International Journal of Advances in Applied Sciences (IJAAS)
Vol. 14, No. 1, March 2025, pp. 235~246
ISSN: 2252-8814, DOI: 10.11591/ijaas.v14.i1.pp235-246

Domestic wastewater treatment system using waste plastic bottle caps as biofilter media

Muliyadi Muliyadi[1], Purwanto Purwanto[2], Sri Sumiyati[3], Budiyono Budiyono[2], Sudarno Sudarno[3], Budi Warsito[4]
[1]Department of Graduate Program of Environmental Science, Faculty of School of Postgraduate Studies, Universitas Diponegoro, Semarang, Indonesia
[2]Department of Chemical Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia
[3]Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia
[4]Department of Statistics, Faculty of Science and Mathematics, Universitas Diponegoro, Semarang, Indonesia

Article Info

Article history:

Received Jun 10, 2024
Revised Jan 5, 2025
Accepted Jan 26, 2025

Keywords:

Aerobe
Anaerobe
Biofiltration
Plastic bottle caps
Reactor

ABSTRACT

The increasing lack of clean water has created a paradigm for treating wastewater directly from the source. This study aimed to determine the effectiveness of processing domestic waste using plastic bottle caps in the anaerobe and aerobe reactor system by measuring several key parameters in wastewater. Experimental study on on-site wastewater treatment system using two bioreactors, a biodegradation made from fruit and vegetable peel waste, and local microorganisms. Domestic wastewater was used in this study. The wastewater treatment system's performance was monitored using parameters like pH, temperature, total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD), collected daily at 9 am during peak wastewater generation. The wastewater treatment system using aerobe and anaerobic reactors with plastic bottle cap media and microorganism biodegradation effectively reduced the TSS, COD, and BOD. The anaerobe reactors were more effective at removing these pollutants, with a maximum TSS reduction of 81.1%, COD removal efficiency of 90.1%, and BOD removal efficiency of 80.2%. The longer acclimatization time of the anaerobe reactor may make it more efficient after acclimatization compared to the aerobe reactor. Although the anaerobe reactor may require a longer acclimatization time, it ultimately results in a higher efficiency in terms of TSS, COD, and BOD reduction compared to the aerobe reactor.

Corresponding Author:

Muliyadi Muliyadi
Department of Graduate Program of Environmental Science, Faculty of School of Postgraduate Studies
Universitas Diponegoro
Semarang-50241, Central Java, Indonesia
Email: muliyadi.dosenternate@gmail.com

1. INTRODUCTION

Water scarcity worldwide is caused by the depletion of clean water sources owing to liquid waste pollution [1]. The increasing lack of clean water has created a paradigm for treating wastewater directly from the source [2]. Wastewater treatment techniques, both physical, chemical, and biological, are known to prevent pollution from water sources. Several processes that are known to be able to reduce pollutant loads include coagulation-flocculation, aeration, chemical oxidation, filtration, and biofiltration [3].

Domestic wastewater contains various kinds of dangerous contaminants including organic matter, nitrogen, phosphorus, and pathogens (bacteria and viruses) [4]. Domestic wastewater content is influenced by several factors, such as weather conditions and temperature. Several studies have stated that weather affects the conditions of wastewater treatment systems and has an impact on wastewater quality. It is known that low temperatures contribute to a long acclimatization process and low nitrification process. The ideal temperature to increase the effectiveness of the biofiltration process is 18 °C [5].

Previous research has shown that polyethylene terephthalate (PET) plastic media can be used as breeding grounds for bacteria in biofilter reactors. Plastic media (Pentair's Sweetwater SWX Bio-Media), which is used as a biofilter, is also known to remove nitrate from wastewater with a removal percentage of 92.57% [6]. Meanwhile, according to research conducted by Dorji *et al.* [7], plastic media with a biofilter reactor within 40 days was able to reduce total suspended solids (TSS) by 80%, Escherichia coli by 84.6-92.4%, chemical oxygen demand (COD)=29-72%, and biochemical oxygen demand (BOD) by 60-90%.

Plastic packaging waste buried in landfills can contribute to air, water, and soil pollution [8]. This type of PET plastic bottle cap can be used as a filter medium or substitute for gravel in wastewater treatment because of its high surface area for biofilm growth. Similar to most plastics, PET is a petroleum-based polymer that does not break down easily when released into the environment. PET bottles were used as single-use packaging and discarded after the first use [9]. For this reason, there must be a technology that utilizes the remaining PET plastic bottle caps as a useful material after its primary use. Biofiltration using PET bottle caps, apart from reducing plastic waste, is also expected to become a new medium for growing bacteria, which is useful for breaking down organic materials and pollutants in wastewater.

Several studies have shown that various types of media can become a place for bacteria to grow in biofilter reactors. Microbes in biofilters consume and convert pollutants into compounds that can be used as alternative energy sources. However, research on biofilm technology has a long acclimatization time [10]. To solve this problem, it is hoped that the use of local microorganisms (MOL) will act as a bioactivator for bacteria that previously existed in wastewater, making it easier to decompose wastewater.

Several studies have discussed the effectiveness of biofiltration in reducing pollutants. In Indonesia, wastewater management remains a serious problem that must be immediately addressed [11]. Various studies have shown that wastewater treatment plants (WWTP) can be designed to reduce production costs and can be used as alternative wastewater treatments using plastic or other media [12]. However, biofilter designers tend to focus more on the sorption properties of the biofilter layer rather than on optimal colonization by bacteria and fungi [13]. In addition, little information is available regarding system performance on semi-technical and technical scales [14].

The aim of this study was to determine the effectiveness of processing domestic waste using plastic bottle caps in anaerobe and aerobe reactor systems by measuring several key parameters in wastewater. The novelty of this research is the use of plastic bottle caps as an inexpensive and environmentally friendly alternative for anaerobe and aerobe reactor system processing of domestic waste. It is hoped that this research will contribute to the development of more effective and affordable waste-processing methods. Thus, it is hoped that this research will provide innovative solutions for overcoming domestic waste problems. It is hoped that the results of this study can serve as a reference for the community and government in environmental conservation efforts.

