



## Optimization of Media Bed Height for Simple Filtration Treatment of Laundry Wastewater

Muhammad Al Kholif<sup>✉</sup> and Afifian Mohamad Mahrus

Department of Environmental Engineering, Faculty of Engineering and Science,  
Universitas PGRI Adi Buana Surabaya

### Keywords

Laundry wastewater;  
Filtration;  
Zeolite;  
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### Abstract

Household and commercial laundry businesses contribute to water pollution by generating liquid waste with high concentrations of Biological oxygen demand (BOD), Chemical oxygen demand (COD), surfactants, and phosphates. This study aims to analyze the effect of varying the height of a combined filtration medium comprising coconut fiber, zeolite, activated carbon, and gravel on the reduction of BOD and COD levels in laundry wastewater in Bratang Perintis Street, Wonokromo District, Surabaya City. Wastewater samples were collected in 30-liter volumes, with initial BOD and COD concentrations of 320 mg/L and 718 mg/L, respectively, exceeding the quality standards set by East Java Governor Regulation No. 72 of 2013. The wastewater was gravity-fed through four 4-inch-diameter acrylic reactors with media bed heights of 8, 10, 12, and 14 cm, each operated at a flow rate of 1 L/h with two treatment cycles. The results showed a maximum BOD reduction efficiency of 53.75% and a maximum COD reduction efficiency of 55.43% in the reactor with an 8 cm media height. Reactors with thicker media did not demonstrate higher efficiency, indicating the influence of hydraulic factors on system performance. The BOD and COD levels of the effluent from all reactors still exceeded quality standards, necessitating integration with advanced treatment processes to meet discharge standards for water bodies.

## INTRODUCTION

Residential and commercial laundry businesses have grown significantly, generating substantial volumes of wastewater containing pollutants such as surfactants, phosphates, organic matter, and suspended solids (Aqilah et al., 2023). Laundry wastewater is predominantly generated during garment washing, where detergents containing surfactants, builders, fillers, and various additives are extensively used, many of which are known to persist in the environment (Khoiriyah & Rahman, 2024; Richards et al., 2015; Tomšič et al., 2024). Multiple studies have demonstrated that laundry wastewater exhibits elevated levels of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), as well as surfactant and phosphate levels exceeding regulatory thresholds.

These conditions may contribute to eutrophication, dissolved oxygen depletion, and adverse effects on both aquatic organisms and human health. (Amin et al., 2024; Sugito et al., 2025; Yu et al., 2008).

The effluent-quality standards for industrial and laundry wastewater are governed by Governor Regulation of East Java No. 72 of 2013 which stipulates maximum allowable concentrations prior to discharge into receiving water bodies: 100 mg/L for BOD, 250 mg/L for COD, 10 mg/L for phosphate, 10 mg/L for surfactants, and a pH range of 6.0-9.0. A preliminary study by Khoiriyah & Rahman (2024) on laundry wastewater collected from Bratang Perintis Street, Wonokromo District, Surabaya, recorded BOD and COD values of 320 mg/L and 718

<sup>✉</sup> alkholif87@unipasby.ac.id. Surabaya, East Java

mg/L, respectively, both far exceeding the established limits. This underscores the urgent need for treatment technologies that are simple, effective, and feasible at small scales (Melián et al., 2023; Sugito et al., 2025).

Filtration using porous media, such as zeolite, activated carbon, gravel, and natural fibers (e.g., palm fiber), has been widely reported to effectively reduce BOD, COD, TSS, phosphate, and surfactant levels in laundry wastewater through a combination of adsorption, physical straining, and biological processes occurring within the media pores (Pungut et al., 2021; Sutrisno et al., 2024). Pungut et al. (2019) reported that a combination of activated carbon, zeolite, silica sand, ferolite, and anthracite achieved reductions in BOD and COD of more than 50% following filtration treatment. Further studies have shown that zeolite and activated carbon filter systems can achieve COD removal efficiencies of 60-67% and TSS removal efficiencies of 88-91% in laundry wastewater (Sugito et al., 2025).

Other researchers have developed multi-media layering (MML) systems to reduce BOD<sub>5</sub> and COD in domestic wastewater, demonstrating high organic load removal efficiencies through the combined action of layered porous media and biological processes within filtration columns (Al Kholif et al., 2023; Nurhayati et al., 2024). The importance of filtration design and hydraulic retention time has also been highlighted in various biofilter and vermifilter systems for domestic wastewater treatment, providing an indirect design basis for simple filtration-based approaches to laundry wastewater management (Nurhayati et al., 2024; Sutrisno et al., 2024). However, most existing studies have focused on relatively complex multimedia or multilayer systems, such as biofilters and anaerobic-aerobic configurations, designed primarily for domestic wastewater treatment. Specific investigations into the effects of media height variation in simple filtration columns combining palm fiber,

zeolite, activated carbon, and gravel for small-scale laundry wastewater treatment are scarce. The present study addresses this gap by evaluating the performance of varying media heights in a single gravity-fed filtration column that can be readily replicated at the household or small-enterprise level.

