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Adsorption of Tofu Liquid Waste Using Rice Husk Activated Carbon

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Abstract

Adsorption of Tofu Liquid Waste Using Rice Husk Activated Carbon. *Rice husk is an agricultural by-product rich in organic matter, and improper management can cause environmental pollution. Given the high carbon content in rice husk, it can be used as an adsorbent. Furthermore, the type of activator and activation technique employed impact the properties of activated carbon. Due to its ability to produce activated carbon with a high pore volume and specific surface area, KOH is a chemical substance that is frequently employed. This study sought to ascertain whether rice husks might be used as activated carbon to lower the amount of organic matter in liquid effluent from the tofu business. The results of this study indicate that rice husk activated carbon can reduce the level of TDS by 27%, TSS by 97%, and pH 6 from the initial level. The optimum contact time is 120 minutes at a ratio variation of 1:130, because at that time the activated carbon has approached saturation by the adsorbed adsorbate and experienced equilibrium and saturation.*

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INTRODUCTION

The food industry is one of the sectors that is expanding quickly at the moment. Both the food industry and the amount of garbage generated will grow as the population rises. Waste from the food sector comes in three different forms: solid, liquid, and gas. These three types of waste can cause soil, water, and air pollution. Of the three types of pollution, the one that has the most impact on the environment is liquid waste. Because the tofu industry is one of the food industries that generates liquid waste, the unprocessed disposal of industrial waste can lead to a decline in water quality. The tofu industry is often not handled properly, so that it has an impact on the environment. Because of the residual tofu water that does not coagulate, the tofu pieces that are damaged because of the defective coagulation process, and the hazy yellowish liquid that, if left alone, produces an unpleasant odor, the tofu industry produces liquid waste. So that it causes pollution because it contains high organic components. At present, most tofu industries are still small-scale household industries that are not equipped with wastewater treatment units. (Amalia et al., 2022).

Protein and amino acids are among the many organic components found in tofu trash. The tofu liquid waste has significant levels of TSS (total suspended solids), COD (chemical oxygen demand), and BOD (biological oxygen demand) due to the presence of these organic chemicals. These organic substances may include lipids, proteins, and carbohydrates. Carbohydrates make up 25–50%, fat makes up 10%, while protein components make up 40–60%. The volume of the tofu liquid waste will rise with the length of time the organic ingredients are present. Tofu liquid waste from soybean processing is included in biodegradable waste. Biodegradable is waste that can be destroyed by microorganisms. The suspended or dissolved materials in tofu liquid waste will transform physically, chemically, and biologically, either producing hazardous compounds or serving as a growing medium for microorganisms. The waste will be brown and smell bad, which is at risk of causing respiratory problems. Additionally, if tofu liquid waste is dumped into a river without being processed, it can contribute to river pollution by causing itching, diarrhea, and nausea in those who are near the river. In addition to liquid waste, the tofu industry also produces solid waste such as sediment. Therefore, if it is disposed of directly, it will pollute the environment. The BOD content of tofu dregs liquid is 5643 to 6870 mg/L, the COD content is 6870 to 10500 mg/L, and the water content is 6870 to 10500 mg/L. Liquid waste that is discharged directly into water channels without prior treatment causes environmental pollution. The acceptable wastewater quality parameters for the soybean tofu processing sector are 300 mg/L of COD, 150 mg/L of BOD5, pH 6–9, and 200 mg/L of TSS, as stated in Peraturan Menteri Lingkungan Hidup No. 5 Tahun 2014 (Sjafruddin et al., 2024).

The usage of adsorbents is one of the various strategies to overcome these challenges. Various forms of adsorbents include activated carbon, activated alumina, silica gel, and zeolite (molecular sieves). However, of all these adsorbents, activated carbon is the most widely available and has the largest surface area for adsorbing organic matter (Indah, 2020). Because of its vast surface area and porous nature, activated carbon finds extensive use in a variety of applications (Adi et al., 2022). Many objects in nature contain carbon elements in the form of organic compounds that can be used as raw materials for making activated carbon. One of them is agricultural waste such as wood, coconut shells, coal waste, wood processing waste, and coffee husks. Cocoa fruit husks, rice husks, straw, corn cobs and leaves (Saputro et al., 2020).

