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ANALYSIS OF THE QUALITY OF WASTEWATER FROM THE TOFU AND MEATBALL INDUSTRY BASED ON BOD, PH, COD AND TSS PARAMETERS IN THE SENDANGGUWO SUB-DISTRICT, SEMARANG CITY

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Abstract

The meatball tofu industry in Sendangguwo Village, Semarang City, is a micro, small, and medium enterprise (MSME) with unique characteristics. It operates as a meat processing unit sourcing raw tofu externally. Its intensive animal protein processing generates liquid waste with a very high organic load. This study aims to analyze the liquid waste quality based on TSS, pH, BOD, and COD parameters, evaluating compliance with recent regulations. The research employs a quantitative descriptive method with longitudinal sampling at three points: upstream (X1), waste convergence point (X2), and downstream (X3). Analyses were conducted in an accredited environmental laboratory using SNI methods. Results indicate the Sendangguwo River's water quality significantly exceeds the Class II standards of Government Regulation No. 22 of 2021. At the discharge point (X2), BOD reached 107.25 mg/L and COD 143.29 mg/L. While statistically below the emission limits for the Meat Processing Industry under Central Java Regional Regulation No. 5 of 2012, technical analysis confirms the raw effluent concentration breaches regulations before river dilution. The river's water quality is categorized as "Heavily Polluted," necessitating interventions like grease traps and communal wastewater treatment systems.

Keywords: Liquid Waste, Meat Processing Industry, Tofu and meatball, BOD, COD, Water Quality.

INTRODUCTION

The food industry sector, particularly the production of tofu meatballs in urban areas such as the city of Semarang, continues to grow in line with rising market demand (Setiawan *et al*., 2023) . The Sendangguwo neighbourhood in Tembalang District serves as the operational base for the tofu meatball business unit that is the subject of this study. Unlike the conventional tofu industry, which processes soya beans in-house, this factory is technically categorised as a meat processing industry. This is because all the white tofu required is supplied by external parties (suppliers), so the main activities at the production site are focused on the meat preparation stage, the making of the filling mixture (a blend of meat, flour and spices), filling the tofu with the mixture, and the final boiling process of the product. Although economically productive, this integration of animal protein processing produces wastewater with pollutant characteristics that are far more complex than those of pure vegetable waste due to the high levels of animal fat and muscle protein residues (Isnaeni, 2022).

Liquid waste from this meatball processing unit originates from several critical stages in its production cycle. The washing of production equipment and meat scraps releases liquid waste rich in dissolved protein and blood residues (Sakti, 2019). The grinding and mixing stages of the meatball filling produce emissions of fine fat particles that are difficult to break down naturally. However, the main contributor to the organic load is the large-scale boiling of meatballs, where the boiling water is contaminated by melted animal fat and denatured protein due to exposure to high temperatures. The specific characteristics of waste from this industry are marked by very high levels of fat, oil and organic nitrogen, which are technically reflected in extremely high Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values (Pagoray, 2021). Field conditions indicate that the factory under study discharges its liquid waste directly into residential drainage channels that flow into a local river in the Sendangguwo area. The lack of treatment facilities, such as an on-site Wastewater Treatment Plant (WWTP), leads to the accumulation of organic pollutants in the receiving water body. The presence of meat processing effluent in the river triggers a significant deterioration in water quality, manifested as increased turbidity (Total Suspended Solids / TSS), the formation of an oil slick on the water’s surface that impedes oxygen transfer, and a foul odour resulting from the anaerobic decomposition of proteins.

In assessing these environmental impacts, the government has established strict quality standards. Government Regulation No. 22 of 2021 serves as the reference for determining the water quality status of receiving rivers. Meanwhile, the compliance level regarding emissions from this business unit must refer to Central Java Provincial Regulation No. 5 of 2012 on Wastewater Quality Standards, specifically the annex setting out specific standards for the Meat Processing Industry. This study aims to provide a longitudinal analysis based on laboratory data to evaluate the effectiveness of environmental management at the meatball factory in question.

