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MORALITY BEFORE KNOWLEDGE

Integrated EM4-based anaerobic and aerobic wastewater treatment for sustainable tofu industry effluent management

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ABSTRACT
Background: The Tahu Sehat Sari industrial area in Cokro Village is one of the largest tofu manufacturers, processing 3 tons of soybeans daily with 88 employees. However, wastewater quality tests reveal that the effluent exceeds regulatory limits set by Central Java Regional Regulation No. 5 of 2012, with BOD at 422.5 mg/L, COD at 845 mg/L, and TSS at 1940 mg/L. Effective wastewater treatment is necessary to ensure compliance with environmental standards and minimize pollution. **Methods:** This study evaluates wastewater treatment alternatives, including Anaerobic Digester, Anaerobic Biofilter, and Aerobic Biofilter, with the addition of Effective Microorganisms 4 (EM4) to enhance organic waste degradation. Wastewater samples were tested for COD, BOD, and TSS levels before and after treatment to assess removal efficiency. **Findings:** The implementation of EM4 significantly improved wastewater quality, achieving an 86% reduction in COD with a 0.3% EM4 concentration in aerobic treatment. EM4's fermentation bacteria effectively minimized organic contaminants. The selected treatment methods—Anaerobic Digester, Anaerobic Biofilter, and Aerobic Biofilter—proved suitable for treating tofu wastewater, with final effluent concentrations of COD at 2.4 mg/L, BOD at 0.3 mg/L, and TSS at 35 mg/L, meeting regulatory standards. The estimated cost for the construction of a Wastewater Treatment Plant (WWTP) is IDR 1,177,378,400, with monthly operation and maintenance expenses of IDR 6,110,297. **Conclusion:** The study confirms that an integrated wastewater treatment system using anaerobic and aerobic biofilters combined with EM4 is effective in reducing organic waste contamination in tofu industry effluent. Further assessment of land use and distribution systems is recommended to optimize wastewater management. **Novelty/Originality of this article**: This research contributes to sustainable wastewater treatment in tofu production by integrating EM4 technology with anaerobic and aerobic filtration, achieving high pollutant removal efficiency. The study also provides a financial analysis of WWTP implementation, highlighting its feasibility for similar small and medium enterprises.

KEYWORDS: wastewater; tofu waste; anaerobic biofilter; aerobic biofilter; EM4.

1. Introduction

Industry processing is defined as the production of raw materials chemically, mechanically, or manually in order to become finished or semi-finished goods, from goods with with less value to high value, which are closer to the end user (Almohaimeed & Abouelnour, 2025). Generally, sources of waste contamination are divided into several main activities, such as industries or factories, residential areas or food activities. However, these industries provide many positives and negatives, such as creating various kinds of jobs but producing liquid, gas, and solid waste (Schoeman et al., 2021). Liquid waste is the rest of the

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processing water that does not clot, while the grayish light yellow turbid liquid waste that is allowed stand tocan turn black and smell. Tofu waste has physical and liquid characteristics (Yudhistira et al., 2016). Liquid waste is waste that is discharged into the environment as well as being able to reduce the quality of the surrounding environment, waste are produced from industrical activity and can be processed by carrying out waste management, such as efforts to minimize the generation of or to utilize waste (Karunasena et al., 2024). Waste treatment is an effort to change the quality of waste so that it can meet the requirements of the applicable waste quality standards.

Nurman et al. (2017) mentioned the composition of organic matter from liquid waste in the form of 98.8% water, 1.74% phosphorus, 4.55% Fe, 0.1% carbohydrates, 0.13% fat, and 0.42% protein. Protein, which is broken down by soil microorganisms, releases nitrogen (N) compounds which are later absorbed by plant roots (Al Amin et al., 2017). Tofu waste contains nutrients N 1.24%, P2O5 5.54%, K2O 1.34% and C-Organic 5.803%, which are essential nutrients needed by plants. Tofu liquid waste has an organic composition of 40-60% protein, 25-50% carbohydrates, and 10% fat (Hardyanti et al., 2023). All of these organic materials can affect the concentration of phosphorus, nitrogen, and sulfur in the water (Marian & Sumiyati, 2019). Tofu waste has a BOD level ranging from 5000 to 10000 mg/l. Therefore, before the waste is discharged into the river, the BOD level must be lowered in accordance with the existing waste quality standards. BOD levels can be minimized by channeling the waste into various streams (Novembrianto et al., 2021). The stream is a jump on a sudden drop. The variation in flow creates different flow characteristics. This condition affects the process of reducing BOD levels (Hendrasari, 2016).

According to Syabana (2007), the main aspect in the use of lactic acid bacteria in the fermentation or processing process is the ability to produce bacteriocins that inhibit the growth of pathogenic bacteria and destructive bacteria, thus producing good results for waste treatment in minimizing harmful bacteria. Yeast can survive in concentrated solutions such as acid, salt, and excess sugar, making it able to survive with other microorganisms while being more optimal in breaking down chemical components with large volumes of output. Yeast is also able to withstand some heavy metals; research shows that Saccharomyces cereviceae (yeast) can act as a waste decontaminant (Satife et al., 2012). Anaerobic Digestion technology produces biogas energy that can replace fossil fuels as a renewable energy source, where the result of mixing two raw materials from different wastes produces 50-75% methane gas (CH_4), 19-34% carbon dioxide (CO_2) and <1% biohydrogen (H_2) (Suanggana et al., 2022).

