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Aerobic Degradation of Linear Alkylbenzene Sulfonate in Activated Sludge with the Addition of Glucose, KNO_3, and KH_2PO_4

Zainal Syam Arifin, Nur Sila Alisi, and Ahmad Zaeni ✉

Chemistry Department, Faculty of Mathematics and Natural Sciences, Universitas Halu Oleo, Kampus Bumi Tridharma Anduonohu, Jl. H. E. A. Mokodompit, Kendari, 93232, Indonesia

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Abstract

As urban populations grow, the demand for laundry services increases, leading to more detergent waste containing linear alkyl benzene sulfonate (LAS) discharged into the environment. This study investigates the ex-situ degradation of laundry waste in an aerobically activated sludge tank by adding 6 g glucose, 1 g KNO_3, and 0.5 g KH_2PO_4 as nutrient sources. Wastewater samples from two laundry sites were treated with indigenous bacteria from contaminated sludge. The study aimed to assess LAS degradation and reductions in biochemical oxygen demand (BOD) and chemical oxygen demand (COD). LAS levels were monitored over ten days, showing 89.1% and 85.3% degradation efficiencies for the two samples, respectively. BOD decreased from 136.05 to 14.64 mg/L and 140.74 to 13.85 mg/L, while COD dropped from 340.56 to 47.52 mg/L and from 337.91 to 47.49 mg/L. Despite significant BOD reduction, COD levels remained high, indicating the presence of non-biodegradable compounds. The food to microorganisms (F/M) ratio increased over ten days, confirming that activated sludge, with nutrient addition, effectively degrades LAS by over 85%. These results highlight the potential for nutrient-augmented activated sludge systems to manage LAS contamination in laundry wastewater. However, further research is needed to address the persistence of non-biodegradable compounds.

✉ Correspondence address:
Jurusan Kimia, FMIPA, Universitas Halu Oleo
E-mail: mailto:ahmad.zaeni@gmail.com

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Introduction

The use of detergents has been increasing over time, in line with annual population growth. As income levels rise, detergent consumption also increases(Seyedsalehi *et al.*, 2019). When wastewater containing detergents is discharged directly into the environment without prior treatment, it can lead to pollution in aquatic ecosystems and degrade the quality of water resources, ultimately impacting public health (Jardak, Drogui and Daghrir, 2016; Wimbaningrum, Arianti and Sulistiyowati, 2020; Badmus *et al.*, 2021; Arora *et al.*, 2023). The chemicals in detergent wastewater primarily originate from the detergent itself. Common active ingredients in detergents include ammonium chloride, linear alkylbenzene sulfonate (LAS)(Painter, 1992), sodium dodecyl benzene sulfonate, sodium carbonate, sodium sulfate, and alkyl benzene sulfonate. These substances are not environmentally friendly (Widya Astuti and Suriani Sinaga, 2015; Ardiyanto and Yuantari, 2016; Arora *et al.*, 2023). Linear alkylbenzene sulfonate is widely used as an active ingredient in detergent formulations (Hendra *et al.*, 2016). LAS functions to remove or precipitate impurities and acts as an emulsifier. Residual LAS concentrations exceeding 0.5 mg/L in river ecosystems can cause acute and chronic toxicity to aquatic organisms. At a concentration of 25 mg/L LAS, fish exhibit increased activity, inactivation, and immobilization, and if not removed from the system, it can lead to death (Budiawan, Fatisa and Khairani, 2010).

Several bacterial genera, such as *Pseudomonas*, *Acinetobacter*, and *Bacillus*, have been reported to effectively degrade linear alkylbenzene sulfonate (LAS) in wastewater systems(Asok and Jisha, 2012; Suresh and Abraham, 2019; Li and Chen, 2022). The effectiveness of microbial degradation processes is influenced by nutrient availability and environmental conditions, such as pH and dissolved oxygen levels in the wastewater. The success of the treatment process relies heavily on the biological activity of the microorganisms present, making it crucial to design processes that support sustained microbial growth (Rahmayetty, Reza and Fathurrahman, 2011). Activated sludge is applicable for treating wastewater from various industries, including the food industry, hotels, residential areas, and schools (Setianingsih, Hermawan and Nilawati, 2015; Pandey *et al.*, 2020; Zhang *et al.*, 2023).

Lusiana's research (2011) demonstrated that detergent wastewater treatment using an up-flow anaerobic filter system acclimatized with activated sludge for 14 days reduced detergent levels from 21.03 mg/L to 3.83 mg/L, achieving a treatment efficiency of 81.83%. Additionally, research by Kruszelnicka *et al.* (2019) demonstrated that domestic wastewater treatment plants utilizing wetland and sequencing batch reactor systems achieved COD removal efficiencies of up to 95% and 89.5%, BOD_5 removal efficiencies of 97.1% and 93.6%, and anionic surfactant removal efficiencies of 98.3% and 88.2%, respectively. This study aims to enhance the reduction efficiency of detergent waste levels through the degradation of LAS using activated sludge.

