Application of Innovative Cost effective flow resistivity measurement system for Acoustic Performance Analysis of Natural fibers

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***Abstract*:** In design of the interior of car, workplace and companies, acoustic material plays very important role. To attenuate unwanted noise, passive noise control technique using acoustic material is used extensively. The non-biodegradable synthetic acoustic material, which are used nowadays cause environmental pollution. This environmental pollution motivates researchers to find eco-friendly and sustainable acoustic materials as an alternative sound absorber. Research is going on to find new acoustic materials for many industrial and domestic applications. The value of sound absorption coefficient has correlation with frequency of sound. Hence, it would be very helpful if the characteristic acoustic properties of these materials are known prior using them for a particular application. This paper presents the utilization of new flow resistivity measurement set up. This flow resistivity set up is developed as per ASTM C522-03 standard. Delany-Bazley model can be used to predict sound absorption coefficient using flow resistivity values. The numerical analysis using MATLAB program based on Delany-Bazley models is made to determine sound absorption coefficient of material prepared from natural fibers of sugarcane waste, wheat straw and PU foam, Glass wool. The sound absorption coefficients of all four materials are also obtained by experimental investigation using impedance tube as per ASTM E 1050 standard. Comparisons of the experimental and the numerical results confirm that the sound absorption coefficients of all material are well corroborated.

***Keywords*:** **Acoustic materials, Glass wool, Impedance tube, Natural fibers ,Sound absorption coefficient.**

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INTRODUCTION

Sound is a kind of energy. The undesirable sound is known as noise. Nowadays noise is a major cause of environmental problem. Sound above particular level can cause permanent hearing damage. Also continuous exposure to excessive level of sound could be physiologically dangerous and not good for human health. Nowadays there is necessity to give enough importance for acoustically better environment around us. Noise control methods and its principles can produce an acoustically pleasing environment. Accomplishing a pleasant acoustic environment by using different techniques that put to use different materials can be done. One of these techniques is by noise or sound absorption [1]. Acoustic materials are largely used in industries, car interiors, theatres, electricity generators, lecture rooms, etc. It can be notice that sounds in all these areas are different due to their intensity, frequency range, amplitude, etc.

The frequency plays important role as absorption behavior of materials depends on it. Hence the same material cannot be used for different noise control scenario. The coefficient of sound absorption data of a material with respective to frequency is very much useful. The acoustic behavior of an acoustic material is also depends upon thickness, density, airflow resistance, porosity and tortuosity [2]. Nowadays synthetic acoustic materials are extensively used. The production of these synthetic materials causes negative impact on the environment. The disposal of such a synthetic acoustic material is also damage to environment. Many of synthetic acoustic materials are not easily recyclable. Glass wool is the most common synthetic sound absorption material which is inexpensive. However, glass wool is hazardous to human being as the tiny particles will enter in the skin and can cause irritation and inflammations of the eyes, skin and these small particles can get inhaled and may become reason for lung disease [3]. Therefore, there is need for sustainable and environment friendly materials to replace these synthetic materials. The undesirable effect of synthetic acoustic material, motivate researchers to explore chance to look for substitute materials from natural fibers like bamboo as a noise controlling material [4]. Acoustic materials can be produced using natural fibers like sugarcane fibre or bagasse as a raw material. Also disposal of natural fibers dose not harms the environment. Noise control with its principles can produce an acoustically.

It has several benefits; cheaper, ample and less harmful during handling and processing [5].The agricultural waste like coir fibers can be used as sound absorption materials. Many researchers have successfully developed particle board using coir fibers [6,7]. Particles from the rice straw are used to produce composite boards. These composite boards are used to absorb noise. It is found that the composite boards of rice straw particle have better acoustical properties than other wooden materials in mid to high range frequency [8]. Major findings from those studies showed importance of natural fibers as acoustic materials. Numerical approach and experimental investigation is done to obtain sound absorption coefficient of acoustic materials.