As one of the solid and liquid waste-producing industries, tofu industry liquid waste has a higher potential to cause pollution to the environment than solid waste (Kurniawan et al., 2024). The main ingredient of the tofu industry is soybean extract, which is produced through the addition of vinegar. Tofu waste is included in organic waste which contains high levels of carbohydrates and proteins so that it is easier to decay by microorganisms (Burhanuddin et al., 2024) . Water as the main ingredient in washing and soaking soybeans in the production process, as a result the use of produces relatively large amounts of liquid waste. The source of pollution of waste, liquid tofu industry is from washing and soaking, soybeans, as well as the remaining ingredients of making tofu (Hartini et al., 2021). The high COD value occurs due to environmental factors that influence the amount of dissolved oxygen in the reactor enough to help bacteria break down pollutant compounds in the reactor (Farhami et al., 2025) . The protein content in tofu is high, so tofu liquid waste will contain high levels of organic matter and it has been proven that the concentration of pollutants in tofu waste is still high (Rizki et al., 2015).

In the case of waste-contaminated water, high TSS can inhibit the process of photosynthesis (preventing sunlight from entering the water), reducing the amount of dissolved oxygen released into the water by plants, thus disrupting the aquatic ecosystem. If the amount of suspended matter settles, the formation of sludge will impede flow, resulting in siltation (Soemirat, 2008). The relationship between TSS and water turbidity is very close. The higher the TSS value, the cloudier the water. Suspended solids will reduce the penetration of light and rays into the water, affecting the photosynthesis process and oxygen levels (Fardiaz, 2000). Hydraulic bacteria are catalyzed by extracellular enzymes in the form of lipase, protease, and cellulase (Said, 2000).

Tahu Sehat Sari is one of the culinary MSMEs engaged in the in tofu industry located Cokro Village, Tulung District, Klaten. The industry produces a variety of tofu products, such as white tofu, rolade and moringa tofu. The production of Industri Tahu Sehat Sari includes 1000 beans/day or 300 boxes/dayso the use of water is recorded at 250 L for soybean processing. The average tofu business in Indonesia is carried out through technology that is so that the still relatively simple level of efficiency in the use of raw materials and water resources is considered low and the level of waste generation is still high. The tofu industry in Indonesia is dominated by small-scale businesses with limited capital, so the business is locally chosen by many Indonesians. The level of education of human resources in it is relatively low, so they have not been able to treat waste.

2. Methods

2.1 Operational objectives of planning

The implementation of the planning will be carried out within six months from October 2023 to April 2024. The location of the planning is the Tahu Sehat Sari industrial wastewater treatment plant in Cokro Village, Klaten Regency, Tulu District. In the planning process, an operational objective is needed in the form of a collection of data that will be needed so that it can be used as a guideline in carrying out the planning. The operational objective can be observed from Table 1.

Table 1. Operational objectives

No	Operational objectives	Required data
1.	Analyzing the characteristics of wastewater in the processtofu production	
	Knowing the discharge, characteristics and sources of wastewater from the production process in the Tahu Sehat Sari industrial area	1. Source of wastewater 2. Characteristics of wastewater 3. Wastewater discharge per day 4. Quality standard in waste
2.	Testing one of the parameters with the anaerobic-aerobic method with the addition of knowing the level of wastewater pollution in the Tahu Sehat Sari industry	
	Conducting COD and TSS at the testing environmental engineering laboratory of Diponegoro University.	1. Tofu Tofu wastewater sample of Healthy Sari industry 2. COD and TSS parameter testing 3. Quality standard equation and COD TSS . test results
3.	Planning the design of WWTP in the Sari Tahu Sehat industrial area	
	Determine the WWTP and treatment system design the WWTP using the selected alternative according to the test results and characteristics of the tofu waste.	1. Removal unit efficiency of the 2. Treatment unit design criteria and calculations 3. Application of EM4 in biological planning 4. Existing condition of the land on which the WWTP will be built
4.	Planning the cost budget required in the construction and operation of WWTP in the Tahu Sehat Sari industry	
	Cost budget plan	1. Semarang City (HSPK) basic unit price

2.2 Sampling technique

Planning for the processing of Tahu Sehat Sari industrial waste involves direct sampling at the factory where the used soy water is collected in drums, to determine its quantity and quality. Sampling to determine the quantity in the form of discharge is done by calculating how many ml are needed in testing the efficiency of treatment in aerobic and anaerobic processes, while sampling to determine the quality is done by time composites in accordance with SNI 6989.59.2008.

The parameters to be tested are COD and TSS by adding EM4 as an acceleration in the removal of COD and TSS in industrial waste from Tahu Sehat Sari. These parameters were tested in the environmental engineering laboratory of Diponegoro University. The test was carried out using different bacterial variants to determine the efficiency of reducing COD and TSS levels through variants of 0.1%, 0.2%, and 0.3% of 1000 ml of EM4 waste as an accelerator. Using one aeration and two aeration variants for each bacterial variant. Aeration is included in physical treatment because it prioritizes mechanization over biological elements. It is a treatment process in which water comes into direct contact with air to increase the oxygen content of the water. The increase in oxygen levels minimizes volatile substances, such as hydrogen sulfide and methane, which cause unpleasant odors (Febiyanto, 2020). The carbon dioxide content in the water is reduced, and dissolved minerals such as iron and manganese are oxidized to form deposits that will be removed through filtration and sedimentation (Yuniarti et al., 2019). The following is table 3. testing techniques for reducing COD and TSS levels using EM4 bacteria. The testing matrix for this study can be seen in Table 2.

