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EXPERIMENTAL STUDY OF COMPRESSOR ENCLOSURE WITH PYRAMID ACCOUSTIC FOAM

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Abstract

This study investigates the performance of compressor enclosures for noise absorption, reverberation, and machine ventilation to ensure a safe and healthy working environment for people. The Multi pro air compressor model BC 150 DMBW 1.5 HP is placed in an enclosure made of wood board, and for absorbing material, use 6 cm thick polyurethane pyramid foam. A fan with a flow rate of 280 CMH is used as a cooling medium and will operate simultaneously with the compressor operation. Flow Air Delivery (FAD) of the compressor is 126 L/min. The Sound Pressure Level (SPL) value is determined using a sound level meter before and after the compressor uses the enclosure. In addition, the enclosure's room temperature is recorded within 30 minutes of operation to determine whether there is a significant increase in heat to ensure that the enclosure for this compressor is still within safe limits. Based on the test results, it is known that after a 30-minute operation, the temperature rises from 29 ^{O}C to 65 ^{O}C in the inlet on the enclosure with the fan off, and the temperature rises from 29 ^{O}C to 51 ^{O}C on the enclosure with the fan on. While from the results of measuring the sound noise level, taken at a distance of 1 meter outside the enclosure, there is no significant difference, with or without using a fan, the decrease in sound noise level is only about 10 dB, which is 84 dB before using the enclosure, to 74 dB after using the enclosure. So, it can be concluded that the use of fans as coolers is quite effective in maintaining the temperature of the enclosure space when compared to natural cooling through ventilation, but the use of enclosures using pyramid foam material is not effective for reducing the noise level produced by the compressor when operating.

Keywords: Sound Acoustic Enclosure, Compressor Enclosure, Foam Acoustic Absorber

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1. Introduction

This study focuses on compressor enclosure performance. Thermal control was the main design hurdle for this product. The enclosure becomes increasingly hot from the heat generated, which could harm the compressor. Such overheating can cause product failure in addition to shortening life expectancy. This study aims to determine whether enclosing the compressor and employing an acoustical enclosure with absorber material will limit noise propagation from the compressor to the surroundings. Almost always, it is discovered that the main applications of acoustical materials involve the decrease of reverberant sound pressure levels and, as a result, the reduction of reverberation time in enclosures (rooms). Noise pollution is getting worse as society develops and industrialization advances, which has a negative impact on people's ability to go about their daily lives and work. Four major environmental pollution causes are acknowledged: pollution of the solid waste stream, the air, the water, and the noise. Currently, people often control noise by one of these three ways: controlling the noise source, controlling the noise as it travels, and controlling the noise at the receptor itself [1]. Research on the use of enclosures to reduce the noise level of compressor sound has been carried out by researchers worldwide.

During the design phase, a study was conducted on melamine cotton, an environmentally friendly material that has not been widely used. This material was chosen as a sound-absorbing solution[2]. Incorporating an acoustical absorption layer inside the enclosure enhances the damping of the enclosed

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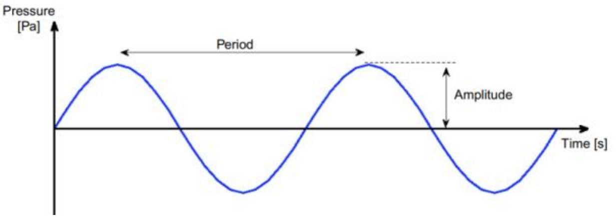

Fig. 1. Simple wave motion, the horizontal axis represents time

air volume and affects the transmission of non-resonant noise across the enclosure walls[3]. The research involved analyzing and comparing noise levels caused by the compressor with and without using an enclosure. Additionally, it examined how different sound frequencies were distributed and compared them against standard values to determine the most effective absorber material. This approach aligns with in-situ assessment techniques for evaluating noise generated by various sources.

A second-order analyzer was employed to study recorded Sound Pressure Level (SPL) values and identify crucial frequencies for designing enclosures. A 25 dB reduction in noise by adding mineral wool as an extra liner on the inside enclosures demonstrates improved effectiveness in controlling compressor noise through this absorber material. To enhance the effectiveness of a trap for low frequency noise, it is necessary to elevate the absorber's thickness and density [4]. When an object experiences a sudden impact from normal static pressure, it leads to air pressure fluctuations that result in the transmission of sound waves through vibrations oscillating back and forth by the object[5].

