INVESITIGATION OF SOUND PROPAGATION THROUGH VARIOUS MATERIALS.

BY

MUGOMBESHA IBRA

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THIS RESEARCH IS TO BE SUBMITTED TO BUSITEMA UNIVERSITY, FACULTY OF SCIENCE AND EDUCATION, NAGONGERA CAMPUS, TO THE DEPARTMENT OF PHYSICS, FOR AN AWARD OF A BACHALORS DEGREE

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DECLARATION.

"I declare that this research is my original work and has not been previously submitted for publication anywhere. I confirm that all sources used in this research have been properly cited and referenced.

Signature:………………

Name: MUGOMBESHA IBRA

Date: 28th/10/2024"

SUPERVISOR'S DECLARATION.

"I ......ANDIMA GEOFFREY......, certify that:

The work presented is original and has been conducted under my guidance.

Signature:..................

Name:...Dr. Andima Geoffrey

Title:...Senior lecturer

Date:...28/10/2024

DEDICATION.

I dedicate this research to my friends, and classmates who maybe interested in the further study of waves.

I also dedicate this research to my family members who financed me during the study.

ACKNOWLEDGMENTS.

I thank God who enabled me through this course and all the experience I have obtained at this level.

I also thank my supervisor, Dr. Andima Geoffrey, for his guidance through all the activities during this research.

I whole heartedly thank my parents who hustled to pay me tuition to attain this degree. I thank and love you so much.

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ABSTRACT.

The propagation of sound waves through various materials is a fundamental aspect of acoustics, impacting numerous fields from architectural design to material engineering. This study explores the mechanisms by which sound waves travel through different media. The research focuses on how material properties such as density and porosity influence sound absorption, reflection and transmission. Experimental methods are employed to measure and simulate sound propagation, providing insights into the acoustic behavior of materials. The findings reveal that material density and structure significantly affect sound wave behavior, with denser materials generally slowing down propagation. The results contribute to the development of advanced materials with tailored acoustic properties for specific applications, offering potential improvements in noise reduction and sound quality in various environments. This abstract encapsulates the essence of the research highlighting its significance and potential application of its findings.

CHAPTER ONE: INTRODUCTION.

1.1 BACKGROUND

Sound is a form of mechanical wave that propagates through a medium by inducing local variations of pressure and density. The propagation of sound is affected by the properties of the medium such as the material's speed of sound, density as well as by the presence of obstacles such as boundaries and objects that may absorb the sound.

Sound absorption is the study of how sound waves lose some of their energy as they pass through a material. The absorbed energy is usually converted into or other forms within material. Sound absorption can reduce intensity and loudness.

Sound absorption can help us design devices and systems such as sound proofing and noise reduction. It can help us explore and monitor the natural world such as the atmosphere, the ocean and biosphere.

Sound absorption can help us to enhance and protect human health and well-being, such as improving speech and music perception, reducing noise pollution and diagnosing and treating diseases.

The research is an active and evolving field that faces many challenges and opportunities in the face of new technology, new demands and demands.

One of the most promising directions of sound absorption is the use of locally available materials that can manipulate sound waves.

These materials can realize ideal absorbers that can absorb sound waves of any frequencies, direction and polarization with almost perfect efficiency.

1.2 PROBLEM STATEMENT.

Sound pollution is a major environmental and health issue that affect many urban areas in Uganda.

Exposure to high levels of noise can cause hearing loss, stress, sleep disturbances and reduced productivity.

Sound absorption is the process of reducing level of sound in a room by absorbing sound waves. Sound absorbing materials are typically lightweight and porous and designed to trap sound waves.

However, most absorbing materials available in market are expensive, imported and synthetic which limits their accessibility and sustainability.

There is need to explore potential of local materials that can be used for sound absorption. These materials are cheap, abundant and biodegradable and may offer comparable or better performance than synthetic materials.

1.3 AIM.

- ✓ Investigate the propagation of sound through various materials.

1.4 OBJECTIVES.

- ✓ To determine physical properties of the materials such as density and porosity.
- ✓ To determine the absorption of sound by the materials.

1.5 SIGNIFICANCE OF THE STUDY.

The study will offer practical and sustainable solutions for sound pollution which is a major environmental and health issues.

Provide valuable information on the acoustic properties and performance of local materials for sound absorption.

