



## **Report of Cooperative Education**

### **Sound Reduction of Flushing Noise in Drainage Pipe**

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### **Abstract**

Noise from the drainage pipe is one of the noise pollutions that causes annoyance for residents, especially in condominiums, apartments, and hotels etc. Most of this noise and vibration are a result of the water hammer that occurs at the elbows and fittings. The objectives of this project were to study about soundproof property and find the polymer materials for reducing of flushing noise in drainage pipe. This work was an investigation of the transmission loss (TL) by using an impedance tube in accordance to ASTM E2611-09 standard, and then selection of materials for cover simulating a drainage pipe. The results show that in most samples the transmission loss increases with the increase in the thickness and density. Three samples are 5 mm thick damper, 5 mm thick damper composited with 3 mm thick cork tape, and 5 mm thick damper composited with 25 mm thick rubber are selected for the simulated drainage pipe. It was found that the damper composited with cork tape has the highest sound pressure level reduction at 9 dB(A) following by the non-composited damper at 8 dB(A) and the damper composited with rubber at 6 dB(A). However, by listening via ears, it was found that the sound of the water flowing inside the pipe was disappeared with the non-composited damper cover only. Therefore, it is suggested that 5 mm thick damper sample is the most suitable for soundproof in the drainage pipe.

**Keywords:** Soundproof property, Transmission loss, Drainage pipe, Impedance tube

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## Nomenclature

$A$	Surface area
$B$	Bending stiffness
$c$	Sound velocity
$E$	Young's modulus
$f_c$	Critical frequency
$I$	Sound intensity
$I_0$	Reference sound intensity = $10^{-12}$ W/m <sup>2</sup>
$L_p, SPL$	Sound pressure level
$L_i$	Sound pressure level at each source
$L_\Sigma$	Sum of sound pressure level
$P$	Sound pressure
$P_0$	Reference sound pressure = $2 \times 10^{-5}$ N/m <sup>2</sup>
$t$	Thickness
$TL, STL$	Transmission loss
$TL_0$	Normal incidence transmission loss
$W$	Sound power
$W_i$	Incident sound power
$W_t$	Transmitted sound power
<i>Greek letters</i>	
$\alpha$	Sound absorption coefficient
$\beta$	Sound intensity level
$\rho$	Sound reflection coefficient
$\rho_s$	Mass of per unit surface area
$\rho_c$	Characteristic impedance of medium
$\rho_m$	Mass density of material
$\nu$	Poisson's ratio
$\lambda$	Average sound insulation coefficient of material
$\tau$	Sound transmission coefficient
$\omega$	Angular frequency of sound

# CHAPTER I

## INTRODUCTION

### 1.1 Background

If referring to the term “noise”, it is an unwanted sound caused by the business or human activities in the rate and time that can cause human health problems and comfort environment [1]. Noise is often found from sources that are noisier than the standard, which directly affects to the nervous system and cause decreased performance of the brain [2]. Noise from the drainage pipe is one of the noise pollutions that causes annoyance for residents, especially in condominiums, apartments, and hotels. Therefore, the construction of large projects particularly the groups of luxurious hotel, condominium, and hospital should be considered and special concerned when designing these buildings in according to WELL building standards for the guests and residents to have full privacy and relaxation [3]. The WELL building standard is revolutionizing the way people think about buildings. It explores how design, operations and behaviors within the places where we live, work, learn and play can be optimized to advance human health and well-being are promoted by the International Well Building Institute (IWBI) [4].

For these reasons, Aeroflex Co., Ltd. which is the manufacturer of Ethylene-Propylene Diene Monomer (EPDM) synthetic rubber in the form of tubes, sheets and accessories recognizes the problem of noise from the drainage pipe in various buildings. Therefore, there is a need to research and invent products to help reduce such problems and to respond the needs of customers.

### 1.2 Objectives

- 1.2.1 To study a soundproof property of materials.
- 1.2.2 To find the polymer materials for reducing of flushing noise in drainage pipe.

For the response of the human ears to sound pressure is not linear. But there is a relationship as logarithm, following the Eq. 2-3 [5].

$$L_p = 20 \log \frac{P}{P_0} \quad \text{Eq. 2-3}$$

where  $L_p$  is the sound pressure level (dB)

$P$  is the sound pressure (N/m<sup>2</sup>)

$P_0$  is the reference sound pressure,  $2 \times 10^{-5}$  N/m<sup>2</sup>

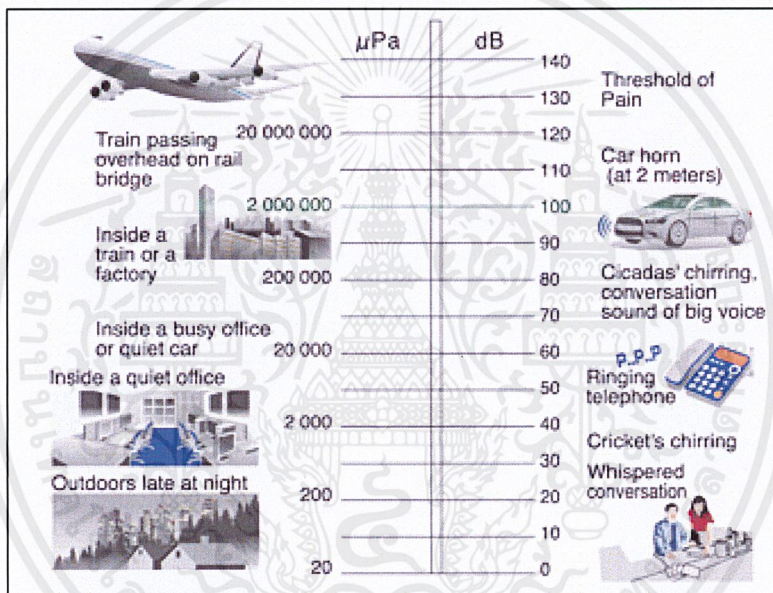


Figure 2-3: Sound pressure and sound pressure level [12].

## 2.6 Loudness

Loudness is a term describing the sense of the human ears on perception of a sound which is a quantity that cannot be directly measured by equipment. The loudness will increase according to the sound intensity or can be said that the loudness is directly proportional to the sound intensity.

For loudness level will expressed a unit in “Phon”, which have the same numerical values of the sound pressure level at a frequency of 1,000 Hz.

In Table 2-2 is a summary of perception of noise level changes in the middle frequency ranges at sound pressures greater than  $2 \times 10^{-3}$  Pa.

**Table 2-2:** Subjective effect of changes in sound pressure level [8].

Change in sound level (dB)	Change in power		Change in apparent loudness
	Decrease	Increase	
3	1/2	2	Just perceptible
5	1/3	3	Clearly noticeable
10	1/10	10	Half or twice as loud
20	1/100	100	Much quieter or louder

For the determination of sound loudness level is adjusting the sound pressure level of a comparison pure tone of specified frequency until it is judged by normal hearing observers to be equal in loudness [8].

## 2.7 Weighted sound level

Weighted sound level is the sound level that is measured by the microphone and passed through the weighting network. There are many forms of weighted sound level, such as A-weighted (dB(A)), B-weighted (dB(B)), C-weighted (dB(C)) and D-weighted (dB(D)) where

- A-weighted is the modifying of the sound frequency for it matches the perception of humans and close to the auditory response characteristics of the human ears than scale B and C.

- B-weighted used to measure the sound in medium sound intensity which will respond well in frequencies between 400-3,000 Hz.

- C-weighted is a measure that is close to the truth and there is less passed through the weighting network. C-weighted used to measure the sound in low frequency ranges because A-weighted has too much passed through the weighting network.

- D-weighted used to measure the sound from aircraft [13].

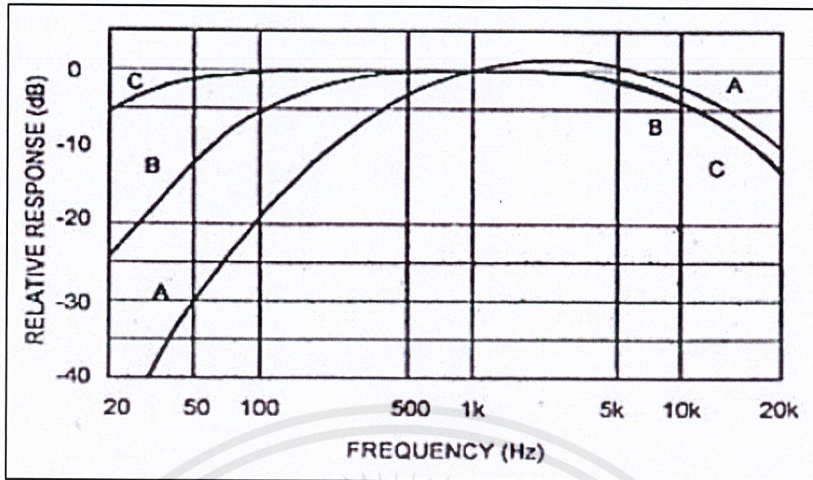


Figure 2-4: Frequency weighting characteristics [13].

### 2.8 Relations of sound reflection, sound absorption and sound transmission

When humans are talking in an opened space, the sound will spread out by without the reflection on anything. But on the other hand, if humans are talking in a closed space, the sound will hit the wall, ceiling or floor inside of the room.

For the phenomenon that occurs when sound waves hit the surface of the room is some of sound waves will reflected back, some will be absorbed by the surface of the wall and some will be transmitted the wall.

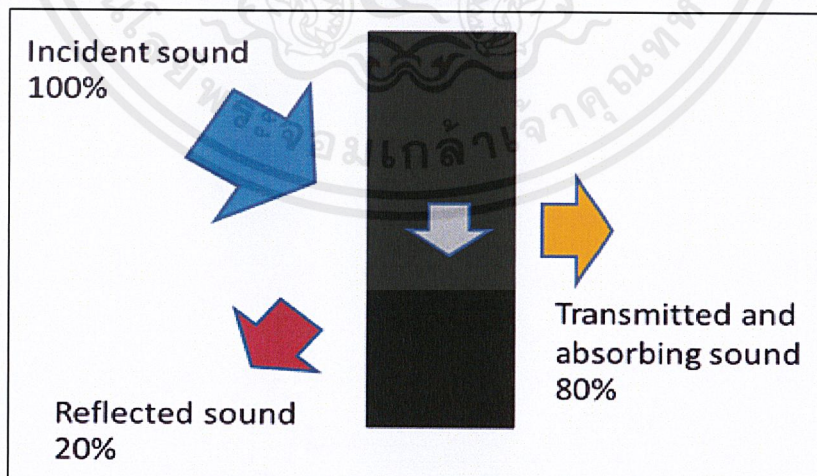


Figure 2-5: The phenomenon of sound waves [14].

In principle, the sum of the energy of the reflected sound + absorbed sound + transmitted sound must be equal to the incident sound energy that hit the surface of the wall, following the Eq. 2-4 [14].

$$\rho + \alpha + \tau = 1 \quad \text{Eq. 2-4}$$

where  $\rho$  is the sound reflection coefficient which is the energy of the reflected sound divided by the energy of the incident sound.

$\alpha$  is the sound absorption coefficient which is the energy of the absorbed sound divided by the energy of the incident sound.

$\tau$  is the sound transmission coefficient which is the energy of the transmitted sound divided by the energy of the incident sound.

## 2.9 Transmission loss

Transmission loss (TL) or sound transmission loss is (STL) the sound insulation value of the structure that measured in quantitative, meaning the number of decibels of sound energy lost when transmitted the structure. The calculation of transmission loss can be calculated according to the standard of The American Society for Testing and Material (ASTM) E90-09 (2016), “Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions” and ISO Recommendation R140 (1960), “Field and Laboratory Measurement of Airborne and Impact Sound Transmission” following the Eq. 2-5 [15].

$$TL = 10 \log \frac{W_i}{W_t} = 10 \log \frac{1}{\lambda} \quad \text{Eq. 2-5}$$

where  $TL$  is the transmission loss through the wall (dB)

$W_i$  is the incident sound power (W)

$W_t$  is the transmitted sound power through the wall (W)

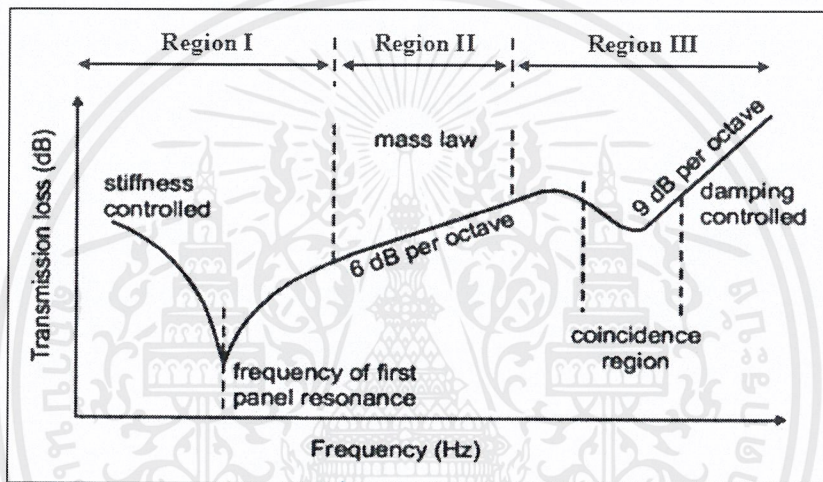
$\lambda$  is the average sound insulation coefficient of material which obtained from the laboratory

For determining the transmission loss, mainly the methods which commonly are used have 2 methods are [15]

1. Reverberant Room Method
2. Impedance Tube Transfer Function Method

## 2.10 Sound transmission through panels

The transmission loss (TL) of an infinite homogeneous panel which there was an illustration of typical behavior as shown in Figure 2-6.



**Figure 2-6:** Theoretical transmission loss for an infinite homogeneous panel [16].

The typical TL behavior can be divided into 3 basic regions in which various characteristic frequency ranges are indicated.

