ANALYSIS OF THE EFFECT OF WASTEWATER QUALITY ON THE EFFECTIVENESS OF ECO-ENZYME

Hariestya Viareco*, Shally Yanova, Jalius, Muhammad Naswir, Nabila Sastra Dewi, Elma Mutmainnah, Besse Syaharani Ziadah, Muhammad Khatamsi, Prameswari Amalia Putri, Kintan Larasati Zahra, Dini Sri Wahyuni, Harry Fajra Meduripa, Jumary Iskandar

Environmental Engineering Department, Universitas Jambi, Indonesia

Abstract

Eco-enzyme represents a biological solution derived from the fermentation of organic materials, evaluated for its effectiveness in industrial wastewater treatment. This study examines to investigate the effectiveness of eco-enzymes in improving the quality of industrial wastewater by analyzing their impact on four specific types of liquid waste: landfill leachate, tofu wastewater, batik wastewater, and laundry wastewater. Samples were treated with eco-enzyme at specific concentrations and incubated for 5 days, followed by chemical analysis. Eco-enzyme reduced ammonia levels in landfill leachate by 57% to 8.83 mg/L, though COD and BOD values rose to 18,114.6 mg/L and 46,709 mg/L, respectively, exceeding effluent standards. In tofu wastewater, COD and BOD decreased by 72% and 75% to 4,189.68 mg/L and 2,395.3 mg/L, respectively, but remained above regulatory limits. Batik wastewater showed increases in most parameters, with COD and BOD reaching 6,838.85 mg/L and 3,193.5 mg/L. For laundry wastewater, surfactants decreased by 55% to 12.97 mg/L, but BOD and TSS increased. These findings indicate that while eco-enzyme can reduce specific pollutants like ammonia and surfactants, its application can also elevate COD and BOD levels in some cases. Additional treatment processes, such as aeration or coagulation, are required to achieve effluent standards. Despite its limitations, eco-enzyme holds potential as an environmentally friendly option for industrial wastewater management when integrated with complementary technologies.

Keywords: *eco-enzyme, wastewater quality, batik waste, laundry waste, tofu waste*

Introduction

The rapid industrial development in Indonesia inevitably leads to an increasing volume of waste. Environmental pollution issues, particularly water pollution, have become an increasingly pressing global concern. Industrial, domestic, agricultural waste, and leachate from landfills are the primary contributors to water pollution. Among industrial sectors, laundry, tofu, and batik industries significantly generate substantial amounts of waste. Waste from these industries contains various pollutants such as organic substances, detergents, dyes, and hazardous chemicals, which can degrade the quality of aquatic environments.

Environmental pollution caused by industrial wastewater, compounded by leachate produced from landfill waste decomposition, has become an environmental problem that requires serious attention. Leachate is produced when water seeps through permeable materials containing dissolved or suspended substances or both (Adriansyah *et al*., 2019). Leachate characteristics differ from other wastewater types, depending on the type of permeable material the water passes through. The higher

*)Corresponding Author:
E-mail: hariestyav2@gmail.com

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the content of organic and inorganic substances, as well as heavy metals in these materials, the more dangerous the pollution becomes, potentially contaminating groundwater and surface water if not properly treated. Factors affecting leachate composition include particle size, uniformity, waste characteristics, hydrology, climate, site age, and waste stabilization level (Sudibyo *et al*., 2018).

Various studies have shown that industrial wastewater, particularly from the textile, food, and craft sectors, significantly impacts environmental quality and human health. Laundry waste contains detergents, fragrances, and other chemicals that are difficult to degrade naturally. Tofu waste contains high levels of protein, fats, and carbohydrates, as well as coagulants used in production processes. Meanwhile, batik waste contains synthetic dyes that are difficult to degrade and potentially toxic to living organisms.

Conventional waste treatment often involves high costs and produces sludge that is challenging to manage. Therefore, alternative, more environmentally friendly, and efficient waste treatment methods are needed. One promising alternative is the use of enzymes. Enzymes are biocatalysts capable of breaking down complex organic compounds into simpler substances. Eco-enzymes have been extensively researched as a natural and versatile biocatalyst.