Method

General. The sample used in this study was laundry waste originating from 2 laundry business points in Poasia District and Kambu District, Kendari, Southeast Sulawesi, Indonesia. The materials used are sewage sludge contaminated with laundry waste as a source of indigenous microbes, glucose ($C_6H_{12}O_6$), potassium nitrate (KNO_3), potassium dihydro phosphate (KH_2PO_4), linear alkyl benzene sulfonate (LAS) surfactant solution, methylene blue, chloroform ($CHCl_3$), potassium dichromate ($K_2Cr_20_7$) 0.25, ferrous ammonium sulfate (FAS) 0.25 N, indicator ferroin, sodium thiosulfate ($Na_2S_2O_3$). The tools used consisted of a series of reflux devices, UV-Vis spectrophotometer, pH meter, hot plate, activated sludge tank plus lamella clarifier, separating funnel, aerator, analytical scales, dropper of various sizes, measuring flask, Erlenmeyer, beaker, measuring cup, stir bar, and spatula.

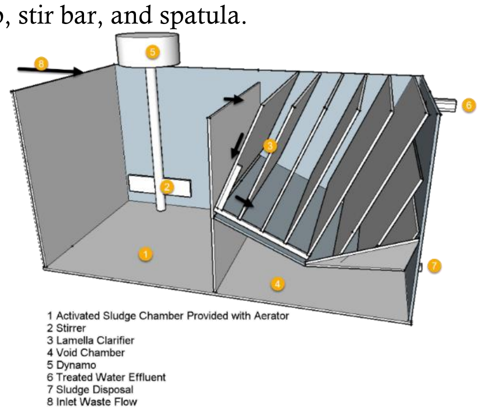


Figure 1. Design Schematic of Activated Sludge Tank Reactor on Laboratory Scale. The Activated Sludge Tank is integrated with the Lamella Clarifier Tank. Lamella's modular plates are arranged opposite to the flow of water to reduce the terminal velocity of the water

Laundry Waste Characterization. Waste characterization includes analysis of total detergent (as LAS concentrate), BOD (biological oxygen demand), COD (chemical oxygen demand), mixed liquor suspend solid (MLSS), food to microorganism's ratio (F/M), and pH.

Waste treatment. The laboratory-scale waste treatment uses an activated sludge tank made of aquarium glass with dimensions of 50 cm x 50 cm x 50 cm, equipped with an aerator, and connected to a lamella clarifier tank or sedimentation tank for sludge deposition. Waste treatment occurs at room temperature (30°C). The schematic design of the laboratory-scale activated sludge tank integrated with a lamella clarifier is shown in Figure 1. After going through the activation process for one day by entering the mud containing indigenous microbes and substrates, the activated sludge tank was added with laundry wastewater until the volume (V) became 40 L. The initial surfactant levels, BOD, COD, and pH were analyzed. Samples were observed every 24 hours for ten days to analyze linear alkyl benzene sulfonate (LAS) levels. The activated sludge system was continually operated with a flow rate (Q) was 1.27 mL/s.

A prediction of the biological degradation mechanism of LAS has been proposed by Mungray & Kumar (2009) in Figure 2.

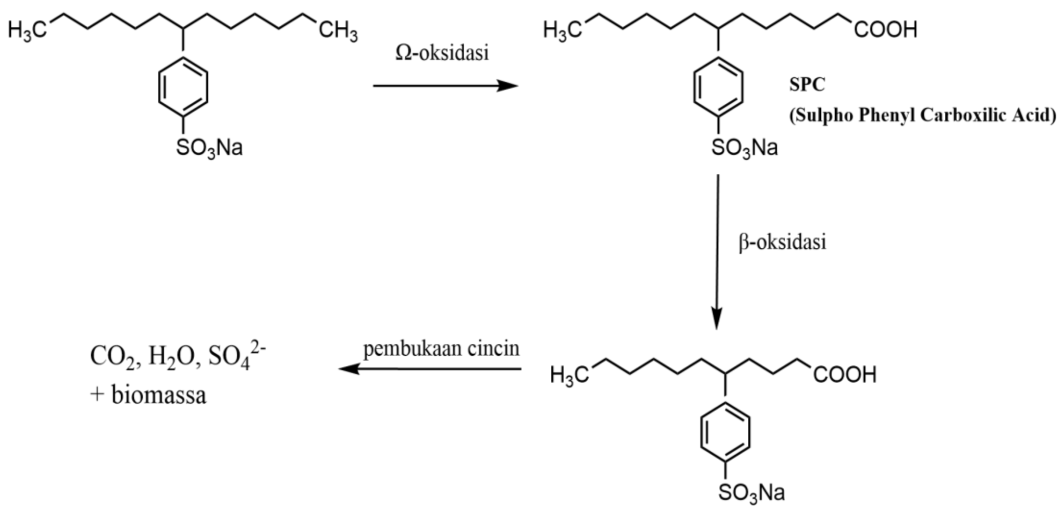


Figure 2. LAS Aerobic Biodegradation Mechanism (Mungray and Kumar, 2009)

Results and Discussion

Preparation of Linear Alkylbenzene Sulfonate (LAS) Calibration Curve.

The calibration curve is made as the basis for measuring the concentration of detergent in laundry waste. This curve is a graph that states the relationship between the concentration of the standard solution versus the absorbance reading of the solution at a maximum wavelength of 651 nm. Then a linear region is determined to provide the measurement limit (Utomo *et al.*, 2018). The standard solution is made from linear alkyl benzene sulfonate (LAS) parent solution. This compound is an anionic surfactant-type compound. The concentration used is a minimum of 5 concentration points. Table 1 shows the absorbance value of the standard solution at a wavelength of 651 nm.