The study will contribute to existing literature on sound engineering and environmental management by exploring potential of cheap, abundant and biodegradable materials that can reduce or absorb unwanted noise.

The study will also help in future studies by providing comprehensive database of acoustic properties and performance of the local materials for sound absorption, which can also be used as a reference for future research.

CHAPTER TWO: LITERATURE REVIEW.

2.1 INTRODUCTION.

Propagation of sound through various materials is a phenomenon that has many applications and implementations in different fields such as acoustics. Sound is a form of mechanical wave that travels through an elastic medium by causing vibrations of the particles of the medium. Propagation depends on several factors such as frequency, wavelength, amplitude and speed of sound and density, elasticity and geometry of the medium. Different materials have different properties that affect the propagation of sound such as absorption and transmission. Understanding how sound propagates through materials can help to design and optimize sound insulation, sound absorption and quality systems and devices.

2.2 BODY

The main research question of this literature review is: How does sound propagate through various materials and what are the factors and mechanisms that influence the propagation of sound. The purpose of this review is to provide a comprehensive and critical overview of the existing research on the propagation of sound through various materials and to identify the current knowledge gaps and challenges. The scope of this review is limited to propagation of sound through…

The objectives of this review are to

Summarize and evaluate main theories, methods and experiments used to study propagation of sound through the various materials.

Analyze and discuss the effects and roles of various factors and parameters such as frequency, thickness on propagation of sound through the materials

Synthesize and highlight the main findings and implications of the existing research for the field of study.

Identify and address the limitations, gaps and challenges of the existing research and suggest some directions and recommendations for future research.

The criteria and methods for selecting and analyzing the sources for the review are as follows

The sources are peer-reviewed journal articles, books and chapters published in English between 2000 and 2024.

The sources are relevant to the topic and research question and provide sufficient and reliable information and evidence.

The sources are searched and retrieved from the following databases: Google scholar, web of science and science Direct using the following keywords and phrases: propagation of sound, sound propagation, sound absorption, sound waves, sound frequency, sound energy, density, sound absorption loss.

There are several theories and models that explain and predict sound propagation through various materials based on different assumptions and simplification. Some of the common ones are;

Wave equation. This is a partial differential equation that describes the propagation of sound waves in homogenous and isotropic medium. It relates the sound pressure and the pressure at any point in the medium. The wave equation can be derived from conservation of mass and momentum and equation can be solved analytically for some geometrics and boundary conditions or numerically for more complex ones.

The sound intensity and pressure. These are two important quantities that characterize the sound field in the medium. The sound intensity is the rate of energy transfer per unit area in the direction of propagation and the sound pressure is the deviation of the local pressure from the ambient pressure due to the sound wave. The sound pressure and intensity are related by the sound impedance which is ratio of the sound pressure to sound velocity. The sound impedance depends on the properties of the medium such as density and sound speed.

Sound speed and impedance. These are two important parameters that describe the properties of the medium for sound propagation. Sound speed is the speed at which sound travels in the medium and it depends on elasticity and density of the medium. Sound impedance is the ratio of sound pressure to sound velocity and it depends on sound speed and density of the medium. The sound speed and impedance affect reflection, transmission, absorption, scattering and diffraction of sound waves at interfaces between different media.

The reflection, transmission, absorption. These are phenomena that occur when sound waves encounter boundaries in the medium. Reflection is change in direction of sound when it hits a surface and it depends on the angle of incidence and impedance contrast between the two media. Transmission is the passage of sound waves through a surface and it depends on the angle of incidence and impedance ratio between the media. The absorption is the conversion of sound waves into heat and other forms of energy in the medium and it depends on the frequency and the material properties. The scattering is redirection of sound waves in multiple directions due to the presence of irregularities in the medium. The diffraction is the bending of sound waves around edges and it depends on the wavelength and geometry of the obstacles.

The acoustic parameters of different materials. These are the parameters that quantify sound absorption, transmission and insulation properties of different materials such as sound absorption coefficient, sound transmission loss and sound insulation index. The sound absorption coefficient is the fraction of the incident sound energy that is absorbed by the material and it varies with frequency and material properties. The sound transmission loss is the difference between the sound intensity levels on the sides of the material and it varies with the frequency, the material properties and the thickness. The sound insulation index is the measure of sound insulation performance of the material and it is calculated from the sound transmission loss over a range of frequencies.

