# Perforation and muffler noise reduction system for a small petrol generator

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**Abstract.** South Africa's electrical infrastructure deficit and poor maintenance plans have resulted in frequently occurring power outages, which has caused a decline in productivity, alongside an increase in vandalism. As a result, many households and businesses have resorted to alternative energy sources, such as petrol generators. However, petrol generators are loud, reaching acoustic levels of roughly 90 dB, and have proven negative impacts on society and the environment. To reduce the noise intensity produced by small petrol generators, a noise reduction mechanism has been designed. The mechanism incorporates several noise attenuation materials such as porous absorbers and perforated panels. The design also features both passive and active ventilation features for optimal cooling of the generator during use. With flow simulating software embedded in SolidWorks, the temperature, pressure and acoustic power level within the noise reduction mechanism was investigated. The sound box is shown to reduce the noise of the generator to approximately 10 dB, whereas the muffler, can reduce the noise intensity to 37 dB. The overall temperature within the sound box is roughly 75 ˚C, and the maximum pressure was determined to be 103 kPa, which is sufficient for operation of the generator, without compromising its performance and functionality. A modified experimental model was built to validate the numerical results. The results from the experiment produced similar results in terms of decrease in sound when the insulator is added. ***Keywords:*** *generator; noise reduction mechanism; acoustic power level; temperature; sound box; muffler.*

## 1 Introduction

As of October 2007, South Africa has been experiencing controlled and frequently occurring power outages known as load shedding [1]. Due to the country's poor electrical infrastructure and maintenance plans, or lack thereof, the high electricity demand cannot be met, and power plants tend to fail [2]. As a result of these ongoing power outages, the country has been susceptive to economic decline, a decrease in productivity, and an increase in vandalism [3].

In 2025 Eskom direct customers will see an average increase of 12.74%, approved by NERSA (South Africa's National Energy Regulator), commencing on April 1, 2025; municipal bulk purchases will have an increase of 11.32%, beginning on July 1, 2025 [4]. This increases the number of individuals who will not have access to electricity. Therefore, alternative energy sources will become more appealing.

Small petrol generators have therefore become a reliable and alternative source of energy for many South African businesses and households [5]. Although these generators can offer temporary benefits at mitigating electricity concerns, they also have proven negative impacts on society and the environment, due to their high noise intensity.

### 1.1 The need for a noise reduction mechanism

Small petrol generators are internal combustion engines, which rely on either petrol or diesel fuel to operate. These engines are known to cause a significant amount of noise due to several reasons, such as pressure variations, the intake and outlet of air, and mechanical vibrations. All of these contributors result in an overall noise intensity of up to 90db, which can be detected from 7m away, and prolonged exposure is known to cause noise pollution, sleeping disorders, hearing impairment and neurological problems [6] [7].

Therefore, it is crucial to design a noise reduction mechanism for small petrol generators, to reduce the noise intensity of commonly used small petrol generators to ensure that it is in alignment with South African noise ordinance, and ISO 8528-10, which states that the legally acceptable noise level is between 45db during the night and 55db during the day in suburban areas [6].

There are minimal noise reduction mechanisms which sufficiently reduce the noise of small petrol generators during operation to a legally acceptable limit, especially without jeopardising the efficiency and functionality of the engine. Furthermore, existing mechanisms hardly incorporate a modular design of both the sound box and muffler. Current muffler designs have increased back-pressure and complexity, and sound boxes are limited to specific generator types, as a result, many generators are not accommodated for, and performance is reduced.

The aim of this report is to design and investigate the suitability and performance of a modular noise reduction mechanism, which comprises of both a sound box and a muffler, whilst meeting legal requirements, and maintaining generator performance.

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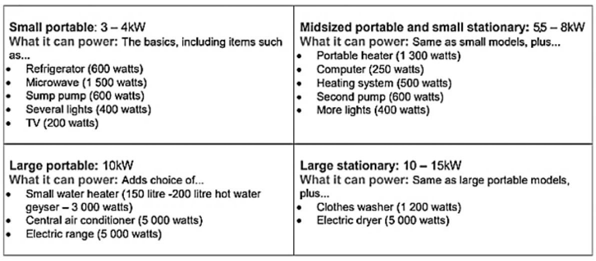
## 2 Review

### 2.1 Classification of generators

Generators have varying applications and power supplying capabilities and can either be classified as industrial or commercial [8]. As seen in Table 1, small petrol generators typically supply between 3kW to 8kW of power, whereas industrial generators can supply as much as 50kW to 3MW of power.

