

## Surface Tension Effect on Sound Absorption Characteristics of a Cavity-Backed Semi-Permeable Membrane

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**Abstract.** This paper describes the analysis on the characteristics of semi-permeable membrane sound absorber. The effects of membrane surface tension on the sound absorption characteristics were investigated. The characteristics of the membrane absorber were measured experimentally in terms of Sound Absorption Coefficient,  $\alpha$  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.

### 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. The sound absorption properties depend on the frequency of the sound. This means that certain materials only good in absorbing the sound at a certain frequency. This property is not really favorable since we are exposed with sound from various frequencies.

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. 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. 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. 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 [1].

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 [2] to the complicated combinations of

the three absorber types [3-11]. 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 [3-5]. The absorption performance improves with increasing size and porosity as well as decreasing mass density [6]. The absorption of a cavity-backed membrane absorber is mainly contributed by the absorption of the membrane's back side [5]. If the number of membrane is doubled, the frequency of absorption is wider. Combination of membrane and porous material produced a better absorber [6]. Combination of membrane and porous blanket also produced an improved performance absorber [7]. Combination of membrane and panel absorber produced a better and wider absorption than a double panel absorber [9-11]. The behavior of a membrane absorber is determined by a combination of both membrane resonance and Helmholtz resonance [8]. The perforated membrane provides better and wider absorption due to better membrane and Helmholtz resonator type effect [9-11]. The sound absorption peak moves towards high frequency region with the increasing of the perforation numbers or perforation sizes [3].

In this paper, some works done on the sound absorption analysis of a semi-permeable elastic membrane are presented. The outcome of this study is intended to understand more on the membrane absorber topic especially the effect of surface tension of absorption characteristics. The membrane surface tensions were varied and the sound absorption performances in terms of Sound Absorption Coefficient,  $\alpha$  and Noise Reduction Coefficient, NRC were analyzed with respect to the membrane surface tension. The specimens' preparations are simple, synthetic latex materials that are long lasting, cheap to produce and environmentally friendly as it can also be made of recycled synthetic waste.

### Theory and Formulation

**Sound Absorption Coefficient.** Sound Absorption Coefficient is the measure of how much sound is absorbed by a material. The absorption coefficient can be expressed as:

$$\alpha = 1 - \frac{I_R}{I_I} \quad (1)$$

where  $\alpha$  is the Sound Absorption Coefficient,  $I_R$  is the Reflected Sound Intensity and  $I_I$  is the Incident Sound Intensity. Referring to Eq.1, it can be seen that the sound absorption coefficient,  $\alpha$ , of materials varies in the range of 0 to 1. Value 0 indicates zero sound absorption while value 1 indicates perfect sound absorption. In the case of  $\alpha = 0$ , the sound is completely deflected by the material. On the other hand,  $\alpha = 1$  represents that the sound is completely absorbed by the material.

**Noise Reduction Coefficient.** Noise Reduction Coefficient, NRC is the arithmetic average value of the sound absorption coefficient at frequencies 250, 500, 1000 and 2000 Hz. It represents the ability of a material to absorb sound. Similar to  $\alpha$ , NRC = 0 indicates a perfect sound deflection and NRC = 1 indicates a perfect sound absorption.

$$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \quad (2)$$

### Experimental Analysis

**Specimens preparation.** The specimens have been prepared in five surface tensions; 0 N, 50 N, 100 N, 150 N and 200 N respectively. 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 thickness of the unstretched membrane is 0.04 mm. 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 Fig. 1(a). Fig. 1(b) shows the specimen placement inside the impedance tube.

