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Determination of the Bulk Modulus of Some Animal Skins Using Acoustic Method

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Abstract: This paper seeks to measure the bulk modulus of some selected animal skins using acoustical method, by determining some physical properties of the skins, to see how they could be used for drum head. From the findings, it was found that the bulk modulus of skins using acoustic method depends on the velocity of sound that the skin can transmit and the density of the skins. Skins with very high ability of transmitting sound through them has high density, hence has high bulk modulus, showing the stiffness of the skin and those with low bulk modulus are flexible and have lesser density. The flexible skins can be used for drumhead so that its tones can be changed when pressure is applied.

Keywords: Bulk Modulus, Animal Skin, Acoustic Method, Physical Properties, Drumhead, Velocity, Density

1. Introduction

The animal skin for several decades has served so many purposes for humanity. The use of animal skin in our society is so obvious and cannot be argued at all. Right from the inception of time, man has depended so much on the use of animal skin for several works. To mention but a few of some of the animal skin today are the use of animal skin for making of shoes, bags, belts and the likes. The use of animal skin for food as meat, the use of animal skin for musical instruments, such as drum head of drums, and the use of animal skin for some special clothing's [14].

Man has explored much from the animal skin and it has helped him solve so many problems, which other membranes could not serve effectively.

Soft tissues generally exhibit nonlinearity, nonhomogeneity, anisotropy and viscoelasticity. Viscoelastic materials present some difficulties for characterising their mechanical response. Energy storage and dissipation within the complex molecular structure produces hysteresis and allows creep and relaxation to occur. Soft tissues are relatively compliant at low strains and become dramatically stiffer at high strains [11]

1.1. Stress and Strain

The change in the dimension of a body produced by system of forces in equilibrium is called a strain and its character will evidently depend on the nature of the force (load) system producing it. The later is called the stress and is always measured by the applied force per unit area of the body. The method of measuring the strain varies according to its character [1].

Considering the long skin, sliced in a form of a long wire is clamped at its upper end and loaded at the bottom. An increase in the load produced and elongation of the animal skin (wire). If however a body is uniformly compressed in all direction, it will be unaltered in shape if it is isotropic, that is, it is elastic properties are uniform in all direction, but it undergoes a change in volume, and strain is measured by the alteration in volume, per unit volume of the original body [3].

When Hook's law is obeyed, an increase in pressure (bulk stress) produce a proportional bulk strain (fractional change in volume) hence the ratio of bulk stress to bulk strain is called Bulk Modulus [11]

When a body is subjected to the mutually perpendicular like and equal direct stresses, the ratio of direct stress corresponding to the corresponding volumetric strain is found to be a constant for a given material when the deformation is within a certain limit. This ratio is known as bulk modulus and is usually denoted by B [12].

1.2. Physics of Drums

A percussion instrument is any instrument that produces sound by being hit with an implement, shaken, rubbed, scraped, or by any other action which sets the object into vibration. Drum belongs the family of percussion instrument known as membranophones.

1.2.1. Vibrations of the Drumheads

The most obvious parts generating sound in drums are the drumheads. A vibrating Drumhead is a complex physical system and to understand its behavior, it is useful to start with a simplified model – the ideal circular membrane.

The Ideal Circular Membrane

An ideal circular membrane is defined by its diameter d [m], surface tension T [N/m] and superficial density [kg/m^2]. Attributes like bending stiffness or a non-uniform material density are neglected in this model.

The vibrational behavior of an ideal circular membrane, fixed at its circumference, is well known. When excited, the membrane vibrates with a superposition of *modes* of order (m, n), where m defines the number of *nodal diameters* and n the number of *nodal circles* including the circular boundary. These nodal lines and circles are defined as regions, where the displacement of the membrane for the particular mode is minimal.

Real Membranes

The model of the ideal membrane neglects two major influences: the properties of the membrane material and the environment, i.e. the air surrounding the vibrating membrane. The vibration of a membrane leads to a bending and shearing of the material. A real membrane will resist this elastic deformations to a certain degree due to the thickness and properties of the membrane material. This resistance is called *bending stiffness* and *stiffness to shear* and will in general raise the modal frequencies of the membrane. Adding to this effect, any irregularity in the material can alter the modal structure. In modern drumheads for example, additional rings or layers of mylar on the membrane are used to specifically create irregularities in the membrane structure. These modifications then dampen or shift certain frequency modes and influence the sound of the drum, e.g. make it more harmonic.

