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Utilization of Recycled Glass as an Alternative to Silica Sand Filter Media in Reducing Total Suspended Solids (TSS), Turbidity, and Phosphates in Laundry Wastewater

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Abstract
This study examines the comparative performance of recycled glass and silica sand as filter media in the slow sand filtration process to treat laundry wastewater. The main objective of this study was to evaluate the efficiency of recycled glass and silica sand in reducing Total Suspended Solids (TSS), turbidity, and phosphate content in laundry wastewater effluent. The selection of recycled glass as a filtration medium is due to its characteristic of having a small sphericity value so that its porosity value is large which results in a small headloss value. The use of recycled glass as an alternative media is an effort to reduce the exploitation of the use of sand media in filtration. The results of the study showed that the use of recycled glass was quite efficient than silica sand in reducing TSS and turbidity with a percentage of TSS removal (94%% vs 90%) and turbidity (90,57% vs 86,04%). While in phosphate removal, silica sand was more efficient than recycled glass with a percentage of removal (46,74% vs 83,48%). Before the research was conducted, a maturation phase was carried out for 2 weeks to form the schmutzdecke layer. The addition of Effective Microorganism 4 (EM4) was carried out to help the growth of the schmutzdecke layer in this study.
Keywords: *recycled glass, silica sand, slow sand filter, laundry wastewater*

Abstrak
Penelitian ini mengkaji perbandingan kinerja recycled glass dan pasir silika sebagai media filter dalam proses filtrasi pasir lambat untuk mengolah limbah cair laundry. Tujuan utama penelitian ini adalah mengevaluasi efisiensi recycled glass dan pasir silika dalam mereduksi Total Suspended Solids (TSS), kekeruhan, dan kandungan fosfat pada efluen limbah laundry. Pemilihan recycle glass sebagai media filtrasi disebabkan oleh ciri khasnya yang memiliki nilai sphericity yang kecil sehingga nilai porositasnya besar yang mengakibatkan nilai headloss yang kecil. Penggunaan recycle glass sebagai media alternatif merupakan upaya dalam mengurangi eksploitasi penggunaan media pasir dalam filtrasi. Hasil pada penelitian menunjukkan penggunaan recycle glass cukup efisien daripada dengan pasir silika dalam penurunan TSS dan kekeruhan dengan persentase penyisihan pada TSS (94%% vs 90%) dan kekeruhan (90,57% vs 86,04%). Sementara dalam penyisihan fosfat, pasir silika sangat efisien daripada recycled glass dengan persentase penyisihan (46,74% vs 83,48%). Sebelum dilakukan penelitian dilakukan fase pematangan selama 2 minggu untuk membentuk lapisan schmutzdecke. Penambahan Effective Microorganism 4 (EM4) dilakukan untuk membantu pertumbuhan lapisan schmutzdecke pada penelitian ini.
Kata Kunci: *recycled glass, pasir silika, filtrasi pasir lambat, limbah laundry*

1. Introduction

The increasing modern lifestyle has made laundry services a practical solution for busy individuals. Unfortunately, many laundry business owners neglect the environmental impact of their operational waste. Phosphate compounds in laundry wastewater are one of the main causes of eutrophication, a phenomenon characterized by excessive growth of algae and cyanobacteria. As a result, water quality drastically declines, threatening the sustainability of aquatic ecosystems (Budiawan et al., 2009).

Filtration is a physical separation process that removes particles from water (Betancourt and Rose, 2004). There are two main types of filtration: rapid sand filters and slow sand filters. Rapid sand filters involve a closed system and high pressure, utilizing media to filter water on a large scale. In contrast, slow sand filters use open containers and media that support biofilm growth. This process is slower but effective in removing various pollutants, especially on a smaller scale (Huisman and Wood, 1974).

