

Effectiveness of a Silica Sand, Bagasse, and Activated Carbon Filtration System with Varying Media Thicknesses in Reducing COD and TSS in Laundry Wastewater

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Abstract:

Purpose:

The increasing number of laundry businesses generates wastewater containing high concentrations of organic matter and suspended solids, which may cause environmental pollution when discharged without proper treatment. This study aimed to analyze the effectiveness of silica sand, bagasse, and activated carbon filtration media with varying media thicknesses and operating times in reducing Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) in laundry wastewater.

Methodology:

An experimental quantitative study used a transparent PVC column reactor operated continuously under a gravity-driven down-flow system. Three media configurations were tested: P1 was dominated by activated carbon, P2 by bagasse, and P3 by silica sand. Each configuration was operated for 30, 60, and 90 minutes, and the COD and TSS results were analyzed descriptively and statistically using IBM SPSS Statistics 29.

Findings:

The initial COD and TSS concentrations were 787 mg/L and 2,304 mg/L, respectively. The highest COD reduction was achieved by P1 at 30 minutes, producing 496 mg/L and 36.98% removal, although all COD effluents remained above the 180 mg/L standard. The highest TSS reduction was achieved by P3 at 60 minutes, producing 42 mg/L and 98.18% removal and meeting the 60 mg/L standard. Regression analysis showed that media configuration did not significantly affect COD but significantly affected TSS, whereas operating time had no significant effect on either parameter.

Implication:

The filtration system was substantially more effective in removing suspended solids than organic matter and is suitable as a pretreatment unit for laundry wastewater. Additional treatment is required to achieve a COD concentration that complies with the applicable discharge standard.

Keyword:

Activated Carbon, Laundry Wastewater, Silica Sand, Chemical Oxygen Demand, Total Suspended Solids

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INTRODUCTION

The growth of laundry businesses has contributed to an increase in the volume of wastewater generated from washing activities. This wastewater contains detergents, organic compounds, textile fibers, dirt particles, and residues of cleaning agents, all of which may deteriorate the quality of receiving water bodies when discharged without appropriate treatment. The presence of organic matter and suspended solids in laundry wastewater can be identified through Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). Therefore, these parameters are essential for assessing the level of pollution and evaluating the effectiveness of wastewater treatment processes (Sari et al., 2021).

The COD concentration in laundry wastewater has been reported to range from 250 to 600 mg/L, depending on the type and concentration of detergent, washing intensity, and volume of water used (Zahro, 2020). A high COD value indicates a substantial concentration of organic compounds that require oxygen during oxidation and may consequently reduce the dissolved oxygen level in receiving water bodies. Meanwhile, TSS originates from textile fibers, dirt particles, and washing residues that are not completely dissolved. High TSS concentrations may increase water turbidity, inhibit light penetration, and adversely affect aquatic organisms (Fatimatus, 2022). According to East Java Governor Regulation No. 52 of 2014, the maximum allowable concentrations of COD and TSS in wastewater from the soap or detergent industry are 180 mg/L and 60 mg/L,

respectively. These standards indicate that laundry wastewater must be treated before being discharged into the environment.

Wastewater treatment in small- and medium-scale laundry businesses remains constrained by limited financial resources, land availability, and technical knowledge. Therefore, a treatment technology that is simple, economical, and easy to operate is required. One applicable method is filtration using a combination of porous media. Silica sand primarily functions through a physical filtration mechanism that retains suspended solids, whereas activated carbon has a large surface area and porous structure that facilitate the adsorption of organic compounds responsible for elevated COD concentrations. Bagasse, or sugarcane residue, also has potential as an alternative filtration medium because of its lignocellulosic structure and fibrous surface. The performance of a filtration system is influenced by the composition and thickness of the media, as well as the operating time, which determines the degree of contact between the wastewater and the filtration media (Hidayat et al., 2022; Nasir et al., 2024).

Although the application of filtration media has been widely investigated, the effectiveness of combining silica sand, bagasse, and activated carbon with different media thicknesses and operating times requires further analysis, particularly in relation to COD and TSS removal. Media thickness determines the filtration path length and pollutant-retention capacity, while operating time may influence adsorption, clogging, and media saturation processes (Wicaksono et al., 2024). Therefore, this study aimed to analyze the effects of variations in the thickness of silica sand, bagasse, and activated carbon filtration media, as well as variations in operating time, on the reduction of COD and TSS in laundry wastewater.

