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Performance Analysis of Coconut Fiber Trickle Bed Filter for Municipal Wastewater Treatment

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Abstract
The large amount of liquid waste generated from urban activities can provide negative impacts, such as disease spread, environmental damage, and others. Therefore, treatment efforts before disposal into the environmental are crucial. One method of treating liquid waste that can be used is the trickling filter. The trickling filter method used in this research utilizes natural fibers, namely coconut fiber, as the packing media, replacing sand or plastic as the packing media in conventional trickling filters. Treatment of municipal liquid waste (domestic waste) using coconut fiber trickling filters is one application of biofilm technology in wastewater treatment, where a biological layer (biofilm) like mucus will grow on the surface of the media. This biological layer will meet the wastewater and degrade the pollutant compounds present in the wastewater, resulting in water with lower biological oxygen demand (BOD) values than before. The result if water that is safe for disposal into the environment. This trickling filter reactor can degrade pollutants with degradation efficiency of BOD 91.3%, nitrate 50.25%, and ammonia 37.5% at the optimal flow rate of this study (0.256 L/min).
Keywords: *biofilm, biological oxygen demand, coconut fiber, domestic waste, trickling filter*

Abstrak
Jumlah limbah cair yang besar yang dihasilkan dari aktivitas perkotaan dapat menyebabkan dampak negatif yang signifikan seperti penyebaran penyakit, kerusakan lingkungan, dan lain-lain. Oleh karena itu, upaya pengolahan sebelum pembuangan ke lingkungan sangat penting. Salah satu metode pengolahan limbah cair yang dapat digunakan dalam penelitian ini menggunakan serat alami, yaitu serat kelapa, sebagai media pengisian, menggantikan pasir atau plastik sebagai media pengisian dalam filter tetes konvensional. Pengolahan limbah cair perkotaan (limbah domestik) dengan filter tetes sabut kelapa adalah salah satu aplikasi teknologi biofilm dalam pengolahan air limbah, di mana lapisan biologis (biofilm) seperti lendir akan tumbuh di permukaan media. Lapisan biologis ini akan bersentuhan dengan limbah cair dan mendegradasi senyawa pencemar yang ada dalam limbah cair, menghasilkan air dengan nilai BOD yang lebih rendah dari sebelumnya. Hasilnya adalah air yang aman untuk dibuang ke lingkungan. Reaktor filter tetes ini dapat mendegradasi polutan dengan efisiensi degradasi BOD 91.3%, nitrat 50,25%, dan amonia 37,5% pada laju alir optimal dalam penelitian ini (0,256 L/menit).
Kata Kunci: *biofilm, biological oxygen demand, serat kelapa, limbah domestik, filter tetes*

1. Introduction

Waste is one of the biggest problems in Indonesia, including in Banda Aceh, which has a population of 249,282 people with the amount of domestic waste generated per person being around 125-250 grams per day. Municipal liquid waste, often referred to as domestic waste, is leftover waste that cannot be reused, originating from kitchen activities, bathrooms, laundry, restaurants, offices, and so on.

Domestic wastewater contains over 90% liquid, containing substances including suspended and dissolved organic matter, inorganic substances, and microorganisms. Pollution caused by municipal waste is one of the biggest problems for people worldwide today, especially in Indonesia, which is one of the most populous developing countries in the world. Municipal liquid waste, often referred to as domestic waste, is waste generated from human activities [1] (households) that worsen environmental conditions, increases human diseases, and damages other environmental components. Domestic waste is waste that originates from private residences, garbage, solid or liquid materials, or animal carcasses [2]. This waste originates from residential settlements (households) and business activities such as markets, restaurants, and offices [3]. According to its original source, wastewater has highly varied compositions [4] from place to place and time to time.

