JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(1), 273–285
https://doi.org/10.12911/22998993/195754
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Received: 2024.10.23
Accepted: 2024.11.15
Published: 2024.12.01

Innovation of Remazol yellow FG dye adsorption using biochar from coffee fruit shell waste

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ABSTRACT

The textile industry produces liquid waste containing synthetic dyes, such as Remazol yellow FG, which are difficult to decompose naturally and negatively impact the environment. This study aims to evaluate the effectiveness of biochar derived from coffee fruit shell waste as an adsorbent for removing Remazol yellow FG dye from aqueous solutions. The method used includes pyrolyzing coffee fruit shell at 300 °C for 120 minutes to produce biochar, which is then tested for its dye adsorption capacity through batch experiments with varying dye concentration, pH levels, and contact time. The results showed that coffee fruit shell biochar had a high adsorption capacity at pH 4 and a contact time of 80 minutes. The process of adsorption followed the Langmuir isotherm model with a value r^2 of 0.91507 for non-active biochar adsorbent and 0.92372 for biochar that had been activated with NaOH. Adsorption kinetics followed second-order kinetics with r^2 reaching 0.96189 for non-active biochar and 0.96697 for biochar activated with NaOH. The effectiveness of biochar under laboratory conditions highlights its potential as a more economical and environmentally friendly adsorbent compared to commercial activated carbon. This research contributes to the development of liquid waste treatment technologies based on renewable materials, supporting the circular economy in the textile industry.

Keywords: adsorption, biochar, Remazol yellow FG dye.

INTRODUCTION

One of the industrial sectors that contributes significantly to global economic growth is the textile industry. But at the same time, it is also known as a producer of liquid waste that is harmful to the environment (Abbate et al., 2024; Suárez et al., 2023; Sukarta et al., 2021). The textile industry is accountable for around 20% of freshwater contamination worldwide due to dyeing and finishing processes, which poses significant environmental hazards (Zhai et al., 2022). One of the main components of this liquid waste is synthetic dyes, such as Remazol yellow FG, which is widely used in textile dyeing processes (Jahan et al., 2022). These dyes are often resistant to natural biodegradation processes and have the potential to pollute groundwater and aquatic ecosystems (Aragaw et al., 2022; Thanavel et al., 2020). The impact of textile waste pollution has raised global concerns, especially in developing countries that are the production centers of this industry. Therefore, there is an urgent need to find effective, low-cost and environmentally friendly waste treatment methods to reduce the negative impact on the environment (Motte and Ostlund, 2022). One promising approach is the use of natural materials or agricultural waste as adsorbents to remove dyes in wastewater. Among the various sources of agricultural waste, coffee fruit shell waste has attracted attention due to its abundant availability and great economic potential, especially in coffee-producing countries. Indonesia is one of the largest coffee producing countries in the world. The amount of coffee shell waste produced by Indonesian farmers in the last 5 years is 1,425.923 tons/year for Robusta coffee and 533.225 tons/year for Arabica coffee (Sukarta et al., 2023). The majority of the debris from coffee shells is thrown away without being used by growers. Unmanaged or carelessly discarded coffee shell debris can contribute to environmental contamination. The utilization of this waste does not only reduce environmental pollution from two sectors at once, namely agricultural waste and textile industry waste, but also supports the concept of a sustainable circular economy.

The management of textile industry wastewater containing synthetic dyes, such as Remazol yellow FG, presents significant environmental challenges. These dyes are known to be difficult to decompose naturally due to their complex chemical structure, so they can persist in aquatic ecosystems for long periods of time and disrupt water quality (Santana et al., 2017). Conventional methods used to treat dye wastewater, such as coagulation, flocculation, or oxidation methods, often involve high costs and the use of additional chemicals that actually cause secondary environmental problems. In addition, the dye removal efficiency of these methods is still limited, especially at high dye concentrations. This challenge is further compounded by the increasing global production of textiles, which is accompanied by an increasing volume of wastewater that must be treated. In relation to this challenge, a more effective and sustainable alternative solution is needed, especially through the use of natural materials that can be processed into affordable and environmentally friendly adsorbents. The adsorption method is one of the efficient, cost-effective and ecologically sustainable alternative methods (Alfei et al., 2023; Elbadawy et al., 2023; Pellicer et al., 2022; Remediation et al., 2022; Sudiana et al., 2022). In this context, the utilization of agricultural waste such as coffee fruit shell as an adsorbent offers great potential, but its effectiveness in adsorbing specific dyes, such as Remazol yellow FG dye, still requires further research.

This study, therefore, aims to explore the potential of activated carbon produced from coffee fruit shell waste as an effective alternative adsorbent in eliminating Remazol yellow FG dye from liquid effluent from the textile industry. In particular, this study focuses on evaluating the adsorption efficiency of activated biochar under different conditions, including variations in dye concentration, contact time, and other operational parameters, to determine the optimal adsorption capacity. In addition, this study also aims to identify critical parameters such as isotherm patterns and adsorption kinetics that affect adsorption performance and measure the feasibility of coffee shell activated biochar as an environmentally friendly solution in liquid waste processing. Thus, this research is expected to provide a significant contribution to the advancement of technology in waste processing based on renewable resources, as well as opening up opportunities for utilizing agricultural waste in efforts to mitigate the environmental impact of the textile industry.