Table 1. LAS Concentrations and Corresponding Absorbance Values at a Wavelength of 651 nm for the LAS Standard Curve

No	LAS Concentration (mg/L)	Absorbance	Wave length (nm)
1.	0	0,001	651
2.	2	0,306	651
3.	3	0,541	651
4.	4	0,735	651
5.	5	0,881	651
6.	6	1,02	651

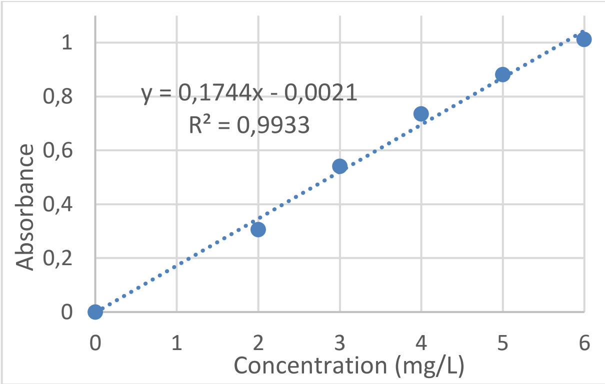


Figure 3. Standard Curve of LAS: Absorbance at 651 nm as a Function of LAS Concentration

Determination of LAS Levels in Laundry Waste.

The initial measurement of LAS concentration in the laundry wastewater samples showed significantly high levels, indicating substantial environmental contamination. The absorbance values recorded were 2.915 for Site 1 and 3.402 for Site 2, corresponding to LAS concentrations of 16.764 mg/L and 19.563 mg/L, respectively. These values exceed the recommended environmental threshold of 0.2 mg/L, as regulated by Indonesian wastewater discharge standards (PP No. 22/2021, Annex VI).

The measurement of LAS levels was conducted using the Methylene Blue Active Substances (MBAS) method, where anionic surfactants form a blue complex with methylene blue, which is then extracted into the chloroform phase (Razmi, 2022). The UV-Vis spectrophotometer readings at 651 nm (as shown in Figure 3) provided a reliable quantification of LAS concentrations. The linear calibration curve obtained (R^2 = 0.993) confirms the accuracy of the spectrophotometric method used, ensuring high precision in LAS detection.

These high LAS concentrations suggest that laundry wastewater poses a significant environmental risk if discharged untreated. LAS, a persistent surfactant, is known to cause acute and chronic toxicity in aquatic organisms, even at concentrations as low as 0.5 mg/L. At 25 mg/L, LAS can lead to fish immobilization and mortality (Budiawan et al., 2010). Given that the measured values are over 80 times the permissible limit, this highlights the urgency of effective treatment solutions before wastewater discharge.

Moreover, the variations in LAS levels between Site 1 and Site 2 suggest differences in detergent formulations, washing practices, or water usage efficiency at these locations. Such variability underscores the need for standardized pretreatment approaches before wastewater enters biological treatment systems.

Thus, the extremely high LAS levels observed in these samples emphasize the necessity of employing highly efficient biodegradation methods, such as the aerobic activated sludge system used in this study. The subsequent sections will discuss the degradation performance and its implications for wastewater management.

Characteristics of Laundry Waste.

The initial characterization of laundry wastewater from two different laundry facilities (Site 1 and Site 2) revealed elevated levels of LAS, BOD, and COD, exceeding Indonesian wastewater discharge standards (PP No. 22/2021, Annex VI). As shown in Table 2, LAS concentrations in the two samples were 16.764 mg/L and 19.563 mg/L, significantly surpassing the regulatory limit of 0.2 mg/L.

Similarly, BOD and COD values were alarmingly high, with initial BOD levels of 136.05 mg/L (Site 1) and 140.74 mg/L (Site 2), far exceeding the standard of 3 mg/L. COD levels were also excessive, reaching 340.56 mg/L and 337.91 mg/L, compared to the regulatory threshold of 25 mg/L. These findings indicate that the wastewater contains a high concentration of organic pollutants, posing a serious environmental risk if discharged untreated.

a. Implications of Wastewater Characteristics

(1) High BOD/COD Ratios Indicate Biodegradability Potential. The BOD/COD ratios in both samples were approximately 0.4, which suggests that a significant portion of the organic matter in the wastewater is biodegradable. This confirms that biological treatment methods, such as activated sludge, are viable options for wastewater remediation. However, the presence of non-biodegradable fractions, as indicated by residual COD after treatment, implies that additional treatment steps (e.g., advanced oxidation or adsorption) may be necessary to achieve full compliance with discharge regulations.