In Region I. At the lower frequencies, the transmission loss is controlled by the static stiffness of the panel. In this region, the panel resonances can also occur and cause dramatically decrease the TL which depending on the internal damping in the panel.

In Region II. In this region, it referred to as the mass law range, due to the approximately linear dependence of the transmission loss on the mass of the panel. The effect of doubling the mass or doubling the frequency will cause the TL to increase by approximately 6-8 dB.

For the calculation of the normal incidence transmission loss ( $TL_0$ ) in this region can be approximated by [17]

$$TL_0 = 10 \log \left[ 1 + \left( \frac{\omega \rho_s}{2 \rho c} \right)^2 \right] \quad \text{Eq. 2-6}$$

where  $\omega$  is the angular frequency of sound (rad/s)

$\rho_s$  is the mass per unit surface area (kg/m<sup>2</sup>)

$\rho c$  is the characteristic impedance of medium, 415 kg/m<sup>2</sup>·s for air at room temperature (20°C) and normal pressure ( $1.01 \times 10^5$  Pa)

In Region III. At the higher frequencies is the region of the critical frequency, which cause the coincidence effect. Then, the TL again rises, being damping controlled, and gradually approaches an extension of the original mass law portion of the curve.

So, mass-controlled region is the most desirable to use for as a soundproof material.

The properties which make for a good soundproof material include:

- High density (gives high TL in mass-controlled region).
- Low bending stiffness (ideally want to resonant frequencies below range of human hearing).
- High internal damping (prevents the resonant modes from ringing) [17].

### 2.11 Coincidence effects

Coincidence effects occurs when the wavelength of sound in air coincides with the structural wavelength and often leads to reduce the TL. At this frequency (and above), efficient radiation of sound occurs. For an infinite homogeneous panel, the critical frequency ( $f_c$ ) can be approximated by [16]

$$f_c = \frac{c^2}{2\pi} \sqrt{\frac{\rho_s}{B}} \quad \text{Eq. 2-7}$$

where  $c$  is the sound velocity (m/s)

$\rho_s$  is the mass per unit surface area (kg/m<sup>2</sup>)

$B$  is the bending stiffness (kg·m<sup>2</sup>/s<sup>2</sup>)

And the bending stiffness ( $B$ ) is defined as [16]

$$B = \frac{Et^3}{12(1-\nu^2)} \quad \text{Eq. 2-8}$$

where  $E$  is Young's modulus (Pa)

$t$  is the panel thickness (m)

$\nu$  is Poisson's ratio

## 2.12 ASTM E2611-09 standard

ASTM Standard: E2611-09 Standard Test Method for Measurement of Normal Incidence Sound Transmission of Acoustical Materials Based on the Transfer Matrix Method is the standard that used to determined transmission loss.

This test method covers the use of a tube, four microphones, and a digital frequency analysis system for the measurement of normal incident transmission loss and other important acoustic properties of materials by determination of the acoustic transfer matrix [18].

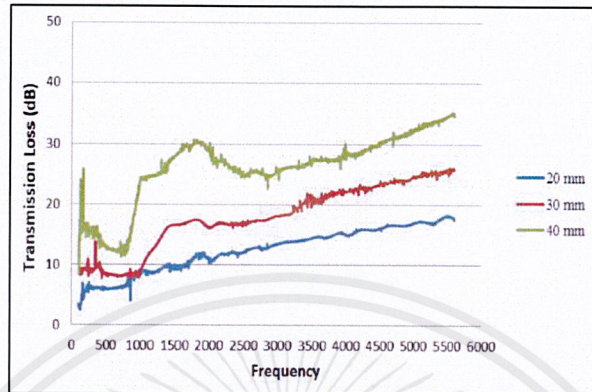
## 2.13 The effect of thickness and density on the acoustics properties of Ceiba pentandra natural fiber

The objective of this paper was study of the acoustic properties of the single layer kapok fiber. The acoustic properties that study are the sound absorption coefficient ( $\alpha$ ) and the value of transmission loss (TL) which result from the thickness and density of kapok fiber. For experimental measurement, will use an impedance tube in accordance to ISO 10534-2 and ASTM E1050-98 standards. By using two sets of diameters, for high frequency experiment is 28 mm and for low frequency experiment is 100 mm.

The tested sample has 3 densities of 40 kg/m<sup>3</sup>, 50 kg/m<sup>3</sup> and 60 kg/m<sup>3</sup> which all the samples having a thickness of 20 mm. For different thicknesses, the sample divided into 3 thicknesses of 20 mm, 30 mm, and 40 mm but having the same density of 40 kg/m<sup>3</sup> [19].

### - Results of kapok fiber transmission loss (TL)

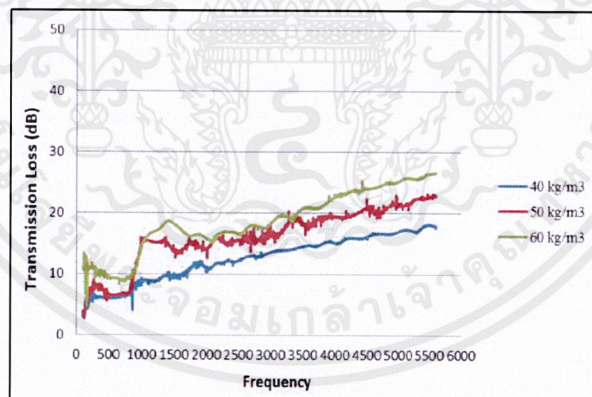
The experimental data of TL with different thickness as shown in Figure 2-7.



**Figure 2-7:** Transmission loss for 3 different thicknesses, density of 40 kg/m<sup>3</sup> [19].

The results shown that the transmission loss is increases when has the increment of thickness and all of the samples also show a much higher value of TL in higher frequency ranges when compare to lower frequency ranges.

For a result of TL with different density can be seen in Figure 2-8.



**Figure 2-8:** Transmission loss for 3 different densities, thickness of 20 mm [19].

Found that the increment of density in test samples will also increase the value of TL and the value of TL will increase in higher frequency ranges compare to lower frequency ranges [19].

## 2.14 Sound transmission testing of polymer compounds

The objective of this paper was studying the effect of the mounting conditions for the samples on the transmission loss (TL) to evaluate the operation and performance of laboratory sound testing system. The polymer and polymer composite samples were used in this paper which will be cut to 5 mm or 6 mm thickness for the impedance tubes that were diameter of 29 mm and diameter of 100 mm [20].

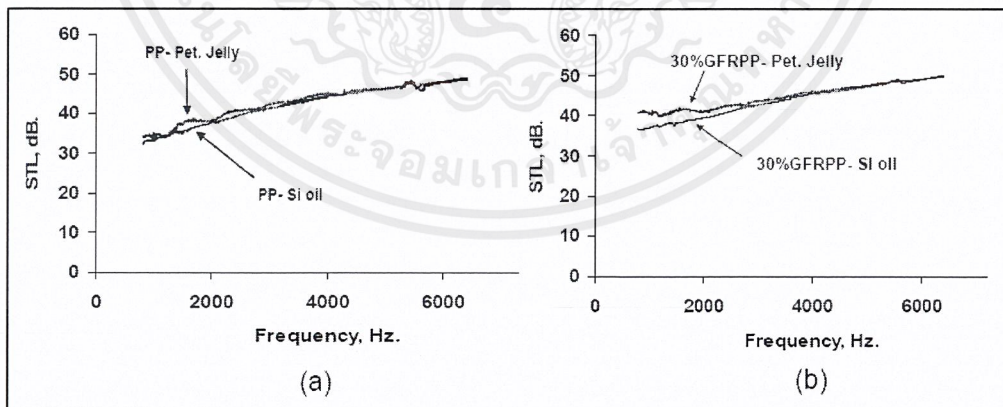
### Effect of the sealant

The effect of the mounting conditions was investigated by 4 sealing conditions are

1. Soft sealants: To represent the effect of interaction of a soft sealant between sample and the wall of the sample holder on the TL value.
2. High viscosity soft sealant: To represent the effect of the viscosity of a soft on the STL value.
3. Tough sealant: To represent the effect of the sample in contact with the wall of the sample holder on the TL value.
4. No sealant: To represent the effect of a sound leak around the sample on the TL value.

### - Results from the impedance tubes 29 mm diameter

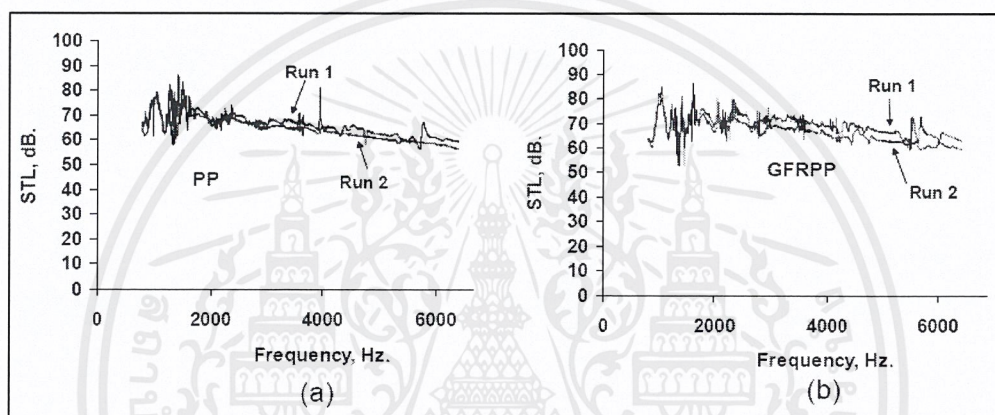
The experimental data for the samples mounted with the soft sealants, silicon oil (Si Oil) and petroleum jelly (PJ) as shown in Figure 2-9.



**Figure 2-9:** TL-Frequency plots of 6 mm thick PP (a) and 30%GFRPP (b) samples sealed with the soft sealants, silicon oil and petroleum jelly [20].

It found that at the lower part of the frequency ranges, the TL value of the samples mounted with the petroleum jelly had a slightly greater than the samples mounted with silicon oil which a small increasing of the TL value may be result from the higher viscosity of the PJ caused a slightly greater interaction between the sample and the wall of the sample holder. From the results suggest that silicon oil is reasonable than the petroleum jelly for mounting these materials in the small impedance tube.

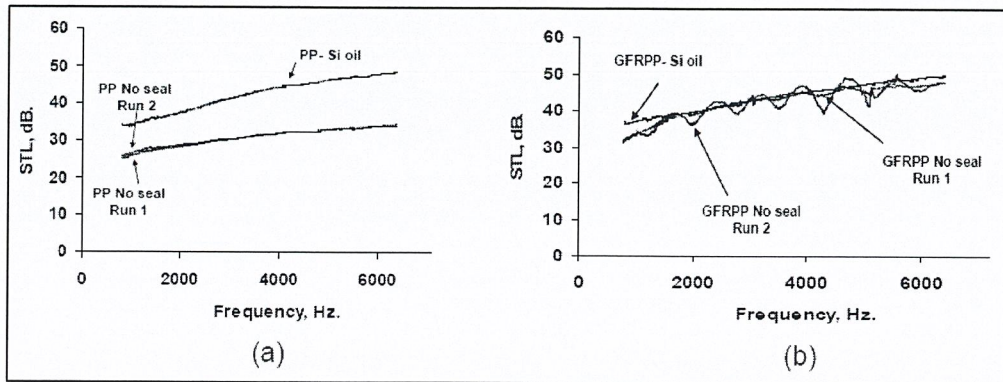
The experimental data for the samples mounted with a tough sealant (PTFE tape) around the edge of the sample can be seen in Figure 2-10.



**Figure 2-10:** TL-frequency plots of 6 mm thick PP (a) and 30%GFRPP (b) samples sealed with a tough sealant [20].

It can be seen that the plots are significantly different from the samples mounted with the soft sealants. At the lower part of the frequency ranges, it is possible that some of the incident sound energy appears to be lost to the wall of the sample holder resulting in the TL data that obtained from this test was unreliable when the samples are in hard contact with the specimen holder wall.

The experimental data for the samples that without any sealant can be seen in Figure 2-11 and the results of the samples sealed with silicon oil are shown for comparison in this tested.



**Figure 2-11:** STL-frequency plots of 6 mm thick PP (a) and 30%GFRPP (b) samples sealed with no sealant applied for the test [20].

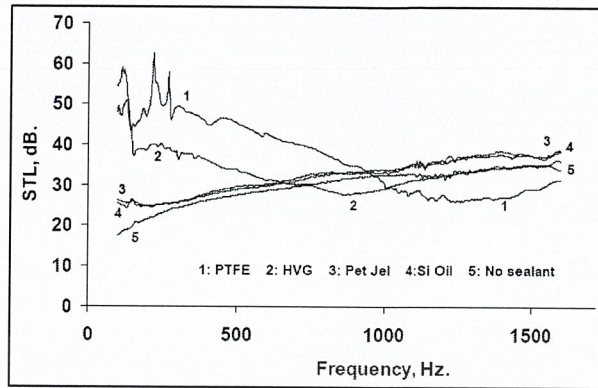
The results for the PP sample can be seen that the TL values plot of the samples without sealant were significantly lower at all of the frequency ranges when compared to the sample mounted with silicon oil which this result show that a consistent leakage of sound around the sample.

The results for 30%GFRPP sample show that the TL values plot of the samples without sealant were close to the sample mounted with silicon oil but were not consistent and showed an unstable response which is indicate that has the sound leaking around the sample at the sample holder wall.

The difference between the results of the PP sample and the 30%GFRPP sample may be caused by the small gap between the samples and the specimen holder wall. In addition, it suggests that the soft sealant can overcome a slight variation in the small gap between the sample and the specimen holder wall.

