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RESEARCH ARTICLE

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THE EFFECT OF FLOW RATE AND RESIDENCE TIME IN A BAFFLED ANAEROBIC REACTOR ON AMMONIA REDUCTIONIN SLAUGHTERHOUSES

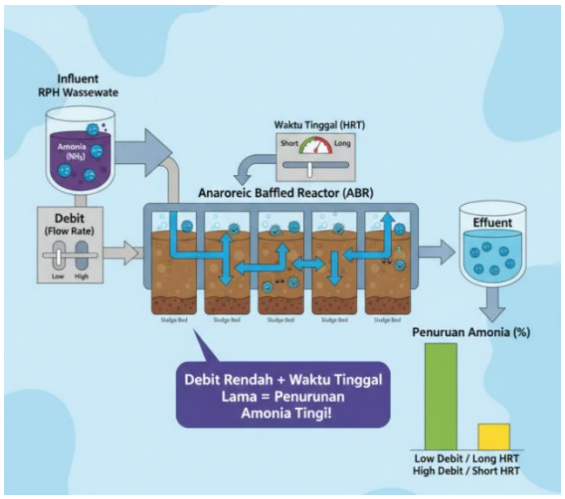
Dian Safitri[1*)], Hery Setyobudiarso[1)], Candra Dwiratna Wulandari[1)]

[1)] Environmental Engineering Department, Faculty of Civil Engineering and Planning, Institut Teknologi Nasional Malang, Jl. Bendungan Sigura-gura No. 2 Malang Kode Pos 65145

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*Corresponding author
diansafitrii888@gmail.com

Graphical abstract



ABSTRACT
This study aims to analyze the effect of variations in flow rate and hydraulic residence time on the performance of an Anaerobic Baffled Reactor (ABR) in reducing ammonia concentrations in slaughterhouse wastewater. The study was conducted experimentally using a laboratory-scale Anaerobic Baffled Reactor (ABR) reactor measuring 85 cm x 40 cm x 30 cm with five compartments. The reactor was operated continuously at two flow rate variations, namely 34 L/hour and 38 L hour, and two residence time variations, namely 6 hours and 12 hours. The main parameter analyzed was the ammonia (NH_3-N) concentration. The results showed that the flow rate and residence time had a significant effect on the efficiency of ammonia reduction. At a flow rate of 34 L/hour, the ammonia reduction efficiency was 55% at a residence time of 6 hours and increased to 70% at a residence time of 12 hours. Meanwhile, at a flow rate of 38 L/hour, the ammonia reduction efficiency was 48% at a residence time of 6 hours and increased to 67% at a residence time of 12 hours. The most effective operational conditions were obtained at a flow rate of 34 L/hourwith a residence time of 12 hours, which resulted in an ammonia concentration in the effluent of 22 mg N/L and met quality standards.

Keywords: Ammonia (NH_3-N), Anaerobic Baffle Reactor, Flow Rate, Slaughterhouse wastewater, Residence Time.

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Corresponding Author: Dian Safitri

diansafitrii888@gmail.com

Environmental Engineering Department, Faculty of Civil Planning and Geo Engineering Institut Teknologi Sepuluh Nopember, Surabaya

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1. INTRODUCTION

Along with increasing human activity and the development of the industrial and service sectors, the volume of waste produced has also increased. Waste on a small scale will not cause problems because nature has the ability to decompose the components contained in the waste. However, if it occurs in large quantities, this condition can cause various negative impacts that have the potential to disrupt the balance of the ecosystem. Liquid waste is residue produced from business activities and/or other activities in the form of liquids that are released into the environment, the presence of which has the potential to cause a decline in environmental quality (Umroningsih, 2022). Livestock slaughterhouse wastewater is the liquid waste produced from slaughterhouse operations.

Slaughterhous wastewater mostly consists of organic substances such as blood, feces, hair, fat, meat, and bone powder (Daffa, 2024). In its operations, a slaughterhouse produces two categories of waste, namely solid waste and liquid waste. Solid waste includes rumen (a digestive system structure similar to a stomach), cow manure, and leftover feed grass. Meanwhile, liquid waste produced by slaughterhouses contains dissolved components such as blood, protein compounds, fat, and suspended solids, which contribute to high organic and nutrient content. Microbial activity in the organic waste process in the air causes an increase in ammonia (NH3-N) concentration, changes in pH, and produces foul odors such as urea and sulfur (Sabela and Ramadhani, 2024). Therefore, treatment technology is needed that can effectively reduce ammonia concentration before the waste is discharged into the environment.