Some experimental methods for sound propagation through various materials are;

The impedance tube method. This uses a cylindrical tube with a loud speaker at one end and two microphones at other ends. The sound waves are generated by the loud speaker and reflected by the material sample placed at the end of the tube. The sound pressure and intensity are measured by the microphones and used to calculate the sound absorption coefficient and sound transmission loss of the material.

Reverberation chamber method. This method uses a large room with diffuse sound field and high reverberation time. The material sample is placed in the chamber and the sound level measured before and after the insertion of the sample. The difference in sound level is used to calculate sound coefficient and sound power of the material.

The anechoic chamber method. This method uses a room with no sound reflection and no background noise. The material sample is placed in the chamber and sound is emitted by the sound speaker and received by a microphone. The sound pressure and intensity are measured and used to calculate the sound transmission loss and sound insulation index of the material.

Some examples of the review of results for sound propagation through various materials are;

Zarastvand et al reviewed more than 200 articles on sound insulation characteristics of plate structures from 1967 to2020. They classified and organized the articles based on the structures, types of materials, boundary conditions, type of incident field, solution techniques and the optimization and control procedures. The also provided some appropriate descriptions, basic equations and generalities in this field.

Rastegar et al reviewed the sound absorption in materials with specifically related properties such as sound absorption coefficient, sound absorption mechanisms and types of metallic and non-metallic sound absorbing foams. They also summarized various kinds of porous kinds of porous polymeric materials and focused on polyurethane composite foams with more details. They discussed the effects of various additives, such as nanoparticles, synthetic and material fibers on the acoustic properties of polyurethane foam formation methods with their advantages and disadvantages.

Kaur et al evaluated the effectiveness of sound proofing materials among various frequencies. They tested four different materials: drywall, insulation, vinyl and cloth. They measured the sound pressure level before and after the insertion of the material and calculated the sound transmission loss and sound reduction index. They found that a combination of drywall, insulation, and vinyl or cloth was the effective in sound proofing.

Zhang et al evaluated sound propagation, absorption and insulation performance of sandwich structures with different core materials and configurations. They used the wave propagation approach to model the sound transmission through the sandwich structures and validated their results with experimental data. They analyzed effects of core material, core thickness, core shape and core arrangement on the sound absorption coefficient and sound transmission loss of the sandwich structures.

Lian et al synthesized highly porous yet transparent mechanically flexible aerogels with excellent solar thermal regulatory cooling performance. They used the finite-difference time-domain method to simulate the sound propagation through the aerogels and measured the sound absorption coefficient and sound transmission loss of the aerogels. They found that the aerogels had good sound absorption and insulation, especially at low frequencies.

The sources are screened and evaluated based on their title, abstract and full text, and most relevant and useful sources are selected and included in the review. The sources are analyzed 48and synthesized using thematic approach, based on the objectives and aspects of the review. The sources are summarized and evaluated in terms of their main arguments, findings, strengths, weaknesses and implications and contrast with other sources. The sources are cited using the APA referencing style.

Sound propagation through various materials is influenced by various factors such as frequency, intensity and direction of sound, the shape, size and the materials of the objects that interact with the sound and properties of the medium such as density, temperature, viscosity and inhomogeneity.

Some of the main challenges and gaps that need to be addressed in the future are;

The improvement of the experimental methods and equipment that can measure and characterize the sound propagation through various materials with higher precision, resolution and repeatability and that can reduce the sources of uncertainty and error such as the background noise, leakage and the calibration.

The optimization and control of the sound propagation through various materials by using different techniques such as the active and passive control, the smart materials and the metamaterials and by considering different criteria such as sound quality, the energy efficiency and the environmental impact.

2.3 CONCLUSION

This literature review has provided a comprehensive and critical overview of the existing research on sound propagation through various materials. It has covered the theoretical background, the experimental methods and the overview of results of previous studies on this topic. It has also identified the knowledge gaps and research challenges and suggested some possible directions and recommendations for future research.

CHAPTER THREE: METHODOLOGY

3.1 HYPOTHESES.

Material density hypothesis

The density of the material is inversely proportional to the speed of sound propagation through it, with denser materials slowing down the sound wave.

1. Material structure hypothesis.

   The internal structure of the material including its porosity and grain alignment significantly affects its ability to absorb or transmit sound waves.

2. Frequency response hypothesis.

   Different materials will have varying frequency response profiles with some materials alternating high frequencies more effectively than low frequencies.