Rice husk is an agricultural by-product that is rich in organic matter, and its improper management can cause environmental pollution. Given the high carbon content in rice husk, it can be used as an adsorbent. Rice husk has a carbon compound content of 84.40% (dry weight) which is stored as cellulose, hemicellulose, and lignocellulose polymer compounds (Luna et al., 2020). Rice husk also has small pores which, when activated, will provide a large surface area. Pore size affects the surface. The smaller the pores of the activated carbon, the larger the surface area, so that the adsorption rate is faster. Based on the Badan Pusat Statistik (2022), rice husk production in East Java in 2022 reached 7,939.57 tons. From 1 kg of rice, it is estimated that around 280 grams of rice husk waste is produced. So far, rice husk handling has only been carried out by landfilling. However, long-term storage of rice husks has the potential to cause new environmental problems, such as sudden fires caused by the flammable nature of rice husks (Hamidu et al, 2025).

Activation treatment aims to increase the carbon absorption capacity. The activation process includes various stages such as dehydration, carbonation, and activation (Ardianti, 2021). In the dehydration process, it is done by removing water content from the carbon material through techniques such as drying and heating in an oven. During carbonization, the material is heated to temperatures between 300 °C and 900 °C in an oxygen-poor environment. This process breaks down organic matter into hydrocarbons, methanol, tar, and acetic acid vapor. The final phase is the activation process, which falls into two types: chemical and physical activation. The primary goal of the activation process is to increase the surface area and porosity of activated carbon by forming new pores and enlarging existing ones (Alfi et al., 2020).

According to Setyaningrum et al (2019), activated carbon from biomass such as rice husks is generally used to adsorb organic materials such as BOD, COD, and TSS. In addition, the characteristics of activated carbon are also related to the activation method and type of activator used (Goncalves et al, 2016). KOH is a chemical molecule that is frequently employed because it may create activated carbon with a large specific surface area and pore volume (Heng et al., 2015). Using a KOH activator, Oktariani (2021) studied the production of activated carbon from rice husks at temperatures between 400 and 600°C. The result was activated carbon with a surface area of 1851.52 m2/g.

By employing rice husk biomass raw materials as activated carbon and KOH as an activating agent, this research aims to develop a method for lowering the water content of tofu waste liquid. Time variables and 2 M KOH activator agents are used in this adsorption process. The purpose of this study is to investigate how intercalating activated carbon affects the pH, TSS, and TDS indicators in liquid waste from tofu.

METHODS

1. Sample Preparation

a. Dehydration of rice husk

In an oven set to 100°C, rice husks were dried until they reached a specific mass.

b. Carbonization of rice husk

The first stage in the carbonization process is to weigh 100 grams of dry rice husk. Then put 100 grams of rice husks into the furnace. Carry out the carbonization process at a temperature of 400 ° C for 2 hours. The temperature is below the silica, which reaches 1710 ° C to prevent the formation of slag that covers the carbon pores (Wibowo et al., 2017). Cool the carbonized rice husks (carbon) to T = 30 ° C. Cool the carbon using an analytical balance. The resulting carbon is sieved until it passes 80 mesh and maintained at a size of 100 mesh. (Erawati & Fernando, 2018).

c. Carbon activation using KOH

In the carbon activation process using 2 M KOH activator. With a ratio of 1:18, the activator is made by dissolving solid KOH into a 250 ml beaker, and a KOH solution will be obtained. Mix 180 ml of 2M KOH solution with 10 grams of carbon. Stir using a hot plate and magnetic stirrer at a speed of 200 rpm for 4 hours. (Wardalia et al., 2021). Carry out the activated carbon filtration process from the 2M KOH solution. Wash the filtered carbon until the pH of the solution is close to the pH of distilled water. Carry out the filtration process on activated carbon. Dry the activated carbon in an oven at a temperature of 60 ° C for 60 minutes. (Safitri et al., 2024).

2. Adsorption

The adsorption process of tofu waste liquid was carried out in batches where the temperature and pH were maintained. The independent variables in this study were variations in the adsorbent-adsorbate ratio, namely 1:100, 1:110, 1:120, 1:130 with time variations of every 30 minutes for 4 hours. The adsorbent ratio will affect how much adsorbate capacity will be absorbed by the adsorbent, while the contact time of 4 hours is the optimum contact time obtained from optimizing the adsorption time at a time variation of every 30 minutes to achieve equilibrium time (Sutama & Megantara, 2018). The adsorption process was carried out by adding 100 ml of tofu industry wastewater into an Erlenmeyer flask, then adding 1 gram of activated carbon. The mixture was stirred using a magnetic stirrer at a speed of 200 rpm, and 10 mL of sample was taken every 30 minutes for 4 hours (Novita et al., 2021).

