9.1 SUMMARY

The sound absorption property of natural fibre reinforced recycled paper pulp composite material is one of the essential properties which decide the suitability of these composites in construction applications where sound control is desired. Natural fibre reinforced composites are well suited for sound absorption in places like conference halls, auditoriums, theatres, classrooms, hospitals, offices, aero planes and automobiles. These composites can be used as ceiling panels, graphic panels or hanging baffles and floor covering. The factors that mainly influence acoustic performance of sound absorptive materials are fibre type, fibre dimension, material thickness, density, airflow resistance and porosity, which can change the sound absorption behavior.

Therefore, the main structural properties of the porous materials affecting sound absorption are density, thickness and porosity. It can be concluded from the above studies that the acoustical properties of material depends on the various parameters chosen and the interaction between the parameters. In such cases, developing a model will help to understand the effect of a chosen variable on sound absorption properties. The regression equation developed from the input composites particulars and output predicted values, can be used as an empirical model for predicting acoustic properties.
However while the acoustical properties of many natural fibres have been investigated, the acoustical characteristics of banana, coir and sisal fibres are rarely studied. It is found that the scientific data on acoustical properties of banana, coir and sisal fibre reinforced recycled paper pulp matrix biocomposites is apparently not available. Hence, the present investigation deals with the modeling of acoustical properties of light-weight composites produced from these lignocellulosic fibres reinforced with recycled paper pulp. The selected variables for study are fibre volume fraction \( V_f \), fibre cut length and composite thickness. An attempt has also been made to develop a model for predicting the acoustical properties of lignocellulosic fibres reinforced recycled paper pulp biocomposites using multiple linear regression models.

The analytical formulation is presented as an important step in the design of the apparatus (impedance tube), mainly in the working frequency range determination. The construction details of the impedance tube (materials and dimensions) and the experimental results are reported. This study is to compare the results of two quite different methods of standard measurement employing the reverberation room and the impedance tube. Reverberation-room absorption measurements on some 45 samples of the biocomposite materials were compared with values experimented and calculated from impedance-tube on the same materials.

### 9.2 CONCLUSIONS

Results obtained from this research led to the following conclusions:

- Noise Reduction Coefficient (NRC) for banana, coir and sisal fibre reinforced biocomposite blocks is good and comparable to other materials commonly used for acoustic control. The various parameters such as fibre cut length, fibre volume
fraction and thickness of the composites, significantly affect the NRC when the composite acts as sound control material. A mathematical model has been suggested to predict the NRC with respect to these parameters.

- The outcomes indicate that composites with bulk density of about 154, 160 and 171 kg/m$^3$ for banana, coir and sisal fibres reinforced biocomposites respectively, provides maximum NRC through the frequency range of 125-4000 Hz.

- It is concluded that for the banana, coir and sisal fibre reinforced recycled paper pulp biocomposite blocks, the optimum fibre length is 3.5 cm with 0.20 fibre volume fraction and 6 cm thickness of the composites in terms of NRC. Therefore, it can be concluded that the optimum fibre length of 2.5 cm to 3.5 cm with 0.20 fibre volume fraction at 6 cm thickness of the biocomposites are suitable for better acoustic performance.

- The porosity range of 0.79-0.80 with 6 cm thickness of the sample number S4 has higher NRC for all fibre (banana, coir and sisal) reinforced biocomposites. Overall, the sound absorption of porous biocomposites are generally poor at low frequencies, but increases significantly at high frequencies.

- The correlation coefficients between the observed values and predicted values using the proposed model show a very good correlation. The correlation coefficient values are 0.95, 0.93 and 0.97 for banana, coir and sisal fibre reinforced biocomposites respectively. It indicates that observed values of fibre reinforced paper pulp biocomposite has a real degree of association with the predicted values of the biocomposite blocks.
For banana fibre based biocomposites: Samples S15, S4, S12 and S11 exhibit better bending strength (0.686 N/mm², 0.685 N/mm², 0.667 N/mm² and 0.653 N/mm² respectively) at lower bulk density (150 kg/m³, 154 kg/m³, 140 kg/m³, 140 kg/m³ respectively) among the various combinations, showed better NRC values in terms of both bending strength and bulk density and therefore, may be considered for efficient construction in preference to materials with otherwise identical parameters.