#### **- Results from the impedance tubes 100 mm diameter**

The experimental data for a 6 mm thick 30%GFRPP samples by using 4 different mounting sealants are PTFE tape, silicon oil (Si Oil), petroleum jelly (PJ), and high vacuum grease (HVG) which had a higher viscosity than other sealants as shown in Figure 2-12.

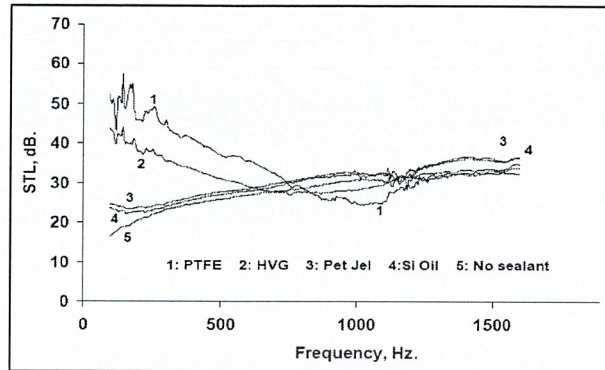


**Figure 2-12:** TL-frequency plots of 6 mm thick 30%GFRPP samples from tests with the sample sealed with the 4 different sealing methods [20].

The results of the sample sealed with PTFE can be seen that the contact with the specimen holder wall creates an increase in the TL at the lower part of frequency ranges, but it shows a decreasing in the TL when compared to other sealants at the higher part of the frequency ranges. For the sample sealed with HVG shows a similar plot in the TL value, but less effect when compared to the sample sealed with PTFE. From the results suggest that the higher viscosity of the HVG caused an interaction between the sample and the sample holder wall that affects in the TL value.

For the results of the sample without sealant represents smoother plot than the sample was sealed with petroleum jelly and silicon oil, but it has a slightly lower value which may be caused by the small gap between the samples and the specimen holder wall.

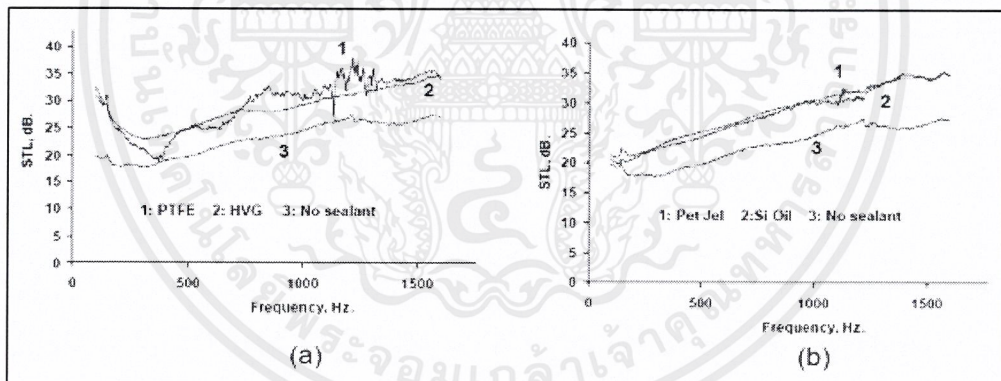
The experimental data for a 6 mm thick PP samples by using the 4 different mounting sealants are PTFE tape, silicon oil (Si Oil), petroleum jelly (PJ), and high vacuum grease (HVG) can be seen in Figure 2-13.



**Figure 2-13:** TL-frequency plots of 6 mm thick PP samples from tests with the sample sealed with the 4 different sealing methods [20].

From the graph, it shows a similar result with the 30%GFRPP sample was sealed with the petroleum jelly and the silicon oil which giving the most consistent result.

In the Figure 2-14 represented the experimental data for a 5 mm thick PP samples by using the 4 different mounting sealants are PTFE tape, silicon oil (Si Oil), petroleum jelly (PJ), and high vacuum grease (HVG).



**Figure 2-14:** TL-frequency plots of a 5 mm thick PP sample from tests with the sample sealed with the 4 different sealing methods [20].

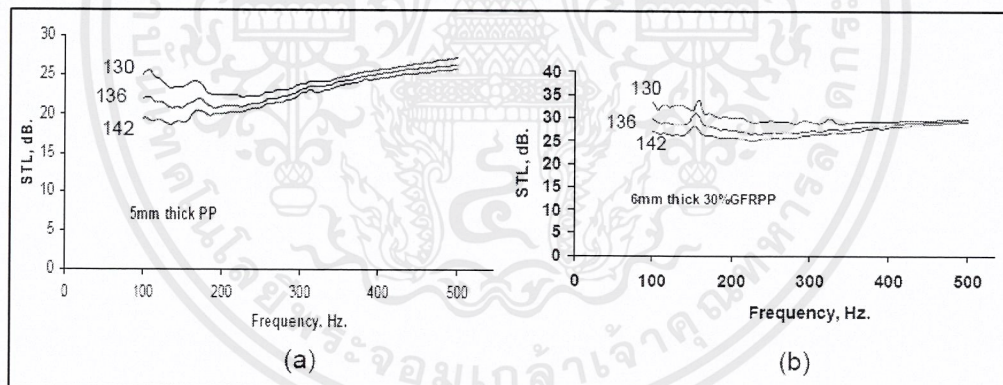
The results of the PP sample sealed with the different mounting conditions shows a similar trend to 6 mm thick 30%GFRPP sample and 6 mm thick PP sample. But the sample without sealant shows a greater drop of the STL value from the 6 mm thick sealed sample which led to the increased leakage of the sound energy through the larger gap between the samples and the specimen holder wall.

When compared the test results between the two sizes of test tube suggests that both of the sealing the samples and the conditions of the mounting should be used to consideration equally in testing both of the test tube.

### Effect of the incident sound power level

In this test as investigate the effect of 3 levels are 130, 136 and 142 dB of the incident sound waves on the TL value of PP and 30%GFRPP samples by using 100 mm diameter of the impedance tubes. Each of the samples was sealed with silicon oil, petroleum jelly, PTFE tape and high vacuum grease.

From the experimental data showed that the samples sealed with the high vacuum grease (HVG) and PTFE tape, there was no significant effect on the TL when change in sound level at all of the frequency ranges. For the samples sealed with the silicon oil and petroleum jelly showed a similar result that there was no significant difference on the TL when change in sound level at the frequency ranges between 500-1,600 Hz. At the lower part of the frequency ranges, the TL was increased when the sound level was decreased which can be seen in Figure 2-15 of the samples sealed with petroleum jelly.



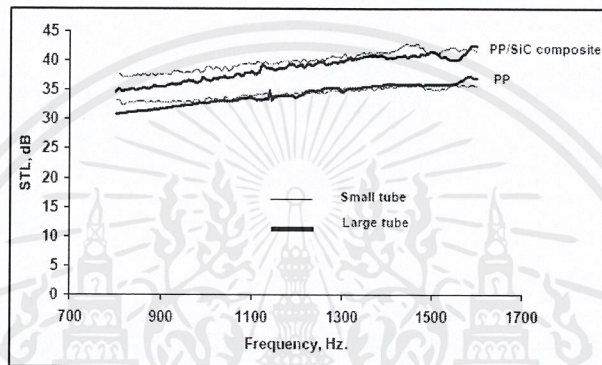
**Figure 2-15:** TL-Frequency plots of (a) a 5 mm thick PP sample and, (b) a 6 mm thick 30%GFRPP sample mounted with petroleum jelly [20].

The results of the TL of the two samples shows a linearity in the frequency ranges of 400-1,600 Hz and has slight deviation from linearity in the frequency ranges between 100-400 Hz. At this stage it is not possible to give an explanation about the result due to maybe has the effect of the method to mounting the sample.

From the result it can be concluded that should be consider the level of the incident sound waves when testing a material because it can be affect to the TL value.

#### **Effect of the continuity between the test tubes**

In this test section as investigate the effect of an overlapping frequency ranges are 800-1,600 Hz between the two tubes as shown in Figure 2-16. For the larger tube, the frequency ranges are 100-1,600 Hz and for the smaller tube, the frequency ranges are 800-6,400 Hz.

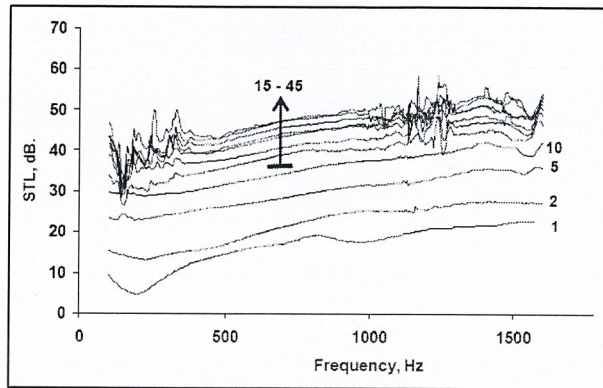


**Figure 2-16:** TL-frequency plots of PP and a composite of PP with 70%w of silicon carbide filler particles [20].

From the graph, represented that there was no different between the two impedance tubes which an indicated that the sample setting and preparation method is consistent.

#### **Effect of sample thickness**

In Figure 2-17 as the experimental data for the high-density polyethylene (HDPE) with various thickness in the 100 mm diameter tube. The sample with thicknesses greater than 10 mm were obtained by stacking and coating with the petroleum jelly before were pressed together for give the thicknesses is 15, 25, 35, and 45 mm.

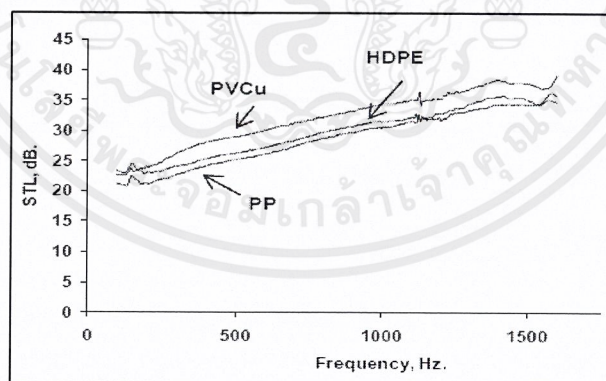


**Figure 2-17:** TL-frequency plots of an HDPE resin for sample thicknesses from 1 mm to 45 mm [20].

The results show that when the thickness of the samples increase, the TL value will be increases and it also when the frequency increase, the TL value will be increases. But for the samples that were obtained by stacking, it there are erratic of TL response to the incident sound waves in two parts of the frequency ranges which still do not have a reason to clearly explain this phenomenon.

#### **Effect of Density and Elastic Modulus**

In the Figure 2-18 represented the experimental data for a 5 mm thick high-density polyethylene, polypropylene homopolymer and unplasticised PVC.



**Figure 2-18:** TL-frequency plots of a 5 mm samples of HDPE, PP and PVCu [20].

And Table 2-3 shows the mean TL values in the frequency ranges 100-1,600 Hz, density and tensile modulus values of the HDPE, PP and PVCu samples.

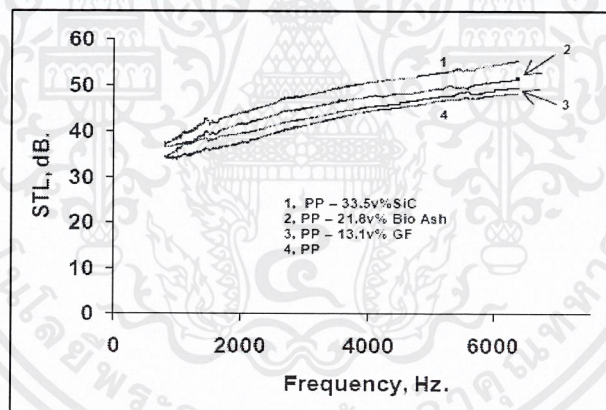
**Table 2-3:** Mean TL, density and tensile modulus values of the HDPE, PP and PVCu samples [20].

Materials	Mean STL for 0.1-1.6 kHz., dB.	Density, g/cc	Tensile Modulus, GPa
PP	28.6	0.91	1.65
HDPE	29.7	0.96	1.00
PVCu	32.7	1.44	3.00

The results show a relationship that when the density of the samples increase, it also the TL value will be increases, but when the tensile modulus values increases, the TL value will not increases following the tensile modulus values.

#### Effect of fillers

In Figure 2-19 as the experimental data for a 6 mm thick polypropylene compounds, PP/0v% filler, PP/13.1v% Glass fiber, PP/21.8v% Bio Ash and pp/33.5v% silicon carbide powder. in the 29 mm diameter tube.



**Figure 2-19:** TL-frequency plots of a 6 mm thick samples of compounds with a PP matrix [20].

From the graph show that when the volume fraction of the filler increases, it also the STL value of the compounds will be increases [20].

## CHAPTER III

### RESEARCH METHODOLOGY

#### 3.1 Selection of the materials

For the selection of materials used in this project, the basic properties that will be considered are

1. A dense material, high density
2. Low porosity, less air flow resistivity

And the materials selected for testing in this research are

1. Damper is synthetic rubbers with add the fillers to produce the material denser than general synthetic rubber which is especially used for as soundproof material.

2. Rubber is the porous synthetic rubbers based closed cell light weight elastomeric thermal insulation.

3. Cork tape is polymer-based material containing synthetic rubbers, asphalt and approximately 50% cork by volume.

4. Finished goods rubber mixed with compound rubber is the finished goods rubber that is not standardized in production which is grinded and mixed with compound rubber.