Household wastewater, which generates leachate, ranks as a leading source of environmental pollution. If not properly managed, this waste has the potential to exacerbate environmental damage. Utilizing organic waste, such as turning it into an eco-friendly multifunctional liquid, offers solutions to household organic waste problems and agricultural and plantation challenges (Sufra et al., 2024). The addition of eco-enzyme to batik waste can change its basic properties from alkaline to acidic. Batik wastewater contains heavy metals such as chromium (Cr) and lead (Pb), which are toxic and originate from dyeing agents like $CrCl_3$ and $K_2Cr_2O_7$ or mordants like $Cr(NO_3)_2$ and $PbCrO_4$ used as dye fixatives. However, the addition of eco-enzyme only alters the acidity of batik waste, indicating that eco-enzyme has not yet been proven effective in neutralizing batik waste (Ardianita *et al*., 2023).

Eco-enzyme is a solution resulting from the fermentation of organic materials like fruits and vegetables. It contains enzymes (proteins), organic acids, and mineral salts produced through anaerobic fermentation with the addition of sugar and water. This fermentation product has various applications. Its functions include decomposition, synthesis, transformation, and catalysis. Eco-enzyme can be used for household purposes such as floor cleaning due to its acidic properties, air purification or odor removal, and detoxifying dissolved gases. It also serves as a food preservative due to its propionic acid content, which effectively prevents microbial growth. Additionally, eco-enzyme contain acetic acid, capable of destroying organisms, making it useful as an insecticide and pesticide. The use of eco-enzyme reduces reliance on conventional chemicals often employed in wastewater treatment (Zultaqawa *et al*., 2023).

The use of eco-enzyme as a wastewater treatment agent has been widely practiced in recent years. Several studies have shown that eco-enzyme is effective in reducing organic matter levels and decreasing the number of pathogenic microorganisms. Laundry wastewater concentrations can decrease because eco-enzyme breaks down pollutants in the water. Eco-enzyme could degrade organic pollutants (Wulandari & Winarsih, 2023). Tofu wastewater contains high levels of organic matter, making biological treatment the most suitable method. However, biological treatment methods are often slow and incapable of handling large amounts of waste unless a catalyst is added. Catalysts in biological processes include enzymes. Eco-enzyme, as a catalyst, not only accelerates the degradation rate of waste but also reduces energy consumption (Widyastuti *et al*., 2023).

Eco-enzyme has shown significant potential in treating various types of wastewater. Research by Sri Widyastuti *et al*. (2023) demonstrated that adding 10% eco-enzyme significantly improved the quality parameters of tofu wastewater. Similarly, Anindita & Wikaningrum (2023) successfully removed 80–82% of the color in textile wastewater using eco-enzyme derived from oranges and dragon fruit. Furthermore, Wahyu Safira Wulandari & Winarsih (2023) determined the optimal dose of eco-enzyme for improving laundry wastewater quality to be 5%.

In wastewater management, previous studies involving the use of eco-enzyme solutions as clarifying agents have shown promising results. Mixing a 10% concentration of eco-enzyme solution with wastewater reduced COD and BOD levels (Agustina, 2021). Eco-enzyme solution also helped decrease Total Suspended Solids (TSS) in dairy wastewater (Sambaraju & Sree Lakshmi, 2020). The large-scale application of eco-enzyme solutions could help reduce pollution from domestic wastewater (Kumar *et al*., 2019). In terms of ammonia reduction, eco-enzyme solutions performed remarkably well, achieving a 97% reduction (Anindita & Wikaningrum, 2023). Eco-enzyme technology is predicted to be the best solution for future organic waste management (Enggar Maharani & Mahendra Dewi, 2022).

Based on several studies, eco-enzyme has been proven effective in improving the quality of various types of wastewater before being discharged into water bodies. Furthermore, eco-enzyme is considered a more effective treatment method compared to conventional methods. Therefore, this research aims to analyze the effectiveness of eco-enzyme in improving the quality of leachate, laundry wastewater, tofu wastewater, and batik wastewater. This study is expected to contribute to the development of more environmentally friendly and sustainable wastewater treatment technologies. Additionally, the findings are intended to serve as a reference for communities, industries, and governments in efforts to manage wastewater more effectively.