Schmutzdecke is a layer of microbial communities that treat water as it passes through the top layer of sand in slow sand filters. This biological layer captures or filters out foreign particles present in the water. The development of the schmutzdecke layer depends on several factors, including the availability of microbes in raw water, nutrient supply, oxygen supply, contact time, and moisture levels in the sand layer (Ranjan and Prem, 2018). Without the schmutzdecke layer, filtration efficiency in slow sand filters starts at only 60%. An optimal schmutzdecke layer takes about one to three weeks to form (Clark et al., 2012), with its height ranging from 2 to 5 cm (Trikannad et al., 2023).

Silica sand has become the industry standard as filter media (AWWA, 2011). Other granular materials such as anthracite, garnet, ilmenite, and activated carbon are also commonly used. In an effort to reduce natural resource exploitation, recycled glass has emerged as a new alternative. Considering that recycled glass is also silica-based with significant porosity and smooth surface characteristics, it has potential as an alternative filtration medium (Cescon and Jiang, 2020).

Research on recycled glass as a filtration medium shows great potential for wastewater treatment and drinking water purification. Salzmann (2019) analyzed the effectiveness of recycled glass as tertiary filtration media and found that it could reduce total suspended solids (TSS) and ammonium nitrogen, although it did not fully meet quality standards for phosphorus. Truong et al. (2021) studied the use of recycled glass for treating septic tank waste and found that glass was more effective in reducing total nitrogen compared to sand. Abdulhasan et al. (2022) explored the combination of recycled glass and sand for removing turbidity from drinking water. Meanwhile, Uddin et al. (2019) reported successful use of recycled glass in domestic wastewater treatment. Previous studies by Horan and Lowe (2007) and Soyer et al. (2010) also support the use of recycled glass as an alternative to sand in filtration systems, showing comparable or better performance across several water quality parameters. Overall, utilizing recycled glass as a filtration medium offers a sustainable solution for improving water quality and addressing waste issues.

This study aims to compare the performance of recycled glass and silica sand as filter media in treating laundry wastewater. The primary focus is on the ability of both media to reduce turbidity, Total Suspended Solids (TSS), and phosphate levels (P).

2. Material and Methods

The reactor used in this study consists of a combination of polyvinyl chloride (PVC) pipes and transparent PVC, shaped as an open cylindrical tube with a height of 1.2 m and a diameter of 10 cm. The filtration media employed are recycled glass and silica sand with particle sizes ranging from 0.7 to 2.0 mm. The height of the filter media in the reactor is 50 cm, with a supporting media height of 20 cm beneath it. The sample water used is wastewater from the laundry industry in Desa Penjaringan Sari, Kecamatan Rungkut, Surabaya. The research was conducted at the Research Laboratory of the Environmental Engineering Study Program, Faculty of Engineering, UPN "Veteran" East Java.

This study employs the slow sand filtration method as a water treatment technique. Prior to operation, an incubation period of approximately two weeks is conducted to form a biofilm layer (schmutzdecke) with a thickness of 2-5 cm on the surface of the filter media. The use of EM4 starter solution aids in the formation of this biofilm layer. Subsequently, the filter performance is tested continuously for 30 hours, with samples taken at 0, 6, 12, 24, and 30 hours. The filtration rate used in this study is 0.15 m/hour.

The analysis conducted during the maturation phase of the schmutzdecke layer includes MLSS and turbidity measurements, while during operation, TSS, turbidity, and phosphate analyses are performed. The gravimetric method is used for TSS and MLSS analysis by weighing the initial weight of filter paper before and after filtering the sample water according to SNI 6889.3:2019. To measure turbidity, a nephelometric method using a turbidimeter is employed, referring to SNI 06-6989.25-2005, which utilizes light scattering as it passes through particles in the liquid (Wiranto and Rahajoeningroem, 2020). Phosphate concentration analysis is conducted using spectrophotometry with a spectrophotometer based on SNI 6989-31:2021, where monochromatic light passes through the sample causing some light to be absorbed, reflected, and emitted (Yanlinastuti and Fatimah, 2016). Phosphate concentration measurements are taken at a wavelength of 880 nm.

