microalgae separately, this study integrates both methods into a single treatment system. Furthermore, the use of broken roof tiles as a biofilter medium demonstrates the potential for utilizing low-cost, locally available materials that can effectively support the phosphate removal process. Additionally, the use of used plastic water jugs as reactor vessels helps communities address the issue of excess plastic waste. These findings can serve as an alternative for small- to medium-scale laundry businesses that require wastewater treatment technology with relatively low operating costs.

Nevertheless, this study has several limitations. The evaluation of the system's performance was conducted over a relatively short observation period and therefore cannot yet reflect the long-term stability of phosphate removal. Additionally, this study did not directly measure the adsorption capacity of the broken roof tile media or the growth rate of *Chlorella* sp. biomass, both of which contribute to phosphate removal. Variations in laundry wastewater characteristics which can change depending on the type of detergent and volume used—also have the potential to affect system performance under different field conditions. The reactor's ability to reduce phosphate levels in the wastewater is not yet fully efficient, although the resulting phosphate concentration after treatment is quite low, based on the findings of (Akram et al., 2021). The presence of phosphate at a concentration of 0.025 mg/L in aquatic environments has the potential to cause eutrophication.

Based on the results obtained, the hybrid *biofilter–phytoremediation* system has the potential to be applied as an alternative method for treating laundry wastewater to reduce the phosphate load before discharge into the environment. Further research is recommended to evaluate the system's performance over a longer operational period, examine the media's adsorption capacity in greater detail, and optimize operational factors such as hydraulic retention time, microalgal density, and biofilter media configuration. Additionally, analyzing the utilization of the resulting *Chlorella* sp. biomass is worth exploring to enhance the added value and sustainability of the treatment system.

CONCLUSION

This study shows that a hybrid *biofilter–phytoremediation* system using broken roof tile fragments and *Chlorella* sp. is effective in reducing phosphate concentrations in laundry wastewater. Phosphate concentrations decreased from 5.79 mg/L in the influent to 0.30 mg/L in the BF+MA treatment and 0.17 mg/L in the BFg+MA treatment, with removal efficiencies of 94.75% and 97.09%, respectively. Statistical analysis results indicate that both treatment systems were able to significantly reduce phosphate levels compared to the influent, although the difference between the BF+MA and BFg+MA treatments was not statistically significant.

The findings of this study indicate that the integration of a biofilter and *Chlorella* sp. is an effective approach for reducing the phosphate load in laundry wastewater. The addition of broken roof tile media tends to increase phosphate removal efficiency and has the potential to support the treatment process through adsorption mechanisms and ionic interactions. Overall, the hybrid *biofilter–phytoremediation* system shows potential as a simple, environmentally friendly, and effective alternative technology for treating laundry wastewater and controlling phosphate pollution.

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