Research Methodology

The research methodology used was quantitative with an experimental approach conducted at a laboratory scale. This study aimed to evaluate the capability of eco-enzyme in improving wastewater quality. Several parameters were observed, including BOD, COD, TSS, surfactants, fats and oils, and ammonia. The research was carried out in two stages. The first stage involved sample collection and the production of eco-enzyme solutions. The second stage included mixing eco-enzyme with wastewater at specific dosages.

Sample Collection

The wastewater samples were collected from leachate sources, laundry wastewater, tofu wastewater, and batik wastewater using the Simple Random Sampling technique. The procedure referred to SNI 6989.59:2008, which is the Indonesian National Standard governing methods for collecting wastewater samples. This standard provided detailed guidelines for collecting representative samples for various environmental analyses, including physical, chemical, and biological parameters. The equipment and materials needed included buckets, measuring glasses, glass bottles with a capacity of 4.5 liters, and 5-liter jerry cans made of HDPE plastic.

The appropriate tools and containers were prepared. The sampling tool could be a clean scoop or a specialized sampling device, while the sample container was ideally made of inert materials such as glass or HDPE plastic. Representative sampling points, such as the main drainage outlet or the point before entering the water body, were determined. Samples were collected aseptically using the prepared tool, ensuring no contamination from external sources. The samples were placed into containers labeled with details such as the type of waste, time of collection, and location. Necessary information on the sample collection form, including the date, time, location, and condition of the sample at the time of collection, was filled out. The samples were immediately sent to the laboratory for further analysis, ensuring proper storage temperatures were maintained for each parameter to be tested.

Production of Eco-enzyme

The process of making eco-enzyme was carried out through several stages according to Jelita (2022). Fresh fruit peels, primarily citrus fruits such as oranges and lemons, along with peels from watermelon, papaya, starfruit, avocado, pineapple, and banana, were collected in a container and washed thoroughly. These types of fruits were chosen because their peels contain essential oils and natural acids that enhance the fermentation process and contribute to the antimicrobial properties of the resulting eco-enzyme.

The three main ingredients were combined in a specific ratio, which included brown sugar, organic waste in the form of fruit peels, and water. The ratio used was 1:3:10, consisting of one part brown sugar, three parts fruit peel waste, and ten parts water. Additionally, 20 ml of Effective Microorganisms-4 (EM4) was added to the mixture. EM4, a microbial inoculant containing beneficial bacteria such as *Lactobacillus spp.*, *Actinomycetes spp.*, and yeast, was included to accelerate the fermentation process and improve the quality of the eco-enzyme by breaking down organic matter more effectively.

The mixture was placed in a covered container, such as a bucket with a tight lid, to prevent air from entering while allowing gas to escape during the fermentation process. The container had a capacity larger than the eco-enzyme mixture to leave sufficient air space, ensuring proper gas release. It was filled to no more than three-quarters full and stored in a cool, well-ventilated location, away from direct sunlight. After three months of fermentation, the eco-enzyme was ready for use. The remaining organic waste could be reused for the next batch of eco-enzyme, added to a composter, converted into fertilizer, or used in a re-fermentation process. To evaluate the quality of the eco-enzyme produced, its chemical characteristics, including BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand), were analyzed. The results of these analyses are detailed in the result and discussion section.

