Removal of BOD_5 and COD from Domestic Wastewater by Using a Multi-Media-Layering (MML) System

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ABSTRACT

This study investigated the ability of the multi-media-layering (MML) to reduce Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels in domestic wastewater. MML used in this study is comprised of two MMLs (MML-1 and MML-2) with a total volume for each MML of 0.056 m^3. Every MML was filled with gravel media, zeolite, activated carbon, and silica sand. The differences between MML-1 and MML-2 were only found at the height of the media, especially the height of gravel and zeolite media. This study showed that MML-1 had the highest efficiency in reducing BOD_5 (95.47%) and COD (93.10%) compared with MML-2 (BOD_5 of 85.39% and COD of 89.65%). Overall, MML showed promising results in removing pollutants from domestic wastewater. The study also suggested that the height of the gravel media and pH greatly influenced the removal of BOD_5 and COD levels in domestic wastewater.

1. INTRODUCTION

Discharging untreated wastewater into the environment can lead to a deterioration in water quality and environmental pollution (Sikiru et al., 2022). Pollutants in water bodies extend beyond industrial effluent, agriculture, hospital wastewater, or municipal activities. Domestic wastewater from household activities also significantly contributes to contaminants (Liang et al., 2018; Liu et al., 2019; Nonfodji et al., 2020; Wang et al., 2023). Greywater and blackwater are the two primary components of domestic wastewater. However, there has been a noticeable rise in the expenses associated with procuring chemicals and utilities for physicochemical domestic wastewater treatment and water body purification (Al-Ajalin et al., 2020). To mitigate this issue, an energy-saving and low-cost alternative is urgently needed. Many methods have been proposed, and of particular interest to the researchers is employing multi-layering techniques utilizing natural substances (Freitas et al., 2018).

The muti-media-layering system (MML) is regarded as a highly innovative and technologically advanced system for household wastewater treatment and environmental protection, particularly in rural areas (Lamzouri et al., 2017; Latrach et al., 2018; Hong et al., 2019). Nevertheless, its potential extends to rapidly expanding urban areas where it can effectively treat domestic sewage. MML has proven to be highly efficient in removing contaminants from various sources, including domestic wastewater and river water, textile wastewater, and industrial effluents (Supriyadi et al., 2016; Latrach et al., 2018). The MML treatment system distinguishes itself from competing treatment systems due to its lower cost, excellent treatment performance, and capacity to accommodate elevated hydraulic loading rates. Additionally, the system exhibits high adaptability to various environmental conditions, rarely clogs, is easy to maintain, and boasts a long service life of over 20 years (An et al., 2016; Lamzouri et al., 2016).

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The MML typically consists of a media layer composed of various natural materials, including soil, zeolite, activated carbon, gravel, and more, making it an attractive option for researchers seeking sustainable wastewater treatment solutions. As other sewage treatment systems utilizing porous supports, the MML employs various mechanisms, including adsorption, filtration, nitrification, denitrification, predation, and microbial degradation, to effectively eliminate contaminants from domestic wastewater (Latrach et al., 2018).

The MML has received considerable global attention in recent times owing to its demonstrated success in several countries, including China (Guo et al., 2019; Tang et al., 2020), Marocco (Sbahi et al., 2020), and Thailand (An et al., 2016; Koottatep et al., 2021). However, the MML technology in Indonesia is scarcely used for domestic wastewater treatment. The MML utilizes physical and biochemical mechanisms to remove contaminants from domestic wastewater. Alternating aerobic and anaerobic phases in a permeable layer (PL) and media-mixture layer are the primary keys to removing nitrogen through nitrification and denitrification processes (An et al., 2016; Zhou et al., 2021). Both physical and chemical adsorption techniques have demonstrated successful removal of organic materials. Meanwhile, continuous aeration processes are required for organic matter removal through decomposition and heterotrophic aerobic metabolism (Zhou et al., 2021). Furthermore, Xiao et al. (2020) have discovered a synergistic adsorption and co-precipitation mechanism for efficiently removing total phosphorus (TP), which has shown excellent results. The composition and metabolism intensity of the microbial community in the MML are also critical factors in effectively removing pollutants from domestic wastewater (Zhou et al., 2021).

Domestic wastewater has a diverse array of contaminants, encompassing biochemical oxygen demand (BOD), chemical oxygen demand (COD), Suspended solids (SS), nitrogen (N), phosphorus (P), pathogenic organisms, microplastics, and more. BOD and COD are crucial parameters used to measure the concentration of organic matter in domestic wastewater and are widely utilized due to their relative ease of measurement. Elevated BOD and COD concentrations indicate correspondingly increased SS, N, and P levels. The presence of N and P in domestic wastewater can lead to eutrophication, posing a threat to aquatic organisms through the depletion of dissolved oxygen (DO) concentrations in the water. This study aims to examine the MML's ability to remove pollutants BOD and COD from domestic wastewater and identify the best MML based on the height of the filter media (gravel, zeolite, activated carbon, and silica sand) for removing household contaminants. By manipulating the height of the filter material in the MML, it is possible to determine the most optimal MML configuration for effectively eliminating household pollutants. The height of the filter media, especially the gravel media in the MML, greatly affects the removal of BOD_5 and COD. While the other media also have diverse functions in removing pollutants from domestic wastewater.