2. RESEARCH METHOD

The reactor was placed in a greenhouse that was previously erected, with a length of 3 m, a width of 3 m, and a height of 3 m as shown in Figure 1. The sample analysis was performed at the Balikpapan Integrated Laboratory. The production of MOL (biodegradable) materials is performed directly in the greenhouse. The following is the detail of the greenhouse:

i) Height: the height of the building is measured from: a minimum pole height of 3 m, top height (building height from ground level to the highest point of the building) 3 m. This is intended so that the air is not hot, it is expected that a good temperature range is achieved, 25-27 °C with a minimum humidity of 50%.
ii) Foundation: the foundation is made of simple concrete which has the strength to withstand the risk of collapse.
iii) Ventilation: the width of the greenhouse ventilation that must be designed is an opening of 18-29% of the floor area. Ventilation functions so that hot air can escape smoothly.
iv) Frame, cover, and roof:
    - The frame is made of wood and light steel
    - The cover is made of glass and plastic
    - The roof is made of zinc which is made of aluminium
v) Building frame shape: the shed type has a sloping roof construction that rests on another building wall (base wall).

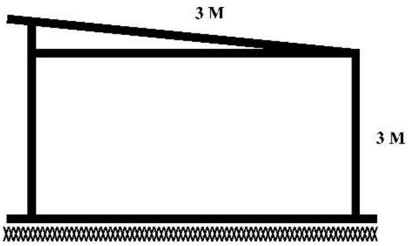


Figure 1. Form of building framework

TSS which are measured in accordance with United States standards, pH (pH meter), and temperature (meter), were recorded to closely monitor the operation of the aerobic wastewater treatment system (APHA, 1998). A DR3900 spectrophotometer and analytical test equipment (Hach, United States) were used to measure COD. BOD5 levels were measured using an OxiTop®OC100 instrument (Germany). To acquire uniform and representative samples, samples were taken once a day at nine hours in the morning, when wastewater generation was at its highest. The samples were taken in triplicate at the start of the procedure owing to their vast collection, which prevented analytical errors from occurring in the laboratory.

MOL is utilized as a starting point for the production of liquid and solid organic fertilizers. MOL's primary constituent is made up of multiple parts, including sources of microbes, glucose, and carbohydrates. Organic waste from homes, plantations, and agriculture can provide the basic materials needed to ferment MOL solutions [15]. We employed basic components from fruit and vegetable peels in this study. Biodegradation MOL is made directly in the laboratory, and the ingredients for making the biodegradation are taken from fruit and vegetable peel waste. The nutrient content in the biodegradation is shown in Table 1.

The research method used was experimental research by controlling all natural conditions and situations that are intended to create artificial conditions and situations that are in accordance with the research objectives and methods. This research is at a laboratory scale where the reactor has a batch system. The reactor that had been made was then placed in a greenhouse that was previously designed by researchers. This reactor will later process wastewater. To ensure that the reactor functioned normally, a reactor design test was carried out to determine the suitability of the reactor for the conditions and processes occurring in the research. The bio activator is then added to the reactor as a form of treatment with a ratio of 1 L (bio activator):70 L (wastewater) in liter, where the bio activator comes from the fermentation of fruit peel waste, which has become a liquid and contains microorganisms in the form of bacteria and yeast. This fermentation fluid is known as a local microorganism. The research was further divided into three stages, where the first stage was seeding, the second stage was acclimatization and the last stage was running. The data obtained are then entered into a table, and a graph is made for each data point.

The biofilm structure on the biofilter media thickened during acclimatization. The acclimatization process was completed when the contaminant concentration decreased. We attempted to gather bio activators during the planting and acclimatization procedures. These bioactivators are naturally occurring bacteria obtained from organic wastes. This accumulation of bioactivators aims to boost the number of microorganisms that form a biofilm structure to shorten the acclimatization period. A quick acclimatization interval decreased the wastewater organic compound breakdown period. Biofilm formation started on day three, which is also considered the best time to differentiate between BOD over the first seven days. It is commonly known that polyethylene media, which have a service life of more than 15 years, is where biofilm formation occurs on days 3 to 15.

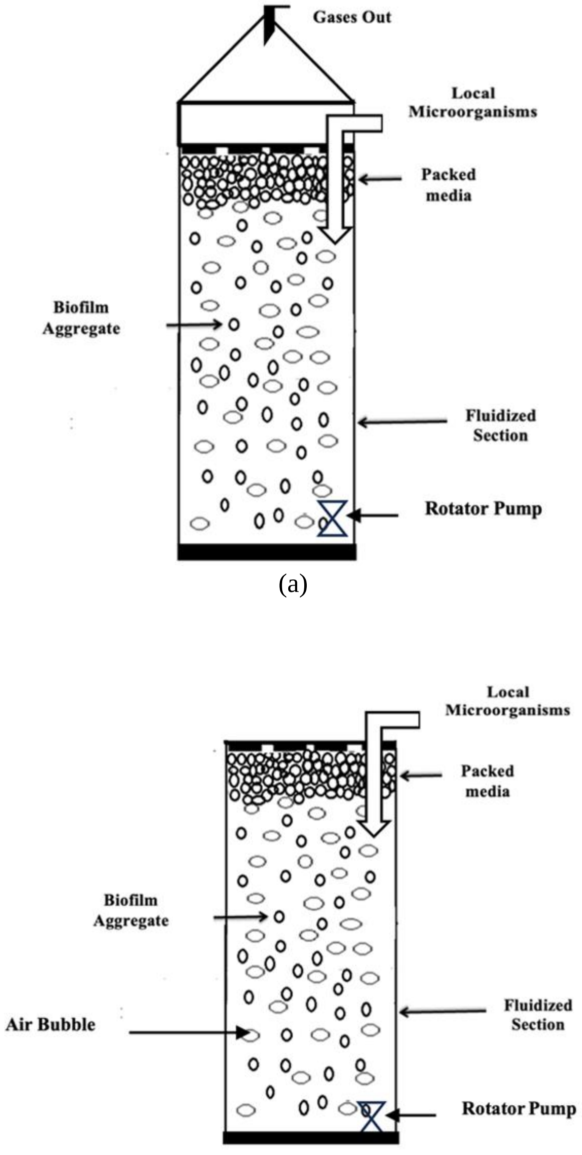
The reactor was 40 cm long, 40 cm wide, 50 cm tall, and 4 mm thick. It was constructed using a fiberglass. The reactor was maintained at 80 liters. Polyvinyl chloride (PVC) pipes were used to design wastewater inputs and outlets. The experiment was conducted over 45 days, with 14 days dedicated to seeding 6 days for acclimatization, and 25 days for running. The primary tank held 1.6 L MOL, 70 L wastewater, and 8.4 L aerobe reactor material. The PET plastic bottle cap medium had a medium diameter of 3 cm and a surface area of 28.26 cm were placed. 14.130 cm was the total surface area of all the media plus the surface area of each medium (500 plastic bottle caps per reactor×28.26 cm), see Table 2 for more information. Figure 2 shows the schematic diagram of the anaerobe and aerobe reactor experimental system using packed bottle caps media.

