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Comparative Efficiency of KOH-Activated Rice Husk Carbon in Adsorbing Pollutants from Laundry and Tofu Wastewater

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Abstract

Comparative Efficiency of KOH-Activated Rice Husk Carbon in Adsorbing Pollutants from Laundry and Tofu Wastewater. *This study aims to compare the adsorption capacity of rice husk-based activated carbon in overcoming pollution from two types of liquid waste, namely laundry waste and tofu liquid waste. The raw material of rice husk is processed through a carbonization process and chemical activation using potassium hydroxide (KOH), then used in a batch adsorption test. The parameters analyzed include Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS). The results show that the adsorbent material produced is able to reduce pollutant levels significantly. COD and TDS are more effectively reduced in laundry waste because the organic content and surfactants are more easily adsorbed, while TSS experiences a greater decrease in tofu waste due to the high suspended solids content. The adsorption process follows the Langmuir isotherm model with the regression values for both laundry and tofu wastewater of* $R^2>0.9$*, which indicates the occurrence of monolayer adsorption on the surface.*
This biosorbent has proven to be economical, environmentally friendly, and has the potential to be applied on a small scale, especially for household industries such as laundry businesses and tofu production. In addition to being relevant for local contexts, this approach can also be adopted globally in areas with high rice husk availability and similar waste management problems.

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INTRODUCTION

Water pollution due to liquid waste from small and household industrial activities, such as laundry businesses and tofu production, is increasingly becoming an important issue in environmental management. Laundry waste is known to contain detergents, surfactants, and phosphates, which are toxic and difficult to decompose in aquatic environments. However, the high levels of organic matter, protein, and Total Suspended Solids (TSS) in tofu liquid waste can result in eutrophication and a drop in dissolved oxygen levels if improperly handled (Amalia et al., 2022).

In Indonesia, these two types of waste are very common, along with the increasing number of small and medium enterprises (SMEs) that do not have adequate waste treatment systems. A study by Lacalamita et al. (2023) shows that one home laundry unit can produce 100–150 liters of liquid waste per day, while a small-scale tofu factory produces up to 300 liters per day (Ningsih et al., 2024). This waste is often discharged directly into waterways without treatment, worsening environmental pollution. One promising technology to overcome this problem is the adsorption process. Adsorption is chosen because of its simple process, low operational costs, and effectiveness in removing various pollutants. Due to its high adsorption capacity and huge surface area, activated carbon is the most widely utilized adsorbent (Kusniawati et al., 2023). However, SMEs cannot afford commercial activated carbon due to its relatively high price.

Alternatively, a lot of research has started to create activated carbon from agricultural waste. Various biomass, such as banana peels, corn cobs, bagasse, and rice straw, have been tested as raw materials for adsorbents (Ahmed et al., 2021; Beyan et al., 2021). Among these sources, rice husk stands out because of its abundant availability in rice-producing countries, including Indonesia. Rice husk has a high silica content and a porous structure that is ideal for adsorption. It has been demonstrated that activation with potassium hydroxide (KOH) increases the activated carbon's surface area and porosity from rice husk (Luna et al., 2020). In addition to its technical potential, the use of rice husk also has socio-economic impacts. Activated carbon production from agricultural waste can support local community empowerment, create added value from waste, and reduce dependence on expensive imported materials. This is in line with efforts to achieve the Sustainable Development Goals (SDGs), especially point 6 (clean water and sanitation), point 12 (responsible consumption and production), and point 13 (addressing climate change).

The Langmuir and the Freundlich isotherm models theoretically explain the adsorption mechanism. The Freundlich model explains adsorption on a heterogeneous surface and is infinite, whereas the Langmuir model presumes that adsorption takes place on a homogeneous surface and generates a single molecule layer (Indah, 2020). This theoretical framework is important for analyzing the adsorption behavior of activated carbon on various types of waste. Although the potential of activated carbon from rice husks has been widely studied, there is still a gap in the literature. Most studies only focus on one type of waste or one parameter. There have not been many studies that comprehensively compare the effectiveness of rice husk activated carbon in treating waste from two different sectors, namely laundry waste containing soluble chemicals and tofu waste rich in solid organic matter. To better understand the selectivity and effectiveness of activated carbon in practical applications, this gap must be closed.

This study aims to evaluate and compare the efficiency of activated carbon from rice husk activated with KOH in adsorbing pollutants from washing waste and tofu liquid waste. The main parameters analyzed include Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS). The method used is batch adsorption to systematically test the adsorption capacity of activated carbon. It is expected that the results of this study can contribute to the development of cost-effective, environmentally friendly, and applicable waste treatment technologies, especially for the small-medium industrial sector in Indonesia and other developing countries.