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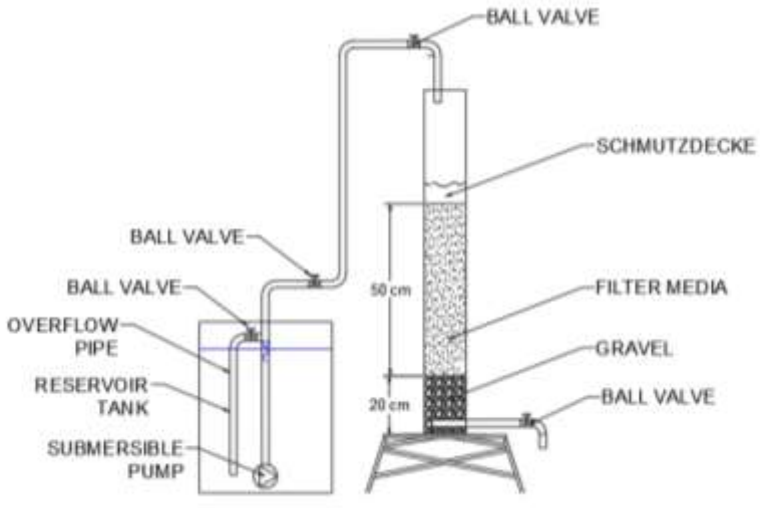

Figure 1. Slow Sand Filter Design

The quality standards used for TSS and phosphate analysis are based on Regulation of the Minister of Environment and Forestry No. 5 of 2014. Meanwhile, for turbidity analysis, Regulation of the Minister of Health No. 2 of 2023 is applied.

3. Results and Discussion

Maturation of Schmutzdecke Layer

The maturation process involves filling the reactor, which is composed of the filtration media, with laundry wastewater. The water inside the reactor is maintained at a height of 5 cm above the top of the media layer, commonly referred to as the static head. The purpose of filling the reactor with laundry wastewater is to allow the bacteria to adapt to the contents present in the laundry waste during their growth process. In this phase, EM4 solution is added as a substance that aids in biofilm formation. During this process, MLSS (Mixed Liquor Suspended Solids) and turbidity tests are conducted to assess the quality of the reactor over the maturation period. The following table represents data on the effects of schmutzdecke layer growth on turbidity and MLSS values. Sampling was carried out on days 2, 5, 7, 9, 12, and 14

A. Mixed Liquor Suspended Solids (MLSS)

The measurement of MLSS (Mixed Liquor Suspended Solids) is conducted to determine the total amount of organic materials, minerals, and microorganisms present. A high MLSS concentration indicates a significant number of microorganisms within the biofilm layer (Herlambang, 2005). The presence of a high concentration of microorganisms in the biofilm layer can aid in the removal of pollutants found in laundry wastewater during operation.

Table 1. Data on the Effect of Schmutzdecke Layer Growth on Filter Media on MLSS

Test	Day -	Reactor Variations Based on Media	
		Recycle Glass	Silica Sand
MLSS (mg/l)	2	190	170
	5	200	260
	7	240	310
	9	270	490
	12	440	540
	14	430	620

As shown in **Table 1**, the highest MLSS concentration is found in the silica sand reactor, with a concentration of 620 mg/L, while the lowest concentration is observed in the recycled glass reactor at 430 mg/L. The analysis results indicate that silica sand has a higher MLSS concentration compared to recycled glass. This difference can be attributed to the surface characteristics of the two filter media. The rough surface of silica sand provides more attachment sites for microorganisms, allowing for more optimal biofilm growth.

