A Natural Convective Passive Noise Control System for Mini-Generators

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Abstract

In this research work, the acoustic characteristics of noise produced by TG950 generator is studied and a suitable physical full scale model acoustic enclosure for it has been designed and evaluated and is hereby presented. The generator was treated as a point source and the insertion loss of the produced model of full enclosure was found to be quite good. The results show that the noise level was reduced by about 17 % at the optimum stack height of 1600 mm. The effect of exhaust tunneling was investigated. Results showed that exhaust tunnel projection beyond 200mm did not significantly improve the enclosure insertion loss. The enclosure model and the generator were discovered to have good thermal conditions under natural convection, with a maximum temperature rise of 9°C from ambient temperature of 30 °C, thereby eliminating the need for artificial cooling and its consequent ancillary power consumption.

Keywords
Mini-generators, Acoustic enclosure; Noise reduction; Petrol engine; composite application.

1. Introduction
Due to the shortfall in power supply in some developing countries like Nigeria, individuals have resorted to portable electricity generators for powering their home lighting units, televisions, laptop and desktop computers, and charging mobile phone batteries. These mini generators also find popular use in small offices, shops, and market stalls for the same or similar purposes. While these generators, no doubt, play key role in the life of the people in the developing countries, they, however, cause enormous noise pollution of the environment and therefore constitute hazard to both the user and the occupants of the immediate neighborhood. These petrol engine powered generators have also been indicated to have caused the death of many people due to the inhalation of carbon monoxide emissions from them as they are usually located close to the user's environment.

The response of the human ear to sound or noise depends both on the sound frequency and the sound pressure level. In psycho-acoustics, both the physical characteristics of noise and the way the human ear responds to it are considered.

Given sufficient sound pressure level (SPL), a healthy, young, normal human ear is able to detect sounds with frequencies from 20 Hz to 20 kHz (Hansen 2022). Sound characterized by frequencies between 1 and 20 Hz is called infrasound and is not considered damaging at levels below 120 dB (Hansen 2022). Sound characterized by frequencies in excess of 20 kHz is called ultrasound and is not considered damaging at levels below 105 dB. Sound which is most damaging to the range of hearing necessary to understand speech is between 500 Hz and 2000 Hz (Hansen 2022).

According to ILO (1979), noise is the cause of various problems. It impedes sound communication, first, by the acoustical masking effect which every sound has on other sounds of the same frequency or immediately higher frequencies and which reduces the intelligibility of speech that is not more than 10 dB louder than the background noise; and second, by temporarily raising the acoustic threshold in the event of exposure to a noise exceeding 78-80 dB. It may cause sensory-motor, neuro-vegetative and metabolic disorders; it has been named as a cause of industrial fatigue, irritation, reduced productivity and occupational accidents. Prolonged exposure to noise above certain levels causes permanent damage to hearing and results in occupational deafness (ILO 1979). According to World Health Organization (WHO) guidelines for community noise, less than 30 dB(A) is recommended in bedrooms during the night for a sleep of good quality and less than 35 dB(A) in class rooms to allow good teaching and learning conditions. The WHO guidelines for night noise recommend less than 40 dB(A) annual average outside of bedrooms to prevent adverse health effects from night noise. Sleep is a biological necessity and disturbed sleep is associated with a number of health outcomes. Noise has also emerged as a leading environmental nuisance in the WHO European region, and the public complains about excessive noise more and more often (WHO 2022). The detectability of the sound is always dependent on the signal to noise ratio (Zhang et al. 2021).

