



Faculty of Mechanical Engineering

**MODELING SOUND ABSORPTION OF MICRO-PERFORATED
PANEL USING WAVE PROPAGATION METHOD**

Muhammad Sajidin Py

Master of Science in Mechanical Engineering

2015

**MODELING SOUND ABSORPTION OF MICRO-PERFORATED PANEL USING
WAVE PROPAGATION METHOD**

MUHAMMAD SAJIDIN PY

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Mechanical Engineering**

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

DECLARATION

I declare that this thesis entitled "Modeling Sound Absorption of Micro-perforated Panel Using Wave Propagation Method" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering

Signature :

Supervisor Name :

Date :

DEDICATION

"To my beloved mother and father"

ABSTRACT

A micro-perforated panel (MPP) absorber has been known widely as an alternative absorber to the conventional fibrous type acoustic material. The MPP system is arranged with distance from a rigid wall to provide an air gap layer. Several theoretical approaches to predict the sound absorption of the MPP have been published. In particular for the double MPPs, approximate expression for the air gap impedance is used which yields deviation in the result when it is compared with the experiment. In this study, wave propagation technique is proposed to represent the behaviour of sound incident and reflected in the MPP system. The motion of the MPP is also included in the model. The proposed models provide an attractive technique to predict the sound absorption as well as the transmission and reflection. The MPP can be set to be a solid panel by adjusting the impedance of the holes to infinity and the solid panel can be turned into a rigid wall by setting the panel impedance to infinity. The model can be applied for the single MPP and multi-layer MPPs; a stand-alone system without rigid wall as well as the system backed with a rigid wall. The results for the MPP system backed by a rigid wall then is compared with experimental data. It is found that the result from the wave propagation technique has a better good agreement with the experiment at higher frequency.

ABSTRAK

Penyerap panel bertebuk mikro (MPP) telah dikenali secara meluas sebagai sistem penyerap suara alternatif kepada bahan akustik konvensional dari jenis serat. Sistem MPP disusun pada jarak tertentu dari dinding untuk menghasilkan lapisan ruang udara. Beberapa pendekatan secara teori untuk meramalkan penyerapan bunyi bagi MPP telah diterbitkan. Persamaan anggaran untuk impedans ruang udara digunakan, khususnya bagi dua lapisan MPP yang menghasilkan sisihan di antara teori dan eksperimen. Dalam kajian ini, teknik perambatan gelombang dicadangkan bagi menerangkan tingkah laku bunyi langsung dan pantulan bunyi dalam sistem MPP. Pergerakan MPP juga disertakan ke dalam model. Model yang dicadangkan menyediakan satu teknik yang menarik untuk meramalkan penyerapan bunyi serta penghantaran dan pantulan. MPP juga boleh disesuaikan menjadi panel yang kukuh dengan mengubah suai impedans pada lubang sehingga menjadi tak terhingga dan panel yang kukuh ini boleh ditukar menjadi dinding pegun dengan menetapkan impedans panel juga kepada nilai tak terhingga. Model ini boleh diaplikasi bagi sistem MPP tunggal dan sistem MPP banyak lapisan; sistem yang berdiri sendiri samada dengan atau tanpa dinding pegun. Hasil untuk MPP dengan dinding pegun kemudian dibandingkan kepada data eksperimen. Didapati bahawa model perambatan gelombang mencapai persetujuan yang baik dengan eksperimen pada frekuensi tinggi.

ACKNOWLEDGEMENTS

In the name of Allah, The Beneficent, The Merciful

Alhamdulillah, I would like to thank Allah the Almighty for His blessing and mercy. My sincere gratitude goes to my supervisor, Dr. Azma Putra for his supervision, support and encouragement towards the completion of this thesis. Also for the late Pn. Nor Liana binti Salleh for her assistance in this project. I would like to acknowledge the Ministry of Higher Education Malaysia (MoHE) for the financial support under the Fundamental Research Grant Scheme (FRGS).

My gratitude is also addressed to my beloved parents, Mustafa Kamal and Murni Mizan for their love and pray for me. To my brothers and sisters, Musnizar Safari, Ali Iqbal Py, Hawa Thayyibah Py, and Muhammad Tanzil Khair Py for their support.

