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Original Research Article

Advanced Treatment of Tofu Wastewater using Multilevel Filtration and TiO2 Photocatalysis as Promising Approach for Effective Wastewater Remediation

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Abstract
Tofu production is known to generate large amounts of wastewater containing a variety of organic compounds, chemicals, and potentially hazardous substances. It is very important to apply proper treatment of harmful substances that impact this wastewater. The aim of this study is to explore advanced techniques for treating tofu wastewater by combining multilevel filtration and TiO_2 photocatalysis methods. To evaluate the efficiency of the treatment process, influent and effluent parameters, including pH, total suspended solids (TSS), and chemical oxygen demand (COD), are carefully monitored and measured. The results clearly demonstrate the impressive removal efficiency achieved through the combined use of multilevel filtration and TiO_2 photocatalysis in treating tofu wastewater. The treated wastewater showed a promising efficiency in pH (100%), a significant decrease in TSS (40%), and COD (72%). the final measurements of pH met the standards set by government regulations, indicating successful remediation of these specific parameters. Even though TSS and COD haven't met the standard limits, each of them shows a very promising efficiency improvement. Towards the end of this study, it is suggested that the combination of these methods holds promise for effectively remediating tofu wastewater.

Keywords: Multilevel filtration; TiO_2 photocatalysis; tofu wastewater

1. Introduction

The rise of the small to medium-sized home tofu industry has been prominent in urban areas, driven by the growing demand for tofu among the general population. Tofu, a nutritious and affordable food option, has become a staple in the daily diet of many individuals. However, the production process of tofu generates a substantial amount of wastewater, consisting of both solid and liquid waste. Solid waste primarily originates from soybeans, while liquid waste is a by-product of soybean washing and tofu manufacturing. Traditionally, solid tofu waste is utilized as animal feed, while liquid waste is often directly discharged into water bodies without proper treatment (Cahyani et al., 2021; Laksono Putro et al., 2021).

Unfortunately, tofu wastewater contains various harmful substances that can pose significant environmental hazards. The high levels of proteins, fats, and carbohydrates in the wastewater contribute to elevated pH levels, chemical oxygen demand (COD), and total suspended solids (TSS), which result in water pollution and unpleasant odours (Faisal et al., 2014). Recognizing the potential detrimental impact of untreated wastewater, regulatory standards have been implemented by the government to control the discharge of wastewater into the environment. Compliance with these standards is essential to prevent pollution and safeguard public health.

High pH, COD, and TSS concentrations that do not meet water quality standards can be treated using various alternative methods (Zuhaela et al., 2021). Basically, tofu wastewater treatment is the same as industrial wastewater treatment in general, which includes physical, chemical and biological treatment. However, the selection depends on the quality parameters of the tofu liquid waste that will be treated. and in line with technological developments in wastewater management, the development of tofu wastewater management is also growing. but it takes the right selection to produce high efficiency (Adriansyah et al., 2019). The development of effective treatment methods for tofu wastewater is crucial for mitigating pollution and ensuring environmental sustainability. There are several other treatment methods that can be employed for tofu wastewater. Some of these methods include anaerobic digestion, aerobic treatment, coagulation and flocculation, membrane filtration, constructed wetlands, and chemical oxidation.

In tofu wastewater, anaerobic digestion involves the microbial breakdown of organic matter in the absence of oxygen. This process leads to the generation of biogas, primarily composed of methane, which can be utilized as a renewable energy source. Additionally, anaerobic digestion effectively reduces the organic load of tofu wastewater, making it a promising method for sustainable wastewater management (Wresta et al., 2021). Aerobic treatment offers a reliable and energy-efficient approach for the remediation of tofu wastewater. Aerobic treatment methods rely on the presence of oxygen to support the growth of aerobic microorganisms that metabolize organic compounds (Dianursanti et al., 2014). Activated sludge, a commonly employed aerobic treatment process, utilizes a mixture of microorganisms to degrade organic matter in tofu wastewater. The activated sludge system provides an oxygen-rich environment, enabling the microorganisms to efficiently break down organic pollutants and reduce chemical oxygen demand (COD) and biochemical oxygen demand (BOD) levels (Viareco et al., 2023).