Noise mitigation can be affected either, at the source, at the path between the source and the receiver and/or at the receiver end. Many factors influence the selection of noise control methods. These may either be of acoustical, mechanical, practical or economical character (Tandon et al. 1998). Power houses are usually built at a distance from the living quarters to curtail the generator noise, while the power house, itself, is mainly to protect the generator from harsh weather conditions like rain, sun heat and dust. According to ILO (1979), the most effective method of noise control is to reduce the noise at source for example, replacing noisy machine or equipment by less noisy ones; this means that these measures must be borne in mind at the design stage of a production process, the construction of a building or the purchase of equipment. The second method is to prevent or reduce noise transmission by the installation of noise-absorbent barriers between the noise source and the worker and by the damping of structures which may be the source of secondary reverberation, or by isolating the noise source in separate premise or a sound-proofed enclosure. The latter measure is the focus of this work. Sound waves loose energy if they have to pass through a medium as the medium absorbs the wave. The medium converts the wave's acoustic energy into heat and thus get weakened. Where such measures are not applicable or are not sufficiently effective, it may be necessary to provide workers with sound-proofed cabins from which they can operate the machines and do their work without having to enter the noisy environment except for short periods. Plugs can reduce exposure to hazardous frequencies by at least 15-20 dB; however, workers sometimes object to this type of protection (ILO 1979). An enclosure is more or less an arranged barrier to house a noise source such as a generator. Barrier effectiveness increases with height, width, and proximity to either the source or the receiver. Generator noise may be controlled by reducing the excitation applied to the structure by the engine combustion process and mechanical impact and/or modifying the structure including the design of a partial or full enclosure. For a reduction of 10 dB(A) or more, it is necessary to attenuate the noise of all external engine parts by a complete encasing of the engine. Enclosure is one of the effective means to modify the transmission path of sound (Tandon et al. 1998). The performance of acoustic enclosures is based upon the principle of trapping the noise radiated by the sound source, by massive, impervious layers, and dissipating the retained sound energy in the porous sound-absorbing lining. Its efficiency depends on the ratio of the sound wavelength to the thickness of the blocking and the absorbing layers. The larger the sound wavelength (the lower is the frequency), the thicker must be the walls of the enclosure (Cuesta and Cobo 2001). Noise reduction is defined as an effective physical measure for quantifying the capability of acoustical enclosures for attenuating noise. Acoustic enclosures made of flexible panels are widely used in the applications of reducing machine noise and protecting human hearing in workplace (Lei et al. 2012).

The purpose of the research is to investigate the acoustic characteristics of noise produced by a commonly used mini-generator in Nigeria (TG950 generator) and to apply reinforced composite material in the design of an acoustic enclosure for reducing the noise from the mini-generator.

2. Theoretical Background of Noise

An unwanted sound, a sound out of place, can be described as noise. Noise, therefore, is a form of sound and has its attributes. Noise is the result of pressure variations, or oscillations, in air generated by a vibrating surface or turbulent fluid flow. When a sound wave propagates in air, the oscillations in pressure are above and below the ambient atmospheric pressure creating a succession of compressions and rarefactions (Hansen 2022).
The sound intensity, I, of a source propagating through air is given by Eq.1

$$I = \frac{P_{rms}^2}{\rho c} \tag{1}$$

Where P_{rms} = root mean square acoustic pressure, ρ = density of air kg/m3 and ρc = acoustic impedance = 414 Ns/m^3 at 20°C

The sound intensity (I) drops as the distance away from the source (d) increases (Piipo and Tang 2011), with a relationship thus given in Eq. 2.

$$I \propto d^{-n} \tag{2}$$

where n is the decay power index, which equals 1 and 2 for a perfectly cylindrical source and a point source respectively.

The measurable sound pressure level, L_p, usually referred to a datum pressure, P_{ref}, corresponding to the lowest sound pressure which the young normal ear can detect is given by

$$L_p = 10log_{10}\frac{P_{rms}^2}{P_{ref}^2} = 20log_{10}\frac{P_{rms}}{P_{ref}} = 20\left(log_{10}P_{rms} - log_{10}P_{ref}\right) \quad (dB) \tag{3}$$