#### 3.2 Materials and apparatus

##### 3.2.1 Materials

###### 1. Test samples

Sample 1: Damper 3 mm thickness (Damper 3 mm), density is  $1,760.06 \text{ kg/m}^3$

Sample 2: Damper 5 mm thickness (Damper 5 mm), density is  $1,861.81 \text{ kg/m}^3$

Sample 3: Rubber 25 mm thickness (Rubber 25 mm), density is  $41.78 \text{ kg/m}^3$

Sample 4: Rubber 50 mm thickness (Rubber 50 mm), density is  $64.24 \text{ kg/m}^3$

Sample 5: Damper 3 mm thickness composited with rubber 25 mm thickness (Damper 3 mm + Rubber 25 mm), density is  $227.63 \text{ kg/m}^3$

Sample 6: Damper 3 mm thickness composited with rubber 50 mm thickness (Damper 3 mm + Rubber 50 mm), density is  $173.63 \text{ kg/m}^3$

Sample 7: Damper 5 mm thickness composited with rubber 25 mm thickness (Damper 5 mm + Rubber 25 mm), density is  $305.61 \text{ kg/m}^3$

Sample 8: Finished goods rubber mixed with compound rubber 2 mm thickness (FG + Compound 2 mm), density is 1,219.10 kg/m<sup>3</sup>

Sample 9: Finished goods rubber mixed with compound rubber 4 mm thickness (FG + Compound 4 mm), density is 1,273.69 kg/m<sup>3</sup>

Sample 10: Damper 5 mm thickness composited with cork tape 3 mm thickness (Damper 5 mm + Cork tape 3 mm), density is 1,386.81 kg/m<sup>3</sup>

2. Sealant (Hayakawa rubber)

3. Golden tape

### 3.2.2 Apparatus

1. Impedance tube system

2. Sound level meter (Handheld audio and acoustic analyzer)

3. Simulated drainage pipe

### 3.3 Impedance tube

Impedance tube as kits consist of testing tubes that are equipped with microphones and sound sources. Material samples are inserted into the sample holder. A loudspeaker in the tube will emit sound, and the microphones measure the sound pressure level at specific locations along the length of the tube. Impedance tube will help to determine sound absorption coefficient and transmission loss which calculates according to the standards ISO 10534-2 and ASTM E1050-98 for sound absorption coefficient and the standards ASTM E2611-09 for transmission loss [20].

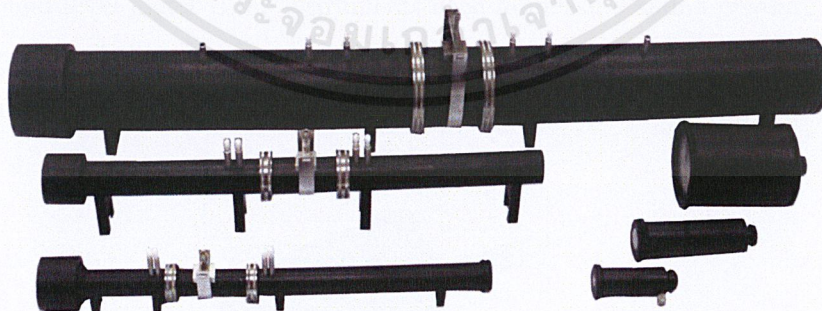


Figure 3-1: Impedance tube [21].

For labels used to describe sound level measurement are defined in the IEC Standard 61672-1: 2013 as follows:

- The first letter is “L” indicates the sound pressure level measured through a microphone.

- The second letter is “A”, “C” or “Z” indicates the frequency weighting including A-frequency-weighting, C-frequency-weighting, and Z-frequency-weighting.

- The third letter is “F”, “S” or “I” indicates the time weighting which is used to easier to read on a sound level meter.

F = Fast, this mode is a response to measurements within 100-125 msec.

S = Slow, this mode is a response to measurements within 1 sec.

I = Impulse, this mode is a rapid response to measurements within 35 msec.

- More parameters including

max = the maximum value measured over a certain period of time.

min = the minimum value measured over a certain period of time.

eq = the equivalent value measured over a certain period of time [23].

### 3.5 Experimental

For the testing method was divided into 2 parts, test with the impedance tube and test with a simulated drainage pipe.

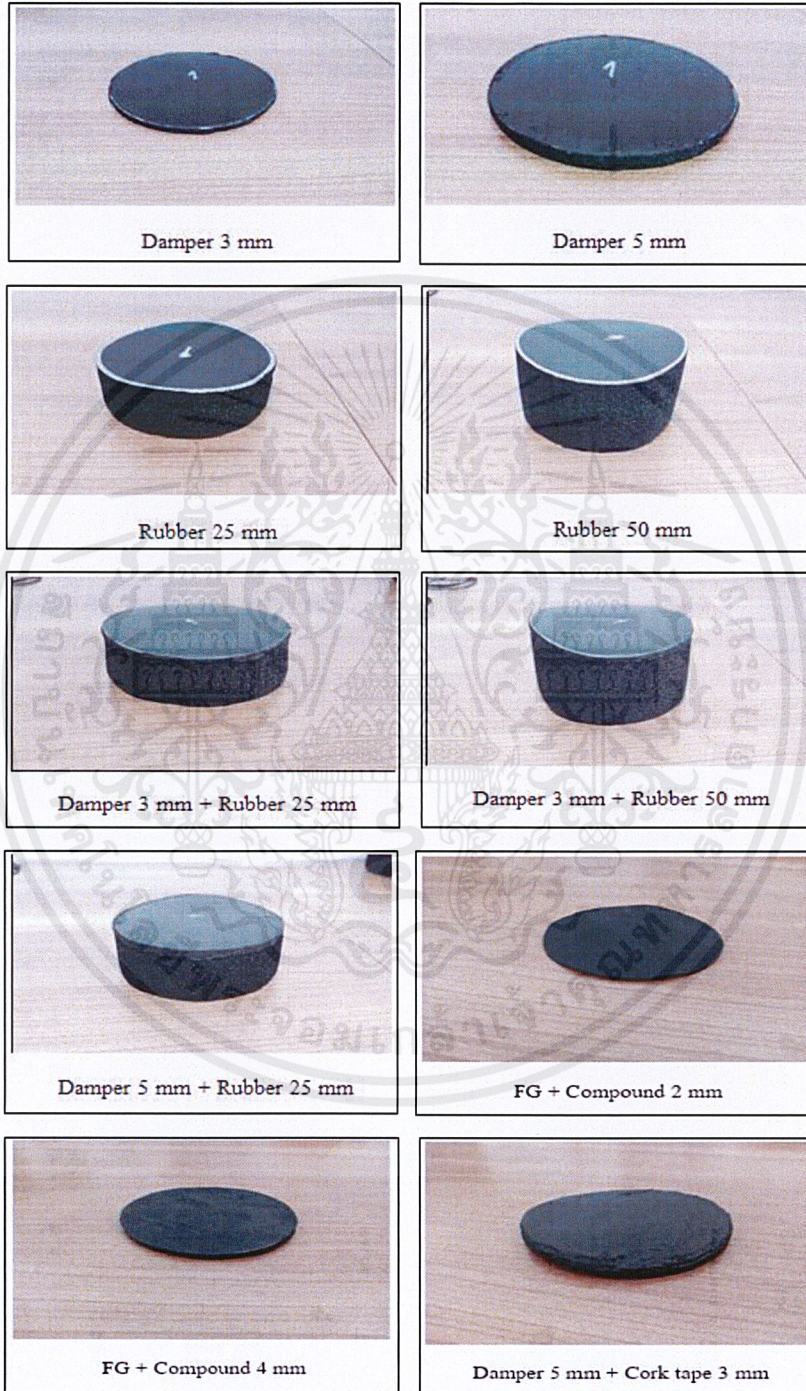
#### 3.5.1 Testing with the impedance tube

Testing in this part will measure and compare the transmission loss (TL) values of each test sample by using the impedance tube as shown in Figure 3-4. with the following steps:



**Figure 3-4:** Impedance tube system in testing room.

1. Prepare each test sample in cylindrical shape to the desired thickness amount  
10 pieces, 5 pieces for diameter 99 mm and 5 pieces for diameter 29 mm.



**Figure 3-5:** Test samples.

2. Connect the impedance tube to the computer and calibrate by setting the temperature of 20°C, the relative humidity of 50% and setting the test as transmission loss test in the VA-Lab4 program.

3. Testing for transmission loss is divided into 3 parts according to the frequency ranges which are low, middle, and high frequency ranges by using a 99 mm sample with the larger tube for measuring at low and middle frequency ranges and a 29 mm sample with the smaller tube for measuring at high frequency ranges.

4. Put the sample into the impedance tube and then test the sample. If there is a gap between the sample and the sample holder, will use sealant to help seal the sample.

5. After all samples have been tested, Combine the test results of each sample that were obtained from all 3 frequency ranges together.

6. Create a graph of relationships between transmission loss and frequency. Compare the test data obtained from each sample, then choose the most effective and suitable samples for soundproof and use these samples to test with simulated drainage pipes.

### 3.5.2 Testing with a simulated drainage pipe

Testing in this part is a measuring the noise of water flowing inside the blank pipe and measuring the noise of water flowing inside the pipe when covered with a sample. For a simulated drainage pipe in the testing room is composed of 3 pieces of elbows, 2 pieces of 90° elbow and 1 piece of 45° elbow.

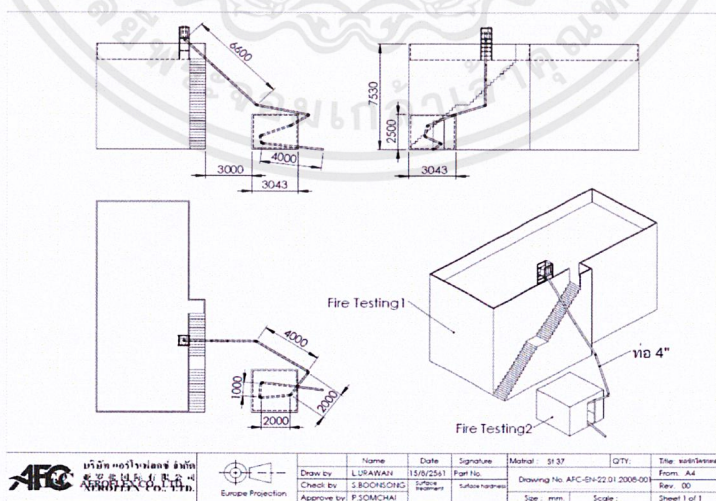
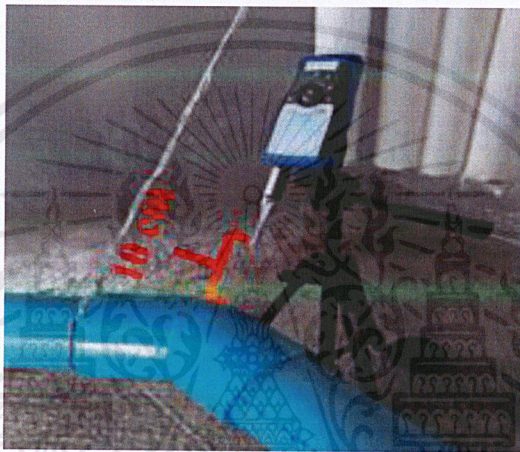


Figure 3-6: Model of the drainage pipe [24].

**- Measuring the noise of water flowing inside the blank pipe**

For measuring the noise of water flowing inside the blank pipe, there are the following steps:

1. Set the sound level meter for measurement to the LZFmax mode to measure the highest sound pressure.
2. Install the sound level meter in the testing room with a distance about 10 cm from the blank pipe as shown in Figure 3-7.



**Figure 3-7:** Installation of a sound level meter.

3. Pour the water from a bucket in the pipe. Then, measure the sound pressure at each elbow 3 times to find the average value of sound pressure.

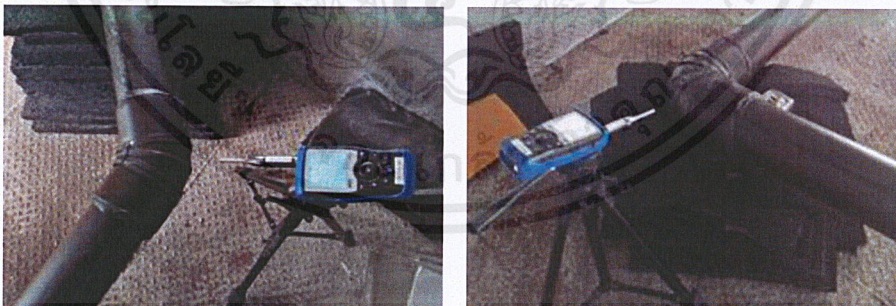


**Figure 3-8:** Method to dump a bucket in a simulated drainage pipe.

**- Measuring the noise of water flowing inside the pipe when covered with the samples**

For this measurement, it is measuring the noise of water flowing inside the pipe when covered with a sample chosen from the testing with the impedance tube, which there are the following steps:

1. Design the way to cover a simulated drainage pipe.
2. Cut each test sample chosen from the testing with the impedance tube in order to cover a simulated drainage pipe. Then, stick the golden tape on the samples so that the samples are in contact with the pipe.
3. Take the sample to cover the pipe which will cover only the parts that are in the testing room.
4. Set the sound level meter for measurement to the LZFmax mode to measure the highest sound pressure.
5. Install the sound level meter in the testing room with a distance about 10 cm from the blank pipe.
6. Pour the water from a bucket into the pipe. Then, measure the sound pressure at each the elbow 3 times to find the average value of sound pressure.
7. Compare and summarize the test results obtained from this test and measuring the noise of water flowing inside the blank pipe.



**Figure 3-9:** Measuring the sound pressure when covered with the sample.

## CHAPTER IV

### RESULTS AND DISCUSSION

For this project, Mr. Chaiyut Hungsasuth and R&D team have done some part of this project that are 7 samples include Damper 3 mm, Damper 5 mm, Rubber 25 mm, Rubber 50 mm, Damper 3 mm + Rubber 25 mm, Damper 3 mm + Rubber 50 mm, and Damper 5 mm + Rubber 25 mm. Therefore, this information has been used as part of this project.

#### 4.1 Results from the impedance tube

The test data for the transmission loss (TL) values of each sample at different thickness can be seen in Figure 4-1.

