Original Article

Investigation of the Acoustic Performance of Bagasse

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ABSTRACT

Bagasse from sugar cane waste is an important agriculture waste and the byproduct of the sugar industry. Generally, bagasse is used as a fuel for many industries which causes environmental pollution while it can be used as a good sound-absorbing material. The acoustic absorption coefficient of the bagasse is investigated in this research work. Three different samples with different thicknesses (t = 10 mm–30 mm) and different stages are considered to conduct the experimental test. Two acoustic parameters viz. 1. The airflow resistivity and 2. The acoustic absorption coefficient is measured to investigate the performance of the bagasse fibrous material in the different frequency ranges. The influence of material thickness and air gap on the acoustical performance of bagasse material samples is discussed. The results obtained from tests show the acoustic absorption coefficient and flow resistivity increase with the increase in bagasse material thickness.

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1. Introduction

In recent years, the environmental impacts of various industrial and nonindustrial sources in the form of air and noise pollution are the main attraction of researchers. Attention is given to the environment and human health to discover innovative methods for the reduction of such pollutants. Acoustic absorption materials have been commonly used in noise reduction and mainly classified into two groups viz. 1. Resonant absorber and 2. Porous absorber. Resonant absorber consumed acoustic energy by the internal resonant effect to reduce the noise level [1]. They are usually divided into the single resonator, membrane, perforated panel, etc. Porous absorber has a large number of interconnected uniformly distributed pores with a small diameter. Different types of foams, fibrous material and green composite material with pores are considered as porous acoustics absorbing material [2–4]. They have strong absorptions properties in a high frequency range, while a weak acoustic absorption coefficient for low-frequency range [5]. A fibrous material has received a great deal of attention in noise reduction due to porous structure. Hence, they are commonly used for noise reduction in various industrial and nonindustrial applications. Fibrous materials are broadly classified into 1. Inorganic and metallic fibrous material, 2. Synthetic fibrous material 3. Natural fibrous material and 4. Nan fibrous membranes [5].
Natural fibrous materials have a wide range of raw material, environmentally friendly, cheap, light in weight and biodegradability [6,7]. These materials are being recycled from natural wastes which are known as ‘green materials’ and a valid alternative to traditional synthetic fibrous materials with low cost. Natural fibrous materials have the characteristics of thermal insulation, low density, high stability, easy processing and no harmful effect on human health [8–10]. Different wood-based natural fibrous material such as bamboo fiber, coir fiber, rice straw, tea-leaf fiber and sugarcane waste (bagasse) were widely studied for acoustic absorption. Natural fibrous materials are widely used in different applications like building, automobiles, aerospace industries and industrial noise instruments [11]. A detailed review study of green composite materials that are used in automobile industries was reported by Koronnis et al. [12]. Apart from that, natural fibrous materials were mainly from the vegetables and plants may have a positive impact on the environment to reduce the CO2. Berardi and Iannace [8] and Iannace [13] reported an extensive study of different natural fibrous materials which were used for the sound absorption. Pickering et al. [14] presented a detailed study different natural fibrous composite (NFC) material. An impact of different process parameters of these materials on the mechanical performance had been listed.

The waste product from sugar factories “Bagasse” is a fibrous material that can be used as a sound-absorbing material and also it is used as a fuel. Few researchers made a study on such types of materials. A short review of previous work on the mechanical and chemical properties of sugarcane waste and their use for different applications was done by Vila et al. [15] and Lei et al. [16]. Othmani et al. [17] studied the acoustic performance of new material developed from sugarcane waste. They used the different models of Delany-Bazley [18], Johnson-Allard [19] and Lafarge-Allard [20] to estimate the sound absorption coefficient for sugarcane-based fibrous material. Different physical parameters such as flow resistivity, porosity, and tortuosity were measured for analyzing acoustic performance with new material. They found good results with this new material and good agreement with the results found with model. Doost-Hosseini et al. [21] did a study to investigate the physical as well as mechanical properties of natural material made up of sugarcane waste. Three-layered insulating boards with different densities were used for the analysis of acoustics absorptions. Different correlations were proposed with physical and mechanical properties and the sound absorber coefficient for sugar cane bagasse particle boards. Putra et al. [22] discussed the utilization of sugarcane waste fibrous material for sound absorptions and their acoustic properties with different parameters. They did an experimental analysis to measure the acoustic absorption coefficient and the results were compared with classical synthetic absorber. Besides the acoustical stability of bagasse material, it can be used for different applications in the field of civil and architectural work. Different types of composite materials can be made with bagasse material which can be used for automobile parts [23].

