EXPERIMENTAL PARAMETERS STUDY OF MICRO-PERFORATED PANEL AND THE APPLICATION ON VACUUM CLEANER

By:

TING KIN CHOON

(Matrix no: 120423)

Supervisor:

Dr. Ooi Lu Ean

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Universiti Sains Malaysia

DECLARATION

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

dB(A)	A-weighted decibels
Z	Acoustic impedance
D	Backing cavity depth
dB	Decibel
Hz	Hertz
V	Particle velocity
%	Percentage
d	Perforation hole diameter
σ	Perforation ratio
α	Sound absorption coefficient
P	Sound pressure
S	Surface
t	Thickness of MPP

LIST OF NOMENCLATURES

ASTM	American Society for Testing and Materials
BNC	Bayonet-Neill Concelman
DAQ	Data acquisition
ISO	International Organization for Standardization
MPP	Micro-perforated panel
MSE	Mean square error
NIHL	Noise induce hearing loss
NR	Noise reduction
REL	Recommended exposure limit
SA	Simulated annealing
SPL	Sound pressure level
SWL	Sound power level

ABSTRAK

Plat berlubang mikro (MPP) merupakan sejenis penyerap akustik yang boleh digunakan semula, tidak mudah terbakar, dan mesra alam berbanding dengan dengan bahan-bahan berliang tradisional. Nilai kehilangan penhantaran bunyi plat berluang mikro (MPP) bergantung kepada empat parameter reka bentuk utama, iaitu diameter lubang saiz, nisbah keluasan, kedalaman rongga udara dan ketebalan. Tujuan kajian eksperimen ini adalah menganalisasi pekali penyerapan bunyi plat berlubang mikro (MPP) dengan ketebalan yang berterusan dan berbeza diameter lubang saiz, nisbah keluasan, dan kedalaman rongga udara dengan menggunakan kaedah pemindahan fungsi (tiub galangan). Hasil uji kaji meninujukan lubang diameter saiz 0.2 mm memberi rintangan akustik yang besar dan beralih kepada meningkatkan keseluruhan pekali penyerapan bunyi plat berluang mikro (MPP). Kemudian, uji kaji tentang peningkatan nisbah keluasan daripada 0.19% kepada 1.72% meningkatkan pekali penyerapan puncak bunyi dan beralih ke arah frekuensi tinggi. Peningkatan kedalaman sokongan rongga dari 5mm kepada 30mm mengalihkan kekerapan puncak pekali penyerapan bunyi kepada julat frekuensi lebih rendah. Keseluruhan keputusan eksperimen menunjukkan kesepakatan yang baik dengan analisis Maa simulasi model. Akhirnya, parameter reka bentuk plat berlubang mikro dioptimumkan melalui simulasi penyepuhlindapan. Kemudian, parameter reka bentuk dioptimumkan telah digunakan dalam pembersih vakum utiliti kecil dengan kuasa 1800W bagi membuktikan MPP dalam permohonan kehidupan sebenar dan hasil kajian menunjukkan bahawa tahap keseluruhan bunyi dikurangkan sebanyak 2.2dB (A) yang merupakan 2.69% daripada bunyi operasi keseluruhan pembersih vakum.

ABSTRACT

Micro-perforated panel (MPP) are acoustic absorbers that are reclaimable, non-combustible, and environmentally friendly compared with traditional porous materials. The acoustic performance of MPP sound absorber depends on four major design parameters, such as perforation diameter, perforation ratio, air cavity depth, and thickness of the panel. In this experimental study, analysis of sound absorption coefficient of MPP sound absorber at constant thickness with different perforation diameter, perforation ratio and backing cavity were conducted by using transfer function method (impedance tube). The result showed that small perforation diameter 0.2mm give large acoustic resistance which turns to increase the overall sound absorption coefficient of MPP sound absorber. Then, the increase in the perforation ratio from 0.19% to 1.72% increased the sound absorption peak coefficient and shifted toward high frequency. The increasing in the backing cavity depth from 5mm to 30mm was shifted the sound absorption coefficient peak frequency to lower frequency range. Overall, the experimental result showed correlation agreement to Maa model. At the last of the paper, the parameter of MPP was optimized tuned by simulated annealing algorithm. Then, the optimized MPP sound absorber was applied to a small utility vacuum cleaner with power 1800W in order to prove the MPP in real life application and the results showed that the overall noise level reduced by 2.2dB(A) which is 2.69% from the overall operating noise of vacuum cleaner.

Keywords: Micro-Perforated Panel (MPP), Sound Absorption Coefficient, Vacuum Cleaner

1.0 INTRODUCTION

Acoustic treatment on the household appliance is one of the concern issues for noise control engineer. Some of the literature has presented on exposure to noises at or above 85dB can lead to a noise-induced hearing loss (NIHL). A recommended exposure limit (REL) from The National Institute for Occupational Safety and Health (NIOSH) following the standard by Occupational Safety and Health Administration (OSHA) for an exposure level of 85 dB(A) is 8 hours [1]. Besides that, the sound pressure level of household appliance like vacuum cleaner now is typical at the range of 75dB to 90dB which is higher than the normal sound pressure level of human conservation range (60dB-68dB) [2]. Totally, it able cause an environmental noise pollution and affect the user's emotion when last longer use of this kind of household appliance. Hence, the choosing of acoustic treatment material is a bother stage for those engineers who need to consider all the aspect of design, cost, environment, effectiveness, and reliability. Obviously, the porous materials are the promising significant for the acoustic insulation solution [3]. However, there is a drawback of using the porous material as sound absorption material due its limited to clean, combustible, cannot resist to high temperature and humidity environment as its fibres will cause dust and deteriorate in the harsh environment. Meanwhile, the porous material may release fibre into the air that can cause harmful to the human respiratory system [4]. Thus, acoustic engineers are trying to find out the alternative material to replace the porous materials which well performance as fibre materials.

Microperforated panels (MPP) sound absorber is one of the alternative methods for the acoustic treatment due to its reclaimable, non-combustible, and environmentally friendly. The basic and design of MPP were first proposed by Maa [5] who established the approximate theory and general theory to predict the acoustic properties of MPP sound absorbers [6, 7]. MPP sound absorber is a thin panel of any flat metal or plastic plate perforated with a lot of submillimeter holes or slits in order to increase the viscous and thermal losses inside the perforations. Since MPP can be made by thin metallic materials, it can be applied in the harsh environment. MPP sound absorber provides high acoustic resistance and low acoustic mass reactance to tune the sound absorption peak frequency. The sound will attenuate due to viscous friction in the submillimeter size pores. It is most effective when the acoustic resistance is maximum in the submillimeter pores [8].