General Characteristics of Laundry Wastewater. Laundry wastewater is generated from clothing-washing processes and generally contains detergents, surfactants, organic matter, textile fibers, and suspended particles. The discharge of untreated laundry wastewater may increase the pollutant load in receiving water bodies and disrupt the balance of aquatic ecosystems. In this study, the quality of laundry wastewater was assessed based on Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). COD represents the amount of organic matter that can be chemically oxidized, whereas TSS indicates the concentration of solid particles suspended in wastewater (Zahro et al., 2023).

Filtration. Filtration is a wastewater treatment method in which wastewater is passed through porous media. Pollutant removal occurs through physical straining, microsedimentation, and adsorption onto the surfaces of the filtration media. This method is relatively simple, easy to operate, and suitable for small- to medium-scale wastewater treatment systems (Hidayat et al., 2022).

A down-flow filtration system directs wastewater from the upper section to the lower section of the reactor by gravity, allowing the wastewater to pass sequentially through each media layer. This system facilitates contact between pollutants and the filtration media and supports the removal of suspended solids and organic matter (Metcalf & Eddy, 2014). The effectiveness of the filtration process is influenced by the type of media, layer thickness, and contact time between the wastewater and the filtration media (Wicaksono et al., 2024).

Filtration Media. Filtration media provide the surfaces and spaces where pollutant straining and adsorption occur. This study employed a combination of silica sand, bagasse, and activated carbon, each of which has different characteristics and pollutant-removal mechanisms.

Silica Sand. Silica sand is a porous filtration medium with relatively uniform particle sizes and high chemical stability. It primarily functions through physical straining and particle sedimentation, making it effective in retaining suspended solids contained in wastewater. Therefore, silica sand generally contributes more substantially to TSS reduction than to the removal of dissolved organic compounds (Pratama et al., 2020).

The particle size and thickness of the sand layer affect the intergranular spaces and the ability of the media to retain particles. A thicker sand layer may extend the flow path and increase the probability of particles being retained during the filtration process.

Bagasse. Bagasse is a lignocellulosic material composed of cellulose, hemicellulose, and lignin. Its fibrous structure has the potential to retain particles and provide surface areas for interactions with pollutant compounds. In addition to being readily available, bagasse can be utilized as a relatively low-cost alternative filtration medium (Rahmawati & Lestari, 2023).

The performance of bagasse is influenced by the preparation process conducted before its application. Washing and drying are necessary to remove impurities and soluble compounds remaining on the material.

Physical or chemical activation may increase its surface area and adsorption capacity. Conversely, the use of inadequately prepared bagasse may result in the release of organic compounds from the media into the effluent (Fadhilah et al., 2022).

Activated Carbon. Activated carbon is an adsorbent medium characterized by a porous structure and a high specific surface area. These characteristics enable activated carbon to adsorb organic compounds, surfactants, color-causing substances, and odor-causing compounds present in laundry wastewater (Collivignarelli et al., 2019).

The adsorption capacity of activated carbon is influenced by its surface area, media dosage, contact time, pollutant characteristics, and degree of pore saturation. Greater contact between wastewater and the media increases the possibility of organic compounds being retained on the activated carbon surface until its adsorption capacity is reached (Almadani, 2023). In laundry wastewater treatment, activated carbon primarily contributes to reducing organic matter that influences COD concentrations (Hidayat et al., 2022).

Laundry Wastewater Quality Parameters. Chemical Oxygen Demand. Chemical Oxygen Demand is the amount of oxygen required to chemically oxidize organic matter and reduced compounds. This parameter is used to describe the magnitude of the organic pollutant load in wastewater. A higher COD value indicates a greater concentration of pollutants that may reduce dissolved oxygen levels in receiving water bodies (Teymouri et al., 2024).

Laundry wastewater may have high COD concentrations due to the presence of detergents, surfactants, dirt, and organic matter released during the washing process. COD concentrations are influenced by the type of detergent, amount of clothing washed, washing intensity, and volume of water used (Zahro, 2020). COD removal through filtration primarily occurs through the adsorption of organic compounds by activated carbon and the retention of particulate organic matter within the media layers.