Then filter with filter paper. Collect the filtrate and test the TDS, pH, and TSS levels. TDS analysis was conducted using a TDS meter, pH testing was conducted using a pH meter/universal, and TSS analysis was conducted using the gravimetric method (SNI 06-6989.3- 2019). All statistical analysis data were obtained by regression.

3. Parameter Analysis

a. FT-IR Test (*Fourier Transform-Infrared*)

FT-IR (Fourier Transform Infrared) analysis was utilized to gather qualitative information from the sample and identify its functional categories. The FT-IR analysis's findings reveal information about the sample's molecular structure and chemical makeup.

b. TDS Test (*Total Dissolved Solids*)

The filtrate that goes through the filter media is evaporated until it is dry, and then it is dried at 180°C until it reaches a constant weight using the principle of homogenous test samples filtered using filter media. A total of 10 ml of filtered liquid waste sample was then poured into a petri dish, which was then dried in an oven at 150°C for an hour, and the petri dish was placed in a desiccator for 30 minutes. This method is used to determine the total dissolved solids in water and wastewater gravimetrically, and the weigh-out results are recorded (SNI 6989.27:2019)

c. TSS Test (*Total Suspended Solid*)

Applying the idea of homogeneous test samples that have been filtered using weighted filter media. At temperatures between 103°C and 105°C, the residue that remains on the filter media is dried until its weight remains constant. Total Suspended Solids (TSS) are represented by the increase in filter weight. Pour sediment-containing filter paper into a petri dish (for the TDS experiment). For one hour, the dish is dried in an oven set between 103°C and 105°C. For half an hour, the filter paper-containing dish is chilled in a desiccator. Recorded once the weight is maintained at a consistent level (SNI 6989.3:2019)

d. pH Test

A solution's degree of acidity or alkalinity is expressed by its pH, or degree of acidity. The logarithm of the activity of dissolved hydrogen ions (H+) is known as pH. The value of the activity coefficient of hydrogen ions is determined theoretically because it cannot be observed empirically. The pH scale isn't a perfect one. It is about a group of reference solutions whose pH is established by global consensus. The pH of pure water is 7.0 at 2 °C, making it neutral. Solutions are classified as basic or alkaline if their pH is greater than seven, and as acidic if their pH is less than seven (Hariyadi, 2020)

RESULTS AND DISCUSSION

1. FT-IR Functional Group Identification (*Fourier Transform-Infra Red*)

In this study, we used FTIR analysis to identify changes in functional groups of the raw materials used, rice husk and carbon, before and after activation with KOH solution. The FT-IR functional groups in rice husk, carbon, and rice husk activated carbon are shown in Table 1.

Table 1. Functional groups found in rice husks, carbon, and rice husk activated carbon

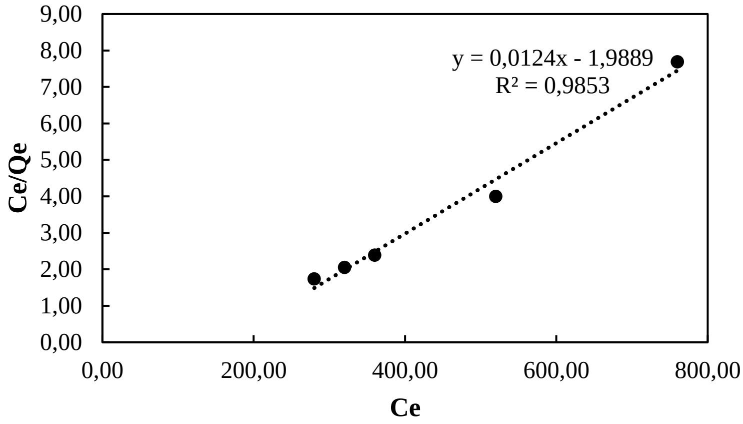
Functional Groups	**Wavelength (cm^{-1})**	**Sample**		
		Rice Husk	**Carbon**	**Activated Carbon**
O-H Alcohol/Phenol	3200-3650	✓	✓	✓
C-H Alkane	2850-2960, 1350-1470	✓	-	- ✓
C=O Aldehyde, Ketone, Carboxylic Acid, Esters	1690-1760	-	✓	-
C-C Alkene	1640-1680	✓	-	-
CO β-diketone	1540-1640	-	✓	-
C=C Aromatic	1500-1600	✓	-	✓
C-N Amine	1000-1250	✓	✓	✓
Bend =C-H	740-800	✓	✓	-
Alkyl C-H	600-700	✓	-	-
$-(CH_2)n$ Other compounds	-722	✓	✓	-