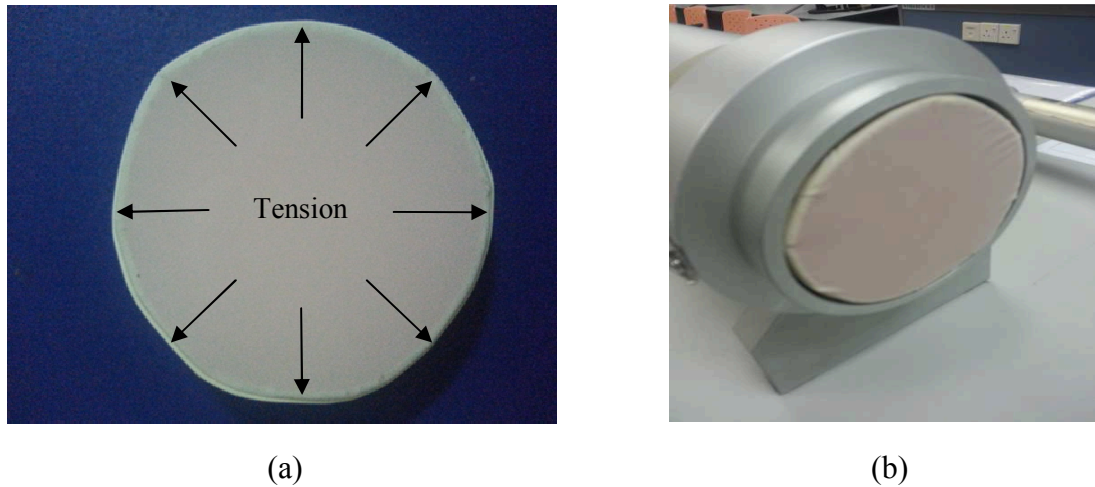


Fig. 1: (a) Membrane specimen; (b) Specimen placement in the impedance tube.

**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 [12]. 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 Fig. 2.

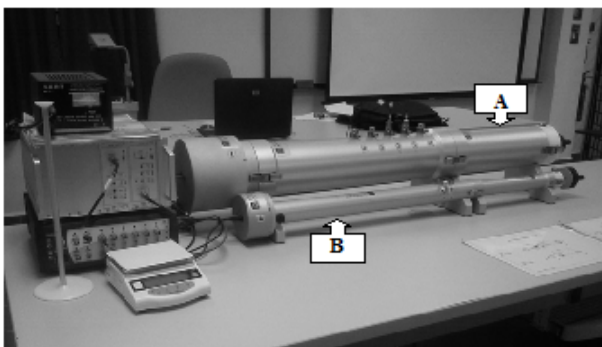


Fig. 2: Impedance tubes; A for low frequency test and B for high frequency test.

## Results and Discussions

**Effect on the Sound Absorption Coefficient,  $\alpha$ .** Fig. 3(a)-(e) shows the effect of the membrane surface tension on the Sound Absorption Coefficient,  $\alpha$ . 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 Fig. 3 (a), the specimen with 0 N membrane surface tension performed the best in terms of stability and maximum  $\alpha$  value which is 9.4 at 1600 Hz . However the curve is very steep hence the frequency range with good  $\alpha$  value ( $\geq 0.8$ ) is very narrow i.e. 1450 to 2000 Hz only. The membrane and the back-air cavity behave like 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 (Fig. 3 (b)-(d)).

