The study of resonator-diffuser acoustics performance using PVC pipe

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Abstract. A preliminary study of a resonator panel and diffuser using polyvinyl carbonate (PVC). The resonator and diffuser parameters of the panels are tested in the chamber reverberation chamber and anechoic chambers in the laboratory of acoustic physics, the physics department of FIA ITS. The resonator parameter tested is in the anechoic chamber by looking spectral for SPL differences when without and the panel existed. As a diffuser, scattering patterns are tested in the anechoic chamber, while scattering coefficients (S) at a reverberation chamber. In this paper, the panel of resonators in the test made from pipes of 0.5 ", 1" and 3/2 "diameters with panel sizes are 60 cm x 60 cm. base on measurement, the panel has a resonance frequency at 540 Hz. While as a diffuser, the scattering coefficient (S) value for a small pipe is 0.98 at a frequency of 125 Hz with an angle of 0°, a medium pipe is 0.99 at a frequency of 500 Hz with an angle of 30°, a large pipe is 0.93 at a frequency of 500 Hz with Angle 0°.

1. Introduction
Resonance and diffusion are an important part at room acoustic, as both events can affect the acoustic quality in a room. Resonance is the process that an object vibrates because another object was vibrated, while diffusion is the event where sound spreading or scattering. In acoustic, resonance and diffusion are controlled by using acoustic panels, like a resonator and diffuser panels.

1.1. Resonator
In acoustics, the resonator is used to adjust the sound frequency by eliminating or amplifying a sound at a certain frequency depending on the resonance frequency of materials. Figure 1 shows the acoustic resonator that called Helmholtz resonator.

![Figure 1. Helmholtz resonator.](image)

Based on the fig. 1, the resonator with open space area A and length of neck l, then the volume of the cavity is v will produce the resonance frequency like equation (1).
\[ f = \frac{c}{2\pi} \sqrt{\frac{A}{IV}} \]  

(1)

Which \( f \) is resonance frequency (Hz), \( c \) is velocity of sound in air (m/s), \( A \) is area of the holes (m\(^2\)), \( l \) is long of neck (m), and \( V \) is volume of cavity (m\(^3\)).

While based on research Mitchell et al (2016) for the resonator with an elastic material, the resonance frequency value can be calculated using the equation (2).

\[ f = \frac{1}{2\pi} \sqrt{\frac{3Ec}{2Rltl}} \]  

(2)

Which \( E_C \) is elasticity modulus of skin (N/m\(^2\)), \( R \) is radius of core (m), \( \rho \) is density of core (Kg/m\(^3\)), \( t \) is thinness of skin (m), and \( l \) is line of organ pipe (m).

In other cases, the resonant frequency value for tube material (sonic crystal) can also be calculated using the principle of open and closed organ pipe used with equation (3).

\[ f = \frac{c}{4l} \]  

(3)

Which \( l \) is leng of pipe and \( c \) is velocity of sound.

1.2. Diffuser

Based on Trevor [1], the performance of the diffuser can be obtained by using the scattering coefficient. Scattering coefficient is the ratio between secularly reflected energy and scattered reflected energy. Specular reflected is the amount of energy reflected in the same way. if the energy is on a flat surface, while scattered is the amount of energy that is not specular reflected or that called is randomly reflected. Figure 1 describes this Phenom of reflected of sound at the surface.

![Figure 1](image1)

**Figure 2.** Scattering of sound at surface material.

Based on fig 1, to find the value of scattering coefficient or \( S \) diffuser can use equation as follows [1] using the reverberation time of the room.

\[ s = \frac{\alpha_{spec}}{\alpha_{spec}-\alpha} = 1 - \frac{E_{spec}}{E_{total}} \]  

(4)

\[ \alpha = 0,16 \frac{V}{A} \left( \frac{1}{T_2} - \frac{1}{T_1} \right) \]  

(5)

\[ \alpha_{spec} = 0,16 \frac{V}{A} \left( \frac{1}{T_4} - \frac{1}{T_3} \right) \]  

(6)

Which, \( S \) is scattering coefficient, \( \alpha_{spec} \) is specular absorption coefficient, \( A \) is absorption coefficient, \( E_{spec} \) is specular energy, \( E_{total} \) is total energy, \( V \) is volume of chamber (m\(^3\)), \( A \) is area of panel (m\(^2\)), \( T_1 \) is reverberation time when the room empty and turn table not rotate (s), \( T_2 \) is reverberation time when turn table and panel are not rotated (s), \( T_3 \) is reverberation time when the room empty and turntable are rotated (second), and \( T_4 \) is reverberation time when turn table and panel are rotated (second).