I. Objective

The objective of this paper is to measure the flow resistance of different acoustic materials by using new developed flow resistivity setup and to demonstrate its use to find sound absorption coefficient using numerical approach. In the present study, acoustic performance of four different material viz. natural fibers of wheat straw, sugarcane waste and PU foam, Glass wool were evaluated. The sound absorption coefficient of all four acoustic sample materials is also determined by experimental investigation using BSWA impedance tube as per ASTM E 1050-98 Standard.

II. Test Material Samples

This section describes the preparation of the test sample of different acoustic materials under study. There are many acoustic materials are easily available in the market. All those are made from synthetic materials. The standard synthetic materials such as Glass wool and polyurethane (PU) foam as shown in fig.1 are tested with the help of an impedance tube.

(a) (b)

Figure 1. (a) Glass wool (b) PU foam Synthetic material Test samples

For experimental investigation, the test samples should have same cross section area as that of the impedance tube cross section. The test sample should fit adequately in sample holder but it should not bulge and come out in center. Also, it should not be so loose that there will be some space between edge of sample and the holder. To ensure there is no gap at periphery of sample petroleum jelly or modelling clay can be used. It is recommended to have the test sample with relatively flat surface. The thickness and mass density of the glass wool material sample is 25 mm and 48 Kg/m^3 respectively. The thickness and mass density of the PU foam material sample is 25 mm and 50 Kg/m^3 respectively. All test samples are cut in circular shape with 100 mm diameter same as that of the impedance tube.

The process of preparing natural fiber test samples may vary material to material. The main purpose of this whole process is to remove moisture from material. Moisture reduces the sound absorption capability on material. Some materials may require more temperature or longer time to remove most of moisture.

This process also insures separation of fibers in material. Flow chart in figure 2 explains this process.

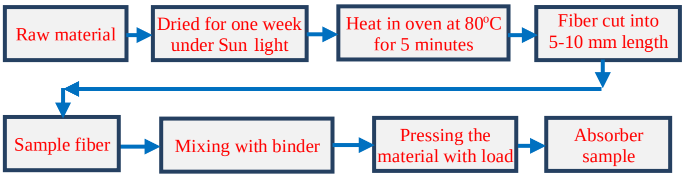

Figure 2 . Flow of Natural fiber absorber sample preparation process

There are various weight composition ratios of fibers to binder possible viz. 90:10, 80:20, 70:30, 60:40 etc, but study suggest 70:30 ratio gives the best results [5]. An absorber samples under study are prepared from sugarcane and wheat straw waste material using proportion of 70% natural fibers and 30% binder of the total mass of the test sample. The absorber sample under study used polypropylene as a binder. The figure 3 shows Test Sample and raw material of sugarcane fibers and figure 4 shows Test Sample and raw material of wheat straws. The sugarcane absorber sample consists of 31.65 gm sugarcane fiber and 13.57 gm polypropylene binder is mixed to make a sample. Also wheat straw sample contains the fibers of 19 gm and binder of 8.14gm. The absorber sample used for numerical and experimental investigation has diameter of 100 mm and thickness is 25 mm.

Figure 3. Test Sample and raw material of sugarcane fibers

Figure 4. Test Sample and raw material of wheat straws

III. Numerical Analysis

In this approach, the sound absorption coefficient of acoustic material is determined by using Delany-Bazley method. The expression of Delany Bazley model is used to predict acoustical properties of porous materials by using their airflow resistivity [9]. The propagation constant γ and characteristic impedance Zc are acoustic properties of sound absorbing materials. Both properties can be expressed as complex expression as follows,

$$Zc = R + jX \quad (1)$$

$$\gamma = \alpha + j\beta \quad (2)$$

Where R stands for real component, X stands for imaginary component, α stands for attenuation constant in nepers per meter (1 neper ≈ 8.686 dB), β which is given by ω /c is known as phase constant in rad per meter, ω stands for angular frequency and c stands for speed of sound in the material. In the Delany Bazley model above quantities are expressed by the following equations [10]

$$R = \rho_0 c_0 \{1 + a (f/\sigma) b\} \quad (3)$$

$$X = -\rho_0 c_0 \{c (f/\sigma) d\} \quad (4)$$

$$\alpha = (\omega/c0)\ p\ (f/\sigma) q \quad (5)$$

$$\beta = (\omega/c0)\ \{1 + r (f/\sigma) s\} \quad (6)$$

Where, ρ_0 stands for density of air, c0 stands for speed of sound in air, f stands for frequency and σ stands for airflow resistivity. The coefficients of (f /σ); a, c, p and r, and the degrees of (f/σ); b, d, q and s, are given by Delany-Bazley. The Delany-Bazley model is used to make a program using MATLAB software [11]. This program gives output in terms of sound absorption coefficient Vs frequency graph. Inputs required for this MATLAB program are airflow resistivity, thickness of the sample and density of air. The density of air is taken as 1.225 kg/m^3.

