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Removal Efficiency of BOD, COD and TSS from Tofu Wastewater Using an Anaerobic System

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ABSTRACT

Tofu industry is one of the agroindustrial sectors that generates wastewater, which can potentially cause environmental pollution if not properly managed. The high organic content in tofu wastewater can be treated using an anaerobic system that produces biogas. One of tofu industry in Banjarbaru City, South Kalimantan, has implemented a biogas system as an effort to treat its wastewater; however, the effectiveness of the treatment is still not optimal. Therefore, this study aims to analyze the quality of tofu wastewater before (influent) and after (effluent) anaerobic treatment, as well as its effectiveness in reducing pollutant parameters. The method used involves laboratory analysis of pH, TSS, BOD, and COD. The research data were processed, analyzed, and presented quantitatively in a descriptive manner. The results show that the wastewater discharge from the tofu industry reached 11.162 liters per day. The influent quality of tofu wastewater contained pH 4,15, TSS 732,5 mg/L, BOD 4.194,7 mg/L, and COD 10.564,7 mg/L. After treatment, the effluent quality improved to pH 7,265, TSS 128 mg/L, BOD 333,6 mg/L, and COD 2.112,9 mg/L. The pollutant load of the influent contained COD 57,2 kg/ton, BOD 144,3 kg/ton, and TSS 10 kg/ton. After anaerobic treatment, the effluent contained BOD 4,6 kg/ton, COD 28,9 kg/ton, and TSS 1,8 kg/ton. The removal efficiencies of TSS, BOD, and COD were 82,5%, 92%, and 80%, respectively.

Keywords: Anaerobic System, Pollutant Load, Removal Efficiency, Tofu Wastewater

INTRODUCTION

The tofu industry is one of the agroindustry sectors that utilizes soybeans as its primary agricultural raw material. Soybeans are an inexpensive food ingredient with high protein content. During its production process, tofu generates both solid and liquid waste. The solid waste produced is tofu dregs, while the liquid waste consists of suspended solids and dissolved organic materials that contain high levels of protein and amino acids. This wastewater has the potential to cause environmental pollution, especially for the water quality in residential areas (Azhari, 2016).

Tofu wastewater originates from the residual liquid that does not coagulate during the tofu making process, fragments of tofu that break apart due to incomplete coagulation, and a yellowish liquid that often produces an unpleasant odor. When it's left untreated, this liquid can turn brownish-black colour and produce a gases such as methane (CH_4), carbon dioxide (CO_2), and hydrogen sulfide (H_2S), which contribute to foul odor and environmental degradation. Tofu wastewater typically contains high levels of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). BOD represents the amount of oxygen required by bacteria to decompose almost all dissolved organic substances and partially suspended organic matter in water, while COD reflects the oxygen demand for chemical oxidation processes in environments (Razie et al., 2016). When BOD and COD levels become too high, they can severely reduce the amount of dissolved oxygen in the water. As a result, aquatic life may suffer, and in severe cases, this can lead to mass mortality due to oxygen depletion (Rahman et al., 2021). Research by Nurman et al. (2017) found that tofu wastewater contains various macromolecules, including approximately 0.1% carbohydrates, 0.42% protein, 0.13% fat, 4.55% iron (Fe), 1.74% phosphorus, and about 98.8% water.

A small-scale household tofu industry in Banjarbaru City, South Kalimantan, has implemented an anaerobic system to utilize tofu wastewater for biogas production. An anaerobic system is a wastewater treatment process that operates without the presence of oxygen. In this system, anaerobic microorganisms break down organic matter and convert it into simpler compounds, producing biogas, such as methane (CH_4) and carbon dioxide (CO_2) as a product. The biogas generated from this process can be utilized as an alternative energy source, commonly used for cooking, heating and other industrial energy needs. This industry processes around 17–18 sacks of soybeans per day (each sack containing 50 kg), resulting in a total daily production of approximately 800–850 kg. The production volume varies according to market demand; higher demand results in increased daily tofu output. Biogas is generated as the final product of the anaerobic degradation of organic matter by bacteria functioning in completely oxygen-free environments (Chusniyah et al., 2019). However, the existing biogas system has several limitations due to inadequate maintenance, one of which is the corrosion of cooking utensils exposed to biogas. This issue is caused by hydrogen sulfide (H_2S), a corrosive component of biogas that accelerates metal deterioration. In addition, the inadequate wastewater treatment system leads to the discharge of untreated wastewater into nearby rivers.