Numerous research have been conducted in recent years to utilize agricultural waste as an adsorbent to degrade dye waste such as corn husks (Bawa, 2023; Walanda et al., 2022), coconut fiber (Baunsele & Missa, 2020), coconut shell (Kumar and Saha, 2024; Singh et al., 2024), candlenut shell (Sugiani et al., 2021), and bamboo (Lou et al., 2023; Zhang et al., 2024). Although various studies have been conducted to develop textile waste processing technology, the use of natural adsorbents is still at the exploratory stage and requires more in-depth studies. Most existing studies focus more on conventional adsorbent materials, such as commercial activated carbon, or other natural materials, but research examining the use of activated carbon from coffee fruit shell waste is still very limited. The available literature shows the great potential of agricultural waste as a dye adsorbent. However, very few studies have explored the effectiveness of coffee husk activated biochar in the context of removing certain synthetic dyes, such as Remazol yellow FG. This gap indicates the need for further studies to prove the feasibility and effectiveness of activated biochar from coffee shell as a solution for liquid waste treatment. By identifying and addressing gaps in the existing literature, this study aims to provide new, relevant contributions to the development of renewable resource-based technologies, as well as provide more sustainable alternatives for the textile industry.

This research offers a new approach in utilizing coffee fruit shell waste as a basic material for activated biochar for adsorption of Remazol yellow FG dye, which has not been studied in depth. The novelty of this research lies in the innovation of utilizing abundant and underutilized agricultural waste into a sustainable solution for processing textile industry waste. Unlike expensive and environmentally unfriendly commercial adsorbents, activated biochar from coffee shell waste offers a more economical, renewable and environmentally friendly solution. In addition, this research contributes to the integration of the circular economy concept, where waste from one agricultural industry sector is processed into valuable resources for other industrial sectors such as the textile industry. The scientific justification of this research is also strong, considering the global urgency for greener and more effective waste processing technologies in reducing environmental impacts. Thus, the results of this study not only provide practical solutions for industry, but also enrich the scientific literature in the field of liquid waste management based on renewable materials.

MATERIALS AND METHODS

The materials used are coffee fruit shell waste, distilled water, aluminum foil, filter paper, NaOH, H_2SO_4, and Remazol yellow FG dyes.

Biochar production

Biochar was produced using a method developed by Kene and Ryan (2022). Coffee fruit shell is heated in a furnace (pyrolysis process) at 300–500 °C temperature for around 120 minutes to form biochar. Next, the coffee fruit shell biochar is sieved using a 100–200 µm sieve to produce biochar with a specific and uniform particle size.

Biochar activation

As much as 100 grams of biochar was added with 2.5% NaOH. The mixture was then left for ± 24 hours. From this process, a biochar paste was produced which was then filtered and washed using distilled water until the pH is pH = 7 (neutral). The biochar paste was dried in an oven at 105 °C for 1.5 hours. The activation process was repeated 3 times.

Biochar characterization

Biochar analysis procedures refer to the Indonesian National Standard 06-3730-19995 on technical activated carbon (SNI 1995).

Proximate analysis

Proximate biochar content analysis includes analysis of water, ash, volatile matter, and total fixed carbon content using the thermogravimetry analyzer (TGA) instrument (Dittmann et al., 2022).

Morphological analysis

Morphological analysis and particle size of biochar were conducted using scanning electron microscope (SEM) instrument. SEM analysis is used to qualitatively ascertain the surface morphology of biochar (Kalina et al., 2022).

The adsorption experiment studies

Effect of pH

A total of 8 Erlenmeyer flasks were each filled with Remazol yellow FG dye solution 25 mL with a 60 mg/L concentration. Each solution was conditioned at pH 3, 4, 5, 6, 7, 8, 9, and 10 by including 0.05 M H_2SO_4 or NaOH of 0.05 M to adjust the pH value. pH level was measured using a previously calibrated pH meter. Biochar with a size of 200µm as much as 0.2 g was put into each Erlenmeyer flask, then homogenized with a shaker for 60 minutes. The mixture of biochar and Remazol yellow FG was filtered using filter paper and centrifuged at a speed of 5000 rpm for 15 min. then the concentration was measured as the final concentration, using a UV-visible spectrophotometer at the maximum wavelength (Setiawan et al., 2019).

Effect of contact time

The dye was created with a concentration of about 60 mg/L, and a UV-visible spectrophotometer was used to measure the actual concentration. As many as 25 mL of dye was made under optimum pH conditions in the pH variation test, then 0.2 g of biochar with a size of 200 µm was added. The solution was homogenized using a shaker with 20, 40, 60, 80, 100, 120, 140, and 160 min time variations (Elystia et al., 2018). The mixture of biochar and Remazol yellow FG was filtered using filter paper and centrifuged at 5000 rpm for 15 min, then the absorbance was measured using a UV-visible spectrophotometer at the wavelength of maximum.

Concentration effect

Remazol yellow FG dye with optimum pH condition was made with concentration variations of around 10, 20, 30, 40, 50, 60, 70, and 80 mg/L, then the actual concentrations were measured using a UV-visible spectrophotometer. Biochar with a 200 μm size was added as much as 0.2 g into 25 mL of the dye solution, then shaken at optimum contact time. The mixture of biochar and Remazol yellow FG was filtered using filter paper and centrifuged at 5000 rpm for 15 min, then the UV-visible spectrophotometer was used to measure the absorbance at the wavelength of maximum. The efficiency of dye adsorption using coffee fruit shell waste biochar by varying pH, contact time, and optimum concentration can be calculated utilizing the equation that follows.

$$\%E = \frac{C_0 - C_e}{C_0} \times 100\% \quad (1)$$

where: *E* is adsorption efficiency, *Co* is concentration of initial before adsorption, *Ce* is equilibrium concentration after adsorption.

Meanwhile, for the adsorption capacity, the following equation is used.

$$Capacity\ of\ adsorption\ (\text{mg/g}) = \frac{C_0 - C_e}{w} \times V \quad (2)$$

where: *w* is the biosorbent weight (g), *V* is the Remazol yellow FG dyes volume (mL).