Research conducted by Youngjoo et al. involved the creation of a nanofiber fabric using an electrostatic process. They utilized melt-spun polyamide fibers with nano diameters and investigated how layers of nanofiber webs on a regular fiber-knitted fabric affected sound absorption[6]. Another study by Liang and Jiang focused on understanding the propagation process and acoustic wave behavior in polymer composites filled with inorganic particles. They proposed a sound insulation mechanism for polymer or inorganic particle composites[7]. Saetung et al. synthesized a polyurethane foam based on natural rubber. They examined the impact of rubber particle size and formula parameters on its morphology, mechanical properties, and sound absorption capabilities. Additionally, Qin Dong et al. successfully developed porous acoustic absorption ceramics through gel injection molding [8]. The first sound absorption frequency reached approximately 2500Hz with a peak value of 0.98, while the Noise Reduction Coefficient (NRC) achieved 0.6.

2. Experimental and Procedures

2.1 Materials and Methods

Acoustic Enclosures are extremely effective made-to-order solutions that block and absorb sounds coming into and going out of a space.

Fig. 1 depicts the waveform of a straightforward sine wave, which sounds like a pure tone, such as a whistle[9]. The horizontal axis denotes time, and the vertical axis shows pressure variations, expressed in Pascal.

The three fundamental properties of sound are frequency, amplitude, and wavelength. The number of oscillations (or cycles) per second is referred to as a wave's frequency (f). Named for the German physicist Heinrich Rudolf Hertz, it is measured in Hertz (Hz). Higher frequency noises are typically perceived as having a higher "pitch" (variations in pitch produce a musical tune); a house alarm, for example, has a high pitch. The period, T, expressed in seconds, is the length of time required to complete one oscillation (repetitive cycle). Period and frequency are related by:

$$f = \frac{1}{T}(Hz) \tag{1}$$

In Fig. 2, the maximum magnitude of pressure in the vertical direction symbolizes a wave's amplitude. It is in accordance with the wave's energy level. A sound's intensity is higher when its amplitude is higher. The distance (in meters) covered by a wave during one oscillation is known as its wavelength, abbreviated as *l*. The wavelength is identical to the period, *T*, above if we plot a wave in the space domain rather than the time domain (Fig. 2), where distance is represented on the horizontal axis rather than time to examine how the wave varies in space. A wave's physical size, or wavelength, can be determined by measuring the distance between two consecutive positive peaks in the cycle.

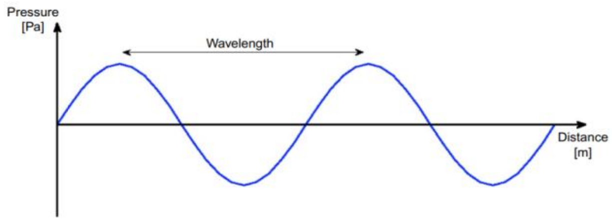

Fig. 2. The graphic shows a simple wave motion, where the horizontal axis represents the distance

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2.2 Speed of Sound, Wavelength and Frequency

Airborne sound waves normally travel at a speed of between 330 and 345 m/s. Although a rough estimate of 343 m/s is most usually used, the speed is greatly dependent on the air's temperature, humidity, and pressure.

Earth's surface sound speed (at 20 °C and 1 atmosphere of pressure). We may establish a link between the period (measured in seconds) and the wavelength (measured in meters) using the speed of sound, indicated by the letter c.

For a moving body:

$$Distance = Speed \times Time \quad (2)$$

So, the speed of sound, c, may be calculated from

$$c = \frac{\lambda}{T} \quad (3)$$

Therefore,

$$c = \lambda f \quad (4)$$

The wavelength of a sound wave at 1000 Hz is approximately 0.343 m. The association holds true regardless of how quickly the sound travels.

2.3 Frequency

People generally experience infrasound rather than hearing it. Sound in this frequency range can potentially result in low-frequency noise issues. Table 1 shows the range of frequencies.

2.4 Sound Propagation in Environment

Sounds are vibrations that travel through a medium and change its pressure as they do so. Our ears pick up on the disruption to the medium brought on by pressure variations. Therefore, the sound is any change in pressure that people can feel or hear.