This study aims to assess the quality of tofu wastewater in one of the tofu industries in Banjarbaru City, South Kalimantan. The results are expected to provide information regarding the organic pollutant load content in the wastewater and the effectiveness of the biogas treatment system in reducing BOD, COD and TSS. The analysis was conducted by comparing pH, TSS, BOD, and COD values in the influent and effluent to see how effectively the anaerobic system improved the quality of the wastewater. This study is expected to serve as a reference for tofu industry practitioners in improving the performance of their wastewater treatment systems and supporting more sustainable environmental management.

MATERIALS & METHODS

Time and Place

This study was conducted over a period of four months, from June to September 2025. Tofu Industry X is located in Loktabat Utara, Banjarbaru Utara, Banjarbaru, South Kalimantan. The tofu wastewater that used in research were collected from industry X in Banjarbaru and later analyzed at the Public Health Laboratory Center in Banjarbaru. The tofu wastewater sample was taken on August 20, 2025, at 10:00 WITA, and laboratory analyses were carried out from August 21 to August 29, 2025.

Data Sources

This study utilized both primary and secondary data. Primary data were obtained directly through field measurements, including wastewater discharge values and the concentration of BOD, COD, TSS and pH from tofu wastewater. The secondary data consisted of information collected by other parties and used to complement this research. These secondary data include theories, previous research findings, and relevant scientific references obtained from books, journals, and other literature sources that support the analysis of tofu wastewater, especially the efficiency of pollutant removal.

Data Collection Process

This study uses a quantitative descriptive method. A quantitative descriptive approach aims to objectively describe a condition using numerical data, encompassing data collection, interpretation, and presentation of the results. The quantitative data in this study were obtained from laboratory analyses of wastewater samples, pollutant load and wastewater discharge measurements.

Data Analysis

1. Wastewater Discharge

The purpose of this analysis is to determine the amount of wastewater generated from daily tofu production. The data were obtained from the volume and time required in the wastewater handling process. These data can then be used to calculate the pollutant load produced per day or per ton of production. The wastewater discharge can be calculated using the following formula:

$Q = V/t$

Note:
Q = Wastewater Discharge (L/day)
V = Volume of Wastewater Generated (L)
t = Time of Production (Day)

2. Tofu Wastewater Quality

The purpose of this analysis is to determine the concentration of wastewater parameters before and after anaerobic treatment. After the laboratory analyses were completed, the results were presented descriptively in the form of tables. The tables include the concentrations of tofu wastewater in the influent (before treatment) and effluent (after treatment), which are then compared with the wastewater quality standards stated in the Regulation of the Minister of Environment of the Republic of Indonesia No. 5 year of 2014 concerning Wastewater Quality Standards for Soybean Processing Activities. The quality standard used to compare the wastewater samples are presented in the following table:

Table 1. Quality Standard for the Tofu Wastewater

Parameter	Tofu	
	Concentration *) (mg/L)	Pollutant Load *) (kg/ton)
BOD	150	3
COD	300	6
TSS	200	4
pH	6 – 9	
Maximum capacity (m^3/ton)	20	

Note *: except pH

(Source: Regulation of the Minister of Environment of the Republic of Indonesia No. 5 year of 2014)

Based on the concentration of tofu wastewater, the pollutant load can be calculated using the following formula:

$L\ (kg/day) = (Q \times C)/1.000.000$

$L\ (kg/ton) = (\text{Pollutant Load (kg/day)}) / (\text{Quantity of raw materials (ton/day)})$

Note:
L = Pollutant Load (Kg/day or Kg/ton)
Q = Wastewater Discharge (L/day)
C = Concentration of Tofu Wastewater (mg/L)

After determining the wastewater concentration and pollutant load, the removal efficiency between the influent and effluent can be calculated using the following formula:

Removal Efficiency (%) = (Cin-Cef)/Cin×100%
Note:
Cin = Influen Concentration (mg/L)
Cef = Effluen Concentration (mg/L)

The standard methods used to analyze the wastewater samples are presented in the following table:

Table 2. Standard Method to Analyze the Wastewater

Parameter	Standard Method
BOD	SNI 6989.72:2009
COD	SNI 6989.73:2009
TSS	SNI 6989.3:2019
pH	SNI 6989.11:2019

Source: (Public Health Laboratory Center, Banjarbaru, South Kalimantan)

RESULT AND DISCUSSION

1. An Overview of Tofu Industry

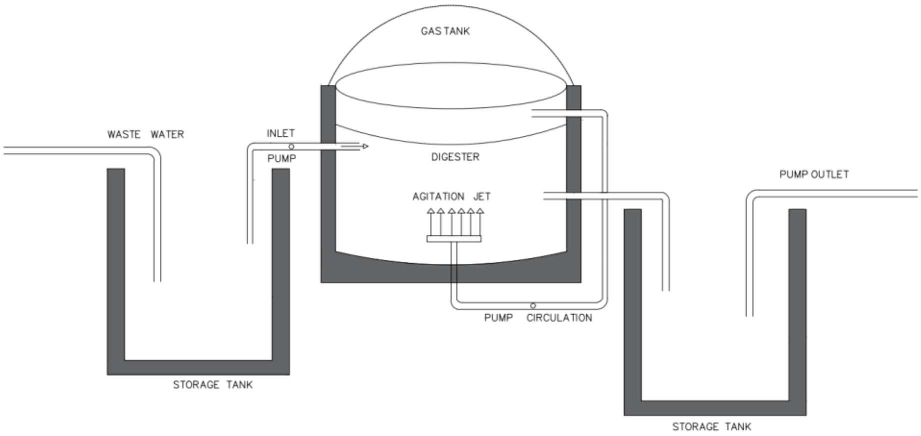

Figure 1. Anaerobic System in Tofu Industry

The tofu industry in Banjarbaru City, has implemented a wastewater treatment system that utilizes biogas through an anaerobic process. The design of this system can be seen in Figure 1. The anaerobic system applied in the tofu industry consists of several main components, namely: a fermentation tank (digester) where organic matter is degraded by anaerobic bacteria, a pipeline that transports wastewater from the production process to the digester, and a storage tank with gas holder to collect and store the produced biogas. This system allows the wastewater to be treated anaerobically, thereby reducing parameters such as BOD, COD, and TSS, while simultaneously producing biogas as an alternative energy source. In anaerobic treatment, agitation jets are used to mix the reactor contents by recirculating wastewater at high velocity through nozzles. This jet induced turbulence helps maintain uniform conditions, prevents solids from settling, and improves contact between microorganisms and organic matter, thereby enhancing the overall stability and efficiency of the anaerobic digestion process. The anaerobic system occurs in four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis.

Hydrolysis is the initial step in which complex organic compounds such as carbohydrates, proteins, and fats are broken down into simpler soluble molecules. In the second stage, acidogenesis, these simpler molecules are further converted by acid-forming bacteria into volatile fatty acids, alcohols, hydrogen, and carbon dioxide. The third stage, acetogenesis, transforms these intermediate products into acetic acid, hydrogen, and carbon dioxide. Finally, in the methanogenesis stage, transform methanogenic bacteria acetic acid and hydrogen into methane (CH_4) and carbon dioxide (CO_2), which form the primary components of biogas. Biogas generally consists of approximately 50–70% methane (CH_4), 30–40% carbon dioxide (CO_2), and <1% of other gases such as hydrogen sulfide (H_2S) and ammonia (NH_3) (Castellanos-Sánchez et al., 2024).