METHODS

1. Sample Preparation

a. Dehydration of rice husk

Rice husk is dried in an oven at 100°C until it reaches a constant mass.

b. Carbonization of rice husk

A total of 100 grams of dry rice husk is put into the furnace and carbonized at 400°C for two hours. This temperature is chosen to remain below the melting point of silica (1710°C) so that no slag is formed that can cover the carbon pores (Wibowo et al., 2017). After carbonization, the sample is resolved to room temperature (±30°C), then sieved to pass 80 mesh and maintained at a size of 100 mesh (Erawati & Fernando, 2018).

c. Carbon activation using KOH

A 2 M KOH activator is used in the carbon activation procedure. A KOH solution is produced by dissolving solid KOH in a 250 mL beaker at a ratio of 1:18 to create the activator. Combine 10 grams of carbon with 180 milliliters of 2M KOH solution (Gonçalves et al., 2015). Utilizing a magnetic stirrer and a heated plate, stir for four hours at 200 rpm (Sutama et al., 2025). Use the 2M KOH solution to carry out the activated carbon filtration procedure. Rinse the charcoal filter until the solution's pH approaches that of pure water. Use activated carbon to complete the filtration procedure. For 60 minutes, dry the activated carbon in an oven set to 60 °C (Safitri et al., 2024).

d. Quality Control

All tools, such as pH meters, TDS meters, and titration tools, were calibrated using certified standards before use. Testing was carried out three times and averaged to minimize errors. The experiment was conducted at a temperature of 25 ± 2°C in a laboratory.

2. Adsorption

The adsorption process was carried out using a solution from laundry and tofu wastewater. Variations in the adsorbent-adsorbate ratio used: 1:100, 1:110, 1:120, and 1:130. The contact time was varied every 30 minutes to 4 hours. pH was maintained using 0.1 M HCl or NaOH solution and detected with a digital pH meter (Sutama & Megantara, 2018). In an Erlenmeyer flask, 100 mL of trash was combined with 1 gram of activated carbon and swirled at 200 rpm. A 10 mL sample was taken every 30 minutes. After completion, the solution was filtered. To obtain the best conditions, a variation test was carried out on pH, adsorbent dose, and contact time.

3. Sample Collection and Storage

Tofu liquid waste and washing samples were collected from local sources, stored in HDPE containers, and stored in a refrigerator at 4°C until used. No preservatives were added to maintain the authenticity of the waste composition.

4. Parameter Analysis

a. TDS Test (*Total Dissolved Solids*)

b. After being dried for an hour at 150°C in a petri dish, 10 mL of filtrate was weighed and examined under a microscope in a desiccator (SNI 6989.27:2019).

c. TSS Test (*Total Suspended Solids*)

The residue on the filter paper was dried at 103–105°C until constant mass, then weighed (SNI 6989.3:2019).

d. COD Test *(Chemical Oxygen Demand)*

A total of 50 mL of sample was titrated using a closed method after free chlorine was neutralized using 0.1 N Na_2SO_3 solution. COD was calculated using the following formula: The following formula can be utilized to ascertain a sample's COD value:

$$COD = \frac{(V_b - V_s)x\ N\ \ x\ 8000}{V_{sample}}$$

V_b and V_s indicate the volume of titrant in the blank and the volume of titrant in the sample, respectively, while N is the normality of the titrant (SNI 6989.73:2009).

To enhance clarity and facilitate understanding of the experimental procedure, a detailed flowchart is presented below. This flowchart outlines each step in the study, from sample collection and adsorbent preparation to the adsorption process and final analysis, as shown in Figure 1.