2. METHODOLOGY

2.1 Materials

The MML material used the study was acrylic, purchased from Jaya Raya Acrylic. The filter media consisted of zeolite, activated carbon, and silica sand supplied by Surabaya Filter Air. Gravel was collected from the nearby study site. pH was determined using the Benchtop pH meter PH-B200E, and temperature was measured using TP3001, both purchased from CV. Sumber Ilmiah Persada.

2.2 Study site description

The experiment was conducted in Siwalankerto, a rural area located in the Wonocolo Sub-District of Surabaya City, which has 40 neighborhood units with over 1,200 houses and 180 rented houses. This area is characterized by a relatively high population density and a substandard drainage system, as depicted in Figure 1. The domestic wastewater generated by residents is directly discharged into the drainage channel without prior treatment, leading to presence of contaminated water with black sediment.

2.3 Explication of MML system

The study was carried out throughout the COVID-19 pandemic, characterized by a significant shift in human behavior toward predominantly domestic settings at home. To address the issue of domestic wastewater generated by the inhabitants of Siwalankerto Village amidst the COVID-19 pandemic, a laboratory-scale MML system was developed. The MML reactor comprised two identical units, as depicted in Figure 2(a). The domestic wastewater treatment MML was made of 4 mm thick acrylic material. This study was conducted by continuously flowing wastewater into the MML reactor employing a predetermined flow rate of 20 L/day. Wastewater drainage to the storage tank is facilitated by a pump. Meanwhile, the influx of wastewater is facilitated by gravitational forces, with the assistance of valves that regulate the intake of each MML. The MML was filled with four media types (gravel, zeolite, activated carbon, and silica sand) with different diameters. The diameters of each media are gravel (±2-3 cm), zeolite (±1 cm), activated carbon (±0,45 cm), and silica sand (±0.25 cm). In this study, the height difference of the media (gravel and zeolite) was utilized as a variable variation for both MMLs, while activated carbon and silica sand served as PL. The objective behind the implementation of varying heights for the media was to evaluate the distinct capacities of each medium in the removal of BOD_5 and COD.

(a)

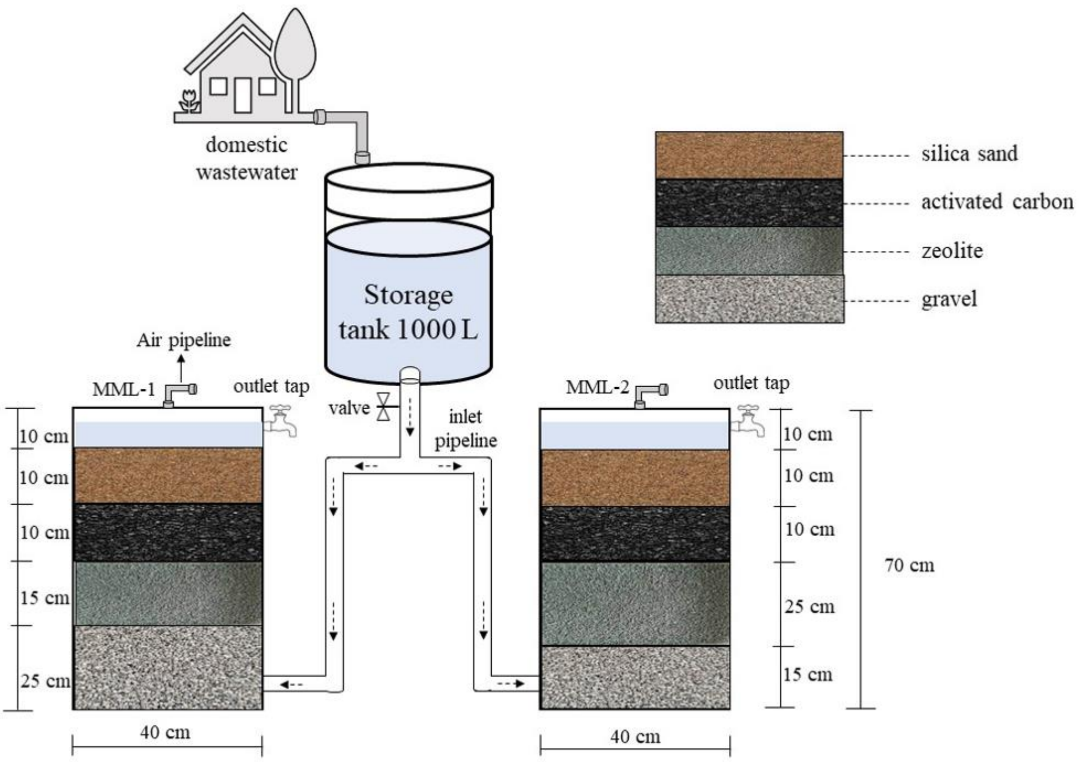
(b)