The Process of Mixing Eco-enzyme with Wastewater

The process of mixing eco-enzyme with wastewater was a crucial step in evaluating the effectiveness of eco-enzyme as a wastewater treatment agent. In this method, three different types of wastewater—leachate, laundry waste, tofu waste, and batik waste—were used as testing media. Eco-enzyme, which had been fermented for 3 months, was mixed with wastewater at varying concentrations, adjusted according to the type and level of contamination of each wastewater, such as batik, laundry, tofu, or leachate wastewater. This procedure aimed to evaluate pollutant reduction by measuring various parameters, including pH, BOD, COD, and others, after the mixing and incubation process. The following is a detailed description of the steps involved in mixing eco-enzyme with wastewater: First, four types of wastewater were prepared: leachate, laundry waste, tofu waste, and batik waste, along with an eco-enzyme that had been fermented for three months. One liter of each type of wastewater was poured into separate containers, using a jerry can for tofu and batik waste, and a glass bottle for laundry wastewater. The eco-enzyme was added to the wastewater at predetermined dosage concentrations: 5% for laundry wastewater and 10% for leachate, batik waste, and tofu waste. The mixture was stirred thoroughly for two minutes, then left to sit for five days at room temperature. The mixing was done in glass beakers, as shown in the photo below, where the eco-enzyme and wastewater have been thoroughly combined. The containers were covered with lids to prevent contamination during the incubation period.

Figure 1. Eco-enzyme mixed with wastewater in a glass beaker.

After the five-day incubation period, specific parameters were analyzed to measure pollutant reduction caused by the eco-enzyme addition. The parameters included pH, BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), oil and grease, surfactants, and ammonia.

Results and Discussion

This study uses several samples, including leachate from the Talang Gulo landfill, as well as wastewater from various sources, such as laundry wastewater from a laundry service in the Simpang III Sipin area, tofu wastewater from a tofu factory in the Buluran area, and batik wastewater from the Batik Jambi Berkah production house in the Telanaipura area. Additionally, this study uses eco-enzyme as a reference control data.

To evaluate the quality of the eco-enzyme produced, its chemical characteristics, including BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand), were analyzed. The results of these analyses are detailed in the Table 1.

Table 1. Results of Chemical Analysis of Eco-Enzyme

Parameter	Units	Lab Results	Quality Standards	SNI Method
pH	mg/L	3	<4	SNI 06-6989.2-2004
BOD	mg/L	13,170.70	30	SNI 06-6989.45-2004
COD	-	22,271.90	100	SNI 06-6989.41-2004
Ammonia	mg/L	20.75	10	SNI 06-6989.48-2004
Nitrogen	mg/L	451.75	20	SNI 06-6989.49-2004
TSS	mg/L	2,345.00	50	SNI 06-6989.44-2004

Based on laboratory test results of the eco-enzyme, it was found that this solution has acidic properties with a pH value of 3, indicating a moderately acidic environment. The BOD (Biochemical Oxygen Demand) concentration of 13,170.70 mg/L indicates a high oxygen demand for the breakdown of organic matter present in the eco-enzyme (Maharani & Dewi, 2022). In addition, the COD (Chemical Oxygen Demand) value recorded at 22,271.90 mg/L shows that this solution contains many organic compounds that require oxidation, both easily and difficulty biodegradable (Shivalik & Goyal, 2022). The relatively high ammonia content, at 20.75 mg/L, and nitrogen at 451.75 mg/L, indicate the presence of nitrogen-containing compounds, which may originate from the decomposition of certain organic materials. On the other hand, the Total Suspended Solids (TSS) value of 2,345.00 mg/L indicates that the eco-enzyme contains a significant amount of solid particles. This data provides an overview that the eco-enzyme has potential for organic waste treatment, but further processing is needed to ensure that the wastewater quality meets environmental standards (Lazuardi & Suryo, 2024).

Result of Laundry Wastewater

The laboratory analysis revealed the following results (Table 2) for laundry wastewater before and after the treatment with eco-enzyme.

Table 2. Results of Laundry Wastewater Before and After Mixing with Eco-enzyme

Parameter	Units	Before	After	Removal Efficiency (%)
BOD	mg/L	18.6	84.5	-354.30
pH	-	6	4	-
TSS	mg/L	49.5	79	-59.60
Oil and Grease	mg/L	<5	31,3	-526.0
Surfactants	mg/L	29.1	12.97	55.43

Table 1 shows the laboratory analysis revealed that the addition of eco-enzyme to laundry wastewater influenced various water quality parameters. For the initial BOD concentration of 18.6 mg/L rose significantly to 84.5 mg/L after treatment with eco-enzyme, indicating a removal efficiency of -345.30%. This increase suggests that the use of eco-enzyme was ineffective in lowering BOD levels and instead contributed to a higher organic pollutant load. On the other hand, for the surfactant parameter, concentrations decreased from 29.1 mg/L to 12.97 mg/L, with removal efficiency of 55.43%. This result demonstrates that eco-enzyme effectively reduced surfactant levels in the wastewater.