Airflow resistivity is a property by which resistance offered by acoustic material to the air flowing through it. It is difficult for sound to propagate through materials from which air hardly pass through. The flow resistivity can be explained as resistance per unit thickness experienced by the air while moving through the test sample with steady flow. Flow resistance σf stands for the ratio of the induced pressure difference to the applied volume flow rate.

$$\sigma = \sigma_f / \Delta x \quad (7)$$

$$\sigma_f = \Delta p / v \quad (8)$$

Where, Δx stands for the thickness of the sample (m), Δp is pressure difference across the absorber test sample [N/m^2], v is air velocity [m/s]. Equation (7) and (8) are used to determine Air flow resistivity (σ) using two parameters, Δp and v. An experimental setup is developed to measure pressure difference, Δp across absorber test sample and air velocity v [12, 13, 14]. Figure 5 shows the schematic diagram of airflow resistivity setup.

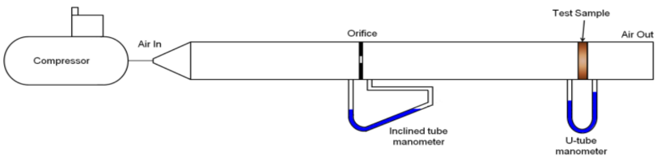

Figure 5. Schematic diagram of airflow resistivity setup

Figure 6 shows the setup used for measurement of air flow resistivity. It consists of air pipe, orifice, absorber test sample holder, an inclined manometer and U tube manometer. The compressed air is supplied through one end of the pipe. The diameter of pipe is 100 mm. In airflow measurement set up, air inlet is kept at one end of the pipe and test sample is kept at another end of the pipe. In between them, an orifice plate is fitted in this pipe to measure the air flow rate inside the pipe. An inclined tube manometer is fitted across the orifice plate for measuring air velocity inside the tube. This inclined manometer is more sensitive than a U-tube manometer which helps in accurate flow measurement. All the parameters are chosen and precautions must be taken to ensure laminar airflow before it reaches the sample. The sample under test is kept at another end of the pipe with the help of sample holder. U-tube manometer is used for measuring pressure difference across the test sample of acoustic material. Kerosene is used as a manometric liquid to increase sensitivity further. Deflection of inclined tube manometer and corresponding deflection in U-tube manometer is measured for different acoustic materials. Further calculations are done to measure airflow resistivity of each acoustic material.

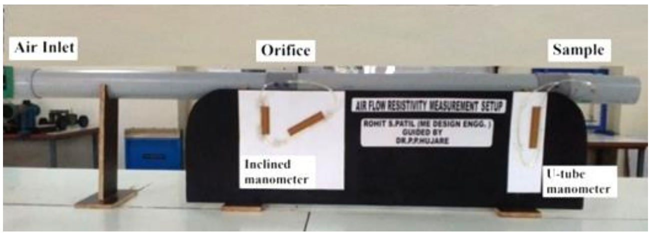

Figure 6. Experimental Setup for Flow Resistivity Measurement

Air is compressed in a compressor up to certain pressure. Initially air is compressed in a compressor up to 500 kPa pressure. Then it is passed through a pipe of uniform diameter 100 mm. By using this simple experimental set up, the parameters Δp and v of four absorber materials viz. glass wool, PU foam, sugarcane fibre and wheat straw are obtained. These two parameters are further used to find air flow resistivity. Table1 shows airflow resistivity of all four absorber material.

