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Comparison Performance of Simple Fatty Acid Adsorption on Banana Peel and Lamtoro Charcoal: Equilibrium and Thermodynamic

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Abstract. The main objective of this study was to compare activated carbon made from the banana peel and lamtoro charcoal for free fatty acids in used cooking oil. All types of activated carbon were chemically activated using KOH with a ratio of 1:1.5 charcoal and KOH and physically at a temperature of 700°C, which was further characterized by Scanning Electron Microscope (SEM) Fourier-Transform Infrared Spectrometer (FT-IR), and X-Ray Diffraction (XRD). Both types of activated carbon have a specific surface area that is not much different, around 66 m²/g. Batch research was conducted to determine temperature, initial free fatty acid content, and adsorbent dose. Percentage removal decreased with increasing free fatty acid content in the oil but increased when the temperature and adsorbent content increased. Both types of adsorbents follow the Langmuir isotherm equilibrium model, and the optimal temperature is 40°C. Thermodynamic studies revealed that the adsorption of free fatty acids was exothermic, non-spontaneous, and had a low degree of randomness.

INTRODUCTION

The food industry is the largest industry in the world that generates significant waste. One of the ingredients used in the food industry is cooking oil. Cooking oil should be used a maximum of 4 times because some compounds are dissolved or solid residues from the fried ingredients. In addition, the temperature conditions and frying time make changes to the structure of the cooking oil [1]. Indonesia's cooking oil consumption is relatively high, reaching 7-8 million tons/year [2]. The high consumption of cooking oil also has an impact on the used cooking oil produced.

Every year, Indonesia produces 3 million tons of used cooking oil [2]. The physical properties of used cooking oil are shown in Table 1, while the chemical composition of fatty acids in cooking oil before and after frying is shown in Table 2. Used cooking oil has a very high free fatty acid, reaching 17.95% [3]. The maximum free fatty acid content of palm cooking oil according to SNI 7709:2019 is 0.3% (w/w). SNI for cooking oil is shown in Table 3. The high acid number indicates the high free fatty acids contained in the oil. The free fatty acids present in the oil degrade the cooking oil's quality, making it unusable and dangerous if consumed. Consumption of cooking oil with high fatty acids increases the risk of atherosclerosis, cardiovascular disease, high blood pressure [4], Low-Density Lipoprotein (LDL) in the blood [5]. Free fatty acids must be removed to improve the quality of the oil. Untreated free fatty acids are usually discharged into the water or on the ground. When discharged into the water will close the waterways. If it is thrown

into the ground, it makes the soil not. However, free fatty acids can be biodegraded for an average of 28 days in water [6].

Several methods are used to remove free fatty acids, namely liquid-liquid extraction [7], physical deacidification [8], using microorganisms [9], membrane technology [10], esterification [11], supercritical extraction [12], liquid-liquid extraction [13], neutralization [14], and molecular distillation [15]. This method has disadvantages such as high operating costs, incomplete removal, and low selectivity, but adsorption effectively removes free fatty acids in oil [16]. Adsorption is also simple, economical, efficient, and requires low energy.

One of the materials for making activated carbon is biomass. Biomass was chosen because of its high lignocellulosic content. Agricultural biomass waste is quite abundant because only 27% is recycled [17]. Banana peel waste is one of the high agricultural wastes. The weight of the banana peel reaches 40% of the weight of the banana [18]. Indonesia's banana production is number 3 in the world [19]. Banana peel contains lignin ($18.1 \pm 0.22\%$), cellulose ($15.7 \pm 0.31\%$), and hemicellulose ($42.2 \pm 0.33\%$) [17]. Besides banana peel, another raw material for activated carbon is lamtoro stem. The stems of lamtoro contained lignin (24.28 ± 1.71), cellulose (47.41 ± 1.58), and hemicellulose (37.88 ± 4.42) [20]. Lamtoro stems are usually only burned or used for animal feed which has little selling value. Lamtoro is also found in abundant and cheap quantities, so it promises to be used for the manufacture of activated carbon. Lamtoro activated carbon is often used in water purification from pollutants such as cadmium [21] and dyes [22], while its use in the adsorption of free fatty acids from cooking oils is still rarely done.

The manufacture of activated carbon made from biomass is carried out by thermally decomposing the material through carbonization followed by activation. Activation can be done through physical activation using steam

[23] or carbon dioxide [24] in contrast to chemical activation using chemicals [25]. Chemical activation has many advantages, such as lower temperature usage and higher yield [26]. The chemicals used were NaOH [27], KOH [28], H_3PO_4 [29], H_2SO_4 [30], $FeCl_3$ [31], $ZnCl_2$ [32], a mixture of KOH-NaOH [33], and a mixture of $FeCl_3$ - $ZnCl_2$ [34]. H_3PO_4 activator produces small pores, $ZnCl_2$ activator produces small and non-uniform pore sizes, and KOH activator produces uniform and honeycomb-shaped pore sizes [35]. In addition, the surface area of activated carbon that is activated using a strong base is higher than that activated using an acid. KOH has several advantages, including developing micropores and forming oxygen functional groups [36], resulting in high surface area and porosity [37]. The surface area of activated carbon activated by KOH is quite large, reaching more than $3000 \text{ m}^2/\text{g}$ [38].

TABLE 1. The physical properties of waste cooking [3]

Parameter	value
Acid number (%)	17.95
Saponification number (mgKOH/g)	147.2
Density (g/cm ³)	0.82
Viscosity (mm ² /s)	4.76
Water content (%)	1-5

TABLE 2. Comparison of fatty acids before and after frying [39]

Fatty acid	frying composition (%)	
	Before	After
Caprylic acid (C8:0)	0.03	0.06
Capric acid (C10:0)	0.02	0.02
Lauric acid (C12:0)	0.25	0.18
Myristic acid (C14:0)	1.39	0.99
Pentadecanoic Acid (C15:0)	0.06	0.02
Palmitic acid (C16:0)	22.63	40.24
Palmitoleic acid (C16:1)	14.05	0.20
Stearic acid (C18:0)	11.43	9.12
Oleic acid (C18:1)	32.56	35.76
Linoleic acid (C18:2)	16.38	12.41
Linolenic acid (C18:3)	0.39	0.33
Arachidic acid (C20:0)	0.03	0.37
Eicosonic acid (C20:1)	0	0.18
Behenic acid (C22:0)	0.03	0.02
Erucic acid (C22:1)	0	0.12

EXPERIMENTAL

Adsorbent Preparation

The banana peel was sliced with a thickness of 0.5 cm, dried in the sun for three days. The lamtoro charcoal was ground and sieved using a 200-mesh sieve. After dried, they were carbonized using a furnace at 500°C for 90min. [40]. Banana peel carbon was mashed and sieved using a 200-mesh sieve. Each carbon is then activated using

KOH dissolved in 1 L of distilled water. The KOH and carbon ratio is 1:1.5. The mixture of carbon and KOH was placed in a 1L beaker heated using an electric stove for 2 h with stirring. After cooling to room temperature, the mixture was neutralized using 0.1 N HCl. The activated carbon was filtered using filter paper, then dried in an oven at 105°C to a constant weight. Dry activated carbon was stored in a desiccator. The cooking oil was heated in the oven for about 30 minutes at 130°C.