(2) Variation in Wastewater Composition Between Sites. Differences in the initial BOD and COD levels between the two sites suggest variations in detergent formulations, washing machine efficiency, or operational practices. Site 2, with higher LAS and BOD concentrations, may use detergents with more persistent surfactants or higher detergent dosages. This highlights the need for site-specific treatment strategies and potentially the implementation of detergent usage guidelines to minimize pollutant loads before wastewater reaches treatment facilities.
(3) pH Levels Within Acceptable Ranges but May Affect Microbial Activity. The pH values in both samples were 7.9 (Site 1) and 8.1 (Site 2), which are within the regulatory range (6–9). However, even slight alkalinity fluctuations can influence microbial activity in biological treatment systems. Studies indicate that microbial degradation of LAS is optimal under neutral to slightly alkaline conditions (pH 7–8), meaning that pH adjustments may be required in cases where detergent composition leads to higher alkalinity.
(4) High Initial Organic Load Reinforces the Need for Pre-Treatment. Given the extreme BOD and COD concentrations, direct discharge of laundry wastewater into natural water bodies could lead to oxygen depletion, eutrophication, and toxicity to aquatic life. These high organic loads reinforce the necessity of effective pre-treatment before biological processing, such as sedimentation or filtration, to remove suspended solids and excess surfactants that might otherwise inhibit microbial activity in the sludge system.

b. Conclusion on Wastewater Characteristics

The results confirm that laundry wastewater is heavily contaminated with surfactants and organic pollutants, necessitating robust treatment solutions before discharge. While biological treatment via aerobic activated sludge is effective, supplementary treatment measures may be required to address non-biodegradable fractions and meet environmental standards. Understanding the variability in wastewater composition across different sites can help tailor more effective, site-specific wastewater management strategies.

Table 2. Characterization of Laundry Waste 1 & 2 (L_1 & L_2) at Initial Conditions (Before Degradation)

Parameter	Unit	Average Test Results at Q = 1.27 mL/s		MCL*
		Waste 1 (L_1)	Waste 2 (L_2)	
LAS	mg/L	16.764	19.563	0.2
BOD	mg/L	136.05	140.74	3
COD	mg/L	340.56	337.91	25
F/M	$\frac{mg_{BOD5}}{(mg_{MLSS} \cdot day)}$	0.078	0.062	N/A
pH	-	7.9	8.1	6-9

*) MCL: Maximum Contaminant Level based on the Indonesian Government Regulation No. 22 of 2021, Annex VI

Based on Table 2, it is evident that the concentrations of LAS, BOD, and COD in the laundry wastewater sampled from two laundry businesses negatively impact the environment and violate the provisions of (Ministry of Environment and Forestry Regulation No. 5 of 2021), which mandates that wastewater discharge into surface water bodies must meet Class 2 water quality standards. The initial characterization results indicate that the detergent, BOD, and COD concentrations in the wastewater are significantly elevated and exceed the permissible limits set by Government Regulation of the Republic of Indonesia Number 22 of 2021, Annex VI (*Peraturan Pemerintah RI No. 22 Tahun 2021 Lampiran VI*). The high levels of those parameters are attributable to the direct discharge of untreated laundry wastewater into water bodies (Lusiana, 2011).

From the analysis results in Table 1 of the laundry waste sample, it appears that the BOD value of laundry waste in sample 2 is higher than the sample in laundry waste 1. Laundry waste 2 shows a BOD with a value of 140.74 mg/L, which has decreased in concentration to 13.85 mg/L while laundry waste 1 BOD value of 136.05 decreased in concentration to 14.64 mg/L. The results for the BOD test parameters obtained were below the quality standard that had been set, 75 mg/L. The percentage reduction in BOD levels was 89.23% and 90.15%, respectively. The decrease in BOD value in the presence of activated sludge treatment is caused by the biological activity of microorganisms in degrading organic compounds contained in laundry waste samples to meet their daily needs (Yuliana, Langsa and Sirampun, 2020). Based on the measurement results of laundry waste samples, it can be seen in Table 1 that each sample of waste has a high COD value of 340.56 mg/L and 337.91 mg/L and decreased in concentration to 47.52 mg/L and 47, 49 mg/L.

Meanwhile, for COD levels, there is a difference in the average COD levels between the samples before and after treatment, where the percentage of COD value reduction is 86.04% and 85.94%, respectively. The decrease in the value of COD in laundry waste treatment using activated sludge is due to the activity of microorganisms that can remodel and optimally oxidize existing organic and inorganic materials, resulting in a decrease in the value of COD (Suastuti, I and Nanik, 2015). This indication means that the higher the COD value, the more oxygen levels are needed to oxidize organic substances contained in the laundry waste sample, which indicates the higher organic pollutant content in the waste sample (Pungus, Palilingan and Tumimomor, 2019).

The results of pH measurements for each sample of laundry waste showed numbers before treatment, namely 7.9 and 8.1 after degradation, 7.1 and 7.2, where the quality standard set for the pH parameter in wastewater was 6-9. This value indicates that the wastewater for each sampling site has a pH within normal limits, which means it still meets water requirements. Ardianto's (2015) research on pH levels in laundry wastewater also shows a pH level of 7.0. This research shows that the pH level of laundry waste is relatively the same within normal limits, so it is still safe. Water conditions that are very acidic or very alkaline can endanger the survival of organisms because they cause metabolic and respiratory disorders. The high or low pH value of water depends on several factors, namely, the condition of gases in the water such as CO_2, the concentration of carbonate and bicarbonate salts, the decomposition process of organic matter at the bottom of the waters (Purnama Sari *et al.*, 2021).