If the reference pressure value is given as 20 x 10^{-6} Pa, which is the minimum threshold of hearing acoustic pressure, then

$$L_p = 20(log_{10}P_{rms} + 4.7) \quad (dB) \tag{4}$$

Placing an object between the noise source and the observer alters the sound pressure level received at observer location and the difference between the levels before and after the placement or removal is termed the **insertion loss**, (IL). A reference level L_{pR} is defined at the point of observation as a level which would or does exist due to straight line propagation from source to receiver. Insertion loss due to propagation over any other path is then assessed in terms of this reference level. Typically, insertion losses would include, spreading due to travel over a longer path, losses due to barriers, reflection losses at reflectors and losses due to source directivity effects. The observed overall noise level due to contributions over n paths is

$$L_p = L_{pR} + 10log_{10}\sum_{i=1}^{n} 10^{-\left(\frac{ILi}{10}\right)} \tag{5}$$

$$IL = L_{pA} - L_{pB} \tag{6}$$

$$IL = 10log_{10}\sum_{i=1}^{n_A} 10^{-(IL_{Ai}/10)} - 10log_{10}\sum_{i=1}^{n_B} 10^{-(IL_{Bi}/10)} \tag{7}$$

where L_{pA} is the sound pressure level at the point of observation and L_{pB} is the sound pressure level after alteration. In a free field, with point source, if the sound pressure level, L_m, is measured at some reference distance, r_m, from the noise source-usually greater than I m to avoid source near field effects-then the sound pressure level at some other distance, r, may be estimated using Eq.8:

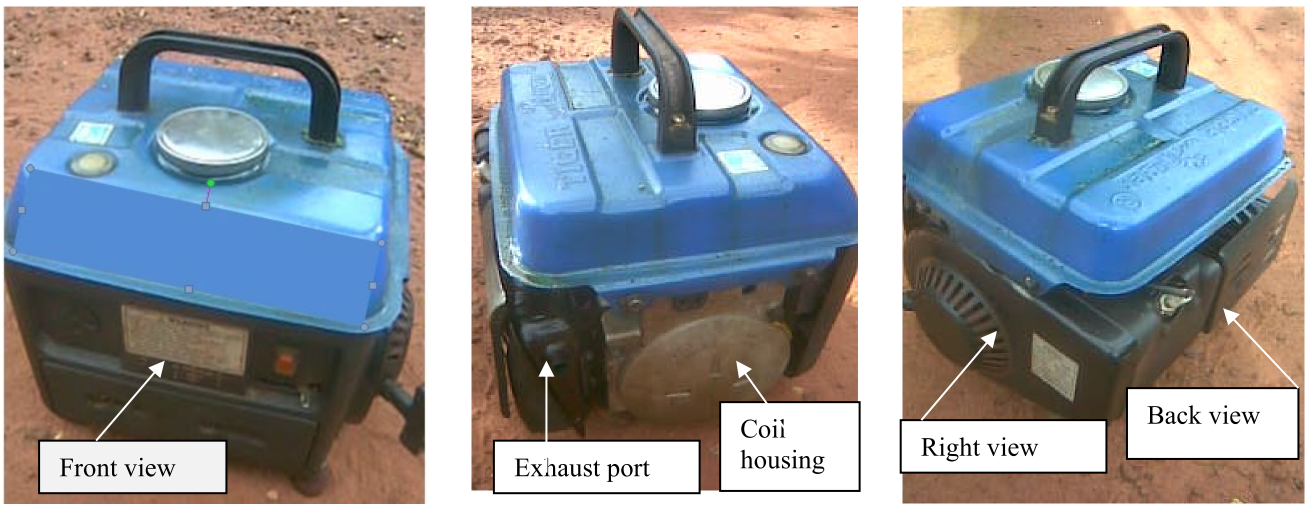
$$L_p = L_m - 20log_{10}\left(\frac{r}{r_m}\right) \tag{8}$$

Thus, if the distance is doubled the noise level is reduced by 6 dB from a point source such as a generator (Hansen 2022).

3. Methods

3.1 Description of Mini-generator used in the Experiment

Figures 1 (a) through (c) shows the different views of a popular type of portable gasoline mini generator used in Nigeria, as procured (without enclosure). The front end (Figure 1a) has the "on switch", choke, ac wiring socket, air intake port, the left side view (Figure 1b) shows the exhaust port and pipe, and coil housing; while the right side view shows the recoil starter and blower, the back view with spark plug. The specification of the mini generator is presented in Table 1. The generator is rated 650 W.