Acid Value Measurement

The oil was weighed 28-56 g into an Erlenmeyer, then added 50 mL of ethanol. The mixture was heated using an electric stove and added five drops of phenolphthalein indicator. The mixture was titrated using KOH until it turned pink. The pink color does not disappear for 30 seconds [41]. Free fatty acids are calculated using Equation

$$\text{Free fatty acid} = \frac{25.6 \times V \times N}{W} \quad (1)$$

V = Volume of KOH used (mL)

N = Normality of KOH. solution (N)

W = Tested sample weight (g)

Oil Preparation

Used cooking oil and fresh oil were mixed [42] to obtain certain free fatty acid levels (0.36; 0.45; 0.54; 0.63; 0.73; 0.82; 0.91% w/w)

Oil Density Measurement

The empty pycnometer was weighed. The pycnometer was filled with oil and then weighed. Density is measured using equation (2)

$$\text{Density} = \frac{\text{the mass of the pycnometer contains oil} - \text{empty pycnometer mass}}{\text{pycnometer volume}} \quad (2)$$

Determine of Adsorption Equilibrium Time

Oil with a free fatty acid level of 0.36% was taken as much as 30 mL in a 100 mL beaker. Added 1% (w/w) activated carbon into the beaker. It was heated using a water bath at a temperature of 32°C. Stirred at 180 rpm [43]. This process was carried out for 6 and 7 hours.

Oil with certain free fatty acids (0.36; 0.45; 0.54; 0.63; 0.73; 0.82; 0.91%) was taken as much as 30 mL in a 100 mL beaker. Added 1% (w/w) activated carbon into the beaker. Heating was carried out using a water bath at 32, 34, 36, 38, and 40°C, stirred at 180 rpm [43] for the previously obtained equilibrium time.

The activated carbon dose was investigated by adding a dose of activated carbon up to 6% (w/w) in used cooking oil. Activated carbon and the temperature used is activated carbon and the optimal temperature during the previous adsorption process. The amount of free fatty acids adsorbed per mass of adsorbent at equilibrium is formulated by equation (3), while the percentage of free fatty acids adsorbed is formulated by equation (4). In this equation, it is

known that he is adsorption capacity (mg/g), C_i is the initial concentration of adsorbate (mg/L), C_e is the equilibrium concentration of adsorbate in solution (mg/L), V = solution volume (L), and W is adsorbent mass (g).

$$q_e = \frac{C_i - C_e}{W} \times V \quad (3)$$

$$\% \text{ removal} = \frac{C_i - C_e}{C_i} \times 100\% \quad (4)$$

Characterization

Cooking oil before and after adsorption and activated carbon characterized by functional groups with Fourier Transform Infrared Spectrometer (FTIR, Thermo scientific Nicolet iS-10). The Brunauer–Emmett–Teller (BET) method was used to assess the specific surface area and pore size using a surface and pore size analysis instrument (BET, Surface Area, and Pore Size Analyzer Quantachrome Nova 4200e) at 77.3 K. Morphology and microstructure of the material. characterized by Scanning Electron Microscopy (SEM, Jeol JSM-IT200).

RESULT AND DISCUSSION

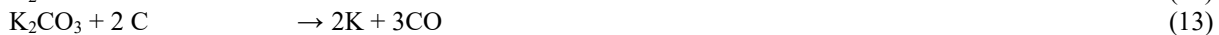
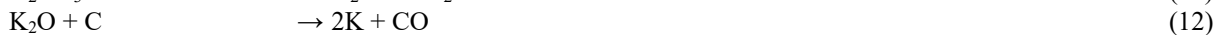
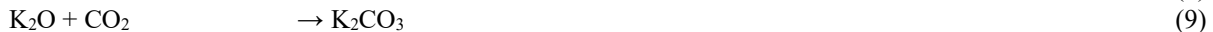
Characterization of Activated Carbon

In the activation process, a reaction occurs between carbon and KOH. The beginning of the activation took place at temperatures under 300°C. The gas of H_2 , CO , CO_2 , and CH_4 were formed, which were shown by equations (5), (6), and (7) [44]. When activated, KOH decomposes into K_2O , K_2CO_3 , and H_2 , as shown by equations (8), (9), and (10) [45]. At temperatures above 762°C, K_2CO_3 is reduced to K , CO , and CO_2 as shown inequations (11), (12), (13) [46].

The washing process involves a metal activator (K, Na, Ca) reacting with water [38] shown in equations (14), (15), and (16). Potassium can increase the surface area of carbon by penetrating the carbon structure, then expanding it, and forming new pores [44], which is shown in Figure 1. After the activation process, the banana peel's surface area of the activated carbon becomes 66.008 m^2/g while lamtoro charcoal is 66,770 m^2/g .

Research by Ahmadi and Ganjidoust [47] made activated carbon from banana peels which were activated using KOH with a KOH ratio of 4:1 which was stirred for 12 hours at room temperature and then activated at 750°C for 1 hour to produce a surface area of 712.28 m^2/g . Luna-Lama et al. [48] prepared activated carbon from banana peels using KOH with a KOH ratio of 1:1, which was stirred at 85°C for 3 hours and then activated at 700°C for 1 hour to produce a surface area of 264 m^2/g . Shen [49] made activated carbon from banana peels using KOH with a KOH and carbon ratio of 3.5:1, which was stirred at room temperature for 2 hours and then activated at 800°C for 3 hours to produce a surface area of 3746.5 m^2/g .

Research Ilnicka et al. [50] made activated carbon from lamtoro wood soaked in 20% (w/w) KOH for 24 hours which was then activated at 600°C for 2 hours to produce a surface area of 567 m^2/g . Hou et al. [51] made activated carbon from lamtoro wood using KOH with a ratio of KOH and carbon 4:1 soaked at room temperature for 30 minutes which was then activated using CO_2 at 800°C for 4 hours to produce a surface area of 2326.5 m^2/g . It proves that the ratio of carbon and activator, activation time, and activation temperature affect the surface area of activated carbon.