Currently, in the laboratory of Physics Acoustics, studies of several forms and designs of resonators and diffusers made of some natural materials is being conducted, like shell (Alfianti et al, 2016), coconut shell (Indrawati et al, 2016). This paper discusses the preliminary study of the resonator and
diffuser design in the form of the cylinder using the PVC pipe material. The panels made has 3 variations of diameter 0.5", 1" and 3/2". While the acoustic parameter that measure is the resonant frequency and the scattering coefficient of the refuser panel was made. In part II, explained about the measurement procedure of the acoustic parameters. Section III discusses the results of measurement and analysis, and the last section is the conclusion.

2. Methods
As mentioned in Part I, the performance of the material designed include the resonance properties and diffusivity of the panel. In this paper, the resonator panels have 3 variations diameter of the pipes, there are 0.5", 1", and 3/2", with panel sizes are 60 cm x 60 cm. The panels are made as shown in Figure 3.

![Figure 3. Refuser panel.](image)

As a resonator, the test is performed at an anechoic chamber by analyzing the sound signals received by the microphone when the panel is installed and empty. By using the method, we can find the difference amplitude of sound energy at some frequency. While the nature of diffusivity (scattering), the measurement of scattering coefficients is done in the room reverberation room, and the measurement of scattering pattern is done in an anechoic room. For measurement of scattering pattern, based on Trevor (2004), the position of the panel, microphone and speaker is in position 0.2, 0.4 and 0.6 from the size of space length. Figure 4 shows the measurement setup.

![Figure 4. Measurement set up.](image)
3. Result and Discussion

3.1. Resonance
Refers to equations (2), (3), and (4), the resonant frequency of the created panels can be obtained. Table 1 shows the magnitude of the resonance frequency.

Table 1. A slightly more complex table with a narrow caption.

| Sample  | Diameter | Kjaer (Hz) | Mitchel (Hz) |
|---------|----------|------------|--------------|
| Resonator | 0.5” | 1082 | 71.53 |
| Resonator | 1” | 1082 | 50.38 |
| Resonator | 3/2” | 1082 | 58.25 |

Theoretically, based on equation 3, the resonance frequency of pipe resonator is not dependent on the dimension, especially area of the hole.

For the result of resonance frequency by measurement, analyze was doing with compare of SPL that received by the microphone when the panel is installed and not installed. Figure 5 is showing the response frequency when panel installs and not installed.

3.2. Scattering
Based on measurement and calculation that refers to equation (1), to get the scattering coefficient, the measurement of RT parameter was done when the room empty and the panels exist. Table 2 shows the RT value of the chamber. Refer to equation (4), (5) and (6), the value of scattering coefficient is follow the table 3.

Based on the data shown in Table 2, the performance of the panel with diameter 0.5” is the best performance, while for a diameter 1.5” has the worst performance. This can be seen from the many scattering coefficient values between 0 and 1. This can happen because a small pipe it can be arranged more when compared to a larger diameter. This means that in small diameter of the resonator, there will be a more surface curve. It can more scatter the sound that comes than the larger diameter of pipes.
### Table 2. The value of reverberation time of the chamber and scattering coefficients

