Progress In Electromagnetics Research, Vol. 137, 687–702, 2013

DEVELOPMENT OF PYRAMIDAL MICROWAVE ABSORBER USING SUGAR CANE BAGASSE (SCB)

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Abstract—The need to find ways to effectively utilize the large quantities of agricultural waste that are produced is indicative of the huge potential associated with producing an alternative pyramidal microwave absorber for anechoic chamber-testing applications. We propose the development of a pyramidal microwave absorber that can use sugar cane bagasse (SCB), a byproduct from the production and processing of sugar cane, as the absorbent. In this paper, we report the results of our use of dielectric probe measurement to determine the dielectric constant and loss tangent of SCB. These values were used to model and simulate an SCB pyramidal microwave absorber in Computer Simulation Technology's (CST's) Microwave Studio. This absorber was operated in the microwave frequency range between 0.1 GHz and 20.0 GHz.

1. INTRODUCTION

Agricultural waste is made up of organic compounds from plants. SCB is the byproduct from the production and processing of sugar cane (*Saccarhum officinarum*) to produce sugar. This residue is obtained after the extraction of the juice that is used to produce sugar. The worldwide production of SCB in 2005 was 54 million dry tons [1]. 1000 kg of raw sugar cane produces 280 kg of baggage. Perlis state

Received 26 January 2013, Accepted 4 March 2013, Scheduled 12 March 2013
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in northern Malaysia has the potential to produce large quantities of SCB, especially in the Chuping area.

Carbon is one of the main elements in most agricultural wastes. The parameters for this carbon material are its pore structure and surface area. The volumes of the pores limit the sizes of the molecules that can be adsorbed. The surface area limits the amount of material that can be absorbed, assuming a suitable molecular size. Carbon is important because it is very suitable for transforming microwave energy to thermal energy [2]. An electric field is produced when microwaves pass through the absorber, and the electrical energy is transformed into thermal energy.

This waste material can be used in many industries and for various applications. Suhardy et al. produced an alternative paper product using this material [3, 4], and his experimental results showed that the carbon and silica contents of the SCB were approximately 90% and 10% respectively, whereas these contents in rice straw were approximately 64% and 36% respectively.

In 2009, Azevedo and Galiana developed a process for extracting ethanol from sugar cane for the power industry sector, especially in Brazil. The implication was the process provided clean and renewable source of energy that could be used as a biofuel and for generating bioelectricity [5]. Similarly other countries have produced ethanol from biological products, including corn in the U.S., sugar beets in Germany and wheat in Europe.

The interior surfaces of the RF anechoic chamber are sometimes similar to those of an acoustic anechoic chamber, but there is a difference between the two chambers. The function of a microwave absorber is to absorb waves that are reflected by the walls and the ceiling of the anechoic chamber [6–16].

Different absorber materials are used for the microwave range frequency (1 GHz to 40 GHz). Polyurethane and polystyrene are the two example materials that are used extensively in laboratory studies. The two most popular microwave absorbers that are currently on the market are Eccosorb's *VHP-8-NRL* absorber [17] and *TDK ICT-030* absorber [18]. The following are references to others who have conducted research on microwave absorbers: Hasnain et al. [19], Salleh et al. [20], Yusof et al. [21], Farhany et al. [22], Noordin et al. [23], Nornikman et al. [24], Malek et al. [25], and Ibrahim et al. [26].

Other than the material used in the absorber, its shape is its main parameter. Many shapes have been used in the design of the absorbers, including pyramidal [27], wedge shapes [28]; oblique, hexagonal shapes [29]; twisted, convoluted, flat shapes [30]; and multi-layer flat shapes [31].

2. MATERIALS AND METHODS

Figure 1 shows a flowchart of the steps followed in an SCB pyramidal microwave absorber. The work begins with collecting raw SCB from the flea market in Kangar, Perlis. The SCB is dried in the sun for a week, cut into small pieces, and ground to make small particles.