Figure 1. (a) The condition of domestic wastewater used as a sampling site; (b) Illustration of Google Earth for rural Siwalankerto, which has a high population density.

In MML-1, the gravel and zeolite media had 25 cm and 15 cm heights, respectively. Conversely, in MML-2, the gravel and zeolite media heights were reversed, with 15 cm and 25 cm, respectively. The activated carbon and silica sand heights remained consistent at 10 cm in both MML configurations. The selection of these filter media is based on their specific advantages. Gravel functions as an effective filter and substrate, fostering the growth of decomposing bacteria that facilitate the breakdown of organic matter in wastewater. In contrast, zeolite and activated carbon exhibit exceptional absorption capacities, enabling them to remove contaminants from the wastewater efficiently. In addition, silica sand serves as a filter medium and can be utilized as a substitute for the soil media often employed in previous MML systems. Replacement of filter media in MML is often carried out when there is a noticeable decline in removal efficiency and hydraulic conductivity.

The MML was designed to treat domestic wastewater with dimensions of 40 cm × 20 cm × 70 cm, with a total volume of every MML of 0.056 m^3. The domestic wastewater sampling used for this study only concentrated on five neighborhood units that generate numerous domestic wastewater. Based on the field data, it can be observed that the five neighborhood units under study consist of around 1,065 individuals residing in around 183 dwellings, together with an additional six rental houses. This population is responsible for generating domestic wastewater. All domestic wastewater from the five neighborhood units flows to a single point in the primary drainage channel, which serves as the sampling point (Figure 2(b)), before joining the leading drainage network.

(a)



(b)

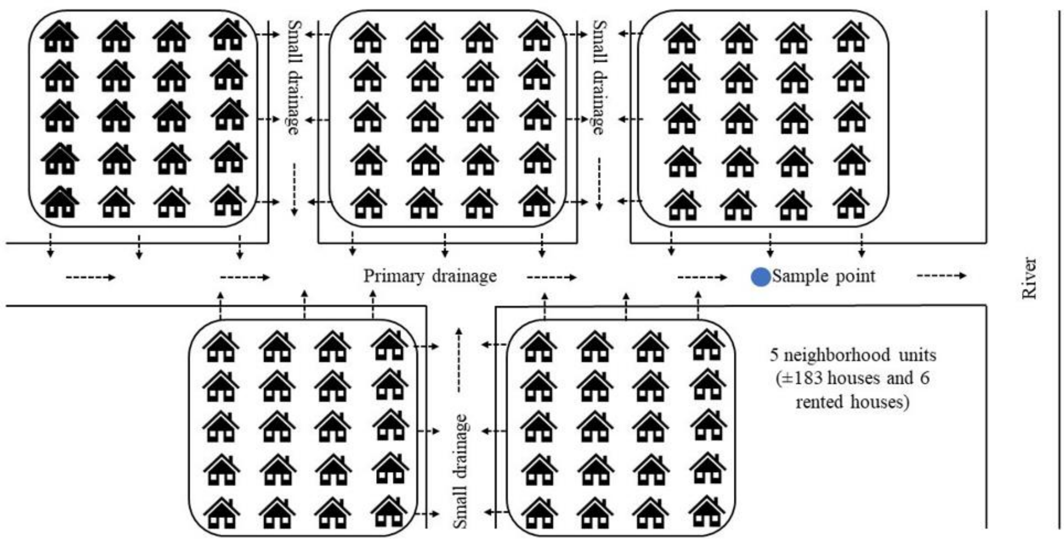


Figure 2. (a) Illustration of MML reactors in this study; (b) Illustrated distribution of domestic sewage and sampling point

2.4 Monitoring system and sampling period during the study

A total of 64 samples were collected for the two types of MML, with an average of 32 samples obtained for each system. The research data were collected during the early stages of the COVID-19 pandemic. Nevertheless, the study was primarily constrained by time limits for sample collection at the sampling location and subsequent laboratory analysis. Consequently, the research was limited to the collection of solely BOD_5 and COD data. The BOD_5 parameter was measured by determining the dissolved oxygen concentration in the sample with a 5-day incubation period. The COD parameter was analyzed using the open dichromate reflux method. Data analysis in this study involved calculating the mean ± standard deviation.