The mechanism of the MPP sound absorber which is typically backed by an air cavity and a rigid wall is based on Helmholtz resonator principle [9] and its sound absorption performance depends on the parameters such as perforation diameter, air cavity depth, perforation ratio, and thickness of MPP. However, the sound absorption performance of MPP sound absorber is limited to a narrow band of the frequency domain. Thus, some of the researchers studied on the parameters of MPP in order to optimize the used on MPP sound absorber. Hence, optimization is part of the process needed to achieve a final optimal design with all parameters are optimized [10] and there had a successful case of applying simulated annealing technique on the acoustical optimization problem on multiple-layer MPP by ignoring the effect of the microperforated panel vibration [11].

Some literature study showed the application of MPP sound absorber in acoustic treatment. They have been used successfully in the German Parliament Building [12] and are commercially used in construction equipment, building interiors, and mufflers. Besides that, there are a people applied MPP sound absorber knowledge in the design of expansion chamber muffler for small utility engine [13]. Furthermore, MPP sound absorber was used in the MRI scanner instead of porous material for reduction noise during the scanning operation due to hygiene consideration [14]. All these studied showed that the important of MPP sound absorber friendly in acoustic treatment. However, some researchers focus on the simulation studied on the parameters of MPP in order to increase the sound absorption coefficient. They make the system much more complex, like multi-size of perforation in a panel and multi-layer of MPP sound absorber. It makes the MPP sound absorber much more difficult to fabricate and measure experimentally [15, 16].

In this paper, the design parameters perforated hole diameter, perforation ratio, and backing cavity of the flat MPP sound absorber at constant thickness was studied by using Maa model. Then, the flat MPP sound absorber was fabricated and measured by impedance tube to verify the Maa simulated model. Finally, the optimized tuned MPP sound absorber was applied in the vacuum cleaner in order to study the noise reduction via MPP sound absorber in real life application.

2.0 THEORY

The acoustic impedance, sound absorption coefficient and the mathematical model development for the MPP sound absorber were presented.

2.1 Acoustic Impedance

Acoustic impedance is the ratio of the acoustic pressure and particle velocity of an acoustic wave impinge on the surface. Mathematically, acoustic impedance, Z, is the ratio of sound pressure, P, to the particle velocity, V, and the surface area, S, of the propagation medium at the particular frequency. The acoustic impedance equation is shown as below:

$$Z = \frac{P}{VS} \tag{1}$$

The acoustic impedance consists of the real and the imaginary part components analogous to those in the electrical impedance. The real part, R, of the acoustic impedance is known as acoustic resistance whereas the imaginary part is the acoustic reactant, M, [17] was written the complex acoustic resistance as below:

$$Z = R + jM \tag{2}$$

2.2 Sound Absorption Coefficient

Sound absorption coefficient, α which is defined as the ratio of sound energy absorbed by the surface material to the incident sound energy on the material. It measures the sound absorption of different medium when the sound propagates through the material. The range of the sound absorption coefficient is from zero to one. **Figure 1** shows the transmission of the incident sound wave at the boundary between two mediums.

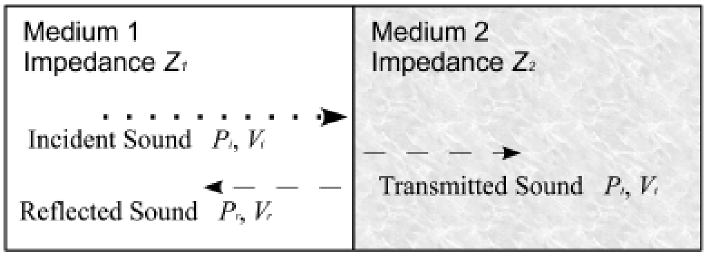


Figure 1. Reflection and transmission of incident sound wave between two mediums

The transmitted sound pressure, P_t is the sum of the incident sound pressure, P_i and reflected sound pressure, P_r. Whereas the transmitted velocity, V_t is the sum of the incident sound velocity, V_i and reflected sound velocity, -V_r. The mathematical equation is shown below:

$$P_t = P_i + P_r \tag{3}$$

$$V_t = V_i + (-V_r) \tag{4}$$

The incident and reflected sound wave propagating in medium 1 and transmitted sound wave propagated in medium 2 will give the acoustic impedance which is $Z_1 and\ Z_2$. The definition of the velocity is the ratio of sound pressure to the acoustic impedance. Thus, a velocity was showed in term of the acoustic impedance was showed below:

$$V_t = \frac{P_i - P_r}{Z_1} \tag{5}$$

In order to obtain the sound absorption coefficient in terms of acoustic impedance, the mathematical model is showed as below:

$$r_p = \frac{P_r}{P_i} = \frac{Z_2 - Z_1}{Z_1 + Z_2} \tag{6}$$

where r_p is the sound pressure reflection coefficient. Then, the relationship between the sound absorption coefficient and sound pressure reflection coefficient was showed as below [3]:

$$\alpha = 1 - \left|r_p\right|^2$$

$$= 1 - \frac{Z_2 - Z_1}{Z_1 + Z_2} \tag{7}$$

2.3 Mathematical Model Development for the MPP

There are four parameters which can affect the sound absorption coefficient of the MPP sound absorber. The four parameters are the perforation diameter, d, thickness of the plate, t, perforation ratio, σ, and backing cavity, D. **Figure 2** shows the four parameters that built up the MPP sound absorber. The sound absorption coefficient of MPP sound absorber is related to the acoustic impedance of the micro-perforation and the backing cavity depth.

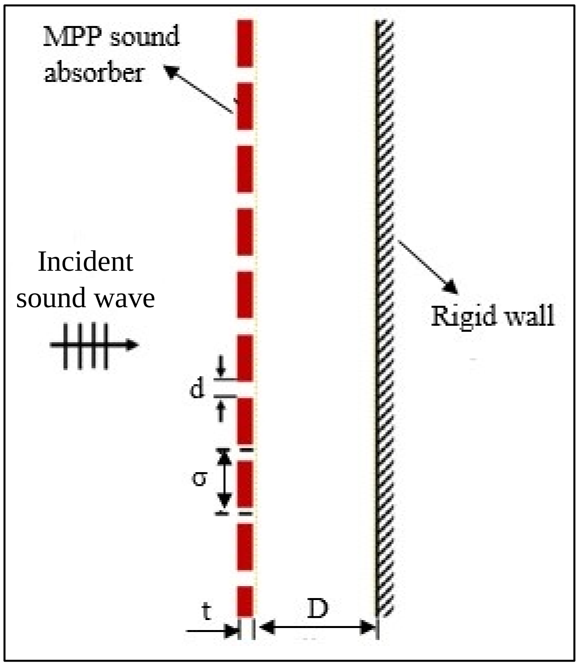


Figure 2. The parameters of MPP sound absorption coefficient modelling

Figure 3 showed the electro-acoustical equivalent circuit of MPP. MPP acoustic impedance in the complex quantity is analogous to those in electrical impedance. In applying this analogy, the real part of the MPP acoustic impedance is termed acoustic resistance, R, and the imaginary part is termed acoustic reactance, M. The similar analogy is also applied to the backed air cavity. According to Maa [16], the acoustic impedance of the perforations on the plate can be written as below:

$$Z_{mpp} = \mathrm{Re}(Z_{mpp}) + \mathrm{Im}(Z_{mpp})$$
$$= R + jM \quad (8)$$

Where,

$$R = \frac{32\mu t}{p_o c d^2}\left[\sqrt{1 + \frac{x^2}{32}} + x\frac{\sqrt{2}d}{8t}\right]$$

$$M = \frac{wt}{c}\left[1 + \frac{1}{\sqrt{x^2 + \frac{x^2}{2}}} + 0.85\frac{d}{t}\right]$$

Where μ = kinematic viscosity

p_o = density of air

c = speed of sound

w = frequency of sound

Where the perforation constant, $x = \sqrt{\frac{P_o w}{4\mu}}$. It is defined as the ratio of perforation diameter to the viscous boundary layer thickness of the air in the perforation.

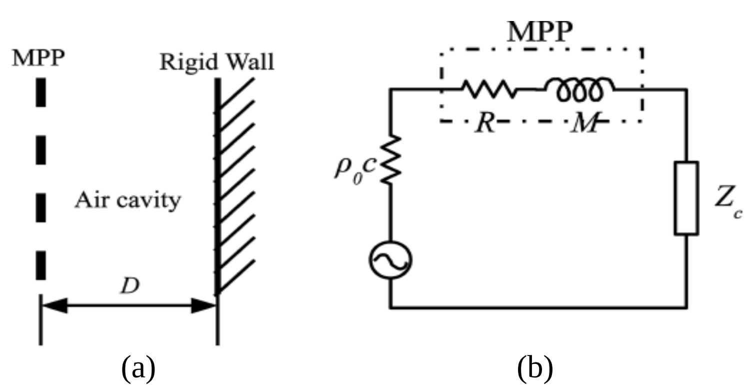


Figure 3. (a) Typical configuration of an MPP sound absorber and (b) its electro-acoustical equivalent circuit *[5]*

The acoustic impedance for the backed air cavity MPP, Z_c [5] is as below:

$$Z_c = -jcot(kD) \tag{9}$$

where k = wave number

D = backing cavity depth

The resulting total acoustic impedance of the MPP sound absorber, Z_{total}, is the summation of the acoustic impedance of MPP, Z_{mpp}, and acoustic impedance of the backing air, Z_c. The mathematical model is shown below:

$$Z_{total} = Z_{mpp} + Z_c \tag{10}$$

Hence, the sound absorption coefficient of the MPP sound absorber was calculated by applied Z_{total} as below:

$$\alpha = \frac{4Re(Z_{total})}{(1 + Re(Z_{total})^2 + (Im(Z_{total})^2} \tag{11}$$

2.4 Optimization Using Simulated Annealing

Figure 4 shows the application of SA optimization solver in Matlab is used to maximize the mean sound absorption coefficient of MPP for a prescribed frequency range in this project. The first step towards the optimization of a MPP sound absorber is to describe possible configurations of the constitutive parameters of the absorber within a variation range: the perforation diameter ($d_{min,}$ d_{max}), the thickness of plate ($t_{min,}$ t_{max}), the perforation ratio ($\sigma_{min,}$ σ_{max}) and air cavity depth ($D_{min,}$ D_{max}). Then, the objective function of the system must be defined. The algorithm developed for this paper defines the objective function as the mean value of the absorption coefficient for a prescribed frequency range ($f_{1,}$ f_2). Due the SA algorithm finds the minimum of function, then the condition of the Metropolis algorithm must be changed to find the maximum mean absorption. This is done by defining $\Delta F = F(X_l) - F(X_l')$. The initial temperature, T_o, the cooling rate, y, and the function tolerance, Ft_{final}, are pre-set and a random initial solution, X_l, is generated to start the simulated annealing optimization algorithm. In order to simulate the evolution of the simulated annealing algorithm, a new random solution, X_l', is chosen from the neighborhood of the current solution. The resulting change in the energy, ΔF, or objective function decides to accept or reject the new random solution. If ΔF ≤ 0, the new solution is accepted as the new current solution for the next iteration. However, if ΔF ≥ 0, the new solution is accepted by referring the Boltzmann's factor $(P(T) = exp(\Delta F/BT))$ in which the ΔF, B, and T are the difference of the objection function, Boltzmann constant, and current temperature respectively. The random number, r, is generated in the interval [0, 1] and is used to compare with $P(T)$. If $P(T) \geq r$, the new random solution is retained, else it is discarded and the existing solution is maintained in the next iteration of the algorithm. This step to avoid the searching process is trapped in a local maximum. The current temperature will be decreased for every successful replacement of the new current solution by referring to $T_{new} = yT_{old}$. The iteration is repeated until the function tolerance is reached. Then, the design parameters of MPP sound absorber is optically tuned.