METHODOLOGY

This study employed a quantitative descriptive method with a longitudinal approach to map the distribution of pollutant loads in the river flowing through Sendangguwo Village. Sampling was carried out at three strategic points: X1 (the river headwaters as a control for initial conditions prior to exposure to waste), X2 (the point where the industrial waste discharge from the meat processing plant meets the river), and X3 (the river mouth to observe the effects of accumulation). Laboratory analysis was carried out at the Environmental Testing and Laboratory Centre using Indonesian National Standards (SNI) accredited by KAN:

1. TSS: Gravimetric method in accordance with SNI 6989.3:2019, in which suspended solids are separated by filtration and dried at a temperature of 103°C to 105°C.
2. pH: Electrometric method using a pH meter calibrated in accordance with SNI 6989.11:2019.
3. BOD: 5-day incubation method at 20°C in accordance with SNI 6989.72:2009. Dissolved oxygen (DO) content is measured using the modified azide iodometric titration method (SNI 06-6989.14-2004).
4. COD: The closed-reflux spectrophotometric method refers to SNI 6989.2:2019

The test results were then compared with Annex VI of Government Regulation No. 22 of 2021 for Class II river quality and Central Java Provincial Regulation No. 5 of 2012 for the Meat Processing Industry standards.

RESULTS AND DISCUSSION

The study yielded primary data illustrating the water quality profile of the river resulting from meat processing activities in Sendangguwo. The results of the laboratory analysis are presented in Table 1.

Table 1. Processed Data from the Environmental Testing and Laboratory Centre

Point Code	Parameter	Unit	Analysis Result	Quality Standard (PP 22/2021 KL. II)	Remarks
X1 (Before Confluence)	TSS	mg/L	28,0667	50	Compliant
	pH	-	7.49	6 - 9	Compliant
	BOD	mg/L	60,07	3	Exceeded
	COD	mg/L	114,9583	25	Exceeded
X2 (Confluence)	TSS	mg/L	51,15	50	Exceeded
	pH	-	7.25	6 - 9	Compliant
	BOD	mg/L	107,25	3	Exceeded
	COD	mg/L	143,2917	25	Exceeded
X3 (After Confluence)	TSS	mg/L	41,4	50	Compliant
	pH	-	7,28	6 - 9	Compliant
	BOD	mg/L	124.88	3	Exceeded
	COD	mg/L	161,625	25	Exceeded

Acidity (pH) Analysis

pH measurements at all observation points (X1, X2, and X3) showed stable values within the neutral range, namely between 7.25 and 7.49. These values meet the Class II river water quality standards according to Government Regulation No. 22 of 2021 (range 6–9). Theoretically, liquid waste from conventional tofu production is highly acidic (pH 4–5) due to the use of acetic acid as a coagulant (Ayu *et al*., 2024). However, in the meatball tofu industry, which focuses on meat processing, the use of mineral salts and alkaline seasonings in the meatball mixture and the cooking water tends to neutralise this acidity. This pH stability indicates that, despite high organic loading, the river water still possesses good buffering capacity against fluctuations in acidity (peraturan pemerintah, 2021). This neutral condition is quite interesting when compared to the tofu industry in general. Theoretically, liquid waste from the conventional tofu industry is usually highly acidic, with a pH of 4–5, as a result of the high use of coagulants in the form of acetic acid. However, as the industry in the Sendangguwo area is a meatball tofu industry focused on meat processing, there is a difference in the characteristics of the waste. The use of mineral salts and alkaline spices in the meatball mixture, as well as the water left over from boiling, tends to neutralise the acidic nature of the tofu-making process itself. The pH stability along this river stretch indicates that although the river receives a high load of organic pollutants, the water still possesses good buffering capacity to mitigate fluctuations in acidity.

