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 delta of 0.02 (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 response of cone type loudspeakers made of bacterial cellulose shows that it has wide frequency range, from low to high.

Keywords: biocellulose - acetobacter - cone type loudspeaker

Introduction

Many materials such as paper, aluminum, 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 (Nishii et al., 1987).

Light metals such as aluminum 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 cellulotic material as an extracelluar 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 Iuguchi (Iuguchi 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 biocellulose as the diaphragm of cone speakers.

Theory

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

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

\[ p(r) = \frac{e_s \omega B L_s f_o}{(r R_g + R_s)(R_s^2 + \omega^2 M_s^2) + r^2 R_s^2} \]

where:

- \( p(r) \): the sound pressure at a distance \( r \)
- \( e_s \): the open-circuit voltage of the generator (audio amplifier) in volts.
- \( B \): the steady gap flux density
- \( L_s \): the length of wire
- \( R_s \): the generator resistance
- \( R_{mg} \): the resistance of the voice coil
- \( R_{mb} \): the resistance in the equivalent circuit which various frequency
- \( R_{mb} \): the mechanical resistance of the suspensions
- \( X_m \): the mass of the diaphragm
- \( X_m^* \): the reactance in the equivalent circuit
- \( C_m \): the total mechanical compliance of the suspensions
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 Grammaturo 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 hot pressed in the same way.
2) The cone paper of marketed loudspeaker is used as a reference without any additional treatment.

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 transducer 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.
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

Figure 5. Frequency response of cone type loudspeaker with the diameter of 4 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, 1.15 gr/cm² and 4522.6 m/sec, respectively. The frequency response of the sheet can be as wide as 200 Hz to 20 kHz.

References


Abstract

Eight of cellulosic microbe isolates selected were used in this study (D-1, D-4, D-8, D-11, B-1, C-6, H-5 and H-6). The objective of this study is to analyze the affinity (Km) of carboxyl methyl cellulose (CMC-one) and β-glucosidase with carboxyl methyl cellulose (CMC) and nitrile phenyl glucopyranoside (NPG) as substrate respectively and their maximum velocity (Vmax) in the optimum condition.

The result showed that isolate D-8 produced the highest cellulase activity (β-glucosidase was 85.4365 ug o-nitropheno/ mg protein/hour, CMCase and YPase activities were 37.69 and 0.61 ug glucose/mg protein/hour respectively). The enzyme was partially purified with ammonium sulfate (100% saturation). Optimum activity of β-glucosidase was obtained at temperature 50°C and pH 5.0, while for CMCase was 50°C and pH 5.5. On the other hand, optimum activity of YPase was obtained at temperature 45°C and pH 6.0. At the optimum condition, β-glucosidase had a Vmax value ca. 14.99 ug o-nitrophenol/mg protein/minute and a Km value of 0.7106 % or 0.0711 g/l, while CMCase had a Vmax value ca. 3.93 ug glucose/mg protein/ minute and a Km value of 0.039 % or 0.1031 g/l.

Keywords: Cellulosic microbe – Rumen of buffalo – cellulases

Introduction

The cellulase has been established that (a) the system is multi-enzymatic, (b) at least three enzyme components are both physically and enzymatically distinct, and (c) all three components play essential roles in the overall process of converting cellulose to glucose. Three components of the cellulase is the C₆ (exoglucanase), C₅ (endoglucanase) and β-glucosidase (Reese, 1975; Stutzenberger, 1985; Lowe, 1986). The C₆ component is required to attack crystalline cellulose. It has been examined to be a crystalline attacking enzyme.

One of the factors that determines the productivity of ruminants is how the animals have capability to utilize crude fiber as energy sources. It means that performance of ruminants depends on the activity of cellulase produced by their rumen microbe. Buffalo is ruminant having good capability in utilization of crude fiber as energy sources compared to other ruminants. Therefore