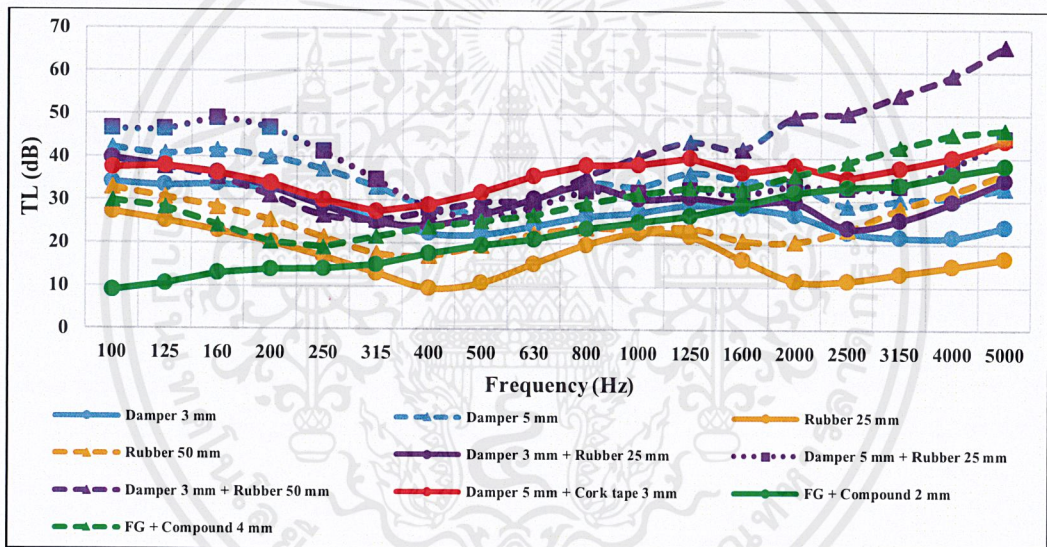


Figure 4-1: TL-frequency plots of each sample.

From the Figure 4-1, the results of each sample are separated to be able to discuss and easier to visualize.

## **Results of R&D team**

### **- Damper samples**

From the Figure 4-1, the results show that for the damper samples, the TL increases with the increase in the section of thickness and density.

The TL values of damper samples is according to the theory described in sound transmission through homogeneous panels:

At the lower frequency ranges, the transmission loss is controlled by the static stiffness of the panel which the panel resonances can also occur and cause dramatically decrease the TL.

At the middle frequency ranges, the TL will increase in accordance to the mass law theory.

And at the higher frequency ranges is the region of the critical frequency, which cause the coincidence effect leads to reduce in the TL values. Then, the TL again rises, being damping controlled, and gradually approaches an extension of the original mass law portion of the curve.

### **- Rubber samples**

From the Figure 4-1, the results show in a similar pattern to the damper samples that when the thickness and density of the samples increase, the TL is increases.

The TL values of rubber samples is according to the theory described in sound transmission through homogeneous panels, as it is happening in the damper samples.

At the lower frequency ranges, the TL is decrease which result from the panel resonances.

At the middle frequency ranges, the TL will increase in accordance to the mass law theory.

And at the higher frequency ranges is the region of the critical frequency, which cause the coincidence effect leads to reduce in TL values. After that, the TL again rises and gradually approaches an extension of the original mass law portion of the curve.

However, the TL of rubber samples is lower than the damper samples because the density is lower.

### - Damper composited with rubber samples

In the Figure 4-1, the results show that for a 3 mm thick damper composited with 50 mm thick rubber samples, the tendency of the TL is similar to the damper and rubber samples. For a 3 mm thick damper composited with 25 mm thick rubber samples and 5 mm thick damper composited with 25 mm thick rubber samples, the tendency of the TL is also similar to the damper and rubber samples, but both samples is strongly affected by the existence of a critical frequency ranges cause the coincidence region may extend than the damper and rubber samples.

### Results of this project

#### - Damper composited with cork tape samples

The test data for the transmission loss (TL) values of damper composited with cork tape samples as shown in Figure 4-5.

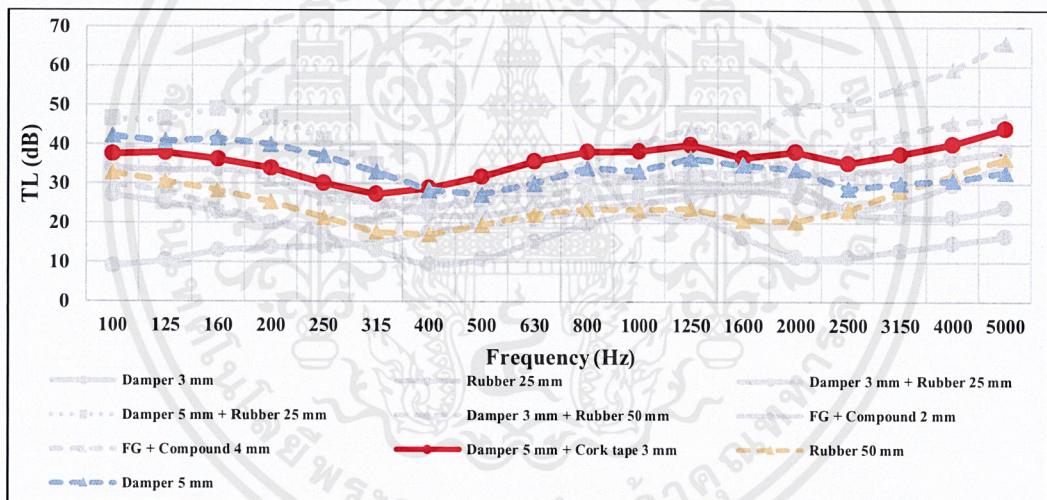
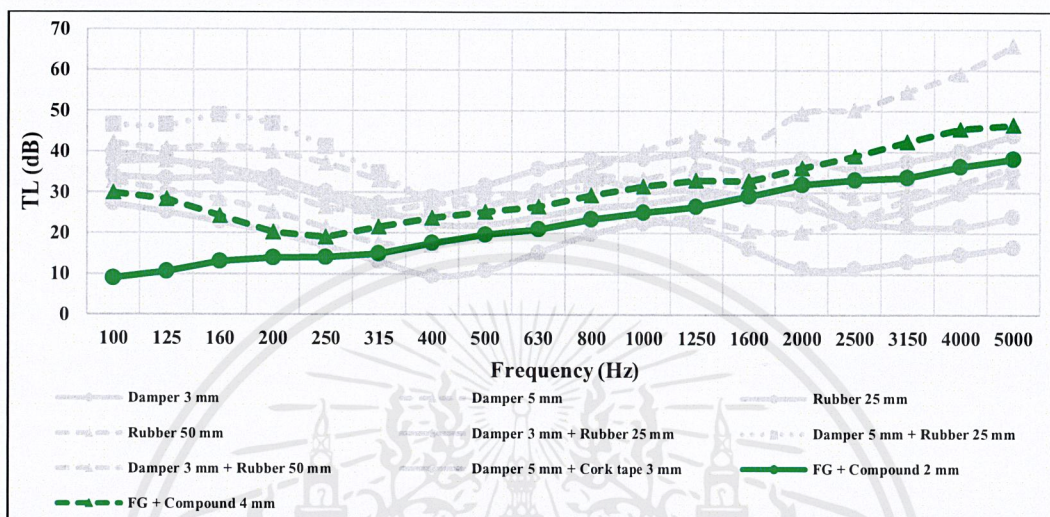


Figure 4-2: TL-frequency plots of damper composited with cork tape sample.

From the Figure 4-2 at the lower frequency ranges, the TL decreases with an increase in the sound frequency due to the panel resonances and the TL for middle and high frequency is higher than the damper and rubber samples.

**- Finished goods rubber mixed with compound samples**

The test data for the transmission loss (TL) values of finished goods rubber mixed with compound samples as shown in Figure 4-3.



**Figure 4-3:** TL-frequency plots of finished goods rubber mixed with compound samples.

In the Figure 4-3, it can be seen that for finished goods rubber mixed with compound samples the TL increases with an increase in the thickness and density and it also shows that the TL for high frequency is higher than the damper and rubber samples.

**Table 4-1:** Summarize the TL of each sample at various frequency ranges.

Samples	TL (dB)			
	Low frequency (100-400 Hz)	Middle frequency (500-2,000 Hz)	High frequency (2,500-5,000 Hz)	Average
- Damper 3 mm	30.26	26.22	22.48	26.31
- Damper 5 mm	37.55	32.80	30.70	33.68
- Rubber 25 mm	19.25	16.81	13.96	16.67
- Rubber 50 mm	24.70	21.92	30.00	25.54
- Damper 3 mm + Rubber 25 mm	32.07	30.07	28.42	30.18
- Damper 3 mm + Rubber 50 mm	31.81	38.70	57.59	42.70
- Damper 5 mm + Rubber 25 mm	41.76	30.82	37.20	36.59
- Damper 5 mm + Cork tape 3 mm	33.06	37.82	42.95	37.94
- FG + Compound 2 mm	13.28	25.22	35.38	24.61
- FG + Compound 4 mm	23.82	30.62	43.44	32.63

\*\*\*  Samples of R&D team  Samples of this project  
 Average TL of samples that use to cover a simulated drainage pipe

When compare the average TL of each sample from the Table 4-1, found that

- At the lower frequency ranges, 5 mm thick damper composited with 25 mm thick rubber sample has the best soundproof performance.

- At the middle frequency ranges, 3 mm thick damper composited with 50 mm thick rubber sample has the best soundproof performance.

- At the higher frequency ranges, 3 mm thick damper composited with 50 mm thick rubber sample has the best soundproof performance.

And from the Table 4-1, the highest average TL of 4 samples are 3 mm thick damper composited with 50 mm thick rubber, 5 mm thick damper composited with 3 mm thick cork tape, 5 mm thick damper composited with 25 mm thick rubber, and 5 mm thick damper, respectively. Therefore, will uses the samples are 5 mm thick damper, 5 mm thick damper composited with 3 mm thick cork tape and 5 mm thick damper composited with 25 mm thick rubber samples to cover a simulated drainage pipe.

For the reason that do not use 3 mm thick damper composited with 50 mm thick rubber sample to cover a simulated drainage pipe because it is too thick cause it unsuitable when being used in testing.

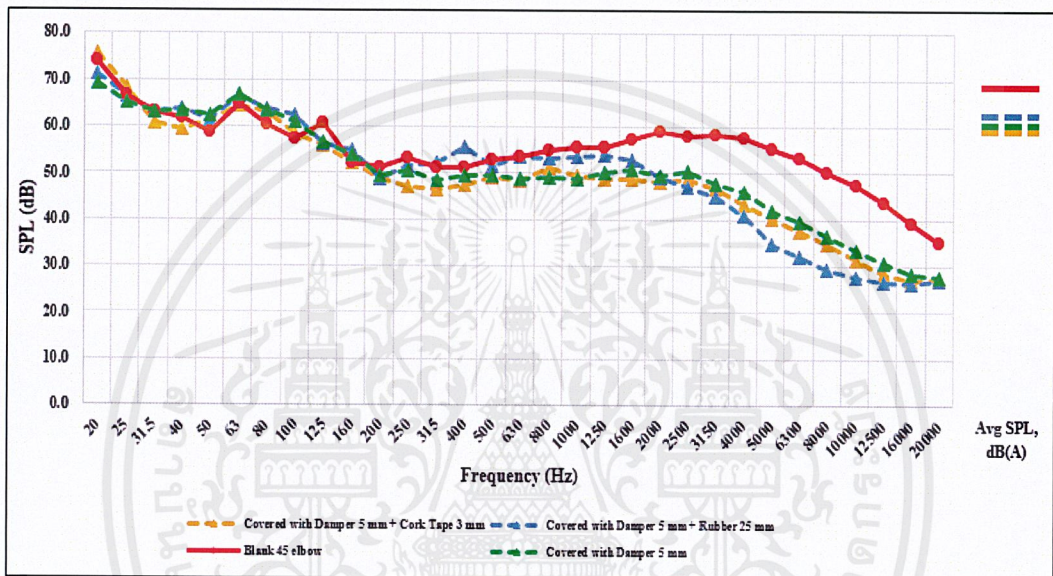
**Table 4-2:** Summarize the effect of doubling the frequency at middle frequency ranges.

Samples	TL <sub>0</sub> (dB)		
	500 Hz	1,000 Hz	2,000 Hz
- Damper 5 mm + Cork tape 3 mm	32.73	38.75	44.77
- FG + Compound 2 mm	17.66	23.62	29.63
- FG + Compound 4 mm	26.14	32.15	38.17

For middle frequency ranges of 3 samples are damper 5 mm thickness composited with cork tape 3 mm thickness, finished goods rubber mixed with compound rubber 2 mm thickness, and finished goods rubber mixed with compound rubber 4 mm thickness, the effect of doubling the frequency cause the normal incidence transmission loss ( $TL_0$ ) to increase by approximately 6-8 dB in according to mass law.

#### 4.2.2 Measuring the noise of water flowing inside the pipe when covered with the samples

The test data for the sound pressure level (SPL) values at various frequencies when covering with a 5 mm thick damper, 5 mm thick damper composited with 3 mm thick cork tape and 5 mm thick damper composited with 25 mm thick rubber sample as shown in Figure 4-5.



**Figure 4-5:** SPL-frequency plots of a simulated drainage pipe when covered with each sample.

From the graph, when using a 5 mm thick damper composited with 3 mm thick cork tape sample to covering the pipe, it was found that the average SPL was 59 dB(A), which reduced the SPL by 9 dB(A). But little heard the sound of the water flowing inside the pipe from the observation by using the ears.

For a 5 mm thick damper sample, the average SPL was 60 dB(A), which reduced the SPL by 8 dB(A) and not hear the sound of the water flowing inside the pipe from the observation by using the ears although from the use of sound level meter will result in the average SPL that is less than when using a 5 mm thick damper composited with 3 mm thick cork tape about 1 dB(A). This is probably due to an error from the sound level meter because the testing room is not a closed room.