The adsorption isotherms studies

Remazol yellow FG dye was pipetted as much as 25 mL and conditioned at pH 6 with a concentration of about 60 mg/L. The actual initial concentration of the dye was measured using a UV-visible spectrophotometer at its maximum wavelength. Then, 0.2 g of 200 μm biochar powder was added, then shaken for 200 minutes. To determine the adsorption isotherm pattern and the maximum adsorption capacity, this procedure was carried out using concentration variations of 10, 20, 30, 40, 50, 60, 70, and 80 mg/L. The concentrations of the dye after the process were accounted as the equilibrium concentrations (C_e), and the amounts of the dye absorbed (Q_e) were calculated. For the Langmuir adsorption isotherm pattern, the C_e/Q_e should be linearly correlated with Ce, following the equation:

$$\frac{Ce}{Qe} = \left(\frac{1}{Qmax}\right)\left(\frac{1}{b}\right) + \left(\frac{1}{Qmax}\right) Ce \quad (3)$$

On the other hand, if the adsorption follows Freundlich isotherm, *log Qe* should be linear with C_e following the equation:

$$\log Qe = \log kF + \frac{1}{n} \log Ce \quad (4)$$

where: *kF* is the Freundlich constant.

Adsorption kinetics

Twenty-five mL of Remazol yellow FG dye solution with a concentration of 60 mg/L was mixed with 2 g of biochar at contact time variations of 20, 40, 60, 80, 100, 120, 140, 160, 180, and 200 minutes. After the experiment was completed on each variation for the adsorption study, the mixture of coffee fruit shell biochar and Remazol yellow FG was filtered using filter paper and centrifuged at 5000 rpm for 15 minutes, then the absorbance was measured using a UV-visible spectrophotometer at a wavelength of 418 nm.

The adsorption kinetic parameters were obtained by analyzing the data obtained and plotting them according to the adsorption kinetic model. For pseudo-first order (PFO), the equation is

$$\frac{dq}{dt} = k_1(q_e - q) \quad (5)$$

where: *qt* is the amount of adsorbate adsorbed by the adsorbent at time *t* (mg/g), q_e is the equilibrium adsorption capacity (mg/g), and *k*1 is the reaction rate constant per minute.

Meanwhile, pseudo-second order (PSO) was calculated using the equation

$$ln(q_e - q) = ln\, q_e - k_1 t \quad (6)$$

RESULTS AND DISCUSSION

Biochar characteristics

The proximate analysis conducted aims to measure the water content, ash (minerals), and organic matters (including carbon and hydrogen), whose results is presented in Table 1.

From Table 1 it can be seen that the water content of biochar meets the SNI 06-3730-1995 quality standards. While the volatile substance content has not been met. This is likely due to

Table 1. Coffee fruit shell activated biochar characteristics

Parameter	SNI 06-3730-1995	Sampel	
		Nonactivated biochar (%)	NaOH activated biochar (%)
Water content (%)	Max 15%	7.18	5.58
Volatile matter (%)	Max 25%	39.28	42.37
Total ash content (%)	Max 10%	11.18	2.51
Carbon content (%)	Min 65%	42.36	49.54

several factors, including the raw materials used to produce the activated carbon having high organic compound contents, such as lignin and cellulose, which produce high volatile substances. In addition, an incomplete carbonization process can also result in activated carbon with a higher volatile content.

The total ash content in the activated biochar is lower than that of the nonactivated biochar. This is because nonactivated biochar contains more impurities (foreign substances) such as minerals, metals and organic compounds that are not completely burned in the pyrolysis process. As a result, these impurities increase the total ash content. In contrary to the nonactivated biochar, in activated biochar, the activation process with NaOH has removed most of these impurities, thus reducing the ash content significantly.

The purpose of determining the bound carbon content is to find out how much carbon is in the activated carbon that is made and also as an indicator of the purity of the carbon. The greater the amount of bound carbon, the purer the activated carbon and the more effective its performance as an adsorbent (Serafin and Dziejarski, 2024; Tarikuzzaman, 2023). In addition to water, ash, and volatile substances, the carbon fraction of the activated carbon from coffee fruit shell waste is also produced from the charring process, indicating that the activated carbon from coffee fruit shell waste meets the quality standards. The carbon content bound to the activated carbon is influenced by the levels of water, volatile substances, and ash, with higher levels related to the amount of carbon produced. In this study, the comparative characterization carried out showed that the activated carbon from coffee fruit skin waste possesses characteristics that meet about 75% of the technical activated carbon standard as in SNI 06-3730-1995.

Morphological analysis

The results of the morphological analysis of the biochar from coffee fruit shell using SEM are presented in Figure 1 for nonactivated biochar and Figure 2 for biochar activated using NaOH.

Figure 1 shows the visualization of the surface structure of nonactivated biochar. It can be seen that at a magnification of 1000–10,000× the biochar from nonactivated coffee fruit shell waste has very thin and small cracks and visible pores as shown in the red circle. The pores of the activated biochar are very important for the adsorption process because they allow the desired molecules to enter and be trapped in them. Without pores, the ability of the activated biochar to absorb and bind substances or molecules will be very limited or even non-existent at all.