3. RESULTS AND DISCUSSION

3.1 Seeding and acclimatization

The BOD and COD reduction process relies on the action of microorganisms, which oxidize organic pollutants in the water. These microbes employ molecular oxygen to facilitate the decomposition of organic materials, producing carbon dioxide and water. The degradation process transpires via growth, death, decay, and cannibalism cycles. Various microorganisms participate in the breakdown of BOD and COD, including *Trichosporon cutaneum*, *Bacillus cereus*, *Klebsiella oxytoca*, *Pseudomonas* sp., as well as yeast strains such as *T. cutaneum*, etc (Meegoda et al., 2018).

This study's seeding and acclimatization were carried out for seven days, as shown in Table 1. Daily monitoring were conducted through COD testing and visual inspection to determine the growth of microorganisms within the MML. The adaptation process of microorganisms typically takes several days to reach a steady-state condition. Various techniques could be conducted to expedite the steady-state process, including adding decomposing microorganisms into the wastewater treatment MML. These microorganisms can be sourced from wastewater treatment plants (WWTP) or through effective microorganisms (EMs) liquid rich in microorganisms.

Table 1. COD analysis results during seeding and acclimatization

Day	Initial concentration (mg/L)	Effluent MML-1 (mg/L)	Effluent MML-2 (mg/L)
1	461.7	352.7	348.8
2	457.2	346.3	345.2
3	454.1	341.4	343.9
4	448.2	325.0	312.1
5	434.0	270.8	306.7
6	441.7	284.3	252.1
7	422.8	252.2	284.3

The acclimatization stage aims to obtain a stable microorganism culture capable of adapting to the specific characteristics of the liquid waste being evaluated. To accelerate the establishment of steady-state conditions for microorganisms, we introduced 1 liter of EM liquid into each MML on the first day of the study. The resulting COD number analysis directly reflects the growth of waste-decomposing microorganisms. In practice, samples from the MML were extracted and analyzed for COD to determine steady-state conditions. Steady-state conditions can be established when the COD removal efficiency exhibits less than 10% fluctuations (Hu and Grasso, 2004; Abu Shmeis, 2018). According to the COD number analysis, steady-state conditions were observed on the seventh day. This result indicates that the waste-decomposing microorganisms had stabilized and successfully adapted to their environment, enabling the progression to the running stage.

3.2 Domestic wastewater characteristics

Understanding wastewater's early properties is paramount in the context of a wastewater study. Furthermore, it can also determine the most suitable treatment technology for effectively treating wastewater. This study specifically focuses on observing the key parameters of the wastewater, such as BOD_5, COD, and pH, as showcased in Table 2, to ascertain its initial characteristics.

Table 2. Initial characteristic test results for domestic wastewater

Parameter	Quality standards*	Value
BOD_5 (mg/L)	30	230
COD (mg/L)	50	455
pH	6.0-9.0	6.7

*(East Java Governor, 2014)

Generally, the test results for domestic wastewater indicate significant deviations from the established standard quality limits, particularly regarding the BOD_5 and COD parameters. The recorded BOD_5 pollutant concentrations of 230 mg/L and COD of 455 mg/L suggest the presence of contamination in the residential wastewater of the area. The main contributors to this pollution are the escalating use of clean water and the lack of an adequate household wastewater management infrastructure. The elevated BOD_5 and COD values in domestic wastewater can be attributed to various factors, including the substantial presence of organic matter in wastewater, utilization of certain chemical products in households, improper disposal of industrial waste, population growth, and insufficient environmental awareness. Given these circumstances, selecting the MML for treating domestic wastewater is an ideal choice. This choice is supported by substantial research and empirical evidence, demonstrating its efficacy in efficiently eliminating BOD_5 and COD.

3.3 Potential of hydrogen (pH) value

The pH and temperature values were measured ex-situ using a portable multiparameter analyzer. Daily monitoring of domestic wastewater collected from the sampling site obtained the pH values in the two MMLs, ranging from 6.0-6.5, averaging 6.22. On the other hand, the average temperature value of domestic wastewater ranged from 30.2-30.4°C. Figure 3 shows the pH values for the two MMLs during the study period.

Lower pH values were observed for the two MMLs from day 4 to day 5, reaching a pH value of 6.0. Meanwhile, the temperature of domestic wastewater in the MML remained stable throughout the study period, ranging from 30-31°C. The decrease in pH value can be attributed to the fermentation process of organic matter and the presence of turbidity. Nevertheless, it is essential to note that a pH value of 6.0 falls within the acceptable range and complies with the established regulatory guidelines for household wastewater quality. The fermentation process can be optimized by monitoring the temperature remains within the ideal 30-35 °C range for the microorganisms involved (Manan and Webb, 2020).