Table 1 shows that the results of the functional group analysis show a peak in the region 3200-3650 cm^{-1} indicating the absorption of the O-H Alcohol/Phenol group in rice husks which has a peak of 3374.42 cm^{-1}, carbon with a peak of 3337.42 cm^{-1}, and activated carbon 3350.17 cm^{-1}. According to Wibowo (2011), the emergence of C-O and O-H groups explains that the activated carbon that has been produced has polar properties. The O-H group may originate from free compounds that are adsorbents that are present on the surface of activated carbon. Carboxyl and hydroxyl functional groups function as active functional groups during the adsorption process. The compounds on the adsorbent's surface are abundant in carboxyl, hydroxyl, amine, and carbonyl functional groups, which will act as active functional groups to carry out the adsorption process of organic materials, according to Dewi (2017). This is by the study (Riyanto et al., 2021) the effect of NaOH on the activation of rice husk activated carbon is shown from the results of the FT-IR spectrum of rice husk activated carbon and rice husk alkali activated carbon showing vibration peaks at 3400-3500 cm^{-1} and 1500-1700 cm^{-1} detected as stretching vibrations -OH (hydroxyl group) and - C=O (carbonyl group) or -C=C (alkene). Therefore, from Table 1 it can be seen that starting from the raw materials of rice husk, carbon and activated carbon, changes in functional groups occur gradually after activation with KOH solution. That being said, this is undoubtedly constrained by the adsorption equilibrium, which is reached when the maximum adsorption capacity is achieved. Therefore, an excessively lengthy contact period results in the adsorbent becoming saturated and the adsorbate being released if it surpasses the adsorption equilibrium time. For the adsorption process to reach a saturated state at 120 minutes (Rahman et al, 2022).

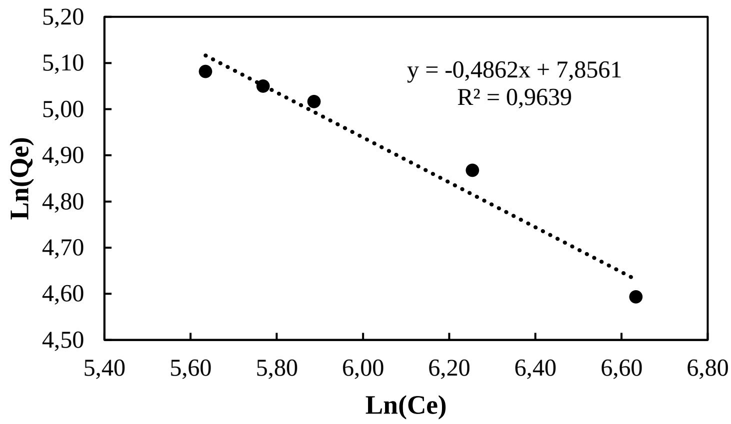
2. Adsorption Capacity of Activated Carbon

In this study, the Freundlich and Langmuir isotherm method approaches were used to see the adsorption mechanism that occurs. The adsorption isotherm indicates the distribution and interaction between the adsorbate and the adsorbent at equilibrium conditions and constant temperature (Dewi et al, 2024).

The tofu waste adsorption process in isotherm analysis was shown in Figure 1. these figures indicated that adsorption follows both Langmuir and Freundlich isotherms as seen from the regression value above (R^2) 0.9. This shows that when all active sides in activated carbon are full in the first layer, the adsorbate molecules will slowly attach to the second layer and so on (multilayer) so that generally when the conditions have passed the saturation limit, the desorption process can occur (Lestari et al, 2022)



(a)



(b)

Figure 1. Isoterm (a) Langmuir (b) Freundlich

a. pH Parameter Analysis

This pH is not recommended for any group because the water is very acidic. So after the adsorption process using activated carbon, the results are obtained in Table 2.

