Application of biocellulose as an acoustic membrane

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Abstract

Traditionally, membrane of cone loudspeakers are made of paper (cone paper), formed with cellulose fibers. Bacterial cellulose or biocellulose is known as nata de coco *which is produced by coconut water fermentation using Acetobacter. A sheet obtained from the biocellulose has good mechanical properties i.e the Young 's modulus of a sheet prepared using hotpress processing was 13 GPa.*

Improvement of the mechanical properties can be achieved by treating the biocellulose with alkali or oxidant solutions. The Young's modulus of the sheet of biocellulose has reached 23.5 GPa with tan 60.02 (an acoustic absorption property), and sound velocity as high as 4522.67 m/sec. These characters showed that biocellulose sheet prepared from coconut water fermentation showed good acoustic characteristic. It means that the replacement of cone paper loudspeaker with a cone biocellulose is prospective .

Based on these characters, an experiment has been conducted to construct cone loudspeaker from the biocellulose material with size and shape similar to those of marketed cone loudspeaker. Frequency respons of cone type loudspeakers made of bacterial cellulose shows that it has wide frequency range, from low to high.

Keywords: *biocellulose – acetobactor – cone type loudspeaker*

Introduction

Many materials such as paper, aluminium, titanium have been widely used as diaphragm of electroacoustic transducer i.e. loudspeaker, headset etc. The function of this diaphragm is to convert electric energy into acoustic energy. The requirement of the diaphragm of a loudspeaker is a wide frequency response character and free from resonances. In term of physical quantities these are a large Young's modulus, a small density and a large loss factor.

Traditionally, diaphragm of loudspeakers are made of paper ("cone paper") formed with cellulose fibers. This material can be processed into a light weight diaphragm with a relatively high internal loss (tan δ), but it has too limited ranges of Young's modulus (E) and sound propagation velocity (V) to provide satisfactory flexural rigidity and attaining sufficient expansion of the width of the reproduction frequency band (Nishi *et al.*, 1987).

Light metals such as aluminium and titanium have been used for loudspeakers, especially for tweeters, however, tan δ of these metals are restricted to a very low value (tan δ < 0.01) (Parker, 1987).

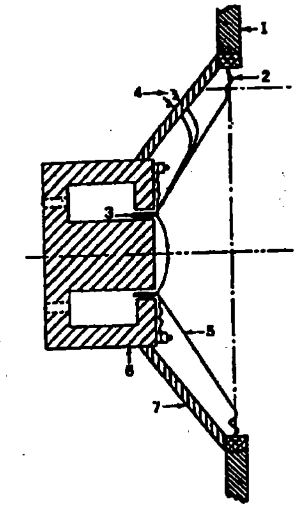
Acetobacter xylinum (A. xylinum), an acetic acid bacterium, have the ability to synthesize cellulosic material as an extracellular polysaccharide. This polysaccharides is called bacterial cellulose in general. It is produced as a gel-like substance on the surface of the culture medium in a static culture. Later investigation by Iguchi (Iguchi *et al.*, 1990) who used synthetic medium has shown that the bacterial cellulose produces a strong sheet and the sound velocity calculated from Young's modulus can be as high as 5,000 m/sec. Because of its good mechanical strength it is expected to be used in a new industrial material.

Presently, in Indonesia, bacterial cellulose is not yet a commodity for industry, instead it is commonly used as food which is called "nata de coco". It is produced from coconut water fermentation using *A.xylinum.* This new application is improving the common utilization of coconut water, which is usually dumped directly to the field. This practice is certainly creating pollution problem in environment, therefore the possible usage of coconut water for producing bacterial cellulose as membrane of speaker is important. Since an extra ingredient is not needed in this process, hence it is an inexpensive carbon substrate as growth medium of the *A. xylinum* for producing cellulose.

In conjuction with the efforts of utilizing bacterial cellulose as a functional material, we investigated the frequency response of sheet biocelluose as the diaphragm of cone speakers.

Theory

A cross - sectional sketch of a typical direct-radiator loudspeaker is shown in Figure 1.