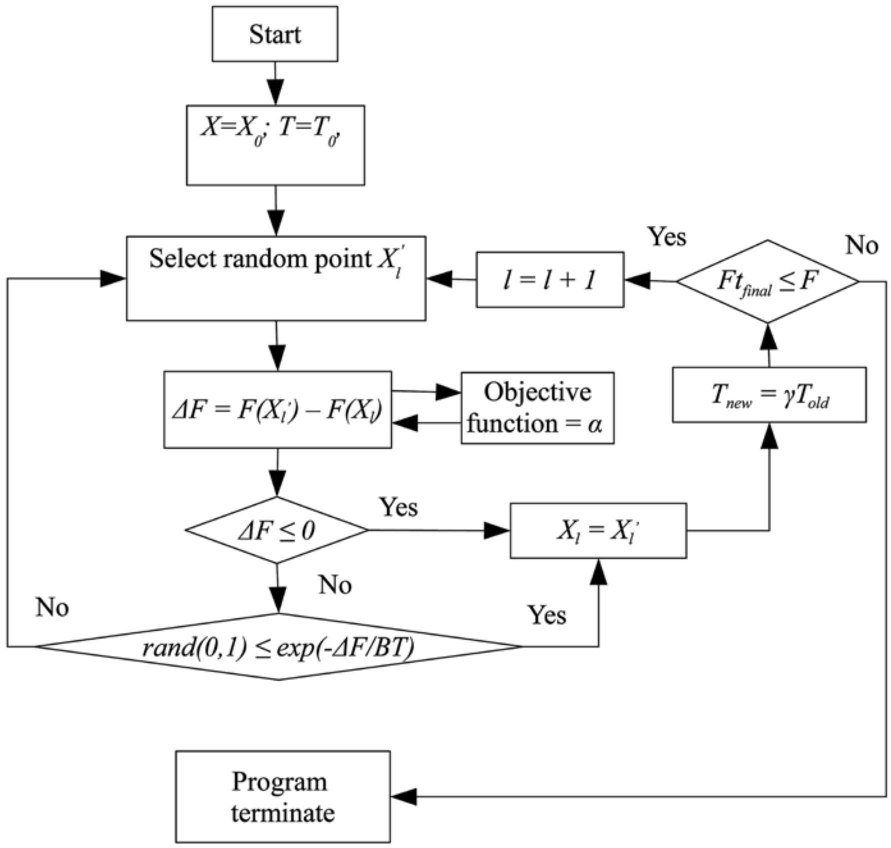


Figure 4. The flow chart of simulated annealing algorithm

3.0 METHODOLOGY

The effect of MPP sound absorber's parameters was studied and simulated by Maa model then was verified by measured experimentally via impedance tube. Besides that, The MPP sound absorber was optimized and applied in vacuum cleaner to reduce its operating noise. In this project, aluminium plate 1050 with characteristic 0.5mm thickness and a light weighted SC5400 Canister Vacuum Cleaner with 1800 Watts motor power were used throughout the whole experiment processes.

3.1 Theoretical Calculation

The effect of the four parameters on the sound absorption is calculated by using **Equation 11**. The four parameters are perforated hole diameter, porosity ratio, backing cavity and thickness. The MPP sound absorber with constant thickness of 0.5mm is used throughout the experiment due to study the other three parameters at constant thickness on the sound absorption and to ease the fabrication work. Hence, three parameters study were listed as below:

a. Relationship between sound absorption coefficient and perforation diameter

Eight MPP aluminium plate with different perforated diameter (0.2mm, 0.3mm, 0.4mm, 0.5mm, 0.6mm, 0.7mm, 0.8mm, and 0.9mm) but constant perforation ratio (0.96%) and backing cavity (20mm) were simulated by using Maa model to study the effect of perforated hole diameter on the sound absorption coefficient value.

b. Relationship between sound absorption coefficient and perforation ratio

Seven MPP aluminium plates with different perforation ratios (0.19%, 0.24%, 0.32%, 0.43%, 0.62%, 0.96%, and 1.72%) but constant perforated diameter (0.4mm) and backing cavity (20mm) were simulated by using Maa model to study the effect of perforation ratio on the sound absorption coefficient value.

c. Relationship between sound absorption coefficient and backing cavity

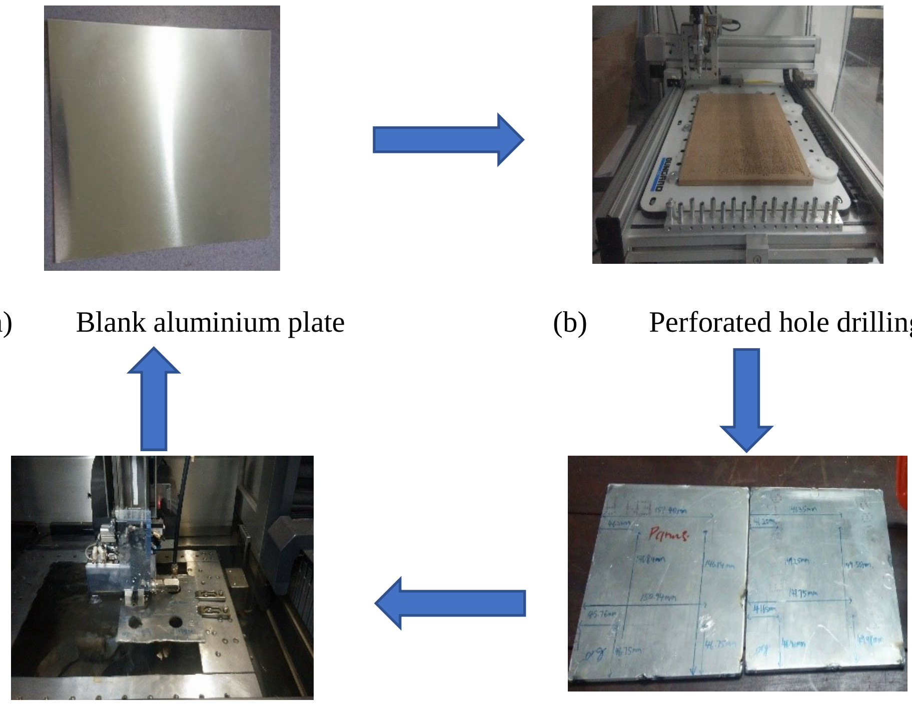
One MPP aluminium plate with different backing cavities (5mm, 10mm, 15mm, 20mm, 25mm, and 30mm) but constant perforated diameter (0.4mm) and perforation ratio (1.72%) were simulated by using Maa model to study the effect of the backing cavity on the sound absorption coefficient value.

3.2 Experimental Measurement

In this section, the MPP sound absorber was fabricated with different parameter configuration. Then, the measurement sound absorption coefficient on each MPP was conducted by using impedance tube. The experimental result obtained was used to verify the simulated result based on Maa model.

3.2.1 Fabrication Method of MPP Circle Plate

Firstly, an aluminium plate with 20mm x 20mm was prepared. Then, a CNC Drilling Machine RoutePro 3000 was used to drill hole on the plate at desired diameter that was drawn by using Autocad Eagle Software. The MPP plate with the perforated hole was sandwiched between 2 thick aluminium plate with thickness 4mm each other. A marking of the centre point of MPP circle is drawn on the upper surface of the thick aluminium plate before welded altogether by using gas welding. Finally, the whole sandwiched aluminium plate was cut into circle shape at the diameter of impedance tube of 34.85mm by using Electrical Discharge Machining (EDM) with reference from the centre marking. **Figure 5** showed the process flow of the MPP circle plate fabrication method. **Table 1** showed the list of seven fabricated MPP circle plate with different design parameters.