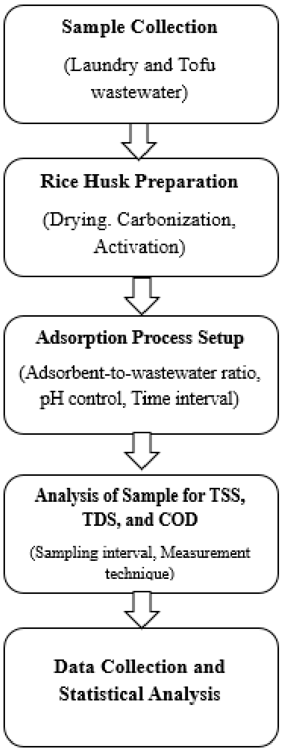
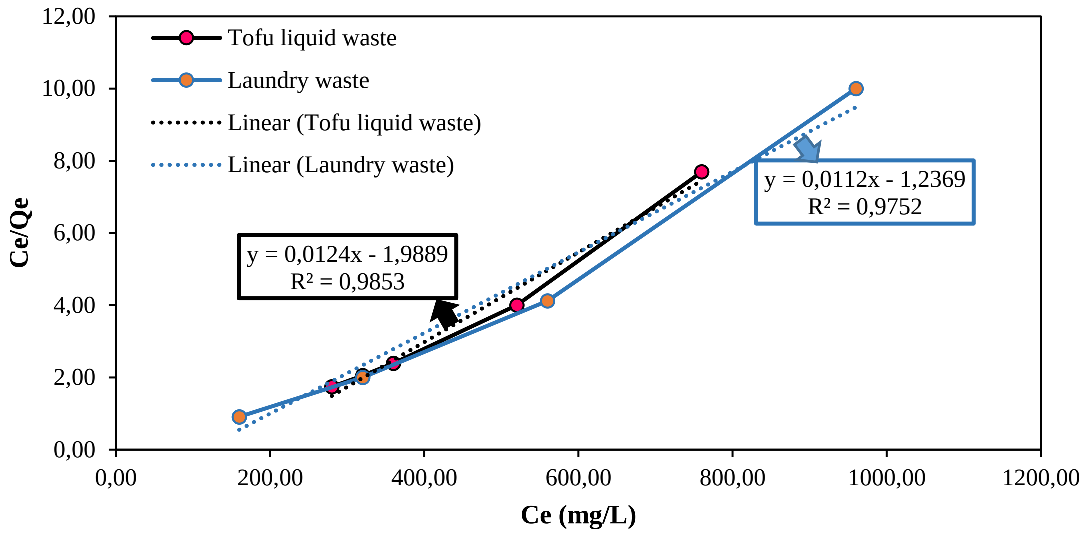


Figure 1. Experimental procedure flowchart.

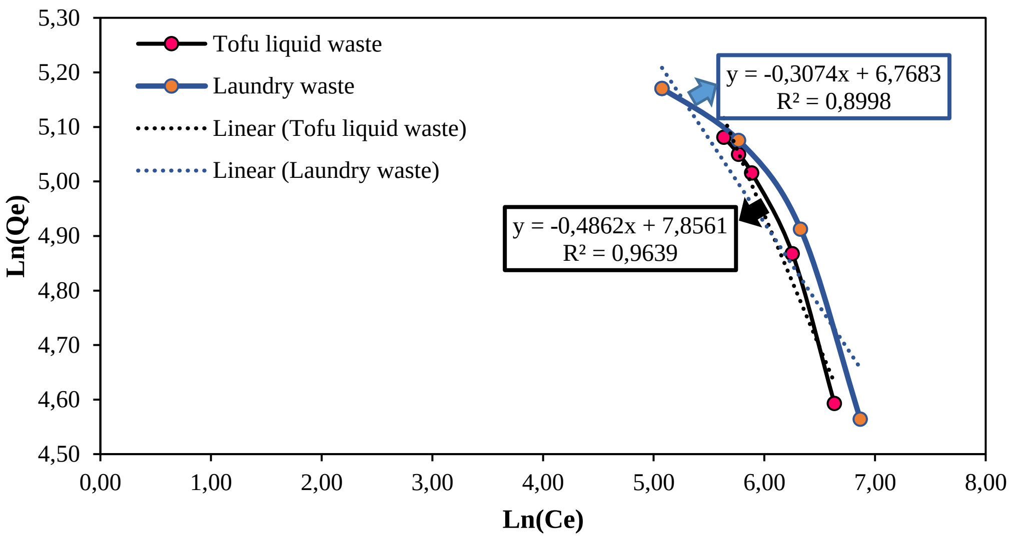
RESULTS AND DISCUSSION

1. Adsorption Capacity of Activated Carbon

The ability of an adsorbent to absorb contaminants is measured by its adsorption capacity. The adsorbent's surface area, pore size and distribution, adsorbate concentration, pH, and chemical interactions between the adsorbent and adsorbate all affect adsorption capacity. The mechanism of the adsorption process seen in Figure 2 is described in this paper using adsorption isotherms in the form of the Freundlich and Langmuir. The distribution and interaction processes between the adsorbent and adsorbate are depicted in this figure (Dewi et al., 2024).



(a)



(b)

Figure 2. The comparison of Isoterm (a), Langmuir (b) Freundlich on Tofu liquid waste and Laundry waste

Figure 2 shows a comparison between the adsorption process on tofu waste and laundry waste. Figure 2(a) shows that both the adsorption of tofu liquid waste and laundry waste have regression values (R^2) of 0.9853 and 0.9752, respectively, demonstrating that there is still no interaction between the adsorbate molecules and the adsorbent and that the adsorbate molecules form a single layer (monolayer) on the adsorbent's surface (Wang et al., 2020).