This study analyzes the effect of varying filtration media heights, using a combination of palm fiber, zeolite, activated carbon, and gravel, on reducing BOD and COD concentrations in laundry wastewater in Surabaya. The primary objective is to evaluate the effect of media height on the efficiency of BOD and COD removal. The findings provide a basis for the development of simple laundry wastewater treatment systems suitable for household and small-scale commercial applications. However, additional treatment processes may be required to ensure compliance with applicable effluent quality standards. Furthermore, utilizing locally sourced, low-cost media such as palm fiber and gravel offers clear economic advantages and ensures ease of installation for small-scale operators.

## RESEARCH METHODS

### *Sample Location and Source*

This study was conducted using laundry wastewater samples collected from a laundry business located on Bratang Perintis Street, Wonokromo District, Surabaya. The site was selected because its wastewater is discharged directly into the drainage system without any prior treatment. The effluent was visibly turbid, foamy, and malodorous, with preliminary indicators suggesting elevated BOD and COD concentrations. Grab samples were collected in clean polyethylene containers and immediately transported to minimize chemical changes.

Laboratory analyses were carried out at the PDAM Surya Sembada Laboratory in Surabaya. The filtration reactors were assembled and operated at the Environmental Engineering Laboratory, Universitas PGRI Adi Buana Surabaya. Standard protocols for sample

storage and reactor operation were strictly followed to ensure the reliability and reproducibility of the experimental data.

#### *Filtration Media, Materials, and Characterization*

A 30-liter wastewater sample was collected at approximately 12:00 PM, which represents the peak window of commercial laundry generation in small-scale enterprises, and stored in jerry cans prior to processing. The collected wastewater was treated using a simple laboratory-scale filtration system comprising four distinct media layers. The base consists of gravel (2-4 mm particle size) to retain finer media and maintain uniform flow distribution. Above the gravel, natural zeolite (14 mesh) serves as an ion exchanger and adsorbent for both organic and inorganic compounds. This is followed by a layer of coconut shell-based activated carbon (6-12 mesh), which functions as a high-porosity adsorbent for a broad range of organic pollutants. Finally, palm fiber is utilized as a natural fiber layer to capture fine particles and enhance the filtration zone.

Media porosity was determined by measuring the volume of water absorbed by a known volume of each medium using a 1,000 mL graduated cylinder. The results indicated porosities of 40% for gravel, 30% for zeolite, 35% for palm fiber, and 28% for activated carbon, values that reflect each medium's capacity to provide pore space for water flow and adsorptive interaction. The initial characterization of the wastewater yielded BOD and COD values of 320 mg/L and 718 mg/L, respectively, both of which substantially exceed the regulatory limits of 100 mg/L for BOD and 250 mg/L for COD set forth under East Java Governor Regulation No. 72 of 2013.

#### *Design and Reactor Configuration*

The filtration units were constructed from cylindrical acrylic columns with an inner diameter of approximately 4 inches (10.16 cm) and a total height of 70 cm. Four parallel reactors were assembled, each designed with a distinct effective volume corresponding to the different media

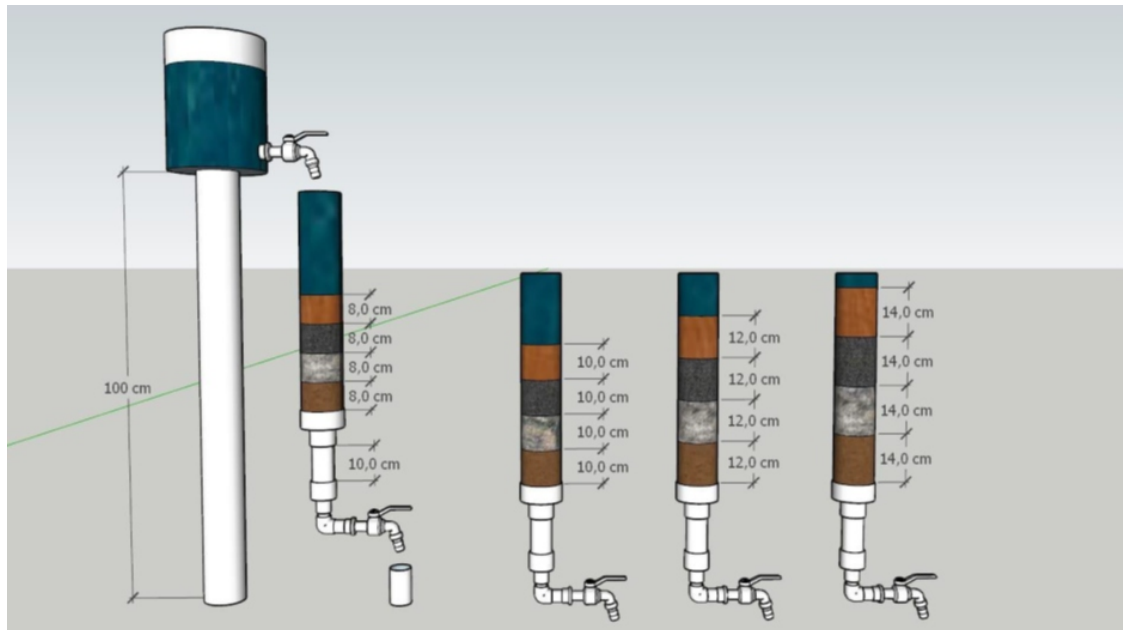
heights investigated. The key design specifications are as follows: column diameter: 0.1016 m (radius: 0.0508 m); total column height: 0.70 m; total column volume: approximately 5.67 L per column; freeboard ranging from 0.14 to 0.38 m, yielding effective volumes of 2.6-4.5 L per reactor; and media height variations (encompassing zeolite, activated carbon, gravel, and palm fiber) assigned to each reactor as follows; Reactor 1: 8 cm, Reactor 2: 10 cm, Reactor 3: 12 cm, and Reactor 4: 14 cm. The media were packed in sequential layers within each column, arranged from bottom to top as gravel, zeolite, activated carbon, and palm fiber. This configuration was designed to maximize contact between the wastewater and the media surfaces while preventing fine particles from passing through the column. Wastewater flow was driven by gravity from a holding tank into each reactor at an operating flow rate of approximately 1 L/hour, such that each reactor's effective volume determined the hydraulic contact time within the media. The reactor setup is illustrated in Figure 1.

