

Enhancing Phosphate Removal from Laundry Wastewater Using a Bio filter with Broken Roof Tile Media Integrated with *Chlorella* sp.

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ABSTRACT: Laundry wastewater contains phosphate, which has the potential to increase nutrient loads in water bodies and trigger eutrophication if discharged without adequate treatment. This study aimed to evaluate the ability of a broken roof tile based bio filter (BFG) to remove phosphate and to determine the improvement in its performance after integration with the microalga *Chlorella* sp. (BFG+MA). The study was conducted experimentally using laundry wastewater as the influent, comparing phosphate concentrations in the influent, BFG, and BFG+MA. Phosphate was used as the primary parameter, while other water quality parameters were analyzed as supporting indicators to evaluate the treatment process conditions. Data were analyzed descriptively based on concentration and removal efficiency, as well as statistically at a 5% significance level. The results showed that the phosphate concentration decreased from 5.789 mg/L in the influent to 0.364 mg/L after treatment using BFG, with a removal efficiency of 93.71%. The integration of *Chlorella* sp. further reduced the phosphate concentration to 0.168 mg/L and increased the overall removal efficiency to 97.10%. The microalgae stage was able to remove approximately 53.85% of the residual phosphate remaining after BFG treatment. Statistical analysis revealed a significant difference between the BFG and BFG+MA treatments ($p < 0.05$), confirming that the addition of *Chlorella* sp. resulted in a significant improvement in phosphate removal. These findings indicate that the BFG is effective as an initial removal stage, while the integration of *Chlorella* sp. optimizes phosphate removal through subsequent biological processes. The combination of a broken roof tile-based bio filter and microalgae has the potential to be developed as an effective and sustainable alternative for laundry wastewater treatment.

KEYWORDS: Laundry wastewater, phosphate removal, hybrid bio filter, broken roof tile media, *Chlorella* sp.

I. INTRODUCTION

The growth of laundry businesses in urban areas has increased the production of wastewater classified as graywater, which contains various pollutants such as surfactants, organic matter, suspended solids, nitrogen, and phosphate Apriyani (2017). Phosphate is a key parameter because it generally originates from the use of sodium tripolyphosphate (STPP) in detergents and can trigger eutrophication if it accumulates in water bodies Setiawati & Ariani (2022). These conditions can lead to excessive algal growth, changes in dissolved oxygen concentrations, and disruption of the aquatic ecosystem's balance Schindler (2021). Therefore, effective treatment technologies are needed to reduce phosphate levels before wastewater is discharged into the environment.

Bio filters are a biological approach that can be used in wastewater treatment by utilizing a medium for microorganisms to attach to and form biofilms. The use of alternative materials as bio filter media can be a simpler and more sustainable option. Broken roof tiles have a surface structure that has the potential to support biofilm formation and interact with pollutants, making them suitable as bio filter media for phosphate removal. A roof tile fragment-based bio filter (BFG) system thus has the potential to serve as an alternative for laundry wastewater treatment. However, the BFG's ability to reduce phosphate on its own may not yet achieve optimal removal levels, so additional approaches are needed to enhance its performance.

The microalga *Chlorella* sp. is a biological agent with potential for use in supplementing the phosphate removal process because it is capable of utilizing inorganic phosphorus as a nutrient for biomass growth Akhere & Chukwuka (2023). Integrating *Chlorella* sp. with the BFG can provide complementary removal mechanisms, namely processes occurring in the BFG medium and biofilm, as well as phosphate assimilation by the microalgae. The addition of microalgae is expected to improve phosphate removal, which has not yet been optimal in a single BFG system.

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Based on these considerations, this study was conducted to evaluate the performance improvement of a roof-tile fragment based bio filter through the integration of *Chlorella* sp. in laundry wastewater treatment. The ability of the BFG system compared to the BFG combined with *Chlorella* sp. (BFG+MA) to reduce phosphate concentrations was analyzed to determine the effectiveness of adding microalgae in optimizing the phosphate removal process. The results of this study are expected to provide an alternative wastewater treatment method based on reusable materials and a more sustainable biological process.

II. METHOD

This study employed an experimental approach to evaluate the effect of adding *Chlorella* sp. on the ability of a roof tile fragment-based bio filter to remove phosphate from laundry wastewater. The study was conducted at Universitas Kristen Duta Wacana, Yogyakarta, Indonesia, using laundry wastewater as the influent. The main treatments consisted of a roof tile fragment based bio filter (BFG) and a roof tile fragment-based bio filter combined with *Chlorella* sp. (BFG+MA), while the influent was used as a reference to determine changes in concentration during the treatment process. A comparison of the two systems was conducted to determine the BFG's ability to reduce phosphate and to evaluate the increase in removal efficiency following the integration of microalgae.