And a 5 mm thick damper composited with 25 mm thick rubber sample, the average SPL was 62 dB(A), it reduced the SPL by 6 dB(A) which can clearly hear the sound of the water flowing inside the pipe when an observe by using the ears.

**Table 4-3:** Summarize the SPL from a simulated drainage pipe at various frequency ranges.

Samples	SPL (dB)		
	Low frequency (20-400 Hz)	Middle frequency (500-2,000 Hz)	High frequency (2,500-20,000 Hz)
- Blank pipe at 45° elbow	52.4	64.7	65.0
- Covered with Damper 5 mm	51.3	57.9	54.9
- Covered with Damper 5 mm + Rubber 25 mm	54.3	60.9	51.1
- Covered with Damper 5 mm + Cork tape 3 mm	49.5	57.4	53.3

When compare the SPL of each sample from the Table 4-3, found that

- At the lower frequency ranges, 5 mm thick damper composited with 3 mm thick cork tape sample has the best soundproof performance.
- At the middle frequency ranges, 5 mm thick damper composited with 3 mm thick cork tape sample has the best soundproof performance.
- At the higher frequency ranges, 5 mm thick damper composited with 25 mm thick rubber sample has the best soundproof performance.

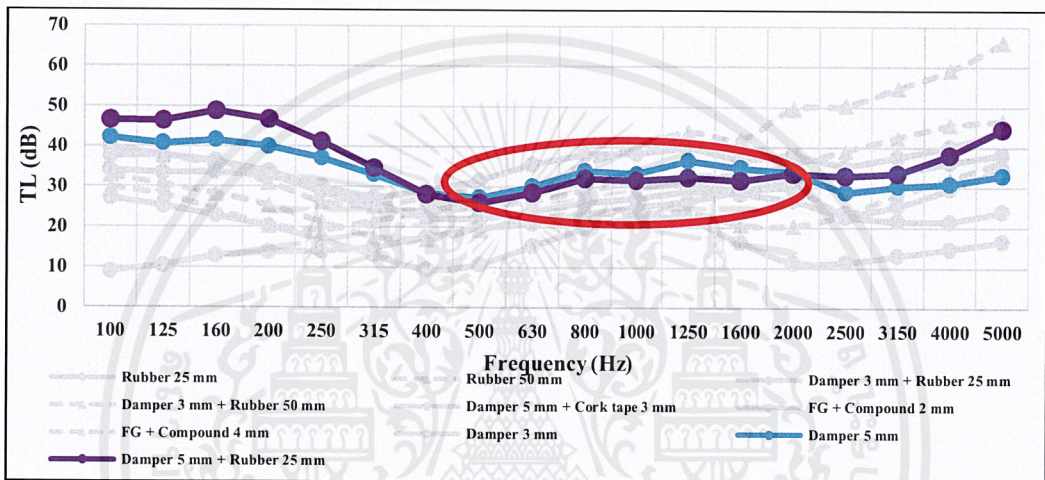
And from the results in Table 4-3, it is suggested that the frequency of the water flowing inside the pipe is not high frequency ranges

From theory, when the materials have more layers, it will also have more soundproof performance as well. Because when the sound waves travel through the material with more layers, it will cause the energy of the sound waves more destructive than materials with less layers.

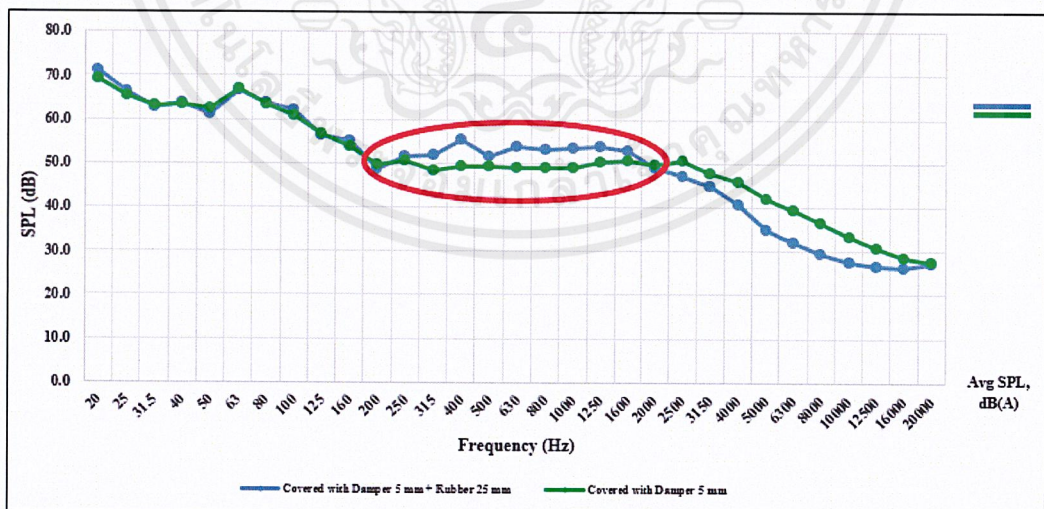
For a 5 mm thick damper composited with 3 mm thick cork tape sample which added the cork tape as another layer, found to be the performance in soundproof similar to a single layer damper.

But for a 5 mm thick damper composited with 25 mm thick rubber sample which added the rubber as another layer, the soundproof performance of this sample was less than that of a single layer damper.

The test result of 5 mm thick damper and 5 mm thick damper composited with 25 mm thick rubber samples that obtained from the impedance tube and sound level meter as shown in Figure 4-6 and Figure 4-7, respectively. It show that there is a relationship of the results in the frequency ranges of 300-2,000 Hz, a 5 mm thick damper sample has more soundproof performance than a 5 mm thick damper composited with 25 mm thick rubber sample which there is no research that can explain the cause of this phenomenon. So, this will be a subject of a further investigation.



**Figure 4-6:** TL-frequency plots of 5 mm thick damper and 5 mm thick damper composited with 25 mm thick rubber samples.



**Figure 4-7:** SPL-frequency plots of a simulated drainage pipe when covered with 5 mm thick damper and 5 mm thick damper composited with 25 mm thick rubber samples.

## CHAPTER V

### CONCLUSIONS AND SUGGESTIONS

#### 5.1 Conclusions

##### 5.1.1 Soundproof property from the impedance tube

The results of soundproof property of each sample by using impedance tube method in according to ASTM E2611-09 found that

- At the lower frequency ranges, 5 mm thick damper composited with 25 mm thick rubber sample has the best soundproof performance.

- At the middle frequency ranges, 3 mm thick damper composited with 50 mm thick rubber sample has the best soundproof performance.

- At the higher frequency ranges, 3 mm thick damper composited with 50 mm thick rubber sample has the best soundproof performance.

And for the normal incidence transmission loss ( $TL_0$ ) at the middle frequency ranges of all samples, the effect of doubling the mass or doubling the frequency will cause the normal incidence transmission loss ( $TL_0$ ) to increase by approximately 6-8 dB in according to mass law.

##### 5.1.2 Soundproof property from a simulated drainage pipe

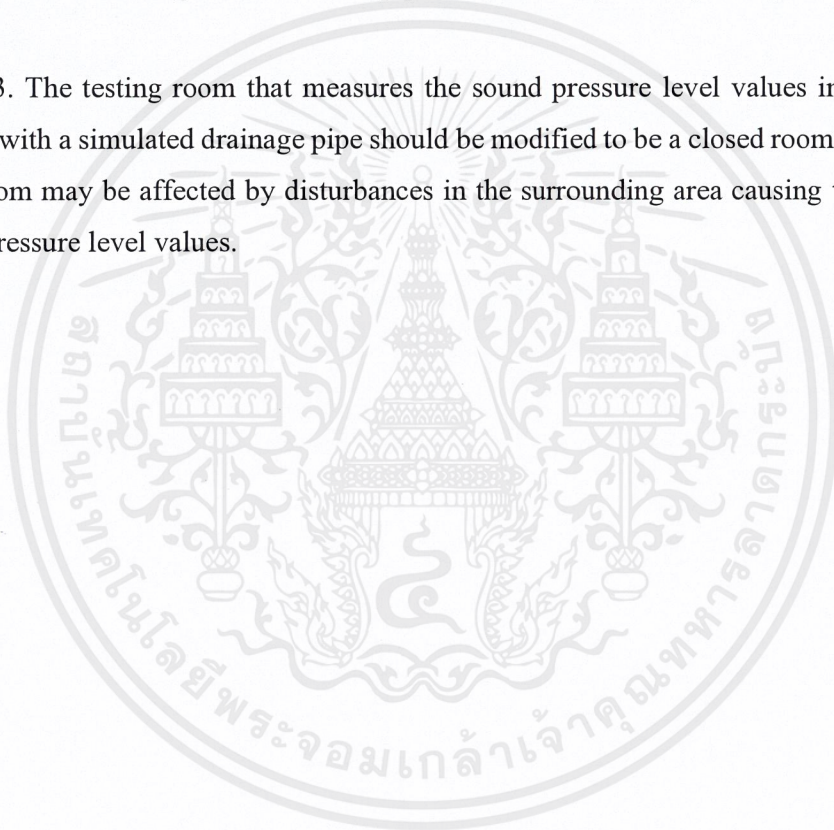
In this experiment, the result show that the average sound pressure level of the blank pipe is approximately 68 dB(A) and when take the samples to cover the pipe, the result show that for 5 mm thick damper composited with 3 mm thick cork tape sample, the average sound pressure level is 59 dB(A). For 5 mm thick damper sample, the average sound pressure level is 60 dB(A). And for 5 mm thick damper composited with 25 mm thick rubber sample, the average sound pressure level is 62 dB(A). It can be seen that all of samples can reduce the sound pressure level. It can summarize that 5 mm thick damper sample is the most suitable in this project because the sound of the water running in pipe was not heard when listen by the ears. But I can hear the sound of running water in the pipe when covered with other samples

## 5.2 Suggestions

1. In the test with impedance tube, the sealant used in the mounting of the sample should also be considered for use. Because each type of sealant may affect the transmission loss values of each sample and may cause errors in the analysis of test results.

2. In testing the soundproof property of samples by using a simulated drainage pipe, the sound pressure level values obtained in each frequency may have human errors due to pouring the water from a bucket into the pipe cannot be the same every time. Therefore, the method of releasing water into the pipe should be adjusted by using a control pump instead.

3. The testing room that measures the sound pressure level values in the testing process with a simulated drainage pipe should be modified to be a closed room because the open room may be affected by disturbances in the surrounding area causing to affect the sound pressure level values.



## References

- [1] C. Ngohpok, “Sound Absorption of Pervious Concrete Containing Various Sizes of Coarse Aggregate,” no. 2, pp. 65–77, 2019.
- [2] H. Panggabean, S. Triono, and Sukardi, “Acoustic Sound Absorption Material Characteristics of Fiber Using the King Banana Stem Polyurethane and Gypsum as Matrix,” vol. 6, no. 03, pp. 315–322, 2017.
- [3] ร. วิฑูรปกรณ์, “เสียงรบกวนในอาคาร,” pp. 30–35, 2017.
- [4] N. Knox, “What is WELL?,” 2015. [Online]. Available: <https://www.usgbc.org/articles/what-well>. [Accessed: 21-Dec-2020].
- [5] A. P. G. Peterson, *Handbook of Noise Measurement*, 9th ed. Massachusetts: GenRad, Inc., 1980.
- [6] G. M. Ballou, *Handbook for Sound Engineers*, 4th ed. New York: Focal Press, 2008.
- [7] C. Ezrailson, N. Hainen, D. Lillie, and D. Zike, *Waves, Sound, and Light*, 1st ed. New York: McGraw-Hill, 2005.
- [8] C. H. Hansen, *Fundamentals of Acoustics*, 3rd ed. London: E. & F.N. Spon, 1996.
- [9] S. W. Smith, *The Scientist and Engineer’s Guide to Digital Signal Processing*, 1st ed. California: California Technical Publishing, 1997.
- [10] R. Bemrose, “Louder Sounds Better: Fletcher-Munson Equal Loudness Curve.” [Online]. Available: <https://docs.microsoft.com/th-th/archive/blogs/audiofool/louder-sounds-better>. [Accessed: 23-Sep-2019].
- [11] M. Long, *Architectural Acoustics*, 1st ed. Massachusetts: Academic Press, 2005.
- [12] L. Rion Co., “NOISE AND SOUND LEVEL METERS: Physical and Sensuous Value of Sound,” 2010. [Online]. Available: [https://rion-sv.com/support/st\\_sound\\_en.aspx](https://rion-sv.com/support/st_sound_en.aspx). [Accessed: 10-Dec-2019].
- [13] B. Truax, *HANDBOOK FOR ACOUSTIC ECOLOGY*, 2nd ed. Cambridge: Cambridge Street Publishing, 1999.
- [14] L. Get Best Sound Co., “ความสัมพันธ์ของการสะท้อน ดูดซับ และทะลุผ่านของเสียง,” 2013. [Online]. Available: <http://www.iso-noise.com/absorb-reflec-transmiss.html>. [Accessed: 10-Dec-2019].