#### *Filtration Operational Procedure*

The filtration process began with a preparation phase that included cleaning and arranging the filter media, assembling the reactors, and conducting leak tests along with flow stability checks. The laundry wastewater was then fed from a holding tank into each reactor by gravity, passing through the filtration media before exiting through a tap at the base of the column. The study was carried out over two treatment cycles (Treatment 1 and Treatment 2) for each reactor under comparable operating conditions, with no media regeneration between cycles, in order to assess the potential for media saturation and any associated decline in BOD and COD removal efficiency. Influent and effluent samples from each reactor were collected and subjected to laboratory analysis for the determination of BOD and COD concentrations.

#### *Analysis Method of BOD and COD*

The water quality parameters assessed in



Source: Original artwork created by the authors, (2026)

**Figure 1**

### Schematic diagram of the experimental filtration setup

this study were BOD, measured using the Lovibond BOD System BOD 600 based on standard procedures for determining biological oxygen demand over a prescribed incubation period, and COD, measured using the closed reflux method in accordance with Standard Methods APHA 23<sup>rd</sup> Edition, Section 5220 D (APHA, 2017). The measured BOD and COD concentrations before and after filtration were used to calculate removal efficiency ( $\eta$ ) according to Equation 1:

$$\eta = \frac{C_0 - C_t}{C_0} \times 100\% \quad (1)$$

where  $C_0$  denotes the initial concentration, and  $C_t$  denotes the concentration following treatment. All measurement data are presented graphically to facilitate trend analysis and comparison across media height variations.

## RESULTS AND DISCUSSION

### Initial Characteristic of Laundry Wastewater

Baseline characterization of the laundry wastewater revealed BOD and COD concentrations of 320 mg/L and 718 mg/L, respectively, both substantially exceeding the permissible limits of 100 mg/L and 250 mg/L established under East Java Governor Regulation No. 72 of 2013. These

values confirm that the wastewater from the study site is heavily contaminated with organic matter and does not meet the standards required for direct discharge into receiving water bodies. Similar conditions have been documented in numerous other studies on laundry wastewater in Indonesia, where COD and BOD concentrations frequently surpass effluent quality standards and necessitate dedicated treatment prior to discharge.

### Sample Preparation Step

Following baseline characterization, the wastewater samples were treated using the filtration system across two sequential cycles (Treatment 1 and Treatment 2, as detailed in the Filtration Operational Procedure subsection) for each BOD and COD parameter in each reactor. In this phase, the same laundry wastewater was gravity-fed through four filtration reactors packed with palm fiber, zeolite, activated carbon, and gravel arranged at different media heights. Effluent from each reactor was collected as a test sample for BOD and COD determination after the first treatment cycle. Once Treatment 1 was completed and the samples had been analyzed, the system was operated again under identical conditions for Treatment 2

without replacing the media, yielding BOD and COD data reflective of repeated media use.