(a) Front end (b) Left side view (c) Right view and Back view

Figure 1. Mini-generator used for the experiment

Table 1. The specifications of the mini generator

Item	Specification
Brand	Tiger TG 950 DC
Engine Type	2-stroke cycle, reed valve, forced air- cooled single cylinder
Rated Power	650 W
AC Output	220 V /50 Hz
AC output Phase	Single Phase
Fuel tank capacity	4.2 litres gasoline
Oil mixture	50:1 ratio
Displacement	63 cc
Weight	22 kg
Overall size	380 x 320 x 330 mm

3.2 Acoustic Enclosure Design and Prototype Scale Construction

The factors that were considered while designing the enclosure are the nature of the noise produced (this informed the choice of material), the size of the generator, the location of exhaust and intake ports to enable proper engine operation, and the weight of the enclosure to ensure portability. The noise frequency is a factor in deciding the type of inner lining absorption material and the outer paneling as it had been observed that noise attenuation is frequency dependent. In heavy duty diesel engine generator sets, Ju et al. (2004) noted that the sound pressure level is most pronounced at the frequency level of 500 Hz and contributions of the two frequency components of 125 Hz and 250 Hz were little. Tandon et al. (1998) observed that the sound pressure spectra of the sides of a kerosene engine driven portable generator set indicated high noise level mainly in the frequency range 265 to 555 Hz. The weight of the barrier, the frequency of the incident sound, the plate dimensions, its flexural rigidity, the loss factor and the angle of incidence of sound waves onto the plate determines sound insulation properties of real one-layered thin plates (Guzas et al. 2008). The best absorption capabilities can be found for the unconsolidated felt. As reported by Koenig et. al. (2008), an increase of density by consolidating hybrid fleece into a composite, results in a decrease of absorption coefficients. Peng (2017) & Mushiri et al. (2017) stated that sound frequency is a strong factor that impacts the sound absorption coefficient of materials.

The absorption coefficients corresponding to room walls and floor are taken as 0.1 and the atmospheric absorption coefficient is 0.0007 m-1 (Sequira and Cortinez 2012). The absorption coefficient of glass wool is over 0.9 within the measurement frequency bands of 5-10kHz, while that of well vanished wood material is 0.05 (Liu and Lu 2010). Fouladi et al. (2011) showed that having more absorptive material in front or behind a perforated plate will enhance the acoustic absorption at higher and lower frequencies respectively. Also, having longer transmission path for the incident sound in absorbers will improve the acoustic absorption (Fouladi et al. 2011).

The shape and structure of enclosure are laid out so as to block-up effectively broad band noise, especially high frequency noise, and supply cooling air with an intake duct and evacuate heated air with an outtake duct sufficiently (Ju et al. 2004).

In addition, while designing an enclosure, two types of enclosure resonances should be considered, the structural resonance of the enclosure panels and the acoustic resonance of the air space between an enclosed engine and the enclosure walls. To suppress the acoustic resonances, absorbing material such as foam with absorption coefficient which varies from 0.08 to 0.75 for frequency range of 125 to 4000 Hz can be used on the inside of the enclosure (Tandon et al. 1998).

The frequency of the TG 950 mini generator noise was therefore measured using frequency analyzer with Android application on Nokia phone and was found to be below 700 Hz. Composite laminate with good damping property, light weight, corrosion free, ability to be molded into various shapes and curves, high strength to weight ratio, becomes the material of choice as the structural panel. Six open 600 by 600 by 400 mm parallelepiped boxes of thickness 2 mm from 2-ply random mat E-glass reinforced polyester resin panels were constructed. The inner surface of the box panel is lined with 20 mm thick polystyrene foam (see Figure 2).

The boxes were stacked during the measurements as shown in Figures 3 (a) - (d). The foam absorbs the low frequency generator noise and attenuates high frequency structural resonance noise. The outer panel attenuates the low frequency structural resonance noise and blocks high frequency generator source noise.