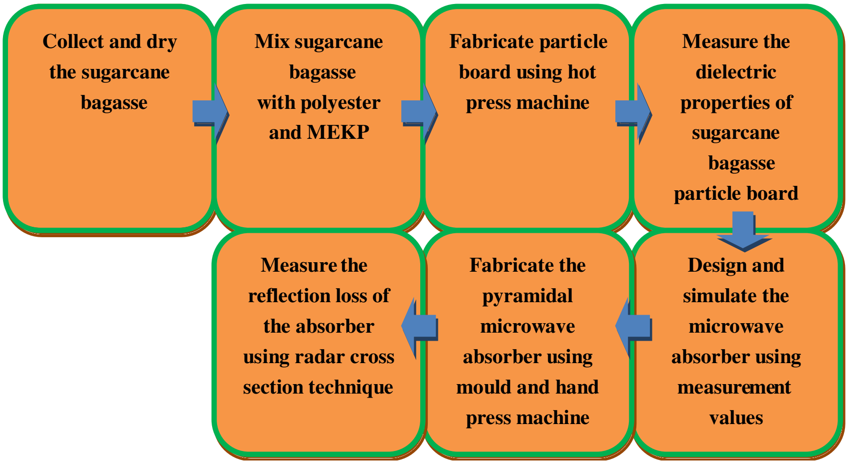

Figure 1. Steps in the use of a pyramidal microwave absorber using SCB.

The dielectric properties, i.e., dielectric constant and loss tangent, of the material are two important parameters that must be considered when modeling a pyramidal microwave absorber. The measurements to define the values of these dielectric properties involve the transmission line, resonant cavity, free space, and the dielectric probe technique. The type of measurement used depends on the physical condition of the material, i.e., whether it is liquid, semi-solid, or solid.

In this work, the dielectric probe method was used to determine the dielectric constant (real part, ε_r', and imaginary part, ε_r'') of the SCB. This measurement is an important factor in defining the physical and chemical properties that are related to the storage and loss of energy with respect to different kinds of materials. Figure 2 shows the measurement of the dielectric properties of the SCB using a dielectric probe.

The equipment used in this measurement is an Agilent dielectric probe with software, a network analyzer, two coaxial cables, and the material to be tested [26]. Coaxial cables were used to connect the dielectric probe to ports 1 and 2 of the network analyzer. The dielectric probe had glass-to-metal contact point that was hermetically sealed.

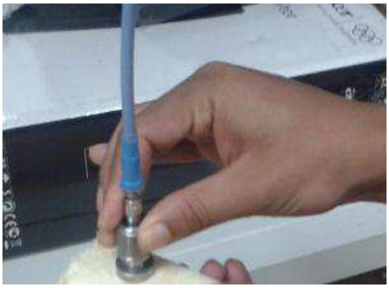

Figure 2. Use of a dielectric probe to measure the dielectric properties of SCB.

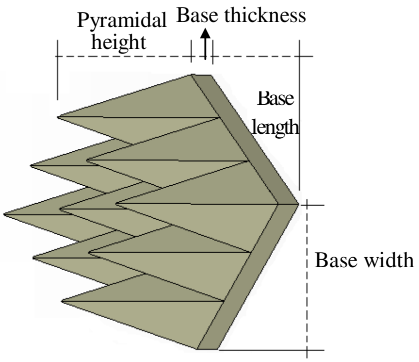

Figure 3. SCB pyramidal microwave absorber designed in CST's microwave studio.

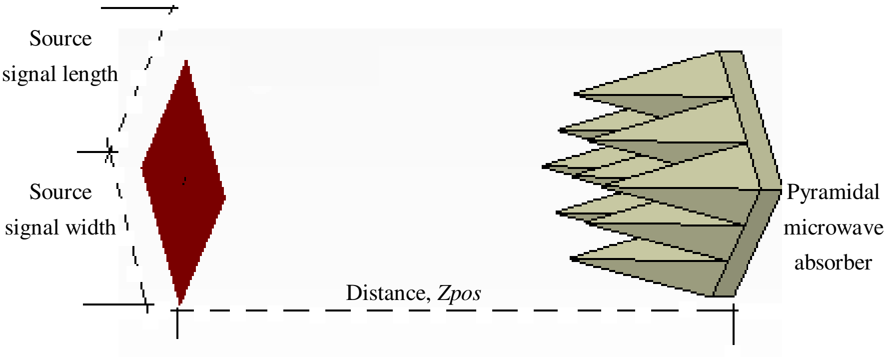

Figure 4. Simulation setup for CST's microwave studio simulation.

