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Characteristics Candlenut shell-based activated carbon for reduction Iron (Fe) in surface water from Bratasena Tulang Bawang, Lampung

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ABSTRACT

Candlenut shells are only used as fuel, and some are thrown away, so their use has not been maximized. Because of their high carbon content, candlenut shells may be used to create adsorbents. This study looks at how different activator concentrations of KOH activators can be used to make adsorbents from candlenut shells. The study will investigate how various activator concentrations affect the ability of adsorbents based on candlenut shells to bind molecules. Furthermore, the investigation will examine the possible uses of these adsorbents in diverse sectors, including air purification and wastewater treatment. This research was carried out using the Completely Randomized Design (CRD) method, which consisted of 1 activator KOH concentration of 0.5 M, 1 M, 1.5 M, 2 M, and 2.5 M with 3 replications each. The finding demonstrated that adsorbent products activated with 0.5 M KOH yield the highest quality and satisfied SNI 06-3770-1995 requirements for an ash and water content of 10.21% and 0.98%, respectively. The adsorbent product has an iodine absorption capacity of approximately 639.39 mg/g, comparable to SNI 06-3770-1995. For iron metal, the adsorbent product exhibits an adsorption capacity and absorption efficiency of 0.14 mg/g and 98.30%, respectively. The Freundlich adsorption isotherm model is suitable for this investigation, with a Kf value of 0.14 mg/g and an R^2 of 0.9999.

Keywords:
candlenut shells; KOH activator; adsorbent; surface water; Freundlich isotherm

Introduction

In Indonesia, candlenut (*Aleurites moluccana*) is a commodity that is grown extensively, because it is native to tropical and subtropical regions. It can be grown in both highly and poorly fertile soils in lowlands and mountains. Candlenut trees are known for their ability to adapt to different soil conditions, making them a popular choice among farmers in Indonesia (Umar et al., 2018). Additionally, these trees are highly resilient and can withstand harsh weather conditions, further contributing to their widespread cultivation in the country. Candlenuts consist of shells and seeds that contain 38.5% fixed oil (Widodo & Ermaya, 2022). Candlenuts have been extensively researched for their potential uses, particularly for their seeds, which are used to make lamp and hair oil (Ristanti, 2023) and raw materials for pharmaceuticals and cosmetics (Shintawati & Widodo, 2022). The skin is thrown away as waste, but recent studies have shown that contains valuable compounds with potential medicinal properties. Researchers are now exploring ways to utilize discarded skin for various purposes, such as in the production of natural dyes or as a source of antioxidants for skincare products.

Plantation Service reports 13,747 metric tons of candlenuts were produced in Indonesia in 2018. Furthermore, more waste materials like shells and husks will be produced by the higher production of candlenuts. The carbon element content of 47.52% in candlenut shells makes them suitable for use in the production of active carbon (González et al., 2003). Nitrogen contents in candlenut shells are < 0,5%, lower than any shells of commercial nuts 1,1-1,6% such as almonds, hazelnut, and walnut; this means lower NO_X pollutants (Fu et al., 2023). Using candlenut shells for active carbon production not only provides a sustainable solution for waste management but also offers Indonesia economic opportunities. Additionally, the high carbon content in candlenut shells makes them a promising alternative to traditional sources of active carbon, contributing to the development of environmentally friendly technologies. With shell waste possibly consisting of roughly 70% shells and 30% fruit, candlenuts generate waste. Sheel production of up to 9,622 metric tons of candlenut shells were was produced in 2018. Consequently, the electrode of capacitive deionization (Anas et al., 2024), a soil amendment to improve soil fertility, carbon sequestration, and mercury (II) removal (Muliani et al., 2022). Additionally, the high oil content in candlenuts makes them a potential source for biodiesel production, further maximizing the utilization of this waste material.