3. Material thickness hypothesis.

   The thickness of a material directly influences its sound insulation properties with thicker materials providing greater attenuation of sound.

4. Composite material hypothesis.

   Composites with layered structures will exhibit superior sound insulation due to multiple reflections and absorptions occurring at the interfaces of different materials.

   These hypotheses can be tested through a combination of experimental measurements. The results of such studies can lead to a better understanding of how sound interacts with different materials, which is essential for applications in acoustics, noise control and material design.

3.2 DETERMINE PHYSICAL PROPERTIES OF THE MATERIALS.

3.2.1 DENSITY.

The following steps were taken in determining the density of the materials;

1). Measure the dimensions. A ruler and a Vernier calipers were used to determine the length, width and thickness. All the measurements were in meters.

2). The measurements were multiplied to find the volume in cubic meters.

3). The materials were weighted, to obtain their masses, each at a time, and recorded in meters.

4). Volume was divided by the mass of the materials to obtain their densities.

Density = mass / volume

3.2.2 POROSITY.

Experimental calculation by saturation.

1). Saturate the sample. The sample was fully saturated with a fluid of known density.

2). Weigh the sample. The sample was weighed before and after saturation.

3). Calculate pore volume. Pore volume was calculated by using weight differences and fluid density.

4). Calculate porosity. Using the pore volume and total volume, porosity was calculated from

$$V_V = ((V_T - V_S) / V_s) * 100\%$$

Since porosity is dimensionless.

3.3 DETERMINE ABSORPTION OF SOUND WAVES BY THE MATERIALS.

3.3.1 MATERIALS.

- ✓ Wood.
- ✓ Piece of cloth.
- ✓ Egg carton
- ✓ Sponge.

These materials were chosen for their diverse physical properties, which affect sound propagation in various ways.

3.3.2 APPARATUS.

- ✓ Signal generator.
- ✓ Cathode Ray Oscilloscope (CRO).
- ✓ A microphone.

3.3.3 PRECAUTIONS.

- ✓ Ensure the volume of the sound source is at a safe level to prevent hearing damage.
- ✓ Secure all equipment to prevent accidents.
- ✓ Ensure enclosure of the experiment through using an isolated room, monitoring sound levels, and use of an enclosure.

3.3.4 EXPERIMENTAL SETUP.

Figure 3.1 showing the setup of the experiment.

3.3.5 PROCEDURE.

1). The materials were gathered and prepared, with similar dimensions for consistency in testing.

2). The signal generator was connected to the sound source. It was set to generate a pure tone of frequency.

3). The microphone was set at a fixed distance from the loud speaker. It was connected to the CRO for visualization of results.

4). A sample was selected and placed between the speaker and the microphone. The signal generator was activated to emit the sound waves and observe the wave forms.

5). The amplitude and frequency of the waves that passed through the sample were recorded.

6). The experiment was repeat with other samples replacing the previous sample with other samples, one at a time. For each sample, the changes in the waveforms on the CRO were recorded.

7). Sound absorption was analyzed. The waveforms for each material were compared to analyze how they absorb or transmit sound. All changes in amplitude, frequency or wave shape were noted.

8). Control variables. The volume of sound source, the distance between the loud speaker and microphone and the environmental conditions throughout the experiment were kept constant.

9). Document results. The wave form characteristics for each material were noted. The data was used to draw conclusions about sound propagation properties for each material.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. PHYSICAL PROPERTIES OF THE MATERIALS

4.1.1 Density.

The masses of the materials were determined using a digital mass scale.

Wood = 0.90 g = 9×10^{-4} kg

Piece of cloth = 0.85 g = 8.5×10^{-4} kg

Egg carton = 0.83 g = 8.3×10^{-4} kg

Sponge = 0.4 g = 4×10^{-4} kg

The materials were of similar dimensions and therefore they had the same volume.

Breadth = 1×10^{-3} m

Width = 92×10^{-3} m

Length = 92×10^{-3} m

The volume was obtained from:

V = length x width x breadth.