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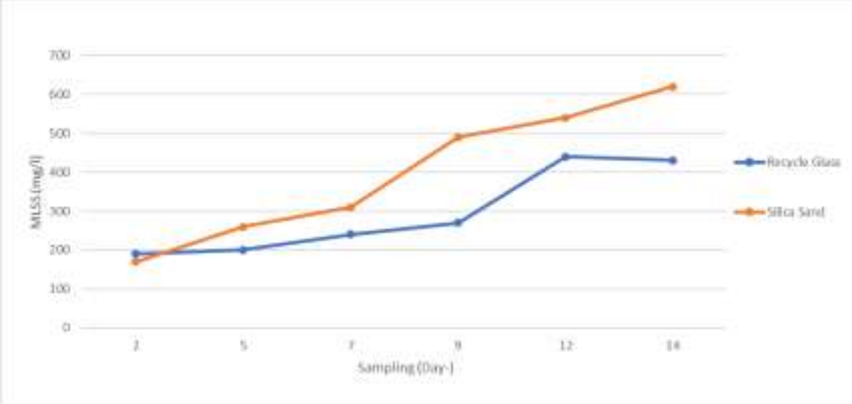

Figure 1. Graph of the Effect of Schmutzdecke Layer Growth for 2 Weeks on MLSS

In contrast, the smoother surface of recycled glass limits the available attachment points, resulting in slower biofilm development (Huisman and Wood, 1974). Additionally, the mineral content in the filter media plays a crucial role in biofilm growth. Silica sand contains minerals such as iron (Fe), calcium (Ca), and aluminum (Al), which can be utilized by microorganisms as nutrients (Gill et al., 2009). Unlike silica sand, recycled glass possesses inert properties that make it less capable of providing nutrients for microbial growth. Consequently, biofilm growth on recycled glass tends to be limited (Shineh et al., 2023).

B. Turbidity

Analysis of turbidity levels was conducted to examine the correlation between the reduction of water turbidity and the formation of the biofilm layer. The decrease in turbidity observed during the maturation of the schmutzdecke layer indicates an increase in the production of extracellular polymeric substances (EPS), which play a crucial role in biofilm formation and structural reinforcement (Lubarsky et al., 2023).

Table 2. Data on the Effect of Schmutzdecke Layer Growth on Filter Media on Turbidity

Test	Day -	Reactor Variations Based on Media	
		Recycle Glass	Silica Sand
Turbidity (NTU)	2	24	26
	5	15	17
	7	13	12
	9	14	12
	12	12	11
	14	10	9

According to **Table 2**, the lowest turbidity removal recorded in the final measurement was noted in the silica sand reactor, with a value of 9 NTU. Conversely, the highest turbidity value in the same measurement was also observed in the silica sand reactor at 10 NTU.

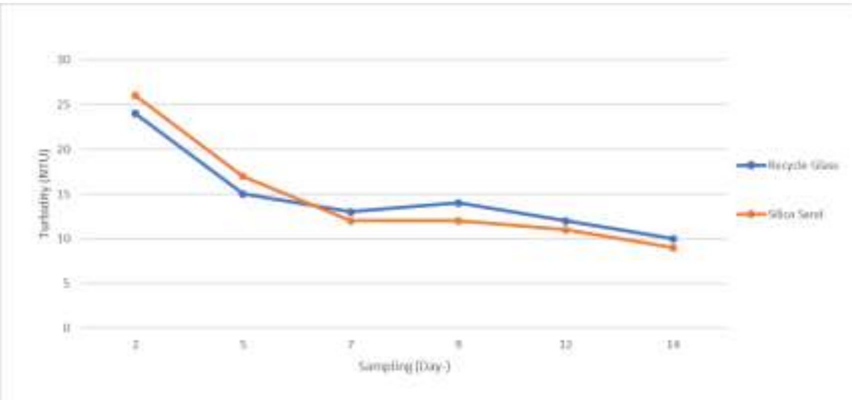

Figure 2. Graph of the Effect of Schmutzdecke Layer Growth for 2 Weeks on MLSS

Although the MLSS in the recycled glass filter media is lower compared to that of silica sand, its ability to reduce turbidity, particularly during the biofilm maturation phase, is nearly comparable to that of silica sand. This can be explained by the physical characteristics of recycled glass, which has angular and sharp particle shapes that provide a broader and more complex surface area. This allows it to capture a wider variety of colloidal particles of different sizes and shapes compared to the generally round particles of silica sand. The unique surface structure of recycled glass enables more effective adsorption and entrapment of particles, thus contributing to turbidity reduction during the biofilm formation phase (Soyer et al., 2010). Additionally, the contact time during the maturation phase of the schmutzdecke layer between recycled glass and wastewater allows this filter media to maximize its capacity for capturing particles, further contributing to turbidity reduction during biofilm formation.