Table 1. Measured Airflow Resistivity of acoustic materials

Material	**Experimental Flow Resistivity (Ns/m^3)**
Glass wool	23344
PU foam	16161
Sugarcane fiber	14312
Wheat straw	3412

By using above equations one MATLAB program is developed to find the sound absorption coefficient by using airflow resistivity. The airflow resistivity values as shown in table I are used in the MATLAB program to obtain the graphs of sound absorption coefficient Vs frequency for each material as shown in Figure 7 to Figure 11.

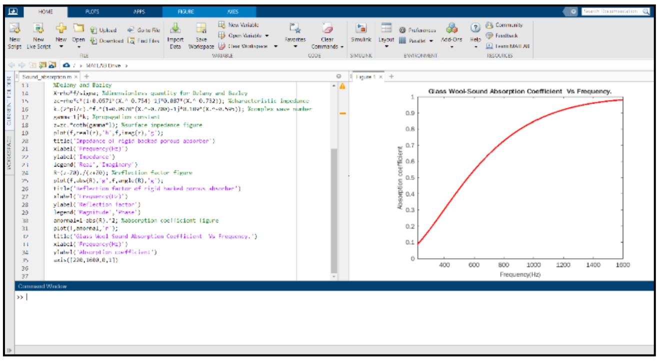

Figure 7: MATLAB Software result

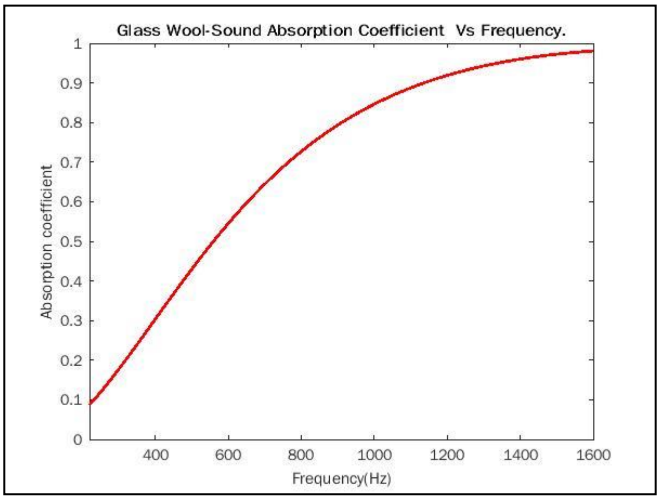

Figure 8: MATLAB result for Glass wool

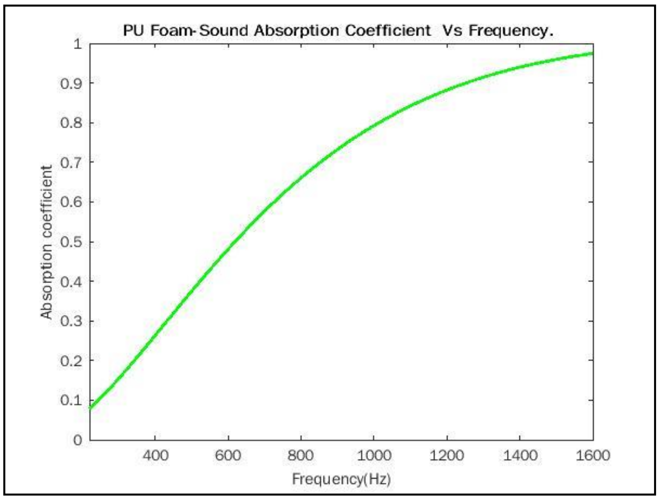

Figure 9: MATLAB result for PU Foam

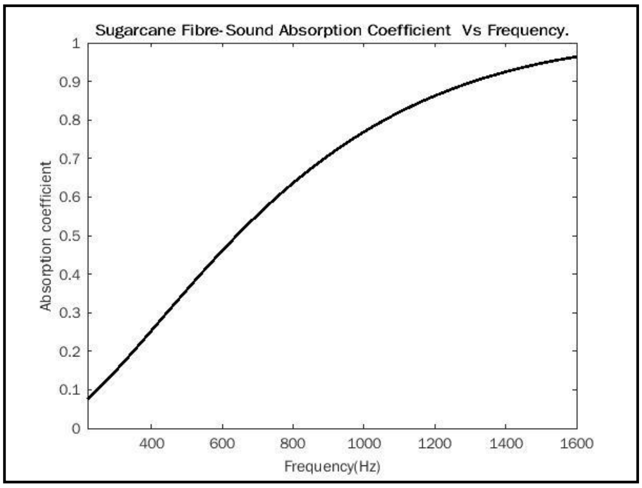

Figure 10: MATLAB result for Sugarcane fibre

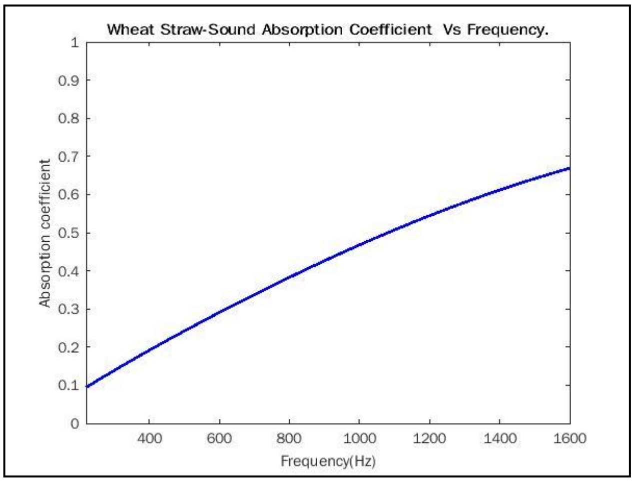

Figure 11: MATLAB result for Wheat Straw

V. EXPERIMENTAL ANALYSIS

The sound absorption coefficient values for acoustic materials are measured by standard experimental setup. Sound absorption coefficient is measured using impedance tube method [15]. As compared to other method, impedance tube method has more benefits because of its compactness, less expenses and instantaneous results. In this method, noise generated by the speaker at one end of the impedance tube is made to incident on the test sample or acoustic material at other end of the tube. Figure 7 shows schematic of sound absorption coefficient measurement setup. It consists of impedance tube along with sample holder, two MP416 microphones (BSWA make), MC3242 data