Total Suspended Solids. Total Suspended Solids are undissolved solid particles suspended in water. In laundry wastewater, TSS may originate from textile fibers, dust, dirt particles, and residues of washing agents. High TSS concentrations may increase turbidity, inhibit light penetration, and adversely affect aquatic organisms (Alfonso, 2021).

Multilayer filtration can reduce TSS through particle straining within the interstitial spaces of the media, microsedimentation, and particle attachment to the media surfaces. Silica sand plays a major role in TSS removal, whereas bagasse and activated carbon may support the retention of particles that pass through the preceding filtration layers (Fatimatus, 2022).

Effects of Media Thickness and Operating Time. Media thickness and operating time are important factors that determine the performance of a filtration system. Thicker media provide longer flow paths and larger contact areas, thereby increasing the likelihood of filtration and adsorption. However, increasing the media thickness may also increase head loss and reduce the flow rate when solids accumulate within the media (Wicaksono et al., 2024).

Operating time is associated with the duration of media use and the volume of wastewater passing through the reactor. During the initial stage of operation, the media generally still contain available pore spaces and adsorption sites. As the operating time increases, pollutant accumulation may cause clogging or media saturation. Consequently, pollutant-removal efficiency does not necessarily increase linearly over time. Therefore, the combined effects of media thickness and operating time must be analyzed to determine the most effective filtration conditions for COD and TSS reduction (Metcalf & Eddy, 2014).

Laundry Wastewater Quality Standards. Wastewater quality standards define the maximum allowable concentrations of pollutants before wastewater is discharged into the environment. The evaluation of filtration results in this study refers to East Java Governor Regulation No. 52 of 2014 concerning wastewater quality standards for the vegetable oil, soap, and detergent industries.

The regulation establishes maximum allowable concentrations of 180 mg/L for COD and 60 mg/L for TSS. The concentrations measured before and after filtration were compared with these limits to evaluate the ability of the filtration system to produce effluent that complies with environmental requirements. Comparison with the applicable quality standards is also necessary to determine whether a single filtration process is sufficient or whether additional treatment units are required.

Previous Studies. Several studies have demonstrated that combinations of filtration media can reduce COD and TSS concentrations in wastewater. Santoso et al. (2020) reported that a combination of sand and activated carbon reduced COD by 40–55% and TSS by approximately 50%. Sari et al. (2021) similarly found that filtration using sand and activated carbon reduced COD from 156 mg/L to 48 mg/L and TSS from 140 mg/L to 52 mg/L.

The use of activated carbon and zeolite in a continuous-flow reactor was reported to reduce COD from 280 mg/L to 95 mg/L and TSS from 160 mg/L to 60 mg/L (Pungut, 2021). Kurniawan et al. (2022) demonstrated that increasing the thickness of activated charcoal and zeolite media improved TSS-removal efficiency to approximately 70%. Meanwhile, the application of a multimedia filter at the household scale reduced TSS from 130 mg/L to 50 mg/L (Fatimatus, 2022).

These findings indicate that media combinations and layer thicknesses influence pollutant-removal performance. However, studies combining silica sand, bagasse, and activated carbon with variations in the thickness of each medium and operating time remain limited. Therefore, this study was designed to evaluate the contribution of each media composition to the reduction of COD and TSS in laundry wastewater.

METHODS

Research Design and Setting. This study employed an experimental design with a quantitative approach and was conducted from February to May 2026. Laundry wastewater samples were collected from a laundry business located on Nyeoran Street, Kaliboto Lor, Jatiroto District, Lumajang Regency, East Java, Indonesia. The filtration experiments were conducted at the Chemistry Laboratory of Universitas Muhammadiyah Jember. The parameters analyzed in this study were limited to Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS), while temperature was maintained as a control variable throughout the filtration process. COD testing was conducted at an accredited environmental testing laboratory, whereas TSS testing was performed at the Chemistry Laboratory of Universitas Muhammadiyah Jember.

