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

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Keywords

laundry wastewater; filtration; zeolite; activated carbon

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 waste-water containing pollutants such as surfactants, phosphates, organic matter, and suspended solids (Aqilah et al., 2023). Laundry wastewater is predominantly generated during garment-washing processes, in which detergents containing surfactants, builders, fillers, and various additives are extensively used. Many of these compounds are environmentally persistent and may contribute to long-term contamination of receiving water bodies. (Khoiriyah & Rahman, 2024; Richards et al., 2015; Tomšič et al., 2024). Multiple studies have demonstrated that laundry wastewater exhibits elevated concentrations of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), as well as surfactant and phosphate concentrations exceeding regulatory thresholds. These conditions can trigger eutrophication, deplete dissolved oxygen, and pose risks to both human health and aquatic organisms (Amin et al., 2024; Sugito et al., 2025; Yu et al., 2008).

Effluent-quality standards for industrial and laundry wastewater are regulated under Governor Regulation of East Java No. 72 of 2013. Before discharge into receiving water bodies, wastewater must comply with the following maximum permissible concentrations: 100 mg/L for BOD, 250 mg/L for COD, 10 mg/L for phosphate, and 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

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BOD and COD values of 320 mg/L and 718 mg/L, correspondingly, 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 effective methode for reducing BOD, COD, TSS, phosphate, and surfactant concentrations in laundry wastewater through adsorption, physical straining, and biological processes occurring within the media pores (Pungut et al., 2021; Sutrisno et al., 2024). Pungus 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_5 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.

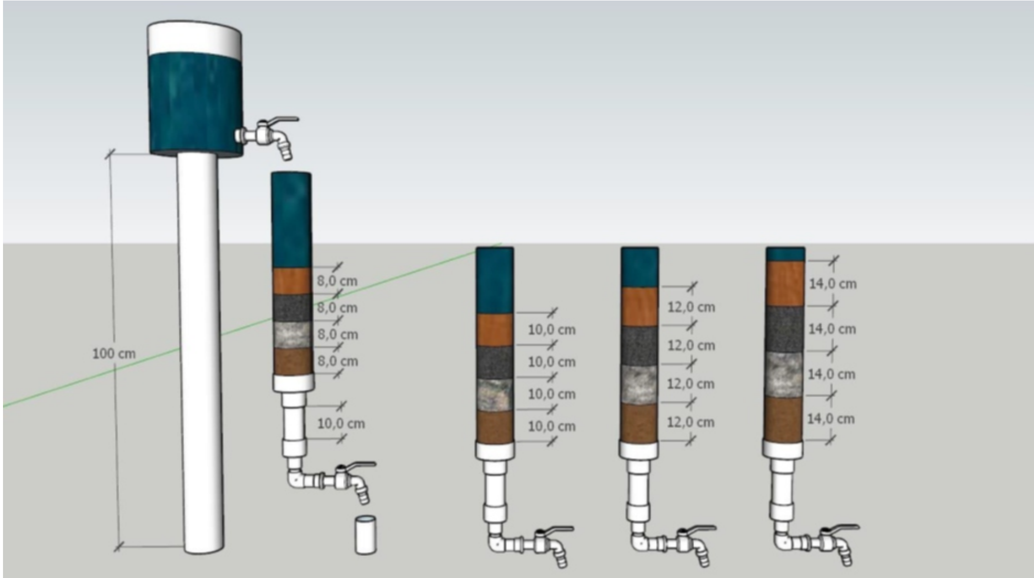
This study analyzes the effect of varying filtration media heights, using a combination of palm fiber, zeolite, activated carbon, and gravel, on reducing BOD and COD concentrations in laundry wastewater in Surabaya. The primary objective is to evaluate the effect of media height on the efficiency of BOD and COD removal. These findings provide a basis for designing simple laundry wastewater treatment units suitable for household and small-business applications, although additional treatment stages may be necessary to achieve full 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 Perusahaan Daerah Air Minum (PDAM) Surya Sembada Laboratory in Surabaya. At the same time, the assembly