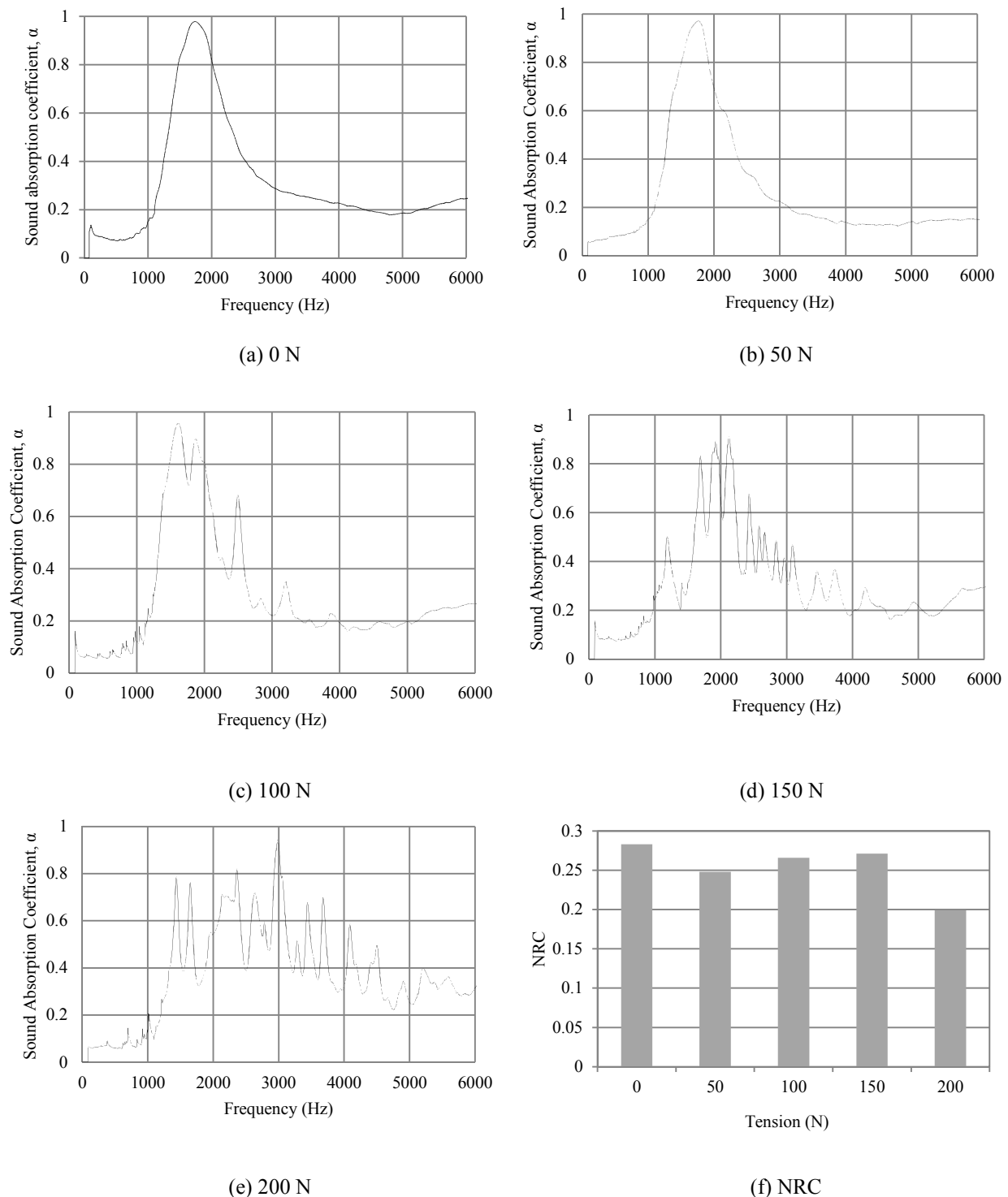


Fig. 3: Effect of membrane tension on the sound absorption characteristics.

**Effect on the Noise Reduction Coefficient, NRC.** Fig. 3(f) shows the effect of membrane surface tension on the Noise Reduction Coefficient, NRC. The 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  $\alpha$  values in Fig. 3(c)-(d). The NRC values for all specimens never exceed 0.3 due to narrow frequency range of good  $\alpha$  values. The maximum NRC value is 0.28 at 0 N surface tension.

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## Conclusion

The membrane surface tensions have significant influence on the sound absorption characteristics. Membrane with non-stretched surface has better Sound Absorption Coefficient,  $\alpha$  and Noise Reduction Coefficient, NRC values over the stretched membranes. The maximum  $\alpha$  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  $\alpha$  values. These findings indicate that for the parameter used in the laboratory work, the un-stretched membrane performed better in absorbing the sound energy.

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