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Submission date: 23-May-2023 09:09AM (UTC+0700)
Submission ID: 2099705400
File name: IJASEIT-vol9_No6pp1976-2019.pdf (2.26M)
Word count: 3479
Character count: 18543

International Journal on Advanced Science Engineering Information Technology

Vol.9 (2019) No. 6
ISSN: 2088-5334

A Low-Cost Radar Absorber Based on Palm Shell Active Carbon for Anechoic Chamber

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Abstract*—Synthesis and characterization of a low-cost Radar Absorber Material (RAM) based on palm shells activated carbon is presented in this work. This low-cost RAM is intended to be used to cover the walls of the anechoic chamber. Palm shells are industrial waste from oil palm plantations and are widely available in West Sumatra. This work aims to investigate the characteristics of RAM based on palm shell for various types of an activating agent. In addition, the characteristics of RAM are also investigated due to the effect of the concentration of the activating agent. In this research, HCl, KOH, H_3PO_4, and $ZnCl_2$ are operated to activate carbon of palm shell by opening the carbon pores. Characterization of the active carbon in term of absorption and morphological on the surface is performed by using a Vector Network Analysis (VNA) and a Scanning Electron Microscopy (SEM). The waveguide technique is operated in the investigation of the absorption of electromagnetic waves of the RAM on the C-band operating frequency (4 to 8 GHz). The measured results present the maximum absorption of the RAM is obtained -26.3 dB at a frequency of 8 GHz and 1M KOH activating agent. The morphological on the RAM surface shows the pore size of activated carbon on a 1M activating agent preferable than 5M and non-activated carbon. Based on the measurement result, the activated carbon of the palm shell can be used as the radar absorber material for the anechoic chamber application.

***Keywords*—radar absorber material; low cost; palm shells; activated carbon; anechoic chamber.**

I. INTRODUCTION

Radar technology has an important role in both civilian and military purposes. Various technological applications such as Synthetic Aperture Radar (SAR) [1], landslide detection [2], weather detection, cloud profiling and land classification are utilizing radar technology [3]. The use of radar technology has many advantages since it works using electromagnetic waves so that it can be used day and night or in various weather conditions. To develop this radar technology, adequate facilities are needed, one of which is the anechoic chamber.

Anechoic chambers are one of the most important facilities in antennas and various radar components characterization [4]. The main function of the anechoic chamber is to absorb electromagnetic waves in all direction. The electromagnetic wave is absorbed using a radar absorber material (RAM). The RAM specification for an anechoic chamber must have a reflection coefficient of at least -20dB [5]. Various techniques have been developed to increase electromagnetic wave absorption such as using microstrip [6], [7] or carbon-based material [8]. In carbon-based, several materials have been developed such as risk hush [9], corncob [10], rubberwood dust [11] and cocoa pods [12]. Nevertheless, these carbon materials have low absorption and cannot be implemented as RAM for an anechoic chamber application.

In this works, active carbon-based electromagnetic wave absorbers will be developed with the materials criteria are widely available, low cost has high carbon content and has low inorganic elements (such as ash) [13]. Therefore, the palm shell will be utilized as an active carbon material. A lot of palm shells are produced from the palm oil industry, especially in West Sumatera Indonesia. As compared to other natural materials, the palm shells have a high carbon content of 55.7% [14,15]. In addition, the palm shell has a hard structure consisting of Lignin, Cellulose and Halocellulose [16[, [17].

II. MATERIALS AND METHOD

The activated carbon was produced using several steps, such as carbonization, activation, and characterization. Steps of the carbon production are illustrated in Fig.1.

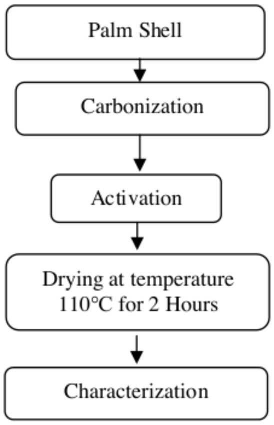

Fig. 1. Step by step of the active carbon production of the palm shell

A. Carbonization

The carbon as raw material was taken from the waste of palm shell that obtained from cooking oil industry in West Sumatra. The palm shell was cleaned from other contaminating materials that are still stuck on the shell. Furthermore, the shell was dried under atmosphere for about 1 day, to reduce its water content in order to produce good activated carbon, this is called dehydration. The carbonization of palm shells was performed by the imperfect pyrolysis of carbonaceous materials. In the meshing of the palm shell carbon, a blender and a sieve having 100 meshes were operated.