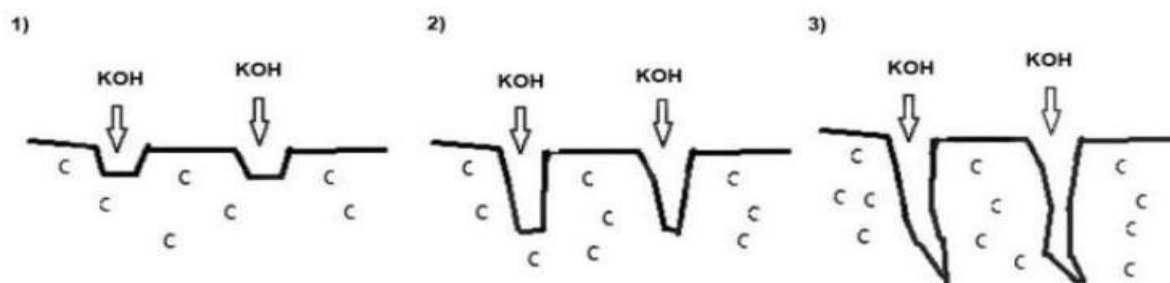


FIGURE 1. Illustration of pore formation using KOH [52]

XRD performed crystal structure analysis. The XRD pattern was shown in Figure 2. The XRD pattern on banana peel activated carbon has peaks of 27.37° , 31.73° , 45.49° , 56.52° , 75.37° . The peak of 27.37° is the presence of K_2O compounds. Research by Mopoung et al. [53] showed the K_2O compound at the peak of 27° . The peak of 31.73° indicates the presence of K_2CO_3 and $K_2CO_3 \cdot 1.5H_2O$ compounds. The research of Mopoung et al. [53] showed compounds K_2CO_3 and $K_2CO_3 \cdot 1.5H_2O$ at the peak of 31.5° . The peak of 45.49° indicates the presence of potassium with a tetragonal structure. Balajii and Niju research. [54] At the 45.56° peak is potassium with a tetragonal structure. The peak of 56.52° indicates the presence of K_2CO_3 compounds. Research by Li et al. [55] at the 56° peak, there is a compound K_2CO_3 . A peak of 75.37° indicates the presence of potassium. Balajii and Niju research. [54] at the peak of 75.54° , there is potassium.

The XRD pattern on lamtoro charcoal activated carbon has peaks of 27.35° , 31.65° , 45.41° , 56.43° , 72.62° , 75.22° . The peak of 27.35° was the presence of K_2O compounds. The research of Mopoung et al. [53] showed the K_2O compound at the peak of 27° . The peak of 31.6546° indicates the presence of K_2CO_3 and $K_2CO_3 \cdot 1.5H_2O$ compounds. Research by Mopoung et al. [53] showed compounds K_2CO_3 and $K_2CO_3 \cdot 1.5H_2O$ at the peak of 31.5° . The peak of 45.41° indicates the presence of potassium with a tetragonal structure. Balajii and Niju research. [54] At the 45.56° peak is potassium with a tetragonal structure. The peak of 56.43° indicates the presence of K_2CO_3 compounds. Research by Li et al. [55] at the 56° peak, there is a compound K_2CO_3 . The peak of 72.62° indicates the presence of tetragonal crystals. Research Sun et al. [56] found that the $72-76^\circ$ peak contained tetragonal crystals. A peak of 75.22° indicates the presence of potassium. Balajii and Niju research. [54] at the peak of 75.54° , there is potassium.

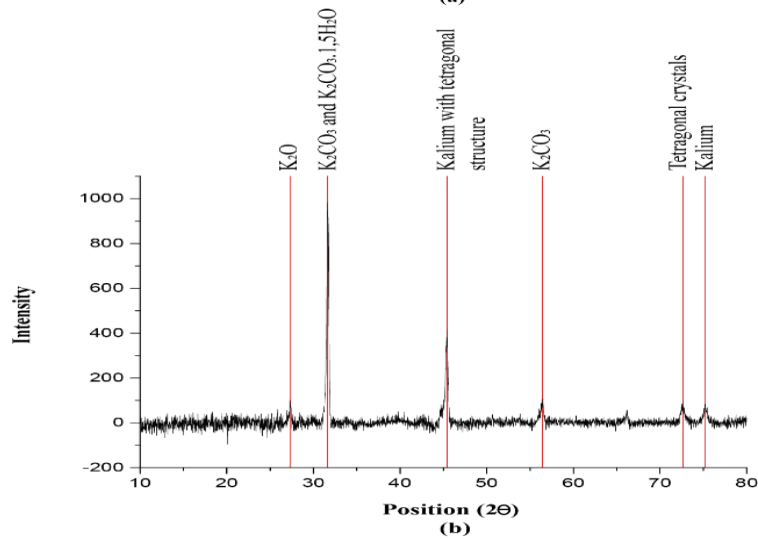
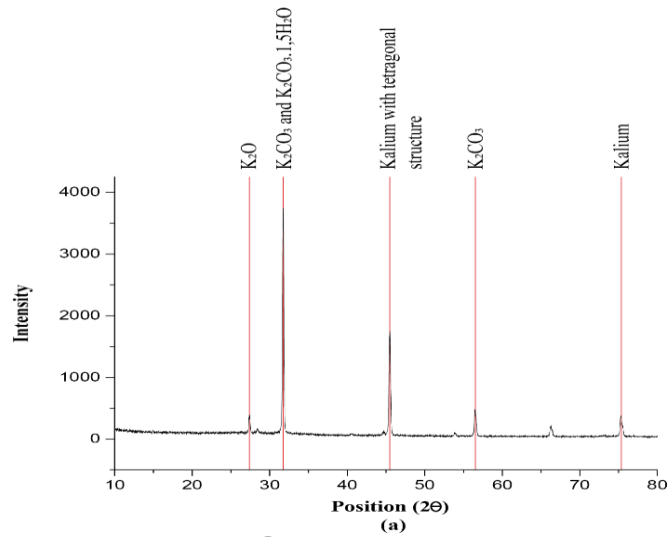


FIGURE 2. XRD (a) banana peel, (b) lamtoro charcoal

Surface morphology analysis was performed using SEM. In Figure 3 the activated carbon looks cleaner or less polluted. Activated carbon also has a uniform shape and pore size like a honeycomb. KOH, which is used as an activator, is useful for removing impurities (tar) in activated carbon during the activation process. This uniform pore shape is by Wei's study [35].