Based on Explanation of Law concerning Health, an environment that poses no more health risks is free from elements that pose health disturbances, including untreated liquid waste, solid waste, and gas waste [5]. Therefore, the biological treatment of domestic wastewater is needed to remove organic pollutants [6], one of which is the trickling filter method. Trickling filter is one of the liquid waste treatment methods that utilize microbial films technology to reduce organic material in the water. The treatment process is carried out by spreading domestic wastewater into a stack or heap of media consisting of crushed stone (gravel), ceramic materials, furnace slag, plastic-based media, or others, where the surface of this media will grow a biological layer (biofilm) like mucus. This biological layer will meet the wastewater and degrade the pollutant content present in the wastewater.

In the use of the trickling filter method, there are many modifications that can be made such as the type and amount of packing, bed height, and others. The appropriate use of packing types includes Luffa cylindrica, which can reduce pollutants in wastewater. Meanwhile, the use of two-stage trickling filter processes can reduce pollutants in wastewater. Using good packing and more than one process stage in reducing pollutants requires higher costs. Therefore, the research to be conducted is modifying the packing of the trickling filter using coconut husks for describing the capacity of Biochemical Oxygen Demand (BOD), nitrate, ammonia removal.

BOD is the amount of oxygen needed by bacteria to degrade organic matter under aerobic conditions [7]. This is an indicator that reflects the level of organic pollution in wastewater and is widely used in water quality monitoring, pollution control, and water management [8]. The BOD value is often expressed in milligrams of oxygen consumed per liter of sample during five days of incubation at 20oC (BOD5) [9]. Untreated wastewater typically contains inorganic contaminants such as mercury metal, nitrogen ions, sulfur, phosphorus, cadmium, arsenic, lead, and some organic pollutants (BOD) such as oil and pesticides [10]. With industrial development and population growth, the amount of wastewater containing ammonia has rapidly increased from various sources, including sewage sludge, cattle excrement, food waste, and biomass [11]. In recent years, the increase in ammonia-nitrogen concentration in water has attracted attention [12].

Generally, more than 80% of domestic waste generated by human activities is disposed of into drainage systems, resulting in over 50 diseases, environmental pollution, odor emissions, and landscape damage [13]. Thus, wastewater treatment is needed that is economical, time-efficient, and requires less land, namely the trickling filter process. This research uses coconut husks as trickling filter packing. The use of coconut husks is because of their flexible and non-rigid shape and their resistance to degradation in anaerobic conditions compared to other natural fibers. The problem to be investigated in this study is the effect of degradation time on the BOD, nitrate, and ammonia contents in the trickling filter.

Based on this background, the objectives of this study can be divided into general objectives and specific objectives. The general objective of this research is to develop a trickling filter system for municipal liquid waste (domestic waste) using coconut husks that are economical, fast, and require less land. The specific objective of this research is to determine the effect of the degradation time on capacity of BOD, total nitrogen, and ammonia contents in the wastewater in the trickling filter, thereby producing wastewater with lower BOD levels that are safe to discharge into the environment. The BOD is a measure of the amount of oxygen required to biochemically oxidize the organic and inorganic matter present in a water sample. The BOD test is commonly used to assess the pollution level of wastewater and the effectiveness of treatment processes.

In general, the results of this research can be used as one of the methods to address environmental pollution caused by domestic wastewater, as well as providing information on the performance of this modified trickling filter in domestic wastewater treatment. Specifically, the expected performance is relatively short degradation time.

2. Material and Methods

Materials

Domestic wastewater was collected using plastic containers from faculty housing in the eastern sector of Syiah Kuala University in Banda Aceh and stored in a refrigerator at a temperature of 4°C [14]. The materials used in this research were coconut fiber husk from an agricultural waste in Darussalam area, sulfanilamide (98%, Alfa Aesar-A1300136), n-(1-naphthyl)-ethylenediamine dihydrochloride (Alfa Aesar-J7321414), sodium hydrosulfite, and glacial acetic acid (>99.7%, Sigma-Aldrich). The equipment used in this research were trickling filter reactor and peristaltic pump.

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Sampling Technique

The analysis of liquid waste characteristics was carried out by first preparing a 50 mL sample of domestic waste in measuring glass. Then, the pH level of the sample was measured using a pH meter. Next, the color of the sample was observed. The parameters to be tested in the research were organic BOD content, total nitrogen, and ammonia content. The characteristics of measured domestic wastewater and standard quality of domestic wastewater [15] were presented in **Table 1**.