Filter Operation

After 14 days of schmutzdecke layer formation, the filter was operated continuously starting from day 15. The results and analysis of the efficiency in removing parameters for each filter media are presented as follows.

A. Total Suspended Solids (TSS)

According to **Table 3** and **Figure 4**, it can be described that the performance of reactors with different filtration media shows variations in TSS removal efficiency. The reactor using recycled glass achieved a removal percentage of 94% at the end of sampling, with a TSS concentration of 24 mg/L. In contrast, the reactor with silica sand had a TSS removal percentage of 90% at the same sampling point, with a TSS concentration of 40 mg/L. Thus, it can be concluded that the TSS removal in the reactor with recycled glass is greater than that in the silica sand reactor.

Table 3. Effect of Sampling Time with Filtration Media on Effluent on TSS Removal

Sampling	TSS Concentrations (mg/l)	
	Recycle Glass	Silica Sand
0	80	92
6	64	84
12	56	68
24	36	52
30	24	40

The final results across all reactors indicated that TSS removal has met the quality standards set by the Regulation of the Minister of Environment and Forestry No. 5 of 2014 regarding Industrial Wastewater Quality Requirements Using Detergents, which stipulates a limit of < 60 mg/L.

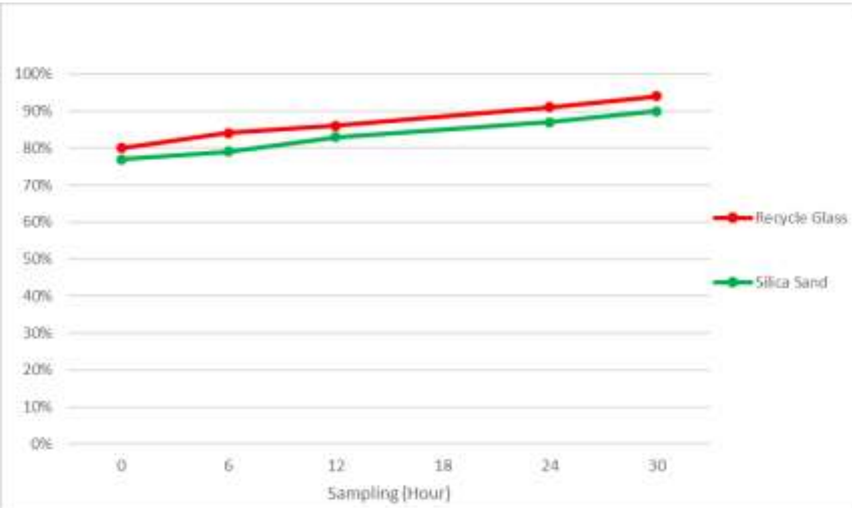

Figure 3. Comparison Chart of TSS Concentration Removal Percentage in Recycle Glass and Silica Sand

The efficiency of slow sand filtration in removing Total Suspended Solids (TSS) is significantly influenced by two main factors: the schmutzdecke layer and the characteristics of the filter media. The TSS removal process in the filter media is dominated by a straining mechanism, where suspended particles are retained on the surface pores of the media as water flows through. This mechanism can be likened to a sieving process, where only very small particles can pass through and be carried away by the water flow. Larger particles are retained on the media surface or trapped through other processes such as sedimentation, interception, and diffusion (Metcalf and Eddy, 2003).