**Table 1.** Generator classification [8].



| | |
|---|---|
| **Small portable:** 3 – 4kW<br>What it can power: The basics, including items such as...<br>• Refrigerator (600 watts)<br>• Microwave (1 500 watts)<br>• Sump pump (600 watts)<br>• Several lights (400 watts)<br>• TV (200 watts) | **Midsized portable and small stationary: 5,5 – 8kW**<br>What it can power: Same as small models, plus...<br>• Portable heater (1 300 watts)<br>• Computer (250 watts)<br>• Heating system (500 watts)<br>• Second pump (600 watts)<br>• More lights (400 watts) |
| **Large portable: 10kW**<br>What it can power: Adds choice of...<br>• Small water heater (150 litre -200 litre hot water geyser – 3 000 watts)<br>• Central air conditioner (5 000 watts)<br>• Electric range (5 000 watts) | **Large stationary: 10 – 15kW**<br>What it can power: Same as large portable models, plus...<br>• Clothes washer (1 200 watts)<br>• Electric dryer (5 000 watts) |

Selecting an appropriately sized generator is crucial and requires knowing the exact amount of electrical load that it is required to support.

### 2.2 Generator components

Petrol generators have several components, each of which provide a specific function in ensuring that fuel is being converted to a useful form of energy. Table 2 depicts the various components of a petrol generator.

**Table 2.** Components of a petrol generator [9].

| Component | Function |
|---|---|
| Frame | A structural component which provides support and protection for other components. It offers vibrational dampening and noise reduction. |
| Engine | Consists of the cylinder, piston and connecting rod, which work together to generate motion and create mechanical energy. |
| Fuel System | Consists of the fuel tank, fuel valve and fuel pump, which maintains the fuel supply to ensure that the generator can provide enough power to support the load. |
| Muffler | A component of the exhaust system, which allows the exhaust gases to escape from the engine and offers noise reduction |
| Cooling Fan | Responsible for generating enough cold air to regulate the temperature of the generator during operation. |
| Voltage Regulator | Regulates the amount of output voltage, to ensure that it remains at a required value, and prevents damage of connected appliances |
| Intake | Contains an intake pipe and an air cleaner, which directs clean air into the generator, to be used during combustion. |
| Alternator | Consists of a stator and a rotor, whereby generated mechanical energy is converted to a usable form of electrical energy. |

Upgrading the components of a generator can improve its performance, improve its fuel consumption, decrease its noise intensity and promote sustainability.

Figure 1 depicts a schematic of a small petrol generator.

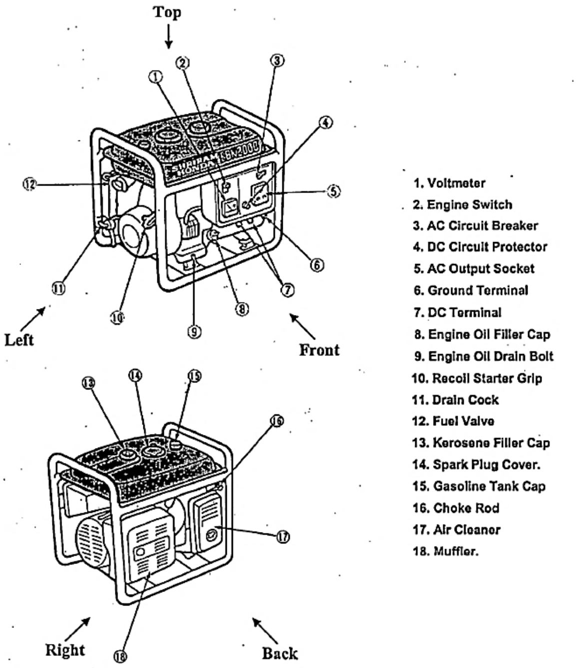


**Fig. 1.** Schematic of petrol small petrol generator [10].

Although the location and assembly of the components may differ between various models, the function and overall interaction amongst the components are the same.