Concentrating on thin, single-layered membranes, another effect plays a more dominant role – *air loading*. This term describes the fact that the membrane interacts with the surrounding air when it is vibrating. Air that is moved by the membrane, can affect the frequency of the resonance modes in two possible directions. The mere presence of air around a membrane causes a *lowering* of the modal frequencies. In contrast, an air volume confined by a second membrane or a closed drum kettle will *raise* the frequencies, especially of the circular modes. In practice, the effect of air loading can be observed in the sound of the kettle drum or *timpani*: the enclosed air volume of the timpani's kettle is responsible for a shifting of modes which results in a nearly harmonic ratio of modes and gives the sound of the timpani a defined pitch and the frequencies of the membrane's vibrational Modes depend on the size, density, and tension of the membrane.

2. Materials and Method

The speed of sound in a material can be determined by making use of the acoustic impedance tube. This is a special apparatus used in determining how sound are absorbed by different materials in acoustic field.

2.1. The Bulk Modulus of a Material

The bulk Modulus of a material is given as;

$$Bulk\ Modulus\ (B) = \frac{Bulk\ stress}{Bulk\ strain}$$

$$B = \frac{-\Delta P}{\frac{\Delta V}{V_o}}$$

Where ΔP is change in pressure, ΔV is change in volume and V_o is the initial or original volume

2.2. Bulk Modulus and Its Relationship to Acoustic Velocity

As shown above, the Bulk modulus of any material is given as $B = \frac{-\Delta P}{\frac{\Delta V}{V_o}}$

Now let ΔP (stress) be represented by Ƞ and $\frac{\Delta V}{V_o}$ (strain) be represented by, so that the relationship between the three parameter can be written as:

$$\eta = B\beta \text{ or } B = \frac{\eta}{\beta}$$

Most of the solids and liquids which are visco-elastic, the relationship that exist between stress and strain are non-linear [2]. For instance, if a low intensity ultra sound is used, the material response almost linearly to the stress (in this case change in pressure). In general, the speed of sound C is given as $C = \sqrt{c/\rho}$

Where, c is the coefficient of stiffness and ρ is the density of the material. The speed of sound increases with the stiffness of the material and decreases with the density of the material. In volume medium, the wave speed takes the general form

$$C = \sqrt{(elastic\ property)/(initial\ property)} = \sqrt{B/\rho}$$

2.3. Density of Skin

To be able to determine the density of the skins, the mass of each of the skin ought to be known and the volume as well. Hence each of the skin cut in spherical shape was weighed in a chemical balance to determine their masses and a meter rule was used to measure the diameter of each of the skins [8]. The result obtained is as tabulated Table 2.

Density ρ is determined thus;

$\rho = \frac{m}{v}$; where m is mass and v is the volume

Volume of a sphere is given as $V = \frac{4}{3}\pi r^3$.

3. Equipment and Set-up

Each of the animal skin is placed at the sample holder of the acoustic impedance tube. At a given frequency, the microphone is pulled until maximum amplitude of a sin wave is seen at that point; the position of the microphone is taken from the scale on the tube. The microphone is again pushed backward to obtain the minimum amplitude of the sin wave at this point again; the position of the microphone is also taken from the scale on the tube. The amplitude is seen and read from the oscilloscope. The amplitude is measured by measuring the height of the amplitude of the sin wave from the oscilloscope. This whole process is repeated several times at different frequencies, ranging from 300 to 600Hz, for all the four skins and the result tabulated.