Figure 3 represents an SCB pyramidal microwave absorber in CST's Microwave Studio simulation software. The two main parts of the microwave absorber the pyramid-shaped body and the pyramidal base (square-shaped particle board). The dimensions of the base were $15\times15\times2$ cm. The dimensions of the pyramidal body were $5\times15\times13$ cm for width, length, and height, respectively. This design was based on four references [27–30]. The dielectric constant, ε_r, for this design of the SCB pyramidal absorber was 1.44, which was consistent with the value of the dielectric constant measured previously in [31].

Figure 4 shows the simulation setup in CST's Microwave Studio. The source signal is the starting point of the signal before transmission occurs. The distance between the pyramidal microwave absorber and the source of the signal source (port), Z_{pos}, was 50 cm [32–37].

The distance also affects the reflection loss of the pyramidal microwave absorber. The source signal dimension is 15 cm width × 15 cm length, same dimension of pyramidal base part. The source signal is located as a normal incident (0°) signal from the pyramidal base part.

The next stage is to fabricate the SCB pyramidal microwave absorber, as shown in Figure 5. The ground SCB was mixed with polyester resin, and methyl ethyl ketone peroxide (MEKP) was used as the hardening agent. Then, the mixture was placed in a pyramidal-shaped mold and pressed with a hand press machine to produce its solid, pyramidal shape.

The next stage is the measurement of reflection loss using the radar cross section (RCS) method [38–41]. The equipment used in this measurement was a signal generator, a spectrum analyzer, a pair of coaxial cables, seven pairs of horn antennas, the reference metal and a

Figure 5. Single units of the SCB pyramidal microwave absorber after fabrication using a pyramidal-shaped mold.

(a)

(b)

Figure 6. (a) Horn antennas with different effective frequency ranges; (b) spectrum analyzer and signal generator.

tripod to hold the horn antennas and the reference metal [42, 43]. The angle between the pyramidal microwave absorber and the horn antenna was 60°. Figure 6(a) shows the different effective frequency ranges of horn antennas, i.e., 1.80–2.60 GHz, 2.80–3.80 GHz, 4.0–5.8 GHz, 6.0–8.2 GHz, 8.4–12.4 GHz, and 12.6–18.0 GHz. Figure 6(b) shows the spectrum analyzer and signal generator that were used in this measurement.

3. RESULTS AND DISCUSSION

The best reflection loss at a certain point cannot be used to determine the overall performance of the pyramidal microwave absorber because it only represents a very limited range of frequencies. The overall performance of pyramidal microwave absorber must be represented by using the average of the reflection losses.

Table 1 shows a comparison of the average values of dielectric constant and loss tangent for rice husks and SCB using the dielectric probe measurement technique. The average dielectric constant of the SCB was 1.44, while that of the rice husk was 2.03. The average loss tangents for rice husk and SCB were 0.132 and 0.161, respectively.

Table 1. Average dielectric constants and average loss tangents for SCB and rice husks.

Material	Average dielectric constant, ε_r	Average loss tangent, $\tan\delta$
Rice husks	2.03	0.132
Sugar cane bagasse	1.44	0.161

Figure 7 shows the dielectric constant of SCB using the dielectric probe measurement technique. The measurement was taken in the frequency range of 0.02 to 10 GHz. The figure shows that the dielectric constant of SCB varies, depending on the frequency. For example, the dielectric constant at a frequency of 0.4 GHz was 2.26, while the dielectric constant was only 0.75 when the frequency was 4.9 GHz. The average dielectric constant for SCB was 1.44.

Figure 8 shows the loss tangent of SCB using the dielectric probe measurement technique. The loss tangent value of the SCB ranged from 0.1 to 1.0. The graph shows that the loss tangent values were 0.38 and 0.28 at 0.4 and 4.9 GHz, respectively.