### 2.3 The sources of petrol generator noise

Small petrol generators produce roughly 90db(A), in terms of A-weighting, which implies that the sound levels were measured 7m from the source [11]. However, according to SANS 10103:2008, the legally accepted noise limits if 55db during the daytime and 45db during nighttime in urban areas [12].

Understanding which components of the generator contribute the largest to noise, as mentioned in Table 3, is important to deploy noise reduction techniques.

**Table 3.** Sources of generator noise and prevention [13].

| Component | Description of noise cause and preventative methods |
|---|---|
| **Engine** | Internal combustion engines produce aerodynamic noise, due to the flow of gases throughout the system and surface vibrations of the various engine components. The piston, cylinder and connecting rods are amongst the many engine components that are in contact with one another and vibrate during operation. Noise can be reduced by improving the fuel quality and using acoustic materials such as aluminium. |

| | |
|---|---|
| **Cooling fan** | Air is transferred at high velocity and pressure as it passes through the engine and radiator. The large volume of cooling air that is required during generator operation, causes the noise. Introducing 90-degree bends in cooling ducts and using thermostatic fans can reduce the noise intensity. |
| **Engine exhaust** | Exhaust gases that are produced during combustion are released at high pressure and temperature A muffler can be attached to the exhaust of the generator to reduce the output noise. |
| **Structural/ mechanical noise** | The collision between the structure and moving mechanical parts are a large contributor to generator noise. Redesigning the frame to incorporate minimal deflection at a greater force, complete isolation or vibration damping components can significantly reduce noise. |
| **Air intake system** | As air travels through the intake, low and high frequencies are generated due to fluctuating pressures and changes in duct area. To limit the amount of noise in the generator, sound absorbent casings can be applied to the intake point. |

In order to meet legal ordinances, the noise of small petrol generators must be reduced, either by altering the components within the generator, or by using noise reduction mechanism adjacent to the generator.

## 2.4 Types of noise insulation

Noise insulation can be defined as noise barriers which deflect or absorb sound by means of either passive or active methods. There are several methods of noise insulation that can be applied to petrol generators, which include the following [14]:

- **Acoustic barriers:** involves the reduction of noise using rigid, high-density materials such as metal. These barriers require proper sealing.
- **Isolation mounts:** involves placing vibration isolating components in between moving components. These minimise vibration transmission but require frequent maintenance and repair due to constant contact.
- **Acoustic insulation:** involves lining air ducts and surrounding panels with sound absorbing materials. This method is easy to implement into existing systems.
- **Cooling air attenuation** involves the attenuation of intake air by means of baffles or chambers. Still possible for air to escape through air openings.
- **Maximising distance:** involves relocating the noise source away from reflective walls. Limited effectiveness due to space constraints.
- **Exhaust silencers:** involves placing a silencer with various channels at the exhaust end of the engine. Possibility of back pressure and reduced generator performance.

Although there are many noise insulating methods available, when considering those applicable to small petrol generators, flammability, cost-effectiveness, ease of implementation and performance are of importance.

### *2.4.1 Porous absorber*

Porous absorbers are materials which allow sound to propagate through several channels, resulting in the dissipation of noise, which is in turn converted to thermal energy [15]. These materials rely on the viscous boundary layer effects of air, which are it travels through the channels, friction is generated, hence noise is dissipated, and heat is produced [15].

Porous absorbers function better when exposed to high velocity particles, and as a result are better located at a certain distance away from the rigid backing. They are able to absorb mid to high frequencies and aren’t typically suitable for lower frequency ranges, as it would require more material, thickness and hence space. As the thickness of the porous absorber increases, so does its ability to absorber lower frequencies.