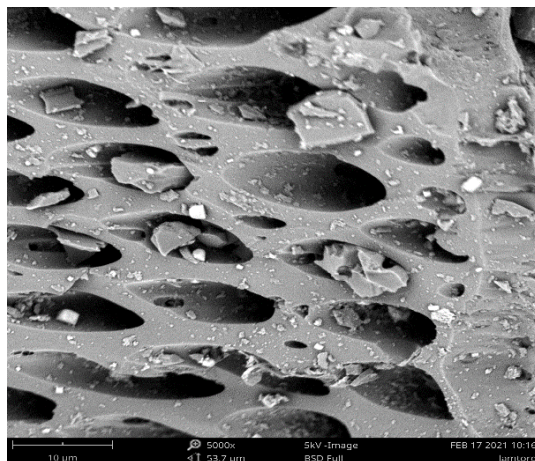


FIGURE 3. SEM Analysis of Lamtoro Charcoal Activated Carbon

Oil functional groups were analyzed using FTIR. Figure 4 shows that oil has absorption peaks at wavenumbers 722, 1236, 1377, 1465, 1750, 2854, 2928, 3006/cm. A wave number of 722/cm indicates the presence of a $\text{HC}=\text{CH}$ group of substituted olefins [57]. The presence of a wave number of 1236/cm indicates the presence of the C-O group of the ester compound. Research by Jović et al. [58] at the wave number 1237/cm shows the C-O group of the ester compound. The wavenumber of 1377/cm indicates the presence of a C-H group from CH_2 . The research of Vlachos et al. [59] at a wavenumber of 1376/cm indicates the presence of a C-H group from CH_2 . The wavenumber of 1465/cm indicates the C-H group of CH_2 and CH_3 aliphatic compounds. Research by Moharam and Abbas. [57] at wave number 1463/cm indicates the C-H group of CH_2 and CH_3 aliphatic compounds. Wavenumber 1750/cm indicates carbonyl group $\text{C}=\text{O}$ of free fatty acid. Research by Jović et al. [58] at a wavenumber of 1711/cm shows the carbonyl group $\text{C}=\text{O}$ free fatty acids. At 2854/cm, wave number shows the C-H group of CH_2 aliphatic compounds. The wavenumber 2928/cm indicates the -C-H group of the aliphatic compound CH_2 . Research by Jović et al. [58] at a wavenumber of 2925/cm shows the -C-H group of CH_2 aliphatic compounds. The wavenumber 3006/cm shows the $=\text{C}-\text{H}$ group. At the wavelength of 1750/cm, there is a very significant decrease in absorption, which can be seen from the decrease in peak sharpness. It occurs due to the reduction of free fatty acids in the used cooking oil after the adsorption process. It is because activated carbon has a hydroxyl group ($-\text{OH}$) which is negatively charged which can attract the carboxyl acid group ($-\text{COOH}$) of free fatty acids, which are more positively charged [60]. It proves that activated carbon is proven to be able to reduce levels of free fatty acids in used cooking oil.

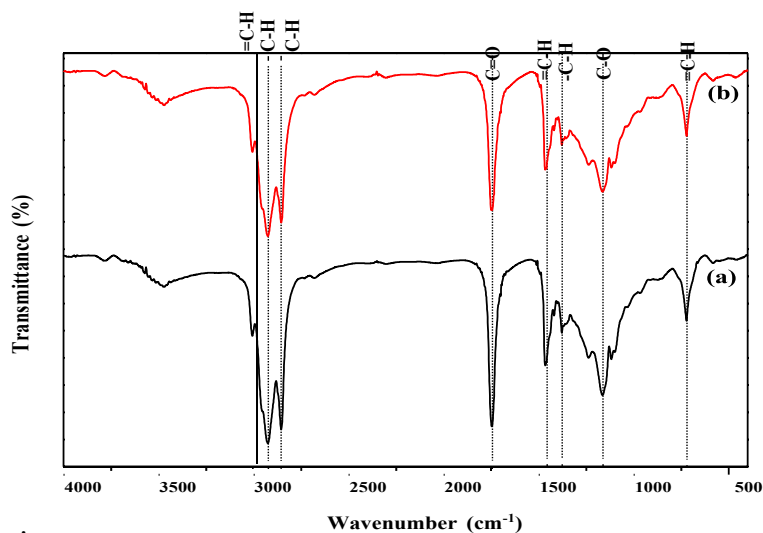


FIGURE 4. FTIR spectrum of used cooking oil (a) used cooking oil before adsorption; (b) used cooking oil after adsorption

The functional groups of activated carbon are shown in Figure 5. Banana peel-activated carbon has an absorption peak at wavenumbers 1054.76; 1634.11; 3432.93/cm. A wave number of 1054.76/cm indicates the presence of a C-O group in the primary alcohol compound. Research by Kurniawan et al. [61] showed the C-O group's absorption wavenumber of 1054/cm. The presence of a wave number of 1634.11/cm indicates the presence of a C=C group in the alkene compound. The research of Pudza et al. [62] shows the C=C group at an absorption wave number of 1634/cm. Wavenumber 3432.93/cm indicates the presence of O-H groups. Research by El-Wahabet al. [63] showed the presence of an O-H group at a wavenumber of 3432/cm. The wavenumber of 3783.93/cm indicates the presence of an O-H group. Research by Rashmi et al. [64] showed the presence of an O-H group at a wavenumber of 3783/cm

Lamtoro charcoal activated carbon has an absorption peak at wavenumbers 1047.68; 1517.96; 3740.53; 3842.8/cm. A wave number of 1047.68/cm indicates the presence of a C-O group in the primary alcohol compound. Research by Pięta et al. [65] shows the C-O group at a wavenumber of 1047/cm. The presence of a wavenumber of 1517.96 indicates the presence of a C=C group. Research Octavian et al. [66] showed the C=C group of aromatic compounds at 1500-1600/cm wave numbers. Sills and Gossett Research. [67] showed a wavenumber of around 1510/cm containing aromatic compounds contained in lignin. Wavenumber 3740.53/cm indicates the presence of O-H groups. Research Astuti and Fatin. [68] showed the O-H group at a wavenumber of 3761/cm. At a wave number of 3761/cm, the O-H group comes from the phenol group of lignin [69]. The wavenumber 3842.8 indicates the presence of an O-H group. The research of Singh et al. [70] shows the O-H group at a wavenumber of 3842/cm.

