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EFFECT OF MEMBRANE SURFACE TENSION AND BACKED-AIR GAP DISTANCE ON SOUND ABSORPTION CHARACTERISTICS

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ABSTRACT

This paper describes the analysis on the sound absorption characteristics of semi-permeable membrane absorber. The effects of membrane surface tension and backed-air gap distance on the sound absorption characteristics were investigated. The characteristics of the membrane absorber were measured experimentally in terms of Sound Absorption Coefficient, α and Noise Reduction Coefficient, NRC. The membrane is made of a thin, flexible, semi-permeable latex material and the tests were carried out by using impedance tube method according to ISO 10534-2 standard. The results showed that the surface tension has significant influence on the sound absorption characteristics. For the parameters used in the laboratory work, the specimen with un-stretched surface tension has the best absorption performance with 94% absorption at 1600 Hz. Membrane absorbers showed best performance at low-middle frequency region i.e. 1450-2000 Hz. The backed-air gap distances determine the location of sound absorption peak. The peak of absorption tends to shift to the lower frequency region when the air gap thickness is increased.

Keywords: membrane, sound absorption, surface tension, backed-air gap distance.

INTRODUCTION

Sound absorbers are used to reduce or control the sound level in an enclosure. It is also used to prevent generation of echoes or reverberation in the closed room. In the recent years, the sound absorbers that not only good in performance but also light in weight, cheap to be produced, easy to install, low in maintenance, high durability, sustainable and posses aesthetic value has been the subject of interest.

Generally, sound absorbers can be classified into three main types' namely porous absorbers, cavity absorbers and membrane absorbers. Porous absorbers are materials with an open pore structure and commonly made of light and porous materials such as cotton, wool, sponge and fiber (Arenas and Crocker, 2010). Cavity absorbers, also known as Helmholtz absorbers are simply air containers with a narrow neck. The air within the cavity has a vacuum effect at the particular resonant frequency of the enclosed air volume. At the mouth, the pressure is near zero and this generates vacuum effects that absorb sound energy from the surrounding areas (Han, 2008). Membrane absorbers are flexible sheets stretched over rigid supports. The membrane is mounted at some distance from the front of a solid wall. Conversion of sound energy to heat energy takes place through the resistance of the membrane to rapid flexing and to the resistance of the enclosed air to compression (Bolton and Song, 2003). Membrane absorbers can be classified further into permeable, semi-impermeable and impermeable membrane depending on its ability to withstand particles to pass through it. Porous, cavity and membrane type absorbers are found useful for high, middle and low frequency range respectively (Kinsler, 2000).

Due to increasing growth in membrane type absorbers as building materials, extensive works had been done in studying the characteristics of sound absorbers ranging from the tedious process of synthetic or nanofibrous membrane preparation (Mohrova and Kalinova, 2012) to the complicated combinations of the three absorber types. The sound absorption characteristics of membrane absorbers are known to be affected by its mass density, air-backed cavity distance, membrane porosity and size. The sound absorption peaks move toward low frequency region with the increasing of the mass density and depth of air-backed cavity (Gai *et al*., 2013), (Bosman *et al.,* 1999), (Sakagami *et al.,* 1996). The absorption performance improves with increasing size and porosity as well as decreasing mass density (Bolton and Song, 2003). The absorption of a cavity-backed membrane absorber is mainly contributed by the absorption of the membrane's back side (Sakagami *et al*., 1996). If the number of membrane is doubled, the frequency of absorption in wider. Combination of membrane and porous material produced a better absorber (Bolton and Song, 2003). Combination of membrane and porous blanket also produced an improved performance absorber (Thomas and Hurst, 1976). Combination of membrane and panel absorber produced a better and wider absorption than a double panel absorber (Sakagami *et al*., 2005), (Sakagami *et al*., 2011). The behavior of a membrane absorber is determined by a combination of both membrane resonance and Helmholtz resonance (Frommhold *et al*., 1994). The perforated membrane provides better and wider absorption due to better membrane and Helmholtz resonator type effect (Sakagami *et al*., 2014). The sound absorption peak moves towards high frequency region with the increasing of the perforation numbers or perforation sizes (Gai *et al*., 2013).

In this paper, the effects of membrane surface tension and backed-air gap distance on the sound absorption characteristics were presented. The outcome of this study is intended to understand more on the membrane type absorber especially the effect of surface tension and backed-air gap distance on absorption characteristics. The

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membrane surface tension and backed-air gap distance were varied and the sound absorption performances in terms of Sound Absorption Coefficient, α and Noise Reduction Coefficient, NRC were analyzed with respect to the membrane surface tension and backed-air gap distance respectively.