I would like to thank all my colleagues in the 'acoustics and vibration' group for the friendship, support and the brilliant discussion until completion of this thesis. Also thanks to PPI UTeM, lecturer, staff and technicians in UTeM who help me directly or indirectly throughout the research.

TABLE OF CONTENTS

	PAGE
DECLARATION	i
APPROVAL	ii
DEDICATION	iii
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENT	iii
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS	xi
LIST OF PHYSICAL CONSTANT	xii
LIST OF SYMBOLS	xiii
LIST OF PUBLICATIONS	xv
CHAPTER	xv
1 INTRODUCTION	1
1.1 Introduction	1
1.2 Background	1
1.3 Type of sound absorbers	2
1.3.1 Porous absorber	3
1.3.2 Helmholtz resonator	4
1.3.3 Panel absorber	6
1.4 Sustainable and green absorbers	7
1.4.1 Natural fibers as acoustic materials	7
1.4.2 Micro-perforated panel as sound absorber	9
1.5 Objectives	13
1.6 Scope of the study	13
1.7 Methodology	13
1.8 Thesis outline	15

1.9	Thesis contributions	16
1.10	Summary	17
2	INTRODUCTION TO WAVE PROPAGATION TECHNIQUE	18
2.1	Introduction	18
2.2	Reflection and transmission of sound waves	18
2.2.1	Wave transmission from one fluid to another	20
2.2.2	Wave transmission through a fluid layer	23
2.2.3	Wave transmission through a solid surface	27
2.3	Summary	29
3	WAVE PROPAGATION TECHNIQUE TO MODEL SOUND ABSORPTION FOR MICRO-PERFORATED PANEL	31
3.1	Introduction	31
3.2	Hole impedance and mean particle velocity	31
3.3	Absorption coefficient of a single micro-perforated panel (MPP)	36
3.4	Double micro-perforated panel (DMPP)	44
3.4.1	Absorption coefficient of DMPP	44
3.5	Micro-perforated panel with solid panel	54
3.5.1	Absorption coefficient of a MPP backed by solid panel	54
3.5.2	Absorption coefficient of a MPP backed by a rigid surface	59
3.5.3	Absorption coefficient of DMPP backed by a solid panel	62
3.6	Electro-acoustical equivalent circuit	69
3.6.1	Summary	75
4	EXPERIMENTAL VALIDATION	76
4.1	Introduction	76
4.2	Samples of micro-perforated panels and experimental setup	76
4.3	Validation for single micro-perforated panel	79
4.4	Validation for double micro-perforated panel (DMPP)	82
4.5	Summary	87
5	CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH	88
5.1	Introduction	88
5.2	Conclusion	88
5.3	Recommendation	89
	REFERENCES	90

LIST OF TABLES

TABLE	TITLE	PAGE
4.1	List of the sample used in the experiment.	77
4.2	List of the equipment and software used in the experiment.	78

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Comparison of global warming potential of conventional and natural materials (Asdrubali, 2006).	2
1.2	Type of porous sound absorbing materials (Arenas and Crocker, 2013).	3
1.3	Diagram of a Helmholtz resonator.	4
1.4	Application of Helmholtz resonator : (a) in home theater (Sensibleaudio, 2009) and (b) in Queen Elizabeth Hall (Barron, 2010).	5
1.5	Construction of panel absorber mounted on rigid wall.	6
1.6	Application of panel absorbers mounted at wall (WSDG, 2014).	7
1.7	Natural fibers materials : (a) coir fiber sheet (Fouladi <i>et. al.</i> , 2011) and (b) sugar cane fiber (Putra <i>et. al.</i> , 2013a).	8
1.8	Applications of MPP in buildings: (a) the Deutsches Historisches Museum, Berlin and (b) studio RTL, Koln (Fuchs and Zha, 2006).	10
1.9	The research methodology flow chart.	15
2.1	Sound waves on a boundary between medium with different characteristic acoustic impedances.	21
2.2	The propagation of wave in three-layer media.	24
2.3	The power coefficient of reflection (black line) and transmission (blue line) — $z_2 = 10z_1$, — — $z_2 = 20z_1$, \cdots $z_2 = 30z_1$, — · — · $z_2 = 40z_1$.	26
2.4	The behaviour of sound energy through medium : (a) some of energy are transmitted and absorbed, $\Gamma = \Gamma_t + \Lambda$ (b) fully transmitted, $\Gamma = \Gamma_t$ and (c) fully absorbed, $\Gamma = \Lambda$.	29
3.1	Schematic diagram of particle velocity around a perforated panel.	32
3.2	Schematic diagram of a perforated panel (Putra, 2008).	33
3.3	Explanation of real and imaginary parts of hole impedance (Putra, 2008).	34
3.4	The real (thin line) and imaginary (thick line) part of the acoustic impedance of a circular hole particular frequencies (-100 Hz, — — 1 kHz, \cdots 5 kHz).	35
3.5	Schematic diagram of a single MPP excited by normal incidence of acoustic loading.	36
3.6	Power reflection coefficient of a single MPP excited by normal incident of acoustic loading ($t = 1$ mm, $\sigma = 1$ %; — $d_o = 0.4$ mm, — — $d_o = 0.6$ mm, \cdots $d_o = 0.8$ mm).	40
3.7	Power reflection coefficient of a single MPP excited by normal incident of acoustic loading ($t = 1$ mm, $d_o = 0.5$ mm; — $\sigma = 0.5$ %, — — $\sigma = 1$ %, \cdots $\sigma = 1.5$ %).	40

