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Rubber *(Hevea brasiliensis)* Seed shell Activated Carbon Preparation, Characterization and Antibacterial Activity Studies

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ABSTRACT. In Thailand, the rubber tree is widely used as a source of natural rubber and their seeds have been found to be rich in oil production. The seed shell is the residue and not edible but abundantly available in the country. Therefore, the objective of this work was to prepare activated carbon (AC) from rubber seed shells. ACs were produced by chemical activation and their characteristics were investigated. The effects of activation temperature and chemical impregnation time in the agent were examined. Proximate analysis was investigated and the results were within the standard of AC. The adsorption capacity was demonstrated with BET, iodine, and methylene blue number. The best produced AC (700 °C of activation temperature and 24 h of impregnation time) provided the highest BET surface area, iodine and methylene blue number were 923 m^2/g, 1,234±24 mg/g and 1,204±10 mg/g, respectively. FT-IR spectrum indicates the presence of oxygen and nitrogen containing surface functional groups such as -OH, $-CH_3$, $-CH_2$, C=C, C-O, and N-H groups. The microstructure of the produced ACs was examined by SEM and the results found that they are porosity. The antibacterial effect results were discovered to be also effective against *E. coli* and *S. aureus* after 3 h and 24 h of contact times, respectively. In addition, the prepared AC also provided many properties that are better than those obtained by the commercial AC. Finally, it can be concluded that, AC from rubber seed shell can be applied as a low cost and possible alternate adsorbent.

Keywords: activated carbon, anti-bacterial, BET, proximate, rubber seed shell

INTRODUCTION

The rubber tree produces lustrous, mottled brown seeds with a length of 2.5–3 cm and a weight of 2–4 g, which are enclosed in a three-ellipsoidal pod (capsule), each of which contains three seeds. The capsule disperses the seeds on the ground by a loud mechanical explosion (Abubakar, 2014; Jisieike & Betiku, 2020). Each rubber seed is composed of a kernel and a shell, which account for around 60% w/wwb and 40% w/wwb of the whole seed weight, respectively (Atabani et al., 2013; Reshad, Tiwari, & Goud, 2015; Reshad, Tiwari, & Goud, 2018; Thaiyasuit, Pianthong, & Worapun, 2012). According to literature, the production of rubber seeds can reach 2060 kg $ha^{-1}year^{-1}$ (Ratnaningsih, Sanders, & Bruins, 2014), even though values of 150–200 kg $ha^{-1}year^{-1}$ are more realistic considering that cultivation conditions make collection and rot prevention difficult; moreover, the employment of a non-dedicated collection system is highly probable (Atabani et al., 2013; Oluodo, Huda, & Komilus, 2018; Iyayi, Akpaka, & Ukpeoyibo, 2008). The main producer countries of rubber seeds are Thailand (3,172,394 tons), Indonesia (5,367,980 tons) and Malaysia (1,735,522 tons), which account for two-thirds of the World's cultivated area (Ratnaningsih, Sanders, & Bruins, 2014; Reshad, Tiwari, & Goud, 2018).

In Thailand, the rubber tree is widely used as a source of natural rubber and their seeds have been found to be rich in oil production. The seed shell is the residue and not edible but abundantly available in the country. The huge amount of rubber seed shell wastes could lead to contamination and environmental problems in rubber tree plantations. Thus, converting rubber seed shells into value-added products such as activated carbon (AC) will help toward zero-waste production and reduce the environmental problem (Jisieike & Betiku, 2020). Moreover, it is abundant availability, cheapness, and promising adsorbent capacity (Yan, Ahmad Zaini, Arsad, & Nasri, 2019). Apart from that, the rubber seed shell is made up of about 30–50% of carbon compounds, which makes it a highly porous activated carbon in comparison with the other biomass wastes. Focus on, the activated carbon based-rubber seed shell production. There are two distinct methods that have been used to prepare activated carbon. In the gas activation process, raw material is first carbonized and the resulting char is secondarily subjected to the oxidizing action of a stream of gas, such as steam (Sun, & Jiang, 2010), carbon dioxide (Yan, Ahmad Zaini, Arsad, & Nasri, 2019). Activation temperatures typically range from 700 to 1100° C. In the chemical activation process, the raw material is impregnated with an activating agent like KOH (Pagketanang, Artnaseaw, Wongwicha, & Thabuot, 2015; Borhan, & Kamil, 2012), NH_4Cl (Okieimen & Imanah, 2005), and HCl (Hutapea, Panggabean, & Wijaya, 2015), and followed by heated at high-temperature carbonization between 400 and 900°C. The physical and chemical properties are particularly dependent on the activation process used.