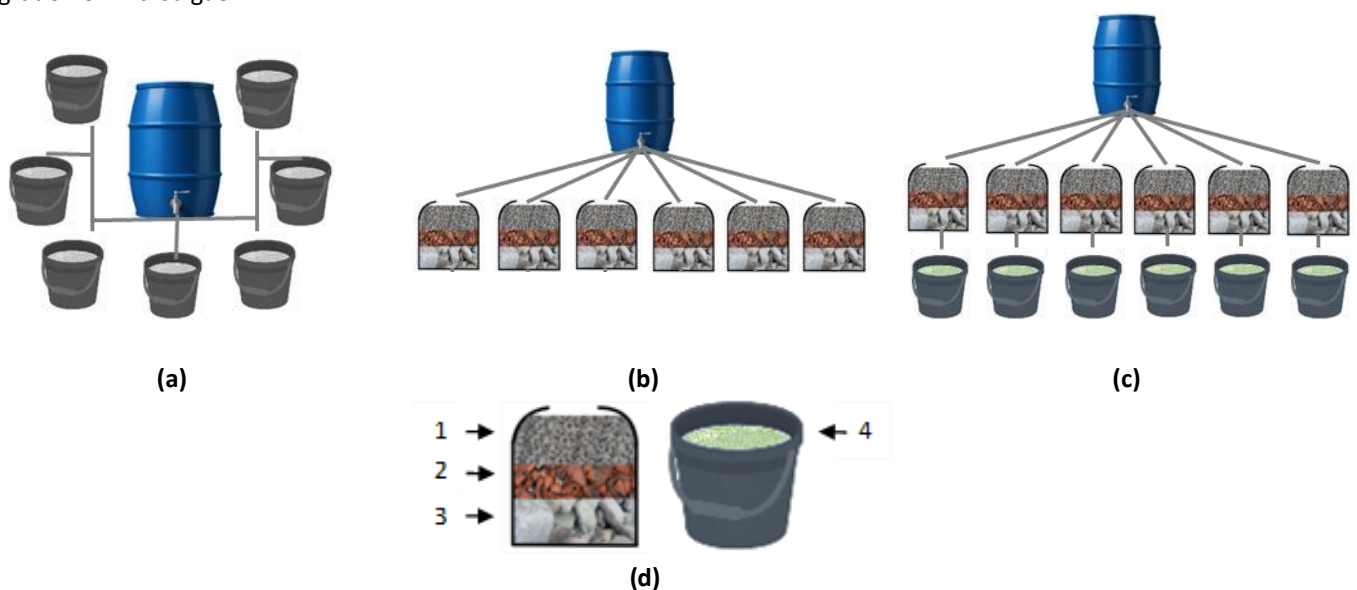


Figure 1. (a) Influent Reactor Desain, (b) BFG Reactor Desain, (c) BFG+MA Reactor Desain, (d) Reactor Composition

Reactor Composition Details:

1. Small gravel 0,5 – 1cm (7,9 cm)
2. Broken roof tiles 1-1,5cm (7,9 cm)
3. Large Gravel 3cm (7,9 cm)
4. *Chlorella* sp. microalgae

The BFG reactor uses broken roof tiles as part of the bio filter media, which serves to provide a surface for biofilm formation and supports the pollutant removal process. Prior to operation, the bio filter media undergoes an acclimatization phase to support the development of a microbial community on the media surface. In the BFG+MA system, effluent from the bio filter unit is further treated using *Chlorella* sp. as an additional biological stage. The microalgae were cultured throughout the study period to facilitate the utilization of dissolved phosphate through nutrient assimilation and biomass formation. Samples were collected periodically from the influent, BFG, and BFG+MA to evaluate changes in water quality during the treatment process. Phosphate was used as the primary parameter, while pH, dissolved oxygen (DO), ammonia, nitrate, total suspended solids (TSS), total dissolved solids (TDS), and temperature were analyzed as supporting parameters to evaluate process conditions and help explain changes in phosphate removal.