Table 2. Research testing matrix

No.	Treatment	Additions
1.	Anaerobic	-
2.	1 Aerator 2 Aerators	-
3.	1 Aerator 2 Aerators	0.1% EM4
4.	1 Aerator 2 Aerators	0.2% EM4
5.	1 Aerator 2 Aerators	0.3% EM4

2.3 Data collection techniques

The data required for planning are primary and secondary data, which must be valid and relevant so that the planning results can be produced correctly and in accordance with existing conditions. The following is a list of data requirements and data collection techniques in Table 3.

Table 3. Data collection techniques

No.	Data Type	Data	Data source	Data collection technique
1.	Primary	Existing condition of WWTP building land	Observation	Field survey
		Wastewater quantity	Observation and calculation	Measuring the quantity required for testing
		Wastewater quality	Laboratory testing results	Testing of wastewater parameters in the environmental engineering laboratory
2.	Secondary	Tofu industry wastewater quality standard	Regional Regulation of Central No. 5 Java Province Year 2012	Literature
		Semarang City (HSPK)Basic Unit Price List	Bina Marga and Cipta Karya Office of Central Java Province	Literature

2.4 Data processing and analysis techniques

The primary and secondary data collected were then analyzed to design the wastewater treatment plant (WWTP) for the Sari Healthy Tofu industrial estate in Cokro Village. The results of the data processing and analysis were the selection of alternative processing units for preliminary testing with treatments, as shown in Table 4.

Table 4. Waste feasibility testing

Testing	Process
Acclimatize EM4 so that the bacterial activation can occur for	Perform acclimatization by pouring EM4 bacteria into a 500 ml beaker to taste, EM4 .theis aerated for 24 hours so that activation can be carried out
Conducted tests using the Aerator on nine samples, one anaerobic aerobic. and eight	Prepare nine containers for testing and then pour 1 liter of tofu waste into each. Prepare six two-hose type aerators in order to insert into each container according to the test matrix. Putting EM4 bacteria in a container where 0.1% (1 ml EM4), 0.2% (2 ml EM4)), and 0.3% (3 ml EM4) correspond to the test matrix.
Conduct COD and TSS testing every two days for ten days of aerobic treatment.	Measurements were to constant every two days test the viability of the samples and the faster decline reaction of the nine aerobic treatments.
Tested and calculated the calibration curve to calculate COD from the test results.	Testing 1000 mg/L KHP solution with standard 100 mg/L, 300 mg/L, 500 mg/L, 700 mg/L, and 900 mg/L concentrations of to determine the calculation of COD concentration (Ccod).

The addition of EM4 has been proven to help accelerate biofilm growth, indicating that aerobic-anaerobic biofilter system treatment with the addition of 5% EM4 to hospital waste can reduce BOD and COD levels by up to 91.22% and 83.26% in 18 days. The tofu industry produces liquid waste that is directly discharged into water bodies, which can cause water pollution. Therefore, research has been conducted on the effectiveness of using EM4 bacteria in reducing COD in tofu wastewater with varying doses. The aim is to develop wastewater treatment technology that is easy to operate, especially for the tofu industry (Badrah et al., 2021).

3. Results and Discussion

3.1 General description

The Tofu Industry MSME in Cokro Village, Klaten Regency is the object of the Final Project case study. In the residential area with a focus on agricultural or food land, the Tofu Healthy Sari MSME is located on Jalan Prenjak, Bareng Kidul, Cokro, Tulung District, Klaten Regency, Central Java. The production process is carried out with simple technology and the resulting wastewater is processed into methane gas so that it can be returned to the water body, but with this treatment planning, more in-depth treatment will be carried out using a biological planning system that can process tofu waste more efficiently according to capacity. The MSME has 88 employees and a total area of 1.6 hectares.

The MSME has integrated processing into methane gas with disposal directly into the river in the lowland behind the MSME factory. The disposal has been tested and has contents that comply with the quality standards in the 2013 Central Java Regional Regulation parameters. With a daily waste production of 57,500 liters/day, with a daily cooking of 10 kg of soybeans per production that will be ground using 250 liters of clean water/production, where the clean water is used in soaking the soybeans before cooking and filtering before mixing with salt. The industry uses 23 kg of soybeans in each cooking process, with a total soybean usage of 4 tons per day. Tofu waste disposal can be seen in Figure 1.

Fig. 1. Tofu waste disposal

3.2 Data acquisition

The data acquisition in this study comes from primary data (field surveys, laboratory test results) and secondary data (quality books, design criteria, construction unit prices). Wastewater is collected using techniques in SNI 2008 so that the generated wastewater discharge can be collected, taking samples of MSME industrial wastewater in the final process of soybean water treatment disposal, in storage drums where tofu straw will be added to salt water as a soybean extract separator for tofu making. The maximum discharge, average discharge, minimum discharge, and peak factor can be determined, namely:
Maximum discharge Q_{max} = 3.93 m^3/h = 3930 liters/h
Minimum discharge Q_{min} = 1.67 m^3/h = 1670 liters/h
Average Flow Rate $Q_{average}$ = 2.4 m^3/h = 0.001 m^3/s
The average Q value is used to find the peak factor by plotting it in the graph above. So that the peak factor is obtained = 3.8

$$Q\ peak = Q\ average \times peak\ factor = 2.4\ m^3/hour \times 3.8 = 9.12\ m^3/hour = 9200\ l/hour \quad \text{(Eq.1)}$$

Based on the results of the calculation, it can be seen that the daily wastewater discharge is 57.6 m^3 per day with a maximum discharge of 3.93 m^3 and a minimum discharge of 1.67 m^3 per hour. Wastewater testing was carried out by adding EM4 with each range of 0.1%, 0.2%, and 0.3%. It can be seen that anaerobic experiments without any additions meet the quality standard criteria, and have a relatively high reduction efficiency of 68% in a residence time of 10 days with checks every two days. Anaerobic experiments without any additions can be seen in Table 5.