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

Figure 1

Schematic diagram of the experimental filtration setup

Analysis Method of BOD and COD

The water quality parameters assessed in 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 23rd Edition, Section 5220 D (APHA, 2017). The measured BOD and COD concentrations before and after filtration were used to calculate removal efficiency (η) according to Equation 1:

$$\eta = \frac{C_o - C_t}{C_o} x\ 100\% \qquad (1)$$

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. During this phase, the same laundry wastewater sample was gravity-fed through four filtration reactors containing palm fiber, zeolite, activated carbon, and gravel 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 and operation of the filtration reactors were conducted at the Environmental Engineering Laboratory of Universitas PGRI Adi Buana Surabaya. Standard protocols were strictly followed during sample storage and reactor operations to ensure data reliability.

Filtration Media, Materials, and Characterization

A 30-L wastewater sample was collected at approximately 12:00 p.m., representing the peak wastewater-generation period in small-scale commercial laundries, stored in jerry cans, and subsequently 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 layer, natural zeolite (14 mesh) was used as an ion-exchange medium and adsorbent for organic and inorganic compounds, followed by coconut shell-based activated carbon (6–12 mesh), a highly porous adsorbent capable of removing 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. Baseline 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 reactor with a different effective volume corresponding to the tested filter-media heights. The key design specifications were as follows: a column diameter of 0.1016 m (radius, 0.0508 m); a total column height of 0.70 m; and an approximate total volume of 5.67 L per column. Freeboard depths ranged from 0.14 to 0.38 m, resulting in effective reactor volumes of 2.6–4.5 L. The total height of the filter-media layers (comprising zeolite, activated carbon, gravel, and palm fiber) was varied across the reactors as follows: 8 cm in Reactor 1, 10 cm in Reactor 2, 12 cm in Reactor 3, and 14 cm in Reactor 4. 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 were collected from all reactors and analyzed in the laboratory to quantify BOD and COD concentrations.

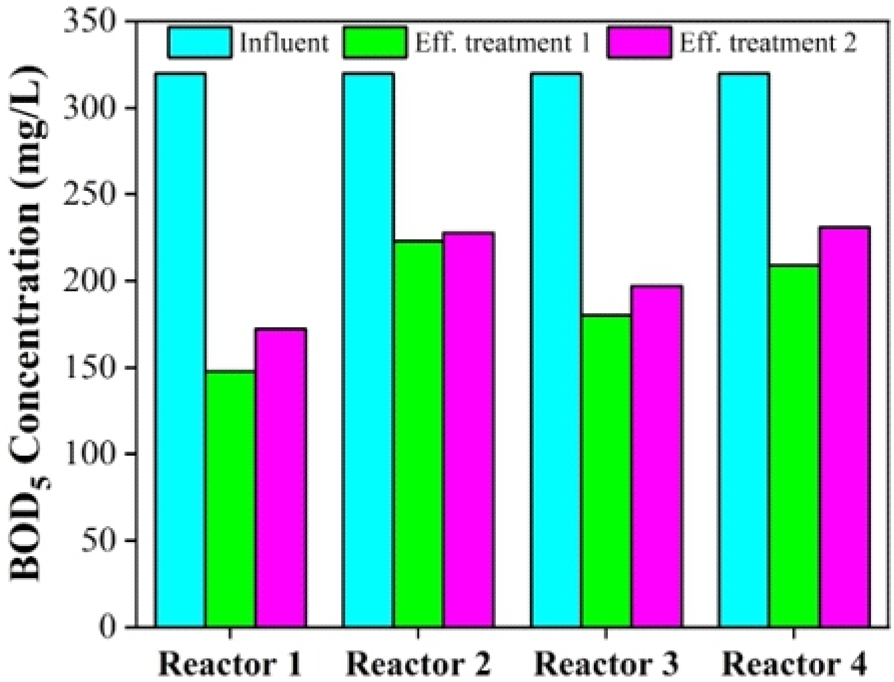
BOD and COD data reflective of repeated media use.