Based on the characteristics of pollutants produced from slaughterhouse wastewater, slaughterhouse wastewater requires treatment technology that can reduce pollutant concentrations. Anaerobic Baffled Reactor (ABR) is a wastewater treatment unit with closed operating conditions. The working principle of Anaerobic Baffled Reactor (ABR) is based on the flow of wastewater entering through partitions or walls arranged in such a way as to form a flow path through the pores between compartments (Pade et al., 2024). The partitions in Anaerobic Baffled Reactor (ABR) function as agitators to increase contact between microorganisms and domestic wastewater. The advantages of Anaerobic Baffled Reactor (ABR) units include that they do not require electricity and have good organic load removal efficiency. The disadvantages of Anaerobic Baffled Reactor (ABR) units include that wastewater still requires additional treatment and pretreatment is necessary to prevent clogging, and that pathogenic bacteria and nutrients are not well reduced (Kusuma and Putro, 2024). In addition, Anaerobic Baffled Reactor (ABR) has the ability to perform natural spatial separation between the hydrolysis, acidogenesis, acetogenesis, and methanogenesis phases to form different groups of microorganisms in process development to achieve optimal unit conditions (Kurniawan et al., 2021). The use of Anaerobic Baffled Reactor (ABR) has advantages in terms of operational and processing aspects that are easy and inexpensive because it does not require electrical energy and has fairly good removal efficiency (Al Kholif et al., 2020).

Anaerobic biological treatment is a wastewater treatment method that relies on the activity of anaerobic microorganisms in degrading organic compounds in conditions without dissolved oxygen. The main characteristic of this process is the production of methane gas (CH4) (Apelabi et al., 2021). Therefore, anaerobic treatment technology is widely applied to liquid waste with high

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organic content, such as industrial waste and slaughterhouse waste, to improve treatment efficiency and support sustainable environmental management efforts.

This study used liquid waste from slaughterhouse x, located in Malang City, East Java, as the object of study. Wastewater treatment was carried out using an Anaerobic Baffled Reactor (ABR). The objective of this study was to analyze the effect of hydraulic residence time variation on the performance of the Anaerobic Baffle Reactor (ABR) in reducing ammonia concentration in slaughterhouse wastewater, thereby obtaining the most effective operational conditions to support the wastewater treatment process before discharge into the environment**.**

2. MATERIALS AND METHODS

Materials:

This study used slaughterhouse wastewater located in the city of Malang. The wastewater was used as reactor influent after undergoing a pre-treatment filtration stage to reduce the solids content and some of the initial pollutants, so that the influent conditions were more stable and supported the anaerobic biological process performance. The main parameter analyzed in this study was the ammonia (NH_3-N) concentration. The anaerobic baffle reactor consisted of 5 laboratory-scale compartments measuring 85 cm x 40 cm x 30 cm. An image of an anaerobic baffle reactor can be seen in Figure 1.

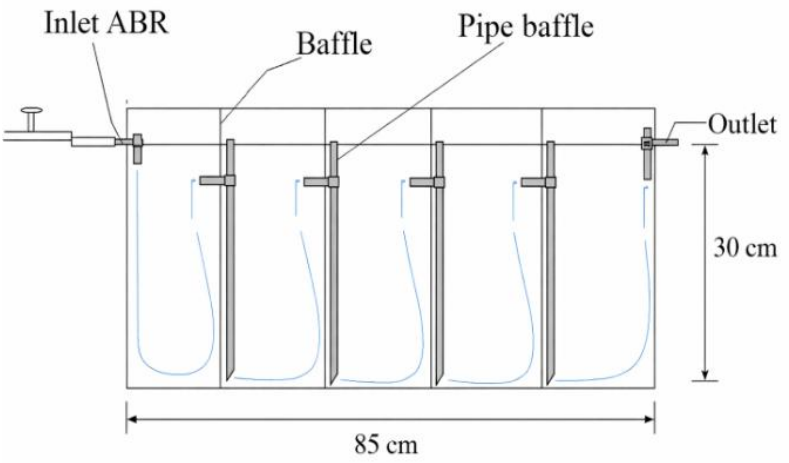


Figure 1. Anaerobic Baffle Reactor Design

The baffles in the ABR reactor create an up-and-down flow pattern that acts as a mixing mechanism, thereby increasing the interaction between domestic wastewater and microorganisms. The ABR reactor is a treatment system that integrates the processes of sedimentation and organic matter degradation by microbial activity in a single unit. The sedimentation process takes place in the initial compartment, while the decomposition of organic matter occurs gradually in the subsequent compartments (Oktaviani, 2023). The research variables used were the application of an anaerobic baffle reactor operated at two flow rates, namely 34 L/hour and 38 L/hour, with residence times of 2 hours and 12 hours, respectively. The test was conducted three times to obtain valid results.