Observation of pH in each sample was done by observing the chemical oxygen demand (COD) value at various ratios between adsorbent and adsorbate against time. COD value is closely related to pH because COD measures the amount of oxygen needed to oxidize organic matter in water. High COD values indicate that many organic substances are decomposed in wastewater, thus lowering the pH value.

Table 2. Data from research on pH parameters of tofu industry liquid waste

Ratio	Initial Concentration	pH								
		Time (minute)								
		0	30	60	90	120	150	180	210	240
1:100	4	5	5	5	5	5	5	5	5	5
1:110		5	5	5	5	5	5	5	5	5
1:120		6	6	6	6	6	6	6	6	6
1:130		6	6	6	6	6	6	6	6	6

Based on Table 2. pH measurement results, after processing tofu wastewater with rice husk activated carbon, the pH value produced was pH 5 at ratio variations of 1:100 and 1:110, then the pH value produced was pH 6 at ratio variations of 1:120 and 1:130. So the optimum ratio in this adsorption is when 1:120 and 1:130. This indicates that the adsorption process successfully removes some organic compounds as evidenced by increasing the pH value. This increase can also be due to the high adsorbate concentration, the basic adsorbent begins to saturate so that it releases OH- ions in the water. This shows that the ratio between adsorbent and adsorbate has a more significant effect compared to observations over time. The pH value, which is generally acidic in tofu waste, can be caused by the fermentation of proteins and carbohydrates. This is because when the protein breaks down, organic acids will be formed which increase the acidity (Sayow et al, 2020).

b. TDS Analysis (*Total Dissolved Solids*)

TDS (Total Dissolved Solids) is a parameter that indicates the level of dissolved solids in water, including contaminants such as heavy metals and organic waste. Determination of TDS can use a TDS meter by calibrating it using distilled water to ensure that the measurement results are accurate (Schlenker, 2021). In this study, the analysis results are shown in Table 3.

Table 3. Data from the research results on TDS parameters of liquid waste from the tofu industry

Time	Initial	TDS (ppm)

(menit)	Concentration (ppm)	1:100	1:110	1:120	1:130
0		1296	1164	932	879
30		1296	1137	922	822
60		1137	1053	855	808
90		1084	986	786	735
120	853	1010	954	775	672
150		993	937	756	646
180		912	828	749	626
210		881	805	715	620
240		875	729	703	619

Based on the tofu waste quality standards, the permissible TDS parameter for tofu waste liquid is 2000 mg/L. Based on the results of the TDS value measurements in Table 3, the TDS value of tofu waste liquid is 853 mg/L. Therefore, tofu waste liquid meets the quality standards set for tofu waste liquid. The higher the TDS value, the higher the concentration of solids in the water sample. The same thing also applies vice versa (Toruan et al., 2022).