In Figure 2(b), the regression value for liquid tofu waste is 0.9639, and laundry waste is 0.8998. This shows that liquid tofu waste tends to have a Freundlich isotherm characteristic, which means that the adsorption process occurs on a heterogeneous surface and states that adsorption can occur in a multilayer manner (more than one layer) (Sutama et al., 2025). The

Freundlich model provides an adequate description of the adsorption mechanism of both types of waste and shows that the adsorption process is physical (physisorption) and occurs on a heterogeneous surface without a fixed adsorption capacity limit (Aichour & Zaghouane-boudiaf, 2019).

In this study, it is shown that when the adsorbent has reached the saturation point, the desorption process will occur. This phenomenon shows that after all active sites on activated carbon are filled in the first layer, the adsorbate molecules will gradually occupy the next layer (multilayer) (Lestari et al., 2022).

Experimental data show that both studies tend to be on the Langmuir isotherm, which means that the surface of activated carbon tends to have a uniform pore size so that the active surface area is limited. From fitting data on the Langmuir isotherm, the adsorption capacity value can be obtained, which shows the maximum amount of adsorbent in absorbing adsorbates (pollutants). In the process of adsorption of tofu liquid waste, activated carbon has a maximum adsorption capacity of 80.65 mg/g, while in laundry waste, the maximum adsorption capacity is 89.29 mg/g. This shows that every 1 gram of activated carbon from KOH-activated sugarcane bagasse can absorb adsorbates (pollutants) ranging from 80 to 89 mg of adsorbate. Meanwhile, in the study of Sailah et al., (2020)It was shown that activated carbon from cassava peel activated with base has an adsorption capacity of 0.49 mg/g in absorbing laundry waste. Research conducted by Khairuddin et al., (2022) shows that activated charcoal from oil palm frond waste has an adsorption effectiveness of up to 80% in absorbing tofu liquid waste.

a. Kinetics Study based on TDS Analysis (*Total Dissolved Solids*) for various condition ratios

The number of dissolved solids in water, including pollutants like organic waste and heavy metals, is indicated by the TDS (Total Dissolved Solids) metric. TDS can be determined with a TDS meter, which can be calibrated with distilled water to guarantee reliable measurement results. Kinetic data based on TDS analysis can provide an overview of how ions or dissolved substances are absorbed by the adsorbent, and also can determine the efficiency of the adsorption operation time (Fakoya et al., 2024). The value of TDS will be related to the kinetic adsorption study. The analysis results data are shown in Figures 3 and 4.

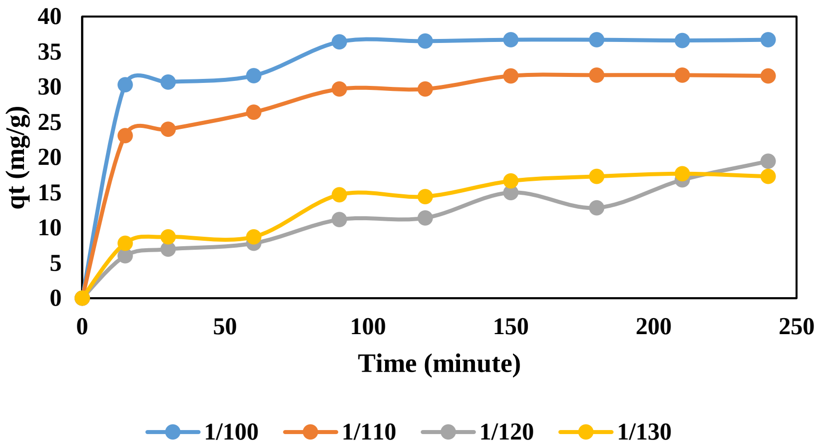


Figure 3. Kinetic TDS Data for various condition ratios between adsorbent and adsorbate on laundry waste

In this study, 4 variations of sample ratios were given, namely 1:100, 1:110, 1:120, and 1:130. Each ratio indicates the volume quantity in milliliters between the adsorbent and adsorbate. The TDS test in this study was carried out 9 times at intervals of 30 minutes with sampling at initial conditions of 0 minutes to 240 minutes. Figure 3 shows the adsorption kinetics data on laundry waste, where the average point at optimal conditions is in the time range of 90-120 minutes, dan adsorption begins to reach the saturation point at 150 – 240 minutes. From Figure 2, it is obtained that the variation of 1:100 is better in the adsorption of the TDS test. This can be because samples with a smaller adsorbate volume have a smaller diffusion distance between the ion and the adsorbent, so that most of the dissolved particles can be easily absorbed by the adsorbent.