1. Infinitely large baffle
2. Flexible edge suspension
3. Voice coil
4. Electrical connections
5. Cone (diaphragm)
6. Permanent magnet
7. Open web supporting structure

Figure 1. Cross-sectional sketch of a direct- radiator loudspeaker assumed to be mounted in an infinite baffle

The diaphragm is in the form of a truncated cone. At the base of the cone is attached a short cylindrical form, on which is wound a relatively small number of turns of wire. The cone is supported at the outer edge and near the voice coil so that it is free to move only in an axial direction.

The sound pressure at a distance r and at low frequency has been found to be

$|p(r)| = (e_g B 1 S_D f_{\rho o})/(r(R_g+R_E)(R_M^2+X_M^2)^{\square})$

where:

- $p(r)$: the sound pressure at a distance r
- e_g : the open - circuit voltage of the generator (audio amplifier) in volts.
- B : the steady air-gap flux density
- 1 : the length of wire
- R_g : the generator resistance
- R_E : the resistance of the voice coil
- R_M : $(B^2 1^2)/(R_g + R_E) + R_{MS} + 2 R_{MR}$
- R_{MR}: the resistance in the equivalent circuit which various frequency
- R_{MS}: the mechanical resistance of the suspencies
- X_M: $\omega M_{MD} + 2 X_{MR} - 1/(\omega C_{MS})$
- ω : angle velocity
- M_{MD}: the mass of the diaphragm
- X_{MR}: the reactance in the equivalent circuit
- C_{MS}: the total mechanical compliance of the suspensions

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S_D : the projected area of the loudspeaker cone
f : the frequency
r_o : the density of the air

At medium frequency the sound pressure at r is:

$$|p(r)| = (e_g B1 (Q \rho_o c R_{MR})^{□}) / 2r (\pi^{□}(R_g + R_E)^{□}) (R_M^2 + X_M^2)$$

where:
c : the velocity of the sound in the air
Q: the directivity factor for one side of a piston in an infinite plane baffle

The quantities of ($R_M^2 + X_M^2$), R_{MR} and Q are the terms that vary with frequncy. These quantities determine the frequency response of the loudspeaker. The first two quantities depend on the material properties such as the Young's modulus, the internal loss and the density.

Materials and Methods

Fermentation production and purification. The culture medium was prepared by boiling coconut water, pH was adjusted to 4.0 by additing acetic acid solution, then the medium is inoculated with suspension of *Acetobacter xylinum*, and followed by incubated at room temperatur under static cultivation. It is harvested after periods of time. Membrane in a gel condition was taken from the surface of the culture medium, collected and washed with water until pH became neutral, then boiled in 2% NaOH solution to remove alkali-soluble components and to eliminate bacterial cellulose. The membrane was then washed with distilled water until the pH of water became neutral.

Improvement of the mechanical properties of biocellulose were achieved by purification methods before or after processing sheet using NaOH (0-12%) and / or NaClO (0-1%) solution.

Measurement of the mechanical properties. To find the best condition to prepare the biocellulose into sheet form prior to be used as a cone of loudspeaker diaphragm, the gel of biocellulose was pressed under various pressure (2.34-18.7 kgf/cm²) and temperature using hydraulic press machine model SA-302-1-S and GONNO 02326.

The mechanical properties, the Young's modulus (E) and tan δ, were measured using Rheolograph solid (Toyo Seiki LTD Japan) with frequency of 100 Hz at room temperature. The size of the specimen was 25 x 3 mm with an average thickness of 50-90 μm. Density (ρ) was measured with method of Grammatur. Sound velocity (V) was calculated from the quantities E and ρ as the square root of E divided by density ρ.

Preparation of the loudspeaker diaphragm. The moulds were constructed with size and shape similar to those of marketed cone loudspeaker with the diameter of 1 inch, 2 inch, and 4 inch, they were made of dural. The surfaces were coated with teflon after preliminary experiment had been done. Using this mould various diaphragms of loudspeakers were made at a pressure of 4.67 kgf/cm² and a temperature of 120°C. An hydraulic press machine, SA-302-1-S (diameter of 1 and 2 inch) and GONNO 02326 (diameter of 4 inch), were used for these purposes.