According to this research, candlenut shells are used as a raw material to create active carbon. The high porosity and surface area of candlenut shell adsorbents effectively absorb various contaminants. Additionally, the utilization of spent candlenut shells as a raw material for active carbon production can contribute to waste reduction and promote sustainable practices in industries. Chemical substances, including acids and bases, are common activators used to produce of adsorbents. These chemicals are crucial in raising the adsorbent's surface area by eliminating non-carbon molecules. Based on the research conducted by Prabarini and Okayadnya (2014) has reported that it is possible to employ candlenut shells with H_2SO_4 activator as active carbon to lower the Fe levels in well water, with 91.38% of the reduction seen. This research suggests that candlenut shells activated with H_2SO_4 can effectively reduce Fe levels in well water. The high reduction percentage indicates the potential of using shell adsorbents as a cost-effective and environmentally friendly solution for water purification. Using candlenut shells and a NaOH activator, generate an absorption capacity of 495.95 mg/g (Maulana et al., 2017). It indicates that candlenut shells activated with NaOH can also be a promising method for water purification, as they show a high absorption capacity.

Further research could explore the effectiveness of combining different activators to enhance the adsorption capabilities of candlenut shells for water treatment purposes, employing coconut shell and a 1.5 M KOH activator concentration, and a 1.5-hour contact period. A recent study by Nurfitria et al. (2019) has reported that the adsorption procedure reduced Pb metal by 1.5645 ppm, or 86%. These findings suggest that the choice of activator and contact period can significantly impact the adsorption capabilities of candlenut shells for water treatment. Additionally, future studies could investigate the potential of using a combination of different types of nut shells as adsorbents to further enhance water purification efficiency. The present investigation examined the synthesis of active carbon from candlenut shells at KOH activator concentrations of 0.5 M, 1 M, 1.5 M, 2 M, and 2.5 M.

Methods

Materials

The equipment used for this research, such as oven (Universal oven), desiccator, furnace, mortar and pestle, analytical balance (Ohaus), test tube, magnetic stirrer (Thermo), beaker glass (Pyrex), Erlenmeyer (Pyrex), measuring pipette, drop pipette, titration, pH meter, turbidimeter, and Atomic Absorption Spectroscopy (AAS). Meanwhile, the materials used are surface water indicated of high Fe (from Bratasena Adiwarna Village, Tulang Bawang Regency, Lampung), distilled water, candlenut shells (from Pardasuka District, Pesawaran Regency), filter paper (Whatman, USA), KOH, 0.1 N Na2S¬2O3, and 1% starch. All the chemicals were purchased from Sigma Aldrich.

Procedures

This research used the Completely Randomized Design (CRD) method, which consisted of one factor (i.e., KOH activator concentration). The research design was modified from Nurfitria et al. (2019) with a ratio of 1:10 for a mixture of charcoal and KOH consisting of 6 concentrations of 0.5 M, 1 M, 1.5 M, 2 M, and 2.5 M. The candlenut shells (1.5 kg) were reduced using mortar to a size of 1 to 1.5 mm. After that, the candlenut shells were dried for 4 hours at 110°C to reduce the water content (Prabarini & Okayadnya, 2014). After the candlenut shells were dry, they were carbonized at 400°C for 2 hours until they became charcoal. The resulting charcoal was activated using KOH at various concentrations. All variations were mixed using a magnetic stirrer at a speed of 200 rpm for 1 hour. The adsorbent was washed with distilled water to a pH of 7 to release the acid, and then filtered using filter paper (Herlambang et al., 2023; Nurfitria et al., 2019). The adsorbent was dried in an oven at 110°C for 4 hours. The resulting adsorbent was tested based on the Indonesian National Standard (SNI, 1995) and applied to surface water from Bratasena Adiwarna Village, Tulang Bawang Regency, Lampung.

Analysis of adsorbent from candlenut shell (i.e., water, ash, and iodine adsorption content)
Water Content Analysis

The water content was determined by weighing 1 g of activated charcoal and placing it in a porcelain cup that has been dried, then placing it in the oven at 110˚C for 3 hours, then cooling it in a desiccator for 30 min before weighing it. Water content was calculated using Equation 1.

$$Water\ content\ (\%) = \frac{b-c}{b-a} \times 100\% \quad (1)$$

Where a, b, and c indicated the mass of the empty cup, the mass of the sample and cup before drying, the mass of the cup after drying, respectively.