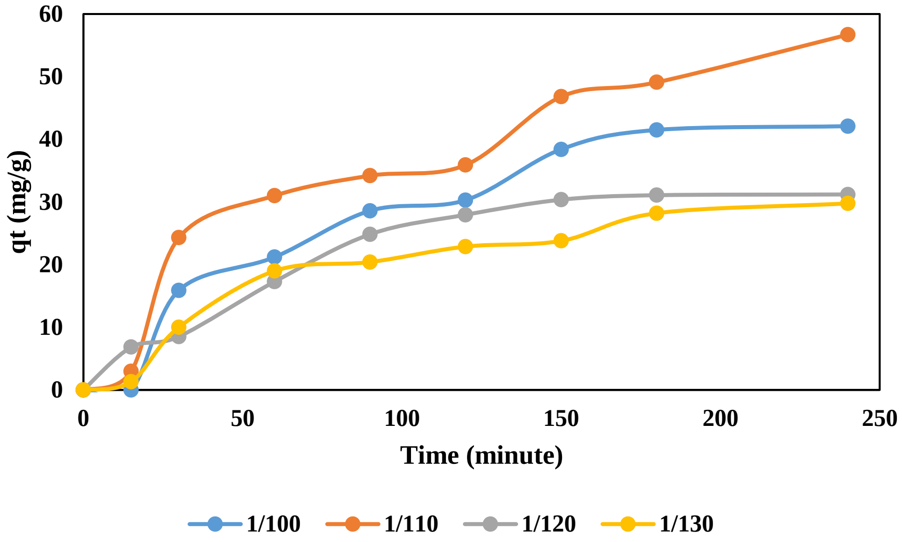


Figure 4. Kinetic TDS Data for various condition ratios between adsorbent and adsorbate on tofu liquid waste

As shown in Figure 4, the adsorption capacity value increases in line with the increasing adsorption process time. It can be seen that the sample ratio of 1/110 has a higher adsorption capacity value compared to the sample ratio of 1/100. In contrast to laundry waste, this can indicate that at a ratio of 1/100, the adsorbent is still not fully saturated because the organic content in tofu (protein, amino acids, and others) is lighter and easily bound by activated carbon, so that at this ratio, the active side of the carbon is not fully saturated. As contact time rises, adsorption keeps decreasing until equilibrium is reached (Sutama et al., 2025). With a dose of 1 g, the ideal contact time is established at 120 minutes since the adsorbent can now absorb the adsorbate to its maximum capacity.

Table 1. Kinetic Parameter comparison between various pollutants

Type of pollutants	**Pseudo 1st Order Parameter**		**Pseudo 2nd Order Parameter**	
	k_1 (min^{-1})	**R^2**	**k_2 (g/(mg.min))**	**R^2**
Laundry wastewater	0.023	0.885	0,002	0.951
Tofu wastewater	0.018	0.956	0,0003	0.929

Overall, adsorption using activated carbon from rice husk showed high effectiveness in removing pollutants from laundry waste and tofu waste. Table 1 gives the kinetic parameters for the adsorption process. This is shown from the kinetic fitting models used, namely pseudo

1st order and pseudo 2nd order. In laundry waste, it tends to be more suitable to use the pseudo 2nd order kinetic fitting model with the regression value (R^2) of 0.951. While tofu waste is more suitable for using the pseudo-first order kinetic fitting model, with a regression value (R^2) of 0.956. The k value for each kinetic parameter indicates the adsorption rate, while the R^2 value indicates the accuracy of the model in describing the experimental data.

Kinetics adsorption tend to be pseudo 2nd order can indicate that the adsorption rate is influenced by chemical interactions such as between functional groups of activated carbon and adsorbate, while kinetics that tend to pseudo 1st order indicate a rate controlling step in the form of external diffusion/surface adsorption so that molecular interactions are generally van der Waals forces and tend to be weaker (Lestari et al., 2022).

The adsorption capacity of the water content and the contact duration between the activated carbon and the well water sample both increase with the amount of activated carbon employed. This gives the pores of the activated carbon more time to expand and adsorb more particles. Furthermore, a high TDS value indicates incomplete gasification of organic waste. The activity of microorganisms that break down organic materials is linked to the drop in TDS levels in wastewater. The growing number of microorganisms in garbage can have an impact on the decline in TDS content (Fisma & Bhernama, 2022).

b. TSS Analysis (*Total Suspended Solids*)

The term Total Suspended Solid (TSS) describes solid particles suspended in water that can block or guide light's path, thus influencing the water's color. The research findings on TSS parameters of liquid waste from the tofu industry are shown in the figure below (Harmiwati et al., 2024).