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In filters made from recycled glass, TSS removal efficiency is generally better than that of silica sand. According to Truong et al. (2022), this advantage of recycled glass is attributed to its particle shape, which tends to be less spherical (low sphericity) and has many angles. These physical characteristics result in higher porosity values for recycled glass compared to silica sand. Consequently, recycled glass provides a larger pore space, offering more surface area for adsorption and entrapment of TSS particles.

B. Turbidity

The final results from all reactors indicate that the turbidity removal in both reactors has not met the quality standards set by the Regulation of the Minister of Health No. 2 of 2023 regarding Hygiene and Sanitation Requirements, which stipulates a limit of < 2 NTU.

Table 4. Effect of Sampling Time with Filtration Media on Effluent on Turbidity Removal

Sampling	Phosphate Concentrations (mg/l)	
	Recycle Glass	Silica Sand
0	80	92
6	64	84
12	56	68
24	36	52
30	24	40

The efficiency of slow sand filtration (SSF) in removing turbidity is influenced by various mechanisms, including physical processes (straining), particle adhesion, and the biological activity of the biofilm layer or schmutzdecke. Generally, particles causing turbidity are larger than 2 µm. In the straining process, particles larger than the pores of the media are retained and cannot pass through the filter media. Over time, the pores of the media become narrower due to the accumulation of trapped particles.

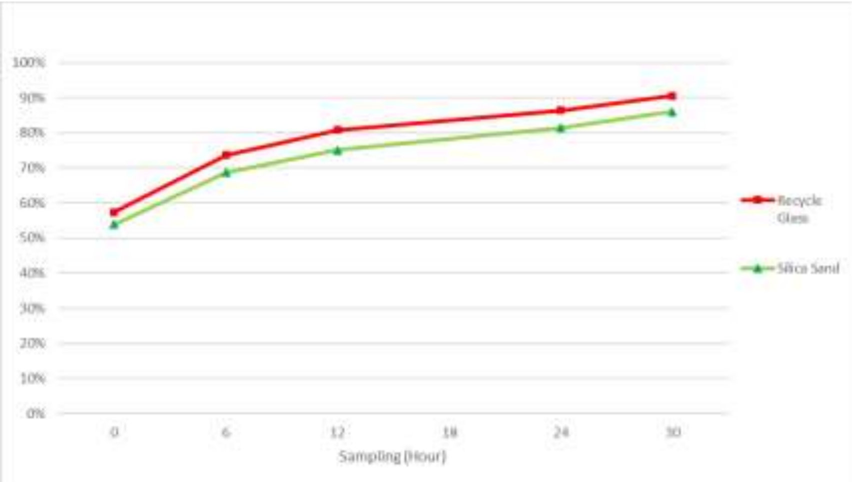

Figure 4. Comparison Chart of Turbidity Concentration Removal Percentage in Recycle Glass and Silica Sand

The ability of recycled glass to reduce turbidity is superior to that of silica sand, primarily due to its physical characteristics. The flat and angular shape of recycled glass particles provides a larger surface area, offering more sites for particles to adhere and be retained. This larger surface area facilitates more effective adsorption and entrapment of particles, resulting in clearer water.

In contrast, silica sand has lower porosity, limiting its capacity to trap particles. As a result, the efficiency of turbidity reduction in silica sand tends to be lower compared to recycled glass (Soyer et al., 2010).

C. Phosphates (P)

According to **Table 5** and **Figure 6**, it can be described that the performance of reactors with different filtration media shows variations in phosphate removal efficiency. The reactor using recycled glass achieved a removal percentage of 46.74% at the end of sampling, with a phosphate concentration of 1.779 mg/L. Meanwhile, the reactor with silica sand achieved a phosphate removal percentage of 83.48% at the same sampling point, with a phosphate concentration of 0.552 mg/L. Thus, it can be concluded that the phosphate removal in the reactor with silica sand media is greater than that in the recycled glass reactor.