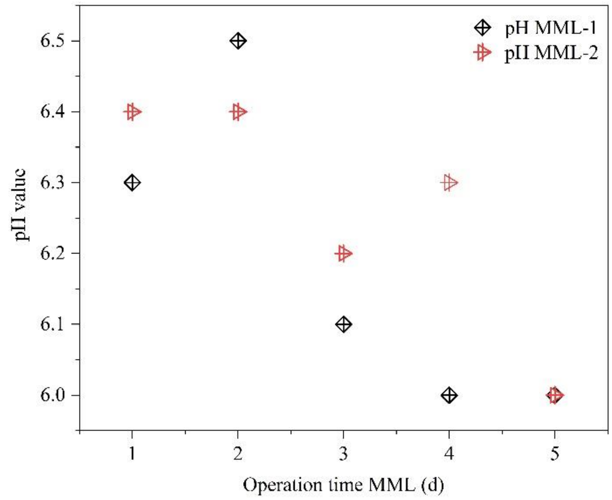


Figure 3. pH value during the studied

3.4 Effect of MML to Alleviate BOD_5 and COD

The effectiveness of MML in BOD_5 and COD removal is influenced by various factors, including the choice of filter media, hydraulic loading rate (HLR), and dimensions of the media mix layer. Previous research indicates that MSL successfully removes up to 98% of BOD_5 from domestic wastewater while achieving a COD removal rate of approximately 50% (Song et al., 2018; Hong et al., 2019). Table 3 demonstrates a significant decrease in the levels of BOD_5 and COD following treatment with MML.

Despite the study's relatively short duration of only five days, the removal efficiency for both parameters exhibited a notably high level. In MML-1, the removal rate exceeded 90%, while for MML-2, it surpassed 84%. These compelling findings demonstrate the successful application of the MML system in effectively removing contaminants from domestic wastewater. The data presented in Figures 4(a) and 4(b) provide compelling evidence of a strong association between the utilization of the MML and the reduction of contaminants in household wastewater. This reduction in pollutants is attributed to the growth and multiplication of waste-decomposing microorganisms in the MML, which is crucial in alleviating pollutant content in domestic wastewater. Furthermore, the filter media employed in both MMLs have a crucial role in reducing the levels of BOD_5 and COD pollutants through adsorption, filtration, and microbial degradation mechanisms.

Table 3. The removal of BOD_5 and COD levels after processing MMLs

Parameter	Initial concentration (mg/L)	Removal in MML-1 (mg/L)	Removal in MML-2 (mg/L)	Efficiency in MML-1 (%)	Efficiency in MML-2 (%)
BOD_5	227.34	73.55±0.22	90.45±0.36	68.02	60.67
	219.25	60.10±0.57	70.40±0.29	86.79	84.53
	224.47	48.55±0.36	68.40±0.15	78.89	70.26
	217.12	28.60±0.36	33.60±0.43	87.54	85.39
	205.05	20.60±0.43	39.50±0.15	95.47	82.83
COD	447.61	219.50±0.03	235.19±0.07	51.76	48.31
	464.66	156.76±0.06	172.56±0.12	65.55	62.07
	454.90	78.40±0.04	109.71±0.08	82.77	75.89
	439.24	31.40±0.06	47.07±0.05	93.10	89.65
	443.08	47.11±0.10	62.70±0.03	89.65	86.22