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_5 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_5 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_5 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_5 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_5 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_5 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_5 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_5 removal efficiency despite the lower total media volume.

The rise in BOD_5 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 media underwent repeated contact with the wastewater without regeneration, adsorption capacity diminished, and pore spaces became progressively blocked by biomass and suspended solids, allowing a portion of the organic compounds to pass through the filter column unretained. 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

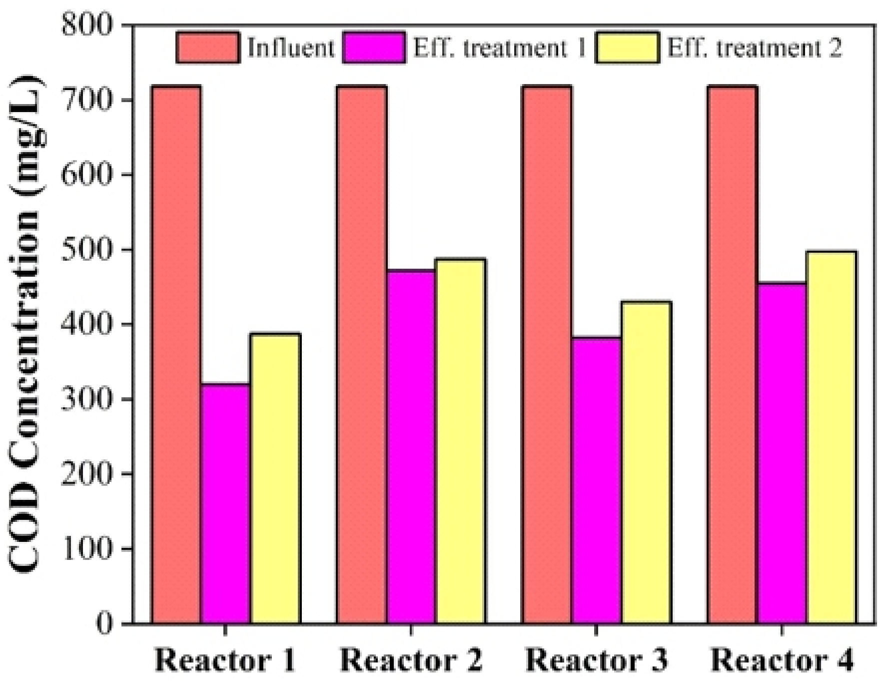
The BOD_5 removal efficiencies for all four reactors across both treatment cycles are presented in Figure 3. Overall, no substantial difference in efficiency was observed between Treatment 1 and Treatment 2. The highest removal efficiency was recorded in Reactor 1 during Treatment 1, at 53.75%, falling to 46.25% in Treatment 2. Beyond Reactor 1, removal efficiency dropped considerably, particularly in Reactors 2 and 4.

The maximum BOD_5 removal efficiency of 53.75% achieved by Reactor 1 was comparable to that reported by Pungus et al. (2019), who obtained BOD and COD reductions of 53% and 54%, respectively, using 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, a zeolite-activated carbon filter in a compact dual-column configuration was reported to achieve COD removal of up to 67% and TSS removal of 91% in laundry wastewater, with several parameters meeting regional quality standards (Pradiko et al., 2025). . Similarly, a zeolite and activated carbon filter system studied

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. 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.