Nevertheless, other parameters showed less favorable outcomes. Oil and grease levels increased from 5 mg/L to 31.3 mg/L, resulting in a removal efficiency of -526.0%, indicating that the addition of eco-enzyme contributed to a significant rise in oil and grease content. This unexpected increase may be due to the presence of oils or lipids in the eco-enzyme itself, which could have been derived from the organic materials used in its production, such as fruit peels. Additionally, the fermentation process could have led to the release of compounds that affected the oil and grease levels. The rise in oil and grease might also be influenced by the flocculation of suspended particles, which could have trapped more oils in the wastewater. Further analysis of the eco-enzyme's composition and its interaction with the wastewater would be necessary to better understand this phenomenon. Similarly, TSS increased from 49.5 mg/L to 79 mg/L, leading to a removal efficiency of -59.60%. A comparative analysis indicates that only surfactants exhibited a significant reduction, while other parameters, including BOD, oil and grease, and TSS, experienced notable increases following the addition of eco-enzyme.

These findings suggest that the eco-enzyme triggered complex biological processes that elevated the concentrations of organic pollutants and suspended solids. This underscores the ineffectiveness of eco-enzyme in reducing the pollution load of laundry wastewater under the tested conditions. Consequently, further research is required to explore the underlying mechanisms driving these outcomes and to evaluate the integration of additional treatment technologies to enhance overall wastewater treatment efficiency.

Results of Tofu Industry Wastewater

Table 3 shows the result of eco-enzyme impact on the wastewater of tofu industry.

Table 3. Results of Tofu Wastewater Before and After Mixing with Eco-enzyme

Parameter	Units	Before	After	Removal Efficiency (%)
COD	mg/L	15,103.7	4,189.68	72.26
BOD	mg/L	9,578.89	2,395.3	74.99
pH	-	5	4	-
TSS	mg/L	584.29	743.3	-27.21

Wastewater from tofu production that has not undergone mixing with eco-enzyme exhibits high levels of pollutants, with a pH of 5, COD of 15,103.7 mg/L, BOD of 9,578.89 mg/L, and TSS of 584.29 mg/L. The addition of eco-enzyme to tofu wastewater has proven effective in reducing pollutant levels significantly. COD decreased by 72.26% following the addition of eco-enzyme, resulting in a final COD value of 4,189.68 mg/L. This reduction is attributed to the biological decomposition process facilitated by eco-enzyme, which contains amylase enzymes that help break down organic matter, leading to a substantial COD reduction.

The use of eco-enzyme also successfully reduced BOD levels by 74.99%, achieving a final value of 2,395.30 mg/L. This reduction indicates that the microorganisms within the eco-enzyme effectively utilized the organic matter in the wastewater as a source of carbon and energy, thereby reducing the overall organic load and oxygen demand. The enzymatic activity of eco-enzyme, supported by biocatalytic enzymes such as lipase, amylase, and protease, plays a critical role in breaking down organic pollutants (Nevya Rizki & Sutrisno E, 2017).

On the other hand, TSS increased after the addition of eco-enzyme, with a final concentration of 743.30 mg/L, resulting in a negative removal percentage of -27.21%. The increase in TSS may be caused by the flocculation of colloidal and suspended particles in the wastewater due to the eco-enzyme. Additionally, the growth of microorganisms induced by the eco-enzyme may have contributed to the increased biomass within the sample (Amri & Widayatno, 2023).

Results of Batik Industry Wastewater

Table 4 shows the result of eco-enzyme impact on the wastewater of batik industry wastewater.