Many authors have done research works concerning the ability of different natural fibers which used as an acoustic absorber. Gle et al. [24] studied the acoustic properties of hemp concrete which were made up of vegetable particles with different porosity. These materials were used for green building. Three different hemp shives having different particle sizes were tested for the analysis of sound absorption. Tang et al. [25] investigated the properties of corn husk fibrous material for acoustic absorption. A multi-layer structure had been made and the acoustic absorption coefficient was calculated. They found not much improved acoustic absorption values with increased layers. Yang et al. [26] suggested use of rice straw-wood particleboard as a substitute for wood. The sound absorber coefficient had been found better compared with common industrial made plywood and fiberboard. Fouladi et al. [27] did a study on coconut husk coir fiber material for acoustic performance investigation. Two types of fiber viz. 1 fresh from the wet market and 2. An industrial prepared mixed binder was used for the study. Impedance tube was used for the experimental measurement and analytical outcomes were validated with two models (Delany-Bazley and Biot-Allard). They concluded that increasing the thickness is useful to improve the sound absorption in lower frequency.

From the above literature work, it can be concluded that limited research work has been done on the acoustic performance of bagasse material. The aim of the work is to investigate the acoustical characteristics of sugar cane waste-based bagasse material and the modeling approaches adapted. Two approaches have been used to investigate the acoustical properties of different bagasse samples viz. 1. An experimental study to characterize the acoustical properties and the sound absorption coefficient, and 2. A numerical study using an empirical model based on airflow resistivity to predict absorption coefficient. The bagasse sample preparation method and physical characteristics are discussed. An experimental test setup developed by M/S Alfa Acoustic has been used for measurement of the airflow resistivity and the sound absorption coefficient (SAC). A renowned, Delaney and Bazley based mathematical model is developed to predict the acoustical absorption properties of the presented bagasse samples. The effects of different physical parameters on the air flow resistivity and the acoustic absorption coefficient are examined. The results from both analytical model and experimental test are compared.

2. Material and methods

2.1. Materials

Raw bagasse material for the test samples was selected for acoustics analysis and obtained from the sugarcane processors. Raw bagasse can be achieved from crushed sugarcane stalks after extracting the juice. Raw bagasse material is sundried to remove the moisture contains and the volatile substances remain. A considerable change in color is happening in raw bagasse if it is dried above 90°C temperature, hence it is dried at local atmospheric temperature for 8 h. Test samples are made from the raw dried bagasse without chemical treatment and the physical modifications. Polyvinyl acetate is also used to make the samples.
2.2. Preparation of the samples

Three different samples were made with different thicknesses ($t = 10, 20$ and 30 mm) for the experimental analysis. The raw bagasse material needs to blend into a blender to form rough fibers later it fed into the grinder to get the finer fibers. The obtained bagasse finer fibers are then sieved in the sieves set. The finer fiber is mixed with polyvinyl acetate with same quantity. Then the mixture of finer fiber is molded using molds by applying the external pressure in required density and sample thickness. All samples are then sundried for removing moisture. Fig. 1 shows the different samples of bagasse used for the experimental test.

2.3. Experimental test setup

An experimental test setup is used for the measurement of airflow resistivity and the normal incidence sound absorption coefficient, shown in Fig. (2a and 2b). An airflow resistivity (AFR) is measured with an AFR test setup shown in Fig. 2a, which is made of Alfa acoustics industries while the normal incidence sound absorption coefficient is calculated using impedance tube test setup (shown in Fig. 3). AFR test setup based on ASTM C522 is having AFR range of 500-1000000 Ns/m$^4$ and overall dimensions 0.45 m x 0.55 m x 1.2 m. The linear airflow velocities of the instrument are between 0.5 to 50 mm/s while a pressure difference across the specimen ranging from 0.1 to 250 Pa. Specimen mounting assembly consists essentially of a mounting plate and a specimen holder.
Two separate holes have been provided on the mounting plate for the pressure measuring device and the airflow supply. A vacuum pump is used to draw air at a uniform rate through the test specimen. A flow meter is used to measure the volume velocity of airflow through the specimen. The steady-state of airflow through the specimen was maintained by a pressure regulator and Differential Pressure Transducer (DPT) is used to measure the static pressure difference between the free faces of the specimen with respect to the atmosphere. The measurement is done for three different airflow velocities and average result was reported. Airflow velocity is well below 50 mm/s. The differential pressure and flow rate were recorded. A series of measurements repeated at least three times at airflow below the turbulent level is made and the flow resistivity is calculated using Eq. (1) and (2).