Coagulation and flocculation are chemical-based treatment methods that involve the addition of coagulants to tofu wastewater to induce the formation of flocs. Aluminium or iron salts are commonly used coagulants, which destabilize suspended particles and organic matter. The coagulated particles subsequently form larger aggregates (flocs) that can be easily separated through sedimentation or filtration. Coagulation and flocculation effectively remove suspended solids and some organic compounds, improving the clarity and quality of the treated wastewater (Amri et al., 2020). Membrane filtration techniques, such as microfiltration, ultrafiltration, and reverse osmosis, are gaining prominence in tofu wastewater treatment (Elystia et al., 2023). These methods employ semi-permeable membranes with varying pore sizes to physically separate suspended solids, dissolved organic compounds, and even some ions from the wastewater. Membrane filtration offers a highly efficient and selective treatment process, yielding high-quality effluent with reduced organic and particulate content. However, it requires careful monitoring and maintenance to prevent fouling and membrane deterioration.

Constructed wetlands provide a natural and sustainable approach to tofu wastewater treatment. These engineered systems mimic the processes that occur in natural wetland ecosystems. Tofu wastewater is directed through specially designed wetland cells containing wetland plants and microbial communities. The plants absorb nutrients and promote oxygenation, while microorganisms in the wetland substrate facilitate the breakdown of organic matter (Oktorina et al., 2019; Seroja et al., 2018). Constructed wetlands offer an aesthetically pleasing and ecologically beneficial solution for nutrient removal and overall wastewater treatment. Chemical oxidation methods involve the use of strong oxidizing agents, such as hydrogen peroxide (H_2O_2) or ozone (O_3), to degrade organic pollutants in tofu wastewater (Cahyani et al., 2021; Karamah et al., 2019; Zuhaela et al., 2021). These agents introduce reactive oxygen species that react with and break down organic compounds. Chemical oxidation is effective in targeting recalcitrant and hard-to-degrade compounds, leading to their mineralization and improved wastewater quality. However, the use of chemicals in large-scale applications should be carefully considered due to potential cost and environmental implications.

The treatment of tofu wastewater is crucial for minimizing its environmental impact and ensuring sustainable tofu production practices. Various treatment methods offer distinct advantages and considerations. The selection of the appropriate method should be based on factors such as pollutant composition, treatment objectives, operational requirements, and environmental considerations. A combination of treatment methods or hybrid systems may offer synergistic benefits and optimize overall treatment efficiency (Karamah et al., 2019). Advanced treatment methods such as multilevel filtration and TiO_2 photocatalysis have emerged as promising approaches to address these concerns and achieve effective wastewater treatment (Apollo et al., 2014; Bazargan, 2022; Wang et al., 2021).

Multilevel filtration has emerged as a valuable approach in treating various types of wastewaters, including that from the tofu industry. Multilevel filtration involves the use of different filter media, including sand, activated carbon, zeolite, and gravel, to remove suspended particles from the wastewater. Each layer of the filtration media serves a specific purpose in the purification process (Sitasari and Khoironi, 2021). Sand acts as a physical barrier, capturing particles that are larger than its pore size. Activated carbon is particularly efficient in removing substances like pesticides, volatile organic compounds (VOCs), and certain heavy metals. Zeolite's unique structure allows it to selectively trap specific ions based on their size and charge. Gravel serves as the final layer in the filtration process. Its main function is to provide support and prevent disturbance to the underlying filter media layers. Additionally, gravel helps to distribute the flow of water evenly across the filter bed, ensuring uniform filtration. It acts as a protective layer, preventing disruption to the underlying media and maintaining the integrity of the filtration system. This method offers a cost-effective and efficient solution for wastewater treatment and has been successfully implemented in various communities (Sitasari and Khoironi, 2021).

Photocatalysis, an advanced wastewater treatment method, relies on catalysts to initiate chemical reactions upon exposure to light, particularly ultraviolet (UV) or visible light. In the realm of photocatalysis, catalysts play a pivotal role in accelerating reactions that lead to the degradation of pollutants in wastewater. Diverse catalysts, such as Titanium Dioxide (TiO_2), Zinc Oxide (ZnO), Ferric Oxide (Fe_2O_3), and various semiconductors, have been explored for their potential to facilitate these reactions. Each catalyst possesses unique properties that make it suitable for specific applications and reaction conditions. However, TiO_2 stands out prominently among catalysts due to its manifold advantages. TiO_2 photocatalysis, on the other hand, harnesses the high photocatalysis activity of Titanium Dioxide to degrade organic compounds and eliminate odours in the treated water. This environmentally friendly catalyst is readily available and has demonstrated significant potential in wastewater remediation (Fathana et al., 2021). The photocatalysis process occurs when TiO_2 is exposed to ultraviolet (UV) light, triggering a series of chemical reactions that break down organic pollutants into harmless by-products (Rahmadhani et al., 2023).