Two types of cone made of bacterial cellulose and paper were provided for the study of the acoustic properties:

1) The gel of biocellulose was soaked in 0.5% NaClO solution and followed washing completely with water until the pH became neutral. The gel of biocellulose was then processed into sheet by squeezing and pressing using the previous mould. The following step was treated the sheet with NaOH 7.5% solution (this condition is the best result in terms of the Young's modulus). And dried by hotpressed in the same way.
2) The cone paper of marketed loudspeaker is used as a reference without any additional treatment.

Measurement of the loudspeaker characteristics. The frequency response is one of the characterization of physical performance of a loudspeaker system. This character was measured by a Sound Level Meter equipment, RION NL 14, in an semi-anechoic room. The schematic diagram of the equipment set up is shown in Figure 2. The distance between the sound level meter and the loudspeaker was 1 m. A Pink Noise produced by a signal generator, RION SF 05, was injected into the loudspeaker. Sound radiated from the loudspeaker was received by Sound Level Meter and come next to FFT analyzer ONOSOKKI CF 305 Z.

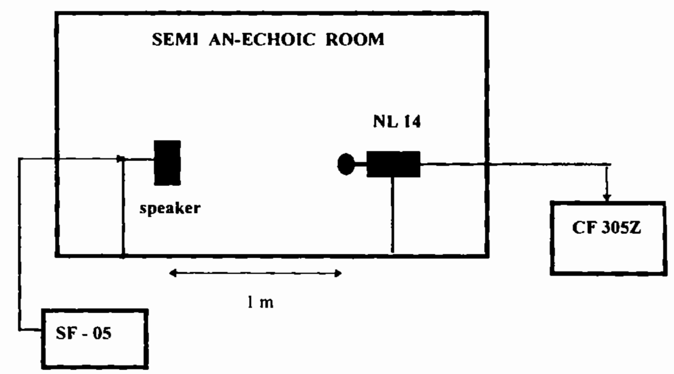

Figure 2. The diagram of the equipment set up for the measurement of the frequency response

Results and Discussions

The Young's modulus of sheets of biocellulose by purification with chemical treatment were obtained at various conditions. Treatment by soaking the biocellulose in 0.5% NaClO solution in the stage of gel, processed into a sheet and then treated with 7.5% NaOH is the best result. The Young's modulus has reached 23.5 GPa with an acoustic absorption property 0.02 (tan δ), sound velocity as high as 4522.67 m/sec and density in the range of 1 -1.5 gr/cm³. E and sound velocity of cone paper, however, are 6 GPa and 2369.15 m/sec, respectively, and both are far below the values for biocellulose sheets, also aluminium and titanium show very low tan δ, at most of < 0.01. Based on these data, biocellulose sheet prepared from coconut water fermentation has suitable characteristics as diaphragm transduser and it will be potentially applicable to make cone speaker. It means that the replacement of cone paper loudspeaker with a cone biocellulose is prospective.

Frequency response characteristics of each cone type loudspeaker made of bacterial cellulose are presented in Figures 3, 4, and 5.

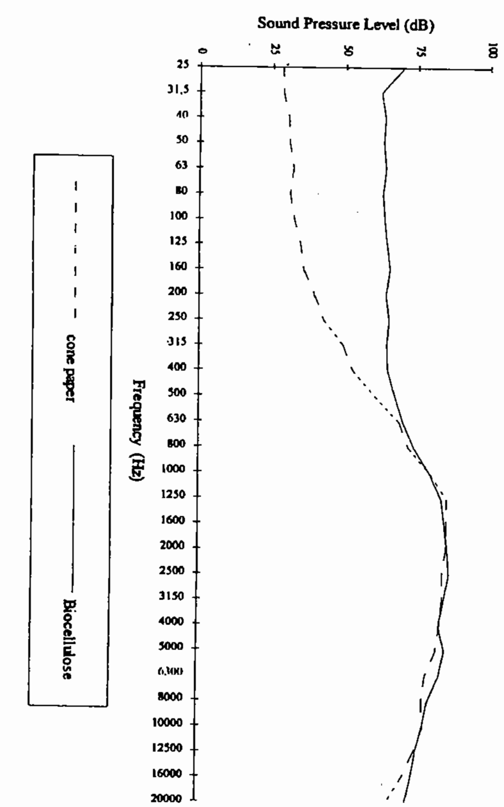

Figure 3. Frequency response of cone type loudspeaker with the diameter of 1 inch