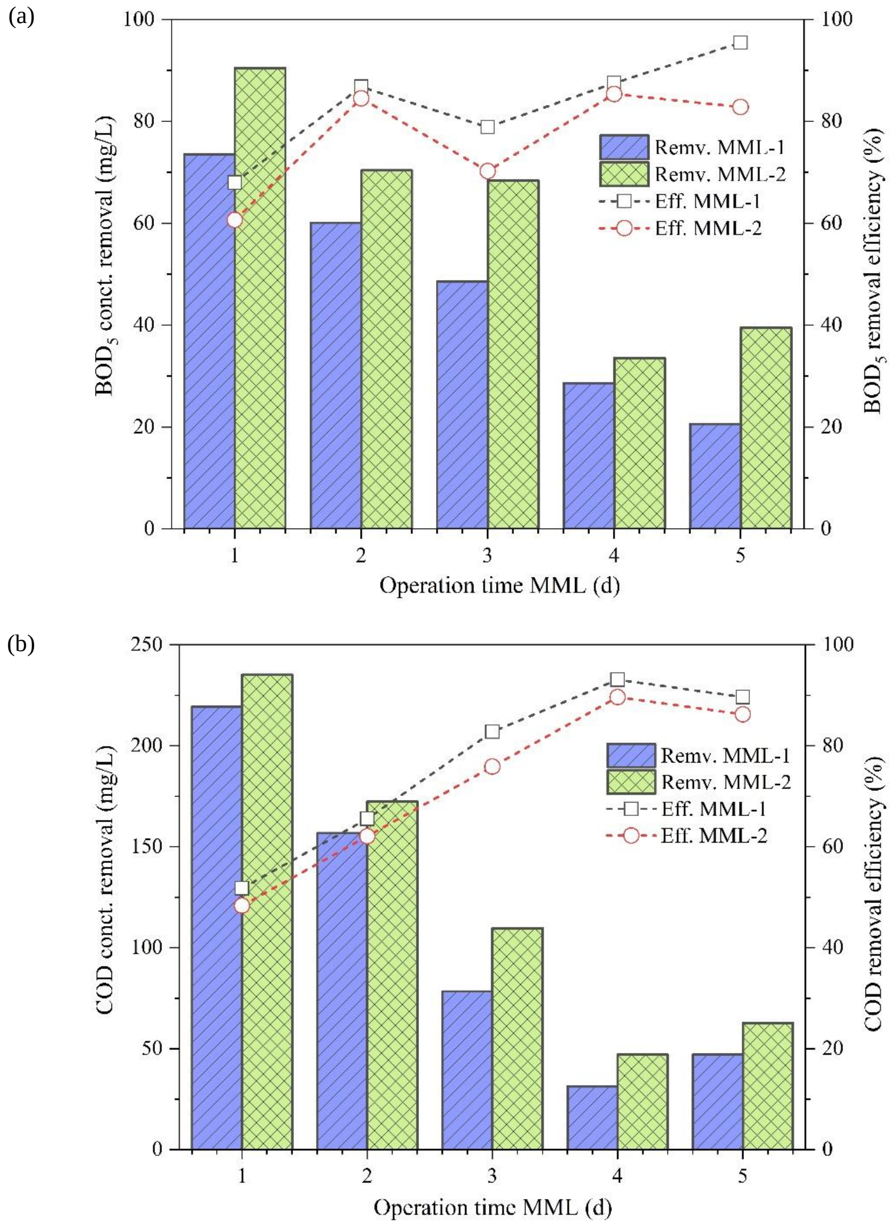


Figure 4. (a) Removal of BOD_5 and (b) removal of COD by MML

The BOD_5 and COD removal for the first day of the study was not too substantial. However, the following days showed significantly improved efficiency figures. The observation results indicate that the highest elimination rates for BOD_5 and COD levels were observed on the fourth and fifth days. MML-1 achieved the highest value for BOD_5 removal at 20.60±0.43 or 95.47% on the fifth day, whereas MML-2 reached 33.60±0.43 or 85.39% on the fourth day (Figure 4(a)). These results underscore the pronounced effectiveness of the MML in removing pollutants from domestic wastewater in a short period.

The highest COD removal rate occurred on the fourth day for both MMLs, with the highest allowance for COD in MML-1 and MML-2 being 31.40±0.06 (93.10%) and 47.07±0.05 (89.65%), respectively (Figure 4(b)). However, the removal efficiency values for BOD_5 and COD slightly decreased in both MMLs on the fifth day of the study, with a reduction of 82.83% for BOD_5 removal and 86.22% for COD removal. This decrease was due to a slight increase in temperature, which reached 32°C. The difference in the height of the gravel media between the MML-1 and MML-2 given the different results. The higher the gravel layer, the greater the removal rate for BOD_5 and COD, as the larger diameter of the gravel media allows more decomposing microorganisms to grow and multiply without causing clogging. Using filter media in MML demonstrated outstanding system performance regarding BOD_5 and COD removal. The MMLs alleviation of BOD_5 and COD is superior to that of the multi-layer artificial wetland, where the highest removal rate for BOD_5 was only 87.9% with an initial BOD_5 level of 207 mg/L and COD reaching 90.6% with an initial COD level of 381 mg/L (Lu et al., 2015).

While Hong et al. (2019) have argued that using an MML system for pollutant removal is somewhat complex, there remain unanswered questions. Other researchers have refuted this argument by demonstrating the effectiveness of MML. For instance, Sbahi et al. (2020) have reported that the use of MML for contaminant removal from domestic wastewater can significantly reduce pollutants, including more than 80% for BOD_5, ammonium (NH_4^+), nitrates (NO_3), total Kjeldahl nitrogen (TKN), and total nitrogen (TN), and up to 91% for orthophosphates (PO_4^{3-}) (TC, until 1.62 Log units).

3.5 Effect of pH on the BOD_5 and COD removal

The pH level is intricately linked to removing contaminants in domestic wastewater, specifically BOD_5 and COD, as depicted in Figure 5. A significant correlation exists between pH and the mitigation of BOD_5 and COD. Previous research has demonstrated that pH plays a fundamental role in reducing COD. Moreover, the decrease in BOD_5 and COD is influenced by various factors, including temperature and the dosage of sodium hypochlorite (NaOCl) (Danil et al., 2017).