Several types of porous absorbers are available, which include the following [16]:

- **Mineral wool and foam:** produced from sand or glass, which are molten and stretched into fibres, then compacted into rigid boards. These materials have the advantage of being inexpensive and recyclable. However, due to their low density are unable to effectively absorb higher frequencies.
- **Recycled materials:** produced from recycled wood, plastic, rubber and cloth, which are granulated, compacted and bound together using a binding agent. These materials are sustainable and recyclable. However, they are less porous than fibre materials and have inconsistent sound absorption properties.
- **Absorbent plaster:** produced by layering granules in decreasing sizes and binding them with an agent. This material is able to effectively absorb lower frequencies, however, takes long to manufacture and is not ideal for projects with limited completion times.
- **Quiet stone:** produced by binding granulated flint with a resin to form rigid sheets. Although the material has high acoustic absorption properties, it is expensive.

These porous absorbing material properties are influences by various factors such as flow resistivity, tortuosity, the shape of the pores, and porosity [15].

## 2.5 Noise Insulation Designs

Akugre et al. [17] used CFD software to analyze the transmission loss, pressure, back pressure, and fluid velocity at the custom muffler's input, throughout the muffler, and at the outlet. This offered a computer evaluation of the muffler's operation, showing the way the exhaust fluid spreads throughout the pipe. Figure 2 presents the results from the study.

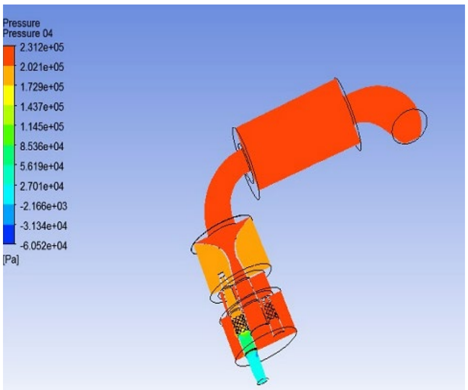


**Fig. 2.** Muffler design simulation [17]

Zhang et al. [18] conducted a study on the features of the metamaterial microperforated panel (MMPP) with local resonators in terms of vibro-acoustic coupling. The metamaterial panel's (MP) vibration equations are obtained by combining the Rayleigh Ritz and Spectral Geometry methods, and the absorption coefficient is solved using the acoustic electrical analogy approach while taking the vibro-acoustic coupling into account. The vibro-acoustic coupling model of the MMPP with different parameters under different boundaries can be studied using the program created using these techniques. Using the finite element method, the host panel's free vibration frequency with local resonators and the MMPP structure's sound absorption coefficient are verified, respectively. Specifically, the analytical or semi-analytical approach suggested in this study only needs a few DOFs and truncation coefficients to compute the complete coupling model and is independent of the quantity and quality of mesh grids. The FEM model must be readjusted and computed to estimate the sound absorption performance of the MMPP with arbitrary parameters, particularly the elastic boundaries. As a result, this approach can significantly reduce computation time and increase efficiency when compared to FEM.

## 3 Concept generation

Design of the noise reduction mechanism focused on several customer requirements, such as effective noise cancellation, ease of operation, ergonomics, adaptability and durability. The concept generation process involved the development of three designs, concept selection and performance analysis.

Small petrol generators have therefore become a reliable and alternative source of energy for many South African businesses and households. Although these generators are able to offer temporary benefits at mitigating electricity concerns, they also have proven negative impacts on society and the environment, due to their high noise intensity.

### 3.1 Conceptual designs

Several conceptual designs were developed for the noise reduction mechanism, whereby meeting customer requirements and design specifications.

### *3.1.1 Conceptual design 1*

The design incorporates a full enclosure with a single layer wooden outer panel. The mechanism features an intake fan for cooling, a combination muffler which is attached to the generator exhaust by means of a flexible stainless-steel hose, as well as a hinged door to allow for easy access into the box, as seen in Figure 3.

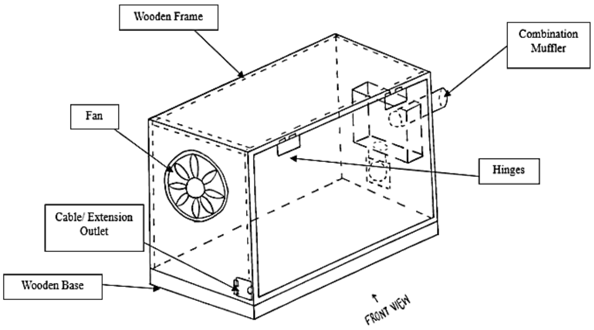


**Fig. 3.** Concept design 1.

The design is inexpensive and easy to manufacture; it also offers good heat dissipation due to the fan. However, wood is difficult to clean and easily tarnished by petrol spills. Back pressure is also a concern due to the complex geometry of the combination muffler.