Methods :

The research was conducted on a laboratory scale at the Environmental Engineering Laboratory, Campus 1, National Institute of Technology (ITN), Malang. The sampling method used in this study was grab sampling (instantaneous sampling), which is the collection of wastewater at a specific time at the observation site. This procedure refers to Indonesian National Standards (SNI 6989.59:2008) concerning the procedures for sampling water and wastewater. The ammonia test was conducted based on Indonesian National Standards (SNI 06-6989.30-2005) concerning the method of ammonia analysis using a phenat spectrophotometer. This study was conducted experimentally by operating an Anaerobic Baffle Reactor (ABR) reactor under anaerobic conditions and a continuous flow system.

Before the main treatment stage, the reactor first a went through a acclimatization process to observe the growth seeding and of microorganisms in the form of a biofilm layer that appeared (Ratnawati and Ulfah, 2020). The biological process was stable when acclimatization where complete, was microorganisms attached to the filter media and multiplied, and adapted to the water quality (Hamonanagn and Yuniarto, 2022). The next step is to flow the wastewater into the anaerobic baffle reactor treatment unit through a baffle (barrier) inside the reactor to help direct the wastewater flow and create conditions that support anaerobic decomposition (Namira and Rachmanto, 2024). The effluent from the treatment unit is then tested for ammonia concentration. Data collection was carried out every 6 hours and 12 hours at each predetermined discharge rate. The data used in this study was secondary data from laboratory research. Next, descriptive data analysis was carried out. Data analysis was carried out by presenting the data in tabular form and then describing it (Al Kholif et al., 2020).

3. RESULT AND DISCUSSION

Initial Characteristics of Waste

Based on initial observations, the physical characteristics of slaughterhouse liquid waste before treatment are cloudy brown in color, have a distinctive odor, and contain solid materials, fat, blood, animal feces, and wash water. Initial testing of slaughterhouse liquid waste parameters is carried out through a pre-treatment stage, namely filtration, to reduce the processing load on the main treatment unit. The results of the initial parameter testing of slaughterhouse liquid waste were the ammonia and pH parameters. Based on the tests conducted in the laboratory, the characteristics of slaughterhouse liquid waste can be seen in Table 1.

Table 1 Initial Characteristics of slaughterhouse Liquid Waste

Parameter	Unit	Concentration*	Quality Standards**
Ammonia	mg N/L	74	25
pH	-	7,2	6-9

*Results of Environmental Engineering Laboratory Tests, National Institute of Technology (ITN), Malang, 2026

** Ministry of Environment Regulation No. 5 of 2014 concerning Wastewater Quality Standards

Based on Table 1, it can be seen that the ammonia concentration in the liquid waste from the slaughterhouse does not meet the of quality standards set in Minister Environment Regulation No. 5 of 2014 concerning Wastewater Quality Standards. The ammonia parameter in the analysis results reached 74 mg N/L. This condition indicates that slaughterhouse wastewater has the potential to cause environmental pollution if it is discharged directly into water bodies without undergoing treatment.

The Effect of Flow Rate and Residence Time on Ammonia Reduction

The reduction efficiency is determined based on the comparison between the initial and final concentrations of ammonia using the following equation:

$$\% \text{ Efficiency} = \frac{(C_0 - C)}{C_0} x\ 100\% \quad (1)$$

Explanation:

% Efficiency = Reduction efficiency (%)

$C_0 =$ Initial concentration before filtration treatment (mg N/L)

$C =$ Final concentration after anaerobic baffle reactor (mg N/L)

Tabel 2 Ammonia Reduction Efficiency

Flow Rate	Residence Time	Decline (mg N/L)	Efficiency (%)
34 L/hour	6 hour	33	55
	12 hour	22	70
38 L/hour	6 hour	38	48
	12 hour	24	67

Based on Table 2, the ammonia concentration in slaughterhouse wastewater after filtration treatment was 74 mg/L. The test results at a flow rate of 34 L/hour with a residence time of 6 hours and 12 hours yielded ammonia concentrations of 33 mg/L and 22 mg/L, respectively, with reduction percentages of 55% and 70%. Meanwhile, at a flow rate of 38 L/hour with a residence time of 6 hours and 12 hours, the ammonia concentrations obtained were 39 mg/L and 24 mg/L, with reduction percentages of 48% and 67%, respectively. Based on the analysis results, it can be concluded that a flow rate of 34 L/hour and a residence time of 12 hours have the highest reduction concentration in reducing ammonia concentration in the anaerobic baffle reactor. Based on the treatment results, the efficiency of ammonia reduction can be seen in Figure 2.