EXPERIMENTAL WORK

Specimens preparation

The experimental works were divided into two separate parts. The first part is to investigate the effect of surface tension on the sound absorption characteristics. In this first part, the specimens have been prepared in five surface tensions; 0 N, 50 N, 100 N, 150 N and 200 N respectively. The surface tensions have been estimated by using Hooke's Law, $F = kx$. The membrane stiffness, k were measured by a simple preliminary force-displacement experiment. Each of the surface tension has been prepared in 2 sizes; large and small. The large size specimen (100 mm in diameter) is for the low frequency test and the small size specimen (28 mm in diameter) is for the high frequency test. The mass surface density, M of the un-stretched membrane is 80 g/m^2. Three specimens for all the membrane tensions were prepared for low and high frequency tests. The average values were then computed. An example of specimen used in the study was illustrated in Figure-1.

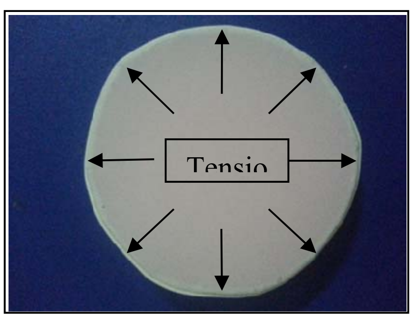

Figure-1. Membrane specimen.

The second part is to investigate the effect of backed-air gap distance on sound absorption characteristics of membrane absorber. The specimens have been tested in four different distances; 0.75 cm, 1.25 cm, 2.25 cm and 3 cm. For this second part, the specimens with 0 N surface tension were used. Figure-2 and Figure-3 show the actual and schematic specimen placement inside the impedance tube.

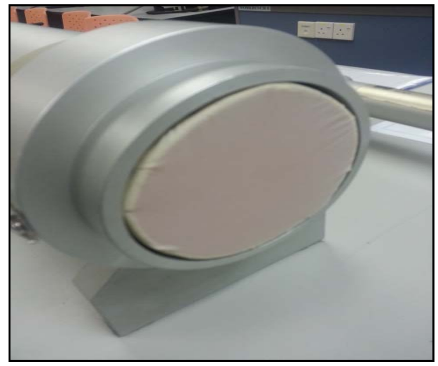

Figure-2. Specimen placement in the impedance tube.

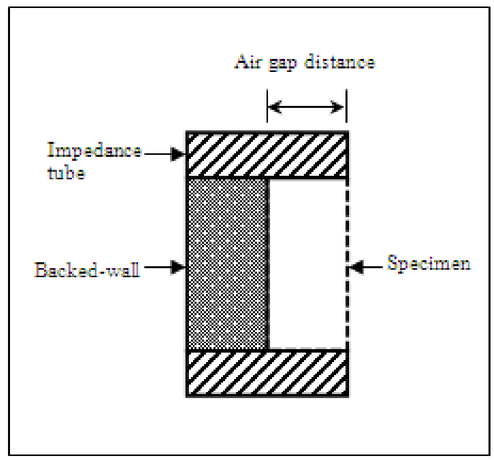

Figure-3. Schematic of specimen placement in the impedance tube.

Sound absorption measurement system

The impedance tube used was SCS9020B system which composed of two sets of tube setup. The large size tube with inner diameter of 100 mm is for low frequency measurement within range of 90 - 1800 Hz and the small size tube with inner diameter of 28 mm is for high frequency measurement within range of 450 - 7100 Hz (Zainulabidin *et al*., 2014), (Zainulabidin *et al.*, 2015). For the surface tension effect analysis, the specimen was placed to a pre-adjusted depth of 1.5 cm from the hard backed-wall at one end of the tube and the loud speaker was placed at the opposite end as a sound source. The two microphones transfer function method according to ISO 10534-2 standard was used to measure the materials sound absorption properties. The measurement systems used in the laboratory work are as illustrated in Figure-4.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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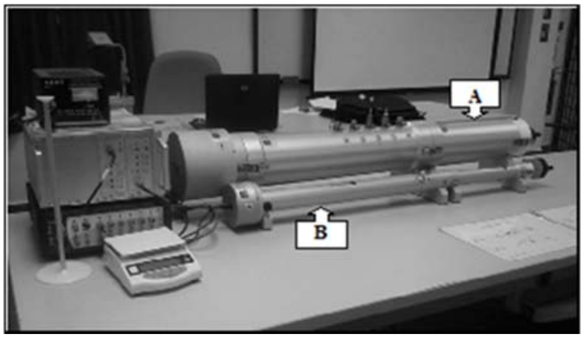

Figure-4. Impedance tubes; **A** for low frequency test and B for high frequency test.