B. Activation

The activation process aims to open pores of materials as well as to make a larger surface area. In this study, chemical activation was performed using HCl, KOH, H_3PO_4, and $ZnCl_2$ activating agents. These activating agents were purchased from Merck. The 20 grams of carbonized material was dissolved and stirred continuously for one hour for the varying concentration of the activating agent 1M, 2M, 3M, 4M and 5M. The activated carbon was precipitated for about 48 hours and neutralized until the pH reaches 6-7. The carbon material was cleaned using aquadest and then filtered using a filter paper. Subsequently, the carbon material was dried at 110 °C for 2 hours and the activated carbon material was collected.

C. Materials Characterization

The reflection coefficient of the absorber materials was measured using a Keysight Vector Network Analyzer (VNA) with E5071C ENA series. This VNA can be operated from 9 kHz to 20 GHz frequency range. The measurements were performed using waveguide system having a dimension 10 x 30 mm. The measurement was made by holding the activated carbon with a thickness variation of 2 mm, 4 mm, 6 mm, 8 mm and 10 mm as shown in Fig 2. This technique was done to simplify the VNA measurement.

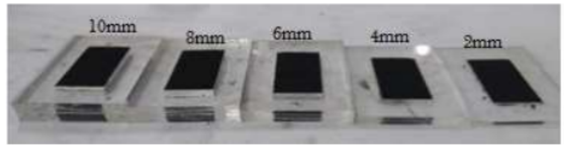

Fig. 2. The activated carbon is attached into a mold made of acrylic having thickness ranges from 2 mm to 10 mm.

The Measurements were done by attaching the adapter over the material located above the Aluminum sheet. The adapter acts as a means of guiding the wave to the material so that the reflection coefficient value can be measured by the VNA, for which the adapter device must be connected to the VNA. The identification and characterization of reflection coefficient values for electromagnetic waves using VNA produces output data that commonly called scattering parameters (S_{11} parameters) means reflection behavior occurring on VNA ports. The parameter S_{11} shows the reflection coefficient corresponding to the Reflection loss value according to the following equation.

$$RL(dB) = 20\log(S_{11}) \quad (1)$$

SEM (Quanta 650) was operated for inspecting the pores of activated carbon. The pores of both non-activated and activated carbon were scanned for several variations in the concentration of the activating agent

III. RESULTS AND DISCUSSION

In this works, the effect of a variable on other variables will be presented. The effect of activating agent types on absorption will be reported. In the second part, the effect of concentration, the thickness of the material on the absorption capacity also is explained. The scanning electron microscopy (SEM) image for non-activated carbon, activated with 1M and 5M will also be presented.

A. The Effect of Activating Agent on Carbon Absorption

The effect of the activating agent type on the absorption of activated carbon was investigated. Fig. 3 shows the measured result of the reflection coefficient of activated carbon palm shell for variation of the activating agent. As shown in Fig. 3, the absorption of activated carbon-based on palm shell is determined by the type of activating agent used. The carbon material without activation has a deficient absorption of -6.31 dB in the C-band range. After activation, the absorption of the material dramatically increased. A good activating agent is a substance that can produce more pores on the carbon. The number of pores in the active carbon material can increase the absorption of the microwave of the material. Material absorption to microwaves can be determined through the value of the reflection coefficient, where the lower the reflection coefficient, the greater the absorption power [18].