The atmosphere serves as the medium for environmental noise. The atmospheric pressure is disturbed by the wave-like phenomenon moving across the atmosphere. There are numerous sources producing noises in a mixed urban environment, and as a result, sounds are not clean. Moreover, a number of obstructions prevent sound from propagating properly. As a result, there is no particular wave pattern created by the sound waves in the surroundings[10].

Table 1. Typical frequency ranges for hearing (Hz)

Source	Frequency (Hz)
Human	20 – 20.000
Dog	40 – 60.000
Piano	27 – 4200
Guitar	63 – 500
Road Traffic	50 - 7000

2.5 Sound Absorption coefficient

Some of the incident energy of sound waves that collide with a boundary between two media is reflected from the surface, while the remaining energy is transmitted into the second medium. It is stated that some of this energy is eventually transformed into heat energy through a variety of processes and is absorbed by that medium. The absorption coefficient (f), a frequency-dependent quantity that expresses the percentage of incident energy that is absorbed, is defined as:

$$\alpha(f) = \frac{sound\ intensity\ absorbed}{soaund\ intensity\ incident} \quad (5)$$

The absorption coefficient has a theoretical range of 0 to 1. In practice, values greater than 1.0 are occasionally measured. This deviation is due to the measurement methods employed to measure large-scale building materials.

A perfect sound-absorbing surface, like an open window, can absorb one Sabin of sound per square meter. How much sound is absorbed by a wall or other surface depends on the surface's area, expressed in square meters, multiplied by the absorption coefficient[11]. Mineral wool added to the enclosures inside reduced noise by 25 dB overall, which shows that adopting such absorber materials could improve the enclosure's effectiveness.

2.6 Sound Power

The rate at which sound energy is radiated per unit time is referred to as sound power. Joules/second or Watts are used to measure the power of sound. Consider a small, spherical sound source as an illustration of sound power. The sound power is a metric for the maximum volume of sound that a source is capable of producing. The source's sound power output is the same no matter how far away you are from it if unimpeded radiation takes place and the source's sound power output is constant.

2.7 Decibel (dB)

Decibel is a unit of gain. This is used in noise as well as in communications engineering. The sound pressure/power levels in sound engineering are measured in decibels, or dB. From a reference value, the Decibel is used to determine variations in sound pressure and power levels. The decibel is equal to 10

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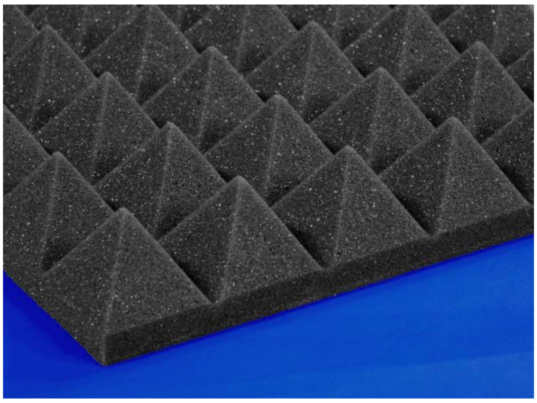

Fig. 3. Polyurethane pyramid foam

Table 2. Test report of Sound Absorption Average (SAA) of the sound absorption coefficient of material for the twelve and a third octave range from 200 to 2500 Hz. Obtained from Foam Factory Inc., July 2011

1/3 Octave Center Frequency (Hz)	Absorption Coefficient	Total Absorption in Sabin
100	0.19	13.92
125	0.19	13.71
160	0.18	12.62
200	0.20	14.38
250	0.22	16.19
315	0.23	23.67
400	0.38	27.40
500	0.45	32.71
630	0.51	36.44
800	0.55	39.62
000	0.55	39.93
1250	0.54	38.98
1600	0.55	39.83
2000	0.60	43.31
2500	0.65	46.76
3150	0.70	50.26
4000	0.76	54.43
5000	0.86	62.09

Note: SAA = 0.46
NRC = 0.45

times the ratio of two quantities' logarithms to base 10, which is typically expressed as follows:

$$I_l = 10\log\frac{I}{I_0} \qquad (6)$$

where I and I_0 are the two physical quantities.