- 3.8 Power transmission coefficient of a single MPP excited by normal incident of acoustic loading ($t = 1$ mm, $\sigma = 1$ %; — $d_o = 0.4$ mm, — — $d_o = 0.6$ mm, $\cdots d_o = 0.8$ mm). 41
- 3.9 Power transmission coefficient of a single MPP excited by normal incident of acoustic loading ($t = 1$ mm, $d_o = 0.5$ mm, — $\sigma = 0.5$ %, — — $\sigma = 1$ %, $\cdots \sigma = 1.5$ %). 41
- 3.10 Power absorption coefficient (excluding the transmission) of a single MPP excited by normal incident of acoustic loading ($t = 1$ mm, $\sigma = 1$ %; — $d_o = 0.4$ mm, — — $d_o = 0.6$ mm, $\cdots d_o = 0.8$ mm). 43
- 3.11 Power absorption coefficient (excluding the transmission) of a single MPP excited by normal incident of acoustic loading ($t = 1$ mm, $d_o = 0.5$ mm; — $\sigma = 0.5$ %, — — $\sigma = 1$ %, $\cdots \sigma = 1.5$ %). 43
- 3.12 The schematic view of double MPP without any rigid backing surface excited by sound wave under normal incidence. 45
- 3.13 (a) Power reflection coefficient and (b) power transmission coefficient of DMPP without any rigid backing surface for varying hole diameters ($t_{\text{MPP}} = 1$ mm, $l = 50$ mm, $\sigma = 1$ %; — $d_o = 0.3$ mm, — — $d_o = 0.5$ mm, — · — · $d_o = 0.7$ mm, $\cdots d_o = 0.9$ mm). 49
- 3.14 (a) Power reflection coefficient and (b) power transmission coefficient of DMPP without any rigid backing surface for varying perforation ratios ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $l = 50$ mm; — $\sigma_{1,2} = 0.5$ %, — — $\sigma_{1,2} = 1$ %, $\cdots \sigma_{1,2} = 1.5$ %). 49
- 3.15 (a) Power reflection coefficient and (b) power transmission coefficient of DMPP without any rigid backing surface for varying air gaps ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $\sigma = 1$ %; — $l = 10$ mm, — — $l = 30$ mm, — · — · $l = 50$ mm, $\cdots l = 70$ mm). 50
- 3.16 Power absorption coefficient of DMPP without any rigid backing surface for varying hole diameters ($t_{\text{MPP}} = 1$ mm, $l = 50$ mm, $\sigma = 1$ %; — $d_{o1,2} = 0.3$ mm, — — $d_{o1,2} = 0.5$ mm, — · — · $d_{o1,2} = 0.7$ mm, $\cdots d_{o1,2} = 0.9$ mm). 52
- 3.17 Power absorption coefficient of DMPP without any rigid backing surface for varying perforation ratios ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $l = 50$ mm; — $\sigma_{1,2} = 0.5$ %, — — $\sigma_{1,2} = 1$ %, $\cdots \sigma_{1,2} = 1.5$ %). 53
- 3.18 Power absorption coefficient of DMPP without any rigid backing surface for varying air gaps ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $\sigma = 1$ %; — $l_{1,2} = 10$ mm, — — $l_{1,2} = 30$ mm, — · — · $l_{1,2} = 50$ mm, $\cdots l_{1,2} = 70$ mm). 53
- 3.19 Schematic diagram of a single MPP backed by a solid panel excited by normal incidence of acoustic loading. 55
- 3.20 (a) Power reflection coefficient and (b) power transmission coefficient of MPP backed by a solid panel for varying hole diameters ($t_{\text{MPP}} = 1$ mm, $l = 50$ mm, $\sigma = 1$ %; — $d_o = 0.3$ mm, — — $d_o = 0.5$ mm, — · — · $d_o = 0.7$ mm, $\cdots d_o = 0.9$ mm). 56
- 3.21 (a) Power reflection coefficient and (b) power transmission coefficient of MPP backed by a solid panel for varying perforation ratios ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $l = 50$ mm; — $\sigma = 0.5$ %, — — $\sigma = 1$ %, $\cdots \sigma = 1.5$ %). 57