Figure 9 shows the reflection losses for SCB and rice husks in the frequency range of 0.01 to 20.0 GHz. The figure shows that SCB

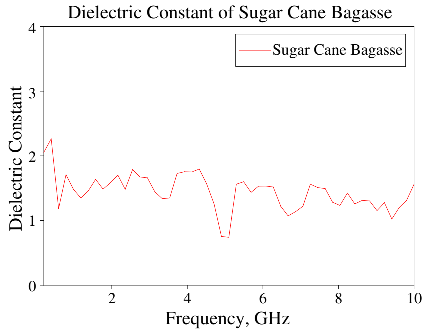

Figure 7. Dielectric constant of sugar cane bagasse using the dielectric probe measurement technique.

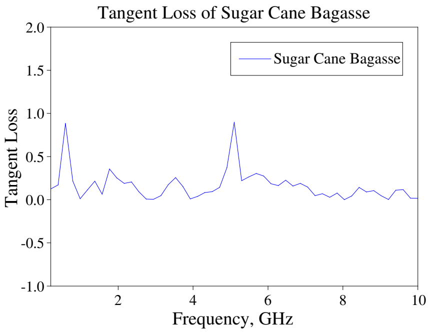

Figure 8. Loss tangent of sugar cane bagasse using the dielectric probe measurement technique.

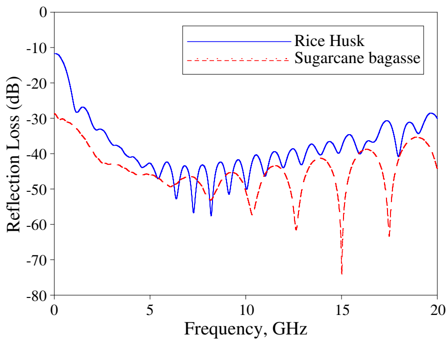

Figure 9. Reflection loss performance of sugar cane bagasse and rice husk pyramidal microwave absorber using CST simulation.

pyramidal microwave absorber had a better reflection-loss performance than the rice husk pyramidal microwave absorber.

Table 2 shows the comparison of the different pyramidal microwave absorbers using different types of materials. The SCB pyramidal microwave absorber had better reflection loss values than the rice husk pyramidal microwave absorber. Their average reflection losses were -44.388 dB and -38.237 dB, respectively.

For the frequency range of 0.01 GHz to 1.0 GHz, SCB absorber show better performance with -29.657 dB compared to rice husk absorber with only -16.031 dB.

Figure 10 and Table 3 represent the reflection loss performance of the SCB pyramidal microwave absorber using different thicknesses of the base of the absorber. Four different thicknesses of the base of the pyramidal microwave absorbers, i.e., 1, 2, 3, and 4 cm, were tested,

Table 2. Average reflection loss performance of pyramidal microwave absorbers using different materials.

Frequency range (GHz)	**Simulated average reflection loss (dB)**	
	Sugarcane bagasse	**Rice husks [24]**
0.01–1	−29.657	−16.031
1–5	−41.295	−35.911
5–10	−48.001	−46.173
10–15	−47.751	−40.749
15–20	−43.055	−34.175
0.01–20	−44.435	−38.237

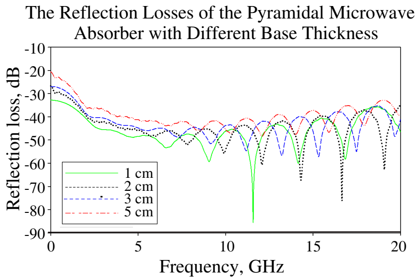

Figure 10. Reflection loss performance of sugar cane bagasse pyramidal microwave absorber with different base thicknesses (B_t).

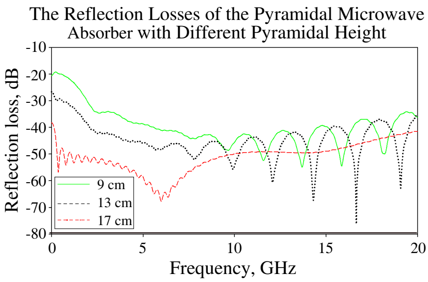

Figure 11. Reflection loss performance of sugar cane bagasse pyramidal microwave absorber with different pyramid heights (P_h).

Table 3. Average reflection loss performance of pyramidal microwave absorber using different base thicknesses (B_t).