The objective of this work was to prepare activated carbon made from rubber seed shells by chemical activation with NaOH and their characteristics were investigated. The effects of activation temperature and impregnation time in NaOH were studied. Proximate and elemental analysis was determined. The adsorption capacity was demonstrated with BET (Brunauer–Emmett–Teller), iodine, and methylene blue number. The surface chemical characteristics of activated carbons were determined by fourier transform infrared spectroscopy (FTIR). The microstructure of the produced activated carbons was examined by scanning electron microscope (SEM). The antibacterial effects of characterized composites were also determined. Finally, the analytical results were compared to commercial activated carbon.

EXPERIMENTAL SECTION

Materials

Rubber seed was collected at a local rubber cultivation field in Songkhla province, Thailand. NaOH and HCl were obtained from Sigma-Aldrich. Iodine was purchased from UNIVAR. Sodium thiosulfate and methylene blue were purchased from LOBA Chemie. Lauryl sulphate MUG X-gal (LMX) broth and butterfield's buffer were purchased from Merck. The chemicals are of analytical grade and were used as received without further purification. Commercial activated carbon was purchased from Fluka.

Preparation of Activated Carbon from Rubber Seed Shell

About 1 kg of fresh rubber seed shell was first washed thoroughly with distilled water to clean up any dirt and organic constituents before being dried at 105°C for 7 h. The dried rubber seed shell was crushed and sieved into smaller particles of about 1 mm. The ground shell was weighed and carbonized to temperatures at 600°C for 3 h under a flow of N_2 gas using a furnace and continuously cooled down with N_2 gas until it achieved room temperature. The cooled product was collected and kept in a desiccator before chemical activation. About 100 g of cooled product was added into 1000 mL of distilled water. The amount of NaOH was added (1:1 ratio) and vigorously stirred for 24 h to ensure uniform mixing, followed by drying at 105 °C for 2 h. Then, a carbonization process was carried out under N_2 atmosphere in a tube furnace at a temperature of 600 to 800°C for 3 h and continuously cooled down with N_2 gas until it achieved room temperature. The samples obtained were washed with warm distilled water a few times until they reached neutral pH and finally dried in an oven at 105 °C for 2 h before being stored in a sealed container for analysis and characterization. The produced AC samples were denoted as AC1-12h-600, AC2-12h-700, AC3-12h-800, AC4-24h-600, AC5-24h-700, AC6-24h-800, AC7-36h-600, AC8-36h-700 and AC9-36h-800.

Characterization of Activated Carbons

Proximate analysis

The moisture was determined by weighing and placing the activated carbon inside the drying oven (Memmert, Germany) at a constant temperature of 105 °C for 1 h. The dried samples were then cooled to room temperature by placing them inside desiccators and re-weighed. Moisture content was then calculated using the Equation (**1**):

$$Moisture = \frac{(W_i - W_f)}{W_i} x100 \tag{1}$$

Where W_i is the initial weight of the samples (before drying) and W_f is the weight of the samples (post drying).

The ash content was determined in a furnace (Nabertherm, Japan). 1.0g of activated carbon was placed in a crucible and inserted into furnace maintained at 600°C for 4h. Then the crucible was removed from the furnace and placed inside the desiccator. The process of heating and cooling was repeated until constant weight was obtained. Ash content was then calculated using Equation (**2**):

$$Ash = \frac{(\text{ash sampel weight (g)})}{\text{sampel weight (g)}} \text{x100} \tag{2}$$

The volatile matter was determined by the following procedure. The activated carbon (1g) was placed in furnace maintained at 950°C for 7 min. The crucible was then removed from the furnace and placed inside the desiccators to cool at room temperature. The volatile matter in the samples was determined by the loss of weight using the following Equation (**3**):

$$Volatile\ matter = \frac{(W_i - W_f)}{W_i} x100 \tag{3}$$

Where W_i is the initial weight of the samples (before heating) and W_f is the weight of the samples post-heating.

Fixed carbon is the carbon-bound fraction in the room beside the fraction of water, volatile matter, and ash. Measurement of fixed carbon content is calculated using Equation (**4**):

$$\text{Fixed carbon} = 100 - (\text{volatile matter} + \text{ash content}) \quad (4)$$

Elemental, BET & SEM analysis

Elemental, specific surface area and surface morphology analysis of AC samples were determined by the Office of Scientific Instrument and Testing, Prince of Songkla University.

FT-IR spectroscopic analysis

The surface chemistry of activated carbon was qualitatively determined using FT-IR (Tracer-100 and IRAffinity-1S, Zhimadzu, Kyoto, Japan). The % of transmission of the sample was recorded over 600–4000 cm^{-1}.