Ash Content Analysis

The ash content was determined by weighing 2 g of activated charcoal in a cup of known weight, then in the furnace at a temperature of 600°C, then cooled in a desiccator to a temperature of 120°C min or a constant temperature. Carbon ash content was calculated using the following Equation 2. Where a, b, and c indicated the mass of the empty cup, the mass of the sample and cup before drying, the mass of the cup after drying, respectively.

$$Ash\ content\ (\%) = \frac{c-a}{b-a} \times 100\% \quad (2)$$

Where a, b, and c indicated the mass of the empty cup, the mass of the sample and cup before drying, the mass of the cup after drying, respectively.

Iodine Absorption Analysis

The procedure for determining the iodine absorption test refers to the Indonesian National Standard (SNI, 1995) regarding quality requirements and testing for activated charcoal based on (Agustina & Mardi, 2011; Herlambang et al., 2023; Laos et al., 2016). The iodine absorption test was carried out by weighing 0.5 g of activated carbon and mixing it with 10 mL of a 0.1 N iodine solution. Then shake with a shaker for 15 min. After that, transfer it into a centrifuge tube until the activated carbon drops, then take 10 mL of the liquid and titrate it with a 0.1 N sodium thiosulfate solution. If the yellow color of the solution starts to become faint, add 1% starch solution, which functions as an indicator. Titrate the dark blue color again until it becomes clear. Equation 3 used for calculating iodine absorption capacity, is as follows:

$$Iodine\ absorptions = \frac{A \times 126.93 \times dilution\ factor}{a} \quad (3)$$

Where A and a are the volume of iodine solution (mL) and the weight of activated carbon (g), respectively.

Analysis of surface water after adsorption using adsorbent from candlenut shell

The adsorption process for candlenut shell adsorbents is carried out by treating surface water. The adsorption process was carried out using a magnetic stirrer with an adsorbent, namely candlenut shells. The water sample used was 100 mL with a contact time of 1.5 hours, an adsorbent amount of 2.5 g, and a speed of 200 rpm. Physical testing on candlenut shell adsorbents includes pH, turbidity, and TDS (total dissolved solids)(Efendi et al., 2023; SNI, 2004). Meanwhile, chemical testing includes Fe reduction using the atomic absorption spectroscopy (AAS) method, adsorption capacity, and adsorption efficiency. This was also investigated using the Langmuir and Freundlich approaches to determine the adsorption isotherm of candlenut shells.

Atomic Absorption Spectroscopy (AAS) Method

The procedure for determining Fe content analysis in surface water refers to the Indonesian National Standard (SNI, 2009). The sample was put into a 50 mL beaker glass. The sample was left overnight, filtered with filter paper to remove impurities, and placed in a plastic bottle. A calibration was carried out on each heavy metal that will be tested with the AAS tool first. Then, the AAS tool was turned on, and the filtered sample was measured with the AAS tool. The tube on the AAS device was inserted into the sample until the absorbance results were obtained on the computer.

Adsorption Capacity and Adsorption Efficiency

The maximum adsorption capacity and efficiency testing procedures were modified (Meila Anggriani et al., 2021). The ability of an adsorbent to carry out the absorption process on an adsorbate can be determined by adsorption capacity and efficiency. The following formula can calculate the maximum adsorption capacity and efficiency with Equation(s) 4 and 5, respectively.

$$Adsorption\ capacity\ (qe) = \frac{(Co - Ce) \times V}{m} \quad (4)$$

$$Eficiency\ adsoption\ (\%BE) = \frac{(Co - Ce)}{Co} \times 100\% \quad (5)$$

Where Co, Ce, V, and M indicated initial concentration, final concentration, volume of solution, and mass of activated charcoal, respectively.

Langmuir and Freundlich Isotherm Approach

According to Edzwald (2011) and Dąbrowski (2001), Equation(s) 6 and 7 represent the Freundlich and the Langmuir isotherm equation models, respectively. These equations are commonly used in adsorption studies to describe the relationship between the solute concentration in a solution and the amount of solute adsorbed onto a solid surface. The Freundlich equation assumes a heterogeneous surface and non-ideal adsorption behavior, while the Langmuir equation assumes a homogeneous surface and ideal adsorption behavior.

$$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{C_e}{q_m} \quad (6)$$

$$\text{Ln qe} \quad = Ln\ qe = \frac{1}{\text{n}}\ Ln\ C\text{e} + \text{Ln Kf} \quad (7)$$

where q_m refers to the maximum adsorption capacity (mg/g), K_L and Kf are the Langmuir and Freundlich isotherm constant (L/mg), Ce is the solute concentration in the solution at equilibrium (mg/L), and q_e is the solute mass adsorbed per unit adsorbent mass at the equilibrium state (mg/g).