= $92 \times 10^{-3} \times 92 \times 10^{-3} \times 1 \times 10^{-3}$

= 8.464×10^{-6} m^3

The density of the materials was then obtained from:

$$\boldsymbol{D = M/V}$$

Density of wood = $9 \times 10^{-4} / 8.464 \times 10^{-6}$

= 1.063×10^{2} kgm^{-3}

Density of piece of cloth = $8.5 \times 10^{-4} / 8.464 \times 10^{-6}$

= 1.004×10^{2} kgm^{-3}

Density of sponge = $4 \times 10^{-4} / 8.464 \times 10^{-6}$

= 4.725×10^{1} kgm^{-3}

Density of the egg carton = $8.3 \times 10^{-4} / 8.464 \times 10^{-6}$

= 9.806×10^{1} kgm^{-3}

Wood had the highest density, the piece of cloth and egg carton had moderate densities and sponge had the least density.

Porosity

Porosity refers to the presence of empty spaces within the material's volume.

The porosity of the materials was obtained by soaking the materials in water for 10 minutes, and the left under the sun for sometime to dry off the dripping water.

The new masses of the materials were obtained using the digital mass scale.

Wood = $9.2x10^{-4}$ kg

Egg carton = $8.8x10^{-4}$ kg

Cloth = $9.1x10^{-4}$ kg

Sponge = $4.8x10^{-4}$ kg

Porosity = (W_2-W_1/W_1) * 100%

Wood = ($9.2x10^{-4}$ - $9x10^{-4}$ / $9x10^{-4}$) *100%

= 2.22%

Egg carton = ($8.8x10^{-4}$ - $8.5x10^{-4}$ / $8.5x10^{-4}$) * 100%

= 3.53%

Cloth = ($9.1x10^{-4}$ - $8.5x10^{-4}$ / $8.5x10^{-4}$) * 100%

= 7.06%

Sponge = ($4.8x10^{-4}$ - $4x10^{-4}$ / $4x10^{-4}$) *100%

= 20%

Sponge had the highest porosity and wood had the least percentage of porosity.

Porosity was attributed to the arrangement of atoms, that was the structural composition of the sample materials.

In comparison, sponge had a unique body structure with a porous and permeable body, with a network of channels to the other materials

4.1.2 DETERMINE THE ABSORPTION PROPERTIES OF THE MATERIALS.

This experiment was conducted using the different materials as selected earlier.

A frequency of 1 KHz was used from the signal generator.

This frequency was used because;

- ✓ The microphone had a high impedance and therefore the signal integrity and sensitivity of the microphone was low.
- ✓ Distortion of this frequency was also minimum and therefore external interferences were also minimized.
- ✓ It allowed for consistent comparisons across different components and materials.

The frequency therefore provided balance between audibility, control and standardization.

No control measures were taken during the experiment due the high internal interferences caused by the high frequency used in the experiment. This was to increase integrity and precision of the results recorded by the microphone.

The CRO recordings were taken for each material. These were as represented below.