For coir fibre based biocomposites: Samples S4, S12, S11 and S2 have better bending strength (0.695 N/mm², 0.667 N/mm², 0.653 N/mm² and 0.651 N/mm² respectively) at bulk density (160 kg/m³, 164 kg/m³, 158 kg/m³ and 161 kg/m³ respectively) among the combinations and show better NRC values in terms of bending strength. Therefore, it may be considered for efficient construction in preference to materials with otherwise identical parameters.

For sisal fibre based biocomposites: Sample number S4 has lower bulk density (171 kg/m³) and higher bending strength (0.715 N/mm²) and shows better NRC values in terms of both bulk density and bending strength. Therefore, it may be considered for efficient construction in preference to materials with otherwise identical parameters.

All the samples exhibited marginally varied pattern of sound absorption at all measured frequencies. For all the samples, when the frequency increased, sound absorption coefficient also increased. The experimental values did not show much significant differences among the fibres (banana, coir and sisal) reinforced biocomposites on average NRC. The specimens made of sisal fibre reinforced biocomposite show
higher NRC (Average: 0.50) in average of 15 different combinations compared to the specimens made of banana (Average: 0.468) and coir (Average: 0.476)

- The acoustic properties of the biocomposite blocks show better acoustic control characteristics when compared to commercial plywood. They have an additional advantage of being lighter in weight than plywood. Hence, the biocomposites blocks could be used as construction material for sound control in buildings.

- The outcomes indicate that composite with bulk density of about 154, 160 and 171 kg/m$^3$ for banana, coir and sisal fibres reinforced biocomposites respectively, provide maximum NRC throughout the range of frequencies 125-4000 Hz using impedance tube technique. It is concluded that, the banana fibre reinforced recycled paper pulp matrix biocomposite blocks; the optimum fibre length is 3.5 cm with 0.20 fibre volume fraction and 6 cm thickness of the composites in terms of NRC. In addition, the multiple linear regression models can be used successfully for predicting the acoustic properties of different biocomposite blocks.

- A good correlation (over all correlation coefficient-0.747) was observed between the reverberation-room and impedance-tube measurement methods of the NRC of various biocomposites. It is concluded that, apart from effects attributable to mounting conditions, the absorption coefficients measured in the reverberation room are generally consistent with the values calculated from the acoustic impedance of the materials.
Bio composites with properly chosen fibres at suitable bulk density can increase the sound absorption for the same biocomposite thickness. These results can serve as a guideline for the future implementation of acoustic absorber using naturally collected banana, coir and sisal fibres.

9.3 SCOPE FOR FUTURE WORK

The results of this investigation reveal the several possibilities for future research too. Some of the important areas include:

- Fabricating multilayered composite structures to analyze their acoustic properties
- Making surface modifications to optimize the sample geometry.
- Applying flame retardant finish to add functional value and analyze the effect on NRC.
- The interaction of fibre and matrix influencing the composites' acoustic properties requires further examination.
- In order to continue impedance-tube design and development work, the experimental results need to be better investigated and possible error sources be identified. More measurements may be incorporated and other parameters which can influence the estimation may be studied: the test specimen mounting, selection of the number of tests, correction for microphone mismatch, pressure-release termination of test sample, modifications in the sample holder in order to improve its rigid and reflexive termination may be considered in future work.
APPENDIX 1

Figure A1 Details of PVC coupler a) Rigid termination 100 diameter; b1&b2) Sample holder – 100 mm diameter; c) Assembled sample holder

Figure A2 Sound source assembled with rigid termination
Figure A3 Hole construction on PVC tube for microphone insertion

Figure A4. Sound source assembled with PVC tube

Figure A5 Sound absorption measurement with assembled Impedance tube setup
Figure A6 Biocomposite samples for reverberation sound absorption test

Figure A7 Banana fibre reinforced recycled paper pulp matrix biocomposites
Figure A8  Coir fibre reinforced recycled paper pulp matrix biocomposites

Figure A9  Sisal fibre reinforced recycled paper pulp matrix biocomposites