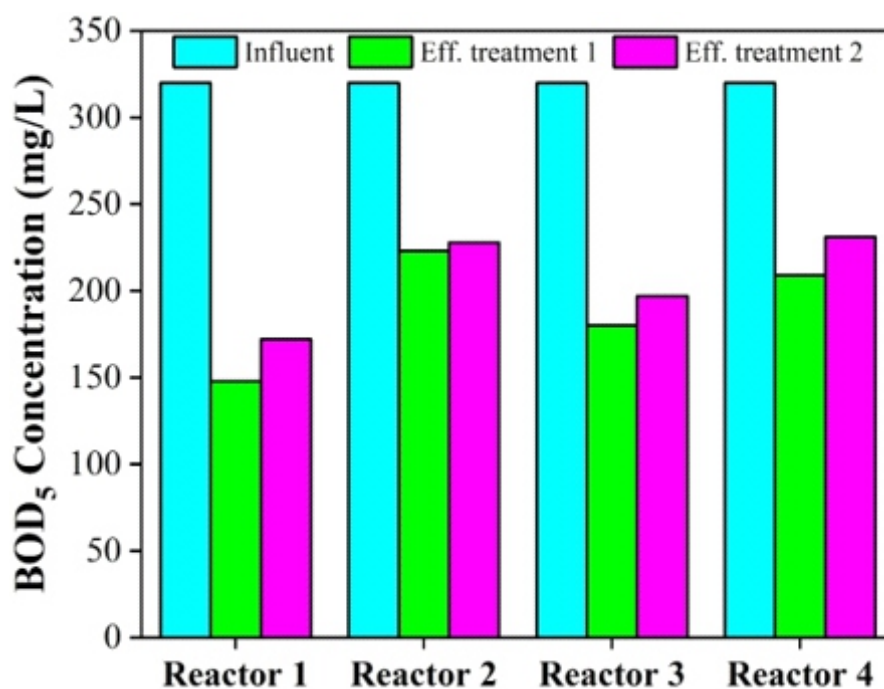
The two-cycle design served two purposes. First, it allowed an assessment of the filtration media's initial capacity to reduce organic load (BOD and COD) under relatively fresh conditions. Second, it enabled an evaluation of performance decline or potential media saturation following repeated exposure to the same pollutant load, thereby providing an estimate of the media's effective service life under practical operating conditions. By incorporating two treatment cycles, the analysis not only captures removal efficiency at its initial optimum but also offers insight into the consistency of system performance in the short term and the need for media regeneration or replacement in small-scale laundry wastewater treatment applications.

#### *BOD Removal by Filtration Media*

Changes in BOD<sub>5</sub> concentration across the four filtration reactors (Reactors 1-4) under three measurement conditions, influent (pre-treatment), Treatment 1 effluent, and Treatment 2 effluent, are illustrated in Figure 2.

The influent BOD<sub>5</sub> concentration was identical across all reactors at 320 mg/L, confirming that each reactor received wastewater with the same initial characteristics. Following Treatment 1, BOD<sub>5</sub> declined to 148 mg/L (Reactor 1), 223 mg/L (Reactor 2), 180 mg/L (Reactor 3), and 209 mg/L (Reactor 4). In Treatment 2, effluent BOD<sub>5</sub> increased across all reactors to 172, 228, 197, and 231 mg/L, respectively, indicating a reduction in removal efficiency relative to the first cycle.

Overall, Reactor 1 achieved the best BOD<sub>5</sub> removal performance in both treatment cycles, while Reactors 2 and 4 consistently produced the lowest removal. This is noteworthy given that the primary distinguishing factor among reactors was the variation in media height (palm fiber, zeolite, activated carbon, and gravel), suggesting that greater media depth does not automatically translate into higher BOD<sub>5</sub> removal. The observed differences in efficiency can be attributed to several hydraulic and operational factors, including the potential formation of preferential flow channels (channeling) in taller media beds, uneven flow



Source: Processed Primary Data, (2026)

Figure 2

Removal of BOD<sub>5</sub> levels before and after filtration in treatments 1 and 2

distribution, and increased head loss, causing portions of the media volume to remain insufficiently wetted (Pradiko et al., 2025).

The research results show that Reactor 1 outperformed Reactor 4; this finding highlights the phenomenon of critical hydraulics in the filtration column, which occurs due to gravity and the absence of pressure. From a mechanical perspective, the packing of a mixed media layer consisting of natural fiber, such as oil palm fiber, combined with structured particles like zeolite and activated carbon, creates a cumulative layer load and downward movement. The increased bed height in Reactor 4 caused the media to pack more densely and tightly (in the lower part of the filter). Consequently, this drastically reduces local interparticle porosity and creates high hydraulic resistance to downward gravitational flow. The result of all this is that the wastewater actively undergoes short-circuiting and tends to seek the path of least resistance. This phenomenon occurs as preferential flow, which generally spreads along the smooth inner boundary of the acrylic column wall. While this preferential flow occurs, the linear velocity of the fluid within the narrow path increases drastically, causing the majority of the wastewater volume to bypass the zeolite and activated carbon core adsorption matrix entirely. This condition creates a local “dead zone” where the media is underutilized or insufficiently saturated with water. On the other hand, the 8-cm-thick shallow bed in Reactor 1 results in minimal downward pressure loss, allowing for a highly uniform horizontal distribution of the influent across the entire cross-sectional area. This maximizes the actual effective contact surface area between dissolved organic pollutants and active media sites, resulting in significantly higher BOD<sub>5</sub> removal efficiency despite the lower total media volume.