acquisition system (BSWA make), PA50 amplifier and noise signal generator (BSWA make). The sample under the test is fitted in the impedance tube and has rigid surface at its back. The loudspeaker generates the white noise signal inside the tube. Microphones record the incident and reflected sound pressure from the test sample. These recorded signals are processed in VA-Lab4 software to have the absorption coefficient of the sample. Noise signal fed has a range of frequency over which values of sound absorption coefficient are to be obtained.

In this experiment, performed in an impedance tube, sound absorption coefficient (also denoted as α) was measured by using two microphone transfer function method according to ASTM E1050 and ISO 10534-2 [16,17]. The 1/4” prepolarised free-field MPA416 microphones are used for sound pressure measurement. The data acquisition system is used to collect data from microphones.

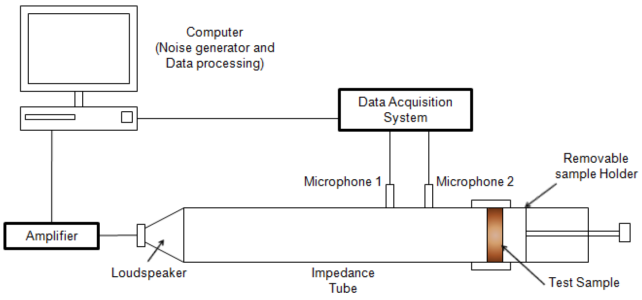

Figure 7. Schematic of Sound absorption coefficient measurement setup

Figure 8 shows the setup for experimental investigation. For experimental investigations SW420 BSWA impedance tube with 100 mm diameter is used. The range of frequency for this impedance tube is 63 Hz to 1800 Hz. The BSWA VA-Lab4 software is used to generate the graph [18].The piston cylinder type sample holder is used in this set up. The depth of cavity which holds the sample can be adjusted in holder. This helps to test the sample of any thickness. The test sample should fit snugly in holder. Also, there should not be any clearance between the test sample and the holder.