4.1.2.0 Initial reading.

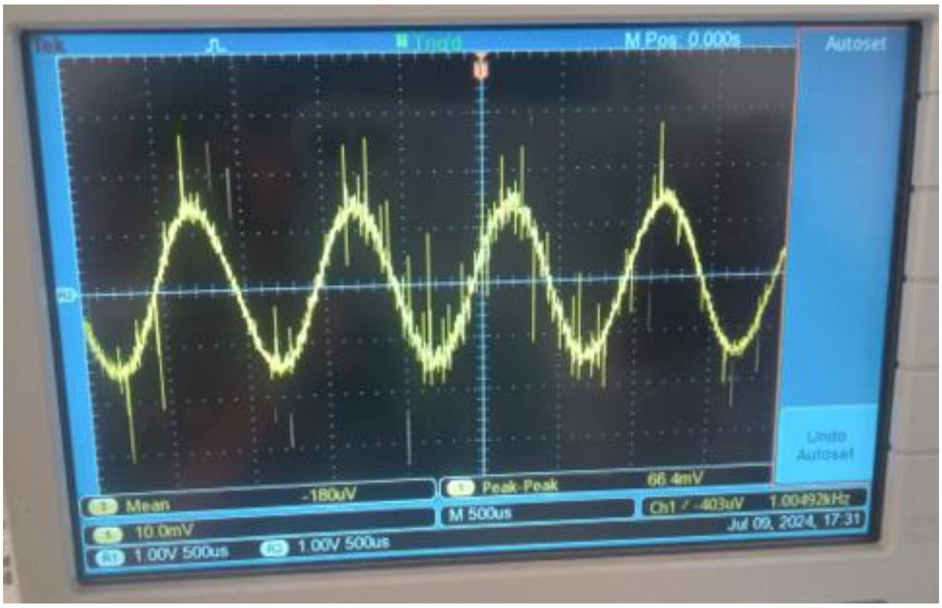

Figure 4.0 showing initial CRO reading

4.1.2.1 Wood.

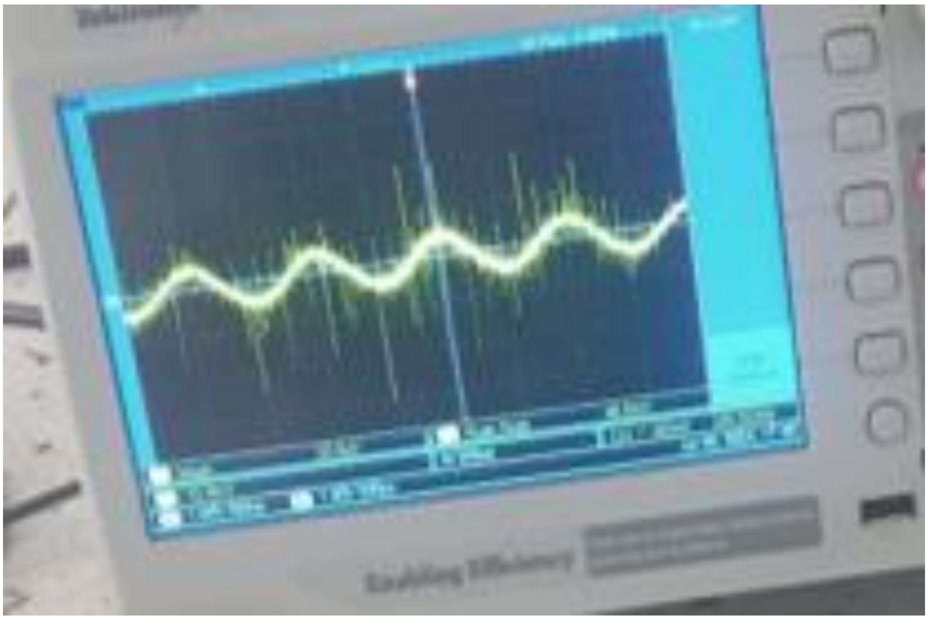

Figure 4.1 showing the CRO waveforms when wood was used.

4.1.2.2 Sponge

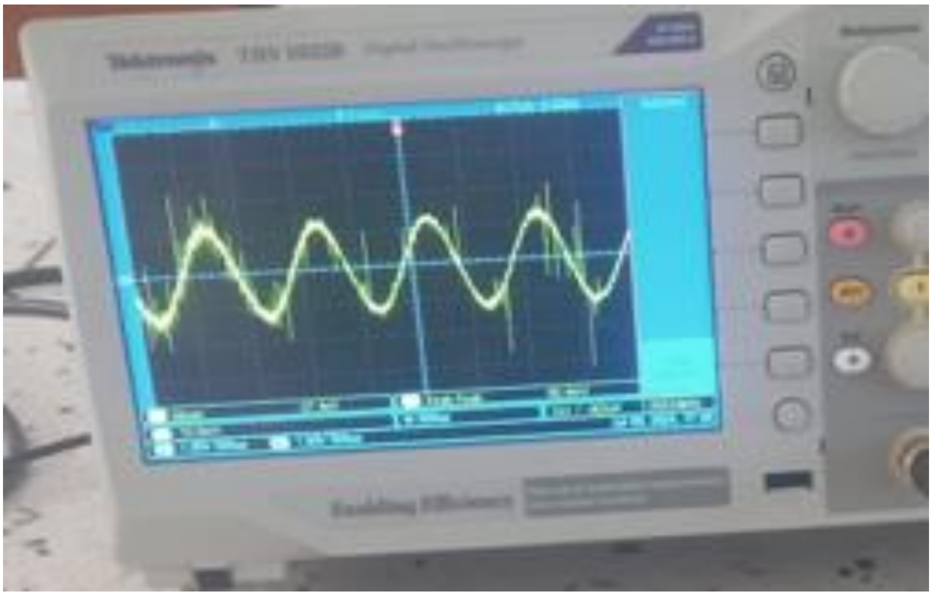

Figure 4.2 showing the CRO waveforms when using sponge.