Table 1. Characterization of USK faculty housing domestic wastewater

Parameter	Quality Standard	Results	Unit
pH value	-	6–9	7.130
BOD	mg/L	30	46.50
NO3	mg/L	-	8.133
Ammonia	mg/L	10	0.800

The efficiency of their removal was calculated by subtracting the concentration of pollutants in the initial wastewater from the concentration of pollutant in the treated water, divided by the concentration of pollutants in the initial wastewater, then multiplied by 100% [16]. The trickling filter was made of glass with dimensions of 30 cm in diameter and 2.6 in height, filled with coconut fiber husks in the range of 2–4 cm. The fiber was first washed with plenty of distilled water and dried until its weight was constant [17]. This reactor packing was made using natural polymer fibers, namely coconut fiber husk, which was wound into rolls. A perforated distribution system was installed on the surface of the trickling filter to ensure even distribution. This unit was equipped with a sufficiently large pipe with a valve to control the flow optimally at a rate of 0.256 L/min, with a retention time of 1.44 hours.

The research samples were taken from the discharge of faculty member housing in the eastern sector of Darussalam, Banda Aceh. Domestic waste from the stage I treatment pond was pumped into the trickling reactor filled with coconut fiber packing. After undergoing the process in the trickling filter unit, the output from the trickling filter reactor was the final effluent of the trickling filter process, which would undergo parameter testing. In this study, seven samples were analyzed from the same reactor, where the sampling time from sample one to sample two was three (3) days apart, and so on until the seventh sample. The sampling times for each sample were at 11.00 a.m. The samples were collected and analyzed for pH, BOD, NO3, and ammonia. The techniques and methods followed for collection, preservation, and analysis were given as follows.

BOD Content Analysis

Conducting BOD analysis followed ASTM D1252 to ensure accuracy, reproducibility, and comparability of results. A representative sample of wastewater was collected from the source in a dark bottle to prevent changes in dissolved oxygen levels because of exposure to light. Proper sample preservation and transport was ensured to the laboratory within the specified holding time. BOD bottles were filled (typically 300 mL) with the sample, leaving minimal headspace to reduce oxygen transfer from the atmosphere. A dilution water blank was also prepared. The bottles were incubated at 20^{o}C in the dark for five days. Before incubation, the initial dissolved oxygen concentration was measured in the sample using a dissolved oxygen (DO) meter. The initial DO value was recorded.

After five days, the final dissolved oxygen concentration was measured in the sample using the same dissolved oxygen meter. The final DO value was recorded. The BOD concentration was calculated using the following formula:

$$BOD = \frac{(DO_{initial} - DO_{final})}{Volume\ of\ Sample} \quad (1)$$

Where:

$DO_{initial}$ = Initial dissolved oxygen concentration (mg/L) in the sample.

DO_{final} = Final dissolved oxygen concentration (mg/L) in the sample after incubation.

Volume of Sample = Volume of the undiluted sample used in the BOD bottle (mL).

Quality control checks were performed, including calibration of equipment, blank tests, and duplicate analyses, to ensure the accuracy and precision of the results. The BOD results were interpreted in the context of regulatory limits or treatment goals.

Nitrate Content Analysis

Measuring nitrate content in wastewater involved a colorimetric method based on the reduction of nitrate ions to nitrite ions, followed by diazotization and coupling reactions to form an azo dye. Conducting nitrate analysis follow namely ASTM D3867-09 to ensure accuracy, reproducibility, and comparability of results. A representative sample of wastewater was collected in a clean, labeled container. Proper sample preservation and transportation to the laboratory were ensured to prevent changes in nitrate concentration.

A stock solution of sulfanilamide was prepared by dissolving the appropriate amount of sulfanilamide powder in distilled water. This solution was typically prepared at a concentration of 1 g/L. A stock of solution of n-(1-naphthyl)-ethylenediamine dihydrochloride (NED) was prepared by dissolving the appropriate amount of NED powder in distilled water. This solution was typically prepared at a concentration of 1 g/L. A reducing agent solution was prepared by dissolving a reducing agent (namely sodium hydrosulfite) in an acetic acid.