- 3.22 (a) Power reflection coefficient and (b) power transmission coefficient of MPP backed by a solid panel varying air gaps ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $\sigma = 1$ %; — $l = 10$ mm, — — $l = 30$ mm, — · — · $l = 50$ mm, · · · $l = 70$ mm). 57
- 3.23 Power absorption coefficient (excluding the transmission) of a single MPP backed by a solid panel with air gap ($l = 50$ mm, $t_{\text{MPP}} = 1$ mm, $\sigma = 1$ %; — $d_o = 0.3$ mm, — — $d_o = 0.5$ mm, — · — · $d_o = 0.7$ mm, · · · $d_o = 0.9$ mm). 58
- 3.24 Power absorption coefficient (excluding the transmission) of a single MPP backed by a solid panel with air gap ($l = 50$ mm, $t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm; — $\sigma = 0.5$ %, — — $\sigma = 1$ %, · · · $\sigma = 1.5$ %). 58
- 3.25 Power absorption coefficient (excluding the transmission) of a single MPP backed by a solid panel with air gap ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $\sigma = 1$ %; — $l = 10$ mm, — — $l = 30$ mm, — · — · $l = 50$ mm, · · · $l = 70$ mm). 59
- 3.26 Schematic diagram of MPP backed by a solid panel adjusted to MPP backed by rigid surface. 60
- 3.27 Power transmission coefficient of MPP backed by a rigid surface ($l = 50$ mm, $t_{\text{MPP}} = 1$ mm, $\sigma = 1$ %; — $d_o = 0.4$ mm, — — $d_o = 0.6$ mm, · · · $d_o = 0.8$ mm). 61
- 3.28 Power transmission coefficient of MPP backed by rigid surface ($l = 50$ mm, $t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm; — $\sigma = 0.5$ %, — — $\sigma = 1$ %, · · · $\sigma = 1.5$ %). 61
- 3.29 Power transmission coefficient of MPP backed by rigid surface ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $\sigma = 1$ %; — $l = 10$ mm, — — $l = 30$ mm, — · — · $l = 50$ mm, · · · $l = 70$ mm). 62
- 3.30 The schematic view of double MPP backed by an air layer and a flexible panel excited by sound wave under normal incidence. 63
- 3.31 Sound absorption coefficient of DMPP backed by a rigid surface ($l = 75$ mm, $(d - l) = 150$ mm, $t_{\text{MPP}1,2} = 1$ mm, $\sigma = 1$ %; — $d_o = 0.4$ mm, — — $d_o = 0.6$ mm, — · — · $d_o = 0.8$ mm, · · · $d_o = 1$ mm). 67
- 3.32 Sound absorption coefficient of DMPP backed by a rigid surface ($l = 75$ mm, $(d - l) = 150$ mm, $t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm; — $\sigma = 0.5$ %, — — $\sigma = 1$ %, · · · $\sigma = 1.5$ %). 68
- 3.33 Sound absorption coefficient of DMPP backed by a rigid surface ($t_{\text{MPP}} = 1$ mm, $d_o = 0.5$ mm, $\sigma = 1$ %; — $l = 20$ mm with $(d - l) = 80$ mm, — — $l = 40$ mm with $(d - l) = 60$ mm, — · — · $l = 60$ mm with $(d - l) = 40$ mm, · · · $l = 80$ mm with $(d - l) = 20$ mm). 68
- 3.34 (a) Micro-perforated panel sound-absorbing constructions and (b) its equivalent electrical circuit 69
- 3.35 (a) Double micro-perforated panel sound-absorbing constructions and (b) its equivalent electrical circuit. 70
- 3.36 Absorption coefficient of MPP backed by a rigid surface; electrical circuit (black line) and wave propagation (blue line) with $t = 1$ mm, $l = 50$ mm, $\sigma = 1$ %; — $d_o = 0.4$ mm, — — $d_o = 0.8$ mm. 71
- 3.37 Absorption coefficient of MPP backed by a rigid surface; electrical circuit (black line) and wave propagation (blue line) with $t = 1$ mm, $l = 50$ mm, $d_o = 0.4$ mm; — $\sigma = 0.5$ %, — — $\sigma = 1$ %. 72