Results and Discussion

Characteristic of adsorbent from candlenut shell

The candlenut shell adsorbent was determined by quality (i.e., water content, ash content, and iodine adsorption capacity), as shown in Table 1.

Table 1. Characteristic of adsorbent from candlenut shell with a comparison of SNI 1995 and SII 0258-88. (Mean ± standard deviation)

KOH activator (M)	Water content (%)	Ash content (%)	Iodine absorption capacity (mg/g)
SNI 06-3730-1995	Max 15%	Max 10%	Min 750 mg/g
SII 0258-88	Max 10%	Max 10%	Min 750 mg/g
0	1.012 ± 1.563	29.548 ± 0.161	452.308 ± 30.037
0.5	0.979 ± 0.114	10.207 ± 1.041	639.391 ± 25.052
1	2.777 ± 0.136	16.767 ± 0.159	493.090 ± 31.999
1.5	2.643 ± 0.170	17.403 ± 0.351	460.580 ± 15.206
2	1.418 ± 0.028	17.809 ± 0.223	513.389 ± 39.795
2.5	1.472 ± 0.061	18.828 ± 0.185	489.025 ± 39.820

The Water content of adsorbent from candlenut shell

Results showed the highest water content in KOH activator 1 M of 2.777 ± 0.136%, followed by 1.5 M of 2.643 ± 0.170 % (Table 1). At the same time, the lowest water content of 0.979 ± 0.114 % and 1.418 ± 0.028 % was achieved for 0.5 M and 2 M, respectively. The findings of this study outperform those of Laos et al. (2016) earlier investigation, which revealed that the candlenut shell adsorbent had a water content of 13%. A recent study by Herlambang et al. (2023) has reported that the water content of adsorbent from palm kernel shell is 1.0002%. The final water content complies with the maximum 15% requirements of the Indonesian National Standard (SNI, 1995) and the requirements of (SII) 0258-88, which specifies a 10% maximum water content for activated carbon. These fluctuations in the weighing process can result in a slightly higher water content in the activated carbon samples. However, despite these variations, the water contents of both the 1 M and 1.5 M KOH activators still fall within acceptable limits for activated carbon production.

Ash content of adsorbent from candlenut shell

Based on Table 1, in the 2.5 M KOH activator, the highest percentage of ash detected in activated carbon was 18.828 ± 0.185 %. The 0.5 M KOH activator has the lowest ash content of 10.207 ± 1.041%. This study also reported that activation carbon using KOH was needed due to its high reactivity and ability to produce highly porous structures. Using KOH as an activator resulted in activated carbon with excellent adsorption properties, making it suitable for various applications such as water purification and gas separation. The 0.5 M KOH activator combined with activated carbon thus satisfies the ash content standards specified by SII 0258-88 and SNI (1995). However, other concentrations (i.e., 1 to 2.5 M) do not satisfy the standards (SNI, 1995) or the requirements of SII 0258-88, which set a maximum of 10%. The results of this investigation are superior to those of earlier studies conducted by Sa'diyah et al. (2021), who reported that the generated activated carbon had an ash content ranging from 10.2% to 19.8%. These findings highlight the effectiveness of using a 0.5 M KOH activator in combination with activated carbon to achieve low ash content. This research contributes to developing more efficient and reliable methods for producing activated carbon with improved quality and performance. A recent study conducted by Fu et al. (2023) has reported that the candlenut shells contain micronutrients such as Mn, Fe, Ni, Cu, and Zn. This means solid waste from candlenut shells adsorbent potential as natural fertilizer.