Considering the effectiveness and potential benefits of these advanced treatment methods, this study aims to investigate the application of multilevel filtration and TiO_2 photocatalysis in the advanced treatment of tofu wastewater. The main focus of this research will be to evaluate the changes in pH, COD, and TSS levels before and after treatment, with the objective of assessing the efficiency of these methods in achieving effective wastewater remediation and environmental protection. This study endeavours to bridge the gap in knowledge regarding advanced treatment methods for tofu wastewater, aiming to pave the way for effective wastewater remediation techniques that can ensure the sustainability and well-being of both the tofu industry and the environment.

2. Methods

This study aims to determine the pH, COD, and TSS content of greywater before and after treatment using a combination of multilevel filtration and TiO_2 photocatalysis (Titanium Dioxide) method. A total of 25 litter of tofu wastewater sample was used as an influent, collected from several home-scale tofu processing units in Simpang IV Sipin Subdistrict, Jambi City. The influent was tested for pH, COD, and TSS parameters as the initial influent measurements. The phase starts with influent treated with a multilevel filtration reactor after that the treated sample as the first effluent was taken into a photocatalysis reactor to be treated for the second phase. Samples of tofu wastewater are put into a multilevel filter for a certain period of time until all of the influent passes through the filter. The filtered influent was collected in a storage vessel, then transported to the photocatalysis reactor for next processing. In this study, the photocatalysis process used TiO_2 (Titanium Dioxide) as a catalyst to increase the reaction rate. The content of titanium dioxide used was 2.5 grams per sample and in this study 3 samples were used in the photocatalysis process with contact times of 30 minutes, 90 minutes and 150 minutes. the end result of this process was used as the second effluent of the second phase.

The second effluent was tested for pH, COD, and TSS parameters as the final effluent measurements. Measurement of parameters pH, TSS, COD refers to the Indonesian National Standard (SNI) no. 06-6989-2004 for pH by electrometric method, TSS by gravimetric method, and COD by open reflux method. The testing of pH, COD, and TSS parameters was performed in a KAN-accredited laboratory. The experiments for a combination of the multilevel filtration and TiO_2 photocatalysis (Titanium Dioxide) method were carried out in the Environmental Engineering Laboratory of Batanghari University in May 2023. Parameter measurement results compared with Minister of Environment and Forestry Regulation No. P.68/Menlhk-Setjen/2016 on Domestic Wastewater Quality Standards.

However, the exact values at specific points might not be available due to limitations in the experimental setup or testing process. The function of the equation in polynomial extrapolation is of paramount significance. The results obtained from the experiments were compiled and presented graphically, forming the foundation for the subsequent utilization of polynomial extrapolation. This extrapolation aimed to predict conditions that align with regulatory standards, facilitated by the utilization of Microsoft Excel software. The software aided in determining the optimal contact time alongside predetermined catalyst levels. The objective was to attain results that conform to the quality standards outlined in the Minister of Environment and Forestry Regulation No. P.68/Menlhk-Setjen/2016 on Domestic Wastewater Quality Standards. This predictive tool enhances the study's applicability by offering insights into the effectiveness of the treatment methods across a wider spectrum of conditions, ultimately contributing to more robust and well-informed wastewater remediation strategies.

2.1 Multilevel Filtration Reactor Design

The multilevel filtration reactor in this study was designed using PVC pipes with a height of 150 cm and a diameter of 4 inches. The filter media used consisted of sand, activated carbon, zeolite, and gravel, with each having a thickness of 15 cm. Cotton wool was used as a separating layer for each layer of the filter media. At the bottom of the reactor, there was an outlet for treated effluent which was equipped with a valve to avoid leakage. The treatment process in a multilevel filtration reactor occurs by gravity without additional booster pumps. Because of that, it requires long time periods to gain the best result. The influent that has been processed will be collected in a container through the bottom outlet. The reactor schematic design can be viewed in Figure 1.