Table 5. Aerobic exercise without additional

COD Treatment	Time	Abs	x	fp	C	Percentage decrease
A_o	H-2	0.29	85	10	845	68%
	H-4	0.199	54	10	542	
	H-6	0.114	26	10	259	
	H-8	0.126	30	10	299	
	H-10	0.117	27	10	269	

It can be seen that the aerobic experiment of treatment with one aerator has a reduction efficiency not far from 66% reduction, but the final result of the 10-day treatment is below the quality standard with testing every two days. The aerobic experiment of treatment with one aerator can be seen in Table 6.

Table 6. Aerobic experiment of treatment with one aerator

COD Treatment	Time	Abs	x	fp	Ccod	Percentage decrease
A_0A_1	H-0	0.157	40	10	402	66%
	H-2	0.271	78	10	782	
	H-4	0.199	54	10	542	
	H-6	0.089	18	10	175	
	H-8	0.082	15	10	152	
	H-10	0.077	14	10	135	

It can be seen that the aerobic experiment of the two aerator treatment has a higher reduction efficiency with a 76% reduction, but the final result of the 10-day treatment is still below the quality standard with testing every two days. The two aerator aerobic experiment can be seen in Table 7.

Table 7. Two aerator aerobic experiment

COD Treatment	Time	Abs	x	fp	Ccod	Percentage decrease
A_0A_2	H-0	0.336	100	10	999	76%
	H-2	0.114	26	10	259	
	H-4	0.12	28	10	279	
	H-6	0.096	20	10	199	
	H-8	0.103	22	10	222	
	H-10	0.107	24	10	235	

It can be seen that the aerobic experiment of treatment with one aerator but with the addition of 0.1% of EM4 bacteria has a lower reduction efficiency with a 28% reduction, but the final result of the 10-day treatment is still below the quality standard with testing every two days. At the beginning of the treatment, before 24-hour aeration, there has been a drastic decrease in the amount of COD in the waste compared to the treatment without the addition. The EM4 0.1% experiment on one aerator treatment can be seen in Table 8.

Table 8. EM4 0.1% experiment on one aerator

COD Treatment	Time	Abs	x	fp	Ccod	Percentage decrease
$A_{0.1}A_1$	H-0	0.16	41	10	412	28%
	H-2	0.134	33	10	325	
	H-4	0.126	30	10	299	
	H-6	0.097	20	10	202	
	H-8	0.084	16	10	159	
	H-10	0.115	30	10	299	

It can be seen that the aerobic experiment of the two aerator treatment with the addition of 0.1% of EM4 bacteria has a higher reduction efficiency than one aerator with a 31% reduction, but the final result of the 10-day treatment is still below the quality standard with testing every two days.

Table 9. EM4 0.1% experiment on two aerators

COD Treatment	Time	Abs	x	fp	Ccod	Percentage decrease
$A_{0.1}A_2$	H-0	0.145	36	10	362	31%
	H-2	0.132	32	10	319	
	H-4	0.144	36	10	359	
	H-6	0.099	21	10	209	
	H-8	0.128	31	10	305	
	H-10	0.111	25	10	249	

At the beginning of the treatment, before 24-hour aeration, there has been a drastic decrease in the amount of COD in the waste compared to the treatment without addition. The EM4 0.1% experiment on two aerators can be seen in Table 9. It can be seen that the aerobic treatment experiment of one aerator with the addition of 0.2% of EM4 bacteria has a higher reduction efficiency than the addition of 0.1%, which is a 55% reduction with the final result of the 10-day treatment being below the quality standard with testing every two days. At the beginning of the treatment, before 24-hour aeration, there was a drastic decrease in the amount of COD in the waste compared to the treatment without the addition. The 0.2% EM4 experiment can be seen in Table 10.

Table 10. 0.2% EM4 experiment

COD Treatment	Time	Abs	x	fp	C	Percentage decrease
$A_{0.2}A_1$	H-0	0.163	42	10	422	55%
	H-2	0.131	32	10	315	
	H-4	0.15	38	10	379	
	H-6	0.099	21	10	209	
	H-8	0.098	21	10	205	
	H-10	0.094	19	10	192	

It can be seen that the aerobic experiment of treating two aerators with the addition of 0.2% of EM4 bacteria has a higher reduction efficiency compared to one aerator, namely a 61% reduction with the final result of the 10-day treatment being below the quality standard with testing every two days. At the beginning of the treatment, before 24-hour aeration, there was a drastic decrease in the amount of COD in the waste compared to the treatment without addition.

Table 11. EM4 experiment 0.2%

COD Treatment	Time	Abs	x	fp	C	Percentage decrease
$A_{0.2}A_2$	H-0	0.16	41	10	412	61%
	H-2	0.131	32	10	315	
	H-4	0.111	25	10	249	
	H-6	0.099	21	10	209	
	H-8	0.08	15	10	145	
	H-10	0.085	16	10	162	

It can be seen that the aerobic experiment of one aerator treatment with the addition of 0.3% of EM4 bacteria has a higher reduction efficiency than the addition of 0.2%, which is an 83% reduction with the final result of the 10-day treatment being below the quality standard with testing every two days. At the beginning of the treatment, before 24-hour aeration, there has been a drastic decrease in the amount of COD in the waste compared to the treatment without the addition.