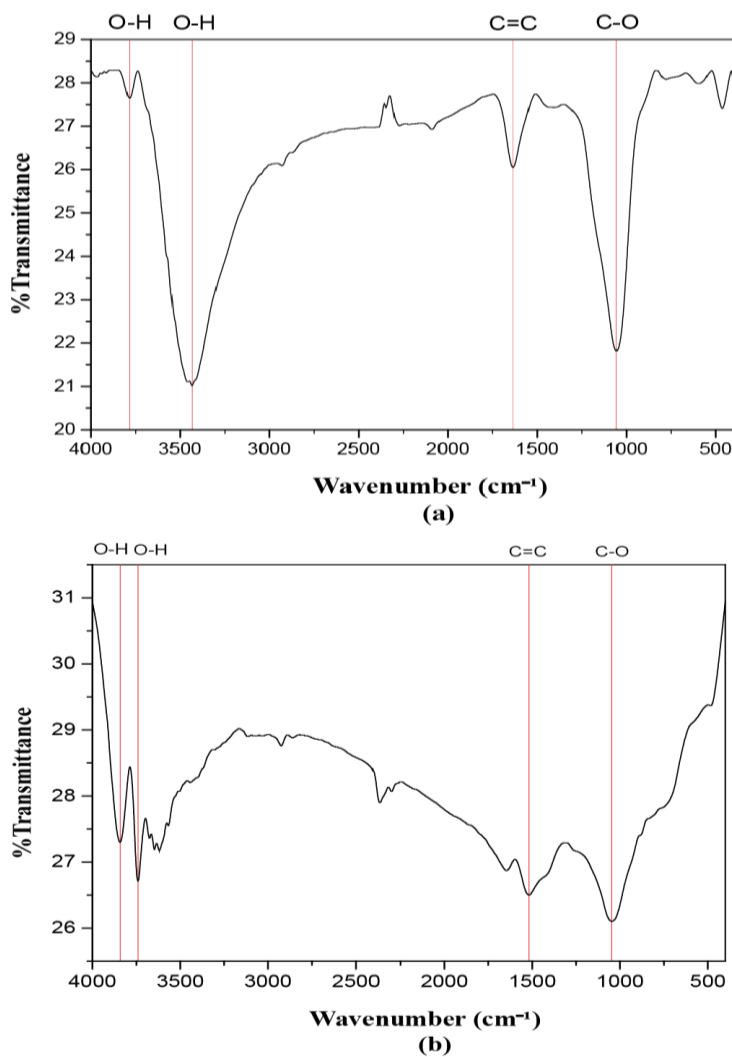


FIGURE 5. FTIR spectrum of activated carbon (a) banana peel, (b) lamtoro charcoal

Equilibrium Isotherm Process

Table 4 shows the adsorption equilibrium time. The effect of free fatty acid content is shown in Figure 6, the adsorption temperature is shown in Figure 7, and the adsorbent content is shown in Figure 8. Table 4 shows that the equilibrium time of 6 hours has been reached. There is no change in free fatty acids at 6 and 7 hours for both types of activated carbon.

The increase in the initial concentration of the adsorbate resulted in a decrease in the percentage of removal. It occurs due to the limited number of active sites on the adsorbent so that the activated carbon will reach saturation under certain conditions [71]. At high temperatures, free fatty acids obtain sufficient energy to interact with the active site on the surface of the adsorbent so that adsorption increases. The adsorption capacity increases with increasing adsorption dose [72].

TABLE 4. Determination of free fatty acid adsorption equilibrium time

Free fatty acid initial (%) (w/w)	Banana peel		Lamtoro charcoal	
	6 h	7 h	6 h	7 h
0,3921	0.2614	0.2614	0.305	0.305

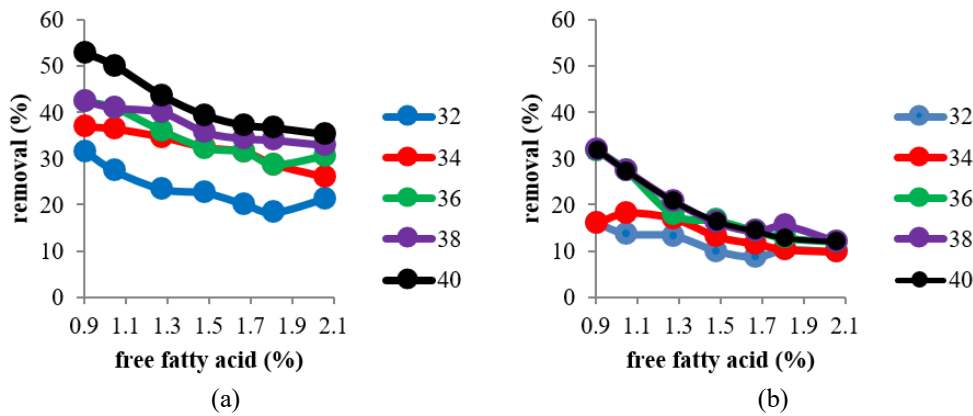


FIGURE 6. Effect of initial concentration, a) banana peel activated carbon, b) lamtoro charcoal activated carbon, on various temperature

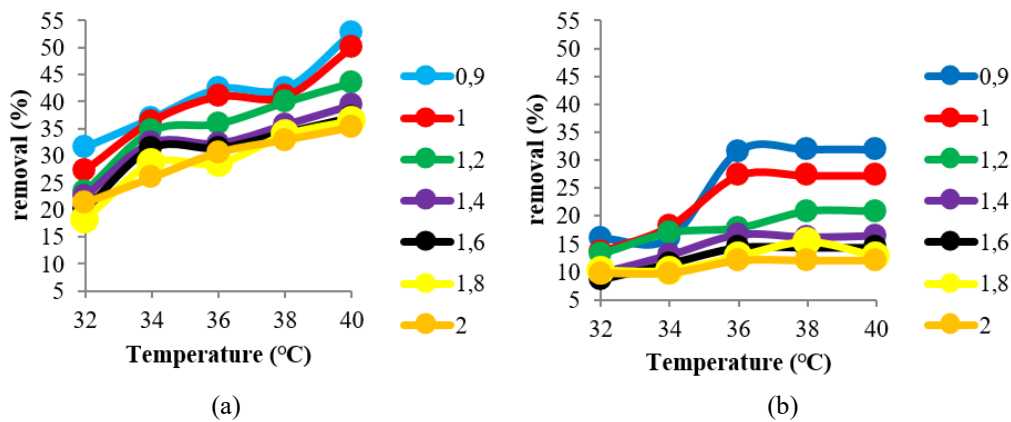


FIGURE 7. Effect of adsorption temperature, a) banana peel activated carbon, b) lamtoro charcoal activated carbon, on various levels of free fatty acids (%)

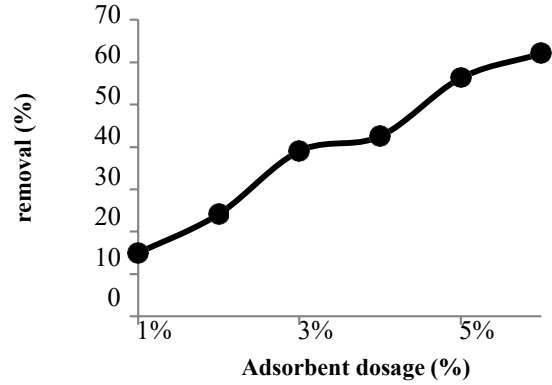


FIGURE 8. The effect of the adsorbent dose on the reduction of free fatty acid levels in cooking oil

Equilibrium models

The isotherm model describes the equilibrium of adsorbate molecules in the liquid and solid phases at a constant temperature. The equilibrium model used in this study is the Langmuir and Freundlich equilibrium model. Langmuir stated that adsorption occurs on a homogeneous surface. Once the adsorbate molecule occupies the active site, no further adsorption can occur at that site [28]. The equation of the adsorption model is shown by equations (17) and (18). Freundlich is stating adsorption occurs on heterogeneous surfaces [28]. The Freundlich isotherm equation is shown by equations (19) and (20). The sum of squares of errors (SSE) was used to estimate the model's validity. The SSE equation is shown by equation (21).