Based on the measurement of the LAS standard solution, the calibration curve is obtained in Figure 3. The results show that the higher the solution concentration, the higher the absorbance, so a straight-line value is obtained. The absorbance value obtained is then plotted against the concentration of the standard solution so that the correlation coefficient value (R^2) is obtained. Furthermore, the calibration curve plot that has been carried out shows the equation $y = 0.174x - 0.002$ with a correlation coefficient (R^2) of 0.993. These results indicate that the absorbance value has a good correlation with the concentration of the solution because the R^2 value is close to 1 or > 0.995, and it can be stated that the results have good accuracy so that a straight line is obtained to determine the levels of anionic surfactants (Razmi et al., 2022).

Laundry Waste Degradation Results.

The degradation of laundry wastewater using an aerobic activated sludge system was monitored over a period of ten days. The initial LAS concentrations in the wastewater were 16.764 mg/L for Site 1 and 19.563 mg/L for Site 2.

The reduction profiles and degradation efficiencies of LAS over ten days are illustrated in Figures 4(a) and 4(b) for Waste 1, and in Figures 5(a) and 5(b) for Waste 2. This rapid decrease suggests that indigenous microorganisms were actively utilizing LAS as a carbon source during the early phase of degradation. Between days six and ten, the rate of LAS degradation slowed, indicating a transition to a deceleration phase, likely due to substrate depletion and the exhaustion of easily degradable organic matter.

After ten days, the final LAS concentrations decreased to 1.827 mg/L for Site 1 and 2.977 mg/L for Site 2, achieving degradation efficiencies of 89.1% and 85.31%, respectively. These results demonstrate the effectiveness of the activated sludge system, although the residual LAS concentrations remained slightly above the regulatory discharge limit of 0.2 mg/L set by Indonesian standards (PP No. 22/2021).

In addition to LAS reduction, significant decreases in BOD and COD levels were recorded. As summarized in Table 3, the BOD levels dropped from 136.05 mg/L to 14.64 mg/L for Site 1 and from 140.74 mg/L to 13.85 mg/L for Site 2, corresponding to reduction efficiencies of 89.23% and 90.15%, respectively. COD values decreased from 340.56 mg/L to 47.52 mg/L (Site 1) and from 337.91 mg/L to 47.49 mg/L (Site 2), achieving COD reduction efficiencies of 86.04% and 85.94%.

Despite the high removal efficiencies, the final COD values remained above the permissible limit of 25 mg/L, suggesting the presence of non-biodegradable organic matter that was resistant to biological treatment.

The trends shown in Figures 4 and 5 clearly illustrate that while aerobic activated sludge with nutrient addition is highly effective in degrading LAS and reducing organic loads, supplementary treatment processes may still be necessary to achieve full regulatory compliance.

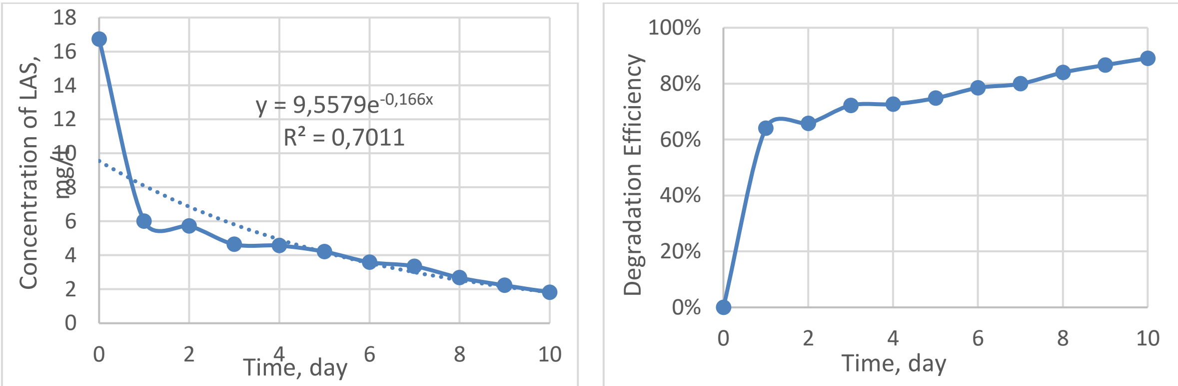
These observations provide a solid foundation for the subsequent discussion on the degradation mechanisms, efficiency analysis, and the development of optimized treatment strategies for laundry wastewater management.

These results are comparable to the LAS removal efficiencies reported in previous studies, such as Maharani and Wesen (2018), who achieved a 97.18% reduction using a continuous system with *Pseudomonas* species, and Sudarminto and Suryandari (2021), who achieved a 72.9% reduction using a photocatalytic process.

Table 3. Characterization of Laundry Waste 1 & 2 (L_1 & L_2) at Initial Conditions and after 10^{th} days degradation