Overall, Figure 5 demonstrates that when the pH value is at a pH of 6.0, the removal rates of BOD_5 and COD are higher. Specifically, the maximum BOD_5 removal efficiency above 85% (Figures 5(a) and 5(b)) and the maximum COD removal efficiency above 60% (Figures 5(c) and 5(d)) were observed on day 2 of the study when the pH ranged from 6.4-6.5. On the other hand, when the pH value reached 6.0, the MML-1 achieved a BOD_5 removal efficiency of 95.47%, and MML-2 reached 85.39% (Figures 5(a) and 5(b)). The COD removal efficiency was 93.10% in MML-1 and 89.65% in MML-2. This study suggests that pH 6.0 is optimal for removing BOD_5 and COD, as the pH value close to acidic conditions indicates that microorganisms' are effectively decomposing contaminants, resulting in higher pollutant removal rates. Nayl et al. (2017) suggested that the optimum pH value for COD and BOD removal percentage was 7.18. As bacteria are susceptible to pH, it is crucial to consider specific conditions when determining the optimal pH level for reducing BOD and COD.

3.6 Effect of BOD_5/COD ratio on the COD removal

The correlation between BOD and COD values might provide valuable insights in monitoring and operating urban wastewater treatment facilities. Measuring the BOD_5/COD ratio can identify the quantity of organic matter in wastewater and the microorganisms' ability to decompose waste. Moreover, the BOD_5/COD ratio indicates the organic matter output's impact on waste treatment, offering a comprehensive assessment of the success of wastewater treatment. Therefore, the BOD_5/COD ratio is a crucial factor in wastewater treatment as it provides information about the organic matter's biodegradability in wastewater. Figure 6 illustrates the effect of the BOD_5/COD ratio on COD removal.

Figure 6 provides insight into the feasibility level associated with treating domestic wastewater. In urban wastewater, the BOD_5/COD ratio typically ranges from 0.3 to 0.8 mg/L, indicating that the wastewater is easily treatable biologically. Conversely, if the BOD_5/COD ratio falls below 0.3, the waste contains several toxic components, necessitating acclimatized micro-organisms to stabilize the pollutants. Figures 6(a) and 6(b) show that the BOD_5/COD ratio ranges from 0.3 to 0.9, suggesting domestic wastewater is biologically easily treatable and requires no further processing. However, when the BOD_5/COD ratio is lower, the COD removal rate decreases, while a higher BOD_5/COD ratio leads to a higher COD removal rate, as shown on the fourth day of the study. It is important to note that the BOD_5/COD ratio's use in wastewater treatment varies depending on the level of wastewater treatment. Hence, managing biodegradable materials is paramount in evaluating the potential for short-term and long-term emissions on environmental sustainability.