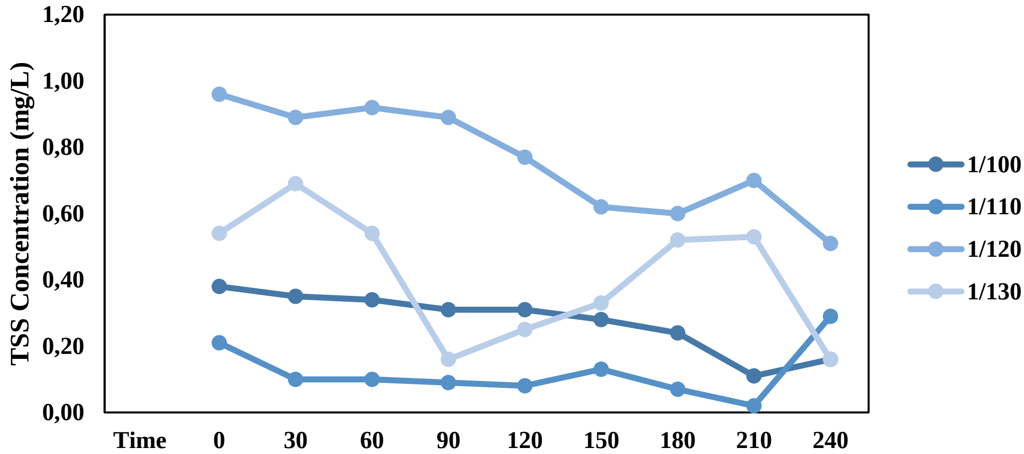


Figure 5. Research results on TSS parameters of laundry waste

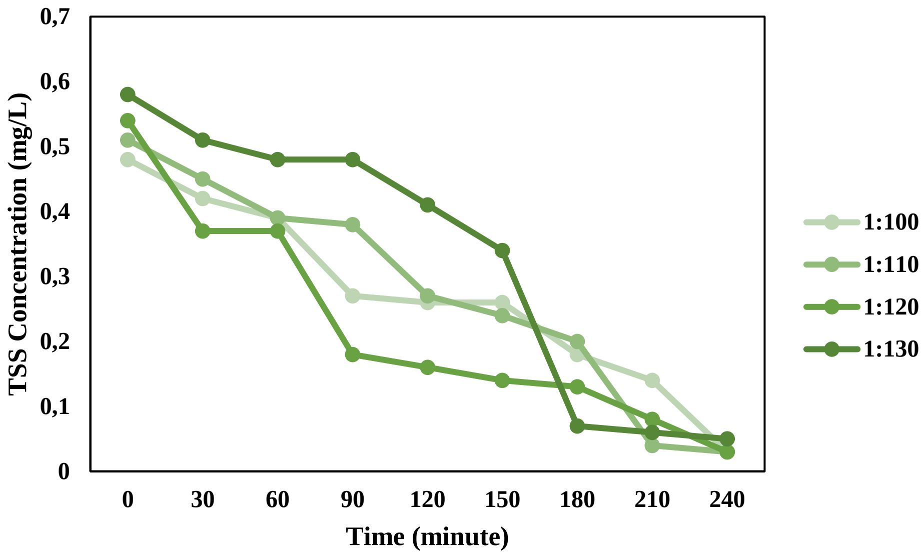


Figure 6. Research results on TSS parameters of tofu liquid waste

TSS analysis aims to measure the amount of suspended solids in waste samples after the adsorption process using activated carbon from rice husks. The data shown in Figure 5 were obtained from variations in the ratio of adsorbent to waste volume, namely 1:100, 1:110, 1:120, and 1:130. In the initial sample of laundry waste, the TSS concentration was recorded at 1.63 mg/L. Based on the graph, it can be seen that the longer the stirring time and adsorption contact, the TSS levels decreased significantly. This decrease shows the effectiveness of activated carbon in absorbing suspended solids from wastewater.