Filtration Reactor and Media Configurations. The filtration reactor consisted of a transparent cylindrical PVC column with a diameter of 8 cm and was operated continuously using a gravity-driven down-flow system. This system was selected to ensure that the wastewater passed sequentially through all media layers, thereby allowing physical filtration and adsorption to occur as the wastewater flowed through the column (Metcalf & Eddy, 2014). The experimental equipment consisted of three filtration columns, an influent storage tank with a capacity of approximately 21 L, distribution hoses, flow-control valves, end caps, and effluent collection containers. The filtration media consisted of silica sand with a particle size of 0.5–1.0 mm, bagasse with an approximate particle size of 2 mm, granular activated carbon with a size of 8 × 30 mesh or approximately 0.60–2.36 mm, and filter cloth placed at the upper and lower sections of each column.

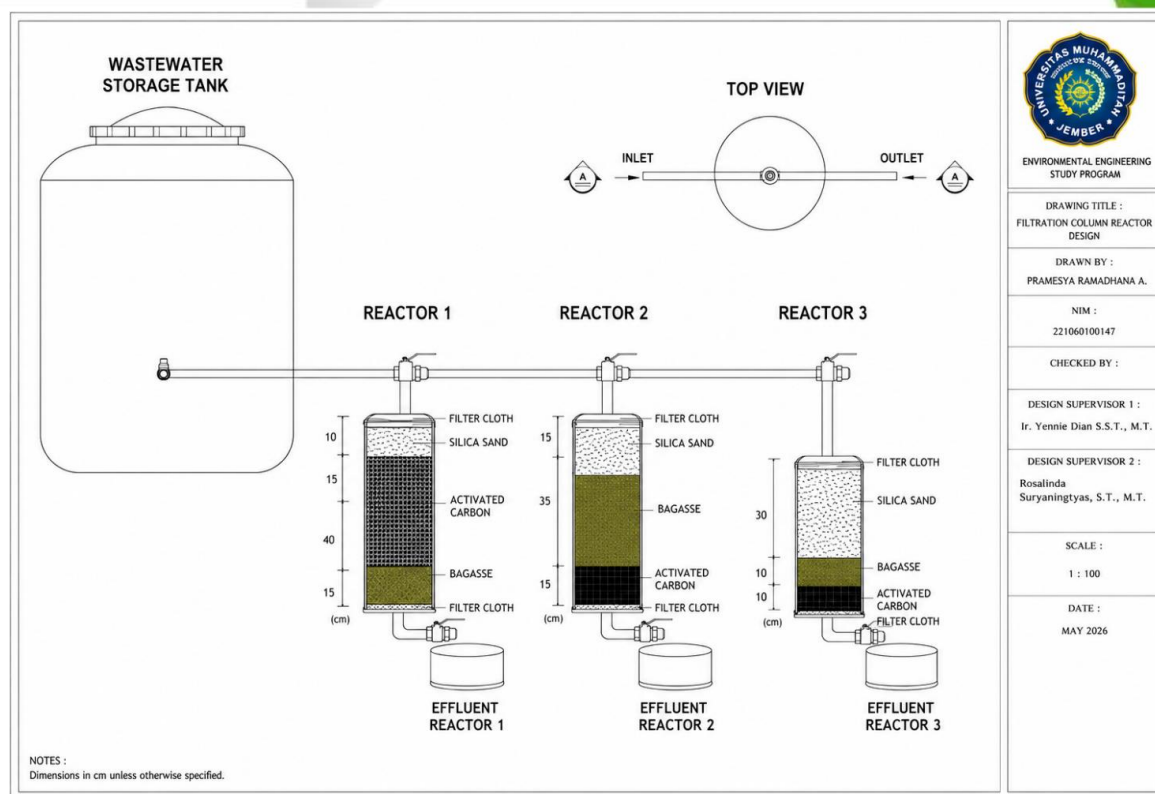


Figure 1. Cross-sectional design of the filtration column reactor along section A–A

Source: Research design (2026).