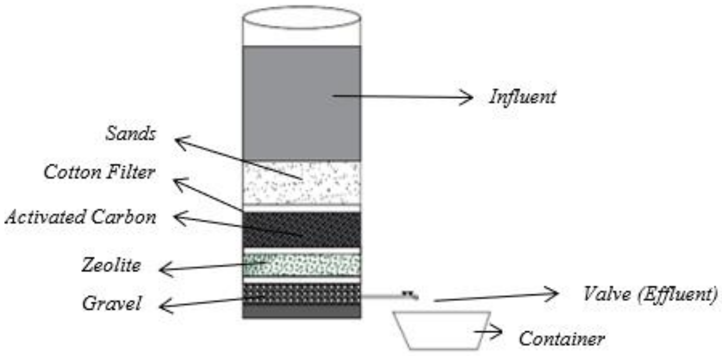

Figure 1. Multilevel filtration reactor schematic design

2.2 Photocatalysis Reactor Design

The photocatalysis reactor is made of glass and coated with aluminium foil on the outside to reflect light toward the influent sample. It is designed in a closed configuration with dimensions of 45 cm x 35 cm x 40 cm and equipped with 4 UV lamps with a power of 8 watts each. The influent treatment involves stirring at a speed of 1000 rpm using a magnetic stirrer, with a stirring temperature of 200ºC. Titanium Dioxide, which has been mixed into the sample, is stirred inside the reactor with the assistance of UV lamps for the photocatalysis process. The photocatalysis reactor schematic design can be viewed in Figure 2.

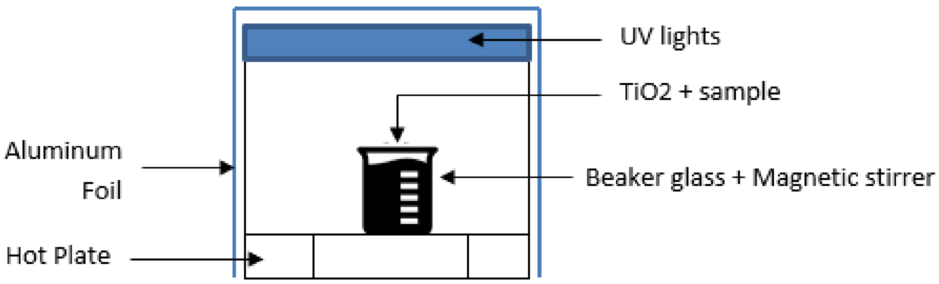

Figure 2. Photocatalysis reactor schematic design

3. Result and Discussion

3.1. Influent Characteristic

The results of the initial sample of tofu wastewater in this study and comparison with other studies are shown in Table 1. Understanding the initial condition of tofu wastewater from different sources holds pivotal importance for several compelling reasons. Firstly, it establishes a foundational baseline, offering a clear snapshot of the wastewater's quality and characteristics before any treatment intervention. This baseline becomes the touchstone against which treatment effectiveness is measured, ensuring accurate evaluation of pollutant removal. The influent in this study was included in the degradation of low acidity compared to other studies which had very high acidity. The suspended solids content in the initial sample was the lowest compared to the other samples. The sample COD level is in the middle range value compared to the others. Based on the Regulation of the Minister of Environment and Forestry Regulation No. P.68/Menlhk-Setjen/2016 on Domestic Wastewater Quality Standards, the characteristics of the influent do not meet the allowable standards discharge limit.

Table 1. The characteristic of initial tofu wastewater

No	Source	Parameter		
		pH	TSS (mg/l)	COD (mg/l)
1.	This study	5.43	157	4147

2.	Seroja et al., 2018	3.9	552	5759
3.	Karamah et al., 2019	3.7	1816	9649
4.	Pramana and Kasman, 2019	4.53	470	768
5.	Amri et al., 2020	3.5	1100	1017
6.	Cahyani et al., 2021	3.6	936	29,700
7.	Minister of Environment and Forestry Regulation No. P.68/Menlhk-Setjen/2016 on Domestic Wastewater Quality Standards	6 - 9	30	100

3.2. Treatment Process

When treatment starts in the first phase, 25 litres of influent was poured into the multilevel filtration reactor. It took 60 minutes for the influent to pass through all the layers of filtration from the top layer to the bottom layer by gravity until nothing remained at the top. The filtered effluent was stored in a container and divided into 9 samples for the photocatalysis process, 3 samples each for the final measurement of pH, TSS and COD waste. The second phase, photocatalysis using TiO_2 (Titanium Dioxide) with a contact time of 30 minutes, 90 minutes and 150 minutes. A total of 2.5 grams of TiO_2 was mixed for each sample in a beaker glass with a stirring speed of 1000 rpm and heated at 200°C. During the mixing and heating process, the mixed sample is irradiated with Ultraviolet (UV) light in a photocatalytic reactor. After that, the samples were cooled to room temperature and the UV was switched off. When the temperature has reached room temperature, the sample was measured for the final measurement of pH, TSS and COD. The final effluent results in this second stage are shown in Table 2.