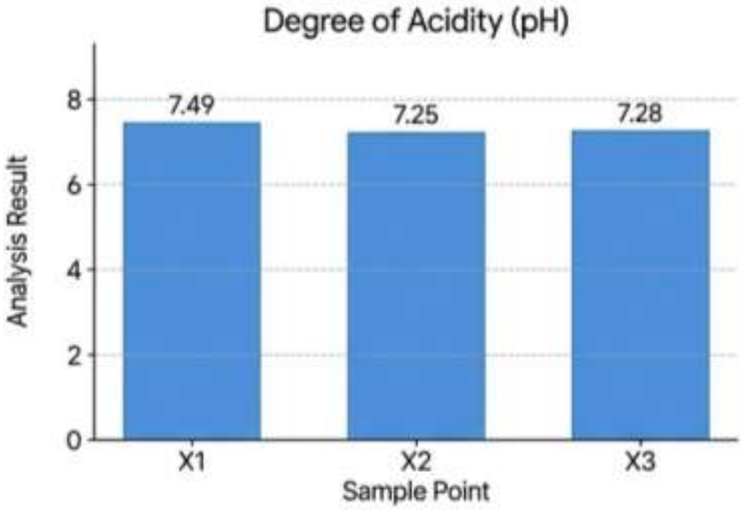

Figure 1. Results of water pH measurements

Total Suspended Solids (TSS) Analysis

The TSS parameter serves as an indicator of the presence of insoluble solid particles in water. At the upstream point (X1), the TSS concentration of 28.07 mg/L remains below the threshold limit (50 mg/L). However, there was a significant surge at the confluence point (X2) to 51.15 mg/L, which has exceeded the quality standard. This increase was triggered by residues from meatball production, consisting of fine meat fibres, tapioca flour residues, and fat particles released during the washing and boiling processes. Research findings *(*Nurbaya *et al*., 2024) confirm that the input of organic residues from domestic industrial activities along the riverbanks directly increases turbidity, which can hinder sunlight penetration and disrupt aquatic photosynthesis. The decrease in TSS values downstream (X3) to 41.4 mg/L indicates the occurrence of natural sedimentation, where solid particles settle to the riverbed, potentially leading to channel siltation in the long term.

River conditions change drastically when the flow reaches the confluence with the discharge channel (X2). At this point, there is a very significant surge in TSS concentration to 51.15 mg/L, meaning water quality has exceeded the established standards. This increase in suspended particles is directly triggered by the influx of residues from meatball production, which generally consist of fine meat fibres, tapioca flour residues, and fat particles released during washing and boiling processes. This analysis aligns with the findings of (Fitrianah & Fawaid, 2023), who confirmed that the input of organic residues from domestic industrial activities along the riverbanks directly increases water turbidity. If left unchecked, this turbidity can hinder the penetration of sunlight to the riverbed, which in turn disrupts the photosynthesis of aquatic plants. On the other hand, the decrease in TSS values at the downstream point (X3) to 41.4 mg/L indicates that natural sedimentation has occurred. These solid particles have begun to settle to the riverbed, a condition that has the potential to trigger the silting up of waterways in the long term.

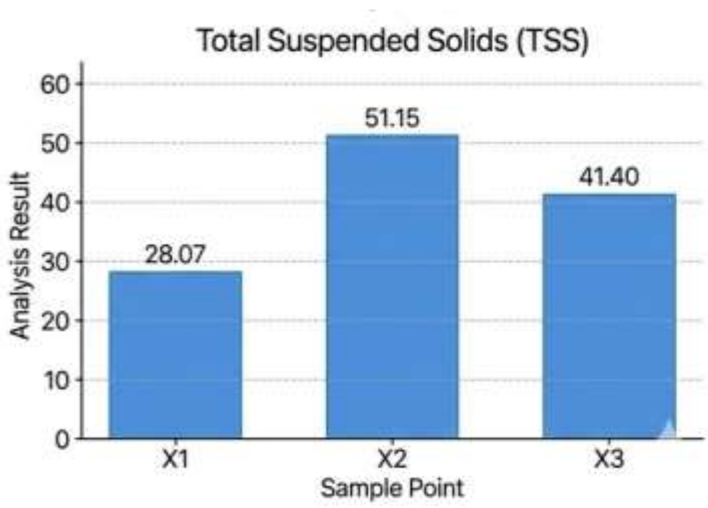

Figure 2. Results of water TSS (mg/L) measurements

Biochemical Oxygen Demand (BOD) Analysis

The Biochemical Oxygen Demand (BOD) parameter is a crucial indicator reflecting the amount of dissolved oxygen consumed by aerobic microorganisms to degrade or break down organic compounds in the water (Zulkifli & Suhelmi, 2018). Based on the analysed data, the river's water quality is at a critically high level of pollution. At the upstream point (X1), a BOD value of 60.07 mg/L was recorded. This figure is deeply concerning as it exceeds the Class II river water quality standard of 3 mg/L (as per applicable environmental regulations) by a factor of 20. The high BOD value in this upstream area provides strong evidence of massive initial pollution pressure. The primary source of this pollution is believed to be domestic waste from local residents, including washing water containing detergents, food waste, and household sanitary waste that is discharged directly into the river without first undergoing wastewater treatment (Napitupulu *et a*l., 2024). The pollution load on the river ecosystem becomes even more severe as the water flow passes the industrial wastewater discharge point (X2), as evidenced by the pollution dynamics observed in the river flow around the Sendangguwo meatball tofu industrial area in Semarang.