The wastewater sample was filtered through a filter paper to remove any suspended solids. A measured volume of the sample was transferred into a reaction vessel. A specified volume of the reducing agent solution was added to the reaction vessel to convert nitrate ions to nitrite ions. The reaction could proceed for a specified period. A specified volume of sulfanilamide solution was added to the reaction vessel to react with the nitrite ions and form a diazonium salt. A specified volume of NED solution was also added to the reaction vessel to react with the diazonium salt and form an azo dye complex. The color could develop for a specified period. The absorbance of the resulting solution was measured at a wavelength of around 540 nm using a Spectrophotometer UV Vis U-1800 (Hitachi, Japan) [18].

The nitrate concentration in the wastewater was determined by extrapolating the absorbance value from the calibration curve. Quality control checks was performed, including blank tests and duplicate analyses, to ensure the accuracy and precision of the results.

Ammonia Content Analysis

Measuring ammonia content in wastewater involved direct measurement using selective electrodes. A representative sample of wastewater was collected in a clean, labeled container. Proper sample preservation and transportation to the laboratory were ensured to prevent changes in ammonia concentration. The ammonia ion-selective electrode was immersed into the wastewater sample. Sufficient time was allowed for the electrode to stabilize and measure the electromotive force (EMF) generated by the ammonia ions in the sample. The EMF reading was recorded and converted to ammonia concentration using a calibration curve established during the electrode calibration process.

3. Results and Discussion

Degradation Percentage of Wastewater

Domestic wastewater contains several unwanted constituents, such as arsenic, motor oil, plastics, etc., which may hinder testing and treatment [19]. Degradation percentage of wastewater represents the percentage reduction in pollutant concentration after treatment compared to the initial concentration. It involves subtracting the final pollutant concentration from the initial concentration, dividing by the initial concentration, and the multiplying by 100 to express the result as a percentage. It indicates the effectiveness of the treatment process in removing pollutants from wastewater, thereby reducing environmental impact and ensuring compliance with regulatory standard. In this study, seven samples are analyzed from the same reactor, where the sampling time from sample one to sample two was three (3) days apart, and so on until the seventh sample (7). Based on analysis result of several test parameters, the degradation percentage in the coconut fiber trickling filter reactor can be calculated. The degradation percentage regarding test parameters can be seen in Figure 1. One factor that can influence the degradation percentage is the type of treatment technology used, namely trickling filter reactor.

Another factor is operational condition, namely pH. Based on **Table 1**, the pH result obtained was 7.13 with a cloudy white color and a temperature of 33^{o}C–37^{o}C. The pH measurement results indicate that the pH value is relatively normal and still meets the standard quality set in several production processes. The pH falls between 3–4, causing the wastewater to have acidic properties. The pH value at the outlet meets the quality standards. Wastewater condition that are highly acidic or basic can endanger the survival of organisms because they can disrupt metabolism and respiration. pH values above neutral will increase the concentration of ammonia, which is highly toxic to organisms. The temperature of the wastewater also can impact the rate of biological and chemical reactions involved in degradation process.