Iodine number analysis

The iodine number is defined as the milligrams of iodine adsorbed by 1.0 g of carbon when the iodine concentration of the filtrate is 0.02 N (0.02 mol/L). About 1.0 g of AC samples was treated with 10.0 mL of 5% HCl. This mixture is boiled for 30 s and then cooled. Soon afterward, 100.0 mL of 0.1 N (0.1 mol/L) iodine solution is added to the mixture and stirred for 30 s. The resulting solution is filtered and 50.0 mL of the filtrate is titrated with 0.1 N (0.1 mol/L) sodium thiosulfate, using starch as an indicator. The iodine number (*X/M*) is calculated by Equations (**5**):

$$X/M = \{(N_1 x 126.93 x V_1) - \{(V_1 + V_{HCl})/V_F] x (N_2 x\ 126.93)\ x V_2\}/M_c \quad (5)$$

Where N_1 is the iodine solution normality, V_1 is the added volume of iodine solution, V_{HCl} is the added volume of 5% HCl, V_F is the filtrate volume used in titration, N_2 is the sodium thiosulfate solution normality, V_2 is the consumed volume of sodium thiosulfate solution and M_c is the mass of activated carbon.

Methylene blue number analysis

The methylene blue number is defined as the maximum amount of dye adsorbed on 1.0 g of adsorbent. In this assay, 0.1 g of activated carbon are placed in contact with 50.0 mL of a methylene blue solution at different concentrations (10, 25, 50, 100, 250, 500, and 1000 mg/L) for 30 min at room temperature. The remaining concentration of methylene blue is analyzed using an ultra violet visible (UV/Vis) spectrophotometer at 645 nm. The amount of methylene blue adsorbed from each solution is calculated by Equation (**6**):

$$\text{Methylene blue number (mg/g)} = (C_0 - C_e) x V/M_c \quad (6)$$

Where C_0 (mg/L) is the concentration of the methylene blue solution at starting time (t=0), C_e (mg/L) is the concentration of the methylene blue solution at equilibrium time, V (L) is the volume of the solution treated and M_c (g) is the mass of activated carbon.

Antibacterial test

The antibacterial test was performed using the plate counting method (Altundag, 2015; Tuan et al., 2011). The following microorganism was used: gram-negative *Escherichia coli* (*E. coli*) and gram-positive *Staphylococcus aureus (S. aureus)* which are much harder to kill. In the tested procedure, 0.05 g of the rubber seed shell activated carbon powders were mixed to 50 mL of a lauryl sulphate MUG X-gal (LMX) broth solution containing bacteria. The mixture was then anaerobically incubated at 35°C±2°C for 18 h and measured the optical density at 600 nm. Then 1.0 mL of the above suspension was cultured in 50 mL Butterfield's buffer and checked at 100 rpm. Then, 1.0 mL of the above suspension was spread on an agar plate and incubated at 35°C±2°C for 24 h, and the growth of bacteria was observed. The exact number of detached colonies was counted as the number of remaining bacteria.

RESULTS AND DISCUSSION

Preparation of Rubber Seed Activated Carbon

Effect of the chemical impregnation time and activation temperature

In this part of the study, the chemical impregnation time (12-36 h) and the activation temperature (600-800◦C) were studied. The rubber seed shell AC samples observed a black particle with a fine powder for all prepared conditions. The results are shown in **Figure 1** (**a**) the impregnation time of 12 h with an activation temperature from 600-800 °C (AC1-12h-600, AC2-12h-700 and AC3-12h-800), (**b**) 24 h (AC4-24h-600, AC5-24h-700, AC6-24h-800) and (**c**) 36 h (AC7-36h-600, AC8-36h-700 and AC9-36h-800), respectively.

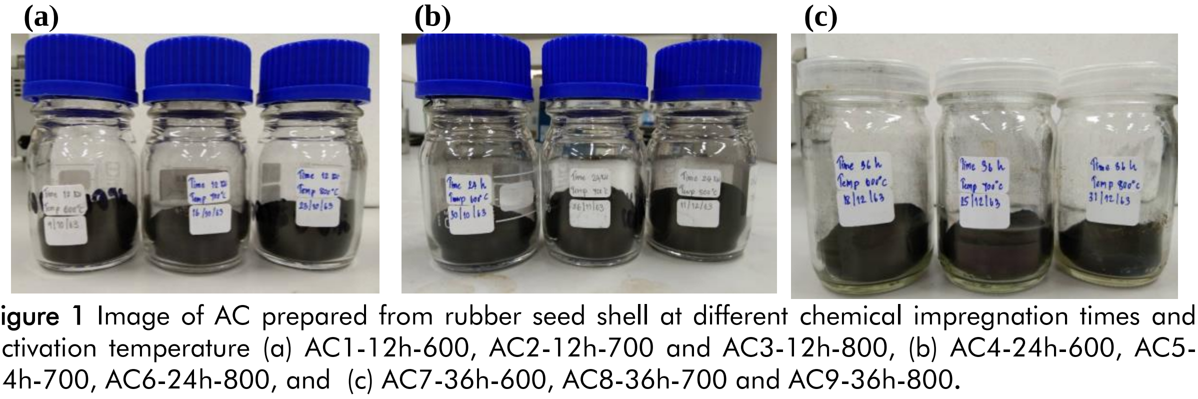

Figure 1 Image of AC prepared from rubber seed shell at different chemical impregnation times and activation temperature (a) AC1-12h-600, AC2-12h-700 and AC3-12h-800, (b) AC4-24h-600, AC5-24h-700, AC6-24h-800, and (c) AC7-36h-600, AC8-36h-700 and AC9-36h-800.