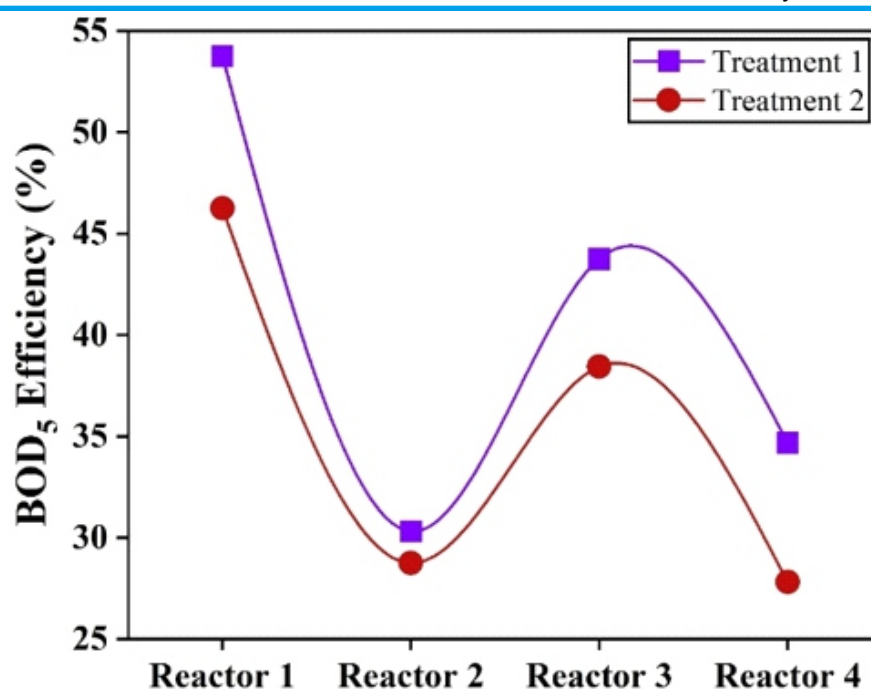
The rise in BOD<sub>5</sub> concentrations in Treatment 2 relative to Treatment 1,

observed across all reactors, is indicative of media saturation, particularly in the activated carbon and zeolite layers, which serve as the primary adsorbents for dissolved organic matter. As the filter media were repeatedly exposed to wastewater without regeneration, their adsorption capacity gradually declined, while pore spaces became increasingly clogged with biomass and suspended solids, allowing a portion of the organic compounds to pass through the filter column without being retained. A similar pattern was reported by Pungus et al. (2019), who observed BOD and COD reductions of approximately 53% and 54% using a combination of activated carbon, zeolite, silica sand, ferolite, and anthracite, with a noted decline in efficiency when the media were not periodically regenerated or replaced.

#### *Removal Efficiency of BOD*

The BOD<sub>5</sub> removal efficiencies for all four reactors across both treatment cycles are presented in Figure 3. Overall, no substantial difference in efficiency was observed between Treatment 1 and Treatment 2. The highest removal efficiency was recorded in Reactor 1 during Treatment 1, at 53.75%, falling to 46.25% in Treatment 2. Beyond Reactor 1, removal efficiency dropped considerably, particularly in Reactors 2 and 4.

Compared to previous studies, the peak BOD<sub>5</sub> removal of 53.75% achieved by Reactor 1 is broadly comparable to the findings of Pungus et al. (2019), who reported BOD and COD reductions of 53% and 54% successively, using a combination of natural adsorbents in a laundry wastewater filtration system. That said, studies employing more optimized designs and longer hydraulic retention times have achieved notably higher BOD reductions. For example, Pradiko et al. (2025) reported that a compact dual-column filtration system packed with zeolite and activated carbon achieved COD and TSS removal efficiencies of up to 67% and 91%, respectively, in laundry wastewater, with several effluent



Source: Processed Primary Data, (2026)

**Figure 3**  
BOD<sub>5</sub> removal efficiency

parameters meeting regional quality standards. Similarly, a zeolite and activated carbon filter system studied in Malang demonstrated COD removal of approximately 60.41% and TSS removal of 88.31%, underscoring the importance of contact time and media arrangement in determining overall performance (Leonardo et al., 2023).