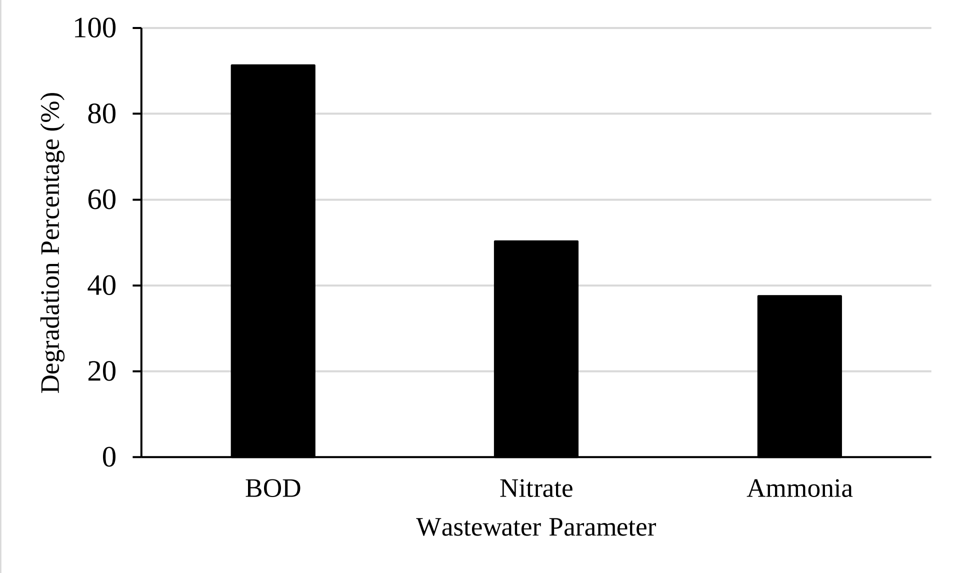

Figure 1. Degradation percentage of wastewater parameter

Based on **Figure 1**, the highest degradation is in BOD, namely 91.3%. Meanwhile, the degradation percentages of nitrate and ammonia are 50.25% and 37.5%, respectively. This is because the reactor undergoes nitrification reactions where NH3 reacts with oxygen gas and degrades with the help of microorganisms, reducing the NH3 content in domestic waste and increasing reactor efficiency.

The Effect of Degradation Time on BOD

In this study, analysis of BOD content reduction is carried out in seven samples as appears in Figure 2. The initial BOD concentration in the reactor was 46.5 mg/L (Figure 2). Figure 2 indicates that BOD content is decreased significantly at the first three days of the study, where the BOD concentration sharply decreased to 15 mg/L. The BOD concentration decreased slightly over the 18 days of the study until the end of the study. The research results indicate that the final BOD in the reactor has a relatively low value of 4 mg/L. The relatively low BOD value reflects a biodegradation reaction that is not very high because of the relatively low abundance of organic compounds. A not very high BOD indicates a low oxygen demand for microorganisms to break down waste, so aquatic organisms may experience oxygen depletion. A relatively low BOD value indicates effective treatment or relatively harmless pollution. Generally, the BOD values still comply with the domestic wastewater quality standards according to Minister of Environment and Forestry Regulation No. P.68/menlhk-Setjen/2016. The efficiency of BOD concentration reduction was 91.4%.

The BOD concentration decreases because the occurrence of degradation of organic compounds by bacteria in wastewater. The number of bacteria affects the amount of degraded organic compounds. Organic materials are used as nutrients and food sources for bacterial growth, resulting in a decrease in BOD concentration. Bacterial will decompose organic compounds into simple compounds, inorganic products, and produce energy for bacterial. The decomposition process is shown in the following reaction:

(COHNS) + O_2 + aerobic bacteria → CO_2 + NH_3 + product + energy

The compounds of CO_2 and NH_3 are nutrients for algae. With sufficient sunlight, algae photosynthesis will occur. In natural conditions, where water receives little organic matter, the oxygen produced in photosynthesis can be used by bacteria, and this cycle repeats. This cycle, called ”algae-bacterial symbiosis”, is a natural phenomenon that occurs in water bodies receiving low organic loads, and the symbiotic reactions of these algae are in a state of dynamic equilibrium.