Table 1. Nutrient content in MOL

MOL	Nitrogen	Phosphorus	Potassium	pH
Fruit and vegetable skin MOL	0.19	18.775 mg/L	254 mg/L	4.0

Table 2. Description of media and reactor

Media properties	Description
Media diameter	3 cm
Medium height	1.5 cm
Media surface area	28.26 cm^2
Type of plastic bottle cap (Media)	PET
Main tank	
Long	40 cm
Wide	40 cm
Height	50 cm
Volume	80,000 cm^3/80 L
Biogas storage tank	
Height	15 cm
Wide	40 cm
Diameter	40 cm
Volume	24,000 cm^3/24 L



(a)

(b)

Figure 2. Schematic diagram of the reactor experimental system using packed bottle cap media of (a) anaerobe and (b) aerobe

2.1. Analysis of the characteristics of wastewater used as an influent in anaerobe and aerobe wastewater treatment systems

The performance of the wastewater treatment system, both aerobically and anaerobically, is closely monitored by recording various parameters, including pH, temperature, total suspended solids, COD, and BOD5. Samples were collected once a day in the morning at 9 o'clock, when wastewater generation was at its peak, to obtain uniform and representative samples. Because the samples were collected in large quantities, they were taken in duplicate at the beginning of the operation, thereby avoiding analytical errors that occurred in the laboratory. Figure 3 shows that the characteristics of the wastewater pollutants TSS, COD, and BOD increased over time without treatment. This can happen because wastewater is not degraded properly, resulting in the pollutant not decomposing optimally.

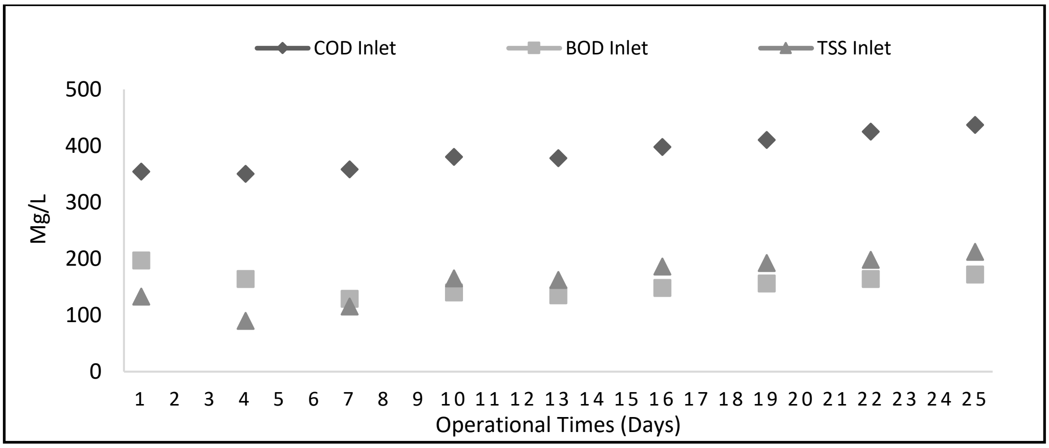


Figure 3. Characteristics of untreated wastewater used as influent in anaerobe and aerobe wastewater treatment systems

3. RESULTS AND DISCUSSION

3.1. General conditions of anaerobe and aerobe reactor during operation

After turning on, the anaerobe and aerobe reactors were operated continuously at a hydraulic retention time (HRT) of 25 days, acclimatization in the anaerobe reactor was achieved after 10 days, and acclimatization in the aerobe reactor was achieved after day 4, as shown by the consistent removal of TSS, COD, and BOD, as shown in the Figures 4-6. The anaerobe and aerobe reactors were operated continuously for 25 days to achieve maximum acclimatization. In this study, in the anaerobic process, acclimatization took quite a long time compared to the aerobic process, which is a major challenge for the anaerobic processing system.

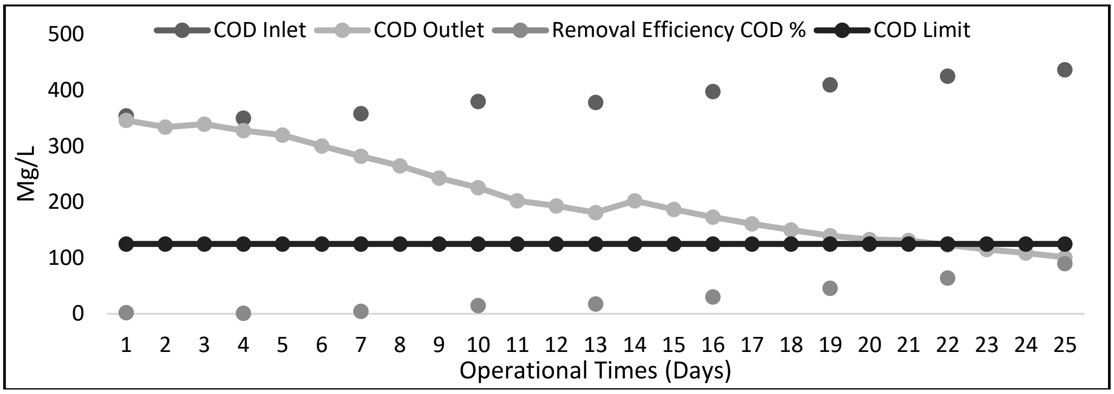
Both aerobic and anaerobic processes are sensitive to temperature and pH and influence changes in other parameters. The average pH values of the two reactors were not significantly different (pH of aerobe waste 6.9±0.4, pH of anaerobe waste 7.1±0.4). The pH of the wastewater produced in both reactors showed a normal pH with the possibility of undetectable acidity during 25 days of operation and even appeared to be close to normal pH.

In this process, the simultaneous metabolic activity that occurs during the anaerobic digestion process is responsible for this because the CO_2 produced as a byproduct partially dissolves in the wastewater to form bicarbonate, which increases the capacity of the wastewater to buffer the pH [16]. Meanwhile, in the aerobic process, the metabolic activity of aerobic bacteria that produce CO_2 is partly dissolved and partly decomposed into the surrounding ambient air. The formation of CO_2 in these two processes is very helpful in stabilizing the overall pH. This is also why the pH of wastewater from the anaerobe reactor is better than that of wastewater from the aerobe reactor.