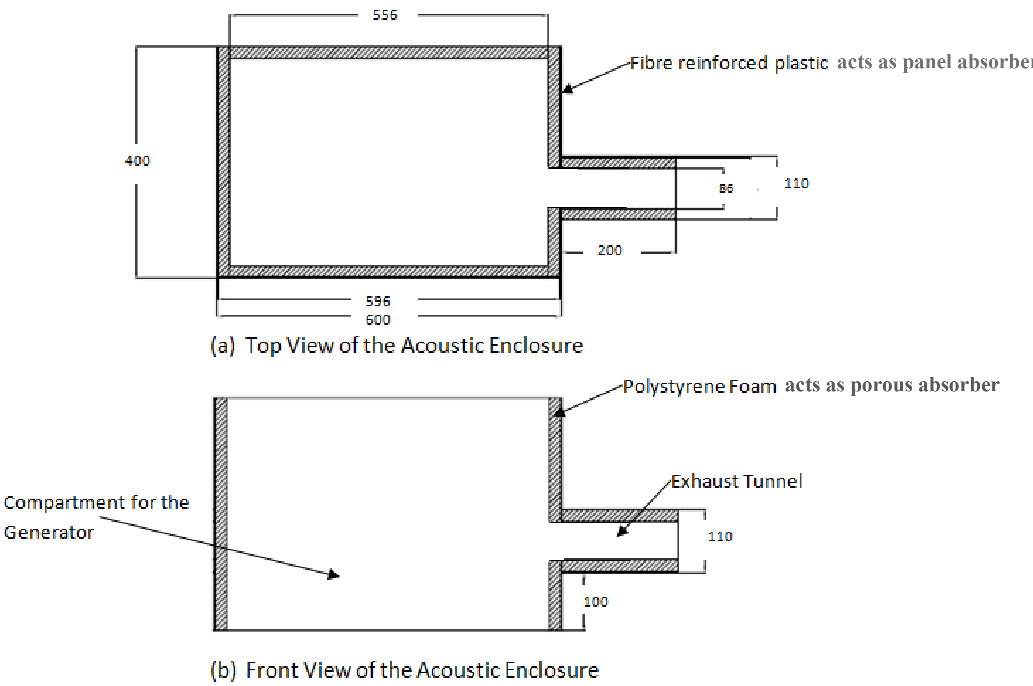


Figure 2. Geometrical model of the Acoustic Enclosure

(a) Stack height 400 mm

(b) Stack height 800 mm

(c) Stack height 1200 mm

(d) Stack height 1600 mm

Figure 3 Physical model of the acoustic Enclosure

3.3 Performance Evaluation of The Enclosure

Basically, two sets of measurements were taken: first, with the generator operated outside of the acoustic enclosure and second, with the generator operated inside the enclosure. The sound pressure levels from the source were taken at predetermined distances away from the generator using the VandA, VA8080 sound level meter (See Figure 4a). The predominant frequencies were also measured using a downloadable frequency spectrum analyzer on android application mobile phone handset (See Figure 4b).

(a) Sound level meter

(b) Frequency spectrum analyzer

Figure 4. Measuring instruments used

4. Results and Discussion

Figure 5 shows the sound pressure level measured for different sides of the generator. It is observed that the noise levels are not distinctively different and thus the generator can actually be regarded as a point source. It is observed that the Sound pressure level (SPL) decreases with the distance away from the generator as well. The sharp drop (16.8%) of the SPL observed closest (1 m from the source) to the generator may be due to the reverberation echo effect from the generator parts. After that, the SPL decreases asymptotically. The SPL on the front panel is slightly less than those obtained from the other sides. The front panel side can therefore be positioned towards the used environment.