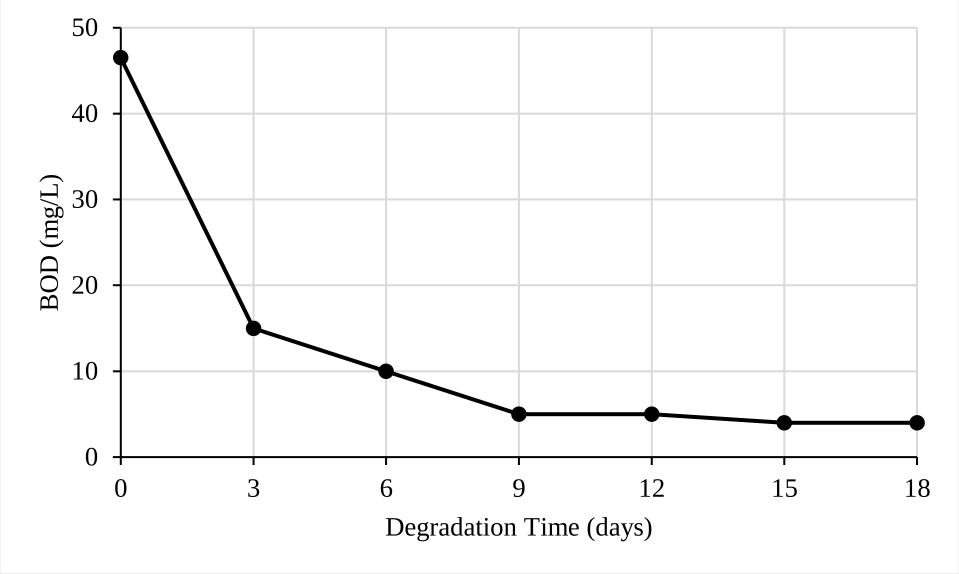

Figure 2. The effect of degradation time on BOD content

The Effect of Degradation Time on Nitrate Content

In this study, analysis of nitrate content reduction is carried out in sample as appears in **Figure 3**. **Figure 3** also indicates the nitrate content start to decline as microbial activity slows down or as other degradation processes become dominant. Nitrate may be further converted to nitrogen gas through denitrification, reducing its concentration in the wastewater. Based on **Figure 3**, there is a decrease in degraded nitrate levels. This can be seen in successive decreases in nitrate levels of 8.133 to 4.046 mg/L. This decline can be attributed to factors such as reduced microbial activity, depletion of organic matter, or the onset of other degradation processes like denitrification. This is because the denitrification process occurs where NO_3 degrades with the help of microorganism, reducing the NO3 content in domestic waste to nitrogen gas.

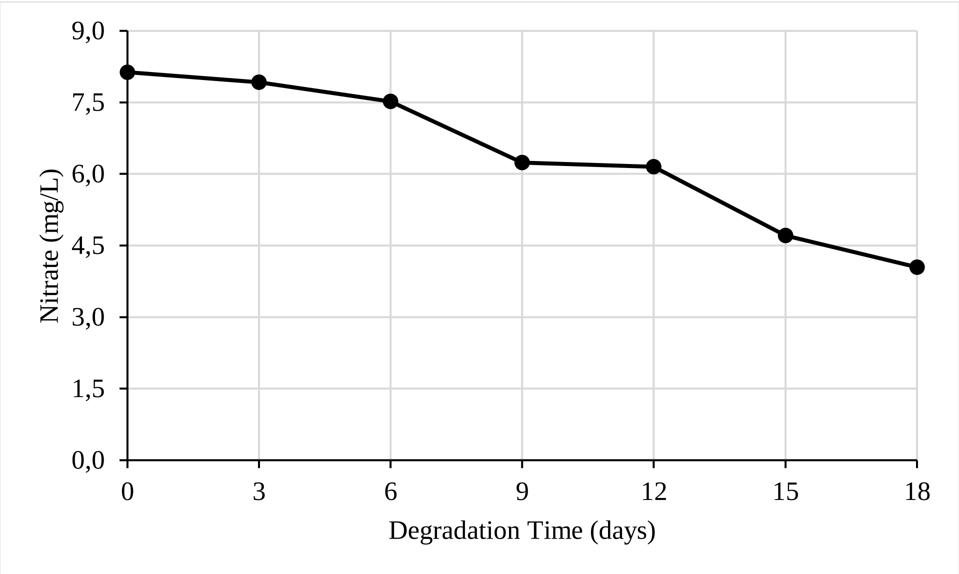

Figure 3. The effect of degradation time on nitrate content

Overall, the change in nitrate levels over time during wastewater degradation is influenced by factors such as microbial activity, nutrient availability, oxygen levels, pH, and the presence of other contaminants. Microorganisms play a crucial role in the degradation of nitrate. Different microbial species have varying abilities to utilize nitrate as an electron acceptor in biochemical processes. Factors such as microbial diversity, population size, and metabolic activity can influence the rate and extent of nitrate degradation. Monitoring nitrate levels over time throughout the degradation process is crucial for assessing treatment efficiency and ensuring compliance with regulatory standards for environmental protection. Overall, trends or patterns in nitrate concentration during wastewater degradation are influenced by a complex interplay of

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biological, chemical, and physical factors. Identifying trends can help optimize treatment strategies for reducing nitrate pollution.