Table 12. EM4 trial 0.3%

COD Treatment	Time	Abs	x	fp	Ccod	Percentage decrease
$A_{0.3}A_1$	H-0	0.247	70	10	702	83%
	H-2	0.133	32	10	322	
	H-4	0.115	26	10	262	
	H-6	0.087	17	10	169	
	H-8	0.079	14	10	142	
	H-10	0.072	12	10	119	

It can be seen that the aerobic experiment of the treatment of two aerators with the addition of 0.3% of EM4 bacteria has a lower reduction efficiency compared to one aerator, which is a 66% reduction with the final result of the 10-day treatment being below the quality standard with testing every two days. At the beginning of the treatment, before 24-hour aeration, there was a drastic decrease in the amount of COD in the waste compared to the treatment without addition.

Table 13. EM4 trial 0.3%

COD Treatment	Time	Abs	x	fp	Ccod	Percentage decrease
$A_{0.3}A_2$	H-0	0.166	43	10	432	66%
	H-2	0.184	49	10	492	
	H-4	0.12	28	10	279	
	H-6	0.087	17	10	169	
	H-8	0.083	16	10	155	
	H-10	0.08	15	10	145	

It can be seen that the efficiency of the reduction in each treatment has a fairly high percentage with the selection of an addition of 0.3% or 3 ml of EM4 bacteria addition in 100 ml of tofu wastewater which has the most ideal end result.

Table 14. TSS testing

Treatment	H-0	H-2	H-4	H-6	H-8	H-10
A0A1	1920	94	119	126	4	71
A0A2	1840	87	48	212	22	41
A0.1A1	179	66	30	106	50	26
A0.1A2	1670	73	36	9	7	22
A0.2A1	153	69	14	23	7	6
A0.2A2	162	76	20	29	9	9
A0.3A1	181	88	9	13	14	26
A0.3A2	176	90	11	4	3	22
A0		86	9	7	62	46

Secondary data focuses on relevant data obtained from the final project and is used as a reference to support the primary data to be processed. The quality standard is a reference for the maximum value based on official government regulations for the estimation of effluent that will be collected or returned to water bodies so as not to cause environmental pollution. Design Criteria are obtained through relevant literature for the determination or calculation of the treatment system that will be used as a reference in the efficiency of pollution from the production of tofu. The Construction Work Unit Price (HSPK) is used to determine the Cost Budget which will be adjusted to the type of work, materials and coefficients in the planning of the waste treatment plant.

3.3 Analysis of existing conditions

3.3.1 Tofu industry

Selected tofu MSMEs are located in Cokro Village, Tulung District, Klaten. The industrial land area in the agricultural area is 1.6 hectares, with the MSME having a vacant land capacity available for processing installations of ha with an elevation of ±223. The production process carried out per day is 230 batches, where each batch uses 10 kg of soybeans, so per day the MSME will use 2300 kg / day of raw soybeans which will be manually filtered and ground, using a boiler with a capacity of 40lt per cooking. The majority of rural MSMEs are in the medium production class and rely on the availability of energy, where the energy sources used during production are water, electricity, and fuel. Tofu production takes place from 8:00 a.m. to 4:00 p.m., and in one day of production 57.61m3/day of wastewater is produced. The wastewater produced is mostly generated from washing tofu production or filtering soybeans, where the waste falls into the nutrient category as it contains fat, carbohydrates, and protein. In the operational aspects, soybean soaking, grinding, filtering, clumping in drums, molding, and soaking with turmeric are carried out. Tofu production can be seen in Figure 2.

Fig. 2. Tofu production

3.3.2 Pipe dimensions and installation

The calculation of wastewater pipe dimensions is based on the calculation of wastewater discharge and wastewater load on each pipe. When using PVC pipes, several things must be considered to calculate the dimensions of the wastewater pipes, at a minimum peak velocity of 0.6 m/second.

$$Average = 2.4\ m^3/hour = 0.000667\ m^3/second \quad \text{(Eq.2)}$$

Calculate the peak discharge with a peak factor of 3.8 because it is in the category of small commercial businesses.

$$\begin{aligned} Qpeak &= fpeak \times Qr \\ &= 3.8 \times 0.000667\ m^3/second \\ &= 0.0025\ m^3/second \end{aligned} \quad \text{(Eq.3)}$$

$$\begin{aligned} Qmin &= fmin \times Qr \\ &= 0.4 \times 0.000667\ m^3/second \\ &= 0.0003\ m^3/second \end{aligned} \quad \text{(Eq.4)}$$

Pipe length = 11 m
Initial elevation = 228 m
Final elevation = 226 m
Planning
Assumption d/D = 0.6

$$\begin{aligned} Ground\ slope &= (Initial - Final) / Pipe\ length \\ &= (228 - 226)/11 \\ &= 0.18 \end{aligned} \quad \text{(Eq.5)}$$

Initial channel planting 0.6 m, final planting 0.7

$$\begin{aligned} Initial\ elevation &= 226\ m - 0.6\ m \\ &= 225.4\ m \end{aligned} \quad \text{(Eq.6)}$$

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$$\text{Final pipe elevation} = \text{Initial pipe T} - (\text{Planned slope x pipe length})$$
$$= 222.4\ m - (0.7\ x\ 11\ m)$$
$$= 218\ m \qquad \text{(Eq.7)}$$

$$\text{Final pipe T} = \text{Final ground elevation - final pipe elevation}$$
$$= 228 - 218$$
$$= 10\ m \qquad \text{(Eq.8)}$$