2.8 Sound Power Level (SWL)

The total sound power (Watts) radiated from a source in relation to a reference power of W_{ref} =10(-12) Watts is known as the sound power level (*Lw* or *SWL*). The following formula can be used to determine the sound power level:

$$SWL = 10\log\frac{W}{W_{ref}} \qquad (7)$$

2.9 Sound Pressure Level (SPL)

$$SPL\ (dB) = 20\log P/P_{ref} \qquad (8)$$

P is the sound pressure in N/m^2

P_{ref} is the reference sound pressure = 20x10^{-6}N/m^2

2.10 Octave

The space between two sounds with a 2:1 frequency ratio. The keyboard of a typical piano has 8 octaves. Eight band is a band of the frequency spectrum that is an octave apart. For instance, our octave band ranges from 63 to 8000 Hz.

2.11 Sound Loudness and Measurement

Weighting filters are used in sound pressure level meters (SPL meters), which minimize the contribution of low and high frequencies to give a value that roughly reflects what the human ear hears.

2.12 Pyramid Foam

Pyramid foam reduces background noise by absorbing sounds from the low to the high frequency range. In studios all around the world, foam panels are utilized to regulate the sound character rooms with diverse characteristics. Studio foam will greatly reduce echoes, reverberations, and other undesirable noises, but it won't entirely soundproof a space.

2.13 Transmission Loss of Sound

The reduction in sound level caused by a sound source as it travels through an acoustic barrier is known as transmission loss of sound. It is measured at various frequencies as the amount of decibels that are blocked by the wall or acoustical barrier.

2.14 NRC (Noise Reduction Coefficient)

Simply said, the Noise Reduction Coefficient (NRC) is a measurement of how much acoustic energy, or sound, a material can absorb. We can better understand what the materials NRC tells us by using the formula below.

NRC = decibels reflected / decibels absorbed

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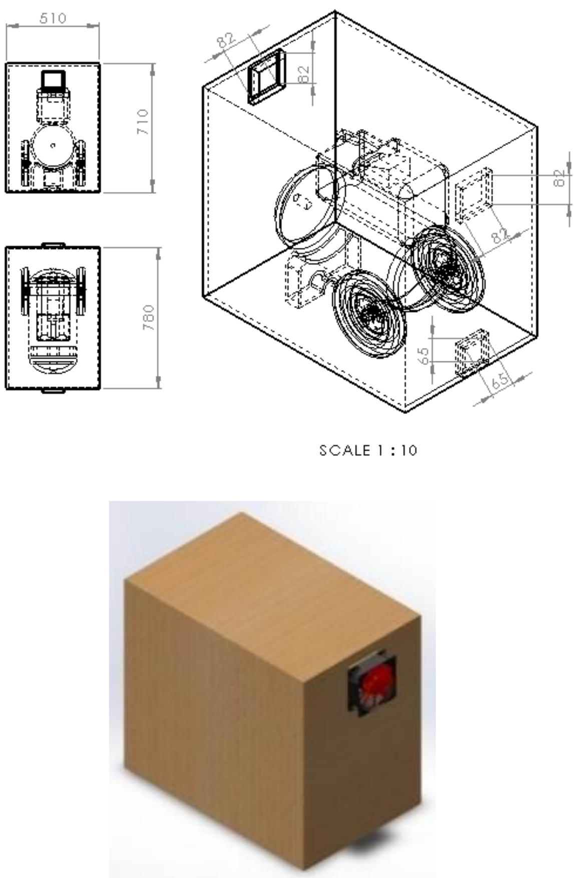

Fig. 4. Sound acoustic compressor enclosure design

Fig. 5. Sound acoustic compressor enclosure

Fig. 6. Compressor Multipro BC150D-DMBW

The format of the *NRC* will be decimal. Let's say, for illustration, that a material has an NRC of 0.30. We are claiming that the material reflected 70% of the acoustic energy while only absorbing 30% of it. The *NRC* ratings of materials vary frequently depending on the frequency range. By averaging the various *NRC* values for each frequency band recorded, the total *NRC* of a material is determined.

2.15 Sound Power

Sound power and sound intensity are related by the area. For a spherical wave front, the relationship is expressed as

$$I = \frac{W}{4\pi r^2} \tag{9}$$

I is a representation of the magnitude of sound, where the surface area of a sphere is given by *4πr^2* and *r* represents the radius of that sphere. It is important to note, as indicated in Equation (4), that the decrease in sound intensity is directly proportional to the square of the sphere's radius. This correlation is commonly known as the inverse square law. Sound intensity values are linked to sound power values through an area factor, resulting in a wide range of potential values. In this context, *LI* denotes the level of sound intensity, *I* represents the measured intensity at a certain distance from its source, and I_{ref} signifies reference sound intensity which is typically used as a baseline measurement:

$$I_l = 10\log\frac{I}{I_0} \tag{10}$$

The overall noise levels of the existing compressor package is quantified using Sound Pressure Level (SPL) based measurements in a free field using the methodology in the international standards ISO 2151- ISO 3744/ ISO 9614-2[12].