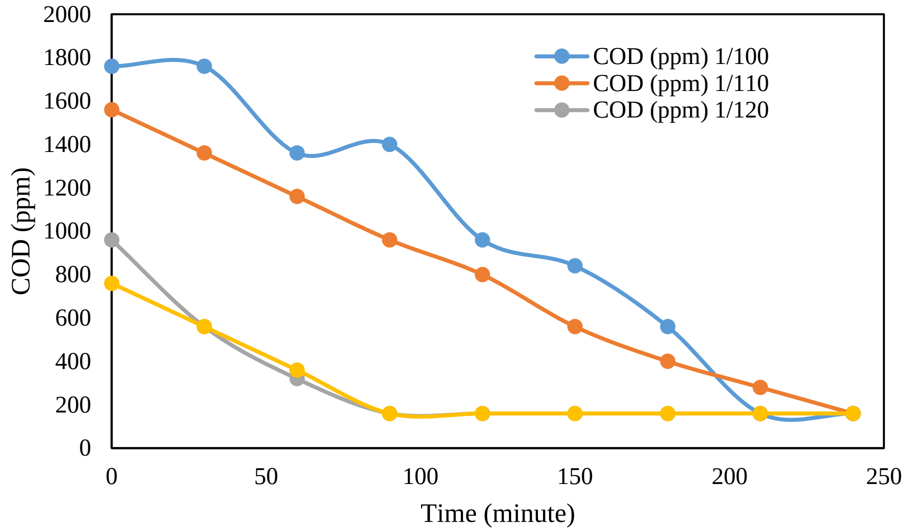
High TSS levels can hurt the aquatic environment, especially by decreasing the photosynthetic activity of microorganisms and aquatic plants. As a result, dissolved oxygen levels decrease, which can cause the death of aquatic biota such as fish (Jiyah, B.Sudarsono, 2017). Therefore, reducing TSS in wastewater treatment is an important parameter in efforts to maintain ecosystem balance.

Figure 6 illustrates that the TSS in tofu liquid waste before processing was 1.04 mg/L, which is significantly less than the TSS standard quality threshold of 200 mg/L specified in the Environment Minister's Regulation No. 5 of 2014. The reduction in TSS levels following rice husk activated carbon treatment demonstrates how effectively this adsorbent may enhance water quality. The main mechanisms that cause the decrease in TSS in this study are thought to occur through two pathways: (1) physical trapping of suspended particles in the micro and meso pores of activated carbon, and (2) chemical surface interactions between active functional groups on carbon (such as hydroxyl and carboxyl) with charged particles in waste. The combination of these mechanisms strengthens the effectiveness of rice husk activated carbon in reducing turbidity and suspended solids from wastewater.

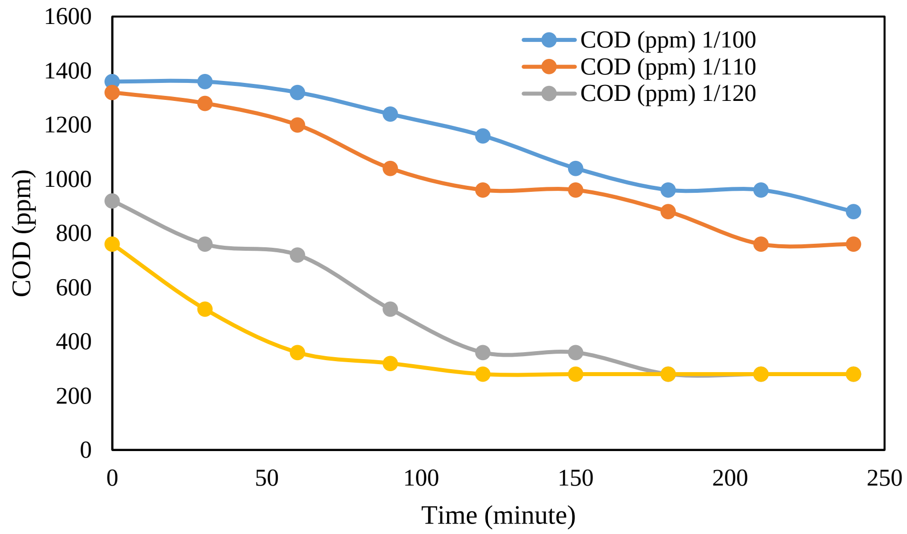
When compared to conventional treatment methods such as coagulation-flocculation using chemicals (such as alum or ferric chloride), adsorption using rice husk activated carbon has advantages in terms of cost, availability of materials, and environmental impact. Coagulation generally produces chemical sludge as a side waste and requires pH adjustment, while activated carbon from agricultural biomass is biodegradable, cheap, and does not produce hazardous waste. Thus, the findings of this study demonstrate the method's potential for sustainable small- and medium-scale waste processing in addition to confirming its efficacy.

c. COD Analysis (*Chemical Oxygen Demand*)

Chemical Oxygen Demand (COD) testing in this study aims to measure the extent to which activated carbon from rice husks is able to reduce the content of organic compounds in wastewater. COD is the main indicator of organic pollutant load, which directly reflects the oxygen requirement for the degradation process of organic matter in aquatic environments.



(a)



(b)

Figure 7. Research data on COD parameters of : (a) Laundry waste and (b) Tofu liquid waste

Tests were conducted on two types of waste: laundry waste and tofu waste, using variations in the ratio of adsorbent to waste (1:100, 1:110, 1:120, and 1:130) with a contact time of 0–240 minutes and a collection interval of every 30 minutes. The test results shown in Figure 7(a) show that the highest COD reduction occurred in laundry waste, with the highest value reaching 160 mg/L at a ratio of 1:120 and a contact time of 90 minutes, resulting in a decrease in efficiency of 92%. After this point, efficiency decreases due to the achievement of saturation and adsorption equilibrium conditions, where most of the active sites on the carbon surface have been filled by adsorbate molecules (Mefiana, 2021).