The experimental treatments consisted of three media-thickness configurations. Configuration P1 consisted of 10 cm of silica sand, 15 cm of bagasse, and 40 cm of activated carbon and was therefore dominated by activated carbon. Configuration P2 consisted of 15 cm of silica sand, 35 cm of bagasse, and 15 cm of activated carbon and was dominated by bagasse. Configuration P3 consisted of 30 cm of silica sand, 10 cm of bagasse, and 10 cm of activated carbon and was dominated by silica sand. Each configuration was operated for 30, 60, and 90 minutes. The independent variables were the media-thickness configuration and operating time, whereas the dependent variables were the COD and TSS concentrations. The down-flow system, column diameter, flow rate, and wastewater temperature were maintained at relatively constant levels across all treatments. Because the thicknesses of the three media were varied simultaneously, the P1–P3 treatments operationally represented differences in media configuration or media dominance rather than the isolated effect of the thickness of a single medium.

Before use, the silica sand, bagasse, and activated carbon were washed with clean water until the rinse water became relatively clear to remove dust, fine particles, and adhering impurities. The media were subsequently dried and placed in the columns according to the designated treatment configurations. The media were arranged from the upper section of the column, beginning with filter cloth, followed by silica sand and activated carbon or bagasse according to the design of each reactor. Filter cloth was also placed at the bottom of each column to prevent media particles from being discharged with the effluent. Wastewater from the storage tank was simultaneously distributed to the three columns at a constant flow rate of approximately 4.17 L/h or 69.5 mL/min. Based on the cross-sectional area of the columns, the applied filtration velocity was approximately 0.834 m/h.

Sample Collection and Laboratory Analysis. An influent sample was collected before filtration to characterize the initial quality of the laundry wastewater. Effluent samples were subsequently collected from the outlet of each reactor after operating times of 30, 60, and 90 minutes. This experimental design generated nine effluent samples obtained from three media configurations and three operating times, in addition to one influent sample. Therefore, a total of ten samples were analyzed. Each sample was tested for COD and TSS, resulting in 20 parameter measurements. Each treatment combination was tested without replication. Consequently, the

findings were used to demonstrate the preliminary trends in COD and TSS responses to differences in media configuration and operating time.

COD concentrations were analyzed using a colorimetric method in accordance with the operational procedures of the accredited environmental testing laboratory. TSS concentrations were analyzed using the gravimetric method with filtration equipment, filter paper, an oven, a desiccator, and an analytical balance in accordance with SNI 6989.3:2019. In this method, suspended solids were retained on filter paper and dried until a constant weight was achieved. The TSS concentration was then calculated based on the change in filter-paper mass and the volume of the sample analyzed (Badan Standardisasi Nasional, 2019).

Data Analysis. The removal efficiencies of COD and TSS were calculated by comparing the initial concentrations with the concentrations measured after filtration using the following equation:

$$\text{Removal efficiency (\%)} = ((C_0 - C_t) / C_0) \times 100\%$$

where C_0 represents the influent COD or TSS concentration, while C_t represents the COD or TSS concentration after filtration for each treatment (Metcalf & Eddy, 2014). The measured concentrations and removal efficiencies were subsequently analyzed descriptively to compare the performance of each media configuration and operating time.

Statistical analyses were performed using IBM SPSS Statistics version 29 at a 95% confidence level, corresponding to $\alpha = 0.05$. The distributions of the COD and TSS data were initially assessed using the Shapiro–Wilk test. The data were considered normally distributed when the significance value was greater than 0.05. The effects of media configuration and operating time on the final COD and TSS concentrations were subsequently analyzed using multiple linear regression based on the following model: $Y = a + b_1X_1 + b_2X_2$, where (Y) represents the final COD or TSS concentration, X_1 represents the filtration-media configuration, X_2 represents the operating time, (a) represents the constant, and b_1 and b_2 represent the regression coefficients. A variable was considered to have a statistically significant effect when its significance value was less than 0.05 (Pallant, 2020). Multiple linear regression was selected because the model included two predictor variables, namely media configuration and operating time.

RESULTS AND DISCUSSION

Initial Characteristics of Laundry Wastewater. The initial characteristics of the wastewater were used as a basis for evaluating changes in wastewater quality after the filtration process. The test results showed that the initial COD and TSS concentrations were 787 mg/L and 2,304 mg/L, respectively. Both parameters exceeded the wastewater quality standards for the soap or detergent industry stipulated in East Java Governor Regulation No. 52 of 2014, which establishes maximum concentrations of 180 mg/L for COD and 60 mg/L for TSS.