| Frequency (Hz) | T1 (s) | T2 (s) | Scattering Coefficients |
|---------------|--------|--------|-------------------------|
|               | 0.5”   | 1”    | 1.5”                     | 0.5” | 1” | 1.5” |
| 125           | 0.398  | 0.900  | 0.896                    | 0.363 | 0.98 | -0.84 | 0.74 |
| 160           | 1.058  | 0.571  | 1.046                    | 1.054 | 0.39 | 1.56 | -6.12 |
| 200           | 1.142  | 1.344  | 1.300                    | 1.107 | 1.60 | -0.70 | -0.34 |
| 250           | 0.813  | 0.834  | 0.847                    | 0.650 | 0.95 | 3.00 | 0.93  |
| 315           | 1.367  | 1.777  | 1.891                    | 2.375 | -43.51 | -5.09 | 0.93  |
| 400           | 2.048  | 2.258  | 2.325                    | 2.364 | 0.56 | 0.16 | 0.10  |
| 500           | 1.425  | 1.478  | 1.484                    | 1.529 | 0.25 | 0.25 | 0.93  |
| 630           | 1.686  | 1.725  | 1.878                    | 1.960 | 0.07 | -0.06 | 0.75  |
| 800           | 2.118  | 2.138  | 2.126                    | 2.113 | -1.92 | -3.44 | -5.60 |
| 1000          | 2.236  | 2.224  | 2.233                    | 2.045 | 0.81 | -2.13 | 0.07  |
| 1250          | 2.112  | 2.295  | 2.368                    | 2.335 | 0.52 | -0.02 | -0.48 |
| 1600          | 2.083  | 2.118  | 2.109                    | 2.145 | 0.89 | 0.33 | -0.55 |
| 2000          | 2.364  | 2.100  | 2.252                    | 2.206 | 0.93 | 4.02 | -0.62 |
| 2500          | 2.111  | 2.061  | 2.147                    | 2.109 | -1.88 | -0.27 | -0.46 |
| 3150          | 2.168  | 2.188  | 2.204                    | 2.263 | 0.51 | 0.33 | 0.63  |
| 4000          | 2.324  | 2.257  | 2.234                    | 2.441 | 7.56 | 25.77 | 0.28  |
| 5000          | 2.226  | 2.214  | 2.217                    | 2.331 | 0.30 | 0.05 | -0.70 |
| 6300          | 2.219  | 2.413  | 2.351                    | 2.350 | 0.69 | 0.56 | -0.07 |
| 8000          | 2.296  | 2.348  | 2.454                    | 2.363 | 1.14 | 0.25 | -0.65 |

#### 3.3. Dispersion pattern of scattering

The distribution pattern is obtained by comparing the SPL value that reflects by the panel and received by the microphone at an angle of 0° with the other angle. As a diffuser, the dispersion of scattering pattern is important to know the directivity of sound will reflect by panels. The purpose of measuring the distribution of sound is to know the direction of the dominant sound reflection when the sound strikes to the panel. Figure 6 shows the distribution pattern of the created diffuser panel.

Based on the scattering diagram that is shown in fig. 6 and 7. It appears that the dispersion pattern of the three diffusers, seen uniformly at low frequency or 125 to 500 Hz, but, at high frequencies, ie, 1000 to 4000 Hz, there are several anomalies. For example, diffuser with diameter pipe 1” for angle 70° and 80° at 1000 Hz, for diameter 0.5" for an angle of 60 ° at 2000 Hz. That same also diffuser with diameter 0.5" for an angle 30 at 4000 Hz.

![Figure 6. Dispersion pattern of panel in frequency (a) 125 Hz, (b) 250 Hz, and 500 Hz.](image-url)
4. Conclusions
Based on the measurement, the resonance frequency of the refuser panel is 546.5 Hz. The value of the scattering coefficient for the diffuser with diameter 0.5" has a good performance, while 1.5" have a poor performance. And at 125 Hz frequency, the performance of the three panels gives the best response that is uniform, this indicates that this panel will be able to distribute the sound well in all directions. But at a frequency of 500 Hz, the panel will propagate to the front only.

For further research is needed regarding the number of pipes and pipe size combinations a panel. Note that as a general principle, for large tables font sizes can be reduced to make the table fit on a page or fit to the width of the text.

5. References
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[5]. Susilo I, Suyatno, 2017, “Innovative Coco Shell Resonator (CSR) Panels for Acoustic Performance”, Procedia Engineering 170, page 293 – 298

Figure 7. Dispersion pattern of panel in frequency (a) 1000 Hz, (b) 2000 Hz, and 4000 Hz.