Table 2. The final measurement for effluent

Parameter	Contact Time		Effluent	Efficiency	Discharge limit
	Multilevel Filtration (minutes)	TiO2 Photocatalysis (Minutes)			
pH	60	30	5.7	47%	6 – 9
	60	90	6.5	>100%	
	60	150	6.9	>100%	
TSS	60	30	133 mg/l	15%	30 mg/l
	60	90	125 mg/l	20%	
	60	150	94 mg/l	40%	
COD	60	30	1511 mg/l	64%	100 mg/l
	60	90	1333 mg/l	68%	
	60	150	1142 mg/l	72%	

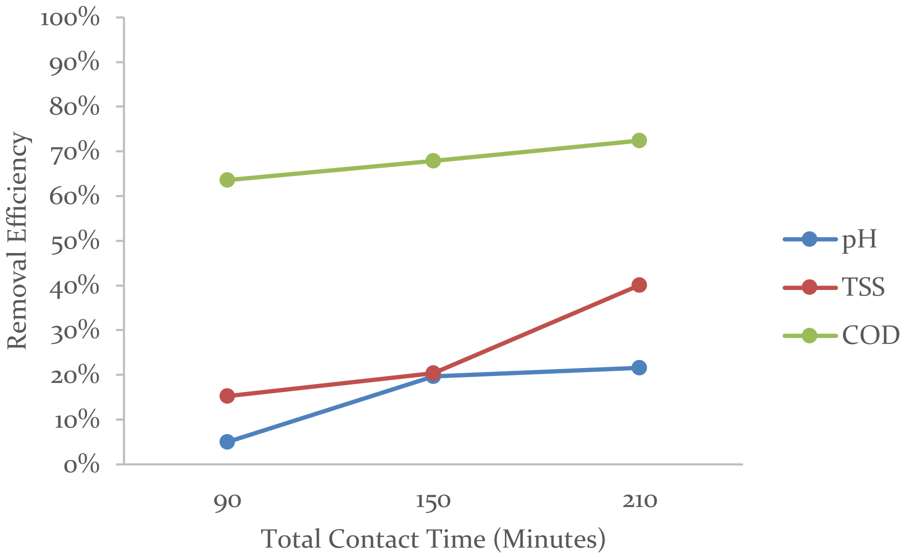

Figure 3. Graph of removal efficiency in different total contact time for each parameter

The results of effluent measurements showed promising results, where the longer the contact time the degree of acidity, TSS and COD levels decreased. Based on Figure 3, the pattern of removal efficiency for each parameter is increasing. The optimum removal efficiency value is the longest total contact time. For the longest total contact time, for pH reached >100% (6.9), the removal efficiency for TSS reached 94 mg/l (40%), and for COD it reached 1142 mg/l (72%). Compared to allowable standards discharge limit, the pH has met the standards. While the TSS and COD content is still very far from the standard value.

3.3. Effluent Characteristic

The final effluent results from the combined multilevel filtration and photocatalyzed TiO_2 method in this study are shown in Table 3 with a comparison of other methods. From table 3, the results of the combination method of multilevel filtration and TiO_2 photocatalysis show promising results, where of the three parameters, two of them meet government standards in short-term treatment processes.

Table 3. The characteristic of final effluent comparison

No	Methods	Parameter			Sources
		pH	TSS (mg/l)	COD (mg/l)	
1.	Combination (Multilevel Filtration + TiO2 photocatalysis)	6.6	94	1142	This study
2.	Multilevel Filtration	6.94	115	1257	Sitasari and Khoironi, 2021
3.	Adsorbent	7.8	136.5	1382.16	Seroja et al., 2018
4.	Coagulation Aluminium Sulphate + TiO2 photocatalysis	6.2	36.1	1972.1	Pebritama and Rachmanto, 2021

5.	Activated Carbon + TiO_2 photocatalysis	6.9	121	274	Analisa, 2022
6.	Electrocoagulant	6.7	100	283	Amri et al., 2020
7.	Government Standard	6 - 9	100	100	Minister of Environment and Forestry Regulation No. P.68/Menlhk-Setjen/2016 on Domestic Wastewater Quality Standards