Table 4. Results of Batik Wastewater Before and After Mixing with Eco-enzyme

Parameter	Units	Before	After	Removal Efficiency (%)
COD	mg/L	1,240.8	6,838.85	-451.16
BOD	mg/L	176.4	3,193.5	-1,710.37
pH	-	7	5	-
TSS	mg/L	314	622	-98.09
Ammonia	mg/L	0.428	1.95	-355.61
Nitrogen	mg/L	4.69	161.3	-3,339.23

Batik industry wastewater showed adverse effects following treatment with eco-enzyme. COD and BOD levels increased significantly, by -451.16% and -1,710.37%, respectively, indicating an inefficacy in organic pollutant reduction under the tested conditions. Similarly, TSS increased by -98.09%, reflecting a surge in suspended particles likely caused by ineffective pollutant breakdown (Lolo & Pambudi, 2020). Ammonia and nitrogen concentrations also increased substantially, with removal efficiencies of -355.61% and -3,339.23%, respectively. The findings highlight the need for more advanced treatment technologies for effective pollutant removal in batik wastewater.

Based on laboratory test results, the BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand) values of wastewater from Batik Berkah Jambi exceed the standards set for textile industry wastewater, as outlined in the Indonesian Ministry of Environment Regulation No. 5 of 2014 on Wastewater Quality Standards. This regulation specifies a maximum BOD value of 60 mg/L and a COD value of 150 mg/L. According to literature (Lolo & Pambudi, 2020), BOD represents the amount of dissolved oxygen required by microorganisms to decompose or oxidize pollutants in a water body. Generally, BOD values are lower than COD values because the quantity of chemicals that can be oxidized chemically exceeds those that can be oxidized biologically. High BOD and COD levels indicate significant pollution in the water body. COD measures the amount of oxygen required by oxidizing agents, such as potassium dichromate, to oxidize organic materials in the water.

Meanwhile, TSS (Total Suspended Solids) indicates the concentration of suspended solids in wastewater. Laboratory results show that the TSS value in the batik industry wastewater is 1.95 mg/L, which remains within the quality standards for the textile industry, as it does not exceed the threshold set by the Ministry of Environment Regulation No. 5 of 2014 on Wastewater Quality Standards.

During the batik-making process, ammonia is generated from the use of nitrite as a salt in auxiliary chemicals during synthetic dyeing. The ammonia concentration in the wastewater from Batik Berkah Jambi reaches 161.30 mg/L, which exceeds environmental quality standards. If discharged into the environment, this could lead to water pollution. This concern is addressed in Regional Regulation of Jambi Province No. 6 of 2017 on Environmental Protection and Management, Article 1, point 22, which defines water pollution as the introduction of living organisms, substances, energy, and other components into water due to human activities. Such pollution results in the degradation of water quality, rendering it unable to function as intended.

Therefore, an effective wastewater treatment system and technology are required to reduce pollutants to levels that comply with the established environmental quality standards (Indrayani, 2019).

Results of Landfill Leachate

Table 5 shows the result of eco-enzyme impact on the landfill leachate.

Table 5. Results of Leachate Before and After Mixing with Eco-enzyme

Parameter	Units	Before	After	Removal Efficiency (%)
COD	mg/L	6,641.86	18,114.6	-172.73
BOD	mg/L	1,622	46,709	-2,779.72
pH	-	7	5	-
TSS	mg/L	1,060	5,830	-450
Ammonia	mg/L	20.75	8.83	57.45
Nitrogen	mg/L	451.75	-	-
E-Coli	CFU/100/ jml/100mL	>10000	>10000	-

Landfill leachate exhibited even more pronounced increases in pollutant levels following Eco-enzyme treatment. The COD value rose from 6,641.86 mg/L to 18,114.6 mg/L (Removal Efficiency: -172.73%), while the BOD value escalated from 1,622 mg/L to 46,709 mg/L (Removal Efficiency: -2,779.72%). The TSS value also increased significantly, from 1,060 mg/L to 5,830 mg/L (Removal Efficiency: -450%), indicating an elevated suspended solids concentration due to organic matter release during treatment.

In contrast, ammonia levels decreased from 20.75 mg/L to 8.83 mg/L (Removal Efficiency: 57.45%), suggesting that Eco-enzyme facilitated partial biological oxidation of ammonia. Despite this reduction, nitrogen levels remained high at 451.75 mg/L (data for post-treatment nitrogen unavailable), requiring further investigation and additional treatment steps.