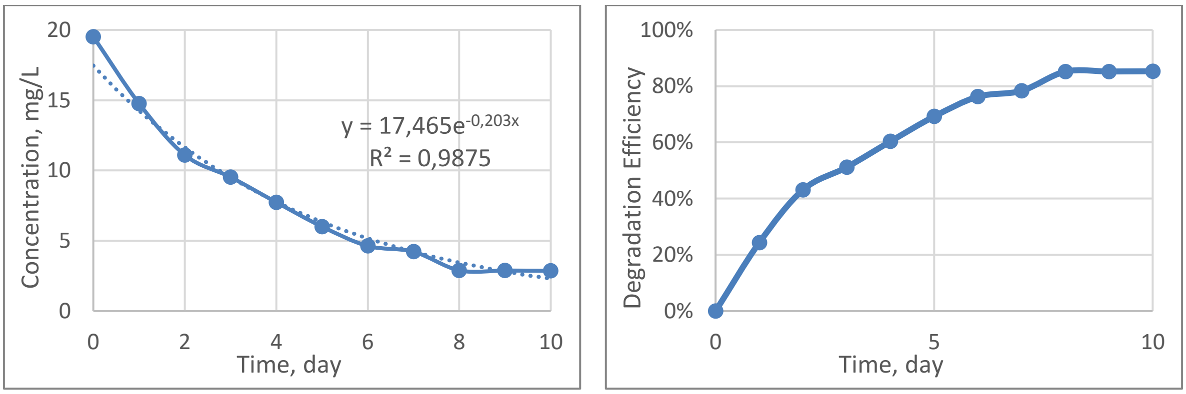
Parameter	Unit	Average Test Results at Q = 1.27 mL/s				MCL
		Waste 1 (L_1)		Waste 2 (L_2)		
		Initial	After 10 days	Initial	After 10 days	
LAS	mg/L	16.764	1.827	19.563	2.977	0,2
BOD	mg/L	136.05	14.64	140.74	13.85	3
COD	mg/L	340.56	47.52	337.91	47.49	25
F/M	$\frac{mg_{BOD5}}{mg_{MLSS}}/day$	0.078	0.197	0.062	0.190	-
Efficiency	%	-	89.10	-	85.31	-
pH	-	7.9	7.1	8.1	7.2	6-9

The decrease in LAS concentration can indicate that the LAS has been broken down into simpler compounds through metabolism by bacteria. The mechanism of LAS biodegradation is the breakdown of LAS starting from the microbial-induced transformation of sulphophenyl carboxylate (SPC) as a result of initial biodegradation. This phase shows the loss of basic molecular properties, interfacial activity, and toxicity to aquatic organisms. Further biodegradation is characterized by breaking the aromatic ring of LAS and SPC into the water; this step is called complete biodegradation. The LAS biodegradation event occurs due to oxidation at the end of the alkyl chain, which produces carboxyl-sulfophenyl acid, followed by a beta-oxidation event which causes the breakdown of the benzene and sulfonate rings to produce CO_2, H_2O, and SO_4, and bacterial biomass (Mungray and Kumar, 2009). The mechanism of LAS biodegradation can be seen in Figure 2.



(a) (b)

Figure 4. LAS Reduction Curve in Waste 1 (a) and degradation efficiency (b) measured for ten days at the same time



(a) (b)

Figure 5. LAS Reduction Curve in Waste 2 (a) and degradation efficiency (b) measured for ten days at the same time

LAS Degradation Efficiency and the Significance of BOD/COD Reduction.

The effectiveness of aerobic activated sludge treatment in degrading linear alkylbenzene sulfonate (LAS) was evaluated based on the percentage reduction of LAS, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) over ten days of treatment. As shown in Table 3, the LAS concentration in Laundry Waste 1 decreased from 16.764 mg/L to 1.827 mg/L, achieving an 89.1% reduction efficiency. Similarly, in Laundry Waste 2, LAS levels dropped from 19.563 mg/L to 2.977 mg/L, corresponding to an 85.31% reduction.

The reduction of BOD and COD followed a similar trend. As depicted in Table 3, BOD levels decreased from 136.05 mg/L to 14.64 mg/L (Laundry Waste 1) and from 140.74 mg/L to 13.85 mg/L (Laundry Waste 2), achieving reductions of 89.23% and 90.15%, respectively. COD levels decreased from 340.56 mg/L to 47.52 mg/L and from 337.91 mg/L to 47.49 mg/L, with reduction efficiencies of 86.04% and 85.94%, respectively.

The observed high efficiency in BOD reduction suggests that microbial degradation successfully removed most biodegradable organic matter. However, the COD levels remained above the regulatory limit (25 mg/L), indicating the presence of non-biodegradable organic compounds that were not fully degraded by the activated sludge system. This suggests that additional treatment steps, such as advanced oxidation or adsorption processes, may be necessary to meet environmental discharge standards.

The detailed trends of LAS concentration decline and degradation efficiency during the treatment period are clearly presented in Figures 4 and 5, which show a rapid decline in LAS concentration during the first five days, followed by a slower degradation rate. This suggests that the availability of biodegradable carbon sources influences microbial activity and that nutrient optimization may further enhance LAS degradation efficiency.

Microbial Mechanism of LAS Degradation.

The biodegradation pathway of LAS involves initial oxidation of the alkyl chain, leading to the formation of sulfoaryl carboxylates (SPCs) as intermediates, which are subsequently broken down into CO_2, H_2O, and SO_4^{2-}. This mechanism, illustrated in Figure 2, is consistent with previous studies by Mungray & Kumar (2009), confirming that aerobic microorganisms play a critical role in the stepwise mineralization of LAS.

Furthermore, the food-to-microorganism (F/M) ratio, as presented in Table 3, increased from 0.078 to 0.197 (Laundry Waste 1) and from 0.062 to 0.190 (Laundry Waste 2) over the ten-day period. This indicates continuous microbial activity, but the decreasing degradation rate after day five suggests that microbial growth might be limited by substrate availability.