Characteristic Properties of Activated Carbon

proximate and elemental analysis

Based on **Table 1** it can be seen that the AC made from rubber seed shell has met the quality standards of activated carbon for all prepared conditions. Increasing activation temperature from 600-800°C progressively decreased the moisture and volatile matter whereas increased ash content and fixed carbon for all prepared conditions. The moisture decreased because chemically water begins to experience changes in the phase into the gas when it reaches its boiling point. These results are in line with the research conducted by (Siahaan, Melvha, & Rosdanelli, 2013). The volatile matter also decreased because of higher temperature, more substances that cover the carbon evaporate so that the previously closed carbon pore surface will open up and increase the absorption capacity (Fauziah, 2009). At the activation temperature of 700◦C with the impregnation time of 24 h, only 8.67±0.55 of volatiles remained in the final product, as most of them were released as gaseous products. Increased ash content can occur due to the formation of mineral salts during the process of drying which if continued will form fine particles of the mineral salt (Fauziah, 2009). In addition to the influence of water content, ash content and volatile matter, the bound carbon content of activated charcoal are also strongly influenced by the carbon content of the raw materials used. But there are several other factors that influence the level of AC, among others, the way of activation, activation temperature, cellulose content and lignin in the raw material. Activation temperature at 700◦C with the impregnation time of 24 h tends to be closer to the specified quality standard and commercial activated carbon when compared with other AC samples. The results were comparable with similar trends to the previously reported by Aulia et al. (2019). It shows that this data reveals that rubber seed shell material is suitable to be used as an activated carbon precursor.

For elemental analysis, as can be seen in **Table 2**. At the impregnation of 12 h, the carbon content increased with increasing of activation temperatures from 600-800°C whereas, at 24-36 h, the carbon content increased with increasing of activation temperatures from 600-700°C and then constant. The amount of hydrogen and nitrogen content decreased and constant as the temperature increased. These findings were due to the release of moisture and volatile compounds to the surroundings during the activation temperature process (Borhan, & Kamil, 2012), leaving ordered pore structure. The best-prepared condition was at the 700°C activation temperature with the chemical impregnation time of 24 h that provided the elemental analysis close to the commercial activated carbon.

BET surface area and pore volume

Table 3. Summarizes the data obtained from the BET and pore volume analysis. The chemical impregnation times have differently affected to the BET surface area. After 12 h of chemical impregnation, the BET surface area and the pore volume of the AC samples significantly increased when the temperature increased from 600 to 700◦C, and then slightly increased when the temperature up to 800◦C. On the other hand, after 24 h, the BET surface area significantly increased from 486 m^2/g to 923 m^2/g when the temperature increased from 600 to 700◦C, and then decreased to 643 m^2/g. A similar trend was observed with the impregnation time of 36 h. The pore volume was obtained with a similar trend and related with the BET surface area. During the activation process, as the activation temperature increased from 600 to 800 ◦C, the weight loss of the sample increased because of the release of volatile matters in a continual carbonization process and carbon burn-off, thus, high carbonization temperature exhibit high BET surface area (Daud, Ali, & Sulaiman, 2000). It is clear that the impregnation time has a significant effect on the ACs. Increasing the impregnation time from 12 to 24 h caused the BET surface area and pore volume to increase (activation temperature of 700◦C). However, an increase in the impregnation time from 24 to 36 h results in a lower BET surface area and pore volume. This is because during carbonization process, pores are developed in the carbon and promote the diffusion of the NaOH molecules into these pores and thereby increase the NaOH–carbon reactions which would then create more pores in the activated carbon. This would enhance the surface area and pore volume of the AC. This reason can be confirmed by the SEM image, at a short impregnation time, the porosity was less (**Figure 2a**) compared to a longer impregnation time that can be observed from the SEM image (**Figure 2b**). However, of the AC that longer duration of impregnation time up to 36 h caused some of the pores to enlarge or even collapse resulting in a lower BET and pore volume (**Figure 2c**). A similar result has also been reported for the activated carbon-based rubber seed shell (Yan et al., 2019). BET surface area and the pore volume are found to reach a maximum of 923 m^2/g and 0.524, cm^3/g at 24 h of chemical impregnation time and 700 ◦C for activation temperature.