Frequency response of cone biocellulose with diameter of 1 inch is 630 Hz - 20 kHz, diameter of 2 inch is 300 Hz - 5 kHz and for diameter of 4 inch is 200 Hz-10 kHz. From these data cone-type diaphragm prepared from biocellulose, product of coconut water fermentation, has a frequency response depended on the housing of the original loudspeaker. Probably the frequency response of the sheet can be as wide as 200 Hz to 20 kHz.

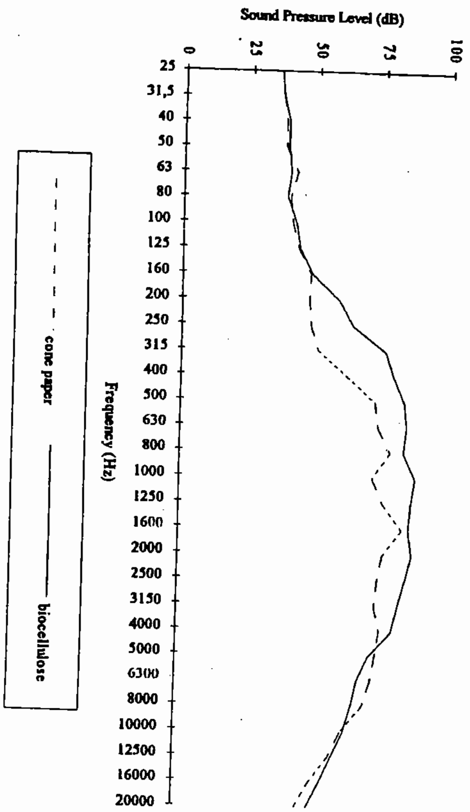

Figure 4. Frequency response of cone type loudspeaker with the diameter of 2 inch

Conclusion

The Young's modulus of sheet of biocellulose using a treatment mentioned in this paper has reached 23.5 GPa. The internal loss, density and sound velocity are 0.02, 1-1.5 gr/cm^3 and 4522.67 m/sec, respectively. The frequency response of the sheet can be as wide as 200 Hz20 kHz.

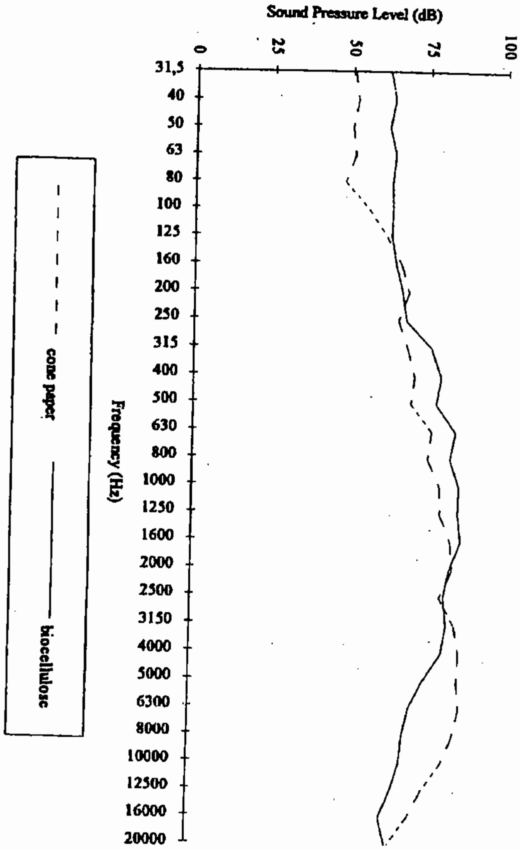

Figure 5. Frequency response of cone type loudspeaker with the diameter of 4 inch

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