Table 1. Initial characteristics of laundry wastewater

Param.	Value	Limit	Unit	Status
COD	787	180	mg/L	Non-compliant
TSS	2,304	60	mg/L	Non-compliant

Source: Laboratory analysis results (2026).

These values indicate that the laundry wastewater contained high concentrations of organic matter and suspended solids and therefore required treatment before being discharged into the environment.

COD Test Results. COD testing was conducted on nine effluent samples obtained from three filtration-media configurations and three operating times. P1 was dominated by activated carbon, P2 by bagasse, and P3 by silica sand.

Table 2. COD concentrations and removal efficiencies

Code	Time	Initial COD	Final COD	Removal (%)
P1	30 min	787 mg/L	496 mg/L	36.98%
P1	60 min	787 mg/L	505 mg/L	35.83%
P1	90 min	787 mg/L	659 mg/L	16.26%
P2	30 min	787 mg/L	583 mg/L	25.92%

Code	Time	Initial COD	Final COD	Removal (%)
P2	60 min	787 mg/L	580 mg/L	26.30%
P2	90 min	787 mg/L	689 mg/L	12.45%
P3	30 min	787 mg/L	575 mg/L	26.94%
P3	60 min	787 mg/L	584 mg/L	25.79%
P3	90 min	787 mg/L	589 mg/L	25.16%

Source: Laboratory analysis results (2026).

All treatments reduced COD concentrations relative to the initial condition. The highest COD removal was achieved by P1 at an operating time of 30 minutes, reducing the concentration from 787 mg/L to 496 mg/L, corresponding to a removal efficiency of 36.98%. In P1, the COD concentration subsequently increased to 505 mg/L at 60 minutes and 659 mg/L at 90 minutes.

P2 produced its lowest COD concentration of 580 mg/L at 60 minutes, with a removal efficiency of 26.30%. At 90 minutes, the COD concentration increased to 689 mg/L, resulting in the lowest removal efficiency of 12.45%. Meanwhile, the COD concentrations obtained using P3 were relatively stable, ranging from 575 to 589 mg/L, with removal efficiencies of 25.16–26.94%.

Although all treatments reduced COD concentrations, all effluent values remained above the applicable quality standard of 180 mg/L. Therefore, the filtration system was unable to produce COD concentrations that complied with the wastewater discharge standard.

TSS Test Results. The initial TSS concentration of 2,304 mg/L decreased after the wastewater passed through the filtration system. The TSS concentrations and removal efficiencies obtained for each treatment are presented in Table 3.

Table 3. TSS concentrations and removal efficiencies

Code	Time	Initial TSS	Final TSS	Removal (%)
P1	30 min	2,304 mg/L	1,512 mg/L	34.38%
P1	60 min	2,304 mg/L	832 mg/L	63.89%
P1	90 min	2,304 mg/L	884 mg/L	61.63%
P2	30 min	2,304 mg/L	180 mg/L	92.19%
P2	60 min	2,304 mg/L	70 mg/L	96.96%
P2	90 min	2,304 mg/L	84 mg/L	96.35%
P3	30 min	2,304 mg/L	54 mg/L	97.66%
P3	60 min	2,304 mg/L	42 mg/L	98.18%
P3	90 min	2,304 mg/L	90 mg/L	96.09%

Source: Laboratory analysis results (2026).

P1 produced a TSS concentration of 1,512 mg/L at 30 minutes, which decreased to 832 mg/L at 60 minutes and subsequently increased to 884 mg/L at 90 minutes. The highest removal efficiency achieved by P1 was 63.89% at 60 minutes; however, all concentrations remained above the applicable quality standard.

For P2, the TSS concentration decreased to 180 mg/L at 30 minutes, 70 mg/L at 60 minutes, and 84 mg/L at 90 minutes. The highest removal efficiency was 96.96% at 60 minutes. Despite the substantial reduction, the lowest TSS concentration achieved by P2 remained slightly above the quality standard of 60 mg/L.

P3 produced the greatest TSS reduction. TSS concentrations of 54 mg/L at 30 minutes and 42 mg/L at 60 minutes complied with the applicable quality standard. However, the concentration increased to 90 mg/L after 90 minutes. The best treatment was therefore P3 at an operating time of 60 minutes, which achieved a removal efficiency of 98.18%.