Table 1. Proximate analysis of rubber seed shell activated carbon

Activated carbon types	Proximate analysis			
	Moisture (%)	Ash (%)	VM (%)	Fixed C (%)
Rubber seed shell ACs				
AC1-12 h-600°C	9.31±0.08	5.94±0.06	15.64±0.53	69.11
AC2-12 h-700°C	8.21±0.03	6.51±0.09	10.21±0.20	75.07
AC3-12 h-800°C	6.98±0.16	6.81±0.14	9.87±1.85	76.34
AC4-24 h-600°C	6.81±0.28	5.32±0.06	14.62±0.29	73.25
AC5-24 h-700°C	4.55±0.22	5.48±0.16	8.67±0.55	81.31
AC6-24 h-800°C	4.32±0.31	5.55±0.18	8.49±0.41	81.65
AC7-36 h-600°C	7.37±0.43	5.33±0.08	15.56±0.47	71.74
AC8-36 h-700°C	4.89±0.79	5.55±0.11	10.85±0.22	78.70
AC9-36 h-800°C	4.84±0.68	6.11±0.31	10.20±0.46	78.85
Commercial AC	4.75±0.02	2.34±0.05	4.76±0.70	88.15
Quality standard	Max. 15%	Max. 10%	Max. 25%	Min.65%

Table 2. Elemental analysis of rubber seed shell activated carbon

Activated carbon types	Elemental analysis		
	N (%)	C (%)	H (%)
Rubber seed shell activated carbon			
AC1-12 h-600°C	0.7±0.03	66.1±0.1	4.24±0.1
AC2-12 h-700°C	0.46±0.06	74.3±1.1	3.02±0.1
AC3-12 h-800°C	0.40±0.07	77.4±1.6	3.00±0.2
AC4-24 h-600°C	0.64±0.02	73.3±1.3	4.15±0.1
AC5-24 h-700°C	0.34±0.03	79.9±1.1	2.39±0.2
AC6-24 h-800°C	0.30±0.02	81.0±1.5	2.37±0.2
AC7-36 h-600°C	0.61±0.03	70.6±1.2	4.34±0.3
AC8-36 h-700°C	0.37±0.05	78.6±1.0	2.34±0.1
AC9-36 h-800°C	0.31±0.02	78.2±1.1	2.30±0.1
Commercial AC	0.12±0.003	88.4±0.02	0.97±0.03

Table 3. BET, pore-volume, iodine, and methylene blue number analysis

Rubber seed shell ACs	BET Surface area (m^2/g)	Pore volume (cm^3/g)	Iodine number (mg/g)	MB number (mg/g)
AC1-12 h-600°C	139	0.056	718±29	654±35
AC2-12 h-700°C	323	0.204	902±21	923±34
AC3-12 h-800°C	328	0.202	802±18	808±65
AC4-24 h-600°C	486	0.343	805±22	910±80
AC5-24 h-700°C	923	0.524	1234±24	1201±54
AC6-24 h-800°C	643	0.462	934±22	1104±54
AC7-36 h-600°C	463	0.361	849±27	838±67
AC8-36 h-700°C	534	0.401	983±20	1080±45
AC9-36 h-800°C	289	0.167	723±19	554±45