2. Wastewater Discharge

The discharge of tofu wastewater is determined by several factors, such as the number of soybeans processed per day, the volume of water used for washing, boiling, and other production stages, as well as the efficiency of water use at each step of the production process (Palevi et al., 2024). Based on observations, the soybean raw material requirement in the tofu industry is measured using sacks, each containing 50 kg of soybeans. The following table presents the soybean raw material requirements of the tofu industry:

Table 3. Soybean Raw Material Requirements

Day	Quantity of Sacks	Quantity of Soybeans (Kg)
1	17	850
2	16	800
3	16	800
Average		817

Source: (Research Result, 2025)

Tofu production is carried out in batches with a capacity of around 15 kg per process. The production stages include washing, soaking, grinding, cooking the soybeans, filtering, coagulating with vinegar (CH_3COOH), and cutting the tofu. Each stage uses different amounts of water, resulting in varying volumes of wastewater. The wastewater volume is measured by calculating the total amount of water used in each production stage, which is then accumulated to obtain the daily wastewater discharge. The water consumption and wastewater discharge data obtained are as follows:

Table 4. Water Demand and Wastewater Discharge of the Tofu Industry

Process	Average Soybean Quantity (Kg/day)	Water Demand (L/day)	Wastewater Discharge (L/day)
Soybean washing and soaking, grinding, cooking, filtering, and coagulation	817	17.600	11.162

Source: (Research Result, 2025)

Based on Table 4, the wastewater discharge generated from a production of 817 kg/day is 11.162 L/day or 11,162 m^3/day, with a water demand of 17.600 L/day. According to a study by Palevi et al. (2024), a tofu factory in Jombang, Indonesia processing 1.200 kg of soybeans per day with a water demand of 22.500 L/day can produce a wastewater discharge of approximately 18.000 L/day or 18 m^3/day. This comparison indicates that the volume of wastewater is strongly determined by the production capacity and the water requirements in the tofu making process.

3. Tofu Wastewater Quality

A. Wastewater Quality

Wastewater samples were collected from the storage tank before treatment (influent) and after the treatment (effluent). The characterization of the wastewater was carried out to assess the parameter values before and after the treatment process. Untreated wastewater is often discharged directly into rivers, posing a risk of contaminating nearby water. The parameters analyzed included BOD, COD, TSS, and pH. The quality standards used as references were based on the Regulation of the Minister of Environment of the Republic of

Indonesia No. 5 year of 2014. The analysis was carried out in duplicate, and the resulting measurements were averaged, as presented in Table 5.

Table 5. Wastewater Concentration

Parameter	Unit	Concentration						Quality Standard
		Influen			Effluen			
		1	2	Average	1	2	Average	
pH	-	4,15	4,15	4,15	7,26	7,27	7,3	6-9
TSS	mg/L	725	740	732,5	126	130	128	200
BOD	mg/L	4.086	4.303,4	4.194,7	363,8	303,4	333,6*	150
COD	mg/L	10.637,5	10.491,8	10.564,7	2.040,1	2.185,8	2.112,9*	300

Note *: Exceeds the quality standard
Source: (Research Result, 2025)

Table 6. Average Concentration and Removal Efficiency of Wastewater

No.	Parameter	Average Influen (mg/L)	Average Effluen (mg/L)	Removal Efficiency (%)
1.	TSS	732,5	128	82,5
2.	BOD	4.194,7	333,6	92
3.	COD	10.564,7	2.112,9	80

Source: (Research Result, 2025)