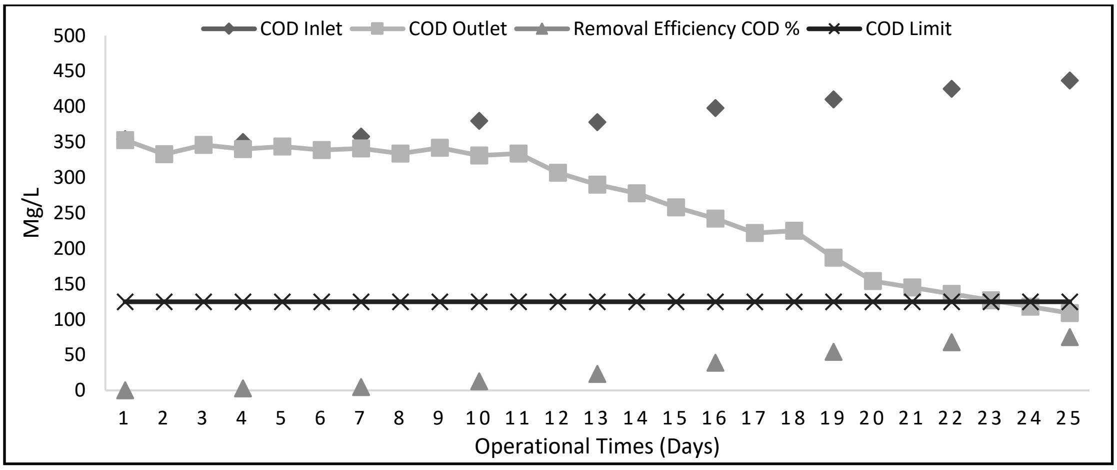
The average temperature in the anaerobe reactor was higher than that in the aerobe reactor (anaerobe temperature 33.8±0.2, aerobe temperature 28.5±0.2). The temperature produced in both reactors allows the development of mesophilic bacteria [17]. This temperature difference can affect the biochemical processes occurring in the reactor. The organic loading rate was maintained stable at 0.9 g/L. Day 1 by keeping the HRT unchanged during operation to maintain stable bacterial conditions during the operation of the aerobe and anaerobe reactors. When the HRT is changed from the initial setting, the effectiveness of reducing the pollutant load decreases, which is most likely due to changes in the organic loading rate (OLR) that cause shock loading on the reactor, as observed during wastewater treatment [18].

3.2. Comparison of COD removal performance in the anaerobe and aerobe reactors

The average COD in the inlet tank is known to be 387.8 mg/l, which is above the limit of the COD value based on [19], which is only 100 mg/l. COD removal in the anaerobe and aerobe reactors is shown in Figure 4. The COD removal efficiency at 25 days HRT in the aerobe reactor (Figure 4(a)) was 75.1%, whereas that in the anaerobe reactor was 90.1% (Figure 4(b)). The efficiency of the anaerobe reactor is higher in COD removal, possibly because CO_2 gas is trapped in the reactor process, which can help the decomposition process. This maximum COD removal indicates methanogenic activity in the anaerobe reactor, which did not occur in the aerobe % reactor. Operations in these two reactors were carried out at an environmental temperature of 28 °C.



(a)

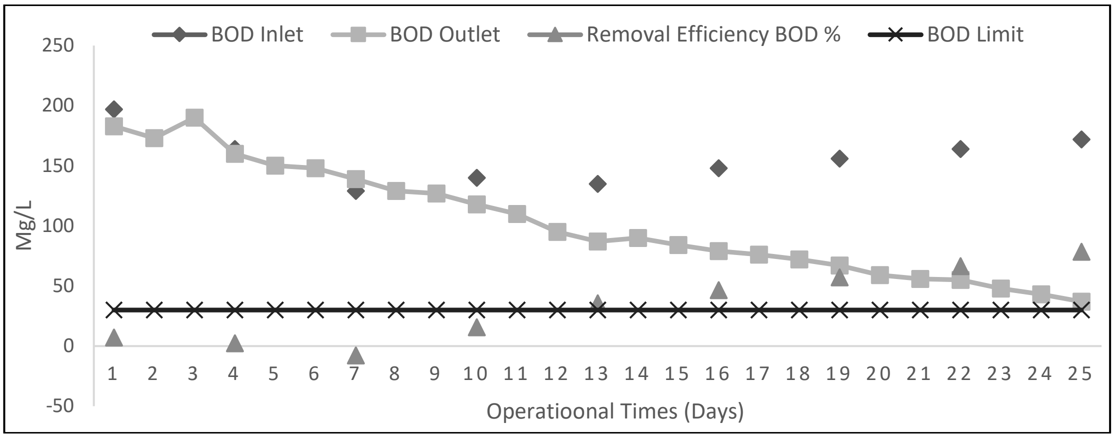


(b)

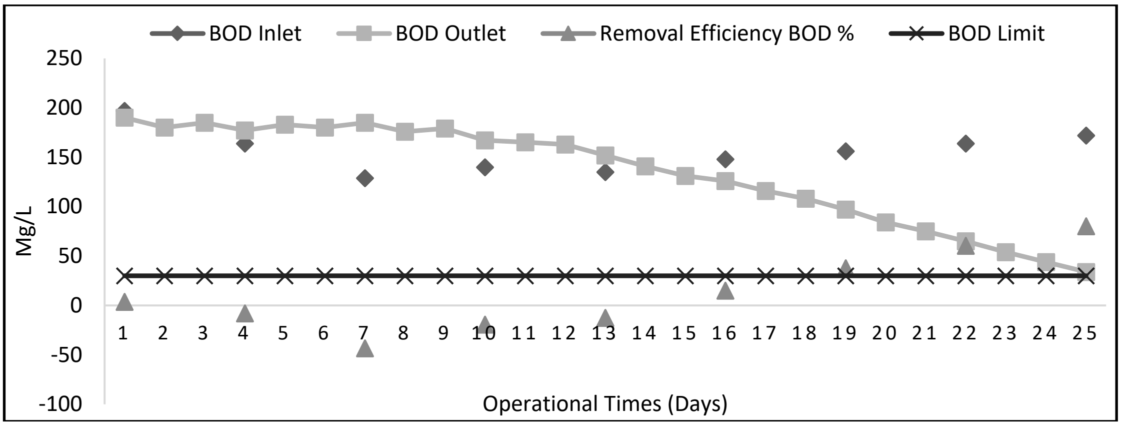
Figure 4. Reactor performance to treat graywater effluent for COD removal of (a) aerobic and (b) anaerobic

3.3. Comparison of BOD removal performance in anaerobe and aerobe reactors

The BOD removal in the anaerobe and aerobe reactors is shown in Figure 5. The BOD removal efficiency at 25 days HRT in the aerobe reactor (Figure 5(a)) was a maximum of 78.5%, whereas in the anaerobe reactor, the maximum was 80.2% (Figure 5(b)). The efficiency of the anaerobe reactor is higher in BOD removal, possibly because CO_2 gas is trapped in the reactor process, which can help optimize the COD decomposition process [20]. This maximum BOD removal indicates methanogenic activity in the anaerobe reactor, which does not occur in the aerobe reactor [21]. In the anaerobe reactor, the maximum BOD refining reaction occurred between days 10-13 and day 20, with the reduction percentage always increasing on that day. However, on day 20, the anaerobe reactor was still able to reduce BOD, although there was a decrease in the percentage. This is possible because of the formation of CO_2 gas. In the aerobe reactor, the BOD value on days 1-4 was still relatively unstable. However, on day 4, it tended to be more stable with a consistent BOD reduction efficiency. Operations in these two reactors were carried out at an environmental temperature of 28 °C.