3.38	Absorption coefficient of MPP backed by a rigid surface; electrical circuit (black line) and wave propagation (blue line) with $t = 1$ mm, $\sigma = 1$ %, $d_o = 0.4$ mm; — $l = 10$ mm, - - $l = 50$ mm.	72
3.39	Absorption coefficient of double MPP backed by a rigid surface; electrical circuit (black line) and wave propagation (blue line) with $t_{1,2} = 1$ mm, $l_{1,2} = 50$ mm, $\sigma_{1,2} = 1$ %; — $d_o = 0.4$ mm, - - $d_o = 0.8$ mm.	73
3.40	Absorption coefficient of double MPP backed by a rigid surface; electrical circuit (black line) and wave propagation (blue line) with $t_{1,2} = 1$ mm, $l_{1,2} = 50$ mm, $d_{o1,2} = 0.4$ mm; — $\sigma = 0.5$ %, - - $\sigma = 1$ %.	74
3.41	Absorption coefficient of double MPP backed by a rigid surface; electrical circuit (black line) and wave propagation (blue line) with $t_{1,2} = 1$ mm, $\sigma_{1,2} = 1$ %, $d_{o1,2} = 0.4$ mm; — $l = 10$ mm, - - $l = 50$ mm.	74
4.1	(a) MPP sample with $d_o = 0.5$ mm, $\sigma = 1$ % and (b) MPP with $d_o = 0.5$ mm, $\sigma = 0.5$ %.	77
4.2	Schematic diagram of experimental setup.	79
4.3	Validation of absorption coefficient of single MPP backed by a rigid surface for MPP = 0.5% (\dots = experiment, - - = equivalent circuit, — = wave propagation); a) $l = 10$ mm, (b) $l = 14$ mm, (c) $l = 18$ mm and (d) $l = 22$ mm.	80
4.4	Validation of absorption coefficient of Single MPP backed by a rigid surface for MPP = 1% (\dots = experiment, - - = equivalent circuit, — = wave propagation); a) $l = 10$ mm, (b) $l = 14$ mm, (c) $l = 18$ mm and (d) $l = 22$ mm.	81
4.5	Validation of absorption coefficient of DMPP backed by a rigid surface with MPP _{1,2} = 0.5 % (\dots = experiment, - - = equivalent circuit, — = wave propagation); (a) $l = 10$ mm and $(d - l) = 19$ mm, (b) $l = 20$ mm and $(d - l) = 29$ mm, (c) $l = 30$ mm and $(d - l) = 39$ mm.	83
4.6	Validation of absorption coefficient of DMPP backed by a rigid surface with MPP ₁ = 0.5 % and MPP ₂ = 1 % (\dots = experiment, - - = equivalent circuit, — = wave propagation); (a) $l = 10$ mm and $(d - l) = 19$ mm, (b) $l = 20$ mm and $(d - l) = 29$ mm, (c) $l = 30$ mm and $(d - l) = 39$ mm.	84
4.7	Validation of absorption coefficient of DMPP backed by a rigid surface with MPP ₁ = 1 % and MPP ₂ = 0.5 % (\dots = experiment, - - = equivalent circuit, — = wave propagation); (a) $l = 10$ mm and $(d - l) = 19$ mm, (b) $l = 20$ mm and $(d - l) = 29$ mm, (c) $l = 30$ mm and $(d - l) = 39$ mm.	85
4.8	Validation of absorption coefficient of DMPP backed by a rigid surface with MPP _{1,2} = 1 % (\dots = experiment, - - = equivalent circuit, — = wave propagation); (a) $l = 10$ mm and $(d - l) = 19$ mm, (b) $l = 20$ mm and $(d - l) = 29$ mm, (c) $l = 30$ mm and $(d - l) = 39$ mm.	86