Regarding biological parameters, E. coli levels consistently exceeded 10,000 CFU/100 mL before and after treatment, indicating that Eco-enzyme lack sufficient disinfectant properties to mitigate pathogenic microorganisms.

Aerosol spraying of leachate using Eco-enzyme solution facilitated the acceleration of organic matter decomposition, leading to an increase in both BOD and COD values as more organic matter was released into the water. Furthermore, Eco-enzyme partially reduced ammonia levels through biological oxidation, although the results were not optimal, as a significant concentration of nitrogen remained (Rochyani et al., 2020). Additionally, Eco-enzyme slightly raised the pH, indicating its limited ability to neutralize the acidity of the leachate. Microbiologically, the E. coli count remained high, suggesting that Eco-enzyme lacks sufficient disinfectant properties to reduce pathogenic microorganisms (Zamri et al., 2017). Since eco-enzyme has a high concentration of COD, the effect of its addition on the wastewater treatment showed increment of COD concentration, especially when COD concentration is lower than that in the eco-enzyme (Yustiani *et al*., 2023).

Environmental Implications of Eco-Enzyme Usage

During the production of eco-enzyme, ozone (O_3) gas may be generated as a byproduct of specific oxidative reactions occurring within the fermentation process. Ozone is a highly reactive molecule that can oxidize various organic and inorganic pollutants, potentially reducing the release of harmful gases like methane and nitrous oxide into the atmosphere. These gases are potent greenhouse gases, and their reduction can contribute to mitigating global warming (Sayali *et al*., 2019). However, additional experimental verification is required to confirm the production of ozone during eco-enzyme preparation and its environmental impacts under real-world conditions.

Moreover, the enzymatic activities of eco-enzyme, supported by biocatalytic enzymes such as lipase, amylase, and protease, play a critical role in breaking down organic pollutants. This highlights its potential use as an environmentally friendly alternative for wastewater treatment. Nevertheless, its limitations in certain types of wastewater, such as batik and landfill leachate, underscore the need for integrating additional treatment technologies to enhance its efficiency.

In conclusion, while Eco-enzyme influenced certain chemical parameters across the four types of wastewater samples (laundry, tofu, batik, and landfill leachate), its application should be complemented with additional treatment technologies, such as aeration, coagulation, or disinfection, to improve wastewater quality. The results demonstrate that Eco-enzyme have a mixed impact on wastewater treatment. On the one hand, it can accelerate the decomposition of organic matter and slightly reduce nitrogen compounds like ammonia, as observed in tofu and landfill leachate samples. On the other hand, its application can also elevate total organic pollutants, as evidenced by the high BOD and COD values in batik and leachate wastewater. Therefore, the use of Eco-enzyme in all wastewater types necessitates additional processing to maximize its benefits, particularly in reducing pollutant concentrations and addressing microbiological contamination.

Conclusions

This study demonstrates that the effectiveness of eco-enzyme in treating wastewater varies significantly depending on the type of wastewater being treated. For tofu wastewater, eco-enzyme has proven effective in reducing organic loads, as indicated by reductions in COD and BOD parameters. Additionally, eco-enzyme effectively decreased surfactant concentrations in laundry wastewater.

However, it should be boldly stated that eco-enzyme worsens the quality of some types of wastewater. For batik wastewater, eco-enzyme did not yield optimal results; instead, increases in several parameters, including COD, BOD, surfactants, ammonia, and nitrogen, were observed, indicating an increase in organic load and the potential hazards of the wastewater. Furthermore, the use of eco-enzyme led to an increase in total suspended solids (TSS) across all types of wastewaters and a reduction in pH values, making the wastewater more acidic.

In the case of leachate, the application of eco-enzyme caused a significant increase in COD, which indicates a rise in the organic load of the leachate. These findings suggest that the effectiveness of eco-enzyme is highly dependent on the specific characteristics of each type of wastewater. A more tailored and specific treatment approach is necessary to optimize the use of eco-enzyme for different types of wastewaters, particularly for those containing heavy metals or high levels of oil and grease.

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