The measurement data were analyzed descriptively based on changes in concentration and removal efficiency in each system and statistically using IBM SPSS Statistics. Normality and homogeneity of variances were tested first to determine the appropriate analysis method. Differences in concentrations among treatments were analyzed at a 5% significance level ($\alpha = 0.05$). For data meeting the assumptions of normality and homogeneity of variances, analysis was performed using One-Way Analysis of Variance

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(ANOVA). If the assumption of homogeneity of variances was not met, Welch's ANOVA was used, followed by the Games–Howell test to identify differences between groups.

III. RESULT AND DISCUSSION

Table 1. shows changes in the characteristics of laundry wastewater after treatment using a roof tile fragment-based bio filter (BFG) and after integration with *Chlorella* sp. (BFG+MA). Phosphate was used as the primary parameter to evaluate system performance, while DO, temperature, pH, TSS, TDS, COD, nitrate, MBAS, and ammonia were used as supporting parameters. In general, the treatment process resulted in a clear improvement in water quality compared to the influent, particularly through a reduction in phosphate concentration and several other pollutant parameters.

Table 1. Characteristics of Laundry Waste Water After Processing

No	Parameters	Unit	Influent	BFG	Ef % BFG	BFG+MA	Ef% BFG+MA
1	DO	(mg/L)	0,000	0,738	-	4,355	-
2	Temperature	(°C)	23,733	25,833	-	24,246	-
3	pH	-	7,567	7,246	-	8,180	-
4	TSS	(mg/L)	254,500	49,167	80,68%	93,808	63,14%
5	TDS	(mg/L)	764,250	532,583	30,31%	437,658	42,73%
6	COD	(mg/L)	874,792	140,742	83,91%	153,350	82,47%
7	Phosphate	(mg/L)	5,789	0,364	93,71%	0,168	97,10%
8	Nitrate	(mg/L)	49,588	21,971	55,69%	14,214	71,34%
9	MBAS	(mg/L)	166,677	28,670	82,80%	12,148	92,71%
10	Ammonia	(mg/L)	12,414	0,809	93,48%	0,572	95,39%

A. Phosphate Removal Performance

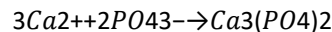
The phosphate concentration in the influent, which was 5.789 mg/L, decreased to 0.364 mg/L after treatment using the BFG, equivalent to a removal efficiency of 93.71%. These results indicate that the roof tile fragment-based bio filter has a high capacity for removing phosphate from laundry wastewater. However, the remaining phosphate concentration in the BFG effluent indicates that the removal process has not yet been maximized. According to a study by Akram et al. (2021), a phosphate concentration of 0.025 mg/L in aquatic environments is already sufficient to cause eutrophication; therefore, after the BFG effluent was further treated using *Chlorella* sp., the phosphate concentration decreased again to 0.168 mg/L in the BFG+MA system, thereby increasing the overall removal efficiency to 97.10% relative to the initial concentration.

The decrease from 0.364 mg/L in the BFG treatment to 0.168 mg/L in the BFG+MA treatment indicates that the microalgae stage was able to remove approximately 53.85% of the phosphate remaining after the biofiltration process. Statistical analysis revealed a significant difference between the BFG and BFG+MA treatments ($p < 0.05$). Thus, the reduction in phosphate concentration following the addition of *Chlorella* sp. is not only evident descriptively but is also statistically supported. These results demonstrate that the integration of microalgae makes a significant contribution to improving BFG performance and support the use of the BFG+MA system to optimize phosphate removal from laundry wastewater.

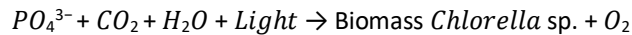
BFG's ability to reduce phosphate is thought to be related to a combination of processes occurring on the roof tile fragments and the biofilm formed on their surfaces Moşiu et al. (2026). The roof tile fragments provide a surface for microbial growth and have the potential to support physicochemical interactions with phosphate. The mineral content in clay-based materials, including calcium and magnesium, has the potential to interact with phosphate ions through mechanisms such as adsorption, ion exchange, or the formation of phosphate compounds with low solubility Lie et al. (2025). Interaction with calcium, for example, can support the formation of calcium phosphate through precipitation, thereby reducing dissolved phosphate in the liquid phase Cory & Kling (2018). However, since the mechanisms of adsorption, ion exchange, and precipitation were not directly measured in this study,

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these mechanisms are considered potential processes that could explain BFG's ability to remove phosphate Agarwala & Mulky (2023).