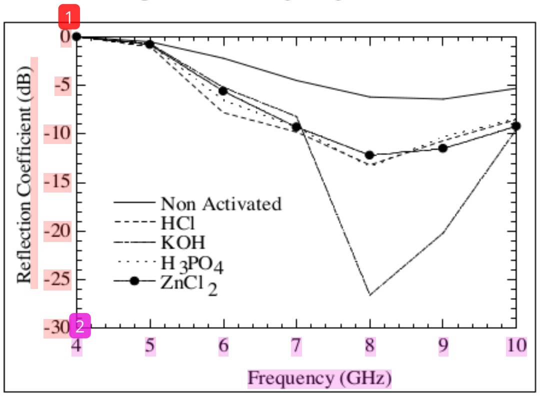

Fig. 3. Measured reflection coefficient of the carbon and the activated carbon with several types of activating agents (HCL, KOH, H_3PO_4, and $ZnCL_2$) at a material thickness of 10mm.

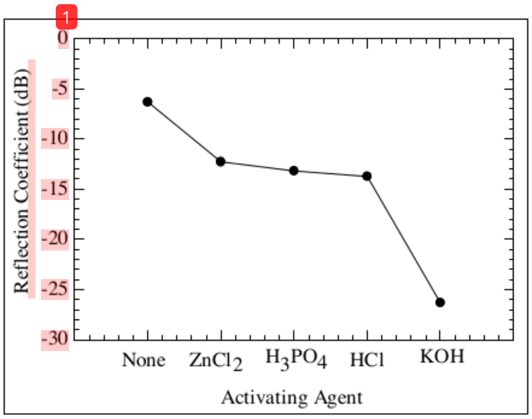

Fig. 4. The maximum reflection coefficient of the activated carbon for several activating agents at a material thickness of 10mm, concentration of 1M and frequency center of 8 GHz.

Based on the variation of activating agent, the largest absorption at the frequency center of 8 GHz obtained for KOH with -26.3 dB and followed by HCl (-13.7 dB), H_3PO_4 (-13.4 dB), and $ZnCl_2$ (-12.3 dB) as seen in Fig. 4. These results indicate that KOH activating agent yields much higher absorption as compared to other activating agents. The higher absorption is due to KOH that is a dehydrating agent. In this activation process, carbon interacts with KOH in such a way that the carbon is eroded and the pores are formed. Outer surface increases due to the creation of pores on the surface of activated carbon, increasing adsorption efficiency [19].

B. Effect of KOH activating agent concentration

The relationship between the frequency and reflection coefficient of the palm shell activated using KOH can be seen in Fig. 5. The concentration of KOH activating agent is regulated by variations in 1,2,3,4, and 5 molars at a carbon thickness of 10 mm. The maximum reflection coefficient of the activated carbon as concentration variation is presented in Table 1.

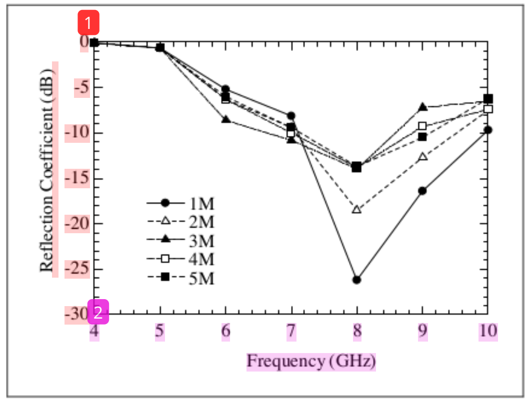

Fig. 5. Measured reflection coefficient of the activated carbon for various concentration of activating agent (1M, 2M, 3M, 4M and 5M) at a material thickness of 10mm.

TABLE I
ABSORPTION OF PALM SHELL ACTIVATED CARBON VARYING THE CONCENTRATION OF KOH

Concentration (M)	Reflection coefficient (dB)
1	-26.30
2	-18.70
3	-13.86
4	-13.68
5	-13.48

The measurement results show that the lowest reflection coefficient is obtained for KOH 1 Molar concentration that reach 26.3 dB. Thus, electromagnetic waves that pass through the palm kernel activated carbon will be absorbed up to 99.9%. In addition, for higher KOH concentrations (3M-5M), the pores will be closed so that the adsorption efficiency is reduced.

The relationship of the activating agent concentration on the absorption of microwave has been investigated. The results of the observation of the absorption of materials with the same thickness and activating agent have also been obtained. The results of the observation showed that the concentration of activating agent from acids (HCl, H_3PO_4) and zinc chloride ($ZnCl_2$) does not have a strong effect on the absorption of activated carbon.