The input of liquid effluent from production activities causes BOD concentrations to surge dramatically, reaching 107.25 mg/L. The food processing industry is known to produce effluent that is highly concentrated in organic matter, which triggers a drastic decline in water quality (Sepriani et al., 2016). This waste carries a combination of pollutants in the form of carbohydrates and plant proteins from soya, as well as fats and animal proteins from meat. When these complex materials enter water bodies, populations of decomposing microorganisms respond with intensive biological breakdown that rapidly consumes large amounts of dissolved oxygen (DO) in a short period of time (Metcalf & Eddy, 2014). This pollution phenomenon shows an alarming cumulative upward trend at the downstream point (X3), where BOD concentrations peaked at 124.88 mg/L. The continued increase in this downstream area is closely linked to the characteristics of the dominant organic waste. Waste rich in animal protein has a complex molecular structure that necessitates a much longer biological degradation phase (Pagoray, 2021). Due to the slow rate of decomposition, organic pollutants are not completely broken down in the initial discharge area, but are carried by the current and accumulate along the length of the river from the mixing point (inlet) far downstream.

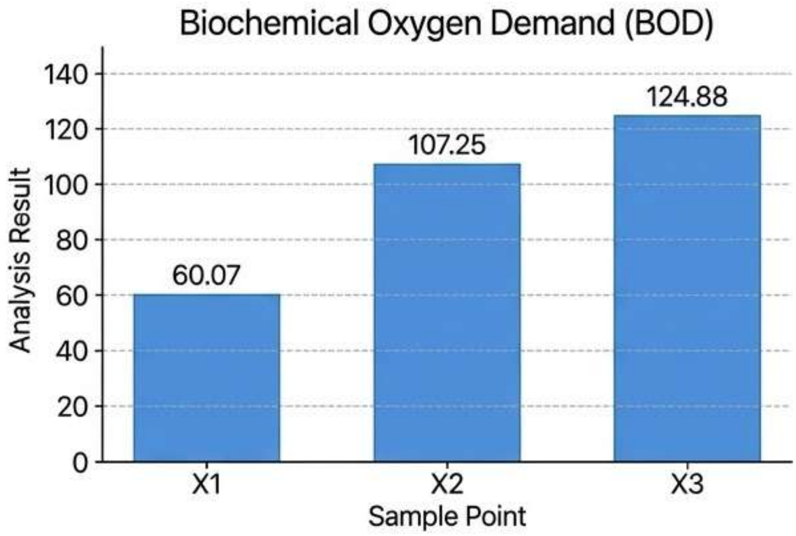

Figure 3. Results of water BOD (mg/L) measurements

Chemical Oxygen Demand (COD) Analysis

Chemical Oxygen Demand (COD) is a crucial indicator of water quality that measures the total oxygen required to oxidise all organic matter both biodegradable and non-biodegradable through vigorous chemical reactions using oxidants in an acidic environment (Metcalf & Eddy, 2014). Based on field observations, a significant trend of increasing pollution load is evident along the river course. At the upstream point (X1), the COD value was recorded at 114.96 mg/L, indicating that the water body was already carrying a fairly heavy organic pollution load likely from domestic or agricultural activities upstream even before reaching the main discharge point under investigation. Upon reaching the discharge point (X2), there is a sharp rise in the COD value to 143.29 mg/L. The high reading at this point is specifically attributable to effluent containing concentrated fats and complex polymeric organic compounds. The nature of these compounds makes them difficult for natural aquatic microorganisms to digest or break down, thus necessitating chemical oxidation. Rather than decreasing due to dilution, this pollution load is carried downstream and the COD value actually peaks at the downstream point (X3) at 161.63 mg/L. This accumulation in the downstream area provides empirical evidence that the rate of organic waste input far exceeds the river's assimilation capacity and natural self-purification ability. The condition of this river is classified as critically severe, as the entire range of COD values from upstream to downstream has exceeded quality standards by an extreme margin. Referring to Government Regulation (PP) No. 22 of 2021 on the Implementation of Environmental Protection and Management, the maximum COD threshold for Class II river water is set at just 25 mg/L. The surge in COD levels, which are four to six times above this safe limit, triggers serious ecological impacts.