Implications and Recommendations for Laundry Wastewater Treatment.

These findings have important implications for the treatment of laundry wastewater, particularly in urban areas where LAS is a major pollutant. Based on the data presented in Table 3, it is evident that aerobic activated sludge with nutrient supplementation can effectively degrade LAS. However, to ensure compliance with Indonesian wastewater discharge regulations (Government Regulation No. 22/2021), further improvements are recommended:

(a). **Extending Treatment Duration** – The ten-day treatment period was insufficient to lower COD levels below 25 mg/L. Extending retention time or periodically replenishing sludge with fresh biomass may enhance performance.

(b). **Integrating Advanced Treatment Technologies** – The persistence of non-biodegradable compounds suggests that combining activated sludge with advanced oxidation (e.g., photocatalysis) or adsorption (e.g., activated carbon) may be necessary.

(c). **Optimizing Nutrient Supplementation** – The nutrient composition (glucose, KNO_3, KH_2PO_4) should be fine-tuned to sustain microbial activity beyond the initial phase of rapid LAS degradation.

Conclusion

The elevated levels of total detergent, BOD, and COD, which exceeded the regulatory standards set by the government, underscore the urgent need for urban wastewater treatment plants (WWTPs) to effectively treat domestic wastewater before discharge into rivers that flow into the sea. Based on the research and findings, it can be concluded that the degradation of laundry wastewater using aerated aerobic activated sludge can significantly reduce LAS levels; however, a treatment period of 10 days is insufficient to lower LAS, BOD, and COD to meet the Class 2 water quality standards set by the government. For laundry wastewater sample 1, LAS levels decreased from 16.764 mg/L to 1.827 mg/L, while in laundry wastewater sample 2, LAS levels dropped from 19.563 mg/L to 2.977 mg/L, with reduction efficiencies of 89.1% and 85.31%, respectively. Similarly, BOD reduction efficiencies were 89.23% and 90.15%, while COD reduction efficiencies were 86.04% and 85.94%. The consistently higher COD values relative to BOD after ten days indicate that the laundry wastewater still contains a significant amount of non-biodegradable organic compounds. Furthermore, the food-to-microorganism ratio (F/M), initially in the range of 0.078 and 0.062 mg BOD5/mg MLSS per day before entering the activated sludge tank, increased over the ten days to 0.197 and 0.190 mg BOD5/mg MLSS per day, respectively. This rise in F/M suggests that the microorganisms are still actively degrading the waste, making the use of activated sludge for a ten days, with the addition of nutrients, effective in reducing LAS levels by up to 85%.

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References

Ardiyanto, P. and Yuantari, M.G.C. (2016) 'Analisis Limbah Laundry Informal Dengan Tingkat Pencemaran Lingkungan Di Kelurahan Muktiharjo Kidul Kecamatan Pedurungan Semarang', *Jukung (Jurnal Teknik Lingkungan)*, 2(1), pp. 1–12. Available at: https://doi.org/10.20527/jukung.v2i1.1055.

Arora, U. *et al.* (2023) 'Surfactants: combating the fate, impact, and aftermath of their release in the environment', *International Journal of Environmental Science and Technology*, 20(10), pp. 11551–11574. Available at: https://doi.org/10.1007/s13762-022-04549-2.

Asok, A.K. and Jisha, M.S. (2012) 'Biodegradation of the Anionic Surfactant Linear Alkylbenzene Sulfonate (LAS) by Autochthonous Pseudomonas sp.', *Water, Air, & Soil Pollution*, 223(8), pp. 5039–5048. Available at: https://doi.org/10.1007/s11270-012-1256-8.

Badmus, S.O. *et al.* (2021) 'Environmental risks and toxicity of surfactants: overview of analysis, assessment, and remediation techniques', *Environmental Science and Pollution Research*, 28(44), pp. 62085–62104. Available at: https://doi.org/10.1007/s11356-021-16483-w.

Budiawan, Fatisa, Y. and Khairani, N. (2010) 'Optimasi Biodegradabilitas dan Uji Toksisitas Hasil Degradasi Surfaktan Linear Alkilbenzena Sulfonat (Las) Sebagai Bahan Deterjen Pembersih', *Makara of Science Series*, 13(2), pp. 125–133.

Hendra, H. *et al.* (2016) 'Photo-Degradation of Surfactant Compounds Using Uv Rays With Addition of Tio2 Catalysts in Laundry Waste', *Sainstek : Jurnal Sains dan Teknologi*, 7(1), p. 59.

Jardak, K., Drogui, P. and Daghrir, R. (2016) 'Surfactants in aquatic and terrestrial environment: occurrence, behavior, and treatment processes', *Environmental Science and Pollution Research*, 23(4), pp. 3195–3216. Available at: https://doi.org/10.1007/s11356-015-5803-x.

Kruszelnicka, I. *et al.* (2019) 'Evaluation of surfactant removal efficiency in selected domestic wastewater treatment plants in Poland', *Journal of Environmental Health Science and Engineering*, 17(2), pp. 1257–1264. Available at: https://doi.org/10.1007/s40201-019-00387-6.