(a) Blank aluminium plate

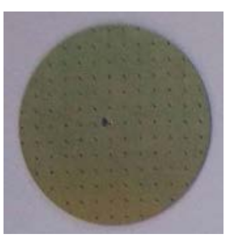
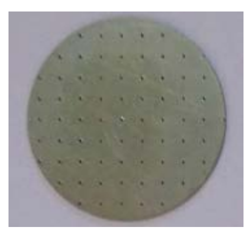
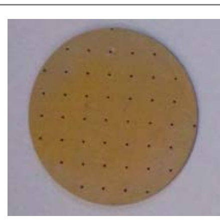
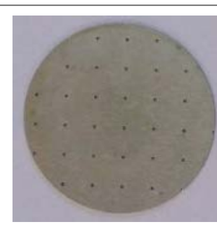
(b) Perforated hole drilling

(d) EDM wire cut

(c) Welded sandwiched MPP between two thick aluminium

Figure 5. Fabrication process of MPP circle plate

Table 1. List of fabricated MPP for sound absorption test

(A)		d = 0.4mm σ = 1.72% t = 0.5mm	(B)		d = 0.4mm σ = 0.96% t = 0.5mm
(C)		d = 0.4mm σ = 0.43% t = 0.5mm	(D)		d = 0.4mm σ = 0.19% t = 0.5mm
(E)		d = 0.5mm σ = 0.96% t = 0.5mm	(F)		d = 0.6mm σ = 0.96% t = 0.5mm

(G)		d = 0.9mm σ = 0.96% t = 0.5mm

3.2.2 Transfer Function Method of Sound Absorption Coefficient Measurement

Impedance tube was used to conduct the sound absorption test to determine the sound absorption coefficient (α) of different configuration MPP parameters that showed in **Table 1**. Impedance tube is a standing wave tube that allows a determination of the normal incidence of impedance surface and absorption coefficient under a controlled condition. However, **Figure 6** showed a transfer function (ISO 10534-2) method that used in this experiment because it is faster and accurate to determine the sound absorption coefficient and applicable over a wide frequency range [18]. There are two plane waves generated by the sound source (speaker), which are incident and reflected sound waves exist in the tube. The prepared MPP circle plate was inserted into the sample holder, which then was locked with the tube termination. The backing cavity of the MPP circle plate was changed by adjusting the distance of the piston at termination tube. The distances from the MPP to each microphone was described as X_1 and X_2.

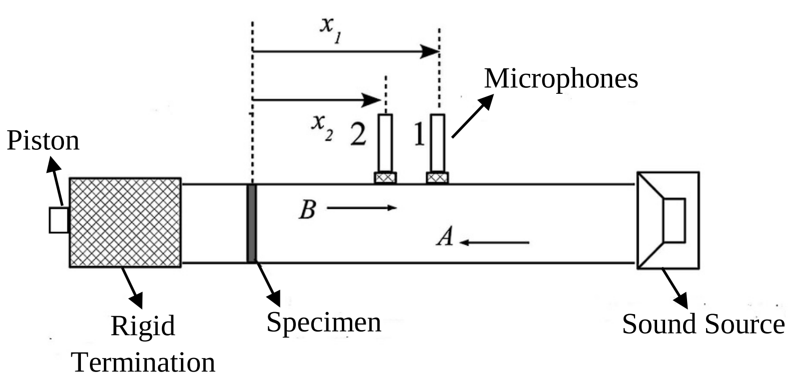


Figure 6. Transfer function method of sound absorption coefficient measurement

Figure 7 showed the experiment set up with two calibrated microphones connected to the data acquisition Scadas Mobile (DAQ). The sound absorption coefficient value obtained in experimental measurement was used to verify the predicted result obtained in theoretical measurement.

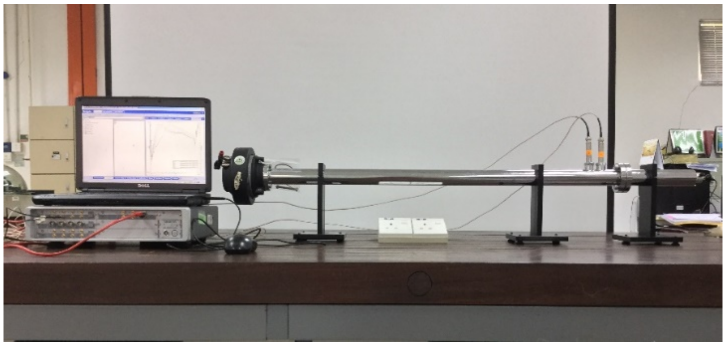


Figure 7. Setup of impedance tube device

3.3 Application of MPP in Vacuum Cleaner

3.3.1 Noise Source Identification

"Microflown Technologies" is a software that used to measure the entire range of the acoustical properties like sound velocity and sound pressure. It was used as one of the noise source identification method for vacuum cleaner in this project. **Figure 8** showed the overall experimental set up for this measurement. The data acquisition (DAQ) was connected to the software and the camera that mounted on a tripod. Then, the Bayonet Neill-Concelman (BNC) connector was used to connect the 2 channel Signal Conditioner to DAQ and PU Probe. The weighted sound pressure level dB(A) of the vacuum cleaner was determined by using PU Probe to scan the bottom surface, the top surface and the front surface of the operated vacuum cleaner. During scanning the sound, PU probe distance should be 1cm away from the surface vacuum cleaner in order to obtain a more accurate result. The measurement result was showed in the sound mapping and total average power spectrum of sound pressure level. Finally, the sound mapping result was compared to identify the noisy part of the vacuum cleaner.