Statistical Analysis Results. The Shapiro–Wilk test was used to assess data normality because each parameter consisted of nine observations. The data were considered normally distributed when the significance value was greater than 0.05.

Table 4. Shapiro–Wilk normality test results

Var.	W	p	Interpretation
COD	0.904	0.274	Normally distributed
TSS	0.743	0.004	Not normally distributed

Source: Research data processed using IBM SPSS Statistics 29 (2026).

The COD data had a significance value of 0.274, which was greater than 0.05, and were therefore considered normally distributed. In contrast, the TSS data had a significance value of 0.004, which was less than 0.05, and were therefore considered non-normally distributed.

Regression analysis was used to examine the relationships between media configuration, operating time, and the final COD and TSS concentrations. Media configurations were coded as P1 = 1, P2 = 2, and P3 = 3.

Table 5. Regression coefficients for COD and TSS

Predictor	B	SE	t	p
COD: Constant	460.778	62.291	7.397	<.001
COD: Media	14.667	21.159	0.693	.514
COD: Time	1.572	0.705	2.229	.067
TSS: Constant	1,659.778	390.968	4.245	.005
TSS: Media	−507.000	132.805	−3.818	.009
TSS: Time	−3.822	4.427	−0.863	.421

Source: Research data processed using IBM SPSS Statistics 29 (2026).

For COD, media configuration had a significance value of 0.514, while operating time had a significance value of 0.067. Both values were greater than 0.05, indicating that neither media configuration nor operating time had a statistically significant partial effect on COD concentration.

For TSS, media configuration had a regression coefficient of −507.000 and a significance value of 0.009. This finding indicates that differences in media configuration had a statistically significant effect on TSS concentration. In contrast, operating time had a significance value of 0.421 and therefore did not have a statistically significant partial effect on TSS concentration.

Effectiveness of the Filtration System in Reducing COD. The results showed that P1, which was dominated by activated carbon, achieved the highest COD removal efficiency of 36.98% at an operating time of 30 minutes. Activated carbon has a porous structure and a high surface area, enabling it to adsorb organic compounds that contribute to COD concentrations. During the initial stage of operation, the activated-carbon surface still contained numerous available adsorption sites, allowing organic matter to be removed more effectively.

The decrease in removal efficiency at 60 and 90 minutes indicates that a longer operating time did not necessarily result in greater COD reduction. The accumulation of organic compounds on the surface and within the pores of activated carbon may have caused media saturation, thereby reducing the number of available adsorption sites. Under certain conditions, previously retained compounds may also have been released back into the effluent. These processes resulted in a non-linear relationship between operating time and COD removal (Metcalf & Eddy, 2014).

The performance of P2, which was dominated by bagasse, was lower than that of P1. Bagasse has a lignocellulosic structure that may function as a natural adsorbent. However, the bagasse used in this study was only washed and dried without undergoing chemical activation. Consequently, its surface area and adsorption capacity may not have been optimal. Furthermore, residual organic matter in the bagasse may have dissolved during operation and contributed to an increase in effluent COD concentrations.

P3 produced relatively stable COD concentrations because silica sand primarily functions through physical filtration. This medium can retain relatively large organic particles but does not have a high adsorption capacity for dissolved organic compounds. Consequently, the ability of P3 to reduce COD was more limited than that of the activated carbon-dominated configuration.

All effluent COD concentrations remained above the quality standard of 180 mg/L. These findings demonstrate that a filtration system consisting of silica sand, bagasse, and activated carbon is insufficient when used as a stand-alone treatment unit. The system would be more appropriately applied as a pretreatment stage before coagulation–flocculation, aerobic biological treatment, or further adsorption using activated carbon with enhanced adsorption properties.

The statistical results support this pattern. Media configuration did not have a statistically significant effect on COD, with a significance value of 0.514, while operating time was also non-significant, with a significance value of 0.067. These non-significant results do not indicate that filtration failed to reduce COD. Instead, they indicate that the reduction pattern could not be consistently explained using a linear relationship. Media saturation, the characteristics of the organic matter, pore size, and the release of compounds from the filtration media may also have influenced COD concentrations.