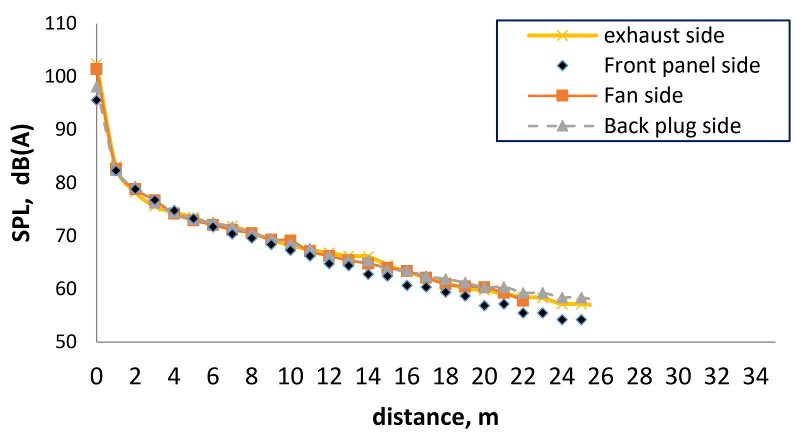


Figure 5. Produced noise level from the different sides of the generator without acoustic enclosure

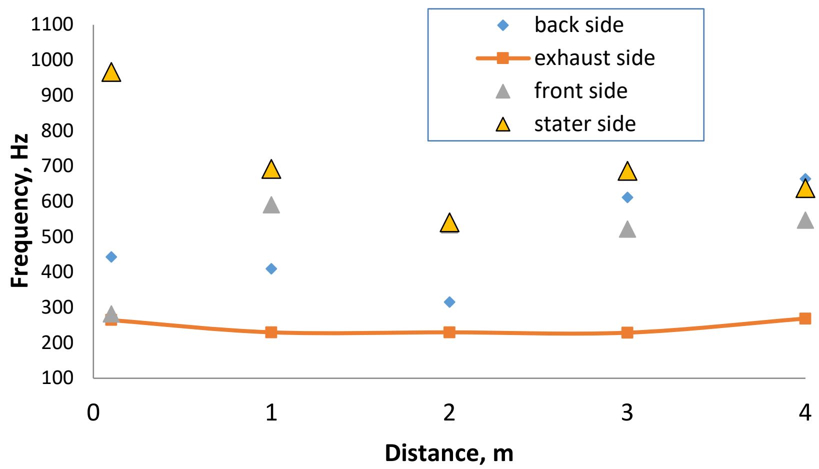


Figure 6. Variation of detected noise frequency (Hz) with distance (m) from the generator

The detected frequencies of the noise produced from different sides of the generator are distinguishable especially at close range from the generator (Figure 6). This is attributed to the particular component located at that side of the generator. The frequency of the starter side is higher because of the fan located there which makes a characteristic high pitch noise detectable by ear at close range of below 1.0 m. There is a good agreement between the experiment and the theoretical prediction whereby doubling the distance reduces the noise level by 6 dB(A) as shown in Figure 7. Figure 8 shows the insertion loss of the acoustic enclosure. It was observed that an insertion loss of up-to 13.3 dB (A) is feasible. The SPL decreases with increasing enclosure height as shown in Figure 8 with an optimal height of 1600 mm recommended, as subsequent increases did not result in any appreciable SPL decrease.

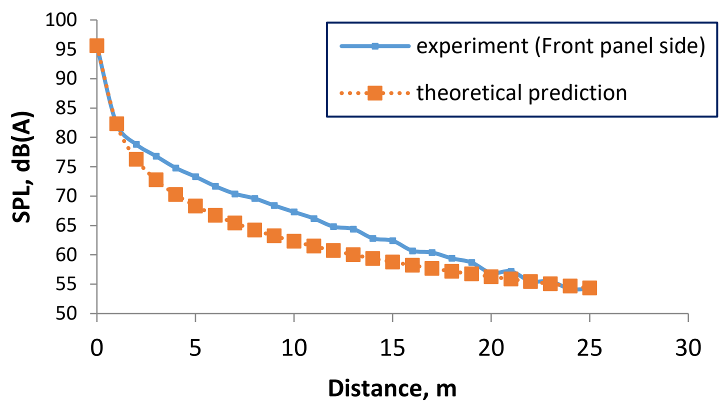


Figure 7. Predicted and experimental sound pressure levels as functions of distance from the generator without enclosure