The Iodine adsorption capacity of adsorbent from candlenut shell

The investigation results (Table 1) show that the 0.5 M KOH activator formed large pore holes, which led to the maximum iodine absorption at 639.391 ± 25.052 mg. Afterward, the iodine absorption capacity decreased to 460.580 ± 15.206 mg in the 1.5 M KOH activator, with an iodine absorption value of 460.58 mg/g. These results are still lower, as compared to Herlambang et al. (2023), iodine adsorption capacity from palm kernel shell was activated with H_3PO_4 of 709.25 mg/g. According to Haji et al. (2013), the nature of the active carbon, the components it absorbs, the nature of the solution, and the contact system are some of the variables that affect activated carbon's absorption performance. Previous research conducted by Agustina and Mardi (2011) has reported that the best results (304.56 mg/g) were obtained with 0.1 M HCl activation. The results of this study are better than those of theirs. It indicates that the iodine absorption test result obtained from this investigation is greater than that of other studies. The maximum iodine absorption capacity of activated carbon is 750 mg/g, according to SII 0258-88, and the minimum requirements SNI (1995) of 750 mg/g are not satisfied by the iodine absorption capacity generated from all concentration variations. Therefore, further research is needed to improve the iodine absorption capacity of activated carbon. Iodine absorption capacity is a crucial metric for evaluating the quality of activated carbon since it demonstrates the material's capacity to absorb colored and odorous solutions (Wardani & Wulandari, 2018). This low iodine absorption is undesirable for applications that require high adsorption capacity. It is essential to consider iodine absorption when selecting activated carbon for such applications.

Application of adsorbent from candle shell for reduction iron (Fe) content in surface water from Bratasena Adiwarna Village, Tulang Bawang Regency, Lampung

Following adsorption in surface water at different concentrations (0, 0.5, 1, 1.5, 2, 2.5 M) for 1.5 hours of contact, tests were conducted on the candlenut shell adsorbent, including turbidity, pH, total dissolved solids (TDS), iron content, adsorption capacity, and adsorption capacity, as indicated in Table 2. This study, utilized 2.5 g of candlenut shells and 100 mL of surface water as the adsorbent.

Table 2. The surface water quality after contact with adsorbent from the candle shell was significantly improved. (Mean ± standard deviation)

KOH activator (M)	pH	Turbidity (NTU)	TDS (mg/L)	Iron content (mg/L)	Adsorption capacity (mg/g)	Adsorption efficiency (%)
0	7.257 ± 0.025	0.30 ± 0.001	97.000 ± 0.816	3.722 ± 0.033	-	-
0.5	7.327 ± 0.038	0.001 ± 0.002	132.557 ± 1.029	0.063 ± 0.001	0.142 ± 0.001	98.305 ± 0.036
1	7.563 ± 0.025	0.001 ± 0.001	126.777 ± 2.078	0.176 ± 0.014	0.137 ± 0.001	95.265 ± 0.374
1.5	7.350 ±0.022	0.001 ± 0.001	136.223 ± 0.565	0.307 ± 0.011	0.146 ± 0.001	91.746 ± 0.297
2	7.380 ± 0.008	0.001 ± 0.001	142.223 ± 0.565	0.071 ± 0.025	0.139 ± 0.001	98.095 ± 0.677
2.5	7.343 ± 0.012	0.00 ± 0.001	119.890 ± 0.954	0.256 ± 0.017	0.146 ± 0.001	93.122 ± 0.469
SNI	6.5-8.5	Max 5	Max 500	0.3	-	-

Effect of adsorbents on pH in surface water

The pH scale, which measures a solution's acidity and alkalinity, is based on the concentration of hydrogen ions (H^+). The results shown in Table 2 indicate that the concentration variation of 0.5 M produced the lowest pH value, 7.327 ± 0.038, while 1 M provided the highest pH value, 7.563 ± 0.025, in this investigation (Table 2). The pH value obtained from this study, which ranged from 6.5 to 8.5, satisfied the the Republic of Indonesia Minister of Health Regulation No. 492/Menkes/Per/IV/2010 requirements. For drinking water, the pH quality requirement is 6.5 to 8.5; for clean water, it is 6.5–9.0. In this experiment, the pH values before and after the adsorption procedure satisfied the standards for health quality.