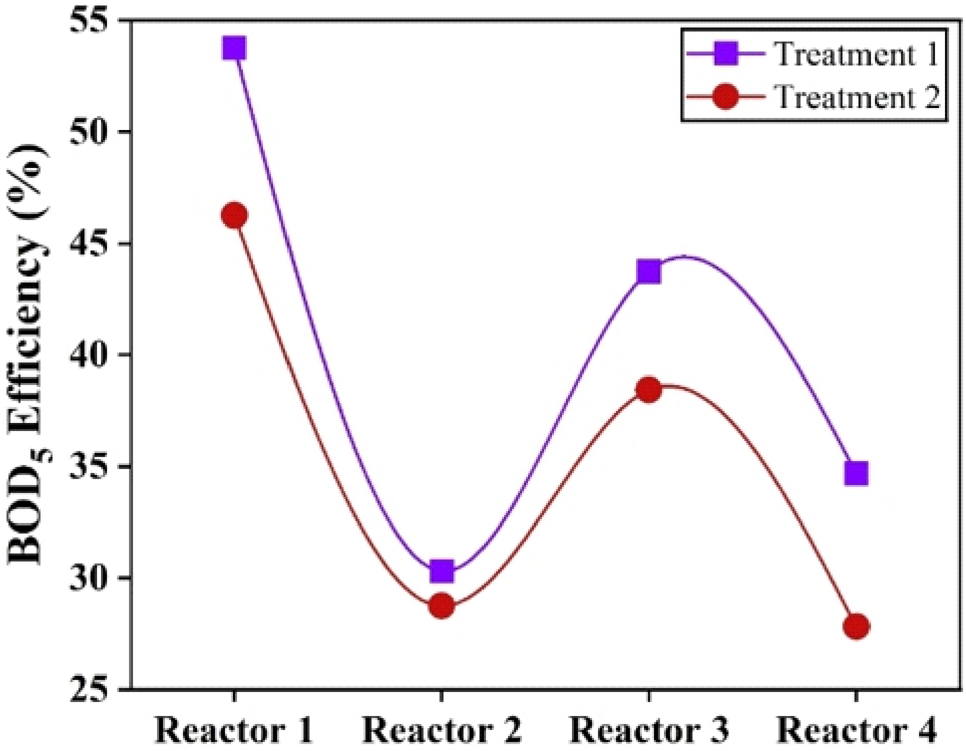
A single-column zeolite and activated carbon filter system tested on industrial laundry wastewater in Malang achieved a COD removal efficiency of 60.41% (Leonardo et al., 2023), exceeding



Source: Processed Primary Data, (2026)

Figure 4

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



Source: Processed Primary Data, (2026)

Figure 3

BOD_5 removal efficiency

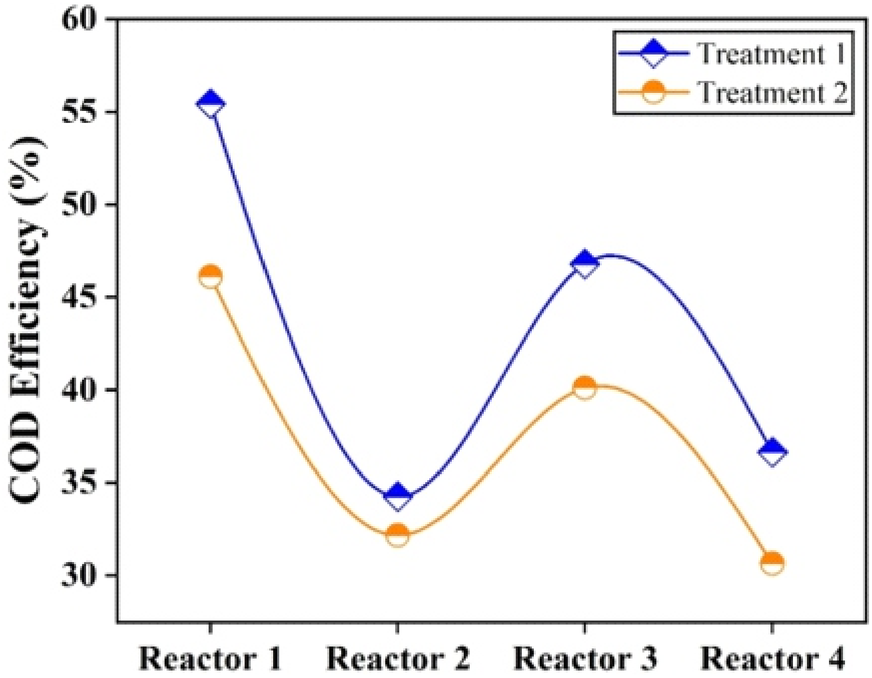
in Malang demonstrated COD removal of approximately 60.41% and TSS removal of 88.31%, underscoring the importance of contact time and media arrangement in determining overall performance (Leonardo et al., 2023).