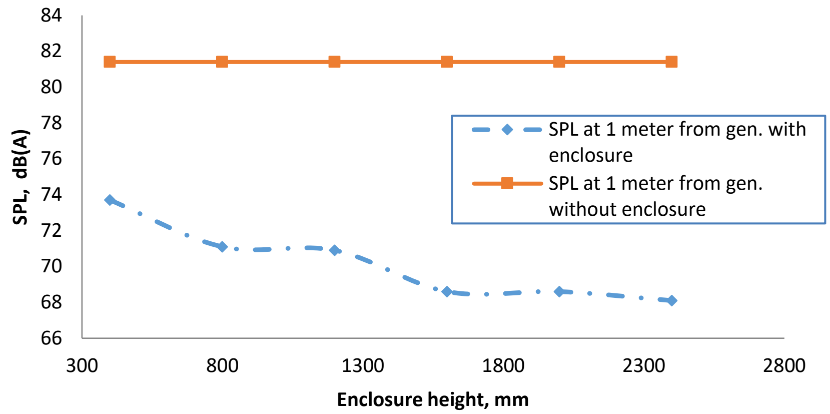


Figure 8. Insertion loss (SPL without enclosure minus SPL with enclosure) as a function of enclosure height

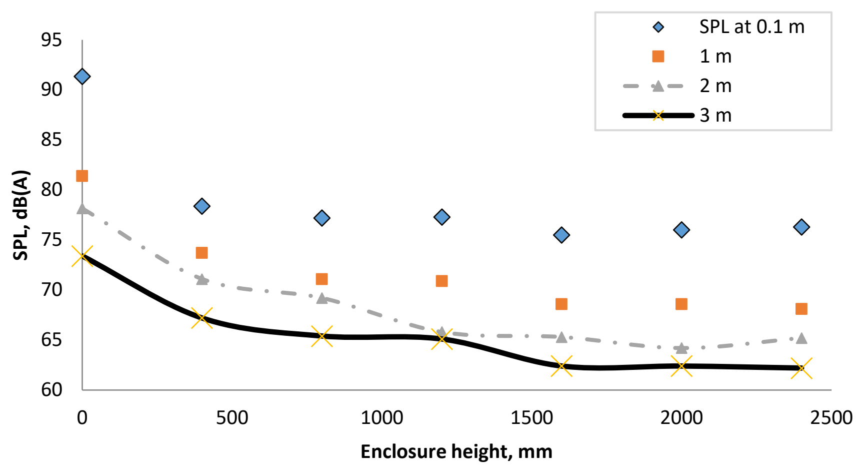


Figure 9. Sound pressure levels as a function of the enclosure height

Figure 9 shows the detected frequencies. The detected sound frequencies from different sides of the generator inside enclosure were low compared to the observed frequencies without enclosure. The enclosure must have absorbed the relatively high frequency sound better. The frequency of the noise from the starter side remained constant both at close range and far distance unlike the other sides (see Figure 10). The exhaust side showed an initial decrease and then grows gradually while the backside and the front side showed a low initial frequency and rises to about 290 Hz and stabilized at a distance of about 2m.

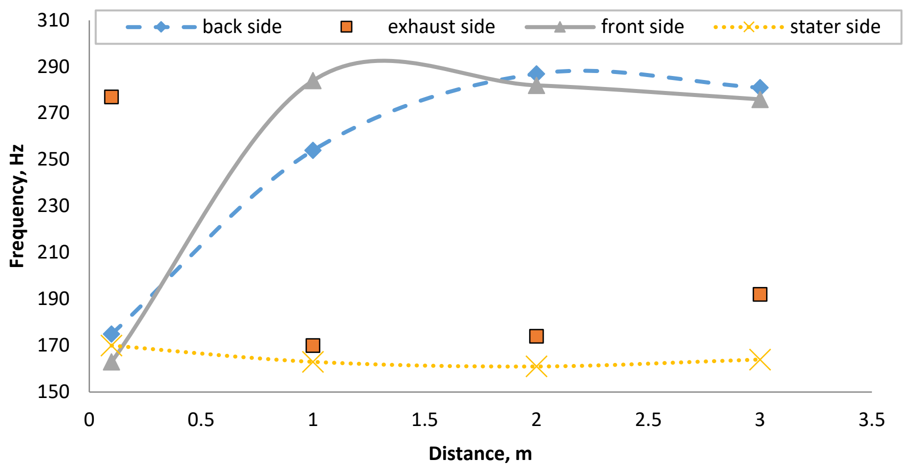


Figure 10. Detected frequency against distance from the generator inside the enclosure