Figure 2 shows the morphology of the surface of biochar that has been activated with NaOH. One of the most striking changes in the morphology

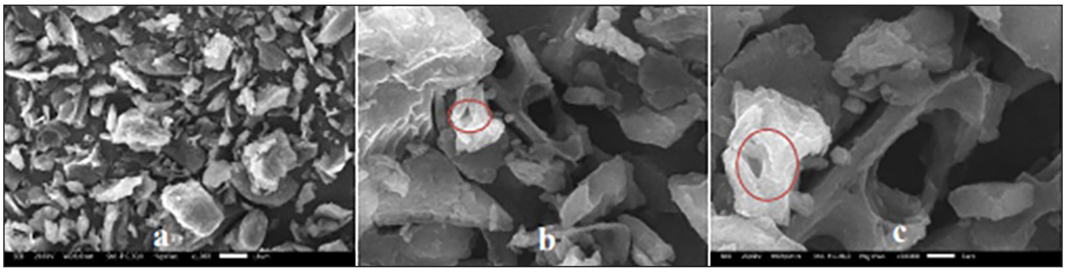

Figure 1. Morphological analysis of nonactivated biochar at ((a) 1.000× magnification, (b) 5.000× magnification, (c) 10.000× magnification)

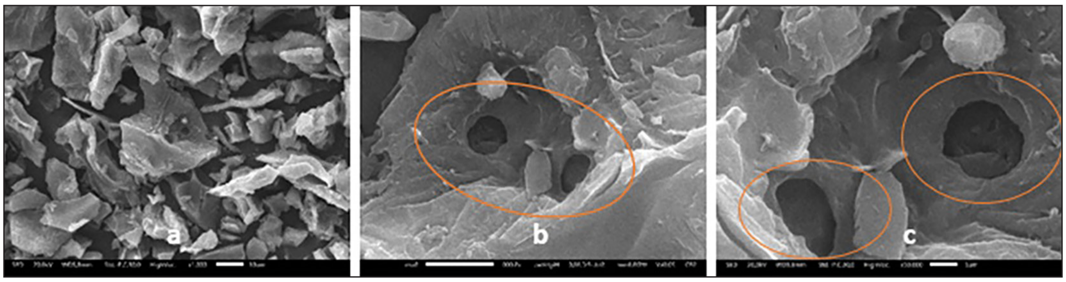

Figure 2. Morphological analysis of NaOH-activated biochar at ((a) 1000× magnification, (b) 5000× magnification, (c) 10,000× magnification**)**

of nonactivated and activated biochar is that biochar activated with NaOH has cracks and pores that are quite large as seen in the red circle of the image with a magnification of 1000× (c). These pores allow target molecules to enter the biochar structure and be adsorbed by the surface in the pores (Sunarti et al., 2022)

Effect of pH on adsorption effectiveness

The pH condition of the solution is one of the valuable factors that must be regarded in adsorption studies. The pH medium is related to the surface charge of the adsorbent and the state of the adsorbed substance. The study results on the pH effect on adsorption efficiency of Remazol yellow FG onto non acyivated and NaOH-activated biochar are shown in Figure 3.

From Figure 3, it can be seen that the best efficiency was obtained at pH 4, which was 44.32% for nonactivated biochar and 55.34% for biochar activated with NaOH. This shows that the adsorption process occurs in an acidic environment. According to research conducted by (Kerie and Alemu, 2022; Vojnovic et al., 2022), it is stated that the pH tendency in the adsorption of sulfonate dyes with activated carbon generally tends towards acid, with an optimum pH ranging from 2 to 6. At low pH level, activated carbon's surface has a positive charge, so that it has the ability to draw in negatively charged and Remazol yellow FG dye molecules at low pH. The primary mechanism of adsorption is the electrostatic interaction between the dye molecules and the opposing charges on the surface of activated biochar. Being an anionic