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_5 data confirm that the palm fiber-zeolite-activated carbon-gravel media combination achieves moderate BOD_5 reductions in the range of 30-54%, though efficiency declines in successive cycles and effluent BOD_5 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 multiple filtration columns, the present system is simpler and more accessible for small and micro enterprises; however, further optimization, such as increasing hydraulic retention time, regenerating the filter media, or integrating a biological treatment stage will be 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 5

COD removal efficiency in treatments 1 and 2

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 efficiencies (%) between Treatment 1 and Treatment 2 for 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 granular activated carbon (GAC) and zeolite as adsorbents for laundry wastewater have reported that adsorption more closely follows the Freundlich isotherm than the Langmuir model, indicating multilayer adsorption on heterogeneous surfaces with varied site energies and gradual saturation as pollutant loading increases (Nasir & Titah, 2024).

more uniform flow distribution.

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 of domestic wastewater treatment using an anaerobic baffled reactor (ABR) combined with filtration have shown that integrating anaerobic biological processes can substantially improve organic-load removal 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 comprising palm fiber, zeolite, activated carbon, and gravel can reduce COD in laundry wastewater by 34–55%, a performance range broadly comparable to that of 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 (Gubernur Jawa Timur, 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 exhibit correspondingly higher removal efficiencies, suggesting that hydraulic factors, such as flow distribution and channeling may have a stronger influence on system performance than media depth alone.. In Treatment 2, BOD and COD removal efficiencies declined across all reactors due to adsorbent saturation in the absence of media regeneration. Despite the substantial reduction in organic load, effluent BOD and COD concentrations across all reactor configurations still exceeded the permissible limits under East Java Governor Regulation No. 72 of 2013. 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.

REFERENCES

Al Kholif, M., Alifia, A. R., Pungut, Sugito, & Sutrisno, J. (2023). Kombinasi Teknologi Filtrasi Dan Anaerobik Buffled Reaktor (ABR) Untuk Mengolah Air Limbah Domestik. *Jurnal Kesehatan Masyarakat Indonesia*, *15*(2), 19–24.

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 or replacement (Assiddieq et al., 2As 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, of activated carbon achieved COD removal efficiencies of up to 62.47%; however, performance declined noticeably when the media were not regenerated or replaced (Assiddieq et al., 2017).

Interestingly, Reactor 1, which had the shortest media bed, consistently achieved the highest removal efficiency across both treatment cycles. This can be attributed to more uniform flow distribution and a reduced tendency for channeling in a shorter column, allowing the entire media volume to interact optimally with the influent. 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 diverges from reported results for an activated carbon and zeolite filter system using a 20 cm activated carbon layer and a 40 cm zeolite layer, which achieved detergent removal efficiencies of up to 99.02%, suggesting that under the right operating conditions and column design, greater media depth can indeed yield superior 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 at a constant flow rate of 1 L/h, flow distribution becomes increasingly sensitive to variations in bed depth.