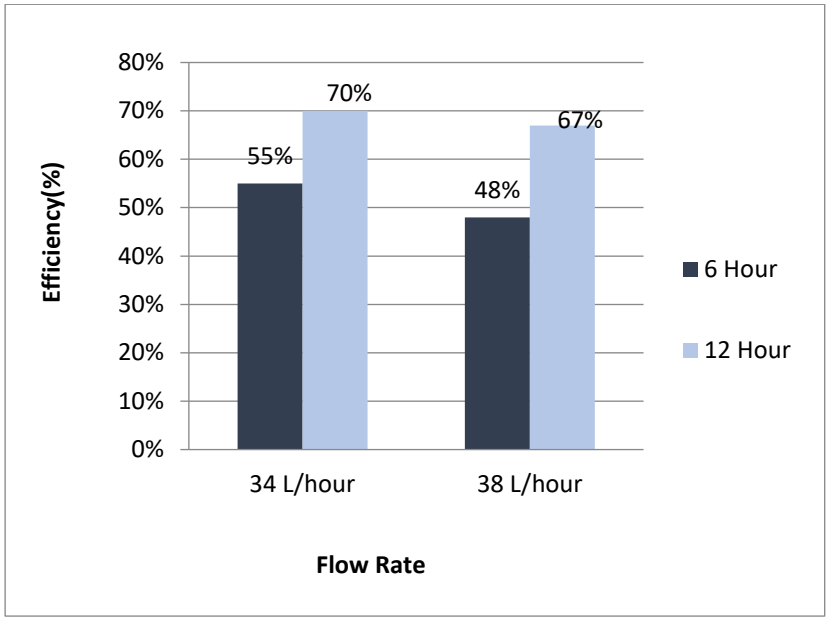


Figure 2. Ammonia Reduction Efficiency

Based on Figure 2, it can be seen that with a flow rate variation of 34 L/hour, the Anaerobic Baffled Reactor (ABR) showed a relatively high reduction in ammonia at both residence times. The efficiency of ammonia reduction in the at a residence time of 6 hours was 55%, then increased to 70% at a residence time of 12 hours. This increase in efficiency indicates that a longer hydraulic residence time provides greater opportunity for anaerobic microorganisms to degrade compounds, particularly nitrogen ammonia.

Meanwhile, at a flow rate of 38 L/hour, the ammonia reduction efficiency tends to be lower than at a flow rate of 34 L/hour, although the pattern of increasing efficiency with increasing residence time is still evident. The ammonia reduction efficiency at a residence time of 6 hours was 47%, then increased to 67% at a residence time of 12 hours. Both flow rate variations experienced an increase in ammonia reduction efficiency in line with the residence time. This was due to the metabolic process by microorganisms, which increased as the reactor residence time increased (Tama et al., 2024). Based on the research results, a smaller flow rate allows for a more stable waste flow rate, so that the contact between the substrate and biomass in the reactor compartment is more optimal and produces more effective ammonia removal performance. Increasing the flow rate reduces the contact time between the waste and microorganisms. However, increasing the residence time still plays a significant role in improving reactor performance, so it can be concluded that a smaller flow rate and longer residence time are more effective operating conditions for ammonia reduction anaerobic baffle reactor.

Discussion

Based on the research results, it shows that ammonia levels decrease with treatment using an anaerobic baffle reactor. The decrease in ammonia indicates that microorganisms in the reactor multiply well during the seeding and acclimatization processes. slaughterhouse liquid waste undergoes a pre-treatment process, namely filtration, to support the operation of the anaerobic

baffle reactor. This is done to reduce the processing load in the next stage and reduce large suspended solids. The design of a 5-compartment anaerobic baffle reactor can increase reduction efficiency. In the ABR system, it is explained that the more space or compartments in the Anaerobic Baffle Reactor (ABR) treatment unit, the greater the efficiency value (Al Kholif et al., 2020).