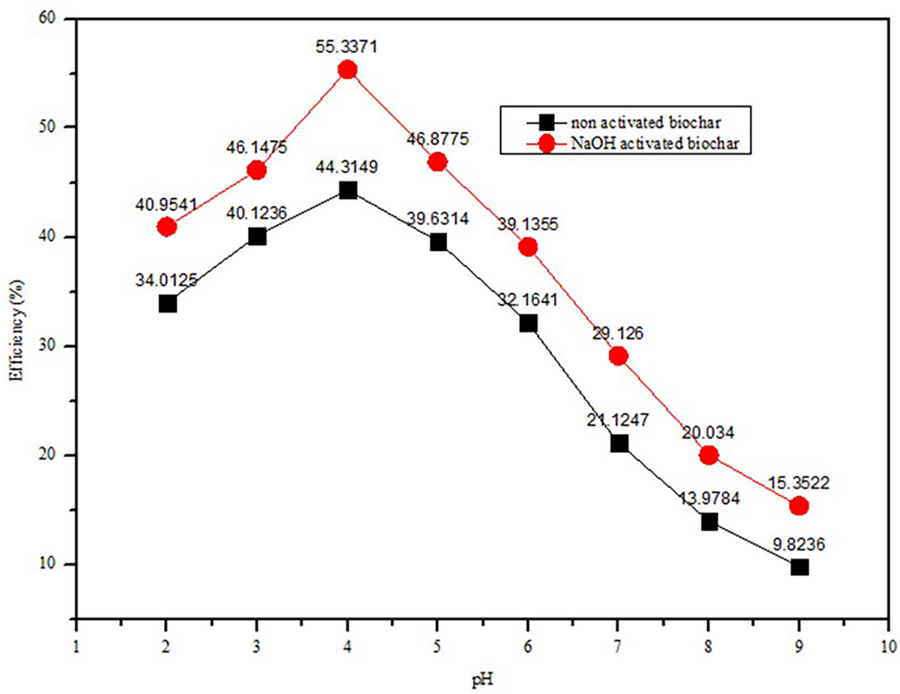

Figure 3. The relationship between pH variation and adsorption efficiency

dye, Remazol yellow FG has a negative charge in solution. At low pH, available functional groups on biochar such as OH and COOH, are protonated with hydrogen ion, so that its positive charge increases, thereby increasing the electrostatic attraction with negative charged of Remazol yellow FG. Therefore, the adsorption at low pH has high adsorption efficiency. Then when passing pH 4 there was a decrease in efficiency up to pH 9. This shows the activated biochar adsorption capacity decreased in basic conditions. Under alkaline conditions, available functional groups on the surface of biochar, undergo deprotonation so that the surface charge of the biochar becomes negative and the interaction with anionic dyes becomes stronger, resulting in increased adsorption efficiency. This finding aligns with Hung et al. (2023), who reported that the higher adsorption efficiency of anionic dyes such as methyl orange and Congo red onto longan seed-activated carbon surfaces was obtained at acidic conditions. Several research results, such as those conducted by Serban et al. (2023), found that the maximum methyl orange dye removal efficiency on the surface of commercial activated carbon was achieved at pH 3, while research by Ayari et al. (2018) found that the maximum adsorption capacity of the anionic dye Congo red on the surface of natural bentonite occurred at pH 4. However, the adsorption process of cationic dyes such as methylene blue appears to occur optimally at alkaline pH due to strong electrostatic interaction between the negative charge of the surface adsorbent and the positive charge of the methylene blue dye (Sharma and Kaur., 2011).

Contact time effect on efficiency of adsorption

The efficiency of the biosorption process is significantly impacted by the duration of contact time between the adsorbate and the biosorbent. In general, the longer the contact time between the biosorbent and the adsorbate, the greater the adsorption capacity. However, when equilibrium has been reached, increasing the contact time in the adsorption process does not increase the adsorption capacity and will even decrease the absorption capacity value because the adsorbate particles undergo a desorption process and are released back into the solution. The adsorption study of Remazol yellow FG dye onto biochar surface was carried out using a batch technique at various contact times (20, 40, 60, 80, 100, and 120 minutes). The treatment conditions were carried out at pH 4, with an initial dye concentration of 60 mg/L and a biochar dose of 0.2 g per 25 mL of dye in an aqueous solution. The effect of contact time on adsorption efficiency of Remazol yellow FG dye onto non activated and NaOH-activated biochar are presented in Figure 4.

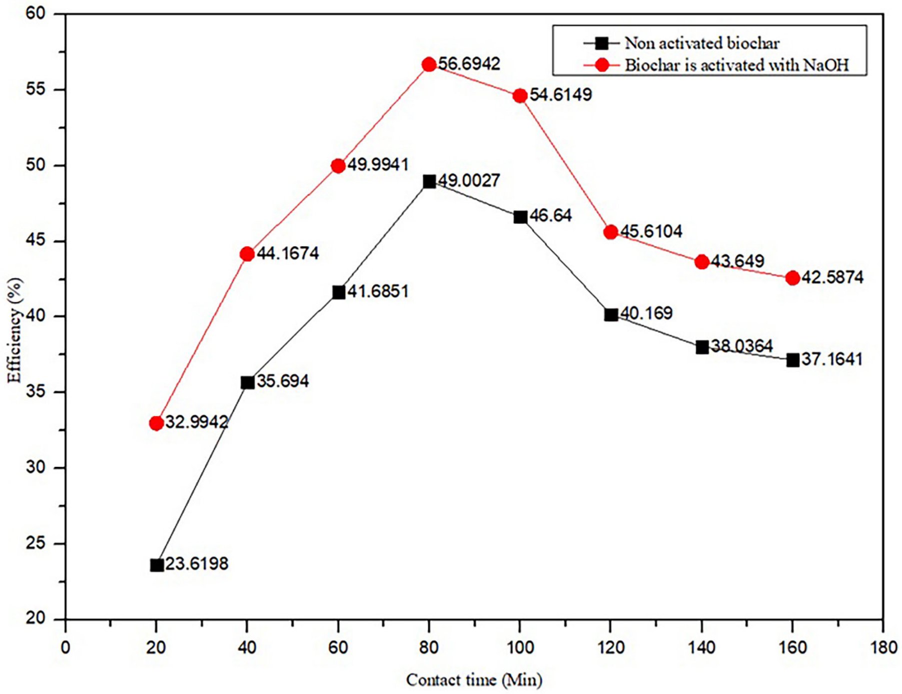

Figure 4. The relationship graph between contact time variation (minutes) and efficiency

Figure 4 shows that the dye adsorption efficiency on the biochar surface increases with increasing contact time from 20 mins. to 80 mins. and then the adsorption efficiency decreases with increasing contact time up to 160 minutes. The ideal contact duration for both biochar is 80 minutes, with an adsorption efficiency value of 49%, and 56.69% for non activated and NaOH-activated biochar, respectively. This finding is in line with Ramadhani and Kurniawati (2021), who reported that the rate of methylene blue biosorption onto longan shell increased with increasing contact time, but after adsorption equilibrium was reached, the adsorption rate tended to decrease due to the release of adsorbate particles into the solution. According to a study by Hartanto and Ratnawati (2010), the process of adsorption is divided into 2 stages: the fast face, which happens at the start of adsorption, and the slowing phase, which lasts longer until it reaches its equilibrium point.

The effect of concentration

The dye absorption on biosorbents is highly dependent on the initial dye concentration. At high dye concentrations, the active sites of the biosorbent become saturated, thus reducing its adsorption capacity. In this study, the adsorption capacity of Remazol yellow FG on biochar from non-activated and NaOH-activated coffee fruit shell waste was investigated at different dye concentrations (10, 20, 30, 40, 50, 60, 70, and 80 mg/L) under operational conditions of pH 4 and a biochar dose of 0.2 g/25 mL of dye solution. The effect of the initial concentration of dye on the adsorption capacity of biochar from non-activated and NaOH-activated coffee fruit shell waste is presented in Figure 5.