The addition of *Chlorella* sp. provides an additional biological mechanism to the processes already occurring in the BFG. Microalgae require phosphorus as a nutrient to support growth and biomass formation; thus, the dissolved phosphate remaining after the biofiltration process can be utilized through assimilation Chicaiza et al. (2020).



The significant reduction in phosphate from the BFG to the BFG+MA indicates that the media-based single process does not utilize all available phosphate, whereas the integration of microalgae enables further removal through biological mechanisms. Thus, the research results demonstrate a complementary mechanism between the processes in the roof tile fragment-based bio filter and nutrient assimilation by *Chlorella* sp., resulting in higher phosphate removal performance compared to the single BFG.

B. Supporting Water Quality Parameters

Changes in supporting parameters also indicate differences in conditions between the BFG and BFG+MA systems. The DO concentration increased from 0.000 mg/L at the influent to 0.738 mg/L in the BFG and further reached 4.355 mg/L in the BFG+MA. The significant increase in DO following microalgal integration is consistent with the photosynthetic activity of *Chlorella* sp., which produces oxygen during growth Permatasari et al. (2018). The pH value changed from 7.567 at the influent to 7.246 at the BFG and increased to 8.180 at the BFG+MA. The increase in pH during the microalgae stage may be related to the consumption of inorganic carbon during photosynthesis and indicates a change in biological conditions following the integration of *Chlorella* sp..

Nitrate and ammonia concentrations also decreased gradually. Nitrate decreased from 49.588 mg/L in the influent to 21.971 mg/L in the BFG and 14.214 mg/L in the BFG+MA, while ammonia decreased from 12.414 mg/L to 0.809 mg/L in the BFG and 0.572 mg/L in the BFG+MA. This pattern indicates that the system affects not only phosphate but also nitrogen compounds that may be involved in microbial activity and the nutrient requirements of microalgae Pashaei et al. (2022). TDS and MBAS showed similar patterns, with TDS decreasing from 764.250 to 532.583 and 437.658 mg/L, while MBAS decreased from 166.677 to 28.670 and 12.148 mg/L in the influent, BFG, and BFG+MA, respectively.

In contrast to these parameters, TSS and COD showed a slight increase after the microalgae stage. TSS decreased sharply from 254,500 mg/L at the influent to 49,167 mg/L at BFG, then increased to 93,808 mg/L at BFG+MA. COD showed a similar pattern, decreasing from 874.792 mg/L to 140.742 mg/L in the BFG before increasing slightly to 153.350 mg/L in the BFG+MA. The increase in TSS following the addition of *Chlorella* sp. may be related to the presence of suspended microalgal biomass in the effluent, while the relatively small increase in COD may be influenced by the contribution of organic matter from that biomass. Therefore, the increase in both parameters after the microalgal stage does not directly indicate a decline in treatment performance but may reflect an increase in biological biomass within the system.

Overall, BFG was able to achieve high initial phosphate removal, but integration with *Chlorella* sp. significantly increased phosphate removal, resulting in a final concentration of 0.168 mg/L. The significant difference between BFG and BFG+MA ($p < 0.05$), accompanied by an increase in overall efficiency from 93.71% to 97.10%, indicates that the addition of microalgae is effective as a subsequent step to optimize the performance of the roof tile fragment-based bio filter. These findings support the use of BFG as an initial removal process that is subsequently enhanced through nutrient assimilation by microalgae to achieve more effective phosphate treatment.

IV. CONCLUSIONS

This study demonstrates that a roof tile fragment-based bio filter (BFG) is effective in reducing phosphate concentrations in laundry wastewater, and its performance can be enhanced through integration with *Chlorella* sp. The phosphate concentration decreased from 5.789 mg/L at the influent to 0.364 mg/L after treatment using the BFG, with a removal efficiency of 93.71%. When combined with *Chlorella* sp. (BFG+MA), the phosphate concentration decreased further to 0.168 mg/L, with an overall removal efficiency of 97.10%. The microalgae stage was able to remove approximately 53.85% of the phosphate remaining after treatment using

BFG. Statistical analysis results showed a significant difference between BFG and BFG+MA ($p < 0.05$), indicating that the integration of *Chlorella* sp. significantly improved phosphate removal performance compared to the use of BFG alone. This improvement reflects a complementary process: initial removal via the roof tile fragment-based bio filter, followed by the utilization of phosphate as a nutrient by *Chlorella* sp. Overall, the integration of *Chlorella* sp. with the roof tile fragment-based bio

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filter has the potential to serve as an effective and sustainable approach for optimizing phosphate removal from laundry wastewater.

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