UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

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

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
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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 : ....

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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

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DEDICATION

”To my beloved mother and father”

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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.

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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.

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LIST OF ABBREVIATIONS

DLMPP	**D**ouble **L**eaf **M**icro **P**erforated **P**anel
Hz	**H**ertz
ISO	**I**nternational **O**rganization for **S**tandardization
ITM	**I**mpedance **T**ransfer **M**ethod
kHz	**k**ilo **H**ertz
MPP	**M**icro **P**erforated **P**anel
NF	**N**atural **F**iber
TLF	**T**ea **L**eaf **F**iber

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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	$=$	1.8×10^{-5} Ns/m^{-5}

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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 cosntant 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_{p_1}, z_{p_2}	Mechanical impedance of the panel
z_1, z_2, z_f	Impedance of air

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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

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LIST OF PUBLICATIONS

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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).

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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

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which are known to not only have negative impacts concerning their risk on pollution, health and fire hazards, but also contribute to CO_2 pollution in their fabrication that can triggers global warming. Figure 1.1 shows the global warming potential caused by synthetic and natural fiber materials. It can be seen that the synthetic material, such as foamglass has higher global warming potential compared to the natural fibers such as coconut fibers.

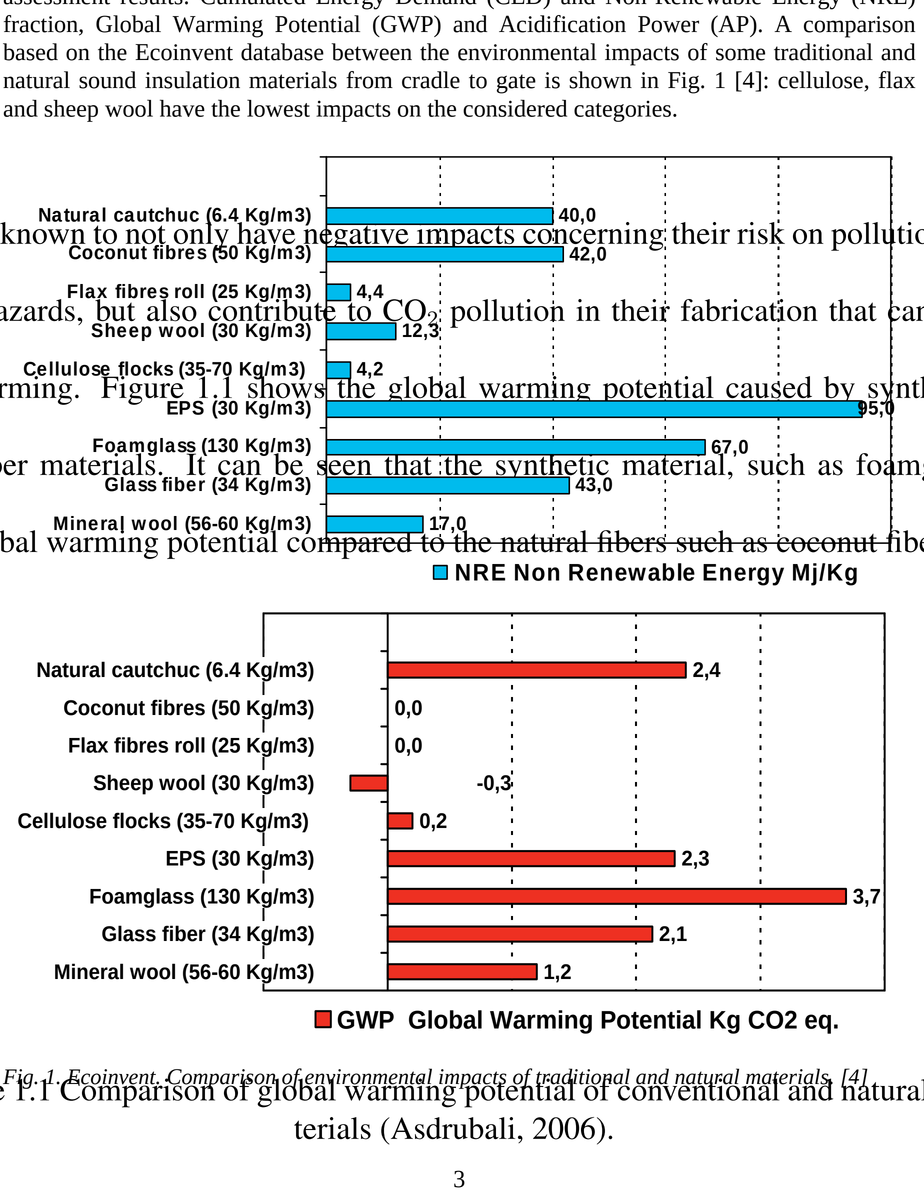

Figure 1.1 Comparison of global warming potential of conventional and natural materials (Asdrubali, 2006).

These issues have attracted attention of researchers for new absorptive materials which are more enviromental 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

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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.

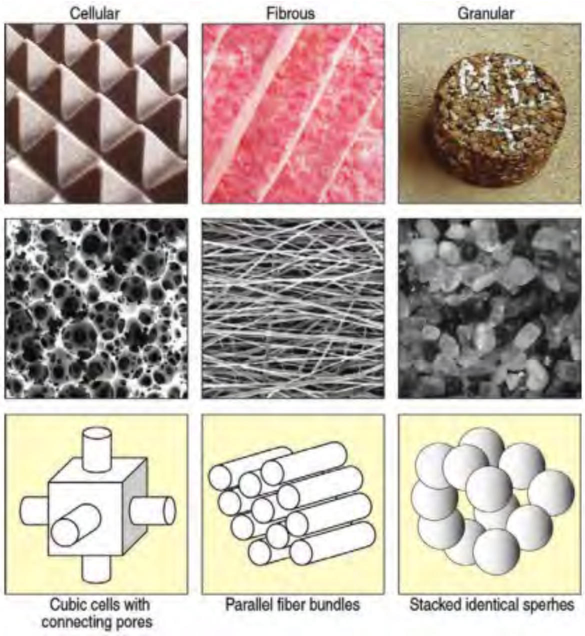

Figure 1.2 Type of porous sound absorbing materials (Arenas and Crocker, 2013).

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

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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.

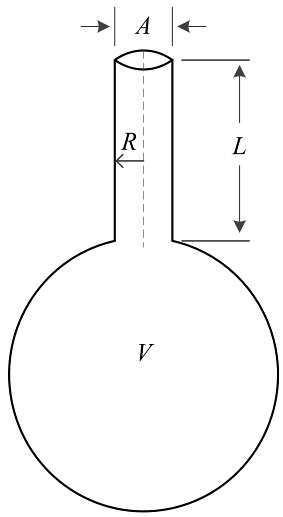

Figure 1.3 Diagram of a Helmholtz resonator.

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