The high efficiency of rice husk activated carbon in reducing COD can be explained by several important characteristics. Activation using 2M KOH produces carbon with a high specific surface area and developed pore structure (micro and mesopores), allowing the adsorption of organic compounds of various molecular sizes. In addition, polar functional groups such as -OH and -COOH on the carbon surface allow chemical adsorption through electrostatic interactions, hydrogen bonds, or surface complexes. This combination of physical and chemical adsorption increases the capacity to remove organic pollutants that contribute to COD (Andika et al., 2020).

This COD removal mechanism is the main advantage of rice husk activated carbon compared to conventional methods. For example, the coagulation-flocculation process using chemicals such as alum or $FeCl_3$ is indeed effective in removing COD, but it produces chemical sludge that requires further treatment and increases operational costs. Meanwhile, agricultural waste-based activated carbon is environmentally friendly, economical, and easily obtained locally, making it an attractive choice for small to medium-scale waste treatment.

For tofu waste, Figure 7(b) shows that the initial COD content was 1520 mg/L, far above the established quality standard (300 mg/L). Although there was a decrease after the adsorption process, the final COD value had not reached the standard threshold. This indicates that tofu waste has a much higher organic load than washing waste, so further treatment or a multi-stage treatment system is needed. Overall, several previous studies have shown that commercial activated carbon has a COD removal efficiency of around 80–90% (Li et al., 2020). In this context, the rice husk activated carbon in this study showed equivalent performance even with local biomass sources, without expensive and environmentally unfriendly production processes. Thus, these results indicate that rice husk activated carbon is an alternative sustainable adsorbent that is not only technically effective but also economically and ecologically beneficial.

CONCLUSION

This study demonstrates that the levels of key contaminants in tofu and laundry wastewater may be effectively reduced by employing an adsorption procedure that uses activated carbon from rice husk. In laundry waste, the reduction in Total Dissolved Solids (TDS) levels reached 27%, Total Suspended Solids (TSS) by 97%, and Chemical Oxygen Demand (COD) by 82%. Meanwhile, in tofu wastewater, the reduction in TDS was recorded at 51%, TSS by 90%, and COD by 92%. These data indicate that adsorption is more effective in reducing the organic load in tofu waste, especially for the COD parameter, while the TSS reduction efficiency is higher in laundry waste. According to these findings, the initial properties of the waste have a significant impact on the adsorption performance, and choosing the ideal operating circumstances is crucial to maximizing efficiency. Activated carbon from rice husk has been proven to be an environmentally friendly and cost-effective adsorbent, making it a potential alternative for the treatment of small to medium-scale domestic and industrial wastewater. In terms of practical application, these findings can support the development of more affordable and sustainable waste treatment systems in the food industry (such as tofu processing) and service sectors (such as laundry businesses). The use of agricultural waste as an adsorbent also encourages the implementation of circular economy principles and the utilization of local resources.

For further research, evaluation of the regeneration and recycling capabilities of the adsorbent is needed, as well as testing in a continuous flow system that is more representative of actual industrial conditions. In addition, direct comparison with commercial adsorbents or conventional methods such as coagulation-flocculation will help assess the relative advantages of this adsorbent material and expand its potential application on a wider scale.

SUGGESTION

Future research should concentrate on investigating alternate adsorbents made from various regional agricultural waste materials, like banana peels, corn cobs, or coconut shells, in light of the study's findings. Comparing their adsorption capacity and pollutant removal effectiveness to that of the activated carbon derived from rice husks utilized in the current investigation is the goal. In order to identify the most effective operating conditions for lowering TDS, TSS, and COD levels, more research should also focus on optimizing the adsorption process parameters, such as contact time, pH, adsorbent dosage, and temperature. The use of experimental design approaches such as factorial design or Response Surface Methodology (RSM) is strongly recommended to systematically evaluate the interactions among variables. Future studies should also investigate the ideal mixing ratio of tofu and laundry wastewater to support an efficient combined wastewater treatment system. Additionally, environmental impact assessments of the adsorption process residues are essential, including evaluations of potential reuse or regeneration of the spent adsorbent through chemical or thermal methods. Pilot-scale testing in continuous flow systems, such as fixed-bed column reactors, should also be conducted to assess the adsorbent’s performance under more realistic operational conditions. These research directions are expected to contribute to the advancement of sustainable and applicable wastewater treatment technologies.

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