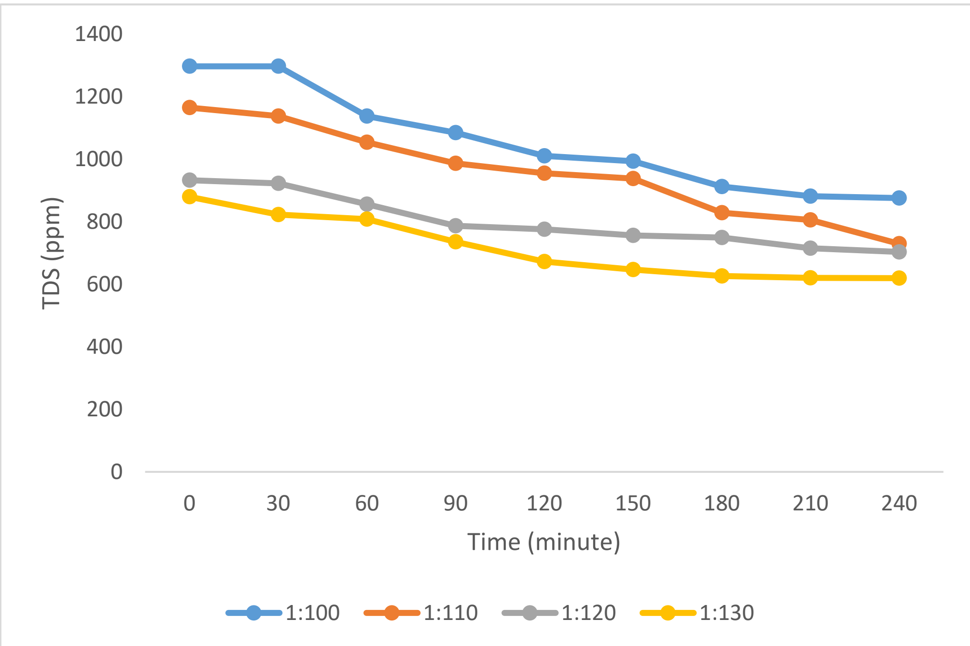


Figure 2. Research results on TDS parameters of tofu industry liquid waste

When tofu liquid waste was treated with rice husk activated carbon, there was a decrease in TDS as seen in Figure 2. The maximum decrease in TDS value occurs at a ratio change of 1:130 at a contact time of 120 minutes of stirring, which is up to 672 mg/L with an efficiency of TDS adsorption by the adsorbent of 21%. Adsorption continues to decrease as the contact time increases until equilibrium is reached (Kusniawati et al., 2023). At this point the adsorbent can absorb the adsorbate maximally so that the optimal contact time is determined at 120 minutes with a dose of 1 g. The more activated carbon used, the more the absorption capacity of the content in the water increases and the contact time between the activated carbon and the well water sample increases, so that the pores of the activated carbon have a longer time to expand and absorb more solids. That will happen. In addition, a high TDS value means that organic waste is not completely decomposed into gas. The decrease in TDS levels in wastewater is related to the activity of microorganisms that decompose organic matter. The decrease in TDS content in waste can be influenced by the increasing number of microorganisms (Fisma & Bhernama, 2020).

c. TSS Analysis (*Total Suspended Solid*)

TSS (Total Suspended Solid) refers to solid particles suspended in water that can inhibit or direct the propagation of light, which ultimately affects the color level of water. The following is a table of research results on TSS parameters of tofu industry liquid waste. These solid particles are substances that are smaller in size and weight than deposits such as clay, some materials, and organic compounds that are insoluble in water (Anggara et al., 2023).

Table 4. Data from the research results on TSS parameters of liquid waste from the tofu industry

Time (minute)	Initial Concentration (mg/L)	TSS (mg/L)			
		1:100	1:110	1:120	1:130
0	1,04	0,48	0,51	0,54	0,58
30		0,42	0,45	0,37	0,51
60		0,39	0,39	0,37	0,48
90		0,27	0,38	0,18	0,48
120		0,26	0,27	0,16	0,41
150		0,26	0,24	0,14	0,34
180		0,18	0,20	0,13	0,07
210		0,14	0,04	0,08	0,06
240		0,03	0,03	0,03	0,05

Based on Table 4, the results of the examination of the TSS parameters of the tofu industry liquid waste are 1.04 mg/L, and the quality standard set by the Minister of Environment Regulation No. 5 of 2014 is 200 mg/L. Wastewater treatment using rice husk activated carbon also resulted in a reduction. These results indicated that the TSS content in the tofu wastewater sample is far below the set quality standard value. Table 4 demonstrates that the adsorption procedure employing activated carbon is the cause of the drop in TSS value in tofu liquid waste. When the TSS value drops, the water turns clear because the suspended concentration is correlated with the water's lowering turbidity, which is brought on by the adsorbent surface's active side bond. This shows that the decrease in TSS value occurs when carbon is effectively used and can meet the quality standards for tofu liquid waste discharge.