RESULTS AND DISCUSSIONS

Surface tension effect on sound absorption coefficient

Figure-5 to Figure-9 show the effect of membrane surface tension on the Sound Absorption Coefficient, α. Increasing the membrane surface tension make the sound absorption characteristics of the specimen less stable. These observations are due to the excessive vibration of the stretched membrane. The higher the membrane tension the more the vibration level is achieved. As depicted in Figure-5, the specimen with 0 N membrane surface tension performed the best in terms of stability and maximum α value which is 9.4 at 1600 Hz . However the curve is very steep hence the frequency range with good α value (≥0.8) is very narrow i.e. 1450 to 2000 Hz only. The interaction between the membrane and the back-air cavity can be likened to a mass-spring-damper system. At 0 N condition, the sound pressure was in tuned with the mass-spring-damper system. As the tension was increased, the membrane-cavity become stiffer hence the sound pressure become less in tune with the mass-spring-damper system. At out of tuned conditions, the membranes vibrate chaotically which produced unstable absorption characteristics (Figure-6 to Figure-9).

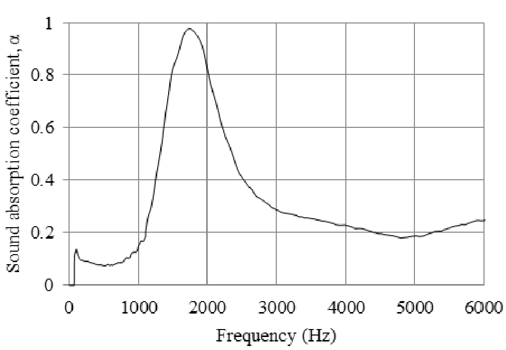

Figure-5. Sound absorption coefficient for 0 N surface tension.

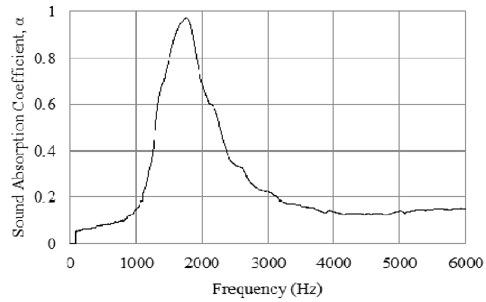

Figure-6. Sound absorption coefficient for 50 N surface tension.

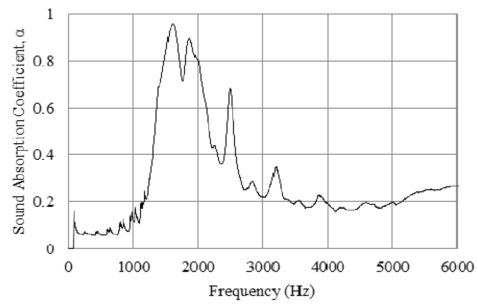

Figure-7. Sound absorption coefficient for 100 N surface tension.

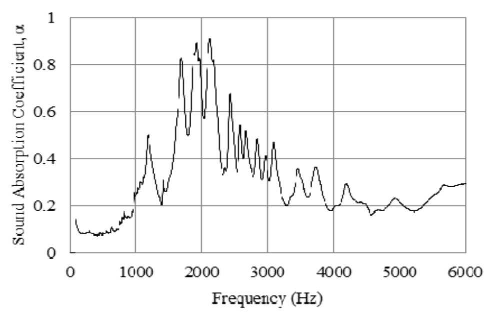

Figure-8. Sound absorption coefficient for 150 N surface tension.

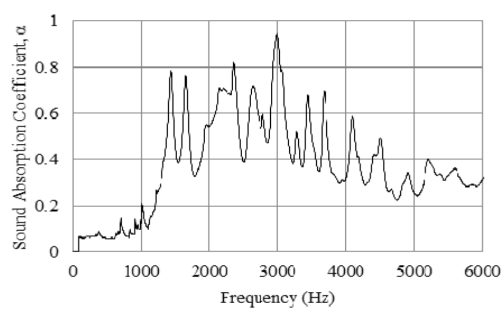

Figure-9. Sound absorption coefficient for 200 N surface tension.

Surface tension effect on noise reduction coefficient

Figure-10 shows the effect of membrane surface tension on the Noise Reduction Coefficient, NRC. The

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specimen with 0 N membrane surface tension has the best NRC value. The specimens with 100 N and 150 N surface tension seem to have good NRC values as well, however these values are not stable due to the fluctuations of its respective α values in Figure-7 and Figure-8. The NRC values for all specimens never exceed 0.3 due to narrow frequency range of good α values. The maximum NRC value is 0.28 at 0 N surface tension.