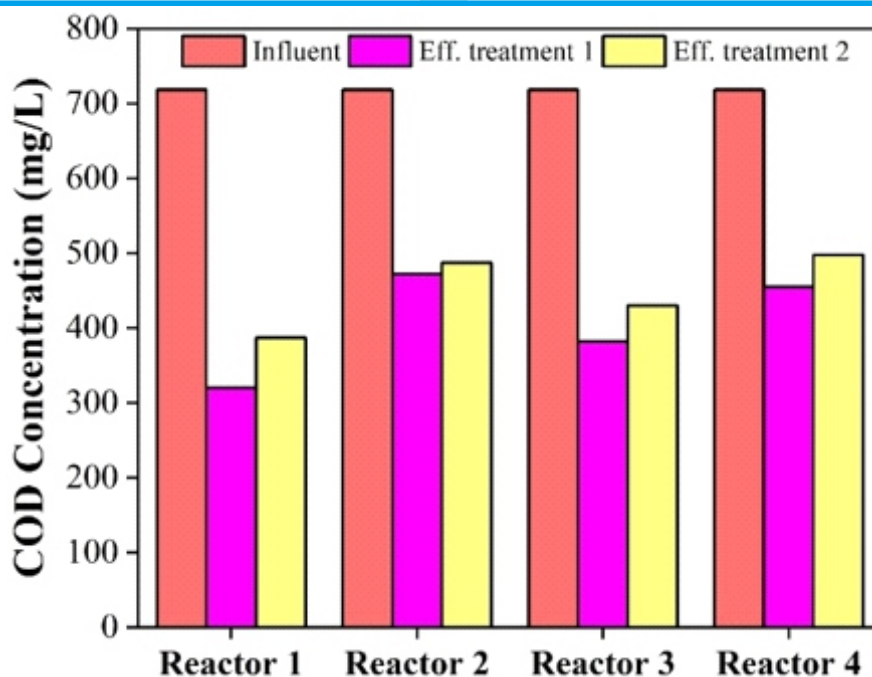
Several factors account for the performance gap observed in this study. First, the single-column gravity-fed design, operating at a relatively low flow rate with varying media heights, provided a shorter hydraulic retention time per unit of media depth than dual-column systems or those with more precise flow control. Second, the absence of an aeration stage or controlled biological process, such as a well-established aerobic biofilm, restricted biological degradation, leaving physical adsorption as the dominant removal mechanism, one that is inherently susceptible to rapid saturation. Third, the relatively high initial BOD concentration of 320 mg/L, compared with the synthetic or more dilute wastewater used in certain reference studies, resulted in a higher organic load-

to-media mass ratio, causing the media to reach capacity more quickly.

Taken together, the BOD<sub>5</sub> data confirm that the palm fiber-zeolite-activated carbon-gravel media combination achieves moderate BOD<sub>5</sub> reductions in the range of 30-54%, though efficiency declines in successive cycles and effluent BOD<sub>5</sub> concentrations remain above the 100 mg/L threshold prescribed by East Java Governor Regulation No. 72 of 2013. Compared with systems incorporating aeration, coagulation, or multi-column configurations, the proposed filtration system offers greater simplicity and accessibility for household-scale and small-to-medium enterprises. However, further optimization, including longer hydraulic retention times, periodic media regeneration, or the integration of biological treatment processes, is required to achieve full compliance with applicable effluent quality standards.

#### *COD Removal by Filtration Media*

Figure 4 presents the COD concentration dynamics in the laundry wastewater across the four filtration reactors under three measurement conditions: influent (pre-treatment), Treatment 1 effluent, and



Source: Processed Primary Data, (2026)

**Figure 4**

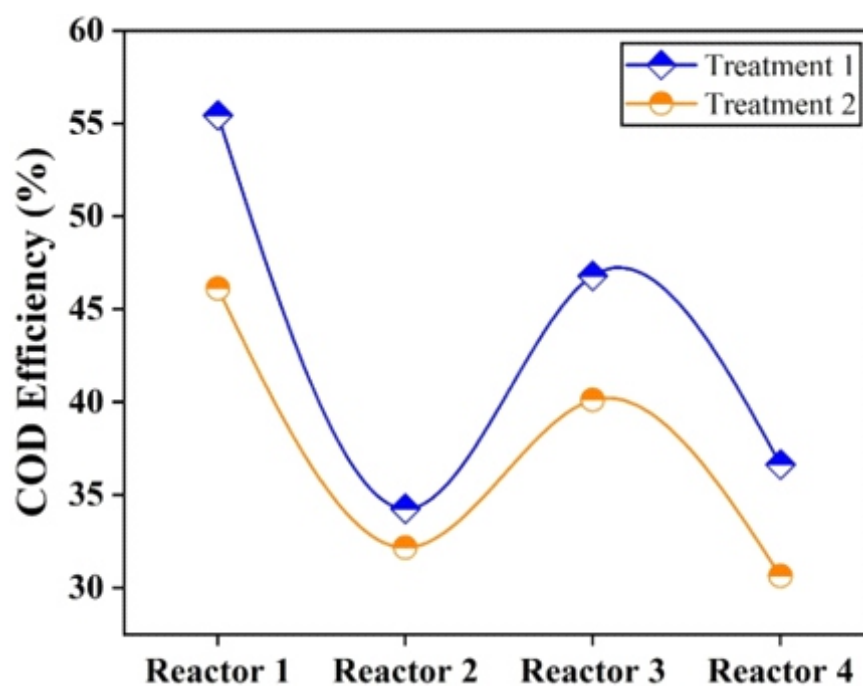
**The removal of COD levels before and after filtration in treatments 1 and 2**