Based on Table 5, the average pH of the influent wastewater is 4,15. This indicates that the wastewater before treatment is highly acidic and exceeds the quality standard. According to Srilestari & Munawwaroh (2021), tofu wastewater generally exhibits acidic characteristics, with typical initial pH values ranging from 3,5 to 4. This low pH results from the use of acidic coagulants (acetic acid or vinegar) in tofu production and microbial activity that generates organic acids in the wastewater. Natural fermentation of tofu wastewater produces organic acids derived from degraded proteins and carbohydrates under anaerobic conditions (Prihartantyo, 2020). After anaerobic treatment, the average effluent pH increases to 7,3, indicating that it meets the quality standard and becomes neutral. This occurs because volatile fatty acids (VFAs), such as acetic and propionic acid, are produced during the acidogenesis stage, lowering the pH. During methanogenesis, methanogenic bacteria convert VFAs into biogas (CH_4 and CO_2), while simultaneously producing bicarbonate ions (HCO_3^-), which are alkaline and help neutralize the pH to approximately 7 (Eryildiz & Taherzadeh, 2020).

The TSS value represents the total amount of suspended solids in the wastewater, including fine soybean pulp, residual proteins, and lipids. The average TSS concentration in the influent is 732,5 mg/L, which exceeds the quality standard. This high value is caused by the presence of solid residues, such as tofu pulp, sediment, and coarse particles originating from washing, boiling, grinding, and filtration processes. After anaerobic treatment, the average effluent TSS decreases to 128 mg/L, which is below the quality standard. The removal efficiency reaches 82,5%. The reduction in TSS concentration occurs because the anaerobic process facilitates the breakdown and settling of suspended solids contained in the wastewater.

BOD represents the amount of oxygen required by microorganisms to degrade dissolved organic matter and some suspended organic particles. The average influent BOD concentration is 4.195 mg/L. After anaerobic treatment, the average effluent BOD decreases to 333,6 mg/L, resulting in a removal efficiency of 92%. COD reflects the oxygen demand for chemical oxidation in water. The average influent COD concentration is 10.564,7 mg/L, while the average effluent COD decreases to 2.112,9 mg/L, with a removal efficiency of 80%. Although both BOD and COD show significant reductions, their effluent concentrations still exceed the regulatory standards. This may be attributed to several factors, including the very high initial concentrations. Even with high removal efficiencies of 80–95%, effluent concentrations may remain above quality standards when influent levels are extremely elevated. Rouland et al. (2024) reported that wastewater from the meat industry with an influent BOD of 3.002 mg/L decreased to 71,3 mg/L, and COD from 12.050 mg/L decreased to 364 mg/L, yet the values still exceeded the allowable limits due to high initial loads. Similarly, Amri & Widayanto (2023) reported BOD, COD, and TSS concentrations in tofu wastewater at 1.825 mg/L, 15.844 mg/L, and 1.100 mg/L, respectively. COD values in tofu wastewater are typically higher than BOD because COD accounts for organic compounds that cannot be degraded biologically, such as fats and complex organic molecules, whereas BOD primarily reflects easily degradable compounds like sugars, proteins, and lipids (Hardyanti et al., 2021). Internal factors such as inadequate maintenance and poor operational management of the biogas system also contribute to elevated organic content. High BOD and COD levels indicate that if the wastewater is discharged into water bodies, the elevated organic load may rapidly deplete dissolved oxygen, resulting in the death of aquatic organisms.

The high BOD and COD values also indicate that the degradation process is still incomplete. The anaerobic process relies on microorganisms to biologically break down organic matter. However, some organic compounds, such as complex organic compounds, inorganic substances, or compounds that are toxic to microorganisms cannot be efficiently degraded through this biological process. Aromatic C–C bonds and lignin found in complex compounds are difficult to degrade because they are highly stable and resistant to breakdown by common enzymes, while long-chain ester bonds in lipids are also not easily hydrolyzed (Pollegioni et al., 2015). This condition indicates that anaerobic biogas treatment can reduce pollutant concentrations, but it is not yet sufficiently effective to meet wastewater quality standards.