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. Therefore, contaminant loading may become concentrated along a limited number of flow pathways, rapidly exhausting adsorption sites while leaving substantial portions of the filter media underutilized. This uneven flow distribution explains why increasing the amount of adsorbent alone does not necessarily enhance COD removal in small-scale gravity-driven columns without an effective mechanism to ensure

https://doi.org/10.26714/jkmi.15.2.2020.19-24

Al Kholif, M., Nurhayati, I., Sugito, Sari, D. A., Sutrisno, J., Pungut, & Mujiyanti, D. R. (2023). Removal of BOD_5 and COD from Domestic Wastewater by Using a Multi-Media-Layering (MML) System. *Environment and Natural Resources Journal*, *21*(6), 534–544.https://doi.org/10.32526/ennrj/21/20230202

Al Kholif, M., Subianto, A., & Sutrisno, J. (2025). Effect of hydraulic retention time (HRT) in an anaerobic baffled reactor (ABR) on the reduction of BOD and COD in slaughterhouse industrial wastewater. *Advances in Environmental Technology*, *11*(1), 1–12. https://doi.org/10.22104/AET.2024.6805.1860

Amin, U. K., Setyobudiarso, H., & Wulandari, C. D. (2024). Reduction of COD, BOD, and phosphate levels in laundry wastewater using aeration-filtration method. *Jurnal Mahasiswa "ENVIRO," 3*(2), 8–8. https://ejournal.itn.ac.id/ENVIRO/article/view/4122

APHA. (2017). Standard Methods For the Examination of Water and Wastewater. In *American Public Health Association, American Water Works Association, Water Environment Federation* (23rd Edition). https://www.standardmethods.org/doi/10.2105/SMWW.2882.103

Aqilah, A. T., Kirana, R. A., Susanto, H. B., Putri, N. H., Sari, M. N., & Suryawan, I. W. K. (2023, December 29). *Laundry Effluent Environmental Impact Potential Analysis using Life Cycle Assessment Approach*. https://doi.org/10.4108/eai.23-11-2022.2341591

Assiddieq, M., Darmayani, S., & Kudonowarso, W. (2017). The use of silica sand, zeolite and active charcoal to reduce BOD, COD, and TSS of laundry waste water as a biology learning resources. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *3*(3), 202–207. https://doi.org/10.22219/jpbi.v3i3.4864

East Java Governor Regulation. (2013). *Peraturan Gubernur Jawa Timur Nomor 72 tahun 2013 tentang Baku Mutu Air Limbah bagi Industri dan/atau Kegiatan Usaha lainnya*.

Haderiah, Sulasmi, & Erlani. (2015). Effectiveness of Simple Screening Media of Activated Chorcoal and Zeolite to Reduce Waste Water Levels in Laundry Detergent. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, *24*(3), 180–186. https://gssrr.org/JournalOfBasicAndApplied/article/view/4676

Khoiriyah, A. F., & Rahman, N. A. (2024). Efficiency of the aeration - multi soil layering (MSL) system in laundry wastewater treatment. *Jurnal ATMOSPHERE*, *5*(2), 26–32. https://doi.org/10.36040/atmosphere.v5i2.13499

Largitte, L., & Pasquier, R. (2016). A review of the kinetics adsorption models and their application to the adsorption of lead by an activated carbon. *Chemical Engineering Research and Design*, *109*, 495–504.https://doi.org/10.1016/j.cherd.2016.02.006

Leonardo, P., Tarigan, Anugroho, F., & Muktiningsih, S. D. (2023). *Penurunan COD dan TSS Air Limbah Laundry Menggunakan Filter Zeolit dan Karbon Aktif*.