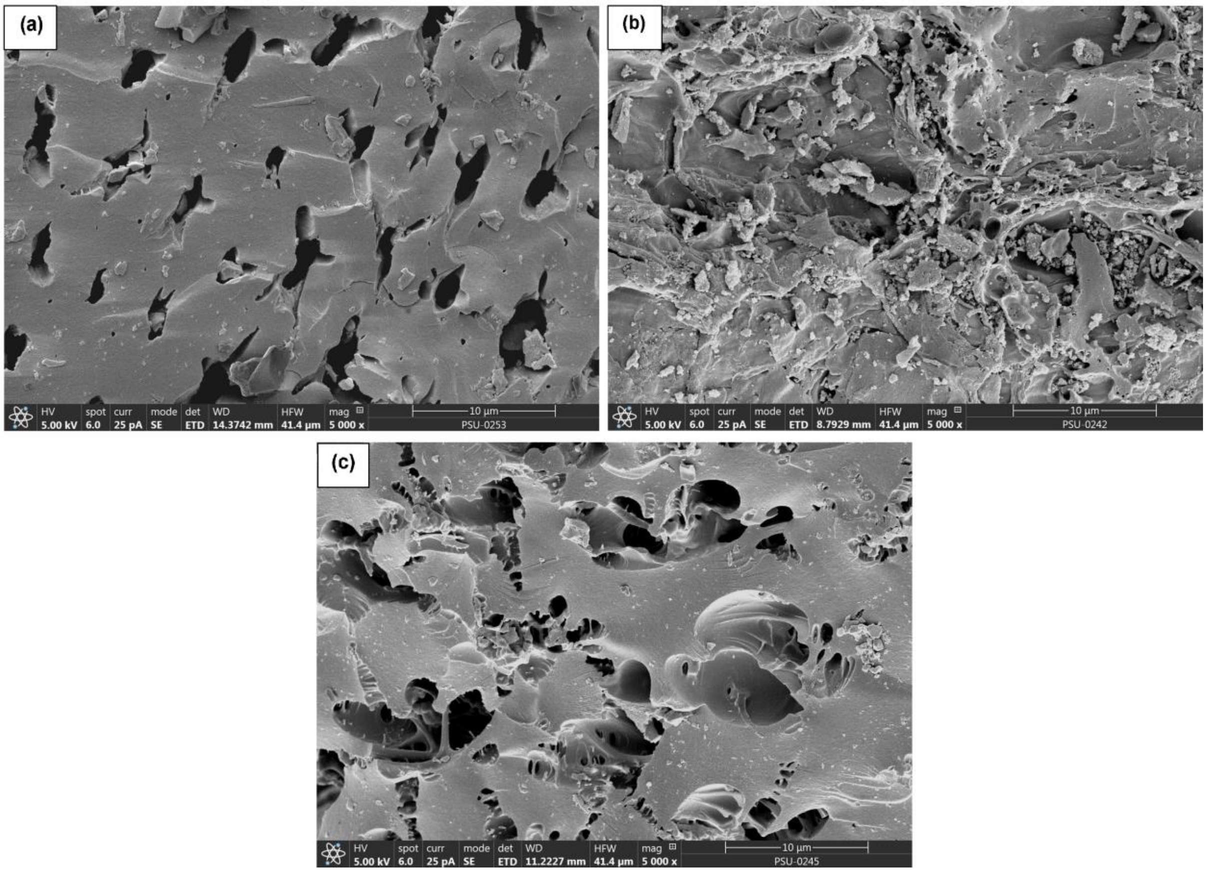

Figure 2. Scanning electron micrographs of produced activated carbon for (**a**) AC1-12 h-800°C, (**b**) AC5-24 h-700°C and (**c**) AC8-36 h-700°C

Iodine number

Determination of the iodine number is one of the methods to determine the adsorption capacity of ACs. It is a measure of the micropore (0–20 Å) content of the activated carbon by adsorption of iodine from the solution. **Table 3** showed that the iodine number increased with the increasing of activation temperature from 600-700°C and then decreased when the temperature up to 800°C for all impregnation times. This is due to more extensive volatile matter degradation and the increased reaction of NaOH and surface carbon at higher activation temperature (Loredo-Cancino et al., 2013). The iodine adsorption at the activation temperature of 700°C was the highest for each impregnation time. When the increasing of impregnation times were considered, the iodine number increased from 12 to 24 h and then decreased. This may be attributed to more extensive reaction of activating agent and surface carbon (Deng, Li, Yang, Tang, & Tang, 2010) and more excessive carbon burn-off (Saka, 2012), leading to increased release of CO_2 and CO gases and creating micropores inside of the mesopores (Mitome et al., 2013). The iodine adsorption of AC prepared with 36h was higher than that of AC prepared with 12h. It was shown that more pores are created, but the content of micropores decreases at high impregnation time more excess carbon burn-off, the collapse of pore walls (Deng, Li, Yang, Tang & Tang, 2010), or expansion of micropores to mesopores (Mitome et al., 2013). Furthermore, the reaction between carbon and activating agent may damage the micropores on the carbon surface because the impregnation time is too long (Yang, Chou, Li, Long, & Yuan, 2013).

Methylene blue number

AC is amphoteric material, which can be positively or negatively charged depending on the solution pH. The attraction between activated carbon and anionic or cationic guest materials is mainly related to the surface characteristics. More negatively charged surfaces are obtained at higher pH values and this favors the uptake of more cationic groups due to decreased electrostatic repulsion between cations and the surface of activated carbon and vice versa (Gokce, & Aktas, 2014). The adsorption of methylene blue involves the electrostatic interaction of methylene blue cations with negatively charged carbon surface functional groups (Gokce, & Aktas, 2014). The methylene blue number increased with the increasing of activation temperature from 600-700°C and then decreased when the temperature up to 800°C for all impregnation times. At high temperature and long impregnation time (AC9-36 H-800°C), the methylene blue number is lowest. It may be a higher coverage AC surface with -OH group, which will inhibit the physical surface (Tseng, Tseng, Wu, Hu, & Wang, 2008; Chen, Huang, Huang, & Cai, 2011). In addition, the high activation temperature, more volatile matter is released and more carbon burn-off takes place (Saka, 2012), leading to more mesopores or macropores (Saka, 2012). Finally, the longer impregnation time might also destroy the pore structure of carbon (Yang, Chou, Li, Long, & Yuan, 2013).