LIST OF ABBREVIATIONS

DLMPP	Double Leaf Micro Perforated Panel
Hz	Hertz
ISO	International Organization for Standardization
ITM	Impedance Transfer Method
kHz	kilo Hertz
MPP	Micro Perforated Panel
NF	Natural Fiber
TLF	Tea Leaf Fiber

LIST OF PHYSICAL CONSTANT

Speed of sound	c	$=$	343 m/s^{-1}
Density of the air	ρ	$=$	1.2 kgm^{-3}
Viscosity of the air	v_a	$=$	$1.8 \times 10^{-5} \text{ Ns/m}^{-5}$

LIST OF SYMBOLS

A, B	Complex amplitude of sound pressure
b_o	The distance between hole
d_o	Hole diameter
f	Frequency
I, I_i, I_r, I_t	Sound Intensity
$j = \sqrt{-1}$	Imaginary unit
k	Acoustic wavenumber
l	MPP distance to the solid plate/MPP/Rigid wall
m	Mass per unit area of the solid panel
M	Mass per unit area of the MPP
p_i, p_r, p_t, p_A, p_B	Sound pressure
r	Damping constant per unit area
R	Sound pressure reflection coefficient
s	Stiffness per unit area
s_1	Separation distance between the two microphones
t	Thickness of panel
T	Sound pressure transmission coefficient
v	Particle velocity
\bar{v}	Average surface particle velocity
v_p	Velocity of the panel
v_h	Velocity of the air inside the hole
v_n	Normal particle velocity
x_n	Specific acoustic resistance
x_1	Distance between the samples and the nearest microphone location
y_n	Specific acoustic reactance
z_p, z_{p1}, z_{p2}	Mechanical impedance of the panel
z_1, z_2, z_f	Impedance of air

Z_o	Hole impedance
$Z_{o,R}$	Hole impedance, real part
$Z_{o,I}$	Hole impedance, imaginary part
Z_{tot}	Total impedance
G_{11}	Auto-spectrum
G_{12}	Cross-spectrum
H_{12}	Transfer function between microphone-1 and microphone-2
ω	Angular frequency
σ	Perforation ratio
τ	Intensity transmission coefficient
γ	Intensity reflection coefficient
Γ	Power transmission coefficient
Ψ	Power reflection coefficient
Λ	Power absorbed by material
Γ_t	Power transmitted beyond the back surface of a material

LIST OF PUBLICATIONS

Journal Articles

A. Putra, M. Sajidin Py, N. L. Salleh, Modelling the Effect of Flexural Vibration on Sound Absorption of a Micro-Perforated Panel Using Wave Propagation Method, *Applied Mechanics and Materials*, Vol.471, pp. 255-260 (2014).

A Putra, A.Y. Ismail, R. Ramlan, M.R. Ayob, M. S. Py, Normal Incidence of Sound Transmission Loss of a Double-Leaf Partition Inserted with a Microperforated Panel, *Advances in Acoustics and Vibration*, Vol.2013, Article ID 216493 (2013).

Proceedings

M. Sajidin Py, A. Putra, N. Salleh, H. Efendy, Modelling the Effect of Vibration on the Sound Absorption Performance of Green Sound Absorber using Wave Propagation Technique. *Proceedings of 3rd International Conference on Engineering and ICT (ICEI)*, Vol.1, pp. 313-316, Melaka, Malaysia, 2012.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the background of the study and the past research works concerning the sound absorbers. This is started by introducing the type of sound absorbers and the potential of natural fibers as alternative sound absorber materials which are more environmentally friendly. Employment of micro-perforated panel (MPP) as the newest method of sound absorber is also presented.