(a)



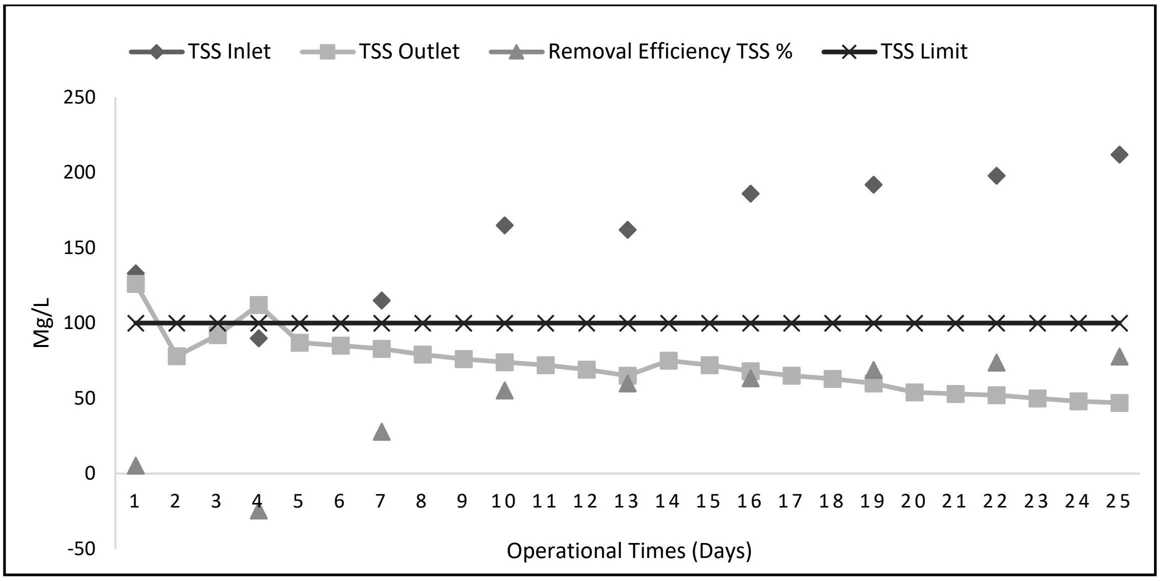
(b)

Figure 5. Reactor performance for treating graywater effluent for BOD removal of (a) aerobic and (b) anaerobic

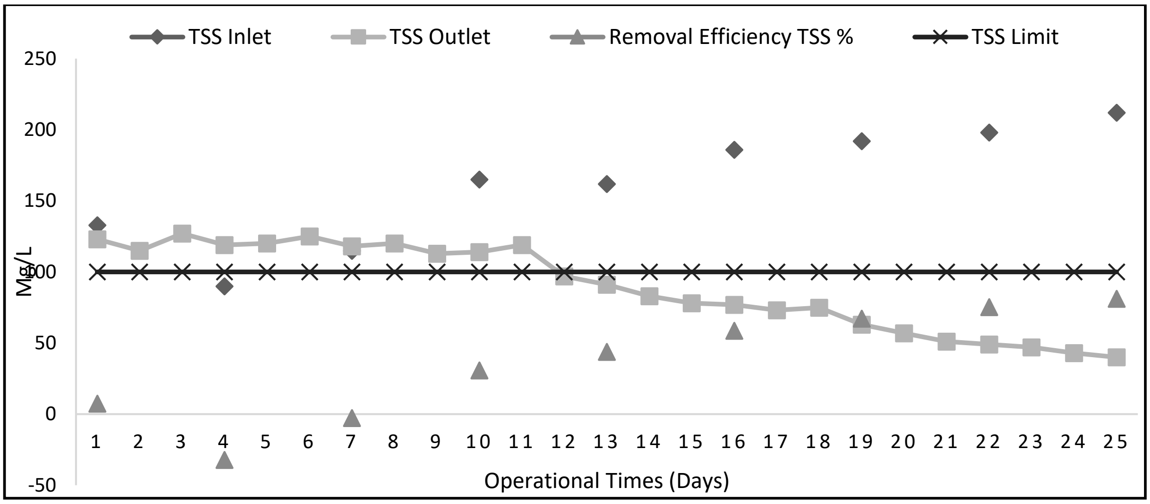
3.4. Comparison of TSS removal performance in anaerobe and aerobe reactors

The performance of the reactor to treat graywater effluent for aerobic and anaerobic TSS removal is shown in Figure 6. Inlet TSS ranged from an average of 161 mg/l, while in the aerobe reactor, the average outlet TSS value reached 72.2 mg/l (Figure 6(a)), and in the anaerobe reactor, the average outlet TSS value reached 89.5 mg/l (Figure 6(b)). The TSS reduction efficiency value in the aerobe reactor reached 77.8% (Figure 6(a)), whereas in the anaerobe reactor, the maximum was 81.1% (Figure 6(b)) at the same designed HRT of 25 days. The reduction in TSS values in the anaerobe reactor began to show consistency on days 10-12 and reached its peak on day 25. The removal of TSS in the aerobe reactor consistently occurred from days to 5-25. In contrast to the removal of TSS in aerobe reactors, consistency tends to take a long time in anaerobe reactors, but the effectiveness after acclimatization is very high, reaching 81.1%. This can occur because CO_2 gas is trapped in the reactor, which can help optimize the COD decomposition process [16]. Operations in these two reactors were carried out at an environmental temperature of 28 °C. Conducted a two-year wastewater treatment trial using an anaerobic baffle reactor (ABR) and observed similar results. TSS elimination (40-95%) was similar to the greatest reduction (60-90%) observed with chemically enhanced initial therapies. During a 2-year trial of wastewater treatment using an ABR and observed similar results. TSS elimination (40-95%) was similar to the greatest reduction (60-90%) observed with chemically enhanced initial therapies [22].