Figure 8. Experimental setup for sound absorption measurement

After experimental investigations on different acoustic materials, the graphs of sound absorption coefficient Vs frequency are obtained. The result shown by BSWA VA-Lab4 software is in the form of scatter point graph which is converted into the average graph as shown in Figure 9. The experimental investigation is conducted over 220 Hz to 1600 Hz frequency range.

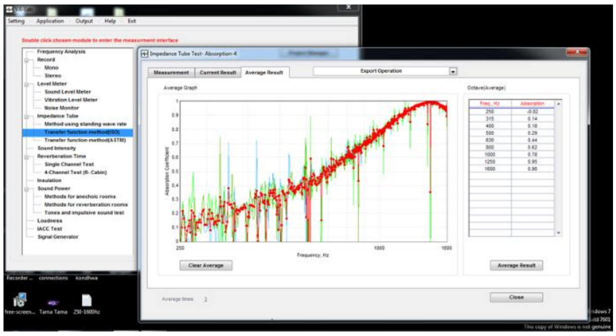

Figure 9 Experimental result shown in VA-Lab4 software

The experimental testing result of all four acoustic materials are shown in Figure 10 to Figure 13.

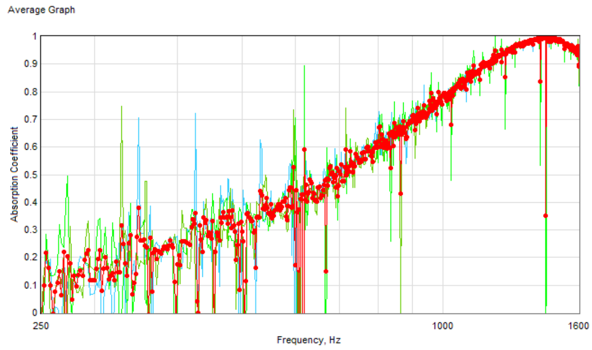

Figure10. Experimental result for glass wool sample

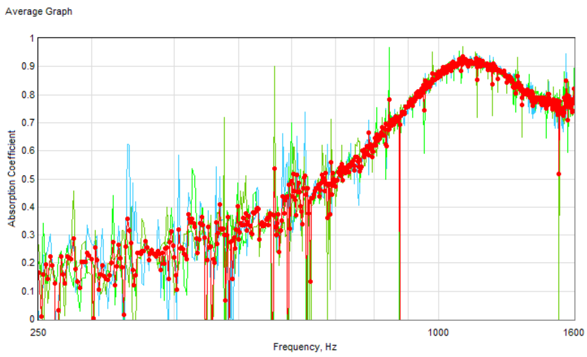

Figure 11 Experimental result for PU foam sample

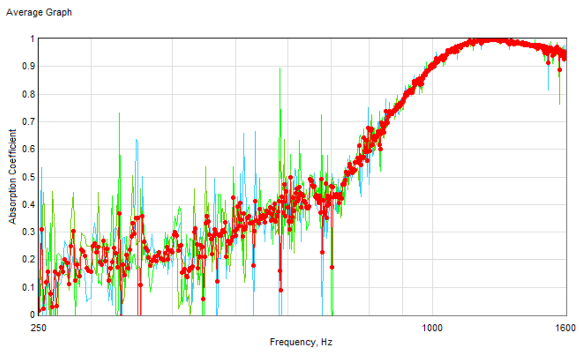

Figure 12 Experimental result for Sugarcane sample

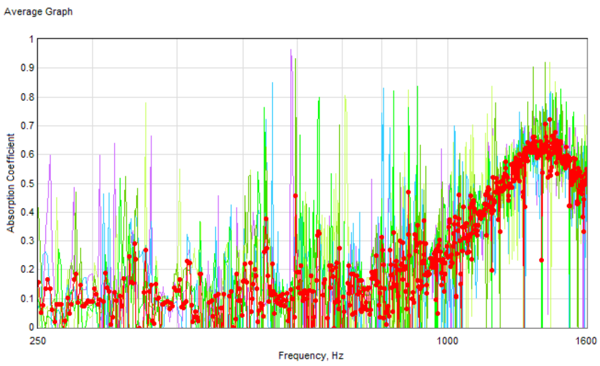

Figure 13 Experimental result for Wheat Straw sample

VI. RESULT AND DISCUSSION

The experimental results from the impedance tube at low and high frequencies (250-1600 Hz) for different acoustic materials viz. Glass wool, PU foam, sugarcane fiber, wheat straw. The experimental result graphs data of all acoustic materials are processed in excel software. The comparison of acoustic performance of all acoustic materials are shown in Figure 14. In numerical approach, the sound absorption coefficient of acoustic material is obtained by using this MATLAB software, which is based on Delany-Bazley model.