Frequency range (GHz)	Average reflection loss (dB) with different base thickness			
	$B_t = 1\,\text{cm}$	$B_t = 2\,\text{cm}$ (normal)	$B_t = 3\,\text{cm}$	$B_t = 5\,\text{cm}$
0.01 to 1	−33.446	−29.657	−27.826	−23.461
1 to 5	−43.819	−41.295	−39.902	−36.479
5 to 10	−50.468	−48.001	−46.497	−42.945
10 to 15	−49.218	−47.751	−45.392	−42.698
15 to 20	−41.758	−43.055	−42.205	−38.071
0.01 to 20	−45.798	−44.435	−42.890	−39.392
Best point	−85.498	−75.676	−57.179	−48.35

and their reflection losses versus frequency graphs were compared. The results showed that the base thickness of 1 cm had the best average reflection loss result, i.e., −45.798 dB. The best reflection loss with the 1-cm base thickness was −85.498 dB at a frequency of 11.58 GHz, while the best loss with the 2-cm thickness was only −75.676 dB at 16.66 GHz. For the low frequency range (0.01 to 1.00 GHz), the 1-cm base thickness also had the best average reflection loss, i.e., −33.446 dB.

The results of using three different heights of the pyramidal shapes, i.e., 9, 13, and 17 cm, are shown in Figure 11 and Table 4. The results of the parametric study showed that the pyramidal microwave absorber that was 17 cm high had the best average reflection loss. The pyramid with this height achieved an average reflection loss of −51.094, whereas the 13 and 9 cm pyramids achieved −44.435 dB and −39.756 dB, respectively. The best single results occurred for the 13-cm pyramid at a frequency of 16.66 GHz.

Table 4. Average reflection loss performance of pyramidal microwave absorber using different pyramid heights (P_h).

Frequency range (GHz)	Average reflection loss (dB) with different pyramid heights		
	$P_h = 9\,\text{cm}$	$P_h = 13\,\text{cm}$ (normal)	$P_h = 17\,\text{cm}$
0.01 to 1	−20.338	−29.657	−48.244
1 to 5	−33.169	−41.295	−53.693
5 to 10	−42.955	−48.001	−57.331
10 to 15	−44.714	−47.751	−49.359
15 to 20	−40.766	−43.055	−45.099
0.01 to 20	−39.756	−44.435	−51.094
Best point	−54.919	−75.676	−67.658

Figure 12 and Table 5 show the effect on the distance between the waveguide port and the pyramidal microwave absorber. The initial distance was 50 cm, while the other distance was 35 cm. The graph shows that the distance = 50 cm had better average reflection loss than the distance = 35 cm. The average reflection loss between 0.01 and 20.0 GHz for 50 cm and 35 cm were −44.435 dB and −43.207 dB, respectively.

Figure 13 and Table 6 compare the average reflection losses with different angles between the waveguide port and the absorber. The three angle values used in the parametric study value were the normal incident angle of 0° and oblique incident angles of 30° and 45°. The results of the simulation indicated that the normal incident angle achieved the best average return loss for frequencies between 0.01

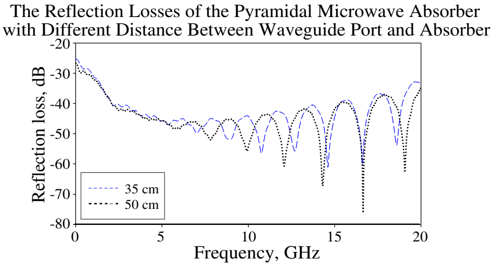

Figure 12. Reflection loss performance of sugar cane bagasse pyramidal microwave absorber with different distances between the waveguide port and the absorber.

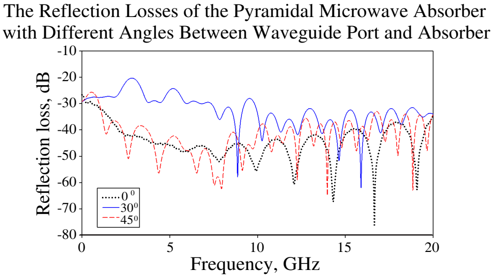

Figure 13. Reflection loss performance of sugar cane bagasse pyramidal microwave absorber with different angles between the waveguide port and the absorber.