The data obtained showed almost the same absorption for 1M, 2M, 3M, 4M and 5M concentrations of each activating agent used. This is because the higher the concentration of the activating agent, the more the water content in material, so that wave absorption is reduced. Fig. 6 and Fig. 7 are graphs of the relationship between the activating agent concentration and the microwave reflection coefficient.

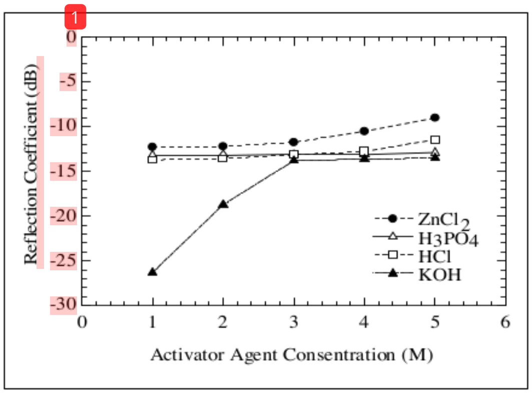

Fig. 6. The relationship between the coefficient of reflection and activating agents concentration at a material thickness of 10mm and frequency center of 8 GHz

The absorption of difference in thickness of the material absorber with 1M KOH activating agent is investigated.

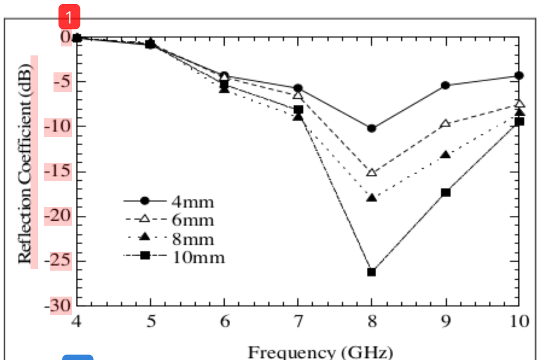

Fig. 7. The relationship between the coefficient of reflection and the frequency using the KOH 1 M activating agent as a variation in thickness from 4 mm to 10 mm.

Fig. 7 is a plot of data from measurements of palm shell activated carbon with thickness of 4, 6, 8 and 10 mm. The maximum reflection coefficient for thickness variation is shown in Table 2.

TABLE III
THE PEAK REFLECTION COEFFICIENT OF PALM SHELL ACTIVATED CARBON FOR THICKNESS VARIATIONS

Thickness (mm)	Reflection coefficient (dB)
4	-10.22
6	-15.25
8	-17.98
10	-26.30

Based on Table 2, the reflection coefficient data obtained has linearly increased with the thickness of the activated carbon as shown in Fig. 8.

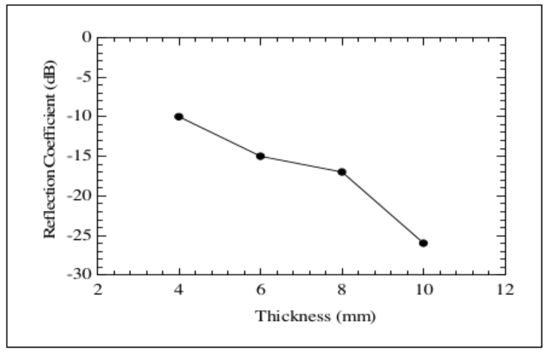

Fig. 8. Dependency between absorption and material thickness of the activated carbon at frequency center of 8 GHz and activating agent of KOH 1M

The surface morphology of carbon and activated carbon of the palm shell was investigated using a SEM. Scanning results on surface morphology for non-activated carbon, activated carbon of the palm shell for 1M and 5M KOH concentration are displayed in Fig. 9, Fig. 10 and Fig. 11, respectively.