$$q_e = \frac{q_{maks} K_L C_e}{1 + K_L C_e} \quad (17)$$

$$\frac{1}{q_e} = \frac{1}{K_L q_{maks}} \frac{1}{C_e} + \frac{1}{q_{maks}} \quad (18)$$

q_{maks} = maximum adsorption capacity (mg/g)

K_L = langmuir constant (L/mg)

$$q_e = K_f C_e^{1/n} \quad (19)$$

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad (20)$$

K_f = frendlich's constant (L/g)

$1/n$ = adsorption intensity

$$SSE = \sum_{i=1}^n (q_{e \text{ model}} - q_{e \text{ data}})^2 \quad (21)$$

Based on Table 5 and Table 6, the Langmuir isotherm is the most appropriate modeling compared to the Freundlich model. It is because the value of R^2 in the Langmuir isotherm is higher than the Freundlich isotherm. Although Freundlich's SSE value is the smallest, the parameter values (q_{max} , K_L , K_F , $1/n$) are not much different from linear modeling. The value of R^2 is used to analyze the degree of fit between the model and experimental data [72]. When a model has an R^2 value close to 1, the model is considered the most suitable for the experiment [73,74]. The Langmuir isotherm assumes that adsorption occurs only in one layer/single layer. Negative values at temperatures of 34, 36 and 40°C indicate that the Langmuir and Freundlich models are not suitable for activated carbon of lamtoro charcoal.

TABLE 5. Non-linear Langmuir and Freundlich Equilibrium Isotherm

Activated carbon type	Temperature (°C)	Langmuir			Freundlich		
		qmax	KL	SSE	KF	1/n	SSE
Banana peel	32	0,0246	3,5231	1,4980	0,0202	0,38392	1,3020
	34	0,0399	2,7429	0,3830	0,0312	0,45284	0,6505
	36	0,0388	3,5150	1,3187	0,0327	0,41640	1,0503
	38	0,0551	2,0443	0,3716	0,0404	0,54786	0,2980
	40	0,0415	5,6867	0,9572	0,0388	0,34017	0,5327
Charcoal lamtoro	32	0,0107	4,3698	0,4206	0,0090	0,30659	0,3888
	34	0,0106	9,5711	0,4815	0,0097	0,15060	0,5130
	36	0,0119	28891	0,8201	0,0119	0	0,8197
	38	0,0124	12592	0,6519	0,0124	0	0,6519
	40	0,0121	33546	0,7198	0,0121	0	0,7198

TABLE 6. Linear Langmuir and Freundlich equilibrium isotherm

Activated carbon type	Temperature (°C)	Langmuir			Freundlich		
		qmax	KL	R2	KF	1/n	R2
Banana peel	32	0,0249	3,3515	0,8055	0,0196	0,3435	0,6738
	34	0,0395	2,7922	0,9639	0,0320	0,4869	0,9302
	36	0,0392	3,4175	0,911	0,0322	0,3975	0,8966
	38	0,0550	2,0501	0,9628	0,0404	0,5482	0,9788
	40	0,0428	5,1603	0,9681	0,0383	0,327	0,9485
Charcoal lamtoro	32	0,0110	3,7788	0,7472	0,0088	0,2755	0,4238
	34	0,0102	11,282	0,9174	0,0098	0,18	0,2327
	36	0,0104	-18,4187	0,9827	0,0104	-0,1872	0,5848
	38	0,0110	-19,2530	0,9699	0,0112	-0,1471	0,4648
	40	0,0102	-13,5036	0,9913	0,0105	-0,2072	0,8433

Thermodynamic equilibrium

The data needed to determine the thermodynamics include the value of Gibbs free energy change (ΔG°), enthalpy change (ΔH°) and entropy change (ΔS°). The adsorption thermodynamics equation is shown by equations (23), (24), (25), and (26). The value of ΔG° describes the type of adsorption that occurs. The value of G° to -40 kJ/mol is physisorption while -80 to -400 kJ/mol is chemisorption [75]. Tables 7 and 8 show that the value of ΔG for both types of activated carbon is positive, which indicates that adsorption does not occur spontaneously and physisorption does not occur. The value of H° on both types of activated carbon is negative, which indicates exothermic adsorption. The value of S° for both types of activated carbon is negative, which indicates a low adsorption capacity.

$$K = \frac{C_e}{C_i} \tag{23}$$

$$\Delta G^\circ = -RT \ln K \tag{24}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S \tag{25}$$

$$\ln K = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{R T} \tag{26}$$

- K = Adsorption equilibrium constant
- C_e = Equilibrium concentration of adsorbate in solution (mg/L)
- C_i = Initial concentration of adsorbate (mg/L)
- ΔG° = Standard Gibbs free energy change (kJ/mol)
- R = Ideal gas constant (8,314 J/mol K)

- K = Equilibrium constant from K_L or K_F
 ΔH° = Perubahan entalpi standar (kJ/mol)
T = Temperature (K)
 ΔS° = Standard entropy change (kJ/mol K)

TABLE 7. Thermodynamic Parameter of banana peel activated carbon

Free fatty acids (%)	Temperature (K)	ΔG° (kJ/mol)	ΔH° (kJ/mol)	ΔS° (kJ/mol K)
0.3650	305	0.9597	-32.9974	-0.1112
	307	1.1729		
	309	1.4143		
	311	1.4234		
	313	1.9496		
0.4563	305	0.8075	-32.6815	-0.1099
	307	1.1536		
	309	1.3515		
	311	1.3602		
	313	1.8037		
0.5475	305	0.6726	-27.7289	-0.0934
	307	1.0838		
	309	1.1438		
	311	1.3175		
	313	1.4877		
0.6388	305	0.6464	-21.3329	-0.0723
	307	0.9966		
	309	0.9979		
	311	1.1383		
	313	1.2972		
0.7301	305	0.5658	-20.8748	-0.0706
	307	0.9630		
	309	0.9692		
	311	1.0855		
	313	1.2082		
0.8213	305	0.5105	-23.2376	-0.0781
	307	0.8613		
	309	0.8670		
	311	1.0716		
	313	1.1847		
0.9126	305	0.6063	-19.3367	-0.0654
	307	0.7650		
	309	0.9358		
	311	1.0295		
	313	1.1274		

TABLE 8. Thermodynamic parameter of lamtoro charcoal activated carbon

Acid number (mg KOH/g)	Temperature (K)	ΔG° (kJ/mol)	ΔH° (kJ/mol)	ΔS° (kJ/mol)
0.3650	305	0.4408	-25.0077	-0.0834
	307	0.4437		
	309	0.9749		
	311	0.9915		
	313	0.9979		
0.4563	305	0.3717	-18.3714	-0.0616
	307	0.5121		
	309	0.8181		
	311	0.8234		
	313	0.8287		
0.5475	305	0.3591	-9.0822	-0.0310
	307	0.4750		
	309	0.5034		
	311	0.6014		
	313	0.6053		