Based on the research conducted, the initial ammonia concentration after pre-treatment was 74 mg N/L. After anaerobic baffle reactor treatment with a flow rate of 34 L/hour and a residence time of 6 hours, the ammonia concentration showed a 55% reduction. Furthermore, with the same flow rate and a residence time of 12 hours, the ammonia concentration showed an increase in the reduction of ammonia concentration, reaching 70%. Meanwhile, at a flow rate of 38 L/hour, the efficiency of ammonia reduction showed a lower value, namely 47% at a residence time of 6 hours and 67% at a residence time of 12 hours. This difference can be concluded that the lack of contact time between waste and microorganisms, So that the degradation process does not take place optimally if the flow rate is too fast. In line with the research conducted by Qurain 2022, the results showed that the reduction of ammonia in the ABR reactor was 6.1 mg/L due to precipitation where ammonia could be absorbed in suspended/colloidal materials. Meanwhile, in a study conducted by Al Kholif, 2022, where liquid waste from a slaughterhouse was treated using an anaerobic biofilter with bioring media with a variation in residence time of 1-3 days, the ammonia concentration was reduced by up to 91.23%. This high efficiency was influenced by the length of the residence time, which allowed the formation of a stable biofilm on the media, enabling the denitrification process to proceed optimally. Compared to the anaerobic biofilter system, the 70% ammonia reduction efficiency obtained in this study through flow rate and residence time adjustments in the Anaerobic Baffled Reactor (ABR) demonstrates competitive performance, considering the differences in reactor characteristics, media, and flow mechanisms. This indicates that Anaerobic Baffled Reactor (ABR) has good potential as an alternative technology for treating slaughterhouse wastewater to remove ammonia with a simpler system. Meanwhile, research conducted by Ivontianti in 2021 shows that with a residence time of 6 hours, the ammonia concentration was successfully reduced from 88 mg/L to 20 mg/L, while with a residence time of 12 hours, there was a much higher reduction to 3 mg/L with an efficiency of 96.59%.

In addition to discharge and residence time, the decrease in ammonia concentration is also due to the denitrification process that occurs under anaerobic conditions, whereby nitrate is converted into nitrogen gas (NO3 → N2). This biofilm system facilitates the process of reducing ammonia levels (Butler et al., 2022). In addition, the reduction in ammonia is caused by microorganisms that are perfectly formed during seeding using added sugar as a carbon source and EM4 as a microorganism inoculum that supports the growth and activity of bacteria in the Anaerobic Baffled Reactor (ABR), so that the nitrogen assimilation process is more effective and the reduction in ammonia concentration can be increased. The ammonia reduction process is caused by EM4 microorganisms in the anaerobic-aerobic reactor. The addition of EM4 specifically aims to decompose organic compounds, such as carbon, hydrogen, nitrogen, and oxygen compounds. With the help of microorganisms, these organic compounds are then further decomposed into simpler organic compounds such as carbon dioxide and ammonia. This decomposition process indirectly reduces ammonia levels (Badrah et al., 2021). Regular nutrient supply is one of the factors that

greatly affects bacteria in biotreatment. The nutrients provided are glucose ($C_6H_{12}O_6$). ammonium chloride (NH_4Cl), monopotassium phosphate (KH_2PO_4), magnesium sulfate heptahydrate ($MgSO_4.7H_2O$), and calcium chloride dihydrate ($CaCl_2.2H_2O$) (Amalia and Prayitno, 2024).

The results showed that the liquid waste treatment plant's ammonia concentration after pre-treatment filtration of 74 mg/L was successfully reduced to around 22 mg/L at a flow rate of 34 L/hour flow rate and a residence time of 12 hours, so that the effluent concentration value met the slaughterhouse wastewater ammonia quality standard, which is a maximum of 25 mg/L according to Minister of Environment Regulation No. 5 of 2014. Thus, the combination of low flow rate and longer hydraulic residence time proved to be the most effective operational conditions in supporting the performance of the ABR reactor.

4. CONCLUSION

The study found that the effects of flow rate and residence time on the anaerobic baffle reactor are effective in reducing ammonia concentration in slaughterhouse wastewater. The highest efficiency was achieved at a flow rate of 34 L/hour and a residence time of 12 hours, with a reduction of 70%. By reducing the ammonia load through treatment using an Anaerobic Baffled Reactor (ABR), the risk of disruption to the aquatic ecosystem and the impact on the environmental health around the slaughterhous can be minimized. Furthermore, the achievement of this removal efficiency indicates that the application of ABR has the potential to support compliance with wastewater quality standards before discharge into the environment, thereby contributing to more sustainable liquid waste management efforts.

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