3. Experimental Procedures

Acoustic performance analysis is done using the experimental test setup of air flow resistivity and impedance tube. An air flow resistivity and the acoustics absorber coefficient has been calculated.

3.1. Measurement of the flow resistivity

Air velocity traversing through a fibrous material is responsible for the pressure difference across it [28]:

Air is used to flow into the test setup. A pressure difference can be created due to the air velocity and can be calculated using Eq. 1.

\[ \Delta P = P_i - P_a = R_f \cdot u \]  

(1)

Where, \( P_i \) specifies the inside pressure into the pipe, \( P_a \) indicates the atmospheric pressure, \( u \) is the air velocity and \( R_f \) is the flow resistance. Hence, the flow resistivity of the bagasse material \( \sigma \) is calculated using \( R_f \) value. Eq. 2 can be used to find the flow resistivity,

\[ \sigma = \frac{R_f}{t_h} \]  

(2)

Where the bagasse sample thickness is denoted by \( t_h \).

From the above equations, it can be seen that the flow resistivity of the samples depends upon the measurement of two parameters, 1. Air velocity \( u \) and 2. The pressure difference \( \Delta P \) found at the ends of the test section. Different experiments can be performed by varying the air velocity and the corresponding pressure difference \( \Delta P \) is measured. An averaged value of \( \sigma \) is calculated for different sets of samples.

3.2. Measurement of the sound absorption coefficient

The measurement of the sound absorption coefficient can be done by using an impedance tube test. The experimental test setup of the impedance tube is as shown in Fig. 3.

A sound-producing source high frequency speaker is attached at one end of the impedance tube, while the bagasse sample is kept on another end. Two microphones are used to capture the sound pressure inside the tube and convert it into the respective voltage signal. Hence, the sound absorption coefficient can be easily calculated by this method. Two microphone transfer function method followed the regulations as per ASTM E1050-98.

4. Modeling of the Acoustic Absorption Coefficient of the Bagasse Material

A mathematical model has been developed to predict the sound acoustical properties of the bagasse material. This model can predict the sound absorption properties for porous material by using its air flow resistivity. Delany–Bazley model presents in details below,

Delany–Bazley [18] presented a model which is used to forecast porous material acoustic characteristics such as impedance \( Z_i \) and propagation coefficient \( \gamma \). Eq. 3 and 4 were proposed by them to calculate impedance \( Z_i \) and propagation coefficient \( \gamma \) values. These two equations are processed to evaluate the acoustic absorption coefficient \( \alpha \) of a bagasse sample of different thickness \( t_h \). The equations are as follows:

\[ Z_i = Z_0 \left( 1 + 9.08 \left( \frac{L}{\sigma} \right)^{-0.75} - j11.9 \left( \frac{L}{\sigma} \right)^{-0.73} \right) \]  

(3)

\[ \gamma = \frac{\alpha}{c_0} \left( 10.3 \left( \frac{L}{\sigma} \right)^{-0.59} + j \left[ 1 + 10.8 \left( \frac{L}{\sigma} \right)^{-0.70} \right] \right) \]  

(4)

\[ Z_p = Z_c \coth (\gamma t_h) \]  

(5)

\[ \alpha = 1 - \left( \frac{Z_p - \rho_0 c_0}{Z_p + \rho_0 c_0} \right)^2 \]  

(6)

where \( Z_0 \) indicates the impedance characteristic of air \( (Z_0 = \rho_0 c_0) \), and \( Z_p \) is the surface characteristic of acoustic impedance for the porous material backed with a rigid backing.

5. Study results

The acoustic performance analysis for the bagasse material was performed. The analysis has been done with two parameters, 1. Air flow resistivity measurement and 2. Acoustic absorption coefficient measurement.

5.1. Air flow resistivity measurement

The results found in air flow resistivity test are tabulated in Table 1. Three samples have been tested and the average flow resistivity is calculated by varying velocity and pressure of the air. The thickness of the samples is increased from 10 mm to 30 mm and analyzed by varying the operating parameters of velocity and pressure of air. It can be concluded that there is a significant effect of the thickness on the air flow resistivity. The maximum average flow resistivity is found 4227.94 Nm⁻² for 10 mm thickness sample, while it is found reduced with 639.43 Nm⁻² by increasing thickness of the sample up to 30 mm, for similar operating conditions.
5.2. Acoustic absorption coefficient

The acoustic absorption coefficient of bagasse material was measured by the impedance tube method (ASTM E 1050-98) to check the possibility of substitute sound absorbing material. Three different samples have been made with different thickness of 10, 20 and 30 mm to investigate the acoustic performance. Theoretical analysis with present correlations in literature is calculated and compared with experimental results.