Effect adsorbents on turbidity in surface water

Table 2 also provides turbidity in surface water from Bratasena Adiwarna Village, Tulang Bawang Regency, Lampung. The result was that the turbidity values ranged from 0.001 to 0.030 NTU, within the acceptable range according to the Republic of Indonesia Minister of Health Regulation No. 492/Menkes/Per/IV/2010 guidelines for surface water quality. These findings indicate that the surface water in Bratasena Adiwarna Village meets the required standards for both pH and turbidity levels for drinking water. It suggests that there has been an improvement in the water quality in Bratasena Adiwarna Village since the previous study conducted by Maulana et al. (2017) reported that the efforts to improve water quality in the village have been successful. Additionally, these findings highlight the effectiveness of any measures or interventions implemented to maintain and improve the surface water quality in the village. Furthermore, it is crucial to continue monitoring and implementing measures to ensure the long-term sustainability of the water resources in Bratasena Adiwarna Village.

Effect adsorbents on TDS in surface water

Table 2, shows the highest TDS of 142.223 ± 0.565 mg/L using adsorbent with 2 M KOH and the lowest TDS of 119.890 ± 0.954 mg/L in 2.5 M KOH activator. These results indicate that adjusting the KOH concentration can significantly impact the total dissolved solids (TDS) levels in the water resources of Bratasena Ad iwarna Village. Therefore, further studies should be conducted to evaluate the optimal KOH concentration for controlling TDS levels in the village's water resources. The research finding fully complies with the Republic of Indonesia Minister of Health Regulation No. 492/Menkes/Per/IV/2010, establishing a maximum allowed level of 500 mg/L for drinking water. Consequently, the study's conclusions show that activated carbon can successfully eliminate activators from drinking water.

Effect adsorbents on Iron content in surface water

Table 2 shows that the most excellent Fe level in surface water was 0.307 ± 0.011 mg. The combination of 0.5 M KOH activator and Fe resulted in the best reduction in Fe at 0.06 mg/L. The quality standard in iron content for clean water sources is 1.0 mg/l, and for drinking water, it is 0.3 mg/l. In this study, all variations of KOH concentrations used to reduce Fe levels met the standards by the Regulation of the Minister of Health of the Republic of Indonesia No. 492/Menkes/Per/IV/2010 as a clean water source of 1.0 mg/L and as drinking water of 0.3 mg/L. Therefore, the variations in KOH concentrations for the activation adsorbent from candlenut shell used in this study were deemed safe for consumption as drinking water. The capability of the adsorbent made from the candlenut shells at different KOH activator concentrations is displayed in Table 2. This investigation yielded adsorption capacities between 0.13 to 0.15 mg/g. The research finding (Table 2) demonstrates that the maximum adsorption capacity, 0.15 mg/g, is exhibited by the 0.5M KOH activator. The present study yielded superior findings than the earlier investigation by Nurafriyanti et al. (2017), which measured an adsorption capacity of 0.03 mg/g. The type of activator employed in this study affects the increase in adsorption capacity. Reducing Fe levels has also been done using another method, such as microbubble aeration (Efendi et al., 2023).

Adsorption Capacity and Adsorption Efficiency

The resulting absorption efficiency in this investigation varied from 91.74% to 98.31%. The study's finding (Table 2) demonstrates the 0.5M KOH activator's 98.31% absorption effectiveness. The present study's outcomes surpass those of earlier research by Nurafriyanti et al. (2017), which reported an absorption efficiency of 86.30% for percent BE. The kind of raw material used in this study has an impact on the increase in efficiency. Activated carbon from candlenut shells, which have a carbon content of 85–95%, is made from materials with carbon elements that have undergone special processing to give them a larger surface area. Because they include cellulose, hemicellulose, and lignin, candlenut shells make excellent starting materials to produce active carbon.

Adsorption Isotherm Calculation with Langmuir and Freundlich approach

The Langmuir isotherm assumes that adsorption occurs through a reversible equilibrium between the adsorbate molecules in the gas or liquid phase and the adsorbed molecules on the surface. Additionally, it suggests no interaction between the adsorbed molecules on neighboring active sites. Meanwhile, the Freundlich isotherm, such as adsorption involving the solid-liquid phase, occurs in a multilayer or many layers. The Freundlich isotherm assumes that adsorption occurs physically, meaning that more absorption occurs on the surface of the activated carbon. The data obtained from each of the isotherm equations above shows that the adsorption of Fe metal using candlenut shell adsorbent is by the Langmuir and Freundlich isotherm patterns with R^2 values of 0.9997 and 0.9999, respectively (Figure 1). The types of adsorption isotherm models (Langmuir and Freundlich) are shown in Table 3.