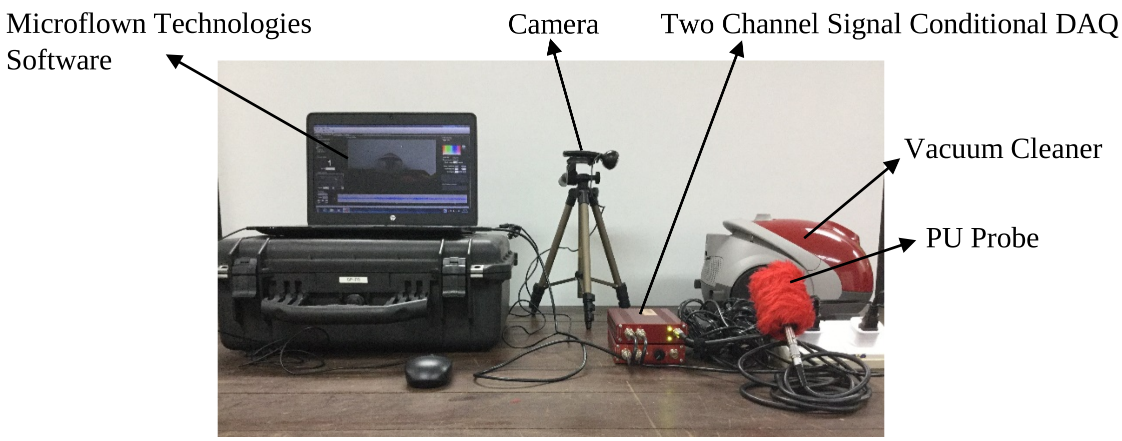
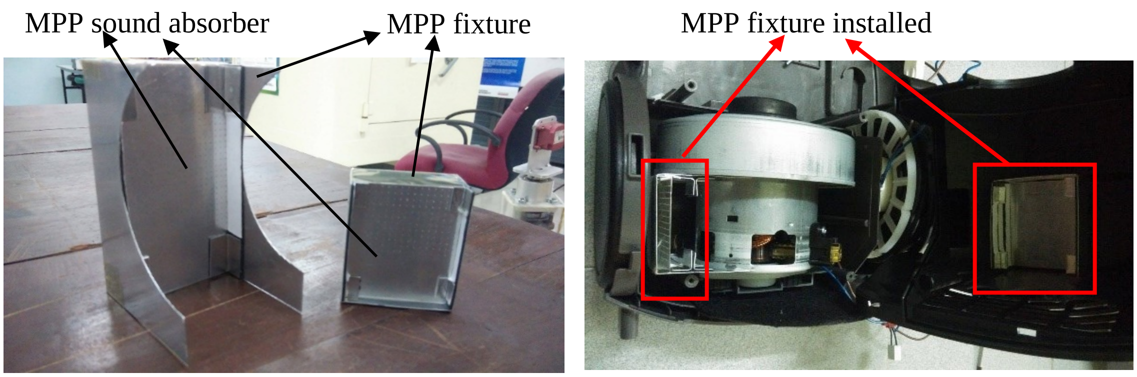


Figure 8. Experiment set up for noise source identification

3.3.2 Installation of MPP and fixture in the vacuum cleaner

After the noise source is identified, the MPP sound absorber is installed around the location of the motor part due to the measurement result of **Section 3.3.1** identified that the noisy part is vacuum cleaner’s motor. Whereas, the available space around the motor part was measured and used as a reference boundaries dimension for optimizing the MPP’s parameter by using simulated annealing algorithm. **Figure 9** showed the optimized MPP was fabricated in rectangle size and secured into the MPP fixture then was installed in the vacuum cleaner.

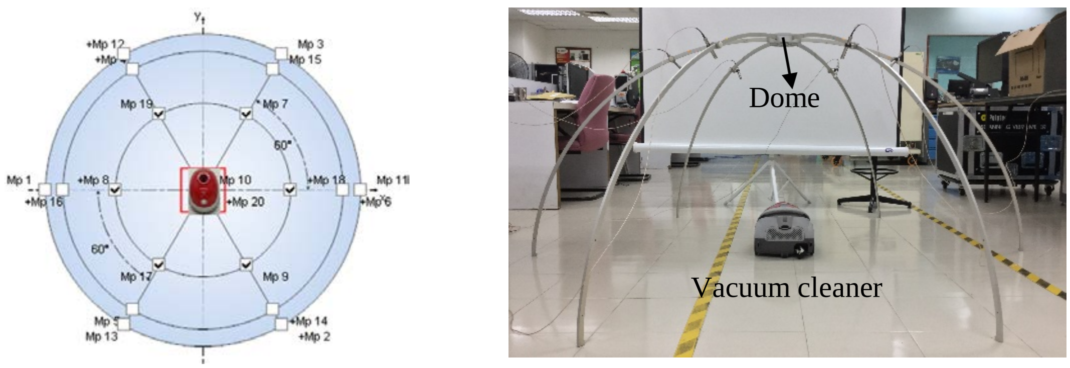


(a) (b)

Figure 9. Installation of MPP; (a) MPP secure in MPP fixture (b) Installation of MPP and fixture in vacuum cleaner

3.3.3 Overall Noise Level Measurement

The overall noise level produced by vacuum cleaner at its operating frequency was measured by LMS dome test. The sound power is determined by using a direct method in a reverberation room (a large room), which follows the ISO 3742 standard. **Figure 10** showed the experimental set up for the overall noise level identification. Six microphones were attached to the dome which the microphone's position are in equal areas on the surface of a dome. This configuration has followed the standard for sound power determination proposed by Erik Cletus Petersen, Brüel and Kjaer [19]. Each microphone has located one meter away from the vacuum cleaner by following the standard of KSC 9101 [20]. Meanwhile, each of the microphones was connected to the Scadas Mobile, a data acquisition device and then connected to the LMS software. Then, the vacuum cleaner is placed in the centre of the dome and all the microphones were calibrated before the measurement started. During the experiment, the background noise will be measured 1st then followed by the operating vacuum cleaner. Then, the overall noise of the vacuum cleaner was analysed after deducting the background noise. Finally, the overall noise in sound power level (SWL) and sound pressure level (SPL) of the vacuum cleaner were recorded before and after the installation of the MPP to identify the overall noise reduction by MPP.



(a) (b)

Figure 10. Configuration of microphone position; (a) in the software and (b) in the experimental setup

4.0 RESULT AND DISCUSSION

4.1 Simulation Parameter's Study of MPP Sound Absorber

a. Relationship between sound absorption coefficient and perforation diameter

Figure 11 showed that the change in the sound absorption coefficient value for eight MPP aluminium circle plate with different perforated diameter (0.2mm, 0.3mm, 0.4mm, 0.5mm, 0.6mm, 0.7mm, 0.8mm, and 0.9mm) at constant perforation ratio (0.96%) and backing cavity (20mm) along sound frequency from 0Hz to 5000Hz. The sound frequency studied was based on the impedance tube sound play frequency. Among the eight MPP, the simulated sound absorption coefficient peak value was in the range of 0.923 to 0.985 and located at a sound frequency around 1200Hz. But, the overall sound absorption coefficient is maximised when the diameter is 0.2mm. However, the simulated overall sound absorption coefficient increased when the diameter of the perforated hole decreased from 0.9mm to 0.2mm due high acoustic resistance and low mass reactance when the perforated hole diameter becomes smaller. The increasing in the acoustic resistance causes more vibration of air molecules at the viscous thermal boundary layers (panel surface) thus enhance the sound absorption of MPP and lead to high sound absorption coefficient [5]. Hence, at constant porosity ratio, the smaller the diameter of the perforated hole of MPP sound absorber, the larger of the overall sound absorption coefficient value.