The Effect of Degradation Time on Ammonia Content

In this study, an analysis of the decrease in ammonia levels in seven samples was conducted with results as seen in **Figure 4**.

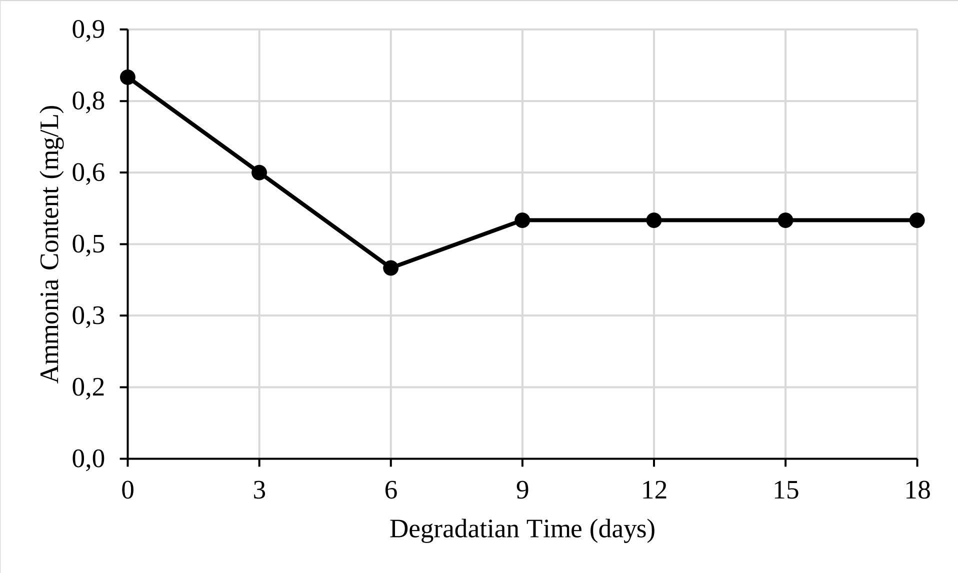

Figure 4. The effect of degradation time on ammonia content

Based on **Figure 4**, there is a decrease in degraded ammonia levels. This can be seen in successive decreases in ammonia levels of 0.8 to 0.5 mg/L. This is because the nitrification process [20] occurs where NH3 degrades using oxygen by nitrifying bacteria, reducing the NH3 content in wastewater over time. Furthermore, there is ammonia evaporation in domestic wastewater because of the influence of the low boiling point of ammonia, namely around 33ºC. Meanwhile, the air temperature in Banda Aceh during the day reaches 33–37ºC, causing some of the ammonia in wastewater to evaporate into the air. In degradation time of six days, the ammonia content is 0.4 mg/L, then in nine days, the ammonia content did not decrease but instead increased by 0.1 mg/L to become 0.5 mg/L. This is contrary to existing theories, but it might occur because the degradation process is not carried out efficiently, some organic nitrogen compounds may not be fully broken down into ammonia, leading to an increase in ammonia content.

During degradation, microbial activity in the wastewater may lead to the release of additional ammonia through processes such as ammonification, where organic nitrogen are converted into ammonia by microbial decomposition. Changes in pH levels during the degradation process can also affect the equilibrium between ammonium (NH_4^+) and ammonia (NH_3). In certain conditions, an increase in pH can result in the conversion of ammonium ions to gaseous ammonia, leading to an apparent increase in ammonia content. Some chemical reactions occurring during degradation may also produce ammonia as a byproduct, contributing to the observed increase in ammonia content. Overall, these factors can contribute to an increase in ammonia content after degradation, highlighting the complex nature of organic matter breakdown in wastewater treatment processes.