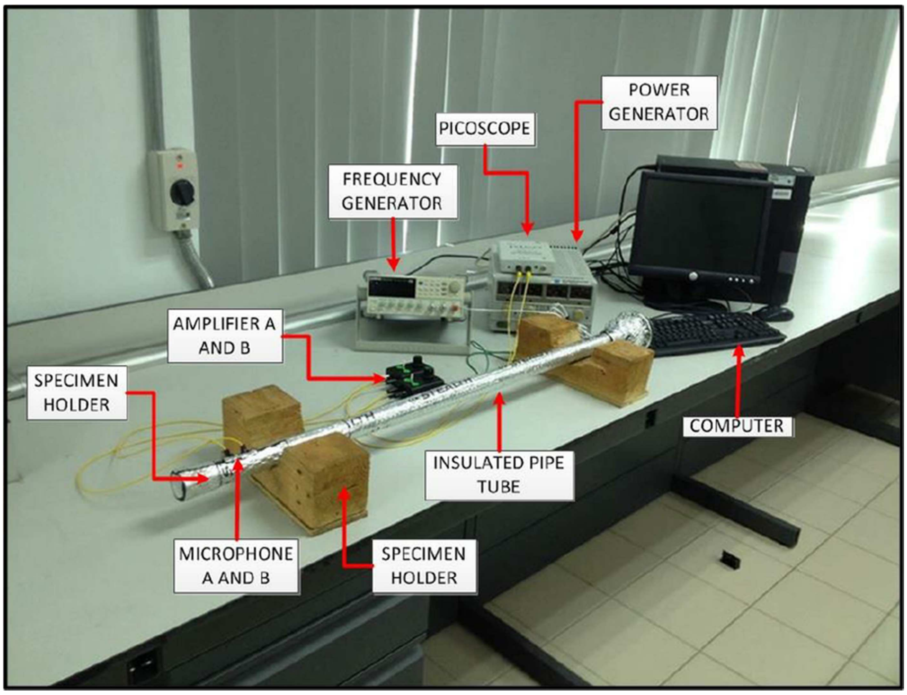

Figure 1. *Experimental set up.*

4. Determination of Bulk Modulus and Results

4.1. Determination of the Bulk Modulus Using the Speed of Sound

The Bulk Modulus of the animal skin can now be determine by using the equation for speed of sound and relating it to the wave length of the wave and the frequency of the wave.

4.2. Finding the Bulk Modulus of Skin

From the well-known general sound equation given as;

$C^2 = \frac{B}{\rho}$, where 'B' is the Bulk modulus of elasticity of the skins, 'C 'is the speed of sound of the skins, ρ is the density of the skin [8]. Since the bulk modulus of elasticity of the skins cannot be determined directly, the speed of sound of each of the skin was first determined by using the acoustic impedance tube.

4.3. Finding the Velocity of Sound of the Skins

Let X_1, X_2 represent Maximum and Minimum position respectively and the difference between the two position taken as $\Delta X = X_2 - X_1$.

It is well known that the speed of sound is related to frequency by;

$$f = \frac{c}{\lambda},$$

where

$$\Delta X = X_2 - X_1 = \lambda,$$

Therefore, $\lambda = \Delta X$

Hence $f = \frac{c}{\Delta X}$

Thus plotting f against $\frac{1}{2}\Delta X$, gives a straight line graph whose slope is the velocity of sound (c) in each of the skins.

The tables below shows the detail of measurements and summary of some calculations

4.4. Results from Measurement

The results of the measurements made are as tabulated in table 1-4 below and the graph for each animal skin is also shown in figure 2-5 below.

Table 1. *Acoustic impedance tube measurement.*

SKIN	Freq. (Hz)	Maximum Amp.(mV)	Minimum Amp.(mV)	Maximum position (cm)	Minimum position (cm)
Goat	300	0.10	6.0	62.8	36.8
	400	0.36	14.0	51.6	30.3
	500	0.40	10.0	42.8	25.8
	600	0.28	8.0	35.6	21.2
Sheep	300	0.14	10.0	63.9	37.7
	400	0.44	12.0	51.8	30.2
	500	0.54	12.0	42.8	25.8
	600	0.32	8.0	36.7	22.8
Crocodile	300	0.12	16.0	63.9	38.4
	400	0.40	14.0	51.3	29.8
	500	0.54	12.0	42.3	25.7
	600	0.32	7.0	37.3	23.1
Alligator	300	0.14	5.5	63.8	37.9
	400	0.40	10.0	49.7	29.9
	500	0.50	20.0	41.6	25.7
	600	0.48	12.0	37.4	22.9

Table 2. *Skin mass and dimension.*

SKIN	Mass (g)	Diameter (mm)	Radius (mm)
Alligator	1.8978 ± 0.001	6.8 ± 0.05	3.40 ± 0.05
Sheep	1.6615 ± 0.001	6.9 ± 0.05	3.50 ± 0.05
Goat	1.6938 ± 0.001	6.9 ± 0.05	3.50 ± 0.05
Crocodile	5.3242 ± 0.001	6.9 ± 0.05	3.50 ± 0.05