- [15] P. Poolsawas, "An Investigation of Sound Insulation Properties of Metal Sheet Roof with Elastomeric Materials," Chulalongkorn University, 2017.
- [16] D. A. Bies and C. H. Hansen, *Engineering Noise Control: Theory and Practice*, 3rd ed. New York: Spon Press, 2003.
- [17] J. S. Lamancusa, "Transmission of Sound Through Structures." [Online]. Available: [https://www.mne.psu.edu/lamancusa/me458/9\\_trans.pdf](https://www.mne.psu.edu/lamancusa/me458/9_trans.pdf). [Accessed: 06-Oct-2019].
- [18] A. International, "ASTM E2611-09 Standard Test Method for Measurement of Normal Incidence Sound Transmission of Acoustical Materials Based on the Transfer Matrix Method." [Online]. Available: <https://www.astm.org/Standards/E2611.htm>. [Accessed: 06-Aug-2019].
- [19] M. F. Mat Tahir, M. H. Nawi, R. Zulkifli, A. K. Elwaleed, and S. M. Mat Yunoh, "The effect of thickness and density on the Acoustics properties of Ceiba pentandra natural fiber," *ARPN J. Eng. Appl. Sci.*, vol. 13, no. 9, pp. 3214–3218, 2018.
- [20] P. S. Allan, A. Ahmadnia, R. Withnall, and J. Silver, "Sound transmission testing of polymer compounds," *Polym. Test.*, vol. 31, no. 2, pp. 1–19.
- [21] Scantek Inc., "Impedance Tubes." [Online]. Available: <https://www.scantekinc.com/products/special-test-systems/bswa/impedance-tubes-2/>. [Accessed: 01-Dec-2019].
- [22] A. Samuelson, "Monitor & Control Noise Chapter 2-Noise Measurement & Surveys." [Online]. Available: [http://cffet.net/noise/noise\\_ch2a.shtml](http://cffet.net/noise/noise_ch2a.shtml). [Accessed: 12-Aug-2019].
- [23] Greg, "What do LAeq and LAFmax mean?" [Online]. Available: <https://blog.nti-audio.com/know-how/what-do-laeq-lafmax-labels-mean>. [Accessed: 07-Aug-2019].
- [24] L. Aeroflex Co., "ท่อซัคโครททดสอบเสียง." 2018.



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## Appendix A

### Bulk density of samples

**Table A.1:** Bulk density of Damper 5 mm + Cork tape 3 mm samples.

Damper 5 mm + Cork tape 3 mm samples								
Pieces	Diameter (mm)	Thickness (mm)	Weight (g)	Radius (mm)	Volume (mm <sup>3</sup> )	Bulk density (g/mm <sup>3</sup> )	Bulk density (kg/m <sup>3</sup> )	
1	31.50	8.10	8.58	15.75	6309.22	0.00135991	1359.91	
2	31.70	8.20	9.05	15.85	6468.48	0.00139909	1399.09	
3	31.70	8.10	8.58	15.85	6389.59	0.00134281	1342.81	
4	31.40	8.10	8.56	15.70	6269.23	0.00136540	1365.40	
5	31.70	8.00	8.75	15.85	6310.71	0.00138653	1386.53	
6	101.60	8.10	92.11	50.80	65636.00	0.00140335	1403.35	
7	101.70	8.50	97.73	50.85	69012.93	0.00141611	1416.11	
8	101.40	8.30	94.43	50.70	66992.11	0.00140957	1409.57	
9	101.50	8.80	98.77	50.75	71167.94	0.00138784	1387.84	
10	100.90	8.30	92.70	50.45	66333.07	0.00139749	1397.49	
<b>Average bulk density</b>								<b>1386.81</b>

**Table A.2:** Bulk density of FG + Compound 2 mm samples.

FG + Compound 2 mm samples								
Pieces	Diameter (mm)	Thickness (mm)	Weight (g)	Radius (mm)	Volume (mm <sup>3</sup> )	Bulk density (g/mm <sup>3</sup> )	Bulk density (kg/m <sup>3</sup> )	
1	30.50	1.60	1.47	15.25	1168.39	0.00125814	1258.14	
2	30.10	1.60	1.32	15.05	1137.95	0.00115998	1159.98	
3	29.80	1.55	1.33	14.90	1080.52	0.00123089	1230.89	
4	29.95	1.55	1.31	14.98	1091.43	0.00120026	1200.26	
5	29.70	1.70	1.45	14.85	1177.15	0.00123179	1231.79	
6	99.30	1.70	15.98	49.65	13158.82	0.00121439	1214.39	
7	99.15	1.65	15.48	49.58	12733.24	0.00121572	1215.72	
8	100.50	1.60	15.88	50.25	12685.91	0.00125178	1251.78	
9	101.60	1.70	16.64	50.80	13775.46	0.00120795	1207.95	
10	101.00	1.70	16.61	50.50	13613.23	0.00122014	1220.14	
<b>Average bulk density</b>								<b>1219.10</b>

**Table A.3:** Bulk density of FG + Compound 4 mm samples.

FG + Compound 4 mm samples								
Pieces	Diameter (mm)	Thickness (mm)	Weight (g)	Radius (mm)	Volume (mm <sup>3</sup> )	Bulk density (g/mm <sup>3</sup> )	Bulk density (kg/m <sup>3</sup> )	
1	29.95	4.10	3.64	14.98	2887.00	0.00126082	1260.82	
2	30.70	4.10	3.84	15.35	3033.40	0.00126590	1265.90	
3	30.75	4.30	3.99	15.38	3191.75	0.00125010	1250.10	
4	30.75	4.00	3.80	15.38	2969.07	0.00127986	1279.86	
5	30.10	4.10	3.77	15.05	2915.99	0.00129287	1292.87	
6	102.00	4.20	45.06	51.00	34301.99	0.00131363	1313.63	
7	101.20	4.30	44.88	50.60	34569.98	0.00129824	1298.24	
8	101.90	4.00	41.43	50.95	32604.54	0.00127068	1270.68	
9	101.50	4.40	45.64	50.75	35583.97	0.00128260	1282.60	
10	101.50	4.50	44.48	50.75	36392.70	0.00122222	1222.22	
Average bulk density								1273.69

**Appendix B**  
**Transmission loss of samples**

**Table B.1:** Transmission loss of samples from the impedance tube.

	Damper 3 mm	Damper 5 mm	Rubber 25 mm	Rubber 50 mm	Damper 3 mm + Rubber 25 mm
Frequency (Hz)	TL (dB)	TL (dB)	TL (dB)	TL (dB)	TL (dB)
100	34.11	42.12	27.20	32.77	39.72
125	33.38	40.74	25.18	30.60	37.89
160	33.62	41.51	22.83	28.29	36.27
200	32.56	39.94	20.18	25.33	32.92
250	30.07	37.14	16.85	21.32	28.70
315	25.89	33.04	13.05	17.59	24.90
400	22.22	28.37	9.47	17.03	24.10
500	22.01	27.25	10.77	19.47	26.58
630	24.01	30.04	15.27	22.09	30.27
800	26.20	34.03	19.73	23.58	33.47
1000	27.21	33.23	22.47	23.34	30.38
1250	29.01	36.52	21.77	23.72	30.80
1600	28.39	34.82	16.29	20.77	29.38
2000	26.69	33.68	11.37	20.46	29.62
2500	22.72	28.75	11.38	23.27	23.71
3150	21.57	30.18	13.07	28.24	25.48
4000	21.54	30.91	14.78	32.10	29.71
5000	23.96	32.96	16.60	36.42	34.76

**Table B.1:** Transmission loss of samples from the impedance tube (Continued).

	Damper 5 mm + Rubber 25 mm	Damper 3 mm + Rubber 50 mm	Damper 5 mm + Cork tape 3 mm
Frequency (Hz)	TL (dB)	TL (dB)	TL (dB)
100	46.48	39.56	39.69
125	46.40	37.71	38.41
160	48.82	35.25	34.90
200	46.64	31.02	31.50
250	41.16	26.41	27.85
315	34.67	25.39	28.08
400	28.15	27.30	30.97
500	25.95	29.52	33.42
630	28.53	30.26	34.42
800	32.07	35.64	38.45
1000	31.72	40.10	39.47
1250	32.40	43.74	42.06
1600	31.65	42.07	38.95
2000	33.42	49.56	37.99
2500	32.78	50.39	37.92
3150	33.40	54.74	40.89
4000	38.11	59.21	45.37
5000	44.51	66.02	47.61

**Table B.1:** Transmission loss of samples from the impedance tube (Continued).

	<b>FG + Compound 2 mm</b>	<b>FG + Compound 4 mm</b>
<b>Frequency (Hz)</b>	<b>TL (dB)</b>	<b>TL (dB)</b>
<b>100</b>	8.98	29.91
<b>125</b>	10.47	28.28
<b>160</b>	12.99	24.17
<b>200</b>	13.85	20.19
<b>250</b>	13.99	19.04
<b>315</b>	14.92	21.49
<b>400</b>	17.60	23.67
<b>500</b>	19.57	25.17
<b>630</b>	20.94	26.49
<b>800</b>	23.40	29.35
<b>1000</b>	25.01	31.52
<b>1250</b>	26.52	33.01
<b>1600</b>	29.13	32.81
<b>2000</b>	31.95	36.03
<b>2500</b>	33.12	39.07
<b>3150</b>	33.75	42.50
<b>4000</b>	36.30	45.58
<b>5000</b>	38.26	46.60

## Appendix C

### Sound pressure level of samples

**Table C.1:** Sound pressure level of blank pipe from sound level meter.

Frequency (Hz)	SPL of blank pipe (dB)											
	At elbow 90° (1)				At elbow 45°				At elbow 90° (2)			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
20	72.5	74.3	75.2	74.0	74.9	73.7	72.7	73.8	72.8	77.5	70.8	73.7
25	67.4	69.1	65.3	67.3	66.5	66.7	66.5	66.6	68.5	71.1	66.8	68.8
31.5	65.0	69.0	63.3	65.8	61.4	65.1	62.1	62.9	64.9	70.2	65.6	66.9
40	59.4	59.9	59.8	59.7	62.1	62.0	60.7	61.6	64.2	68.5	63.6	65.4
50	61.0	60.1	58.4	59.8	59.4	59.1	57.4	58.6	58.2	67.3	57.9	61.1
63	65.9	63.2	61.8	63.6	64.2	64.3	65.4	64.6	64.1	62.2	62.3	62.9
80	61.1	60.9	63.1	61.7	61.4	59.0	60.6	60.3	59.5	60.0	61.2	60.2
100	59.6	61.3	60.1	60.3	59.0	55.3	57.1	57.1	58.1	58.5	60.2	58.9
125	65.9	63.2	58.8	62.6	63.0	59.4	59.6	60.7	53.8	56.1	52.6	54.2
160	59.2	55.6	54.6	56.5	52.0	52.3	52.4	52.2	52.6	51.8	53.4	52.6
200	55.5	54.6	55.8	55.3	53.2	48.9	51.4	51.2	54.4	50.5	52.4	52.4
250	57.2	56.7	57.0	57.0	53.3	52.9	53.3	53.2	54.8	53.9	51.7	53.5
315	51.0	53.7	51.4	52.0	52.3	50.5	50.4	51.1	49.5	49.2	48.1	48.9
400	50.0	51.4	51.4	50.9	51.0	51.9	50.2	51.0	50.6	50.7	51.1	50.8
500	51.2	50.3	53.0	51.5	53.0	53.1	52.2	52.8	54.5	52.8	52.7	53.3
630	52.1	53.1	54.1	53.1	53.6	53.9	52.9	53.5	53.0	52.1	52.1	52.4
800	54.3	54.6	55.6	54.8	54.7	54.0	55.5	54.7	55.4	54.3	53.7	54.5
1000	55.4	58.2	55.5	56.4	55.1	55.5	55.8	55.5	53.2	53.5	53.2	53.3
1250	56.0	54.0	54.7	54.9	55.3	54.8	56.3	55.5	53.9	53.2	53.3	53.5
1600	55.7	55.9	55.2	55.6	58.3	55.6	58.2	57.4	54.1	52.6	54.6	53.8
2000	56.1	57.2	57.1	56.8	60.3	57.7	58.9	59.0	55.9	53.7	54.1	54.6
2500	56.8	57.9	57.2	57.3	58.8	56.7	58.3	57.9	53.9	52.3	53.7	53.3
3150	57.4	57.8	57.0	57.4	58.5	57.3	59.4	58.4	54.4	53.6	52.6	53.5
4000	56.9	57.3	57.6	57.3	57.7	56.6	58.1	57.5	53.9	52.3	52.7	53.0
5000	54.4	55.0	55.8	55.1	55.6	53.4	56.1	55.0	51.6	49.3	51.0	50.6
6300	52.0	52.9	52.7	52.5	55.4	51.6	52.8	53.3	49.6	47.4	49.7	48.9
8000	48.4	49.4	49.5	49.1	50.8	49.1	50.5	50.1	46.5	44.7	46.2	45.8
10000	45.2	46.5	45.9	45.9	47.6	46.5	48.0	47.4	42.7	41.5	41.7	42.0
12500	41.9	42.2	40.9	41.7	44.5	42.1	44.2	43.6	37.3	36.6	37.3	37.1
16000	36.7	38.1	37.2	37.3	40.0	38.0	39.8	39.3	32.6	33.1	33.0	32.9
20000	32.7	34.0	32.7	33.1	35.5	33.9	35.5	35.0	29.7	30.3	31.4	30.5
<b>Average SPL, dB(A)</b>				<b>67.28</b>				<b>67.98</b>				<b>64.50</b>

**Table C.2:** Sound pressure level of Damper 5 mm + Cork tape 3 mm samples from sound level meter.

Frequency (Hz)	SPL of pipe covered with Damper 5 mm + Cork tape 3 mm at elbow 45° (dB)			
	1	2	3	Average
20	73.3	74.0	79.1	75.5
25	67.7	67.4	69.5	68.2
31.5	60.3	59.6	62.2	60.7
40	59.1	59.2	59.3	59.2
50	60.9	60.8	61.8	61.2
63	63.4	64.7	65.4	64.5
80	65.6	62.4	61.3	63.1
100	58.1	59.0	57.8	58.3
125	57.7	56.3	53.6	55.9
160	51.9	51.5	53.3	52.2
200	46.8	53.5	46.2	48.8
250	46.0	47.1	47.6	46.9
315	46.9	46.6	45.6	46.4
400	49.0	46.3	47.3	47.5
500	48.5	48.6	50.4	49.2
630	46.7	48.3	50.5	48.5
800	49.0	49.2	55.6	51.3
1000	47.0	48.0	53.1	49.4
1250	48.2	48.3	49.7	48.7
1600	49.3	48.6	48.3	48.7
2000	49.3	48.0	46.7	48.0
2500	49.1	49.8	47.1	48.7
3150	48.5	46.8	45.1	46.8
4000	43.4	43.9	43.0	43.4
5000	40.3	39.8	41.0	40.4
6300	37.8	37.0	37.4	37.4
8000	35.3	34.8	34.7	34.9
10000	32.1	31.4	30.3	31.3
12500	29.1	28.5	27.3	28.3
16000	27.3	26.9	26.9	27.0
20000	27.3	27.1	27.2	27.2
<b>Average SPL, dB(A)</b>				<b>59.30</b>