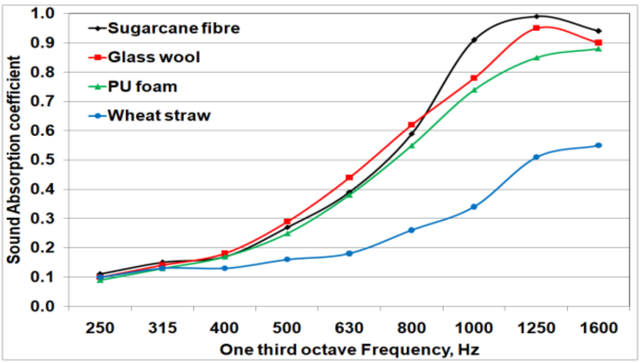

Figure 14. Experimental results for all tested acoustic materials

Figure 15 shows the comparison of experimental and numerical results of glass wool. It is observed that the values of sound absorption coefficient obtained from numerical and experimental approaches are well corroborated.

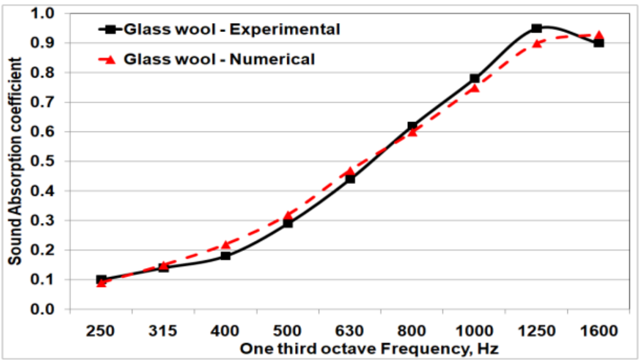

Figure.15. Comparison of experimental and numerical results of glass wool

we can say that the efficiency and accuracy of this newly developed airflow measurement setup is established as the sound absorption coefficient graphs of glass wool obtained by numerical and experimental approach are nearly equal. Air flow resistivity of wheat straw material is less as its fibers are not as fine as sugarcane fibers. Hence the acoustic performance of wheat straw is found less. From numerical and experimental investigations, it is found that the sound absorption coefficient of sugarcane fiber is more at higher frequencies as it has more density than other materials. The sugarcane fiber has highest value of sound absorption coefficient (α), which is nearly same as glass wool. The acoustic performances of natural fiber materials are compatible.

VII . CONCLUSIONS

This paper explained the development of simple setup for flow resistivity measurement. This set up is used to obtained air flow resistivity of different porous fibrous acoustic materials. The expressions of the Delany-Bazley models, which help to predict the acoustical properties of acoustic materials from the airflow resistivity, were examined from the measurement of natural fibers of sugarcane, wheat straw and synthetic material such as PU foam, glass wool. The acoustic performance of these materials was evaluated by measuring the normal incidence sound absorption coefficient. Thickness and density of material plays significant role in performance of acoustic materials. These properties can affect air flow resistivity of material which directly influences sound absorption capacity. It is found that the acoustic performance of natural fibers as good as that of synthetic acoustic materials. It can be concluded that the Sugarcane fiber material possesses acoustic properties as good as glass wool. The experimental investigations shows that sugarcane fibers show good acoustic performance at low and high frequency range. This implies that Sugarcane fibers can be used as the alternative or replacement of PU foam and glass wool. Synthetic acoustic materials are not environment friendly, so use of natural fibers as an acoustic material should be promoted. Comparisons of the experimental and the numerical results confirm that the sound absorption coefficients of all material are well corroborated.

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