Table 5. Average reflection loss performance of pyramidal microwave absorber using different distances between the waveguide port and the absorber, Z_{pos}.

Frequency range (GHz)	Average reflection loss (dB) with different distances between the waveguide port and the absorber, Z_{pos}	
	$Z_{pos} = 35\,\text{cm}$	$Z_{pos} = 50\,\text{cm}$ (normal)
0.01 to 1	−28.044	−29.657
1 to 5	−40.608	−41.295
5 to 10	−46.936	−48.001
10 to 15	−46.969	−47.751
15 to 20	−40.847	−43.055
0.01 to 20	−43.207	−44.435
Best point	−60.170	−75.676

Table 6. Average reflection loss performance of pyramidal microwave absorber using different angles between the waveguide port and the absorber.

Frequency range (GHz)	Average reflection loss (dB) with different angles between the waveguide port and the absorber		
	Angle = 0° (normal)	Angle = 30°	Angle = 45°
0.01 to 1	−29.657	−27.966	−27.269
1 to 5	−41.295	−26.011	−42.222
5 to 10	−48.001	−31.042	−48.665
10 to 15	−47.751	−37.686	−41.823
15 to 20	−43.055	−35.398	−39.242
0.01 to 20	−44.435	−32.636	−42.244
Best point	−75.676	−61.650	−62.331

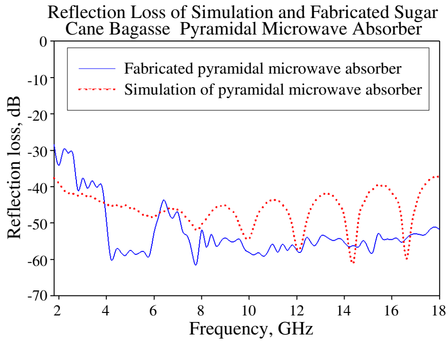

Figure 14. Reflection loss performance of sugar cane bagasse pyramidal microwave absorber (simulation and fabrication).

and 20.0 GHz, i.e., −44.435 dB, than the 30° and 45° oblique incident angles, i.e., −61.650 dB and −62.331 dB, respectively.

Figure 14 compares the simulation results with the results achieved by the fabricated SCB pyramidal microwave absorber. The created region was done because of the limitation of the frequency range of the horn antennas. The seven regions (Regions A to G) were created from 1.80 to 18.0 GHz.

Table 7 compares the results achieved via simulation and actual operation of a fabricated pyramidal microwave absorber using SCB. The simulated results had a better average reflection loss (range between 1.80 and 18.0 GHz), i.e., −52.380 dB than the fabricated absorber, i.e., −45.900 dB.

Table 7. Average reflection loss performance of fabricated pyramidal microwave absorber using sugar cane bagasse and rice husks.

Region, based on different horn antenna	Frequency range (GHz)	Average reflection loss (dB)	
		Simulated microwave absorber	Fabricated microwave absorber
A	1.80–2.60	−30.890	−40.250
B	2.60–3.80	−38.360	−42.820
C	3.80–5.80	−55.880	−45.920
D	5.80–8.20	−52.270	−48.210
E	8.20–12.4	−56.410	−48.380
F	12.4–18.0	−54.410	−44.820
G	1.80–18.0	−52.380	−45.900

4. CONCLUSIONS AND FUTURE WORK

The cost of the pyramidal microwave absorber can be reduced by using SCB as the main material. This SCB-polyester-MEKP absorber was less expensive than microwave absorbers on the commercial market, and the main materials of the latter absorbers are not environmentally friendly. This is due to their usage of nearly 100% of non-environmentally chemical materials. Both polystyrene and polyurethane can increase the pollution that enters the environment. The SCB-polyester-MEKP absorbers can reduce the use of chemical-based material by almost 90%. The results of this study proved that agricultural waste, such as SCB, has huge potential for being used as an alternative material in fabricating microwave absorbers. In the future, this work could be extended to compare the performance of the proposed SCB microwave absorbers with commercially available microwave absorbers.

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