Based on Table 3, the comparisons from different studies on tofu wastewater treatment using various methods reveal a consistent pattern: stand-alone methods alone are insufficient to bring the pollutant contents of tofu wastewater within government discharge standards. Multilevel filtration, for instance, is unable to reduce COD and TSS content adequately to meet government standards (Sitasari and Khoironi, 2021). While multilevel filtration makes a significant contribution to reducing TSS, its effectiveness in lowering COD remains limited. In contrast, the combination of coagulation using Aluminium Sulphate and TiO_2 Photocatalysis exhibits the highest efficiency in reducing TSS content (Pebritama and Rachmanto, 2021). Furthermore, the results highlight the significant impact of TiO_2 Photocatalysis on lowering COD content, although it still falls short of meeting allowable discharge levels. Numerous parameters affect the photocatalysis process, including pH, temperature, the presence of oxidants, pollutant concentration, catalyst loading, light intensity, and wavelength (Bazargan, 2022). It's crucial to consider the unique characteristics of each wastewater type. Understanding the influent characteristics is essential for optimizing the photocatalysis process to achieve maximum efficiency. The comparison of the multilevel filtration and TiO_2 photocatalytic combination methods gives promising final results compared to several other methods, but further research is still needed to obtain more optimum results. More analysis is needed in terms of wastewater characteristic and process parameters as a comparison of the application of several methods. so that a more effective and low-cost method can be sought.

3.4. Data Analysis

By using a polynomial extrapolation approach with the help of Microsoft Excel software, it is possible to predict the optimum contact time for TiO_2 photocatalysis, which in turn can meet the quality standards of the Minister of Environment and Forestry Regulation No. P.68/Menlhk-Setjen/2016 on Domestic Wastewater Quality Standards. The polynomial extrapolation results from Microsoft excel for each parameter are shown in Figure 4, Figure 5, and Figure 6. The extrapolation uses an equation of order 3 polynomial to form a trend line of forecast data as close as possible to real results. The results provide a numerical equation for each parameter that can be used to predict the optimal contact time. Predicted values based on the equations given for each parameter are shown in Table 4.