Fig. 4 shows the experimental and theoretical results of the acoustic absorption coefficient found for sample 1. A 10 mm thickness sample has been selected and tested for the different frequency ranges. From Fig. 4, it can be observed that the sound absorption coefficient increases with increase in frequency of the sound for the frequency limit of 4500 Hz. The maximum acoustic absorption coefficient can be found 0.60 for the 4500 Hz frequency. The theoretical results for the calculation acoustic absorptions coefficient can be achieved using Eq. 6 and the results are shown in Fig. 4. The maximum acoustic coefficient has been found with theoretical results are 0.54 for 4500 Hz frequency. The results from the experimental and theoretical calculations have a good agreement. It can be noted that a typical shape can be seen from the experimental test of porous material.

A graph of sound absorber coefficient versus frequency for samples 2 and 3 of bagasse material having 20, and 30 mm thickness, respectively are shown in Figs. 5 and 6. A similar observation can be found with sample 2 and 3, the maximum absorption coefficient is found during the frequency band, then the values reducing with the beyond frequency. The maximum absorption coefficient of samples 2 and 3 found 0.70 and 0.78 for the sound frequency of 3000 and 2250 Hz, respectively. The experimental results are compared with the theoretical results and found a slight difference after a frequency 3250 Hz in sample 1 and 2250 Hz in sample 2. The difference may be increased due to the following reason, similar observation also observed by Othamani et al. [17].
1 Only one parameter of flow resistivity is considered for the model used for theoretical calculation.
2 The experimental errors during the flow resistivity measurement may affect the acoustic absorption coefficient.
3 In most of the practical applications, the variation between flow resistance is a very important parameter for various fibrous material, the influencing factor of flow resistance is bulk density and fiber size. A standard procedure is used for the manufacturing of the fibrous material, but unfortunately the manufacturer not set these standards due to this the error can come during measurement [18].
4 Flow resistivity is the most influencing parameter in low frequency while the porosity, tortuosity, and characteristic length affect more in high-frequency region, hence theoretical model has good agreement in low frequency region of the plot. Similar observations were explained in Atalla and Panneton [29].

5.2.1. Effect of thickness of bagasse material

Fig. 7 deduce the frequency variation plot with the sound absorption coefficient for three different samples. A significant effect can be observed with Fig. 7, the sound absorption coefficient found good with higher thickness material. A maximum sound absorption coefficient is found 0.75 for 30 mm thickness sample. By comparing the results, the sound absorption coefficient of 30 mm thickness sample is 2.4 times the sound absorption coefficient of 10 mm thickness sample at 2500 Hz frequency. Hence, thickness of the material has played an important role during acoustic absorption.

Fig. 8 and 9 predicts the effect of the air gap between the samples on the sound absorption coefficient. A 10 mm thickness sample with air gap of 15 mm and a 30 mm thickness sample with 20 mm air gap are considered for the analysis. From Fig. 8, it observed that the sound coefficient is increased with increased air gap. The maximum coefficient found 0.64 at 2500 Hz for sample with 15 mm air gap. Similarly, when the thickness increased from 10 mm to 30 mm, the maximum sound absorption coefficient for higher for 1250 Hz frequency rather than the 2500 Hz, shown in Fig. (9). Hence, it is concluded that air gap between the material has a significant effect on the sound absorption coefficient. This study validates the proposed natural fibrous based bagasse material is a resourceful alternative absorbent that can be used for the industrial as well as non-industrial applications with good acoustic performances.

6. Conclusion

Experimental and theoretical investigations have been done to estimate the acoustic performance of natural fiber-based bagasse material. Three samples of the bagasse material with different thickness has been prepared and analyzed. The air flow resistivity and the acoustic absorption coefficient of the bagasse were calculated by varying operating parameters. The suggested material revealed its efficiency to absorb the sound with high acoustic absorbing coefficient (0.7 to 0.8) between different frequencies. Further study has been extended to investigate the effect of sample thickness and air gap, and found good results. The results are compared with the results calculated by theoretical expression in literature and found good agreement. The following conclusions can be drawn,

- The experimental results have a good agreement with the theoretical results at low frequency range, beyond some limit the more error was found.
- The thickness of the fibrous material has a significant impact on acoustic performance. The flow resistivity and
the acoustic absorption coefficient increases with an increase in thickness of the material.
- The addition of air gap improves the sound absorption characteristics.

**Conflict of interest**

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We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We confirm that the manuscript has been read and approved by all named authors.

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