Pipe diameter
Assumption d/D = 0.6

$$Qp/Qfull = 0.65$$
$$Qfull = Qp : 0.65$$
$$= 0.0025\ m^3/second : 0.65$$
$$= 0.0038\ m^3/second \qquad \text{(Eq.9)}$$

Manning coefficient for PVC pipes, n = 0.012
Diameter

$$D = \frac{Qfull\ x\ n}{\left(0.312\ x\ \sqrt{s}\right)^{0.375}}$$
$$= \frac{0.0038\ m3/second\ x\ 0.012}{\left(0.312\ x\ \sqrt{0.18}\right)^{0.375}}$$
$$= 0.0001\ m \qquad \text{(Eq.10)}$$

Installed D = 0.1 m = 100 mm

$$V\ full = \frac{1}{n}\left(\frac{D}{4}\right)^{\frac{2}{3}} S^{\frac{1}{2}}$$
$$= \frac{1}{0.012}\left(\frac{0.1}{4}\right)^{\frac{2}{3}} 0.18^{\frac{1}{2}}$$
$$= 3.02\ m/second \qquad \text{(Eq.11)}$$

$$Qfull = A\ x\ V$$
$$= 0.25\ x\ 3.14\ x\ (0.1)2\ x\ 3.02\ m/second$$
$$= 0.024\ m^3/second \qquad \text{(Eq.12)}$$

$$Qp/Qfull = 0.0025\ m^3/second: 0.024\ m^3/second$$
$$= 0.1 \qquad \text{(Eq.13)}$$

$$d/D = 0.100$$
$$d = 0.100\ x\ 100\ mm$$
$$= 10\ mm$$
$$= 1\ cm \qquad \text{(Eq.14)}$$

$$Vp/Vf = 0.35$$
$$Vpeak = Vfull\ x\ 0.35$$
$$= 3.02\ m/second\ x\ 0.35$$
$$= 1.1\ m/second\ \ \text{(meets self-cleansing velocity of 0.6–3 m/second)} \qquad \text{(Eq.15)}$$

3.4 Design calculation

3.4.1 Equalization tank

The Equalization Tank is used as a wastewater quantity stabilization unit to prevent hydraulic and organic surges (Hamid and Razif, 2014). The tank functions to minimize shock loading and stabilize the discharge that enters the IPAL, with a detention time ranging from 4 to 8 hours. Cumulative volume calculation can be seen in Table 15.

Table 15. Cumulative volume calculation

Hour	Debit	Outgoing volume	Cumulative inbound volume	Cumulative volume out	Cumulative Differentiation
24 – 1	1.67	2.4	1.67	2.4	0.730
2- 1	1.83	2.4	3.5	4.8	1.300
2 – 3	2.19	2.4	4.02	7.63	3.610
3 – 4	2.28	2.4	4.47	10.46	5.990
4 – 5	2.25	2.4	4.53	13.29	8.760
5 – 6	2.31	2.4	4.56	16.12	11.560
6 – 7	2.33	2.4	4.64	18.95	14.310
7 – 8	2.42	2.4	4.75	21.78	17.030
8 – 9	2.34	2.4	4.76	24.61	19.850
9 –10	2.08	2.4	4.42	27.44	23.020
10-11	2.32	2.4	4.4	30.27	25.870
11 – 12	2.34	2.4	4.66	33.1	28.440
13- 12	3.32	2.4	5.66	35.93	30.270
13 – 14	3.41	2.4	6.73	38.76	32.030
14 –15	3.68	2.4	7.09	41.59	34.500
15 –16	3.93	2.4	7.61	44.42	36.810
16 –17	2.47	2.4	6.4	47.25	40.850
17 – 18	2	2.4	4.47	50.08	45.610
18 - 19	1.95	2.4	3.95	52.91	48.960
19 –20	2.39	2.4	4.34	55.74	51.400
20 – 21	1.85	2.4	4.24	58.57	54.330
21 – 22	2.39	2.4	4.24	61.4	57.160
22 – 23	1.94	2.4	4.33	64.23	59.900
23 – 24	1.92	2.4	3.86	67.06	63.200

$Q_{max.}$ = 3.93 m^3/h = 0.00109167 m^3/s
Q_{min} = 1.67 m^3/hour = 0.00046389 m^3/second
$Q_{average =}$ 0.24 m^3/hour = 0.00006667 m^3/second
Q/day = 57.61 m^3/day = 2.4 m^3/hour
For wastewater quality, the level of organic compounds entering the tank with parameters:
$COD_{influent}$ = 845 mg/L
$TSS_{influent}$ = 1940 mg/L
$BOD_{influent}$ = 845 mg/L x 0.5 = 422.5 mg/L

3.4.2 Anaerobic digester

Tofu liquid waste is included in organic waste that has protein, fat, and carbohydrate content which are organic compounds that can produce methane and carbon dioxide if decomposed aerobically or anaerobically (Widayat et al., 2019). Methane is a gas that serves as the primary component for biogas production. The liquid waste from tofu production contains up to 50% methane, making it highly suitable as a feedstock for biogas generation (Soenarno, 2022; Rajabya, 2023).