After a pilot study employing plastic bottles (PET and polypropylene (PP)) was conducted for 262 days at an average temperature of 23.4 °C, the plastic medium in the biofilter could also be a destroyer and a way to remove total suspended particles. In this study, the total suspended solid content was reduced by up to 80%. Furthermore, according to the same study, plastic media can eliminate up to 92.4% of Escherichia coli [7]. Another excellent source of heavy metals is total suspended solids. If these compounds are found in liquid waste, then it is definitely very bad for water.



(a)



(b)

Figure 6. Performance of reactors for processing greywater waste for TSS removal of (a) aerobic and (b) anaerobic

It should be noted that the media most widely used to reduce biological and COD are plastics (31.25 %), where the study states that biofilters with media made of plastic can reduce the level of COD by up to 90% and BOD to 98% (Ekokan), where the time needed was only 142 days, and the media thickness was 200×1.4 mm. PET and PP bottles can be used as media and succeeded in reducing COD by 29-72% and 60-90% biological oxygen, respectively, on a pilot scale with a working time of 262 days at 23-4 °C [7]. Other reports have stated that plastic media can reduce COD by 80% at 17-23 °C in just 109 days [23].

Based on several findings, biological wastewater treatment can reduce pollutant loads, including BOD and COD, and several biological treatments that are often found in wastewater treatment systems, such as biological filters, bioreactors, trickling filters, bio scrubbers, and biofilms [24]. Changes in the number and quality of microbes are closely related to changes in temperature. The rate of enzymatic reactions encourages temperature improvement, allowing microbes to grow better. It is also known that the development and growth of bacteria and biofilm are highly dependent on pH.

The type of media surface greatly influences bacterial attachment. In the initial adhesion step, surface roughness increases the adhesion of bacteria to substrates with a wider adhesion medium. The roughness of the bacteria reduces the possibility of attached bacteria falling back to the bottom of the reactor, which can be affected by the flow rate of the water and the type of reactor material used. The presence of divalent cations (Ca2+), both on land and in the sea, is one of the factors that influences biofilm formation.

Pollutants are harmful to the environment, and pollution occurs in wastewater samples, biotrickling filters, and biofilms. This has encouraged the development of processing methods for removing both organic matter and heavy metals. Biofiltration is an alternative method for removing organic matter and heavy metals [25]. This is because, in the biofiltration reactor, there is a medium where bacteria can grow and assist in the process of reducing existing pollutants. Microorganisms that grow on media degrade and form biofilms. Good media have good surface area [26], and water retention for biofilms to live on [27]. These conditions provide space for microorganisms to reduce pollutants in liquid waste [28].

Owing to the capacity of bacteria to disseminate organic processes beneath the flow of organic matter for the formation and refinement of biofilms that have been and will be created, the organic loading rate factor may have an effect on the rate at which biofilms grow. The accumulation of biomass, biofilm development, and denitrification processes are affected by the organic loading rate. Excessive wastewater foam, which prevents the development of biofilms, is a drawback that increases the organic loading rate and decreases the number of potential adsorption sites. The gas formation rate remained constant as the organic loading rate increased, but the percentage of effluent increased [29].

By changing the temperature in the biofilter reactor, which impacts how well microorganisms develop on the formed biofilm, the performance of the biofilter can be controlled [30]. Low temperatures are not ideal for the development of microorganisms, because some bacteria cannot endure them. Therefore, when low temperatures are present, bacteria that have already attached to the biofilm or are currently doing so die. Low temperatures are also known to contribute to long acclimatization and low nitrification rates [5]. Additionally, it has been stated that 18 °C is the ideal temperature for producing effective biofilter performance [5].

Temperature stimulation of biofilms has a significant effect on the metabolism and growth of bacteria. Thus, relatively warm temperatures may cause bacteria in biomass and biofilms to multiply. Some studies have suggested that increasing the temps may encourage the development of bacteria in biofilms. Every living entity in the reactor experienced an increase in metabolism as the temperature increased. The composition of bacteria residing in the reactor varies with temperature. Ciliates are microorganisms that thrive in reactors. Instead of causing an increase in the number of microbial populations or the rate of photosynthesis, an increase in temperature may also result in a change in taxonomy [31]. Although temperature is beneficial for the activity of photosynthetic enzymes, low nutrient levels can prevent bacterial growth [32], [33].

In the three-dimensional biofilm framework, the microbial communities were closely packed. The reaction of the biofilm to heat microbes adhering to the biofilm is modulated by the interactions between microbial groups [34]. Increasing temperatures can result in community changes when microbial species interact, which cannot be anticipated from the reactions of a single species. Bacteria in biofilms fight one another for nutrients, while also taking advantage of one another [35].

4. CONCLUSION

The wastewater treatment system using aerobe and anaerobe reactors with plastic bottle cap media and local microorganism biodegradation was able to reduce TSS, COD, and BOD with an anaerobe temperature of 33.8±0.2, aerobe temperature of 28.5±0.2. The average pH of the aerobe waste was 6.9±0.4, and the pH of the anaerobe waste was 7.1±0.4, using a hydraulic retention time of 2 days. Anaerobe reactors are more effective at removing TSS, COD, and BOD than aerobe reactors. The TSS reduction efficiency in the aerobe reactor reached 77.8%, whereas, in the anaerobe reactor, the maximum efficiency reached 81.1% at the same designed HRT, that is, 25 days. The efficiency of COD removal at 25 days HRT in the aerobe reactor reached a maximum of 75.1%, whereas, in the anaerobe reactor, the maximum was 90.1%. The BOD removal efficiency at 25 days HRT in the aerobe reactor reached a maximum of 78.5%, whereas, in the anaerobe reactor, the maximum was 80.2%. The acclimatization time required for an anaerobe reactor is also known to be longer, namely around 10-13 days compared to an aerobe reactor, which only takes 4-5 days. However, a longer acclimatization time can make the anaerobe reactor more efficient after acclimatization than the aerobe reactor.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Diponegoro for supporting this research by providing access to various reputable journal databases.

REFERENCES

[1] M. B. Bahrodin, N. S. Zaidi, A. Kadier, N. Hussein, A. Syafiuddin, and R. Boopathy, “A novel natural active coagulant agent extracted from the sugarcane bagasse for wastewater treatment,” *Appl. Sci.*, vol. 12, no. 16, p. 7972, Aug. 2022, doi: 10.3390/app12167972.

[2] R. Malila, S. Lehtoranta, and E.-L. Viskari, “The role of source separation in nutrient recovery – comparison of alternative wastewater treatment systems,” *J. Clean. Prod.*, vol. 219, pp. 350–358, May 2019, doi: 10.1016/j.jclepro.2019.02.024.