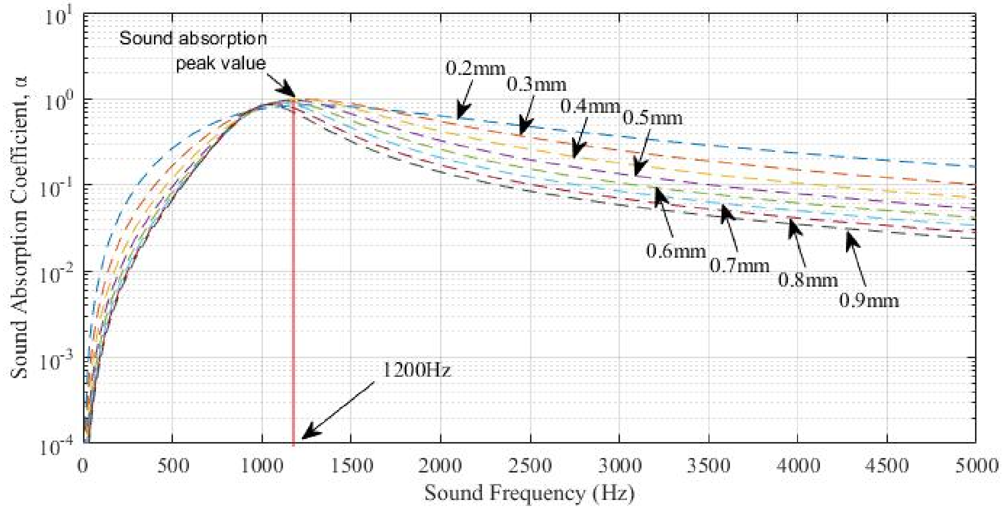


Figure 11. Graph of simulation study on sound absorption coefficient with different perforated diameter

b. Relationship between sound absorption coefficient and perforation ratio

Figure 12 showed the relationship between sound absorption coefficient value at seven different porosity ratios (0.19%, 0.24%, 0.32%, 0.43%, 0.62%, 0.96%, and 1.72%) at constant perforated diameter (0.4mm) and backing cavity (20mm). At perforation ratio, 0.19%, the sound absorption coefficient peak value is 0.674 which is located at sound frequency 520Hz. However, the sound absorption coefficient peak value at porosity 1.72% is 0.978 and located at sound frequency 1590Hz. The overall trend showed simulated sound absorption peak value increased with increasing perforation ratio. Besides that, the simulated sound absorption peak value is shifted little to higher sound frequency when the perforation ratio increased from 0.19% to 1.72%. The trend of the simulated result correlated to literature study from D. Borelli, C. Schenone [21]. Thus, the increase in the perforation ratio will increase the sound absorption coefficient peak value and border the sound absorption coefficient peak frequency range.

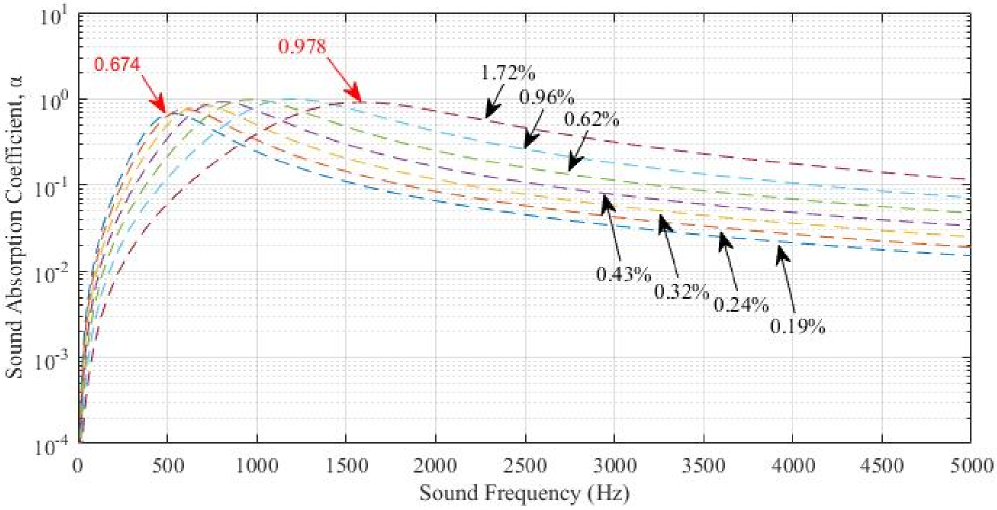


Figure 12. Graph of simulation study on sound absorption coefficient with different perforation ratio

c. Relationship between sound absorption coefficient and backing cavity

Figure 13 showed the effect of backing cavity distance (5mm, 10mm, 15mm, 20mm, 25mm, and 30mm) on the simulated sound absorption coefficient at constant perforated diameter (0.4mm) and constant perforation ratio (1.72%). From the results, the sound absorption peak values for six different backing depth cavities was almost same at 0.935. There was showed the sound absorption coefficient peak value at backing cavity 5mm located at sound frequency 3325Hz whereas the sound absorption peak value for backing cavity 30mm was located at sound frequency 1350Hz. The simulated sound absorption coefficient peak value shifted to the left side (lower sound frequency) when the backing cavity increased. Meanwhile, there is less effect on the changing in the sound absorption coefficient peak value when a change in backing cavity because there was no change in perforated hole diameter and perforation ratio. Changing the backing cavity depth only modifies the imaginary part of MPP and the particle velocity in the pores is maximum when the backing cavity depth is approximately one-quarter acoustic wavelength. Therefore, the cavity depth dictated the frequency at which the acoustic particle velocity is maximum. The simulated result also correlated to frequency bands on the effect of changing the cavity depth on the absorption coefficient for an MPP absorber while holding perforation ratio and hole diameter constant at 1.5% and 0.25mm respectively [8]. The observation showed the increase at the backing cavity could be used in reducing the low frequency noise as it shifted the sound absorption coefficient to lower frequency range.