2.16 Source sound power level (Lw)

This is the initial sound power level emitted by the noise source, usually in decibels (dB). Source-receiver distance (R): The distance between the noise source and the point at which you want to calculate the side-line noise level, in this case, 200 feet. Frequency (f): The frequency of the sound, typically measured in Hertz (Hz). Environmental factors: These can include atmospheric absorption, ground effects, and any other relevant factors that might affect sound propagation. With these parameters, you can use the formula for spherical spreading to calculate the sound pressure level (SPL) at the specified distance. The formula is:

*SPL = Lw - 20 * log10(R) - 11 + 20 * log10(f)*

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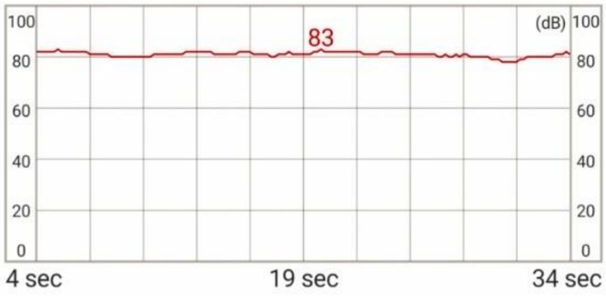

Fig.7. Sound level compressor measurement before using enclosure

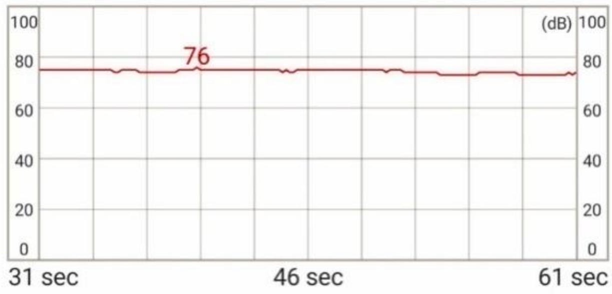

Fig. 8. Sound level compressor measurement after using enclosure

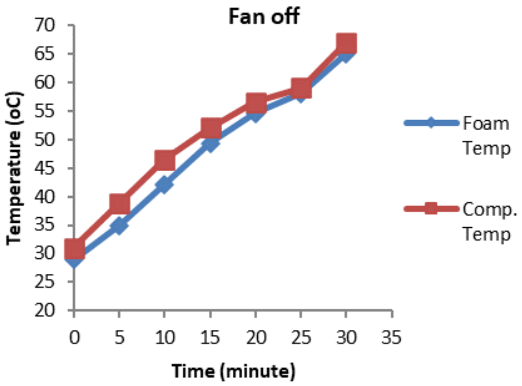

Fig. 9. Temperature of inner enclosure with fan off condition

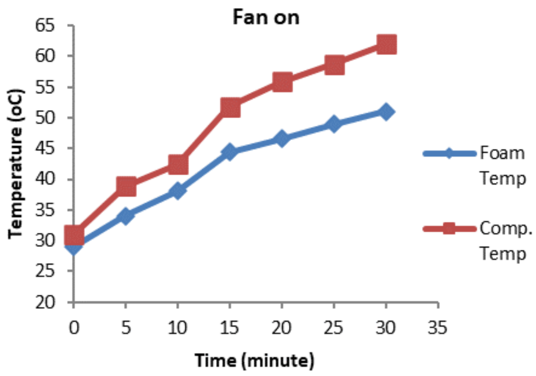

Fig.10. Temperature of inner enclosure with fan on condition

Table 2. Enclosure room temperature data for 30 minutes when operation

Time (Minute)	Fan Off			Fan On		
	Foam Temp (°C)	Compressor Temp (°C)	Sound Level (dB)	Foam Temp (°C)	Compressor Temp (°C)	Sound Level (dB)
0	29	31	74	29	31	75
5	35	38.9	73	34	38.9	74
10	42.1	46.5	75	38.1	42.4	75
15	49.3	52.1	76	44.4	51.8	75
20	54.6	56.5	77	46.6	55.9	76
25	58	59	77	48.9	58.7	75
30	65	67	77	51	62	76
Average	47.57	50.14	75.57	41.71	48.67	75.14

where *SPL* is the sound pressure level at the specified distance. *Lw* is the source sound power level. *R* is the distance from the source to the receiver. *f* is the frequency of the sound.