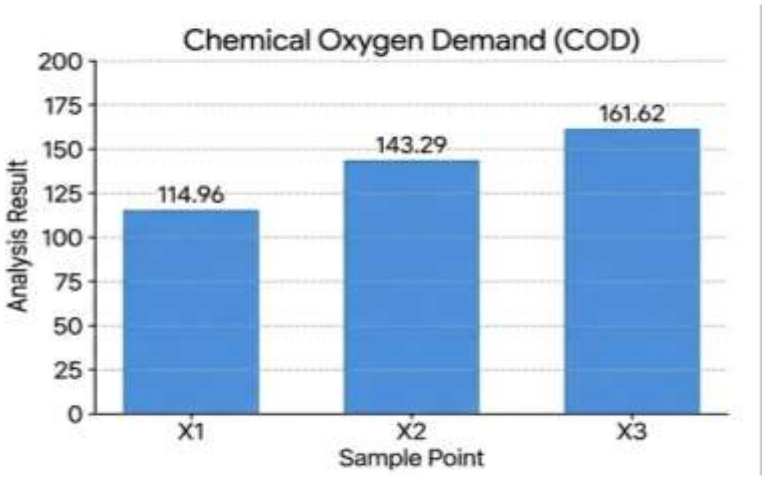

Figure 4. Results of water COD (mg/L) measurements

Compliance with Regulations

From a legal perspective, industrial compliance is assessed against the standards for the Meat Processing Industry set out in Central Java Regional Regulation No. 5 of 2012.

Table 2. Evaluation of Water Quality Parameters at the Receiving River Body (Point X2) Based on Central Java Regional Regulation No. 5 of 2012.

No.	Parameter	Central Java Regional Regulation No. 5 of 2012	Result in River (Point X2)	Status
1	BOD	125 mg/L	107.25 mg/L	Compliant (in river)
2	COD	250 mg/L	143.29 mg/L	Compliant (in river)
3	TSS	100 mg/L	51.15 mg/L	Compliant (in river)
4	pH	6.0 - 9.0	7.25	Compliant

Based on the statistically analysed water quality test results in Table 2, the Biochemical Oxygen Demand (BOD) value at the monitoring point of the receiving river body (point X2) was recorded at 107.25 mg/L. At first glance, this figure appears to still meet the industrial wastewater quality standard set at a maximum of 125 mg/L under Central Java Provincial Regulation No. 5 of 2012. However, drawing a direct conclusion from this figure is inaccurate if hydrological dynamics are not taken into account, given that the sample was taken from a river body with a far greater volume, rather than from the outfall of the production facility's raw wastewater discharge pipe. This significant difference in flow rate naturally creates a substantial dilution effect. Referring to the principle of environmental mass balance, the figure of 107.25 mg/L in the diluted river logically proves that the untreated effluent, prior to mixing, must have had a concentration that was many times higher. Therefore, it can be concluded that the liquid effluent from the facility has, in fact, significantly exceeded the 125 mg/L threshold.

This excessive waste discharge is causing serious ecological degradation to the local aquatic ecosystem. The high BOD levels in the river reflect the significant consumption of dissolved oxygen by microorganisms as they break down organic waste, which ultimately triggers an oxygen deficit that is fatal to aquatic life and reduces the river's ability to naturally self-purify. Referring to the criteria and parameters set out in Government Regulation of the Republic of Indonesia No. 22 of 2021 on the Implementation of Environmental Protection and Management, this high pollution load legally classifies the Sendangguwo water body as a river with a 'Heavily Polluted' status. This status confirms that the river's carrying capacity and assimilation capacity have been exceeded, resulting in the degradation of its ecological functions and its failure to meet the national water quality standards for its designated class.

CONCLUSION

Based on the analysis of physical and chemical parameters, the meatball factory in Sendangguwo Village, which operates as a meat processing unit, has a significant negative impact on water quality. Firstly, BOD and COD parameters at all longitudinal points have exceeded the Class II river quality standards under Government Regulation No. 22 of 2021 by a factor of tens, placing the water body in the 'Heavily Polluted' category. Secondly, the BOD concentration in the river at the discharge point (107.25 mg/L) technically demonstrates that the raw industrial effluent violates Central Java Regional Regulation No. 5 of 2012 when accounting for dilution by river flow. Thirdly, the surge in TSS at point X2 (51.15 mg/L) confirms the presence of unfiltered animal-derived organic solid residues.

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