B. Wastewater Pollutant Load

Pollutant load refers to the total amount of pollutants discharged into the environment, expressed in kilograms per day (kg/day) or kilograms per ton (kg/ton). The pollutant load value is important to assess the extent to which the wastewater has the potential to contaminate the environment. The pollutant load is calculated by converting the concentration of pollutants in the wastewater per day (kg/day) into kilograms per ton (kg/ton). The quality standards used as references were based on the Regulation of the Minister of Environment of the Republic of Indonesia No. 5 year of 2014. Based on the concentration data of tofu wastewater, the resulting pollutant load values were obtained and are presented in the following table:

Table 7. Wastewater Pollutant Load

No.	Parameter	Wastewater Discharge	Pollutant load		Quality Standard	Unit
			Influen	Effluen		
1.	BOD	11.162 Liter/day	57,2	4,6*	3	Kg/ton
2.	COD		144,3	28,9*	6	Kg/ton
3.	TSS		10,0	1,8	4	Kg/ton

Note *: Exceeds the quality standard
Source: (Research Result, 2025)

Based on Table 7, the pollutant load values in the effluent are lower than those in the influent, due to the anaerobic treatment process which helps reduce the concentrations of wastewater parameters in the tofu industry. Nevertheless, the pollutant load produced still exceeds the quality standard for BOD (4,6 kg/ton) and COD

(28,9 kg/ton). This indicates that the effluent wastewater contains high levels of organic matter and has the potential to cause environmental pollution. Meanwhile, the TSS value (1,8 kg/ton) remains below the quality standard, indicating that the remaining solid residues from the biogas process have been filtered or separated within the anaerobic system. According to Rahmalia et al. (2021), a tofu industry with a production capacity of 150 kg of soybeans generates a BOD pollutant load of approximately 7,5 kg/day, COD of 16,5 kg/day, and TSS of 1,35 kg/day. In comparison, the COD pollutant load is higher because complex organic and inorganic compounds remain in the wastewater and are not fully degraded during the biogas process. This indicates that wastewater management in tofu industries is still not optimal, both in terms of wastewater concentration and pollutant load, particularly for BOD and COD parameters.

A recommended improvement is to further treat the tofu wastewater using a combined anaerobic–aerobic system. The existing anaerobic treatment has been effective in reducing concentrations BOD, COD, and TSS of wastewater; however, additional treatment is still required. Aerobic processes can further oxidize the simpler compounds produced from anaerobic digestion, resulting in a more significant reduction of BOD and COD. Technologies that can be applied, such as aerobic biofilters with aeration using biofilm media such as honeycomb plastic or nipah fibers (Cahyani et al., 2024; Pratiwi & Roanisca, 2022); activated sludge systems with aeration using active microbial sludge (Avia et al., 2022); and aerobic granular sludge (AGS) technology using microbial granules in batch reactors (Zunidra et al., 2025).

CONCLUSION

Tofu industry X in Banjarbaru has implemented an anaerobic system, which has been proven to reduce TSS, BOD, and COD by 82,5%, 92%, and 80%, respectively. This treatment relies on anaerobic microorganisms that break down organic matter in the absence of oxygen, producing biogas as a useful by-product while reducing pollutant concentrations. These results indicate that the anaerobic process is effective in lowering the pollutant concentrations and load in tofu wastewater, however, the effluent BOD and COD levels still exceed the regulatory quality standards, indicating the need for additional treatment. An aerobic process can serve as a secondary treatment stage. By supplying sufficient oxygen, the aerobic system such as an aeration tank or activated sludge process enhances pollutant degradation, removes odors, and stabilizes the effluent quality, ensuring the treated wastewater is clearer, safer, and more suitable for reuse or environmental discharge.

Declaration by Authors

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