3. Results and Discussion

Enclosure specifications: the enclosure is made using a hollow iron frame measuring 3 cm x 3 cm which is welded and, on the wall, using teak block board material with a thickness of 10 mm. The size of the enclosure box is described as follows.

Dimension (LxWxH) : 71 x 51 x 78 cm
Fan dimension : 15 cm x 15 cm
Inlet hole (fan) : 8.2 cm x 8.2 cm
Outlet hole 1 (up) : 8.2 cm x 8.2 cm
Outlet hole 2 (down) : 6.5 cm x 6.5 cm

Compressor specifications:
Discharge : 126 L/MIN
Voltage/Frequency : 220 volts /50 Hz
Cylinder : 42 mm
Pressure : 8 Bar/116 Psi
Motor : 1.5 HP
Dimension (LxWxH) : 42 x 38 x 65 cm
Speed : 2,850 rpm
Tank : 30 L

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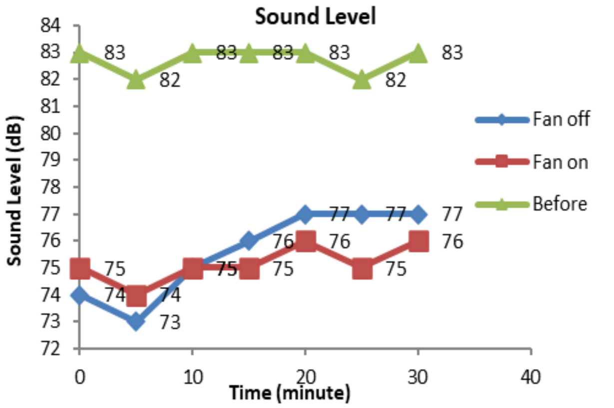

Fig.11. Sound level data before and after using enclosure

Graphical data of noise level measurement results using a sound level meter (measured at a distance of 1 meter from the outer side of the enclosure).

The figure shows that the sound intensity level of the compressor is 75 dB, respectively. It indicates that the enclosure using a pyramid foam absorber successfully reduced the sound noise level by 5 - 10 dB.

Based on the results of room temperature measurements, the data obtained that the temperature of the enclosure room after 30 minutes of operation is 51 ℃, up by 22 degrees since the compressor started, meaning that there is a significant temperature increase due to heat dissipation that occurs directly flowed out by the fan that is installed and turns on along with the operation of the compressor. The experiment results show the heat distribution that occurs in the enclosure space. From the experiment, it can be seen that the cooling fan in the compressor enclosure is not good enough to cool down an enclosure space.

4. Conclusions

The experiment on the effectiveness of the enclosure in reducing the noise level of the compressor has yielded important findings. While acoustic foam was able to decrease echoes, reverberations, and some unwanted noises, it was not sufficient to completely soundproof the area. There was a 12 % decrease in noise level after using the enclosure. Li Zhang et al. managed to reduce the noise of the compressor to 60 dB, using rock wool and glass wool. Forouharmajd et al. managed to reduce the average noise of the compressor to 25 dB, using mineral wool as an extra liner on the inside of the enclosure, so, it can be concluded that the acoustic sound of the enclosure coated with mineral wool will cause better noise reduction when compared to using polyurethane foam material. Applying other materials like rock wool was recommended to improve the enclosure's sound reduction capabilities. Enclosures solely coated with foam were found to be ineffective in significantly reducing sound levels.

Additionally, it was observed that the enclosure space heated up quickly due to its limited dimensions, leading to potential risks such as damage to the compressor or even the risk of fire if operated for extended periods. Considering these limitations, it can be concluded that the enclosure was unsuccessful in adequately reducing the noise level of the compressor, and its safety for long-term usage is questionable. Furthermore, incorporating larger dimensions and additional soundproofing materials may be necessary to achieve the desired noise reduction and safety levels.

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