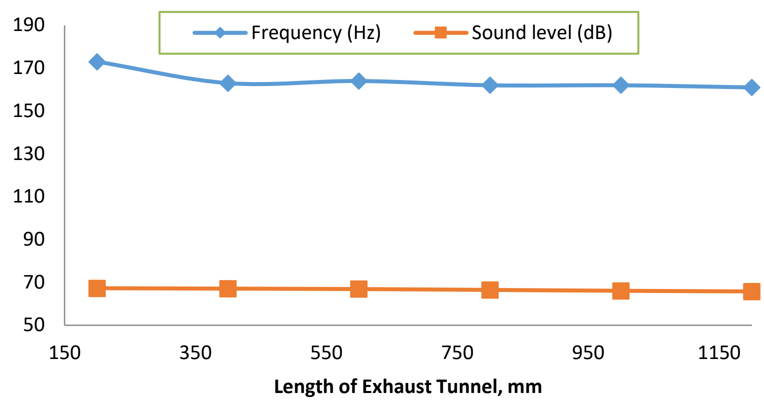


Figure 11. Effect of exhaust tunneling on the sound level and frequency

It is clear as shown in Figure 11 that increasing the length of the enclosure exhaust tunnel projection beyond 200 mm did not improve the enclosure insertion loss appreciably except for a little decrease of about 10 Hz in frequency level.

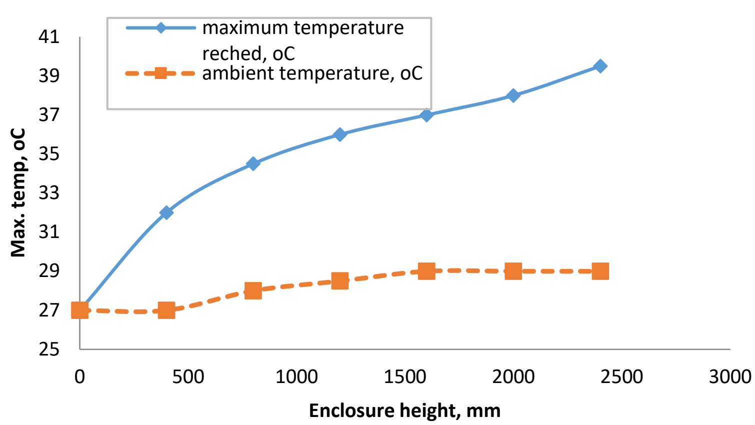


Figure 12. Maximum temperature reached with increase in enclosure height

Increasing the height of the enclosure beyond 1600 mm did not substantially improve the effectiveness of the enclosure, while it increases the temperature inside the enclosure as shown in Figure 12.

5. Conclusion

It has been observed that the mini generator set can be approximated to a point source with no directivity at a minimum listener position of 1 m from the source. The generator noise decays with increasing distance away from the generator and at a rate which is in agreement with the theoretical prediction. The insertion loss of the full acoustic enclosure is substantial and hence can provide succor to the menace of noise pollution from these categories of generators. Worthy of mention is the fact that the generator can be operated at safe temperatures inside the enclosure. Hence, the enclosure which would provide protection as well as noise reduction can therefore be put outside the immediate user's environment, under rain or sunshine, without fear of damage or loss. This will therefore save the population from the harmful effects of the generator fumes which has been pointed to have caused the death of many users.

Acknowledgements

The authors acknowledge the support received from the Africa Centre of Excellence for Sustainable Power and Energy Development (ACE-SPED), University of Nigeria, and the Research & Development Division of Comdalytics Nigeria Limited, that enabled the timely completion of this research.

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