Li, S. and Chen, P. (2022) 'Screening of a novel bacterium that degrades LAS and removes nitrogen', *International Journal of Environmental Science and Technology*, 19(10), pp. 9669–9678. Available at: https://doi.org/10.1007/s13762-021-03812-2.

Lusiana, U. (2011) 'Wastewater Treatment Efficiency Using Up Flow Anaerobic Filter and Activated Sludge Acclimatization', *Biopropal Industri*, 2(1), pp. 13–19. Available at: https://doi.org/10.36974/jbi.v2i1.719.

Mungray, A.K. and Kumar, P. (2009) 'Fate of Linear Alkylbenzene Sulfonates in The Environment: A review', *International Biodeterioration and Biodegradation*, 63(8), pp. 981–987.

Painter, H.A. (1992) 'Anionic Surfactants BT - Detergents', in N.T. de Oude (ed.). Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 1–88. Available at: https://doi.org/10.1007/978-3-540-47108-0_1.

Pandey, A. *et al.* (2020) 'Micropollutant Removal from Laundry Wastewater in Algal-Activated Sludge Systems: Microbial Studies', *Water, Air, & Soil Pollution*, 231(7), p. 374. Available at: https://doi.org/10.1007/s11270-020-04749-x.

Pungus, M., Palilingan, S. and Tumimomor, F. (2019) 'Penurunan kadar BOD dan COD dalam limbah cair laundry menggunakan kombinasi adsorben alam sebagai media filtrasi', *Fullerene Journ. Of Chem*, 4(2), pp. 54–60.

Purnama Sari, I. *et al.* (2021) 'Pengolahan Air Bungan Limbah Laundry Menggunakan Bottom Ash Sebagai Media Adsorpsi Laundry Waste Water Treatment Using Bottom Ash As Adsorption Media', *Jurnal Kinetika*, 12(02), pp. 21–28.

Rahmayetty, R., Reza, A. and Fathurrahman, D. (2011) 'Pengaruh Laju Alir Aerasi Terhadap Kualitas Effluent dalam Pengolahan Limbah Cair Industri Tepung Aren', *Teknika: Jurnal Sains dan Teknologi*, 7(2), p. 140.

Razmi, T.A.Y.Y. (2022) 'Analisis Kadar Surfaktan Anionik Pada Air Sungai Martapura Dengan Metode Spektrofotometri Visible', *Journal of Pharmaceutical and Sciences*, 1(1), pp. 55–61.

Setianingsih, N.I., Hermawan, D.W. and Nilawati, N. (2015) 'Pengolahan Air Limbah Kadar Garam Tinggi dengan Sistem Lumpur Aktif', *Jurnal Riset Teknologi Pencegahan Pencemaran Industri*, 6(2), p. 45.

Seyedsalehi, M. *et al.* (2019) 'Performance evaluation of several sequencing batch biofilm reactors with movable bed in treatment of linear alkyl benzene sulfonate in urban wastewater', *International Journal of Environmental Science and Technology*, 16(11), pp. 6763–6772. Available at: https://doi.org/10.1007/s13762-018-2082-3.

Suastuti, D.A.N., I, S. and Nanik, A. (2015) 'Efektivitas Penurunan Kadar Surfaktan Linier Alkil Sulfonat (Las) dan COD dari Limbah Cair Domestik dengan Metode Lumpur Aktif', *Jurnal Kimia*, 9(1), pp. 86–92.

Suresh, A. and Abraham, J. (2019) 'An Overview on the Microbial Degradation of Linear Alkylbenzene Sulfonate (LAS) Surfactants BT - Phyto and Rhizo Remediation', in N.K. Arora and N. Kumar (eds). Singapore: Springer Singapore, pp. 301–313. Available at: https://doi.org/10.1007/978-981-32-9664-0_13.

Utomo, W.P. *et al.* (2018) 'Penurunan Kadar Surfaktan Anionik dan Fosfat dalam Air Limbah Laundry di Kawasan Keputih, Surabaya menggunakan Karbon Aktif', *Akta Kimia Indonesia*, 3(1), p. 127. Available at: https://doi.org/10.12962/j25493736.v3i1.3528.

Widya Astuti, S. and Suriani Sinaga, M. (2015) 'Pengolahan Limbah Laundry Menggunakan Metode Biosand Filter untuk Mendegradasi Fosfat', *Jurnal Teknik Kimia USU*, 4(2), p. 53.

Wimbaningrum, R., Arianti, I. and Sulistiyowati, H. (2020) 'Efektivitas Tanaman Lembang (Typha angustifolia L.) di Lahan Basah Buatan dalam Penurunan Kadar TSS, BOD dan Fosfat pada Air Limbah Industri Laundry', *Berkala Saintek*, (1), pp. 25–28.

Yuliana, Y., Langsa, M.H. and Sirampun, A.D. (2020) 'Air Limbah Laundry : Karakteristik dan Pengaruhnya Terhadap Kualitas Air', *Jurnal Natural*, 16(1), pp. 25–33. Available at: https://doi.org/10.30862/jn.v16i1.48.

Zhang, D. *et al.* (2023) 'Surfactant recovery and efficient separation of PAHs from surfactant solutions by low-cost waste activated sludge and two-stage design optimization', *Environmental Science and Pollution Research*, 30(17), pp. 50484–50495. Available at: https://doi.org/10.1007/s11356-023-25921-w.