As can be observed from Figure 5, the adsorption capacity or absorbed substance increases with the adsorbate concentration. The growing number of adsorbate molecules that can interact with the active sites on the surface of the activated biochar is what causes the increase in adsorption capacity. However, at a certain point after passing the equilibrium point, which is above 60 mg/L, the adsorption capacity decreases slightly. This is as a result of the biochar's surface-active sites being completely occupied. So, there is no more space to absorb dyes as the adsorbate concentration increases. This study supports the findings of research by Sait et al. (2022) where increasing dye concentration increases the number of dye molecules competing to occupy active sites on the surface of activated carbon. Previous research conducted by Pimentel et al. (2024) also revealed that the adsorption capacity of anionic dyes on NaOH-activated *Pinus radiata* sawdust carbon more effective at lower dye concentration compared to higher dye concentration.

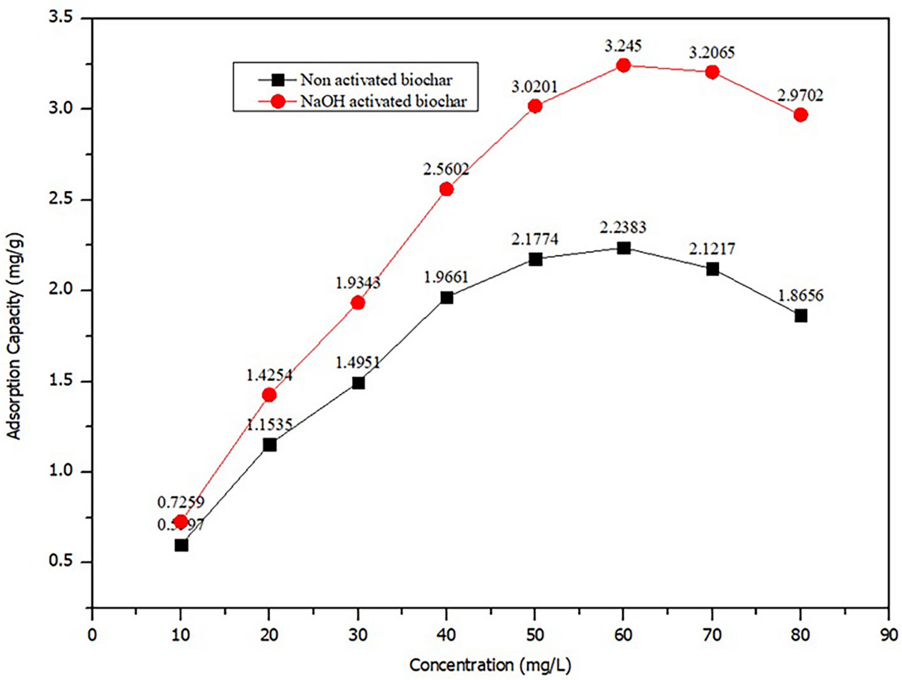

Figure 5. Graph of the relationship between the initial concentration of Remazol yellow FG dye by coffee fruit shell biochar and the adsorption capacity

This is caused by the active groups of the adsorbent becoming increasingly saturated so that an electrostatic repulsion force occurs between the absorbed dye and the dye in the bulk solution. This causes an increase in the demand for adsorption sites and a decrease in adsorption efficiency at higher dye concentrations. In addition, at small concentrations, there are many empty surface-active sites of the activated biochar, but as the dye concentration increases, the adsorption sites on activated carbon become saturated. This is what causes a decrease in the amount of dye that can be adsorbed at higher concentrations. The adsorption capacity of biochar from coffee fruit shell waste activated by NaOH to the dye used in this study was almost equal to the adsorption capacity of the biosorbent from date seed powder. The removal efficiency of 10 mg/L Remazol yellow FG dye using a biosorbent from coffee fruit shell activated by NaOH was obtained of 57.50% with a biochar dose of 0.2 g for contact time of 120 min, while the removal efficiency of methyl violet dye with a concentration of 80 mg/L for 120 min of contact time and a dose of 5 g date seeds was obtained at 55% (Ali et al., 2022).

Adsorption isotherm pattern

The adsorption isotherm determination aims to determine the mechanism of adsorption that occurs in activated biochar from coffee fruit shell waste to reduce the Remazol yellow FG levels. Figure 6 is the Langmuir isotherm pattern, and Figure 7 is the Freundlich isotherm pattern of adsorption using coffee fruit shell biochar adsorbent that has been activated with NaOH.

Figure 6 shows that the adsorption of the adsorbate follows the Langmuir model with r^2 of 0.91507 for nonactivated biochar adsorbent and 0.92372 for biochar that has been activated with NaOH. Further, from the figure it can also be seen that the adsorption isotherm does not follow the Freundlich adsorption isotherm. This can be identified from the r^2 values for biochar without activation and activated with NaOH of 0.79059 and 0.8733, respectively. So, it can be concluded that in this process of the adsorption tends adhere to the Langmuir isotherm pattern which assumes adsorption occurs in a monolayer. By using Equation (3), the maximum adsorption capacity value ($q_{(max)}$) for the nonactivated biochar and activated using NaOH is obtained, respectively, are 2.42 and 4.15 mg/g. The adsorption capacity using biochar activated with NaOH is greater than without activation because the activated biochar has more active sites that are used to adsorb the dye of Remazol yellow FG.