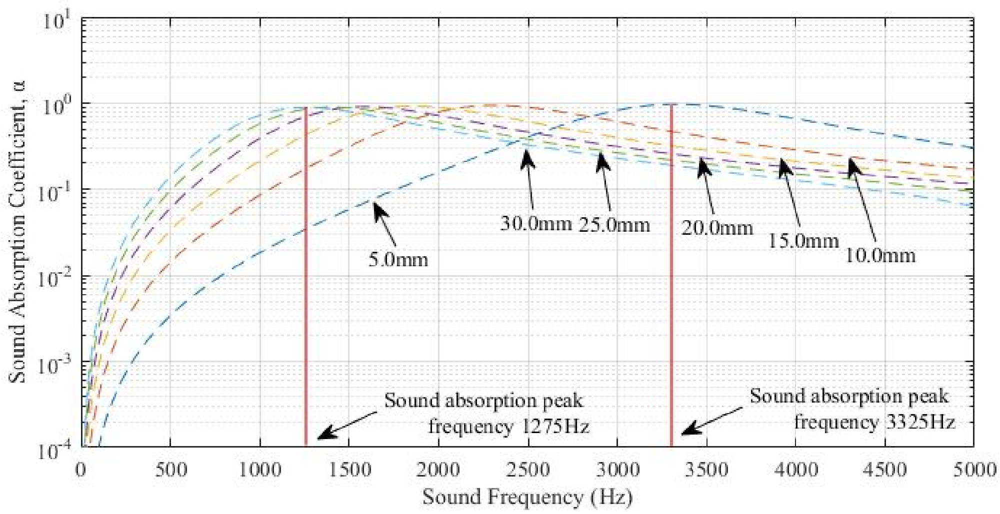


Figure 13. Graph of simulation study on sound absorption coefficient with different backing cavity

4.2 Experimental Parameter's Study of MPP Sound Absorber

a. Relationship between sound absorption coefficient and perforation diameter

Figure 14 showed the experimental measurement of the sound absorption coefficient of four microperforated panels (MPP) with different perforated hole diameter (0.4mm, 0.5mm, 0.6mm, and 0.9mm) at constant perforation ratio (0.96%) and constant backing cavity (20mm) to verify the four selected simulated results obtained in **Figure 11**. Meanwhile, **Table 2** showed percentage error between the four simulated and measured sound absorption coefficient peak values at different perforated hole diameter is less than 20%.

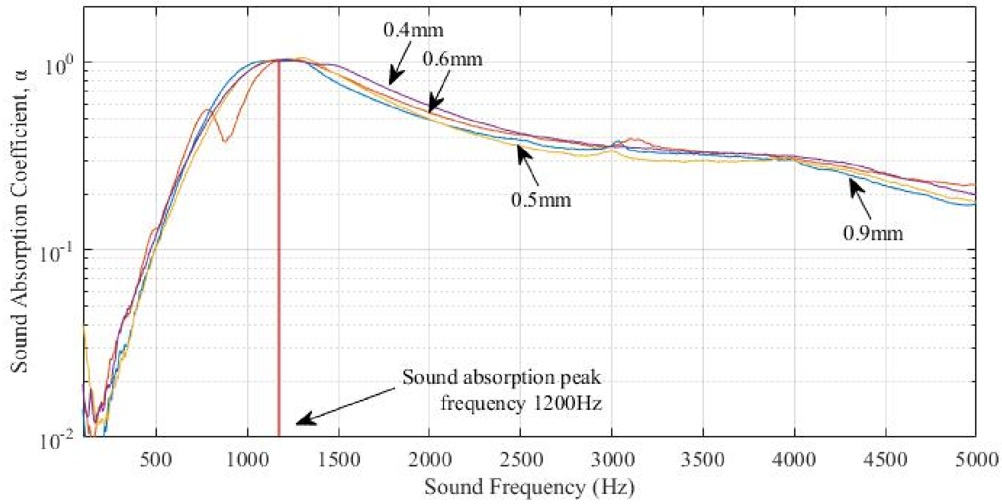


Figure 14. Graph of experimental study on sound absorption coefficient with different perforated diameter

Table 2. Percentage difference of sound absorption coefficient peak value between simulation and experimental at different perforated diameter

Perforated diameter (mm)	Simulation result	Experimental result	Percentage error (%)
0.4	0.996	1.040	4.23
0.5	0.968	1.040	6.92
0.6	0.934	1.040	10.19
0.9	0.851	1.030	17.38

b. Relationship between sound absorption coefficient and perforation ratio

Figure 15 showed that the experimental measurement of the sound absorption coefficient of four microperforated panels (MPP) with different perforation ratio (0.19%, 0.43%, 0.96%, 1.72%) at constant perforated hole diameter (0.4mm) and constant backing cavity (20mm) to verify the four selected simulated results obtained in **Figure 12**. The trend of the measured result was correlated with the four selected simulated results in

Figure 12 but there was some fluctuation of the sound absorption value obtained. Then, **Table 3** showed the percentage error between the four simulated and measured sound absorption coefficient peak values at different perforation ratio is less than 20%.

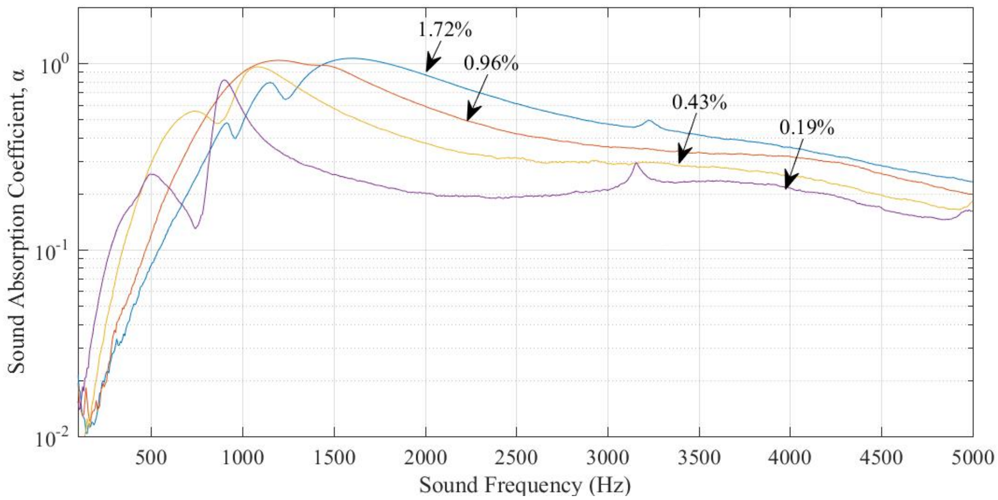


Figure 15. Graph of experimental study on sound absorption coefficient with different perforation ratio

Table 3. Percentage difference of sound absorption coefficient peak value between simulation and experimental at different perforation ratio

Porosity Ratio (%)	Simulation result	Experimental result	Percentage error (%)
0.19	0.674	0.815	17.30
0.42	0.916	0.952	3.78
0.96	0.996	1.030	3.30
1.72	0.910	1.060	14.15

c. Relationship between sound absorption coefficient and backing cavity

Figure 16 showed that the experimental measurement of the sound absorption coefficient of one microperforated panel (MPP) with five different backing cavities (5mm, 10mm, 15mm, 20mm, and 25mm) at constant perforated hole diameter (0.4mm) and constant perforation ratio (1.72%) to verify the five selected simulated results obtained in