Table 3. *Density of animal skins.*

SKIN	Density (kg/m^3)
Alligator	11527
Sheep	9251
Goat	9432
Crocodile	19624

Table 4. *Measurement for each graph.*

Skin	Frequency (HZ)	ΔX(mm)	$\frac{1}{2}\Delta X\ (m^{-1})$
Goat	300	31.0 ± 0.001	1.610
	400	19.8 ± 0.001	2.530
	500	15.5 ± 0.001	3.230
	600	14.5 ± 0.001	3.450
Sheep	300	24.4 ± 0.001	2.050
	400	20.8 ± 0.001	2.300
	500	16.6 ± 0.001	3.010
	600	13.6 ± 0.001	3.680
Crocodile	300	24.0 ± 0.001	2.080
	400	21.3 ± 0.001	2.350
	500	16.6 ± 0.001	3.010
	600	13.9 ± 0.001	3.600
Alligator	300	25.5 ± 0.001	1.960
	400	20.6 ± 0.001	2.430
	500	16.6 ± 0.001	3.010
	600	14.2 ± 0.001	3.520

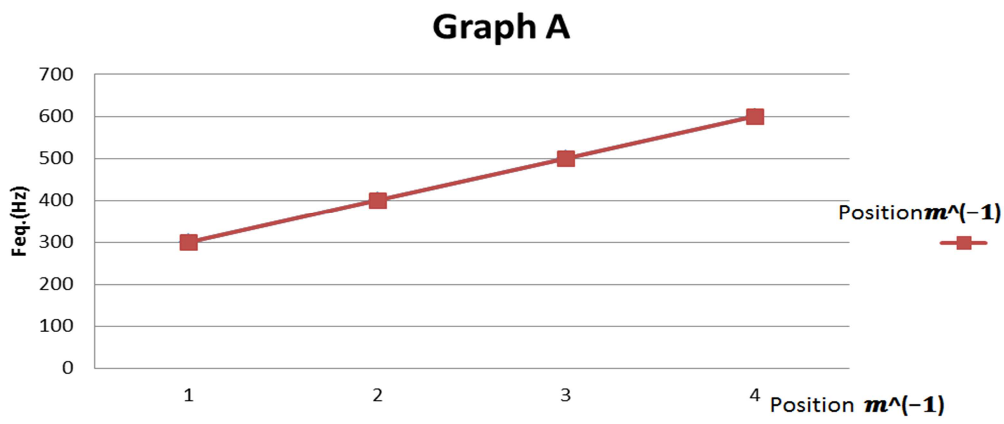

Figure 2. *Graph A (Graph for Goat skin).*

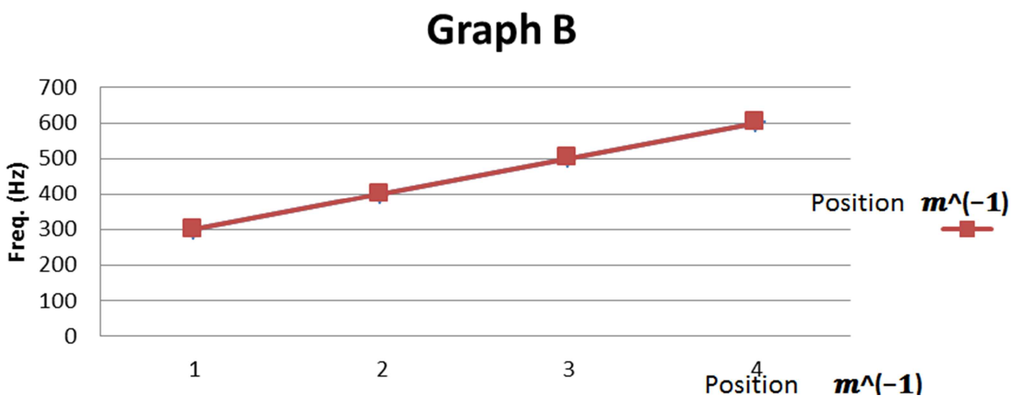

Figure 3. *Graph B (Graph for Sheep skin).*

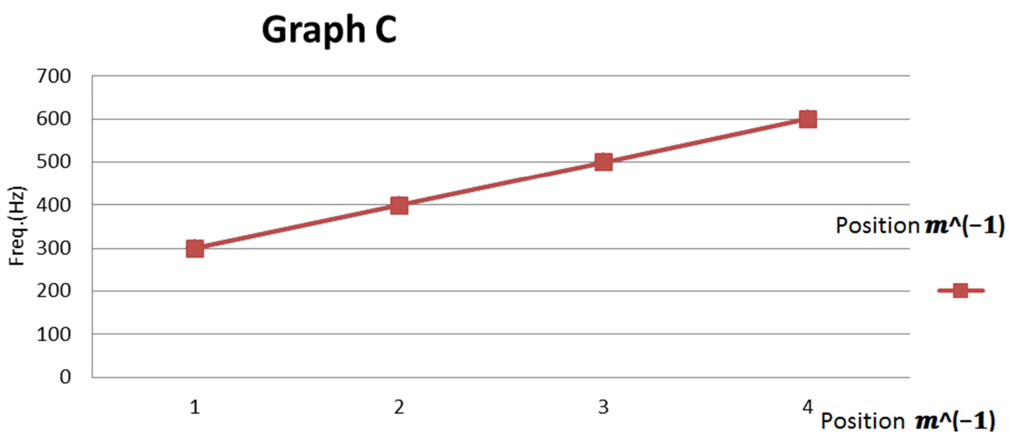

Figure 4. *Graph C: (Graph for Alligator Skin).*

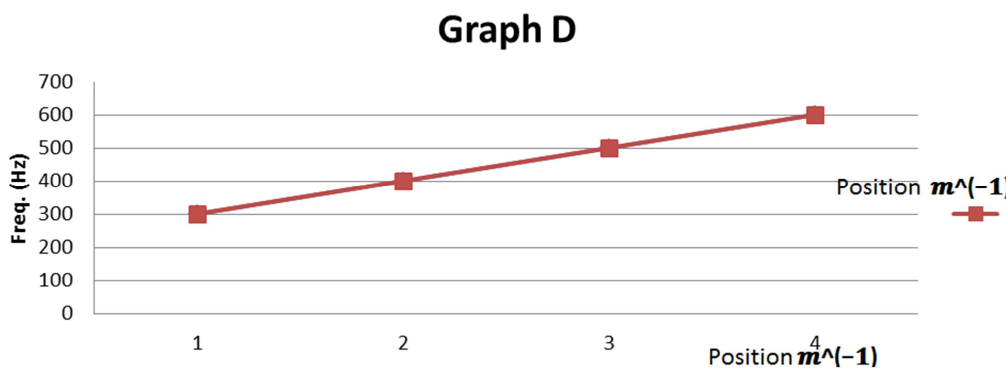

Figure 5. *Graph D: (Graph for crocodile skin).*

4.3. Slope of Graph A-D

From all the graph above; f plotted against $\frac{1}{2}\Delta X$ (m^{-1}) for each skin the following slope was obtained

i. goat skin C_g = 1809.476 m/s
ii. sheep skin C_s = 1787.864m/s
iii. crocodile skin C_c = 1840.476m/s
iv. Alligator skin C_a = 1730.512 m/s

The speed of sound in this skins are a bit high because they were stretched and warmed to increase the temperature, this help to get louder sounds in drums.

4.4. Summary of Results

Using the formula for speed, density and Bulk Modulus as shown above yields the following result as summarized in the table below

***Table 5.** Summary of Result.*

SKIN	Speed (m/s)	Density (kg/m^3)	Bulk Modulus (N/M^2)
Sheep	1787.864	9251	29.570 x 10^9
Goat	1809.476	9432	30.882 x 10^9