Treatment 2 effluent. The influent COD concentration was consistently 718 mg/L across all reactors, far exceeding the 250 mg/L limit set by East Java Governor Regulation No. 72 of 2013 (Gubernur Jawa Timur, 2013). This elevated concentration reflects the high dissolved organic load characteristic of laundry wastewater, primarily attributable to detergents, surfactants, and other persistent organic residues (Pungut et al., 2021; Sutrisno et al., 2020). After Treatment 1, COD decreased to 320 mg/L (Reactor 1), 472 mg/L (Reactor 2), 382 mg/L (Reactor 3), and 455 mg/L (Reactor 4). In Treatment 2, effluent COD rose again across all reactors to 387, 487, 430, and 498 mg/L, respectively, representing a meaningful decline in removal efficiency compared to the first cycle. This trend suggests that the adsorptive capacity of the media, particularly zeolite and activated carbon, was diminished due to saturation following repeated contact with high-organic-load wastewater in the absence of any regeneration process.

The primary mechanisms driving COD removal in this filtration system are physical adsorption by activated carbon and zeolite, combined with

mechanical straining through the gravel and palm fiber layers. Activated carbon is well recognized for its exceptionally high specific surface area, which enables effective uptake of dissolved organic compounds via van der Waals interactions and chemical bonding at its surface. A study employing a mixture of granular activated carbon (GAC) and zeolite as combined adsorbents reported COD and phosphate removal efficiencies of 63.11% and 57.14%, respectively, at a contact time of 150 minutes, demonstrating that longer exposure between wastewater and the adsorbent material yields progressively higher removal efficiency (Nasir & Titah, 2024). By comparison, the COD removal efficiencies recorded in the present study, ranging from 34% to 55%, fall short of that benchmark, a shortcoming attributable in part to the shorter hydraulic retention time (HRT) inherent in a gravity-fed system operating at a flow rate of approximately 1 L/hour.

A single-column zeolite and activated carbon filter system tested on industrial laundry wastewater in Malang achieved a COD removal efficiency of 60.41% (Leonardo et al., 2023), exceeding the 55.43% recorded by Reactor 1 in the



Source: Processed Primary Data, (2026)

**Figure 5**  
COD removal efficiency in treatments 1 and 2

present study. This discrepancy is most likely linked to differences in contact time: the Malang study identified an optimal treatment duration of 120 minutes for COD reduction, whereas the hydraulic retention time in this study was not precisely controlled, relying instead on a gravity-driven flow rate that inherently fluctuates. This aligns with the well-established principle that longer contact time between wastewater and the filter media yields a proportional reduction in effluent COD (Leonardo et al., 2023). Pungut et al. (2021), who examined COD and phosphate removal from laundry wastewater through adsorption using zeolite and activated carbon media, reported peak COD removal efficiencies of 72.48% for the activated carbon reactor and 64.55% for the zeolite reactor. These figures surpass those of the present study, largely because that work employed a batch system with a lower initial COD concentration and a higher adsorbent-to-wastewater mass ratio, resulting in a more favorable adsorption capacity per unit volume of treated wastewater.

#### *COD Removal Efficiency*

Figure 5 compares the COD removal

efficiency (%) between Treatment 1 and Treatment 2 across all reactors. A consistent decline in efficiency from Treatment 1 to Treatment 2 was observed in every reactor. Reactor 1 recorded the highest efficiency in Treatment 1 at 55.43%, which dropped to approximately 46.10% in Treatment 2. Reactor 2 yielded the lowest efficiency in both cycles at 34.26% and 32.17%, while Reactors 3 and 4 fell between these two extremes.

The decline in efficiency during Treatment 2 can be explained through the theory of adsorbent saturation. The adsorptive capacity of any given medium is finite; each gram of adsorbent can bind only a limited quantity of adsorbate before its active sites become fully occupied and no longer reactive (Largitte & Pasquier, 2016). Studies using GAC and zeolite as adsorbents for laundry wastewater have reported that the adsorption behavior more closely follows the Freundlich isotherm model than the Langmuir model, suggesting that adsorption occurs on heterogeneous surfaces in a multilayer fashion with varied site energies and a tendency toward gradual saturation as pollutant loading increases (Nasir & Titah,

2024). As the active sites on the activated carbon and zeolite surfaces became progressively occupied by organic molecules during the first treatment cycle, the number of available binding sites for subsequent pollutant uptake decreased substantially, resulting in a consistent drop in COD removal efficiency across all reactors in Treatment 2. A comparable phenomenon has been documented in a study using silica, zeolite, and activated carbon filtration media for laundry wastewater, where 2 kg of activated carbon achieved COD reductions of up to 62.47%, but performance declined noticeably without media regeneration (Assiddieq et al., 2017).