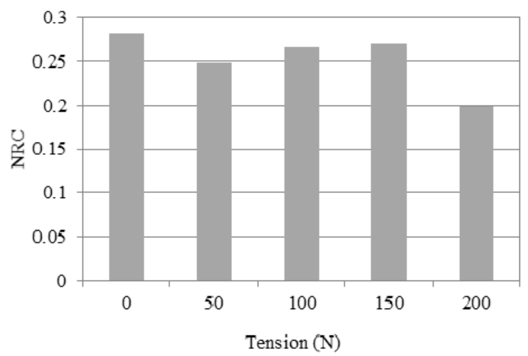

Figure-10. Effect of surface tension on NRC.

Backed-air gap distance effect on sound absorption coefficient

Figure-11 shows the effect of backed-air gap distance on sound absorption coefficient. As the backed-air gap distance of the studied membrane absorber is increased, the peak of sound absorption coefficient move to the left down to a certain frequency. The frequency did not drop much around that concentrated point. As the speed of sound is constant, the lower frequency sound will has longer wavelength. These obervations are consistent with the well known sound wave theory; $v = f\lambda$. The peak value of sound absorption is determined based on how well the membrane and the backed-air gap distance is tuned to its natural frequency. This natural frequency value depends on the material properties of the membrane and the properties of the contained air. The peak frequency or resonance frequency, f_r of diafragm material having an air gap backed by a rigid wall has been predicted by Crocker (2007).

$$f_r \approx \frac{59.5}{\sqrt{Md}} \tag{1}$$

The comparison of this prediction resonance frequency to the frequency obtained experimentally is presented in Figure-12. It can be seen that the formula is valid only for membrane absorber with small backed-air gap distance.

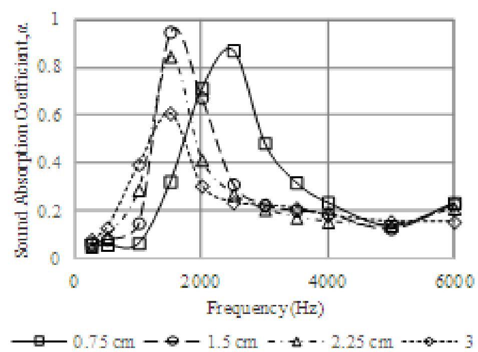

Figure-11. Effect of backed-air gap distance on the sound absorption coefficient.

d (cm)	**α**	***M*** (g/m^2)	***f*** (Hz)	***fr*** (Hz)	**Diff.** (%)
0.75	0.98	83	2378	2385	-0.3
1.5	0.97	83	1663	1686	-1.4
2.25	0.89	83	1400	1377	1.7
3	0.81	83	1388	1192	14.1

Figure-12. Comparison of predicted resonance frequency to the frequency obtained experimentally.

Backed-air gap distance effect on noise reduction coefficient

There is no clear relation between NRC and the backed-air gap distance of the studied membrane absorber. The NRC chracteristics are affected by peak value and the width of sound absorption coeffient against frequency graph. The combination of these parameters determine the values of NRC for each backed-air gap distance. The effect of backed-air gap distance on NRC for four studied distances is presented in Figure-13.

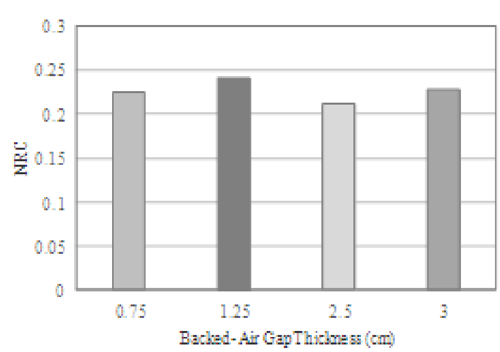

Figure-13. Effect of backed-air gap distance on NRC.

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CONCLUSIONS

The membrane surface tensions and backed-air gap distance have significant influence on the sound absorption characteristics. Membrane with non-stretched surface has better Sound Absorption Coefficient, α and Noise Reduction Coefficient, NRC values over the stretched membranes. The maximum α value obtained is very good which approximately 0.94 at 1600 Hz. The specimens' performance was at its best between 1450 to 2000 Hz. The NRC values for all specimens never exceed 0.3 due to the narrow frequency range of good α values. These findings indicate that for the parameter used in the laboratory work, the un-stretched membrane performed better in absorbing the sound energy. The backed-air gap distance determine the location of sound absorption peak. Increasing the backed-air gap distance will move the absorption peak to the lower frequency down to a certain frequency.

ACKNOWLEDGEMENT

We are grateful for the Universiti Tun Hussein Onn Malaysia funding to the main author.

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