Adsorption kinetics model

The pseudo first order (PFO) kinetic model was used to study the mechanism of adsorption

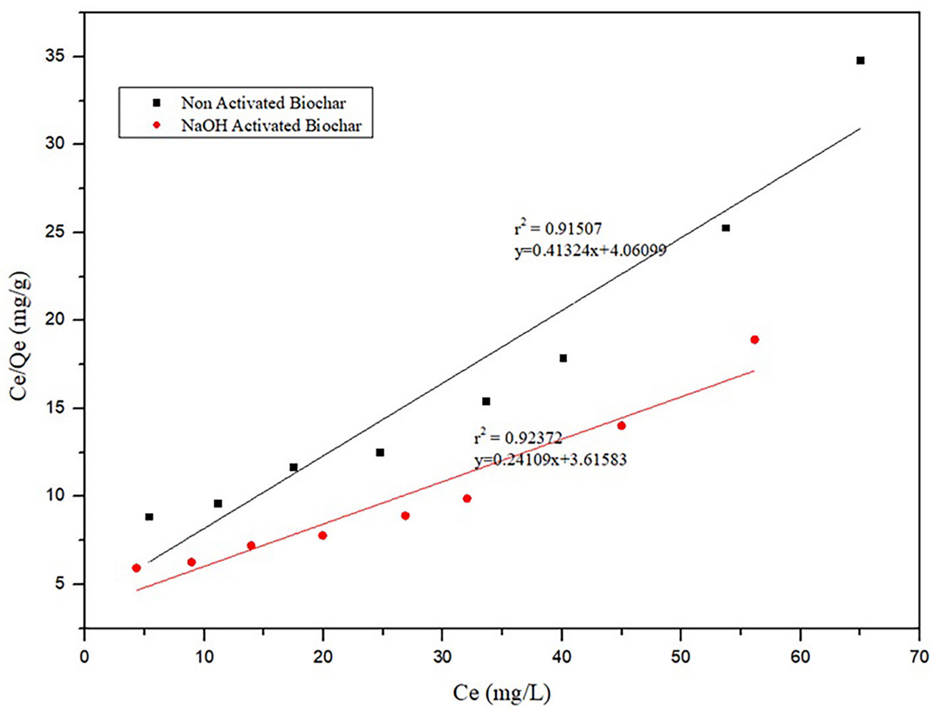

Figure 6. Langmuir adsorption isotherm pattern on coffee fruit shell biochar

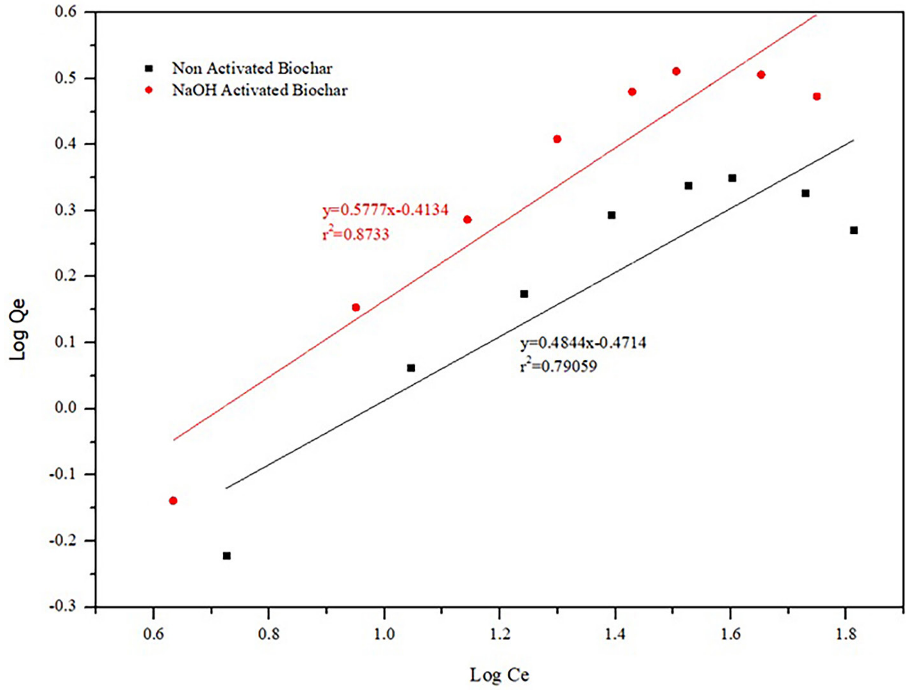

Figure 7. Freundlich adsorption isotherm pattern on coffee fruit shell biochar adsorbent