Table 5. Effect of Sampling Time with Filtration Media on Effluent on Phosphates Removal

Sampling	Phosphate Concentrations (mg/l)	
	Recycle Glass	Pasir Silika
0	2,365	1,122
6	2,243	0,839
12	2,090	0,729
24	1,937	0,655
30	1,779	0,552

The final results from all reactors indicate that phosphate removal has met the quality standards set by the Regulation of the Ministry of Environment and Forestry No. 5 of 2014 regarding Industrial Wastewater Quality Requirements Using Detergents, which stipulates a limit of < 2 mg/L.

The presence of buffering ions in the filter media is crucial for phosphate removal processes. Filter media rich in buffering ions, such as K+, Na+, and Mg2+, are more effective in reducing phosphate content in water, especially under aerobic conditions. Heterotrophic bacteria involved in the biological removal of phosphate require these ions as nutrients for metabolism and for binding phosphates (Arvidsson, 2015).

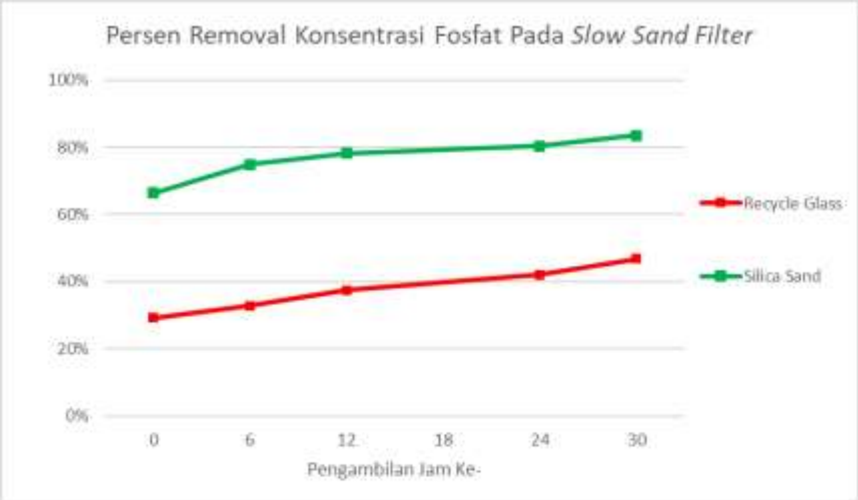

Figure 5. Comparison Chart of Turbidity Concentration Removal Percentage in Recycle Glass and Silica Sand

Silica sand, as a filter media, contains various minerals and buffering ions that assist bacteria in binding phosphates. The complex chemical composition of silica sand provides a reactive surface, facilitating interactions between bacteria, phosphates, and the media surface. In contrast, recycled glass, although primarily composed of silica, has a different chemical composition due to its manufacturing process. The presence of other compounds in recycled glass can alter the surface properties of the media, reducing its ability to interact with phosphates and bacteria. Consequently, the efficiency of phosphate removal on recycled glass media tends to be lower compared to silica sand (Gill et al., 2009).

4. Conclusion

This study successfully demonstrated that the use of recycled glass as an alternative filter media in the filtration process of laundry wastewater has significant potential in reducing Total Suspended Solids (TSS) and turbidity compared to silica sand. The research findings indicate that recycled glass achieved a TSS removal efficiency of 94%, while silica sand reached only 90%. Additionally, the turbidity reduction achieved by recycled glass was satisfactory, with a removal value of 90.57%, compared to 86.04% for silica sand. However, in terms of phosphate removal, silica sand outperformed recycled glass with an efficiency of 83.48% compared to only 46.74% for recycled glass. This indicates that while recycled glass is effective in reducing TSS and turbidity, it still has limitations in removing phosphates from wastewater. The addition of EM4 as a starter also contributed to accelerating the growth of biofilm, which is crucial for the filtration process. Data show that although the Mixed Liquor Suspended Solids (MLSS) concentration in recycled glass was lower than that in silica sand, its ability to remove colloidal particles remained effective. Overall, the use of recycled glass as a filtration medium not only offers a technical solution for laundry wastewater treatment but also supports sustainability efforts by utilizing recycled materials.

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