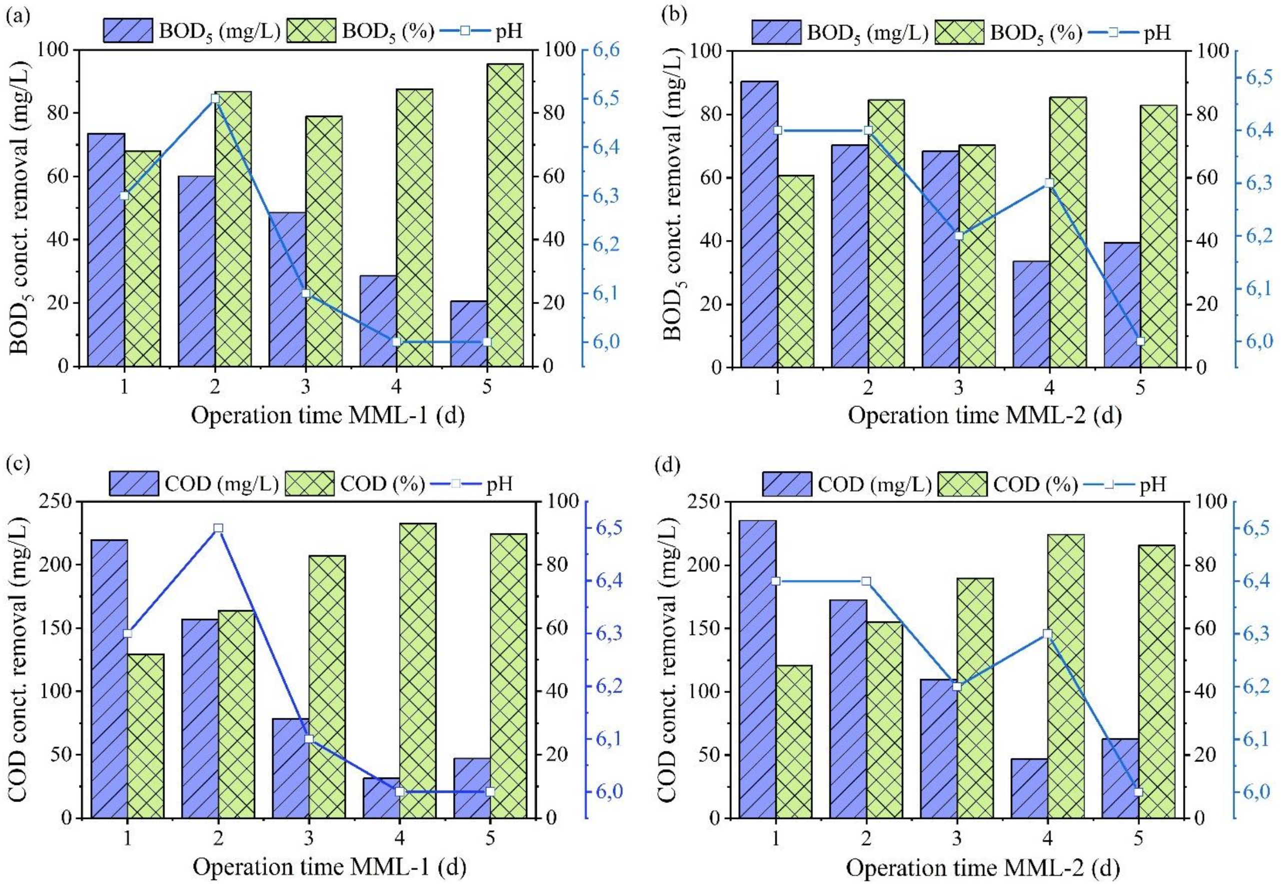


Figure 5. Effect of pH on the BOD_5 and COD removal

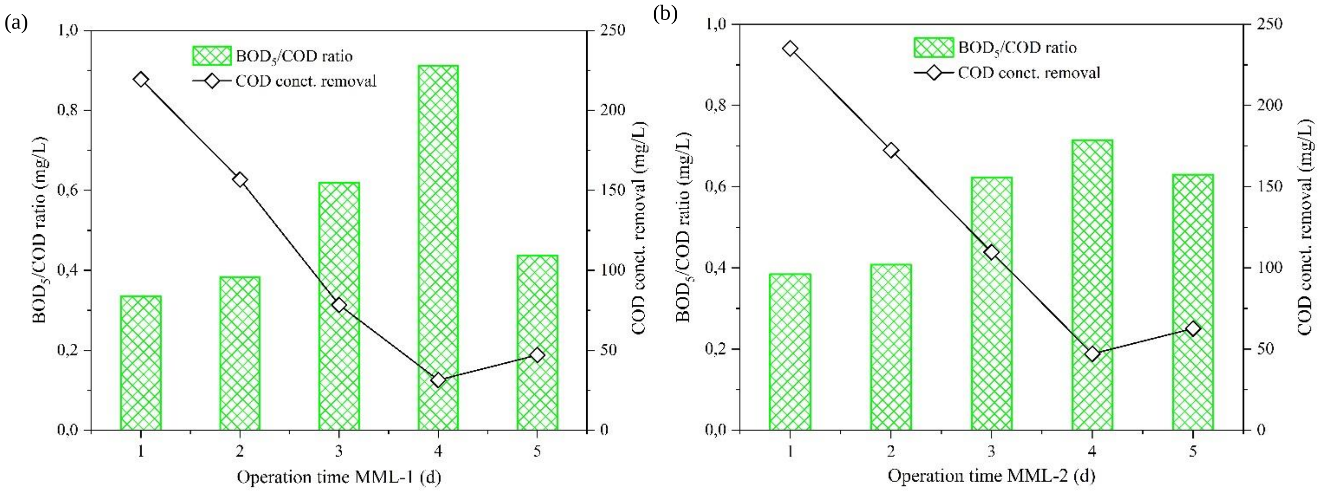


Figure 6. Effect of BOD_5/COD ratio on the COD removal

4. CONCLUSION

The use of MML for the treatment of domestic wastewater has exhibited significant efficacy in decreasing BOD_5 and COD pollutants. This is supported by the impressive removal efficiency rates, which showed MML-1 successfully removing over 93% of BOD_5 and COD, while MML-2 removed 85%. Notably, the greater depth of gravel in MML-1 resulted in more efficient removal of pollutants than in MML-2. The irregular surface of the gravel is responsible for this disparity, as it promotes the growth and multiplication of decomposing microorganisms on the media's surface. With increasing gravel media, more decomposing microorganisms thrive to break down contaminants. Hence, gravel assumes a significant role in MML in eliminating BOD_5 and COD from household wastewater.

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