Interestingly, Reactor 1, which had the shortest media bed, consistently achieved the highest removal efficiency across both treatment cycles. This performance can be attributed to a more uniform flow distribution and a lower tendency for channeling in the shorter filter column, enabling more effective contact between the influent and the entire filter media. In contrast, reactors with taller media beds (Reactors 2 and 4) likely experienced increased head loss and uneven flow distribution, leaving portions of the media bed underutilized. This finding contrasts with the results reported for a filtration system incorporating 20 cm of activated carbon and 40 cm of zeolite, which achieved detergent removal efficiencies of up to 99.02%. These findings suggest that, under appropriate operating conditions and optimized column configurations, greater media depth can enhance treatment performance. The discrepancy points to the conclusion that media height alone is insufficient to predict system performance; flow distribution, particle size, and influent characteristics each play a critical role in determining overall filtration efficacy (Haderiah et al., 2015).

The steady decline in COD removal efficiency as the media bed height increased from 8 cm to 14 cm further highlights the importance of column fluid

dynamics. Although a taller column theoretically contains a larger quantity of adsorbent material (activated carbon and zeolite), its actual performance depends primarily on how the wastewater moves through the bed. Under gravity-fed conditions with a constant flow rate of 1 L/h, flow distribution becomes increasingly sensitive as the bed depth increases.

In reactor 1, the flow pattern more closely resembles plug flow, allowing the liquid to pass relatively uniformly through the media and maximizing contact with the available adsorption sites. As a result, most of the active pores contribute effectively to the removal of organic contaminants. In contrast, increasing the bed height to 12 cm and 14 cm introduces greater variability in media packing, which is typical of gravity-settled multi-layer systems. These packing irregularities promote the development of preferential flow channels, causing much of the influent to bypass large portions of the adsorbent bed. As a result, contaminants become concentrated within preferential flow pathways, resulting in the rapid depletion of adsorption sites along these channels while reducing the effective utilization of the remaining filter media. This uneven flow distribution explains why simply increasing the amount of adsorbent does not necessarily improve COD removal in small-scale gravity-driven columns without an effective mechanism to distribute flow more uniformly.

As a comparison with alternative treatment technologies, the constructed wetland systems examined by Al Kholif et al. (2023) and Majid et al. (2025), for domestic wastewater, achieved COD and BOD reductions in the range of 14.5-39%, which is lower than what was observed in the present filtration study. Constructed wetlands, however, offer advantages in terms of long-term sustainability and do not require periodic media replacement. At the other end of the spectrum, the combination of PAC coagulation and activated carbon adsorption investigated

by Sugito et al. (2025), for laundry wastewater, a dramatically higher removal was achieved, with COD efficiency exceeding 90% and phosphate removal reaching 96%, far outperforming the single-pass filtration system used in this study. This underscores the potential of integrating coagulation as a pre-treatment step. By first aggregating colloidal particles and dissolved organic compounds into larger flocs, coagulation substantially improves the subsequent filterability and adsorptive uptake by the media. Furthermore, studies have shown that integrating filtration with an Anaerobic Baffled Reactor (ABR) can significantly enhance organic matter removal from domestic wastewater compared with filtration alone (Al Kholif et al., 2023; Al Kholif et al., 2025).

Overall, this study demonstrates that a simple gravity-fed filtration system using a palm fiber-zeolite-activated carbon-gravel media combination can reduce COD in laundry wastewater within an efficiency range of 34-55%, which is broadly comparable to other simple filtration systems reported in the literature. Nevertheless, the treated effluent still exceeds the COD limit of 250 mg/L stipulated under East Java Governor Regulation No. 72 of 2013. These findings highlight the need for treatment systems that integrate filtration with advanced processes, such as coagulation, batch adsorption, anaerobic bioreactors, or multi-media layering, to consistently and sustainably achieve the required effluent quality standards (Al Kholif et al., 2023; Sugito et al., 2025; Sutrisno et al., 2020).

## CONCLUSION

This study demonstrates that a simple gravity-fed filtration system using a combination of palm fiber, zeolite, activated carbon, and gravel media can meaningfully reduce BOD and COD concentrations in laundry wastewater. The highest removal efficiencies, 53.75% for BOD and 55.43% for COD, were

recorded in Reactor 1, which had the shallowest media bed at 8 cm, during Treatment 1. Reactors with greater media heights did not perform correspondingly better, suggesting that hydraulic factors such as flow distribution and the potential for channeling are more decisive in determining system performance than media depth alone. In Treatment 2, BOD and COD removal efficiencies declined across all reactors, reflecting progressive adsorbent saturation in the absence of media regeneration and the consequent reduction in available adsorption sites. Despite the substantial reduction in organic load, effluent BOD and COD levels across all reactor configurations still exceeded the permissible limits under quality standard. This indicates that the simple filtration system, while promising as a low-cost and accessible treatment option, must be integrated with further treatment processes, such as coagulation, anaerobic bioreactors, or multi-media layering systems, before it can reliably meet the effluent quality standards required for discharge into receiving water bodies.

## ACKNOWLEDGMENTS

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