Table 16. Anaerobic digesters

Parameters	Unit	Value	
		Low – rate	High – rate
Digestion Time	Day	30 – 60	10 – 20
Organic Solids Loading	$KgVVS/m^3 \cdot day$	0.64 – 1.6	2.40 – 6.40
Depth	m	3.66 – 13.7	
Diameter	m	4.57 – 38.1	

(Reynolds & Richards, 1996)

Therefore, anaerobic digesters are used to break down wastewater contamination while providing benefits for tofu factories and can be seen in Table 16. It can be concluded that the removal efficiency of the anaerobic digester in the three representative parameters uses the formulas (Sasse, 2009; Polprasert, 2007), which are as follows:

Table 17. Anaerobic digester removal efficiency

Parameters	In	Preliminaries	Out
BOD	422,5 mg/L	67%	139 mg/L
COD	845 mg/L	61%	330 mg/L
TSS	1940 mg/L	50%	970 mg/L

3.4.3 Initial settling tank

The Initial Settling Tank is used to settle particles and break down solid organic compounds such as sand, sludge and suspended organic matter.
Design Criteria:
Average residence time = 3-5 hours
Surface load = 20-50 m^3/day
BOD influent = 139 mg/L
COD influent = 330 mg/L
TSS influent = 970 mg/L
It can be concluded that the removal efficiency of the settling tank in the three representative parameters uses the formulas (Tchobanoglous et al., 2014; Said, 2000), which are as follows:

Table 18. Initial settling basin removal efficiency

Parameter	In	Efficiency	Out
BOD	139 mg/L	42%	81 mg/L
COD	330 mg/L	38%	205 mg/L
TSS	970 mg/L	65%	340 mg/L

3.4.4 Anaerobic biofilter tank

Anaerobic Filter Tank is an easy-to-operate alternative that uses generally smaller land and is built underground (Singh et al., 2023). The tank includes two tanks or two units, namely a settler and an anaerobic filter. It can be concluded that the removal efficiency of the anaerobic biofilter tank in the three representative parameters uses the formula (Sasse, 2009; Said, 2000), which are as follows:

Table 19. Removal efficiency of the anaerobic filter tank

Parameters	In	Efficiency	Out
BOD	81 mg/L	85%	13 mg/L
COD	205 mg/L	76%	52 mg/L
TSS	340 mg/L	21%	mg/L

3.4.5 The aerobic filter

The aerobic filter receives wastewater from the anaerobic filter using a special medium made of plastic wasp nest material, by aerating or adding air so that microorganisms can break down organic substances in the wastewater (Abdulgani et al., 2025).
Discharge = 57.61 m^3/day
BODin = 31 mg/L
CODin = 50 mg/L
TSSin = 268 mg/L
HRT (residence time) = 6 - 8 hours (Said, 2000)

It can be concluded that the removal efficiency of the aerobic biofilter in the three representative parameters uses the formulas (Sasse, 2009; Said, 2000; Tchobanoglous et al., 2014), which are as follows:

Table 20. Removal efficiency of the aerobic filter tank

Parameters	In	Efficiency	Out	EM4 Addition	Out
BOD	13 mg/L	79%	2.7 mg/L	90%	0.3 mg/L
COD	52 mg/L	73%	14 mg/L	83%	2.4 mg/L
TSS	268 mg/L	8%	250 mg/L	86%	35 mg/L

3.5 Hydraulic profile

The hydraulic profile is a calculation that is needed to determine the elevation of the water level drop using the headloss equation in buildings and wastewater pipes due to drops, turns, and water flow velocity in treatment buildings. The hydraulic profile determines the depth of the excavation during construction and the placement and requirements of auxiliary buildings.
The hydraulic profile is calculated using the headloss equation in each building unit.
Equalization Tank
Initial Elevation Height of the Tank = 0.0183

$$\begin{aligned} \text{Pump head} &= \text{Static } Hf + \text{Velocity } Hf + \text{Major } Hf + \text{Minor } Hf \\ &= 4\text{ m} + 0.57\text{ m} + 0.0221\text{ m} + 0.034\text{ m} \\ &= 4.63\text{ m} \end{aligned} \quad \text{(Eq.16)}$$

$$\begin{aligned} \text{Final elevation} &= \text{Initial elevation} + \text{pump head} - (\text{major } Hf + \text{minor } Hf \\ &\quad + \text{residual pressure}) \\ &= 0.0183\text{ m} + 4.63 - (0.0221\text{ m} + 0.034\text{ m} + 0.5\text{m}) \\ &= 4.1\text{ m} \end{aligned} \quad \text{(Eq.17)}$$

Anaerobic Digester
Initial elevation height of tank = 4.1 m
Major Hf = 0.1 m
Minor Hf = 0.03 m

$$\begin{aligned} \text{Final elevation} &= \text{Initial elevation} - \text{Major } Hf - \text{Minor } Hf \\ &= 4.1\text{ m} - 0.1 - 0.03 \\ &= 3.96\text{ m} \end{aligned} \quad \text{(Eq.18)}$$

Initial Settling Tank
Initial tank elevation height = 3.96 m
Outlet pipe Hf = 0.0723 m

$$\textit{Final elevation} = \textit{Initial elevation} - \textit{Pipe Hf} = 3.96\ m - 0.0723\ m = 3.89\ m \quad \text{(Eq.19)}$$