1.2 Background

Good acoustic performance is important in buildings such as classrooms, health care facilities, auditoriums and concert halls. In classrooms, the ability to hear and understand what is being said is vital for learning. When acoustical performance in classroom is poor, this will affect speech understanding, attention, concentration and eventually academic achievement. The characteristic of auditorium contributes greatly to the perceived sound of speech. It is hard to understand speech when echoes are too strong. People tend to slow down their speech, talk louder and try to pronounce words more precisely in an effort to make the received speech intelligible. The same applies to concert halls where great acoustic performance is important to provide an enjoyable auditory experience.

To maintain good acoustic quality in a room due to late reflections which cause the echos and high reverberation time, the surfaces of walls or ceiling in general, are covered by absorptive layers. Commonly, the materials are made from synthetic chemical substances

assessment results: Cumulated Energy Demand (CED) and Non Renewable Energy (NRE) fraction, Global Warming Potential (GWP) and Acidification Power (AP). A comparison based on the Ecoinvent database between the environmental impacts of some traditional and natural sound insulation materials from cradle to gate is shown in Fig. 1 [4]: cellulose, flax and sheep wool have the lowest impacts on the considered categories.

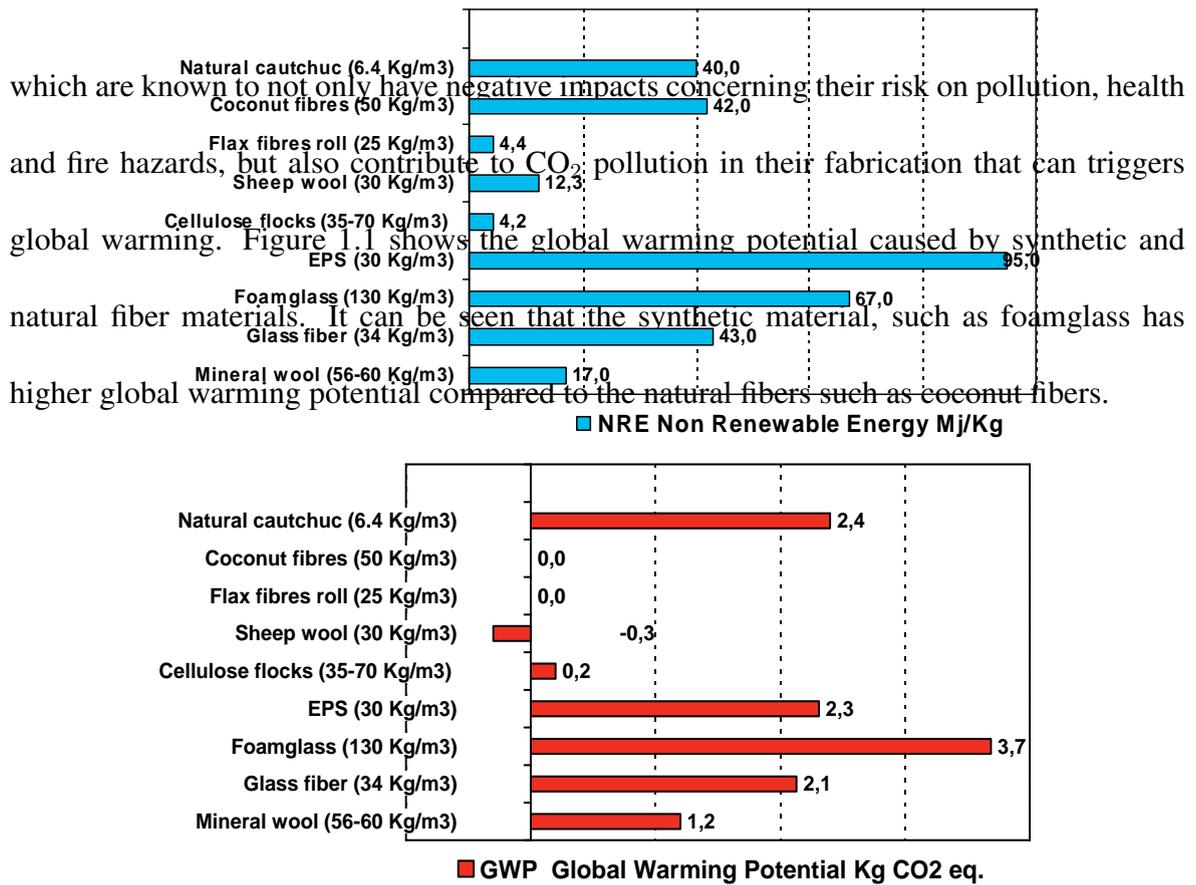


Figure 1.1 Comparison of global warming potential of conventional and natural materials (Asdrubali, 2006).