Comparison of Coconut Fiber Trickling Filter Biofilling Reactor with Other Types of Reactors

This subsection discusses the comparison of the efficiency of the coconut fiber trickling filter reactor tested in this study (Table 2) with a trickling filter biofilling reactor using composite ceramic cow bone [21] and eggshell adsorber [22]. The previous system used [21] is a combination of trickling filter reactor, denitrification reactor, and post-treatment reactor with composite ceramic cow bone biofilling made from 80% materials commonly used in making porous ceramics and 20% cow bone powder. Meanwhile, the next study used a fixed-bed adsorber containing eggshell serving as an adsorbent with a feed flow rate of 0.004 L/minute. **Table 2** shows that the efficiency of the reactor in this study is still lower compared to the study conducted [21] with a composite cow bone trickling filter reactor with degradation ratio in both reactors for COD, ammonia, and nitrate being 91.30%:60.00%; 50.25%:80.00%; and 37.5%:92.00%, respectively. This could be because of several factors, including:

1. The use of fewer reactors, i.e. one compared to three reactors; the absence of denitrification reactor in this study creates a significant difference in reactor efficiency in degrading nitrate;

2. Shorter reactor startup time, i.e. two weeks of packing immersion plus one week of wastewater circulation compared to four months of wastewater circulation in the reactor for biofilm formation;
3. No addition of nutrients in the feed compared to nutrient addition to the feed.

Table 2. Comparison of coconut fiber trickling filter biofilling reactor efficiency with other reactors

Parameter	Type of Reactor		
	Trickling Filter (Coconut Fiber)	Trickling Filter (Composite Cow Bone)	Adsorber (Eggshell)
BOD (%)	91.30	60.00	-
Nitrate (%)	50.25	80.00	28.26
Ammonia (%)	37.50	92.00	27.78

Based on the reasons above, this research differs from the study conducted [21], resulting in different performances of each reactor in degrading wastewater. Both coconut fiber and cow bone the potential to adsorb organic and inorganic pollutants from wastewater. However, for BOD degradation, the coconut fiber trickling filter performs better than the composite cow bone trickling filter. Coconut fiber is known for its high porosity, which allows for good water retention and air circulation. It typically has a large surface area because of its fibrous structure, providing ample attachment sites for microbial growth and adsorption of contaminants. It is generally durable and resistant to degradation, especially when properly processed. Coconut fiber is also biodegradable and can serve as a sustainable option for filter media. It is readily available in tropical regions where coconut palms are cultivated, and it is relatively inexpensive compared to synthetic filter media. It primarily consists of cellulose, lignin, and hemicellulose, which are organic compounds that can contribute to biological filtration and nutrient retention. Coconut fiber is often relatively inexpensive, especially in regions where coconut palms are cultivated abundantly, thus it is potential to be used as trickling filter.

4. Conclusion

Based on the research conducted, the optimal sample flow rate obtained in this study is 0.256 L/min, with a retention time of 1.44 hours. During the degradation of wastewater over 0-18 days, the BOD levels in the samples were 4-46.5 mg/L. Furthermore, during the degradation of wastewater over 18 days, the nitrate levels in the samples were 4.046-8.133 mg/L. During the degradation of wastewater over 18 days, the levels of ammonia in the samples were 0.4-0.8 mg/L. The reactor efficiency in degrading BOD is 91.3%, nitrate 50.25%, and ammonia 37.5% at the optimal flow rate of this study (0.256 L/minute). The reactor performance in this study is still below the performance of the reactor in the previous study [21], but it is still better compared to the next study [22]. This study is expected to develop of Trickling Filter technology in Indonesia and can be continued by varying variables to improve the quality in research related to urban wastewater degradation. The addition of denitrification reactors integrated with trickling filter reactors could be one alternative for increasing denitrification efficiency.

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6. Abbreviations

BOD	Biological Oxygen Demand
DO	Dissolved Oxygen

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