4.1.2.3 Egg carton

Figure 4.3 showing the CRO waveform when an egg carton was used.

4.1.2.4 Piece of cloth

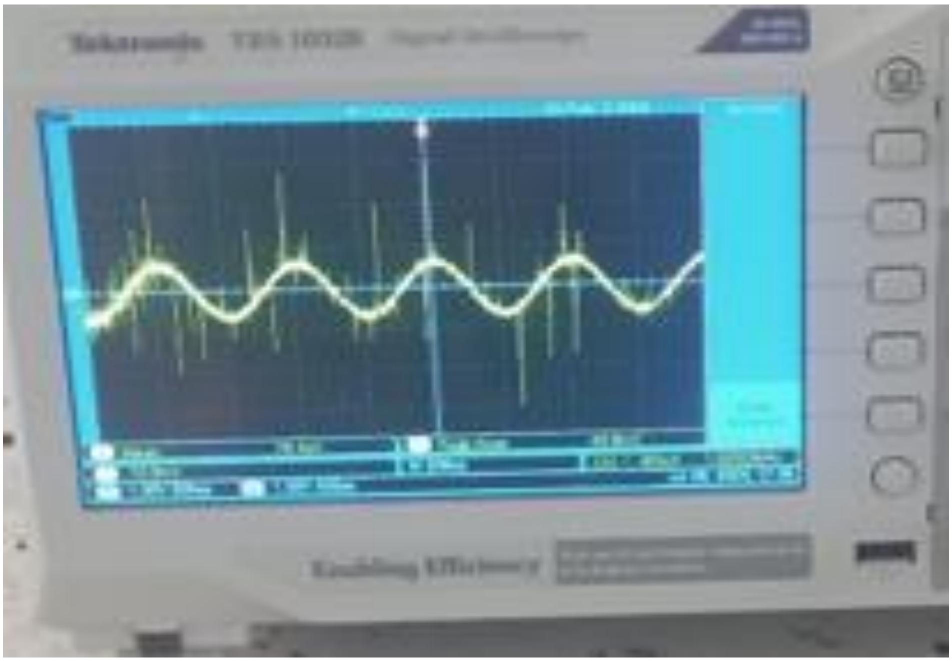

Figure 4.4 showing the CRO waveforms when a piece of cloth was used.

From the above figures, the wood had the highest absorption, followed by the egg carton, then the piece of cloth and finally the piece of sponge.

This was attributed to factors like;

- ✓ Density. Wood had the highest density compared to the rest of the materials.
- ✓ Grain pattern. Irregular patterns in wood that scattered sound waves and reduced reflections.
- ✓ Surface roughness. This increased sound absorption by creating more surface area for absorption.
- ✓ Internal damping. Wood's internal damping properties helped to reduce sound wave reflections. Internal damping is the ability to absorb and dissipate vibrational energy, reducing its amplitude and duration. Factors affecting internal damping include; *Hysteresis*, energy loss due to material deformation, *Viscous behavior* of the material, *Friction*
- ✓ Flexibility. This allowed for vibration and increased sound absorption.
- ✓ Viscoelastic property. This allowed wood to absorb sound waves and convert them into heat.

CHAPTER FIVE: RECOMMENDATIONS

Based on the research,

Wood can be used as a suitable material for sound absorption due to its ability to take in a high percentage of the sound from the signal generator, hence a much more reduced signal was observed on the CRO.

Egg cartons can be used as cost-effective and eco-friendly material for soundproofing, especially in Do-It-Yourself projects.

A piece of cloth can be used for noise reduction in a room, making it suitable material for homemade noise reduction panels.

Using materials like wood, cloth and egg cartons can provide sustainable soundproofing solutions.

When selecting materials for soundproofing, consider the sound absorption properties of different materials to optimize sound quality and noise reduction.

CHAPTER SIX: CONCLUSIONS.

Wood is the most effective material for sound absorption among the tested materials.

Egg carton can be viable, eco-friendly, and cost-effective alternative for sound absorption.

Cloth has a relatively high sound absorption, making it potentially useful for sound reduction.

The research highlights the importance of considering the physical properties of materials when selecting them for soundproofing and sound absorption properties.

Further research can explore the use of combination of materials to optimize soundproofing and absorption.

In conclusion, the findings have practical implications for various fields, including construction, Architecture, music and home décor.

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