3

These issues have attracted attention of researchers for new absorptive materials which are more environmental friendly. Several studies are therefore focused in investigating natural fibers to be employed as sound absorber. The natural fibers give more advantages than synthetic ones as they are renewable and available in abundance amount in certain countries. The next sections first discuss the type of sound absorbers in practice followed by the concept of green and sustainable acoustic absorbers.

1.3 Type of sound absorbers

Sound absorbers can be considered as porous absorber, volume absorbers and panel absorbers. Generally, porous absorbers are most effective at mid to high frequencies, while

panel and volume absorbers are most effective at lower frequencies.

1.3.1 Porous absorber

Porous absorbers are often used for the purpose of absorbing sound due to their ability to absorb most of the sound energy striking them. Common examples are mineral wools, fiberglass, open cell foams, acoustic tiles, carpets and curtains.

Based on their microscopic configurations, porous absorbing materials can be classified as cellular, fibrous or granular. Their main types, typical microscopic arrangements and physical models are shown in Figure 1.2.

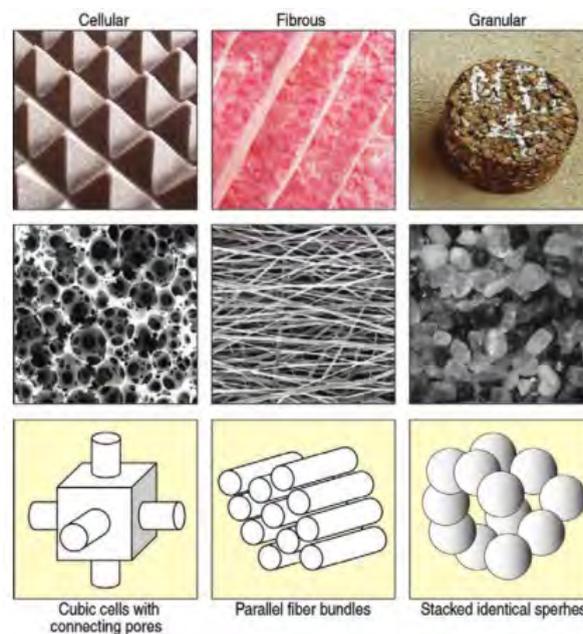


Figure 1.2 Type of porous sound absorbing materials (Arenas and Crocker, 2013).

When sound wave propagates in a porous absorber, the movement of air motion induced by sound wave through narrow constrictions produces losses of momentum. This due to viscous friction and the direction of flow changes as the sound waves through the irregular

pores. This account for most significant at high frequency losses (Long, 2005). At low frequencies, more significant absorption due to thermal conduction from the air to the absorber material (Cox and D'Antonio, 2009).

1.3.2 Helmholtz resonator

Helmholtz resonator is widely used to achieve absorption at low frequency. This type of sound absorber was invented by German physicist Hermann von Helmholtz (1821-1894). Resembling a spring system with damping to provide absorption at the resonant frequency of the system. A simple Helmholtz resonator is illustrated in Figure 1.3 which consists of an enclosed volume V , having a small neck of area A (opening at one end) which length L . The principle is that the air in the neck acts like a fluctuating mass and the air in the cavity acts like a spring (Vigran, 2008). The sound energy is 'consumed' to vibrate the mass-spring system and thus the optimum energy absorbed by resonator is at the resonant frequency.

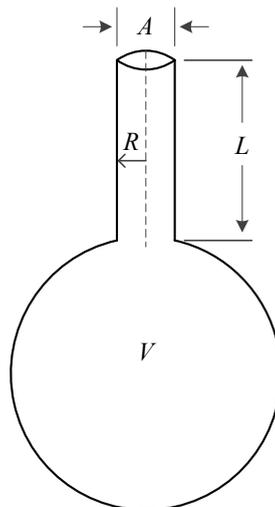


Figure 1.3 Diagram of a Helmholtz resonator.