FTIR

Additionally, FTIR analysis was used to identify the functional groups in the rubber seed shell carbon at the impregnation time of 24 h with the 700°C of activation temperature (AC1-24h-600) compared to commercial activated carbon as shown in **Figure 3**. Based on the FTIR spectra, there was similar comparision to the commercial activated carbon. The adsorption capacity of activated carbon depends upon porosity as well as the chemical reactivity of functional groups at the surface (Gonzalez et al., 2009). The strong band at 3422 cm^{-1} corresponds to O–H stretching of carboxyl and phenol group and N–H stretching of amine groups. Meanwhile, the weak band observed at 2920 and 2850 cm^{-1} corresponds to the asymmetric and symmetric $-CH_3$ and $-CH_2$ stretching groups, respectively (Alabadi, Razzaque, Yang, Chen, & Tan, 2015; Guo et al., 2020). The band located at 1629 cm^{-1} is assigned to the C=O stretching of carbonyl group, which consists of ketone and aldehyde groups, while the band is 1568 cm^{-1} belongs to the C=C stretching in alkene group (Guo et al., 2020; Rahman, & Chin, 2019). The band ranging from 1369 to 1000 cm^{-1} belongs to C–O and C–N stretching, while the weak band between 900 and 600 cm^{-1} represents the N–H and C–H out-of-plane vibration (Fan, Zhang, Zhang, Shu, & Shi, 2013; Rahman, & Chin, 2019). The bands of C-O stretching at 1369 cm^{-1} and 1260 cm^{-1} was only present in the rubber seed shell activated carbon. Meanwhile, the C–N stretching was only present in the commercial activated carbon.

Antibacterial properties

The antibacterial effects of activated carbons were evaluated and shown in **Figure 4**. As can be seen from **Figure 4(a)**, the percentage of reduction in bacterial count of gram-negative *E. coli* were 44±1.4 %, 85±0.1% and 86±1%, when the contact to rubber seed shell activated carbon were 1, 3 and 24 h, respectively. The results were similar to those obtained when in contact with to commercial activated carbon. The percentage of reduction in the bacterial count were 19±0.4 %, 77±0.9 % , and 83±1.2%, when the contact were 1, 3, and 24 h, respectively. The antibacterial property of rubber seed shell activated carbon provided better than the commercial activated carbon. From our experimental results, the antibacterial effects of characterized ACs were discovered to be effective against *E. coli* and *S.aureus* after 3 h and 24 h of contact times, respectively. Thus, the rubber seed shell-activated carbon could be used for the prevention of microbial contamination in a different area.

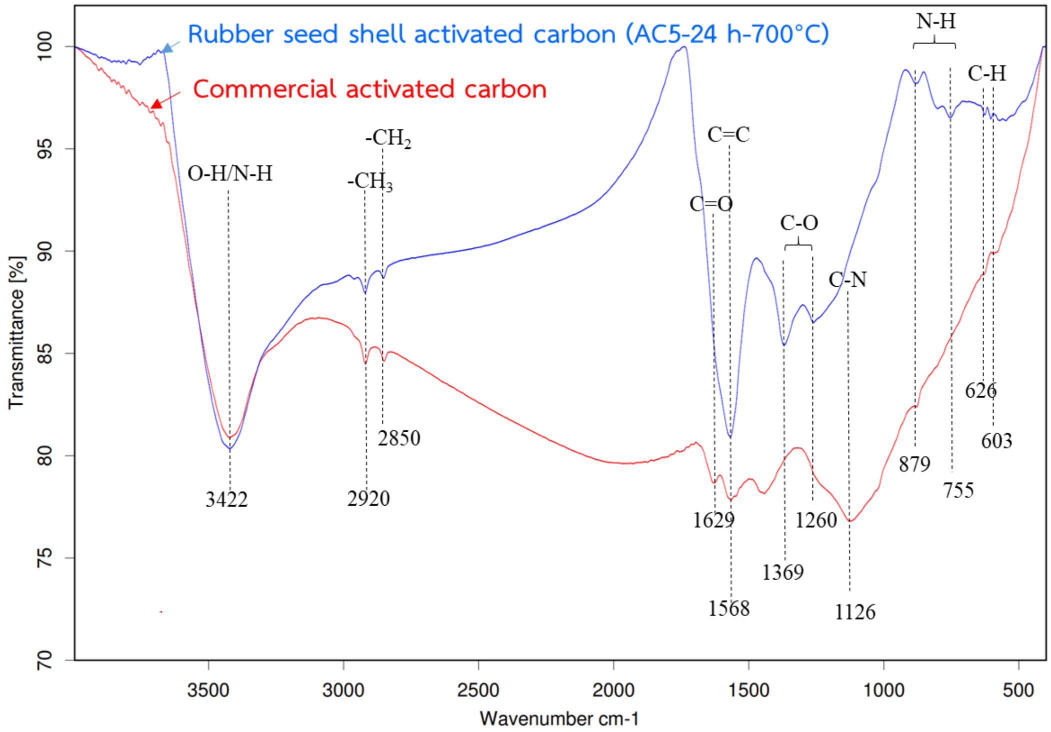

Figure 3. FTIR spectra of activated carbon produced from rubber seed shell.