**Table C.3:** Sound pressure level of Damper 5 mm samples from sound level meter.

Frequency (Hz)	SPL of pipe covered with Damper 5 mm at elbow 45° (dB)			
	1	2	3	Average
20	69.8	69.9	67.5	69.1
25	65.8	65.6	64.1	65.2
31.5	65.1	62.6	61.7	63.1
40	63.5	63.3	63.4	63.4
50	59.5	64.2	63.3	62.3
63	65.1	67.6	67.8	66.8
80	61.2	65.9	63.4	63.5
100	60.2	63.6	59.1	61.0
125	57.3	56.5	55.9	56.6
160	52.9	54.2	54.3	53.8
200	47.3	50.1	51.3	49.6
250	48.9	53.5	49.2	50.5
315	46.6	48.6	49.8	48.3
400	48.3	49.4	50.2	49.3
500	49.4	49.3	49.3	49.3
630	48.1	48.3	50.1	48.8
800	48.2	48.7	49.8	48.9
1000	46.9	49.2	50.5	48.9
1250	50.2	49.0	51.4	50.2
1600	51.0	49.3	51.7	50.7
2000	49.2	49.3	50.2	49.6
2500	51.1	50.5	49.9	50.5
3150	48.5	47.4	47.2	47.7
4000	46.7	46.0	44.9	45.9
5000	42.5	41.8	41.6	42.0
6300	40.1	39.5	38.9	39.5
8000	37.1	37.0	35.1	36.4
10000	32.5	34.8	33.0	33.4
12500	30.7	30.7	30.7	30.7
16000	28.7	28.0	28.3	28.3
20000	27.7	27.5	27.7	27.6
<b>Average SPL, dB(A)</b>				<b>60.26</b>

**Table C.4:** Sound pressure level of Damper 5 mm + Rubber 25 mm samples from sound level meter.

Frequency (Hz)	SPL of pipe covered with Damper 5 mm + Rubber 25 mm at elbow 45° (dB)			
	1	2	3	Average
20	72.6	70.9	69.7	71.1
25	66.4	66.4	66.3	66.4
31.5	62.7	63.2	62.7	62.9
40	62.9	64.0	64.4	63.8
50	60.5	62.9	60.1	61.2
63	62.9	68.3	68.3	66.5
80	62.4	64.5	64.3	63.7
100	62.4	62.8	61.6	62.3
125	55.1	55.5	58.1	56.2
160	55.2	54.1	55.5	54.9
200	48.2	48.3	49.5	48.7
250	49.4	54.5	50.9	51.6
315	51.6	52.6	51.7	52.0
400	53.7	56.5	56.2	55.5
500	51.6	51.8	51.1	51.5
630	52.7	54.0	54.2	53.6
800	53.2	53.2	53.0	53.1
1000	54.1	53.2	53.5	53.6
1250	54.2	52.1	55.3	53.9
1600	52.3	52.8	53.1	52.7
2000	47.1	49.6	50.0	48.9
2500	45.3	47.3	48.3	47.0
3150	42.5	46.5	45.6	44.9
4000	38.3	42.2	41.8	40.8
5000	33.0	35.6	35.7	34.8
6300	31.7	32.1	32.5	32.1
8000	28.1	30.1	30.1	29.4
10000	25.8	28.5	28.1	27.5
12500	25.3	27.6	26.4	26.4
16000	25.9	26.2	26.5	26.2
20000	27.0	27.1	27.1	27.1
<b>Average SPL, dB(A)</b>				<b>62.12</b>

**Table D.3:** Calculation A-weighting sound pressure level of blank pipe at elbow 45°.

Frequency (Hz)	Average SPL from sound level meter	A-weighting correction	Adjust the SPL from linear to A-weight	
10	0.0	-70.4	-70.4	0.0
12.5	0.0	-63.4	-63.4	0.0
16	0.0	-56.7	-56.7	0.0
20	73.8	-50.5	23.3	213.8
25	66.6	-44.7	21.9	154.9
31.5	62.9	-39.4	23.5	223.9
40	61.6	-34.6	27.0	501.2
50	58.6	-30.2	28.4	691.8
63	64.6	-26.2	38.4	6918.3
80	60.3	-22.5	37.8	6025.6
100	57.1	-19.1	38.0	6309.6
125	60.7	-16.1	44.6	28840.3
160	52.2	-13.4	38.8	7585.8
200	51.2	-10.9	40.3	10715.2
250	53.2	-8.6	44.6	28840.3
315	51.1	-6.6	44.5	28183.8
400	51.0	-4.2	46.8	47863.0
500	52.8	-3.2	49.6	91201.1
630	53.5	-1.9	51.6	144544.0
800	54.7	-0.8	53.9	245470.9
1000	55.5	0.0	55.5	354813.4
1250	55.5	0.6	56.1	407380.3
1600	57.4	1.0	58.4	691831.0
2000	59.0	1.2	60.2	1047128.5
2500	57.9	1.3	59.2	831763.8
3150	58.4	1.2	59.6	912010.8
4000	57.5	1.0	58.5	707945.8
5000	55.0	0.5	55.5	354813.4
6300	53.3	-0.1	53.2	208929.6
8000	50.1	-1.1	49.0	79432.8
10000	47.4	-2.5	44.9	30903.0
12500	43.6	-4.3	39.3	8511.4
16000	39.3	-6.6	32.7	1862.1
20000	35.0	-9.3	25.7	371.5
<b>Average SPL, dB(A)</b>				<b>67.98</b>

**Table D.4:** Calculation A-weighting sound pressure level of blank pipe at elbow 90° (2).

Frequency (Hz)	Average SPL from sound level meter	A-weighting correction	Adjust the SPL from linear to A-weight	
10	0.0	-70.4	-70.4	0.0
12.5	0.0	-63.4	-63.4	0.0
16	0.0	-56.7	-56.7	0.0
20	73.7	-50.5	23.2	208.9
25	68.8	-44.7	24.1	257.0
31.5	66.9	-39.4	27.5	562.3
40	65.4	-34.6	30.8	1202.3
50	61.1	-30.2	30.9	1230.3
63	62.9	-26.2	36.7	4677.4
80	60.2	-22.5	37.7	5888.4
100	58.9	-19.1	39.8	9549.9
125	54.2	-16.1	38.1	6456.5
160	52.6	-13.4	39.2	8317.6
200	52.4	-10.9	41.5	14125.4
250	53.5	-8.6	44.9	30903.0
315	48.9	-6.6	42.3	16982.4
400	50.8	-4.2	46.6	45708.8
500	53.3	-3.2	50.1	102329.3
630	52.4	-1.9	50.5	112201.8
800	54.5	-0.8	53.7	234422.9
1000	53.3	0.0	53.3	213796.2
1250	53.5	0.6	54.1	257039.6
1600	53.8	1.0	54.8	301995.2
2000	54.6	1.2	55.8	380189.4
2500	53.3	1.3	54.6	288403.2
3150	53.5	1.2	54.7	295120.9
4000	53.0	1.0	54.0	251188.6
5000	50.6	0.5	51.1	128825.0
6300	48.9	-0.1	48.8	75857.8
8000	45.8	-1.1	44.7	29512.1
10000	42.0	-2.5	39.5	8912.5
12500	37.1	-4.3	32.8	1905.5
16000	32.9	-6.6	26.3	426.6
20000	30.5	-9.3	21.2	131.8
<b>Average SPL, dB(A)</b>				<b>64.50</b>

**Table D.5:** Calculation A-weighting sound pressure level of Damper 5 mm + Cork tape 3 mm samples.

Frequency (Hz)	Average SPL from sound level meter	A-weighting correction	Adjust the SPL from linear to A-weight	
10	0.0	-70.4	-70.4	0.0
12.5	0.0	-63.4	-63.4	0.0
16	0.0	-56.7	-56.7	0.0
20	75.5	-50.5	25.0	316.2
25	68.2	-44.7	23.5	223.9
31.5	60.7	-39.4	21.3	134.9
40	59.2	-34.6	24.6	288.4
50	61.2	-30.2	31.0	1258.9
63	64.5	-26.2	38.3	6760.8
80	63.1	-22.5	40.6	11481.5
100	58.3	-19.1	39.2	8317.6
125	55.9	-16.1	39.8	9549.9
160	52.2	-13.4	38.8	7585.8
200	48.8	-10.9	37.9	6166.0
250	46.9	-8.6	38.3	6760.8
315	46.4	-6.6	39.8	9549.9
400	47.5	-4.2	43.3	21379.6
500	49.2	-3.2	46.0	39810.7
630	48.5	-1.9	46.6	45708.8
800	51.3	-0.8	50.5	112201.8
1000	49.4	0.0	49.4	87096.4
1250	48.7	0.6	49.3	85113.8
1600	48.7	1.0	49.7	93325.4
2000	48.0	1.2	49.2	83176.4
2500	48.7	1.3	50.0	100000.0
3150	46.8	1.2	48.0	63095.7
4000	43.4	1.0	44.4	27542.3
5000	40.4	0.5	40.9	12302.7
6300	37.4	-0.1	37.3	5370.3
8000	34.9	-1.1	33.8	2398.8
10000	31.3	-2.5	28.8	758.6
12500	28.3	-4.3	24.0	251.2
16000	27.0	-6.6	20.4	109.6
20000	27.2	-9.3	17.9	61.7
<b>Average SPL, dB(A)</b>				<b>59.30</b>

**Table D.6:** Calculation A-weighting sound pressure level of Damper 5 mm samples.

Frequency (Hz)	Average SPL from sound level meter	A-weighting correction	Adjust the SPL from linear to A-weight	
10	0.0	-70.4	-70.4	0.0
12.5	0.0	-63.4	-63.4	0.0
16	0.0	-56.7	-56.7	0.0
20	69.1	-50.5	18.6	72.4
25	65.2	-44.7	20.5	112.2
31.5	63.1	-39.4	23.7	234.4
40	63.4	-34.6	28.8	758.6
50	62.3	-30.2	32.1	1621.8
63	66.8	-26.2	40.6	11481.5
80	63.5	-22.5	41.0	12589.3
100	61.0	-19.1	41.9	15488.2
125	56.6	-16.1	40.5	11220.2
160	53.8	-13.4	40.4	10964.8
200	49.6	-10.9	38.7	7413.1
250	50.5	-8.6	41.9	15488.2
315	48.3	-6.6	41.7	14791.1
400	49.3	-4.2	45.1	32359.4
500	49.3	-3.2	46.1	40738.0
630	48.8	-1.9	46.9	48977.9
800	48.9	-0.8	48.1	64565.4
1000	48.9	0.0	48.9	77624.7
1250	50.2	0.6	50.8	120226.4
1600	50.7	1.0	51.7	147910.8
2000	49.6	1.2	50.8	120226.4
2500	50.5	1.3	51.8	151356.1
3150	47.7	1.2	48.9	77624.7
4000	45.9	1.0	46.9	48977.9
5000	42.0	0.5	42.5	17782.8
6300	39.5	-0.1	39.4	8709.6
8000	36.4	-1.1	35.3	3388.4
10000	33.4	-2.5	30.9	1230.3
12500	30.7	-4.3	26.4	436.5
16000	28.3	-6.6	21.7	147.9
20000	27.6	-9.3	18.3	67.6
<b>Average SPL, dB(A)</b>				<b>60.26</b>

**Table D.7:** Calculation A-weighting sound pressure level of Damper 5 mm + Rubber 25 mm samples.

Frequency (Hz)	Average SPL from sound level meter	A-weighting correction	Adjust the SPL from linear to A-weight	
10	0.0	-70.4	-70.4	0.0
12.5	0.0	-63.4	-63.4	0.0
16	0.0	-56.7	-56.7	0.0
20	71.1	-50.5	20.6	114.8
25	66.4	-44.7	21.7	147.9
31.5	62.9	-39.4	23.5	223.9
40	63.8	-34.6	29.2	831.8
50	61.2	-30.2	31.0	1258.9
63	66.5	-26.2	40.3	10715.2
80	63.7	-22.5	41.2	13182.6
100	62.3	-19.1	43.2	20893.0
125	56.2	-16.1	40.1	10232.9
160	54.9	-13.4	41.5	14125.4
200	48.7	-10.9	37.8	6025.6
250	51.6	-8.6	43.0	19952.6
315	52.0	-6.6	45.4	34673.7
400	55.5	-4.2	51.3	134896.3
500	51.5	-3.2	48.3	67608.3
630	53.6	-1.9	51.7	147910.8
800	53.1	-0.8	52.3	169824.4
1000	53.6	0.0	53.6	229086.8
1250	53.9	0.6	54.5	281838.3
1600	52.7	1.0	53.7	234422.9
2000	48.9	1.2	50.1	102329.3
2500	47.0	1.3	48.3	67608.3
3150	44.9	1.2	46.1	40738.0
4000	40.8	1.0	41.8	15135.6
5000	34.8	0.5	35.3	3388.4
6300	32.1	-0.1	32.0	1584.9
8000	29.4	-1.1	28.3	676.1
10000	27.5	-2.5	25.0	316.2
12500	26.4	-4.3	22.1	162.2
16000	26.2	-6.6	19.6	91.2
20000	27.1	-9.3	17.8	60.3
<b>Average SPL, dB(A)</b>				<b>62.12</b>

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