Alligator	1730.512	11527	34.520 x 10^9
Crocodile	1840.476	19624	66.473 x 10^9

Different material transmits sound wave at different speed (velocity) and velocity in some materials, particularly plastics and skin varies with temperature.

5. Discussion of Result

Skin that has very high ability of transmitting sound through them and also have high density will eventually have high bulk modulus, showing that such material is stiff. And those with low bulk modulus are flexible and have lesser density. From the four skins selected and tested, we saw that sheep skin has the lowest bulk modulus, showing that it's more flexible, hence more elastic than the rest, while Crocodile has the highest Bulk modulus due to its thickness which contributed to its large value of density and subsequently to its Bulk modulus.

The elasticity of animal skin has a lot to do with what you want to use it for. Drum heads falls under percussion instrument and the drum head vibrates and extends into two dimensions, hence bulk modulus of skin determine the resonance frequency of the drumhead as this has to do with the vibration of skin when stroke or tapped.

6. Conclusion

In this paper the Bulk Modulus of some animal Skins was determined using acoustic method, from our findings, Bulk modulus of any material depends on how fast sound can travel through a materials and its density.

Having studied the elasticity of the physical properties of some few skins, we will like to recommend flexible skins like that of goat and sheep for drumhead that can change tones when pressure is increased, and hard skins like those of Crocodile and alligator, their lower abdomen could be used for home carpet, industrial foot wears and Belts.

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