Table 4. The comparison of characteristic properties of the rubber seed shell activated carbon with the previously published data

Treatment Methods	Characteristic properties of the rubber seed shell activated carbon													Ref.
	Proximate				Elemental			BET (m^2/g)	Iodine number (mg/g)	MB value (mg/g)	FTIR	Anti-bacteria test		
	M (%)	Ash (%)	VM (%)	Fixed C (%)	N (%)	C (%)	H (%)					*E. coli* (%)	*S. aureus* (%)	
NaOH impregnation (24 h) and activation temperature (700°C)	4.55±0.22	5.48±0.16	8.67±0.55	81.31	0.34±0.03	79.9±1.1	2.39±0.2	923	1,234±24	1,201±54	✓	85±0.1	73±0.2	This work
Commercial activated carbon	4.75±0.02	2.34±0.05	4.76±0.70	88.15	0.12±0.003	88.4±0.02	0.97±0.03	885	1002±15	1,204±10	✓	77±0.9	77±0.2	
ionic liquid impregnation (24 h) and activation temperature (800°C)	-	-	-	-	1.14	85.47	1.86	394	-	-	✓	-	-	Mokti et al., 2021
carbonization temperature (600°C for 3 h)	2.03	2.57	19.64	76.15	-	-	-	-	-	-	✓	-	-	Aulia et al., 2019
Steam activation temperature (880°C for 1 h)	-	-	-	-	-	-	-	948	1,366	265		-	-	Sun and Jiang, 2010
Steam activation temperature (900°C for 1.5 h)	-	-	-	-	-	-	-	852	-	-	✓	-	-	Yan et al., 2019

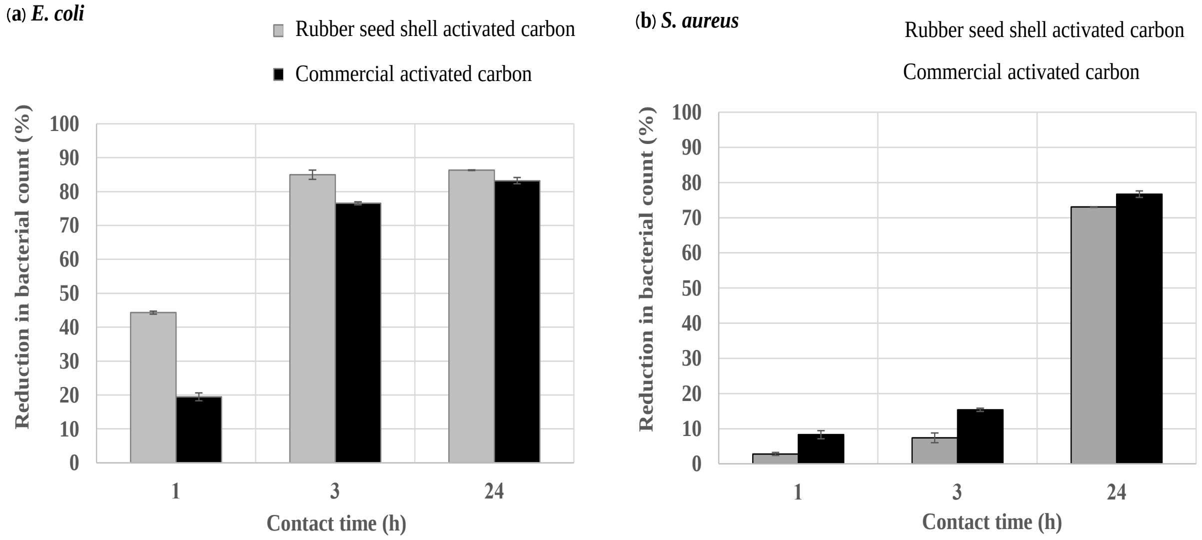

Figure. 4 Percentage of reduction in bacterial count (**a**) *E. coli* and (**b**) *S. aureus*

Comparison of characteristic properties with the other reports

The characteristic properties of the rubber seed shell activated carbon obtained from this study were compared with the previously published data including commercial activated carbon and is summarized in **Table 4**. This work showed complete data information that will help to apply in various fields.

CONCLUSIONS

ACs were successfully produced from rubber seed shells by chemical activation with sodium hydroxide and their characteristics were investigated. The effects of activation temperature and impregnation time in the agent were investigated. Proximate and elemental analysis was investigated and the results were within the standard of all prepared activated carbon. BET surface area of the best produced activated carbon was 923 m^2/g at activation temperature of 700 °C and impregnation time of 24 h. These results are related to the SEM photographs that the surface of activated carbons is porosity. This condition provided the highest iodine number of 1,234±24 mg/g and methylene blue number of 1,204±10 mg/g. FT-IR spectra indicate the presence of oxygen and nitrogen containing surface functional groups -OH, -CH$_3$, -CH$_2$, C=C, C-O, and N-H groups. Moreover, the rubber seed shell AC also showed effectiveness against *E. coli* and *S. aureus* after 3 h and 24 h of contact times, respectively. Thus, it could be used for the prevention of microbial contamination in a different area. Finally, it can be concluded that, AC from rubber seed shell can also be applied as a low-cost and possible alternate adsorbent as well as to help rubber tree plantations generate profit by turning rubber seed shells into value-added activated carbon products. Recommendations for future works include the application in various industries such as the separation and purification industry, food and beverage industry, pharmaceutical and cosmetic industries, and forensic science.

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