Effectiveness of the Filtration System in Reducing TSS. The filtration system exhibited substantially better performance in removing TSS than COD. The highest TSS removal efficiency was achieved by P3 at an operating time of 60 minutes, reaching 98.18% and producing a final concentration of 42 mg/L. This value complied with the applicable quality standard of 60 mg/L.

The predominance of silica sand in P3 improved the system's ability to retain suspended solids. These solids may be removed through physical straining, sedimentation within intergranular spaces, and particle entrapment throughout the media layer. The longer the flow path through the filtration medium, the greater the likelihood that particles will be retained before the wastewater exits through the reactor outlet (Metcalf & Eddy, 2014).

P2 also achieved substantial TSS removal, reaching 96.96% at 60 minutes. The fibrous structure of bagasse allowed suspended particles to become trapped between the fibers and within the pores of the medium. However, the final concentration of 70 mg/L remained slightly above the applicable quality standard.

P1 produced a lower TSS removal efficiency because activated carbon is generally more effective in adsorbing compounds at the molecular level than in filtering high concentrations of suspended solids. Although the TSS concentration decreased to 832 mg/L at 60 minutes, this value remained substantially above the quality standard.

For all three configurations, the lowest TSS concentrations were obtained at an operating time of 60 minutes. After 90 minutes of operation, the TSS concentrations increased again. This pattern indicates that solids had accumulated within the media and that the media were approaching their particle-retention capacity. Pore clogging may have altered the flow pattern and caused breakthrough or the release of previously retained particles. Therefore, the media should be cleaned or regenerated before exceeding their optimum operating period.

The coefficient analysis showed that media configuration had a statistically significant effect on TSS, with a significance value of 0.009. The negative coefficient of -507.000 indicated a tendency for TSS concentrations to decrease as the coded configuration shifted from activated carbon dominance toward silica sand dominance. However, this coefficient should not be interpreted as the decrease in TSS resulting from each one-centimeter increase in media thickness. P1, P2, and P3 were configuration codes in which the thicknesses of all three media were varied simultaneously. Therefore, the statistical results more appropriately represent the effect of differences in media composition and dominance.

Operating time did not have a statistically significant effect on TSS, as indicated by a significance value of 0.421. This result occurred because the relationship between operating time and TSS concentration was non-linear. TSS concentrations decreased until 60 minutes and subsequently increased at 90 minutes because of media saturation and breakthrough.

The TSS data were also not normally distributed. This condition was influenced by the substantial differences between the results obtained using P1 and P3, as well as by the limited sample size. Therefore, the

TSS regression results should be interpreted as exploratory findings and should not be used to support broad generalizations.

CONCLUSION

The filtration system consisting of silica sand, bagasse, and activated carbon reduced COD and TSS concentrations in laundry wastewater, although its effectiveness differed among media configurations. The greatest COD reduction was achieved by the activated carbon-dominated P1 configuration at an operating time of 30 minutes, reducing COD from 787 mg/L to 496 mg/L and producing a removal efficiency of 36.98%. Nevertheless, all effluent COD concentrations remained above the applicable quality standard of 180 mg/L.

The greatest TSS reduction was achieved by the silica sand-dominated P3 configuration at an operating time of 60 minutes, reducing TSS from 2,304 mg/L to 42 mg/L and producing a removal efficiency of 98.18%. This concentration complied with the applicable quality standard of 60 mg/L. The TSS concentration produced by P3 after 30 minutes also complied with the standard, with a final concentration of 54 mg/L.

The statistical analysis showed that differences in media configuration did not have a statistically significant effect on COD concentrations but had a significant effect on TSS concentrations. Operating time did not have a statistically significant effect on either COD or TSS. These findings indicate that media characteristics and media dominance played a more decisive role in suspended-solids removal, whereas organic-matter removal was influenced by more complex adsorption mechanisms and media saturation.

Overall, the filtration system was more effective in reducing TSS than COD and has the potential to be applied as a pretreatment unit for laundry wastewater.

Additional treatment is still required to reduce COD concentrations to the applicable quality standard. Future research should replicate each treatment, isolate the thickness effect of each filtration medium, and use a larger sample size. The statistical results should be interpreted as preliminary findings because the original treatments were conducted without replication and the thicknesses of the three filtration media were varied simultaneously.

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