[3] N. S. Zaidi, J. Sohaili, K. Muda, and M. S. Saidi, “Optimisation of static magnetic field (SMF) on physical properties of biomass using central composite design experiment,” *J. Phys. Conf. Ser.*, vol. 1529, no. 4, p. 042094, Apr. 2020, doi: 10.1088/1742-6596/1529/4/042094.

[4] K. Farkas *et al.*, “Viral indicators for tracking domestic wastewater contamination in the aquatic environment,” *Water Res.*, vol. 181, p. 115926, Aug. 2020, doi: 10.1016/j.watres.2020.115926.

[5] Q. Zhang *et al.*, “Effects of temperature on the characteristics of nitrogen removal and microbial community in post solid-phase denitrification biofilter process,” *Int. J. Environ. Res. Public Health*, vol. 16, no. 22, p. 4466, Nov. 2019, doi: 10.3390/ijerph16224466.

[6] D. Paul and S. G. Hall, “Biochar and zeolite as alternative biofilter media for denitrification of aquaculture effluents,” *Water*, vol. 13, no. 19, p. 2703, Sep. 2021, doi: 10.3390/w13192703.

[7] U. Dorji *et al.*, “On-site domestic wastewater treatment system using shredded waste plastic bottles as biofilter media: pilot-scale study on effluent standards in Bhutan,” *Chemosphere*, vol. 286, p. 131729, Jan. 2022, doi: 10.1016/j.chemosphere.2021.131729.

[8] P. Benyathiar, P. Kumar, G. Carpenter, J. Brace, and D. K. Mishra, “Polyethylene terephthalate (PET) bottle-to-bottle recycling for the beverage industry: a review,” *Polymers (Basel).*, vol. 14, no. 12, p. 2366, Jun. 2022, doi: 10.3390/polym14122366.

[9] M. Mishra, *Encyclopedia of polymer applications*, 1st ed. Boca Raton: CRC Press, 2018. doi: 10.4324/9781351019422.

[10] S. M. Safwat, “Performance of moving bed biofilm reactor using effective microorganisms,” *J. Clean. Prod.*, vol. 185, pp. 723–731, Jun. 2018, doi: 10.1016/j.jclepro.2018.03.041.

[11] Y. A. Sari and M. Pamadi, “Current situation of wastewater treatment plant for sewage in Batam City,” *J. Phys. Conf. Ser.*, vol. 1351, no. 1, p. 012109, Nov. 2019, doi: 10.1088/1742-6596/1351/1/012109.

[12] J. Sun, X. Dai, Q. Wang, M. C. M. van Loosdrecht, and B.-J. Ni, “Microplastics in wastewater treatment plants: detection, occurrence and removal,” *Water Res.*, vol. 152, pp. 21–37, Apr. 2019, doi: 10.1016/j.watres.2018.12.050.

[13] R. Ghasemi *et al.*, “A comparison of biofiltration performance based on bacteria and fungi for treating toluene vapors from airflow,” *AMB Express*, vol. 10, no. 1, p. 8, Dec. 2020, doi: 10.1186/s13568-019-0941-z.

[14] S. Le Borgne and G. Baquerizo, “Microbial ecology of biofiltration units used for the desulfurization of biogas,” *ChemEngineering*, vol. 3, no. 3, p. 72, Aug. 2019, doi: 10.3390/chemengineering3030072.

[15] I. Indasah and A. Muhith, “Local microorganism from ‘tape’ (fermented cassava) in composition and its effect on physical, chemical and biological quality in environmental,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 519, p. 012003, Jul. 2020, doi: 10.1088/1755-1315/519/1/012003.

[16] M. Chiappero *et al.*, “Review of biochar role as additive in anaerobic digestion processes,” *Renew. Sustain. Energy Rev.*, vol. 131, p. 110037, Oct. 2020, doi: 10.1016/j.rser.2020.110037.

[17] F. Ben Rebah, A. Kantardjieff, A. Yezza, and J. P. Jones, “Performance of two combined anaerobic-aerobic biofilters packed with clay or plastic media for the treatment of highly concentrated effluent,” *Desalination*, vol. 253, no. 1–3, pp. 141–146, Apr. 2010, doi: 10.1016/j.desal.2009.11.018.

[18] U. Dorji *et al.*, “Exploring shredded waste pet bottles as a biofilter media for improved on-site sanitation,” *Process Saf. Environ. Prot.*, vol. 148, pp. 370–381, Apr. 2021, doi: 10.1016/j.psep.2020.09.066.

[19] Ministry of Environment and Forestry of the Republic of Indonesia, *Domestic wastewater quality standard (in Indonesian: baku mutu air limbah domestik)*. 2016. [Online]. Available: https://ppkl.menlhk.go.id/website/filebox/5/170314114854P.68 BAKU MUTU LIMBAH DOMESTIK.pdf

[20] S. R. Sousa, L. S. Rodrigues, R. R. Sampaio, J. C. F. Dutra, and I. J. Silva, “Efficiency of the anaerobic baffled reactor followed by anaerobic filter in the removal of nutrients and pathogenic organisms in fish processing effluents,” *Arq. Bras. Med. Veterinária e Zootec.*, vol. 74, no. 5, pp. 892–900, Oct. 2022, doi: 10.1590/1678-4162-12504.

[21] B. Muñoz-Palazon, S. Gorrasi, A. Rosa-Masegosa, M. Pasqualetti, M. Braconcini, and M. Fenice, “Treatment of high-polyphenol-content waters using biotechnological approaches: the latest update,” *Molecules*, vol. 28, no. 1, p. 314, Dec. 2022, doi: 10.3390/molecules28010314.

[22] H. Mishra, G. Gaurav, C. Khandelwal, G. S. Dangayach, and P. N. Rao, “Environmental assessment of an Indian municipal wastewater treatment plant in Rajasthan,” *Int. J. Sustain. Eng.*, vol. 14, no. 5, pp. 953–962, Sep. 2021, doi: 10.1080/19397038.2020.1862349.

[23] Y.-X. Liu, T. O. Yang, D.-X. Yuan, and X.-Y. Wu, “Study of municipal wastewater treatment with oyster shell as biological aerated filter medium,” *Desalination*, vol. 254, no. 1–3, pp. 149–153, May 2010, doi: 10.1016/j.desal.2009.12.003.

[24] M. De Sanctis *et al.*, “An innovative biofilter technology for reducing environmental spreading of emerging pollutants and odour emissions during municipal sewage treatment,” *Sci. Total Environ.*, vol. 803, p. 149966, Jan. 2022, doi: 10.1016/j.scitotenv.2021.149966.