Majid, D., Al Kholif, M., Arif, M. N., Sutrisno, J., & Zhang, J. W. (2025). Eco-friendly solutions for urban wastewater: evaluating constructed wetlands and filtration methods. *Advances in Environmental Technology*, *11*(2), 182–194. https://doi.org/10.22104/AET.2025.6887.1887

Melián, E. P., Santiago, D. E., León, E., Reboso, J. V., & Herrera-Melián, J. A. (2023). Treatment of laundry wastewater by different processes: Optimization and life cycle assessment. *Journal of Environmental*

Chemical Engineering, *11*(2), 109302. https://doi.org/10.1016/j.jece.2023.109302

Nasir, F. N., & Titah, H. S. (2024). The Use of Granular Activated Carbon and Zeolite as an Adsorbent to Reduce the Concentration of Phosphate, Chemical Oxygen Demand and Total Suspended Solid in Laundry Wastewater. *Journal of Ecological Engineering*, *25*(4), 170–183. https://doi.org/10.12911/22998993/184089

Nurhayati, I., Maulidhani, N. D., Sutrisno, J., & Al Kholif, M. (2024). Sustainable pre-treatment of tempeh industry wastewater: Efficiency of vermifiltration in pollutant mitigation and compost production. *Desalination and Water Treatment*, *320*, 100820.https://doi.org/10.1016/j.dwt.2024.100820

Pradiko, H., Rochaeni, A., & Grahandikha, M. B. (2025). Optimalisasi pengolahan air limbah laundry menggunakan media zeolit dan karbon aktif dalam filter kombinasi dua tabung kompak. *SPECTA Journal of Technology*, *9*(3), 303–314.https://doi.org/10.35718/specta.v9i3.8481751

Pungus, M., Palilingan, S. C., & Tumimomor, F. (2019). Penurunan kadar BOD dan COD dalam limbah cair laundry menggunakan kombinasi adsorben alam sebagai media filtrasi. *Fullerene Journal of Chemistry*, *4*(2), 54–60. https://indochembull.com/index.php/fulerene/article/view/58

Pungut, Al Kholif, M., & Pratiwi, W. D. I. (2021). Penurunan kadar chemical oxygen demand (COD) dan fosfat pada limbah laundry dengan metode adsorpsi. *Jurnal Sains & Teknologi Lingkungan*, *13*(2), 155–165. https://doi.org/10.20885/jstl.vol13.iss2.art6

Richards, S., Paterson, E., Withers, P. J. A., & Stutter, M. (2015). The contribution of household chemicals to environmental discharges via effluents: Combining chemical and behavioural data. *Journal of Environmental Management*, *150*, 427–434.https://doi.org/10.1016/j.jenvman.2014.12.023

Sugito, Ambima, A. R., Al Kholif, M., & Fitria, F. L. (2025). Optimizing Laundry Wastewater Treatment: A Hybrid Approach Using Poly-Aluminum Chloride Coagulation and Activated Carbon Adsorption. *International Journal of Marine Engineering Innovation and Research*, *10*(1), 2548–1479. https://doi.org/10.12962/j25481479.v10I1.22559

Sutrisno, J., Al Kholif, M., Purwanti, L., & Nurhayati, I. (2024). Bibliometrics Analysis and Future Study Trends in Anaerobic Biofilter Systems for Laundry Wastewater Treatment. *International Journal of Marine Engineering Innovation and Research*, *9*(3), 486–494. https://doi.org/10.12962/j25481479.v9i3

Sutrisno, J., Al Kholif, M., & Rohma, A. N. (2020). Penerapan adsobsi, pertukaran ion, dan variasi ketinggian media filtrasi dalam menigkatkan kualitas air sumur. *Jurnal Sains Dan Teknologi*, *19*(2), 69–75.https://doi.org/10.31258/JST.V19.N2.P69-75

Tomšič, B., Ofentavšek, L., & Fink, R. (2024). Toward sustainable household laundry. Washing quality vs. environmental impacts. *International Journal of Environmental Health Research*, *34*(2), 1011–1022. https://doi.org/10.1080/09603123.2023.2194615

Yu, Y., Zhao, J., & Bayly, A. E. (2008). Development of Surfactants and Builders in Detergent Formulations. *Chinese Journal of Chemical Engineering*, *16*(4), 517–527. https://doi.org/10.1016/s1004-9541(08)60115-9