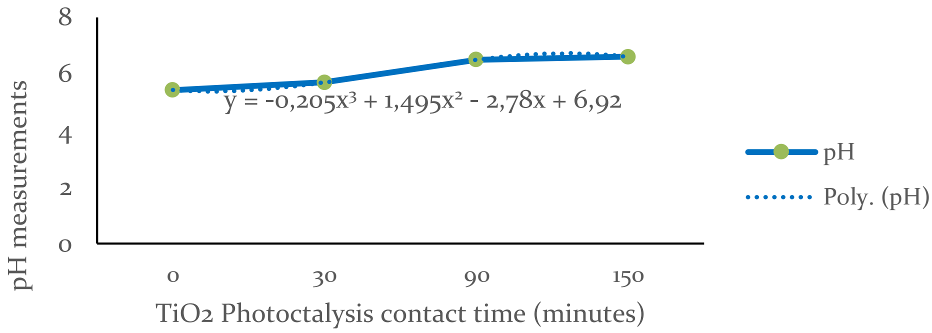

Figure 4. Graph of polynomial extrapolation for pH parameters

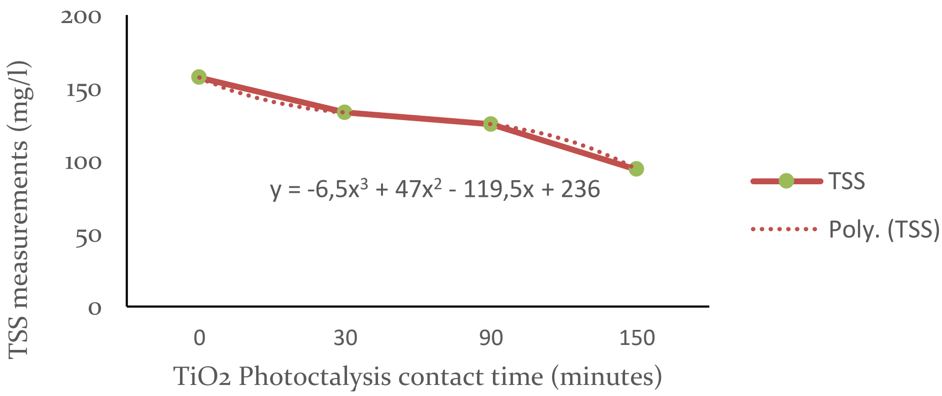

Figure 5. Graph of polynomial extrapolation for TSS parameters

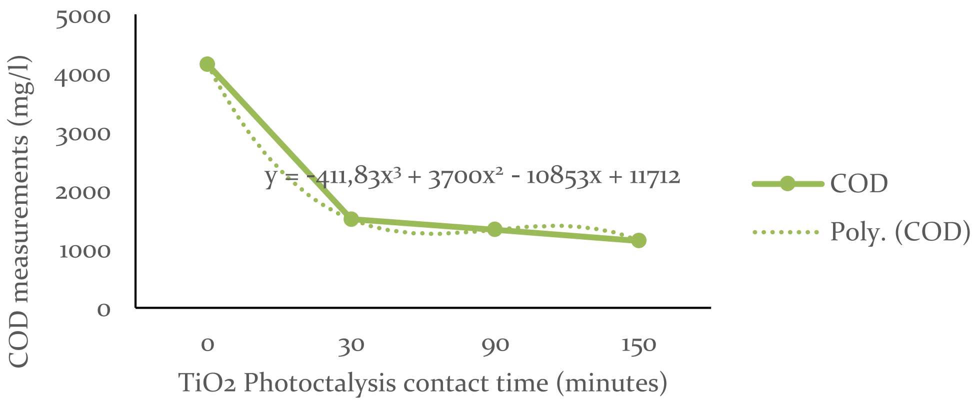

Figure 6. Graph of polynomial extrapolation for COD parameters

Table 4. Tabulation of polynomial extrapolation data for each parameter

TiO2 Photocatalysis Contact Time (Minutes)	Parameter		
	pH	TSS (mg/l)	COD (mg/l)
0	5.43	157	4147.17
30	5.7	133	1511.36
90	6.5	125	1333.59
150	6.6	94	1142.88

156	6.52	88.13	1027.96
162	6.43	81.61	885.74
168	6.31	74.38	713.73
174	6.17	66.42	509.47
180	6.00	57.69	270.49
186	5.81	48.14	-5.68
192	5.59	37.73	-321.53

Based on Table 4, the optimum contact time of TiO2 photocatalyst results which can meet government standards for each parameter is above 180 minutes and less than 186 minutes. These results can be used as a basis for further research in the future.

4. Conclusions

Based on the final results given, the study on the advanced treatment of tofu wastewater using multilevel filtration and TiO2 photocatalysis presents a promising approach for effective wastewater remediation. The highest removal efficiency performance reached 22% for pH, 40% for TSS, and 72% for COD. The combination of the two methods proved to be efficient in reducing the levels of pH to the normal ranges, decreasing COD content, and lowering TSS compound in the tofu wastewater samples. The multilevel filtration system effectively removed solid particles and suspended solids from the wastewater. Sequential layers of sand, activated carbon, zeolite, and gravel acted as effective filtering media, facilitating the removal of impurities and improving the water quality. Even it takes a long time for tofu wastewater to penetrate all the layer. Furthermore, the TiO2 photocatalysis process show its capability to degrade organic pollutants and enhance the overall wastewater treatment. The photocatalytic reaction, facilitated by UV light and TiO2 catalyst, effectively reduced the levels of organic compounds, improved water clarity, and eliminated unpleasant odours.

The combination of multilevel filtration and TiO2 photocatalysis exhibited synergistic effects, resulting in enhanced wastewater remediation. The sequential treatment process effectively reduced the levels of pH and TSS, meeting the required government standards for wastewater discharge. even though the COD level is still far from the set standard. Overall, this study highlights the potential of advanced treatment methods, such as multilevel filtration and TiO2 photocatalysis, in addressing the challenges associated with tofu wastewater treatment. These methods offer a sustainable and effective approach for wastewater remediation, contributing to the preservation and protection of the environment. Further studies and optimizations are recommended to explore the full potential of these techniques, considering factors such as optimal contact time, catalyst dosage, and system scalability. The findings of this research provide valuable insights for industries and wastewater treatment facilities in adopting advanced approaches for effective and sustainable wastewater management.

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References

Adriansyah, E., Agustina, T.E., Arita, S., 2019. Leachate Treatment of TPA Talang Gulo, Jambi City by Fenton method and adsorption. Indonesian Journal of Fundamental and Applied Chemistry 4, 20–24.

Amri, I., Pratiwi Destinefa, Zultiniar, 2020. Pengolahan limbah cair tahu menjadi air bersih dengan metode elektrokoagulasi secara kontinyu. Chempublish Journal. 5, 57–67.

Analisa, P., 2022. Kombinasi fotokatalisis titanium dioksida (TiO2) dan arang aktif untuk mendegrasi polutan limbah tahu. Universitas Islam Negeri Ar-Raniry.

Apollo, S., Onyongo, M.S., Ochieng, A., 2014. UV/H2O2/TiO2/zeolite hybrid system for treatment of molasses wastewater. Iran. Journal of Chemistry and Chemical Engineering 33, 107–117.