TABLE 8. Thermodynamic parameter of lamtoro charcoal activated carbon

Acid number (mg KOH/g)	Temperature (K)	ΔG° (kJ/mol)	ΔH° (kJ/mol)	ΔS° (kJ/mol)
0.6388	305	0.2631	-7.4475	-0.0254
	307	0.3551		
	309	0.4646		
	311	0.4547		
	313	0.4655		
0.7301	305	0.2272	-6.4481	-0.0219
	307	0.3097		
	309	0.3960		
	311	0.3985		
	313	0.4011		
0.8213	305	0.2712	-4.7905	-0.0165
	307	0.2730		
	309	0.3514		
	311	0.4333		
	313	0.3560		
0.9126	305	0.2584	-3.0990	-0.0110
	307	0.2600		
	309	0.3285		
	311	0.3306		
	313	0.3327		

CONCLUSION

This research produces activated carbon from banana peels and lamtoro charcoal, removing free fatty acids in used palm cooking oil. Removal efficiency increases with increasing temperature but decreases with increasing free fatty acid content. The optimal temperature for adsorption is 40°C Adsorption process. According to the Langmuir model, the Adsorption process occurs non-spontaneous, exothermic, low randomness, and physisorption.

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REFERENCES

1. O.B. Kapitan, *Jurnal Kimiaterapan* **1**, 17 (2013).
2. B. Riedo, *KOMPAS.com* (2021).
3. S. Kumar, M.R. Shamsuddin, M.S.A. Farabi, M.I. Saiman, Z. Zainal, and Y.H. Taufiq-Yap, *Energy Conversion and Management* **226**, 113366 (2020).
4. R.P. Venkata and R. Subramanyam, *Toxicology Reports* **3**, 636 (2016).
5. M.L.T.A. Putranti, S.K. Wirawan, and I.M. Bendiyasa, *IOP Conference Series: Materials Science and Engineering* **299**, (2018).
6. R.F. Resende, P.V.B. Leal, D.H. Pereira, R.M. Papini, and Z.M. Magriotis, *Colloids and Surfaces A: Physicochemical and Engineering Aspects* **605**, 125340 (2020).
7. C. Vaisali, S. Charanyaa, P.D. Belur, and I. Regupathi, *International Journal of Food Science & Technology* **50**, 13 (2014).
8. B.M. Bhosle and R. Subramanian, *Journal of Food Engineering* **69**, 481 (2005).
9. S.Y. Cho, T.W. Kwon, and S.H. Yoon, *Journal of the American Oil Chemists' Society* **67**, 558 (1990).
10. L.P. Raman, M. Cheryan, and N. Rajagopalan, *Journal of the American Oil Chemists' Society* **73**, 219 (1996).
11. J.-Y. Park, Z.-M. Wang, D.-K. Kim, and J.-S. Lee, *Renewable Energy* **35**, 614 (2010).
12. N.T. Dunford and J.W. King, *Journal of the American Oil Chemists' Society* **78**, 121 (2001).
13. C.E.C. Rodrigues and A.J.A. Meirelles, *Journal of Chemical & Engineering Data* **53**, 1698 (2008).
14. M.-J. Dumont and S.S. Narine, *Food Research International* **40**, 957 (2007).
15. P.F. Martins, V.M. Ito, C.B. Batistella, and M.R.W. Maciel, *Separation and Purification Technology* **48**, 78 (2006).
16. A. Adewuyi, A.A. Yusuf, W.J. Lau, M. Hojamberdiev, and R.A. Oderinde, *Surfaces and Interfaces* **21**, 100715 (2020).
17. S. Zafar, *Www.bioenergyconsult.com* (2019).
18. K.N.S. Buihary and I. Sumantri, *IOP Conference Series: Materials Science and Engineering* **1053**, (2021).
19. FAO, *Fao.org* (2019).
20. M.Z.N. Nadiha and B. Jamilah, *KnE Social Sciences* (2020).
21. W.M.H.W. Ibrahim, M.H. Mohamad Amini, N.S. Sulaiman, and W.R. Wan Abdul Kadir, *Applied Water Science* **11**, (2020).
22. Y.C. Lee, M.H.M. Amini, N.S. Sulaiman, M. Mazlan, and J.G. Boon, *Songklanakarin Journal of Science and Technology* (2018).
23. B. Tsyntsarski, I. Stoycheva, T. Tsoncheva, I. Genova, M. Dimitrov, B. Petrova, D. Paneva, Z. Cherkezova-Zheleva, T. Budinova, H. Kolev, A. Gomis-Berenguer, C.O. Ania, I. Mitov, and N. Petrov, *Fuel Processing Technology* **137**, 139 (2015).
24. I.P. da P. Cansado, C.R. Belo, and P.A.M. Mourão, *Bioresource Technology* **249**, 328 (2018).
25. Suhas, V.K. Gupta, P.J.M. Carrott, R. Singh, M. Chaudhary, and S. Kushwaha, *Bioresource Technology* **216**, 1066 (2016).
26. R.K. Liew, E. Azwar, P.N.Y. Yek, X.Y. Lim, C.K. Cheng, J.-H. Ng, A. Jusoh, W.H. Lam, M.D. Ibrahim,
27. N.L. Ma, and S.S. Lam, *Bioresource Technology* **266**, 1 (2018).
28. Y. Zhang, X. Song, Y. Xu, H. Shen, X. Kong, and H. Xu, *Journal of Cleaner Production* **210**, 366 (2019).
29. W. Astuti, T. Sulistyarningsih, E. Kusumastuti, G.Y.R.S. Thomas, and R.Y. Kusnadi, *Bioresource Technology* **121426** (2019).
30. K.K. Beltrame, A.L. Cazetta, P.S.C. de Souza, L. Spessato, T.L. Silva, and V.C. Almeida, *Ecotoxicology and Environmental Safety* **147**, 64 (2018).
31. S. Nethaji and A. Sivasamy, *Chemosphere* **82**, 1367 (2011).
32. Z. Xu, Y. Zhou, Z. Sun, D. Zhang, Y. Huang, S. Gu, and W. Chen, *Chemosphere* **241**, 125120 (2020).
33. D. Hong, J. Zhou, C. Hu, Q. Zhou, J. Mao, and Q. Qin, *Fuel* **235**, 326 (2019).
34. R.K. Liew, E. Azwar, P.N.Y. Yek, X.Y. Lim, C.K. Cheng, J.-H. Ng, A. Jusoh, W.H. Lam, M.D. Ibrahim,