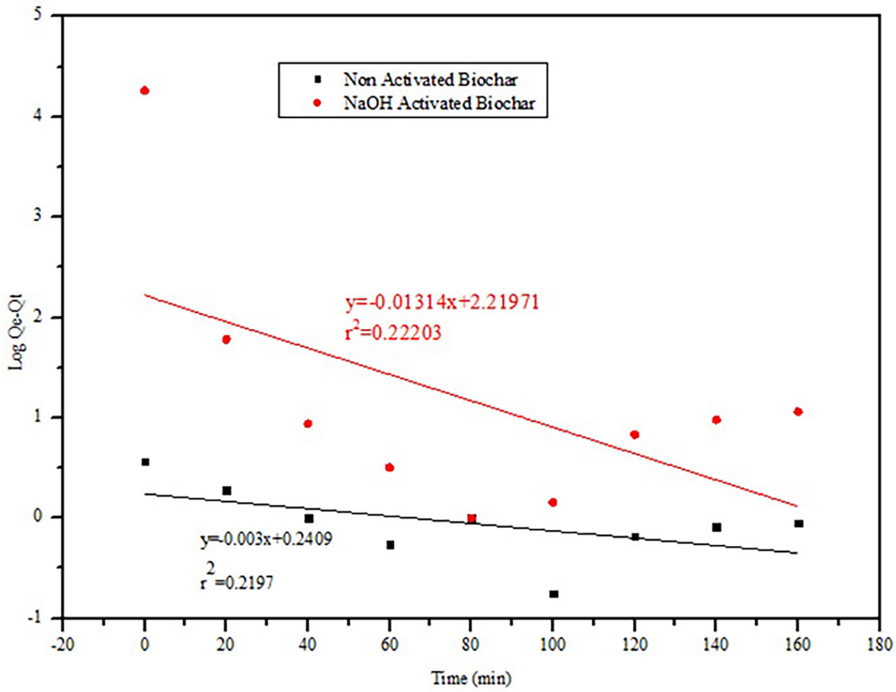

Figure 8. Pattern of PFO adsorption kinetic for Remazol yellow onto the coffee fruit shell biochar adsorbent

with the assumption that the adsorption rate is controlled by adsorption of chemical, which includes the sharing or electrons transfer between Remazol yellow FG and the groups of functional found on the coffee fruit shell biochar adsorbent surface. This pseudo first order kinetic model was determined by examining the correlation between log (Qe-Qt) and t as shown in Figure 8. Meanwhile, a pseudo second order model (PSO) is used under the presumption that the Remazol yellow FG dye's adsorption rate on the adsorbent's surface is second order (Aula Sari et al., 2017). This model is then used to determine the value of the adsorption rate constant (k) and adsorption

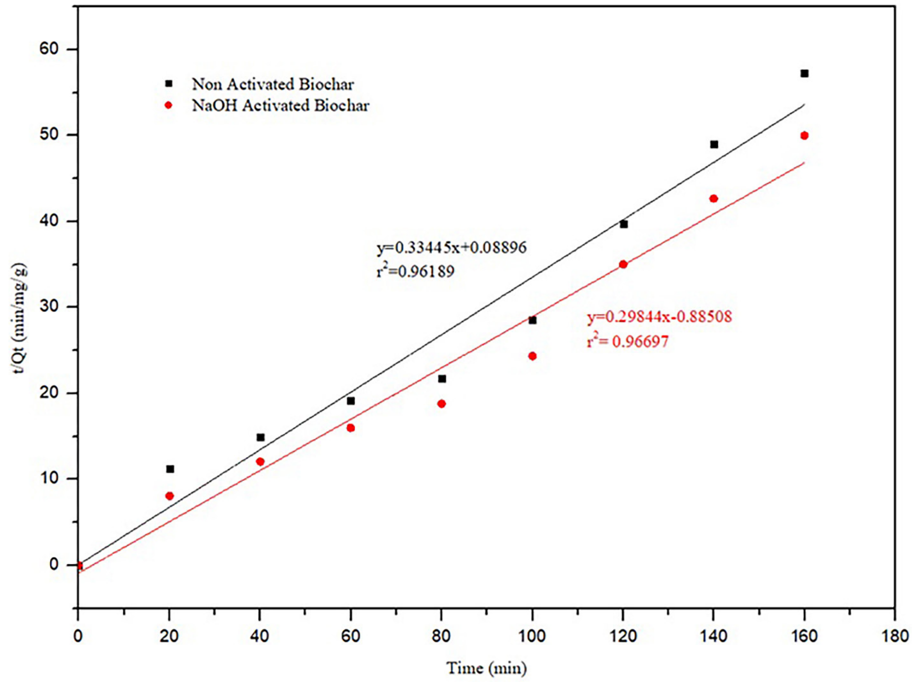

Figure 9. Pattern of PSO adsorption kinetic pattern for Remazol yellow onto coffee fruit shell biochar adsorbent

capacity (Qe) of Remazol yellow FG dye with coffee fruit shell biochar, both without and with NaOH activation. The determination for this model is carried out by examining the correlation between t/Qt and t, as shown in Figure 9.

Based on these data, it can be reported that the adsorption kinetics of Remazol yellow FG dye with coffee fruit shell biochar is better explained using the model of pseudo second order kinetic. This is because the correlation coefficient values are higher than those for the pseudo first order. The r^2 for the pseudo second order kinetics are 0.96189 for nonactivated biochar and 0.96697 for biochar activated with NaOH; while the Qe value obtained is 2.99 for nonactivated charcoal and 3.35 for charcoal activated with NaOH, and the rate constant (k) obtained are 1.26 for nonactivated biochar and 0.1006 for biochar that had been activated with NaOH. The adsorption rate constant values indicate the adsorption rate of Remazol yellow FG dye on both coffee fruit shell biochar adsorbents to reach optimum adsorption time and equilibrium.

CONCLUSIONS

On the basis of the outcomes obtained, Adsorption of Remazol yellow FG dye with activated biochar from coffee fruit shell waste is effective if carried out using biochar that has been activated with NaOH at pH 4, contact time 80 minutes, and concentration 60 mg/L. The average efficiency value obtained is 58.49%. The adsorption isotherm pattern of Remazol yellow FG dye was carried out following the Langmuir pattern model which defines adsorption occurring in a single layer (monolayer) with a maximum adsorption capacity value of 0.24 mg/g for nonactivated biochar and 0.27 mg/g for biochar activated by NaOH. The adsorption kinetic model that occurs is in accordance with the pseudo second order which defines that the adsorption capacity is proportional to the amount of activated biochar surface.

Biochar from coffee wood has great potential to be an innovative solution in processing liquid waste from the textile industry that is more environmentally friendly and efficient. In addition, unlike expensive commercial adsorbents, biochar from coffee shell waste offers a more economical and renewable solution.

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