Bazargan, A., 2022. Photocatalytic Water and Wastewater Treatment, 1st ed, Photocatalytic Water and Wastewater Treatment. IWA Publishing, London.

Cahyani, M.R., Zuhaela, I.A., Saraswati, T.E., Raharjo, S.B., Pramono, E., Wahyuningsih, S., Lestari, W.W., Widjonarko, D.M., 2021. Pengolahan Limbah Tahu dan Potensinya. International Proceedings of Chemical, Biological and Environmental Engineering 6, 27.

Dianursanti, Rizkytata, B.T., Gumelar, M.T., Abdullah, T.H., 2014. Industrial tofu wastewater as a cultivation medium of microalgae Chlorella vulgaris. Energy Procedia 47, 56–61.

Elystia, S., Nasution, F.H.M., Sasmita, A., 2023. Rotary Algae Biofilm Reactor (RABR) using microalgae Chlorella sp. for tofu wastewater treatment. Mater. Today Proc.

Faisal, M., Mulana, F., Alam, P.N., Daimon, H., 2014. Wastewater characteristics from tofu processing facilities in Banda Aceh. Proc. 4th Annu. Int. Conf. Syiah Kuala Univ. (AIC Unsyiah) 22–25.

Fathana, H., Iqhrammullah, M., Rahmi, R., Adlim, M., Lubis, S., 2021. Tofu wastewater-derived amino acids identification using LC-MS/MS and their uses in the modification of chitosan/TiO2 film composite. Chem. Data Collect. 35, 100754.

Karamah, E.F., Primasto, A.R., Najeges, R.R., Bismo, S., 2019. Treatment of Tofu industry's wastewater using combination of ozonation and hydrodynamic cavitations method with venturi injector. Journal of Physics: Conference Series. 1198.

Laksono Putro, P.G., Hadiyanto, H., Amirudin, 2021. Water Quality Parameters of Tofu Wastewater: A Review. IOP Conference Series: Materials Science and Engineering. 1156, 012018.

Oktorina, A.N., Achmad, Z., Mary, S., 2019. Phytoremediation of tofu wastewater using Eichhornia crassipes. Journal of Physics: Conference Series 1341.

Pebritama, E.R., Rachmanto, T.A., 2021. Degradasi Limbah Tahu Dengan Koagulasi Flokulasi Alumunium Sulfat Dan Fotokatalis Tio2 Dalam Tangki Berpengaduk. envirous 2, 56–60.

Pramana, M.A., Kasman, M., 2019. Reduksi Total Suspended Solid dari Limbah Cair Tahu dengan Adsorban Sabut Kelapa Pada Batch System: Pendekatan Response Surface Method. Jurnal Daur Lingkungan. 2, 47.

Rahmadhani, A., Nasution, H., Prasetya, P., Dayumita, N., Siregar, S.H., 2023. Synthesis and characterization of TiO2-Fe for photocatalytic applications of domestic waste. Acta Chimica Slovenica. Asiana 6, 295–300.

Seroja, R., Effendi, H., Hariyadi, S., 2018. Tofu wastewater treatment using vetiver grass (Vetiveria zizanioides) and zeliac. Appl. Water Sci. 8, 1–6.

Sitasari, A.N., Khoironi, A., 202 Applied Water Science. Evaluasi Efektivitas Metode dan Media Filtrasi pada Pengolahan Air Limbah Tahu. J. Ilmu Lingkung. 19, 565–575.

Viareco, H., Adriansyah, E., Sufra, R., 2023. Potential Sequencing Batch Reactor in Leachate Treatment for Organic and Nitrogen Removal Efficiency. Journal of Environment and Health 15, 143–151.

Wang, C., Sun, X., Shan, H., Zhang, H., Xi, B., 2021. Degradation of landfill leachate using uv-tio2 photocatalysis combination with aged waste reactors. Processes 9.

Wresta, A., Sintawardani, N., Adisasmito, S., Kurniawan, T.A., Setiadi, T., 2021. Characteristics of tofu whey degradation during self-sustaining batch anaerobic process for methane production. Journal of Environmental and Chemistry Engineering 9, 106359.

Zuhaela, I.A., Cahyani, M.R., Saraswati, T.E., Raharjo, S.B., Pramono, E., Wahyuningsih, S., Lestari, W.W., Widjonarko, D.M., 2021. Penguraian Limbah Tahu Menggunakan Bakteri dan Plasma Ozonasi. Proceeding Chem. Conf. 6, 22.