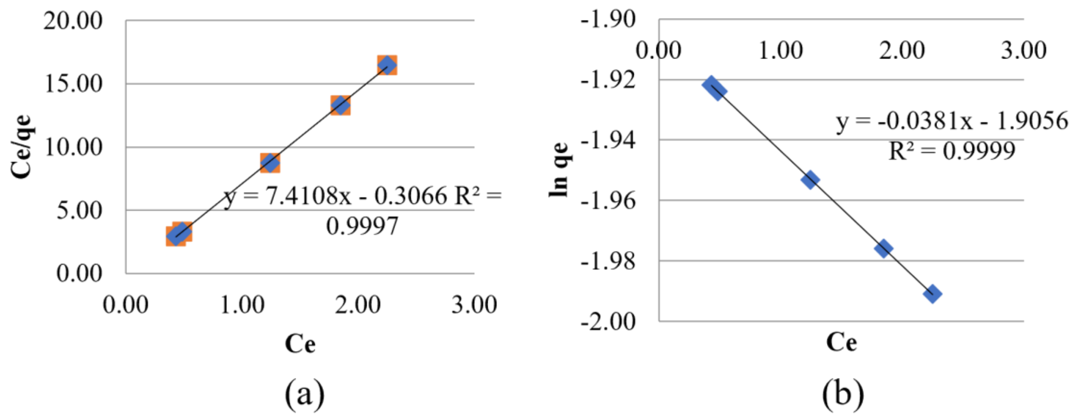

Figure 1. Linear regression of both equations (a) Langmuir isotherm model and (b) Freundlich isotherm model.

Table 3. Adsorption process computation using Langmuir and Freundlich

Langmuir calculation	**Freundlich calculation**
$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{C_e}{q_m}$	Ln qe $= Ln\ qe = \frac{1}{n} Ln\ C$e + Ln Kf
y = 7.41 x – 0.30	y = -0.03x – 1 .90
$\frac{Ce}{qe}$ = -0.30 + 7.41 Ce	$\frac{1}{n}$ = -0.03
$\frac{1}{q \max B}$ = -0.30	n = $-\frac{1}{0.03}$
$\frac{1}{q\ max}$ = 7.41	n = -26.24
$q_m = \frac{1}{7.41}$	Ln Kf = -1.90
q_m = 0.13 mg/g	Kf = 0.14

The results of the data analysis show that the q max value on the Langmuir isotherm using candlenut shell adsorbent is 0.13. The q_m value calculates the maximum monolayer adsorption capacity on the Langmuir isotherm. In this way, the candlenut shell adsorbent follows the Freundlich isotherm model. Therefore, the adsorption capacity of the activated carbon for Fe is significantly enhanced. The results indicate that Fe forms a multilayer layer on the surface of the activated carbon, resulting in a Freundlich constant of 0.14, indicating a favorable adsorption process. Additionally, the Langmuir isotherm model suggests that the adsorption of Fe onto the activated carbon is a monolayer process. This indicates that there is a maximum adsorption capacity for Fe on the activated carbon surface. Furthermore, the high absorption efficiency of 98.30% suggests that candlenut shell-activated carbon can be a promising solution for removing Fe from solutions in various industrial applications.

Conclusion

The study that indicates that the 0.5 M KOH activator is the adsorbent made from candlenut shells that yields the best quality. The study also found that the adsorbent made from candlenut shells activated with 0.5 M KOH satisfied the requirements of SNI 06-3730-1995, with an iodine absorption capacity of 639.39 mg/g and water content and ash content of 0.98% and 10.21%, respectively. Additionally, this adsorbent demonstrated a high absorption efficiency of 98.31% and an adsorption capacity of 0.15 mg/g with a Freundlich constant (Kf) of 0.14 mg/g. The candlenut shell adsorbent's mechanism of iron metal absorption is based on the Freundlich isotherm model. The Freundlich isotherm model allows for a higher adsorption capacity at lower concentrations.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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