[25] K. Vikrant *et al.*, “Biofiltration of hydrogen sulfide: trends and challenges,” *J. Clean. Prod.*, vol. 187, pp. 131–147, Jun. 2018, doi: 10.1016/j.jclepro.2018.03.188.

[26] E. R. Rene *et al.*, “Effects of concentration and gas flow rate on the removal of gas-phase toluene and xylene mixture in a compost biofilter,” *Bioresour. Technol.*, vol. 248, pp. 28–35, Jan. 2018, doi: 10.1016/j.biortech.2017.08.029.

[27] K. Mačaitis, A. Misevičius, A. Paškevičius, V. Raudonienė, and J. Repečkienė, “Effectiveness research on a wavy lamellar plate-type biofilter with a capillary system for the humidification of the packing material applying introinduced microorganisms,” *J. Environ. Eng. Landsc. Manag.*, vol. 22, no. 4, pp. 254–263, Dec. 2014, doi: 10.3846/16486897.2014.972409.

[28] I. E. Ibanga, L. A. Fletcher, C. J. Noakes, M. F. King, and D. Steinberg, “Pilot-scale biofiltration at a materials recovery facility: the impact on bioaerosol control,” *Waste Manag.*, vol. 80, pp. 154–167, Oct. 2018, doi: 10.1016/j.wasman.2018.09.010.

[29] K. Ganesan, V. Saravanan, S. Rajamohan, P. Saravanan, and M. Rajasimman, “Performance studies on biofilter for VOC removal under various organic loading rates and gas empty bed residence times,” *Am. Int. J. Res. Sci. Technol. Eng. Math.*, vol. 25, no. 1, pp. 55–62, 2019.

[30] J. Qu, H. Yang, Y. Liu, H. Qi, Y. Wang, and Q. Zhang, “The study of natural biofilm formation and microbial community structure for recirculating aquaculture system,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 742, no. 1, p. 012018, Apr. 2021, doi: 10.1088/1755-1315/742/1/012018.

[31] A. Ibáñez, S. Garrido-Chamorro, and C. Barreiro, “Microorganisms and climate change: a not so invisible effect,” *Microbiol. Res. (Pavia).*, vol. 14, no. 3, pp. 918–947, Jul. 2023, doi: 10.3390/microbiolres14030064.

[32] C. E. Moore *et al.*, “The effect of increasing temperature on crop photosynthesis: from enzymes to ecosystems,” *J. Exp. Bot.*, vol. 72, no. 8, pp. 2822–2844, Apr. 2021, doi: 10.1093/jxb/erab090.

[33] J. Zhou, P. Li, and J. Wang, “Effects of light intensity and temperature on the photosynthesis characteristics and yield of lettuce,” *Horticulturae*, vol. 8, no. 2, p. 178, Feb. 2022, doi: 10.3390/horticulturae8020178.

[34] S. O. Akinbode, P. A. Okuneye, and C. O. Onyeukwu, “Inequality, population growth, and hunger in sub-Saharan Africa,” *SN Soc. Sci.*, vol. 2, no. 11, p. 250, Nov. 2022, doi: 10.1007/s43545-022-00554-x.

[35] E. Burman and J. Bengtsson-Palme, “Microbial community interactions are sensitive to small changes in temperature,” *Front. Microbiol.*, vol. 12, May 2021, doi: 10.3389/fmicb.2021.672910.

BIOGRAPHIES OF AUTHORS

Muliyadi Muliyadi is a lecturer in the Department of Environmental Health, Ternate Poltekkes, who majors in liquid waste management as his main midwife. Muliyadi was recorded as a student at the Department of Graduate Program of Environmental Science, Faculty of School of Postgraduate Studies, Universitas Diponegoro, Semarang, Indonesia. He can be contacted at email: muliyadi.dosenternate@gmail.com.

Purwanto Purwanto received an engineering degree from Chemical Engineering, Diponegoro University, Semarang in 1985. Then he took the Master’s Program and Doctoral Program at INPT University of Toulouse, France, in the field of Chemical Engineering so that he succeeded in holding the degree of advanced studies (DEA) and Doctoral degrees respectively in 1991 and 1994 respectively. The professor who was born in Demak on December 28, 1961, began his career as a lecturer at Diponegoro University in 1985 and is now actively teaching at the Department of Chemical Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia. He is an expert in process system engineering and chemical reaction engineering. For his hard work and perseverance, in 2015 he was appointed Dean of the 2015-2019 Diponegoro University Postgraduate School Program. In addition, he obtained a position as a Professor at Diponegoro University in 2009 and now serves as Chair of Commission IV of the Academic Senate. He can be contacted at email: p.purwanto@gmail.com.

Sri Sumiyati is a lecturer at Diponegoro University with expertise in waste, both solid waste and liquid waste, currently, she holds the position of head of the environmental lab at the Department of Environmental Engineering, Faculty of Engineering. He is active in research and has published in many journals, he also teaches in several fields of science, especially in the field of environmental engineering. She can be contacted at email: noesri71@gmail.com.

Budiyono Budiyono is currently listed as the dean of the Vocational School of Diponegoro University. He is also listed as affiliated with the Department of Chemical Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia. Prof. Dr. Ir. Budiyono, M.Si has extensive experience in the field of chemical engineering and has contributed greatly to the development of vocational education in Indonesia. As the dean of the vocational school, he is responsible for the management and development of educational programs that are relevant to current industry needs. He can be contacted at email: budiyono@live.undip.ac.id.

Sudarno Utomo is a senior lecturer in environmental engineering and is registered as a lecturer at the Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia. He has extensive experience in research and teaching in the field of environmental engineering. In addition, Dr. Sudarno Utomo is also actively involved in environmental conservation projects in Indonesia. He has published various scientific articles and books related to the environment, as well as being a speaker at various international seminars and conferences. Dr. Sudarno Utomo also has an extensive network with various environmental institutions and organizations in Indonesia. He can be contacted at email: sudarno_utomo@yahoo.com.

Budi Warsito is a senior lecturer in statistics at Diponegoro University. He is a lecturer at the Department of Statistics, Faculty of Science and Mathematics, Universitas Diponegoro, Semarang, Indonesia. Dr. Budi Warsito has decades of teaching experience and has published various scientific articles in leading journals. In addition to being active in academics, he is also a frequent speaker at international seminars and conferences. Dr. Budi Warsito is also involved in various research projects related to statistics and has been a supervisor for many undergraduate and master's students. With his dedication to academics, Dr. Budi Warsito continues to contribute to the development of statistical science in Indonesia. He can be contacted at email: budiwrst2@gmail.com.