Anaerobic Biofilter Tank
Basin initial elevation height = 3.89
Head loss and turning height = 0.9 m
Filter media head loss = 0.00062 m
Pipe friction head loss = 0.034 m

$$\textit{Final elevation} = 3.89\ m - 0.9\ m = 2.99\ m \quad \text{(Eq.20)}$$

Aerobic Biofilter Basin
Initial tank elevation height = 2.99 m
Filter media height = 0.00035 m
Pipe friction height = 0.049 m

$$\textit{Final elevation} = 2.99\ m - 0.104\ m = 2.98\ m \quad \text{(Eq.21)}$$

Final Settling Tank
Basin initial elevation height = 1.59 m
Outlet pipe head loss = 0.0723 m

$$\textit{Final elevation} = \textit{Inlet elevation} - \textit{Pipe head loss} = 1.59\ m - 0.0723\ m = 1.51\ m \quad \text{(Eq.22)}$$

3.6 Operations and maintenance

Operational and maintenance activities are carried out for the continuity of the planning pipeline network function, operational of the wastewater distribution system such as the drainage of wastewater from the service and collection system, then processing at the wastewater treatment plant. The operational maintenance of the Tofu MSME Wastewater Treatment Plant in Cokro Village requires procedures to maintain the performance of the treatment units, each of which has a different operation. Employees who are given responsibility must periodically check the pump in the equalization tank to ensure that it is running smoothly so that the waste continues to run as planned. Maintenance is carried out by ensuring that the tank is free of solid waste, ensuring that the manhole is closed again, and avoiding contact between the electronic accessories and the water (Györki et al., 2023).

Anaerobic degradation does not require complicated operation, but it is necessary to pay attention to the biogas produced by the treatment unit (Elsayed et al., 2024). It is necessary to pay attention to the biogas outtake so that it can be an indicator of damage where a decrease in biogas is a sign of damage to the treatment unit. The initial and final settling tanks must be checked along with the unit and accessories once a month. The anaerobic biofilter tank uses a wasp nest medium for the growth and adhesion of bacteria in the process of degrading organic substances contained in wastewater. Sludge checks must be carried out periodically as sludge can reduce the capacity of the pond. The aerobic biofilter tank has a blower to supply air so that maintenance activities, namely checking the specifications of the blower once a week, ensuring that electrical equipment is protected from water, and maintaining the pump once every four months, are carried out in addition to repairing any damage.

3.7 Budget plan

The following is a recapitulation table of the procurement planning for the waste water management system for tofu SMEs in Cokro Village, Klaten Regency, which consists of preparatory work and construction of the wastewater treatment plant.

Table 21. Recapitulation of the wastewater treatment plant budget plan

No.	Description	Cost
A	Preparatory work	IDR 24,862,734
B	Structural work	IDR 70,768,781
II	Equalization basin structure work	IDR 66,228,719
III	Anaerobic degradation structure work	IDR 23,454,370
IV	Preliminary settling basin structure work	IDR 62,033,544
V	Anaerobic biofilter structure work	IDR 50,624,531
VI	Aerobic biofilter structure work	IDR 43,620,600
VII	Structural work of final settling basin	IDR 127,978,248
C	Accessories	IDR 63,220,995
D	Mechanical and electrical	IDR 31,308
Total		IDR 532,823,831

There are also monthly operational and maintenance costs that are calculated with the aim of maintaining the wastewater treatment plant so that it can continue to operate for a long period of time.

Table 22. Operational and maintenance budget calculation

Activity/Item	Quantity	Unit	Unit cost (IDR)	Total cost (IDR)
EM4 addition	900	ml	IDR 45,000	IDR 45,000
Sludge drainage	1.1	m3	IDR 70,000	IDR 77,000
WWTP officer	2	people	IDR 2,244,012	IDR 4,488,024
Electricity cost	16.54	kW	IDR 944,297	IDR 944,297
Sludge transportation	1.1	m3	IDR 40,000	IDR 44,000
Subtotal				IDR 5,598,321

4. Conclusions

The research was conducted in Cokro Village, Klaten Regency at the Sari Healthy Tofu Industry. After transporting the wastewater, it was tested with COD and TSS parameters by assessing the quality standards in accordance with Central Java Regional Regulation No. 5 of 2012 on Tofu Industry Wastewater Quality Standards with a wastewater quantity of 57.6 m3/day, which produced BOD parameters of 422.5 mg/L, COD of 845 mg/L, and TSS of 1940 mg/L. These results indicate that it does not meet the requirements and must undergo integrated waste treatment. The research was determined using EM4, which is suitable for reducing organic waste, where tofu waste is full of protein, fat, and carbohydrates. And tests show that EM4 can minimize COD content by 86% for the use of 0.3% of the waste in aerobic use. EM4 contains fermented fungi and bacteria that can minimize organic contaminants and other microorganisms, resulting in a fairly high percentage of removal efficiency.

The chosen treatment alternatives are Anaerobic Digester, Anaerobic Biofilter, and Aerobic Biofilter. Where the anaerobic digester is suitable for dealing with the methane gas emitted by liquid waste from tofu. The final result of the treatment selected was COD of 2.4 mg/L, BOD of 0.3 mg/L, and TSS of 35 mg/L. The Cost Budget Plan for the Wastewater Treatment Plant (WWTP) Development reaches IDR 1,177,378,400 for a description of the construction activities, and there is operation and maintenance of the installation which costs IDR 6,110,297 per month. A re-examination of the distribution system and land use of the WWTP unit by relevant parties and experts to reduce errors in planning and direct cooperation in planning development. Further utilization and planning is needed for the biogas produced for the maximum development of industry and the village. This research contributes to sustainable wastewater treatment in tofu production by integrating EM4 technology with anaerobic and aerobic filtration, achieving high pollutant removal efficiency. The study also provides a financial analysis of WWTP implementation, highlighting its feasibility for similar small and medium enterprises.

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Author Contribution
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