35. N.L. Ma, and S.S. Lam, [Bioresource Technology](#) **266**, 1 (2018).
36. D. Tian, Z. Xu, D. Zhang, W. Chen, J. Cai, H. Deng, Z. Sun, and Y. Zhou, [Journal of Solid State Chemistry](#) **269**, 580 (2019).
37. Q. Wei, Z. Chen, Y. Cheng, X. Wang, X. Yang, and Z. Wang, [Colloids and Surfaces A: Physicochemical and Engineering Aspects](#) **574**, 221 (2019).
38. K.Y. Foo and B.H. Hameed, [Microporous and Mesoporous Materials](#) **148**, 191 (2012).
39. X. Yang, Y. Wan, Y. Zheng, F. He, Z. Yu, J. Huang, H. Wang, Y.S. Ok, Y. Jiang, and B. Gao, [Chemical Engineering Journal](#) **366**, 608 (2019).
40. Y. Gao, Q. Yue, B. Gao, and A. Li, [Science of the Total Environment](#) **746**, 141094 (2020).
41. D.N. Faridah, H.N. Lioe, N.S. Palupi, and J. Kahfi, [Journal of Oil Palm Research](#) **27**, 156 (2015).
42. Y. Gao, Q. Yue, B. Gao, Y. Sun, W. Wang, Q. Li, and Y. Wang, [Chemical Engineering Journal](#) **232**, 582 (2013).
43. T.-W. Chung, Y.-L. Wu, and S.-H. Hsu, [IOP Conference Series: Materials Science and Engineering](#) **362**, (2018).
44. L. Kamariah, A. Azmi, A. Rosmawati, M. W. Ching, M. D. Azlina, A. Sivapragasam, A. & O. M. Lai, [Journal of tropical agriculture and food science](#) **36**, 2 (2008).
45. G.L. Maddikeri, A.B. Pandit, and P.R. Gogate, [Industrial & Engineering Chemistry Research](#) **51**, 6869(2012).
46. M. Hunsom and C. Autthanit, [Chemical Engineering Journal](#) **229**, 334 (2013).
47. S. Li, K. Han, J. Li, M. Li, and C. Lu, [Microporous and Mesoporous Materials](#) **243**, 291 (2017).
48. H. Arslanoğlu, [Journal of Hazardous Materials](#) **374**, 238 (2019).
49. S. Ahmadi and H. Ganjidoust, [Journal of Environmental Chemical Engineering](#) **9**, 106010 (2021).
50. F. Luna-Lama, J. Morales, and A. Caballero, [Materials](#) **14**, 5995 (2021).
51. X. Shen, R. Ou, Y. Lu, A. Yuan, J. Liu, J. Gu, X. Hu, Z. Yang, and F. Yang, [Environment International](#) **143**, 105774 (2020).
52. A. Ilnicka, P. Kamedulski, H.M. Aly, and J.P. Lukaszewicz, [Arabian Journal of Chemistry](#) **13**, 5284 (2020).
53. C.-H. Hou, N.-L. Liu, and H.-C. Hsi, [Chemosphere](#) **141**, 71 (2015).
54. H. Teng and L.-Y. Hsu, [Industrial & Engineering Chemistry Research](#) **38**, 2947 (1999).
55. S. Mopoung, P. Moonsri, W. Palas, and S. Khumpai, [The Scientific World Journal](#) **2015**, 1 (2015).
56. M. Balajii and S. Niju, [Renewable Energy](#) **146**, 2255 (2020).
57. X. Li, Y. Zuo, Y. Zhang, Y. Fu, and Q. Guo, [Fuel](#) **113**, 435 (2013).
58. L. Sun, H. Guo, H. Peng, S. Gong, and H. Xu, [Ceramics International](#) **39**, 3447 (2013).
59. M. Moharam and L. Abbas, [African Journal of Microbiology Research](#) **4**, (2010).
60. O. Jović, T. Smolić, Z. Jurišić, Z. Meić, and T. Hrenar, [Croatica Chemica Acta](#) **86**, 335 (2013).
61. N. Vlachos, Y. Skopelitis, M. Psaroudaki, V. Konstantinidou, A. Chatzilazarou, and E. Tegou, [Analytica Chimica Acta](#) **573-574**, 459 (2006).
62. L.H. Rahayu, S. Purnavita, and H.Y. Sriyana, [Jurnal Ilmiah MOMENTUM](#) **10**, (2014).
63. Y.S. Kurniawan, M.R.G. Fahmi, and L. Yuliaty, [IOP Conference Series: Materials Science and Engineering](#) **833**, (2020).
64. M.Y. Pudza, Z.Z. Abidin, S. Abdul-Rashid, F.Md. Yassin, A.S.M. Noor, and M. Abdullah, [ChemistrySelect](#) **4**, 4140 (2019).
65. H.A. El-Wahab, M.A. El-Fattah, H.M.Z. El-Alfy, M.E. Owda, L. Lin, and I. Hamdy, [Progress in Organic Coatings](#) **142**, 105577 (2020).
66. V. Rashmi, A. Darshana, T. Bhuvaneshwari, S.K. Saha, L. Uma, and D. Prabakaran, [Current Research in Green and Sustainable Chemistry](#) **4**, 100051 (2021).
67. E. Pięta, C. Petibois, K. Pogoda, K. Suchy, D. Liberda, T.P. Wróbel, C. Paluszkievicz, and W.M. Kwiatek, [Sensors and Actuators B: Chemical](#) **313**, 128039 (2020).
68. R. Oktavian, B. Poerwadi, M.R. Pahleva, M.W. Muharyanto, and S. Supriyono, [Malaysian Journal of Fundamental and Applied Sciences](#) **16**, 374 (2020).
69. D.L. Sills and J.M. Gossett, [Biotechnology and Bioengineering](#) **109**, 353 (2011).
70. W. Astuti and D.M. Fatin, [Jurnal Bahan Alam Terbarukan](#) **6**, 183 (2018).
71. M.A.K.M. Hanafiah, W.S.W. Ngah, S.H. Zolkafly, L.C. Teong, and Z.A.A. Majid, [Journal of Environmental Sciences](#) **24**, 261 (2012).
72. M. Singh, J. Singh, D. Sharma, B. Kaur, and M. Rawat, (2018).
73. K.M. Al-Qahtani, [Journal of Taibah University for Science](#) **10**, 700 (2016).
74. T.M. Elmorsi, [Journal of Environmental Protection](#) **02**, 817 (2011).
75. M.K. Seliem, S. Komarneni, T. Byrne, F.S. Cannon, M.G. Shahien, A.A. Khalil, and I.M. Abd El-Gaid,

- [Separation and Purification Technology](#) **110**, 181 (2013).
76. R.A. Fitri, A. Wirakusuma, A. Fahrina, M.R. Bilad, and N. Arahman, *International Journal of Engineering* **32**, (2019).
77. M. Mushtaq, H.N. Bhatti, M. Iqbal, and S. Noreen, *Journal of Environmental Management* **176**, 21 (2016).