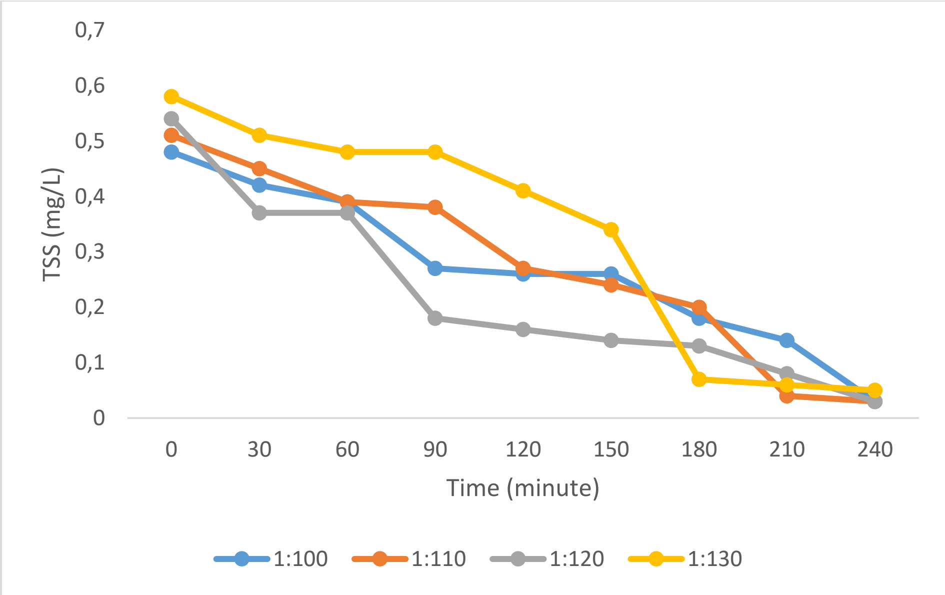


Figure 4**.** Research results on TSS parameters of tofu liquid waste

Table 5 Comparison of TSS values of various types of adsorbents for adsorption of tofu liquid waste

No	Adsorbent Type	Result
1.	Activated carbon from coconut shells (Chairunnisa, 2023)	TSS level < 200 mg/L
2.	Alum and commercial activated carbon (Nurlina, 2015)	TSS level < 200 mg/L
3.	Activated carbon from merbau wood (Setyaningrum, 2019)	TSS level < 200 mg/L
4.	Activated carbon from young coconut skin (Patulak, 2022)	TSS level < 200 mg/L
5.	Activated carbon from bagasse (Purnawan, 2014)	TSS level < 200 mg/L
6.	This research	TSS level < 200 mg/L

Based on the comparison of TSS value data on various types of adsorbents such as Table 5 above, it can be identified that activated carbon from rice husk with KOH activation treatment can be assessed as the best activated carbon in adsorbing tofu liquid waste. Because this study states that this activated carbon has the ability for liquid tofu waste with TSS levels less than the quality standard, up to 200 mg/L. Therefore, tofu wastewater meets the requirements set by law, and its water quality meets the standards for soybean waste treatment. This is a positive indicator because it shows that waste from the tofu production process has been properly treated before being discharged into the environment, thus minimizing negative impacts on the environment.

CONCLUSION

In this study, activated carbon was found to be almost saturated with adsorbed adsorbates and experienced equilibrium and saturation, so that the optimal contact time was 120 minutes with a ratio varying 1: 130. As well as a decrease in TDS by 27%, TSS by 97%, and pH by 6 from the initial level. The TDS and TSS parameters of tofu liquid waste have met the established quality standards, namely TDS 2000 mg / L and TSS 200 mg / L. This is a positive indicator because it shows that waste from the tofu production process has been processed properly before being discharged into the environment, thus minimizing negative impacts on the environment. To facilitate its application, it can be formed into pellets or granules as an adsorbent for treatment of tofu liquid waste, not necessarily in powder form.

SUGGESTION

Further research suggests that further research be conducted, including: in research with different adsorbents, it is necessary to carry out the carbonization stage of raw materials using a carbonization reactor flowed with nitrogen gas (inert gas to prevent oxygen from entering the reactor), with different temperature variations, for example 600-900°C to produce activated carbon with better properties. Therefore, instrumentation is needed that can indicate the occurrence of adsorption equilibrium. The adsorption process of tofu liquid waste using activated carbon from KOH-activated rice husks using a fixed bed adsorption column continuously. The need for research on the capacity of activated carbon for different types of organic waste with a modified adsorbent and adsorbate ratio. Because the raw materials for making adsorbents are easy to obtain and are quite abundant, they are more effective and efficient for adsorption processes on both small and large scales. In addition, research can be carried out using various analysis parameters contained in the tofu industry wastewater such as heavy metal content, COD content, BOD, and microbiological contamination.

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