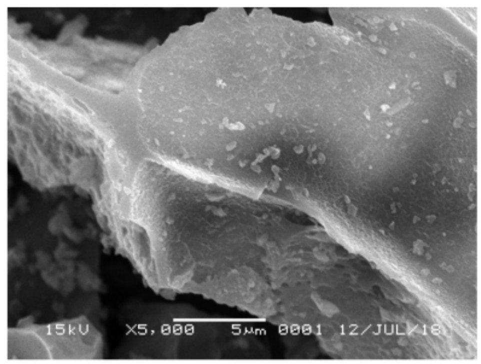

Fig. 9. The scanning electron microscopy (SEM) image of non-activated carbon of the palm shell with a magnification of 5000x

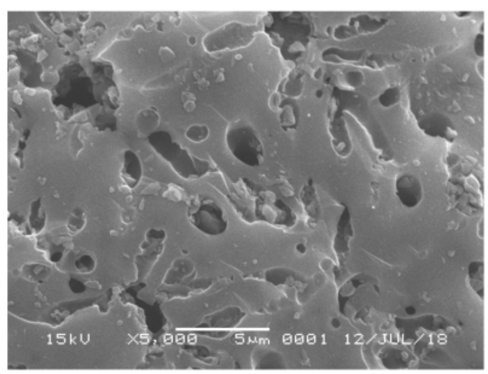

Fig. 10. The scanning electron microscopy (SEM) image of activated carbon of the palm shell with a magnification of 5000x for 1M KOH concentration

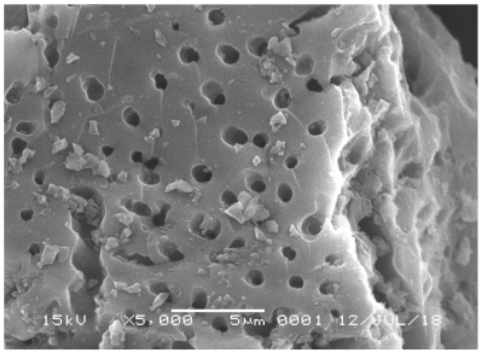

Fig. 11. The scanning electron microscopy (SEM) image of activated carbon of the palm shell with a magnification of 5000x for 5M KOH concentration

The activation process of carbon material causes the release of gases such as CO and CO_2 which are spread on the carbon surface which erodes the surface to form pores [20]. In general, SEM observations show that surface morphology of activated carbon has more pores than that of non-activated carbon. Based on Fig. 9, 10 and 11 there is a clear difference pore size of each activated carbon. Pore size is very influential on the absorption of an absorbent. In activated carbon with 1M KOH (Fig. 10), the pore size is greater than that of activated carbon activated by 5M KOH (Fig. 11). The greater the pore size of an absorbent, the higher the absorption is due to the increased surface area of the absorbent [21], [22]. In addition, the large pores ease the microwaves to propagate into the inside of the material. Meanwhile, for small pores it can interfere with the propagation of waves entering the material. As a result, the absorption of material to microwaves become lower [23].

In general, the synthesis of activated carbon from palm shell as a radar absorber present the satisfactory results. As compared with other natural materials that have been reported in other works, Palm shell has a higher absorption. Table 3 shows the results of the comparative absorption of microwaves from other natural materials.

TABLE IIIII

ABSORPTION OF PALM SHELL ACTIVATED CARBON AS COMPARED TO OTHER BASED ON NATURAL MATERIAL

Material	Absortion (dB)
Rubber wood dust	7 [11]
Cocoa Pod	-14.0 [12]
Rice Husk	-12 [9]
Coconut Shell	-19.5 [24]
Palm shell	-26.30

IV. CONCLUSIONS

The radar absorbing material using the activated carbon palm shell for the anechoic chamber has been synthesized. Based on experimental results, the optimum microwave absorption of the palm shell activated carbon can be achieved using a KOH activating agent. The carbon surface determines the absorption of the radar material. The surface area is enlarged by creating pores on the carbon surface. Based on surface morphology inspection, the large size of the pores was produced at 1M activating agent concentration. In this work, the waste palm shell is successfully converted as a low-cost radar absorber material.

ACKNOWLEDGMENT

This work was supported by a grant from the Directorate of Research and Community Service (DRPM), Ministry of Research, Technology and Higher Education, Indonesia (No.436/UN35.13/LT/2019).

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