### *3.1.2 Conceptual design 2*

The design incorporates a full enclosure, made with a double layered case, comprising of an outermost layer of steel and an inner layer of porous absorbing material. The mechanism is suspended on four supporting legs and has an anti-vibrational mount at its base. It also features passive ventilation slots on its walls, and has no exhaust silencer or outlet, as seen in Figure 4.

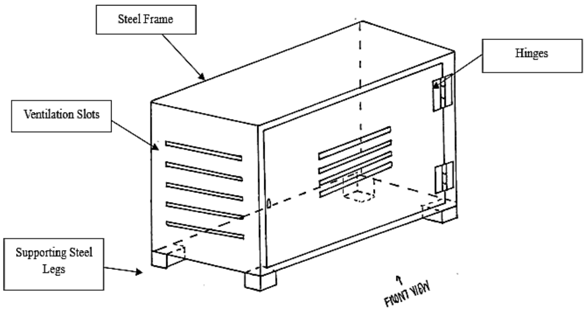


**Fig. 4.** Concept design 2.

The design is comprised of few components, hence easy to manufacture, it is also weather resistant and durable. However, due to no active ventilation, there is insufficient airflow within the box, and the elevated box requires more effort to insert the generator during use, making it less ergonomic.

### *3.1.3 Conceptual design 3*

The design, as seen in Figure 5, incorporates a full enclosure, which has a multi-layered casing, comprising of a rigid steel casing, followed by an air gap, then a porous absorber adhered to a perforated metal sheet. The mechanism also features both active and passive ventilation features, including a fan and slots. Additionally, a thin rubber base is used, and an absorptive muffler is present at the exhaust end, which is connected to the generator exhaust by means of a flexible stainless-steel hose.

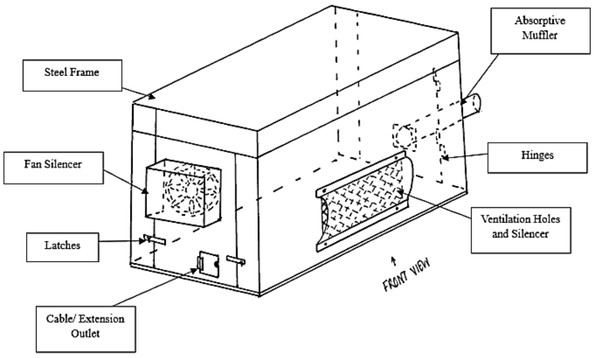


**Fig. 5.** Concept design 3.

The design is weather resistant due to its steel casing, and ventilation covers. It also offers sufficient cooling and outlet of exhaust gases. However, due its complexity, it requires more manufacturing and hence is more expensive.

### 3.2 Concept selection

Each of the three conceptual designs were ranked according to the specified customer requirements and assigned a score in terms of how well they perform and satisfy customer expectations, as seen in Table 4.

**Table 4.** Ranking of conceptual designs.

| Selection criteria | Weight | Conceptual designs | | |
|---|---|---|---|---|
| | | Design 1 | Design 2 | Design 3 |
| **CR1** | 0.1500 | 0.3000 | 0.4500 | 0.7500 |
| **CR3** | 0.1000 | 0.3000 | 0.4000 | 0.3000 |
| **CR4** | 0.1222 | 0.1222 | 0.3666 | 0.4888 |
| **CR5** | 0.1278 | 0.6390 | 0.5112 | 0.3834 |
| **CR6** | 0.0806 | 0.1612 | 0.2418 | 0.3224 |
| **CR7** | 0.0722 | 0.2888 | 0.2888 | 0.2888 |
| **CR10** | 0.1167 | 0.2334 | 0.2334 | 0.5835 |
| **CR11** | 0.1306 | 0.2612 | 0.5224 | 0.6530 |
| **CR12** | 0.1000 | 0.2000 | 0.3000 | 0.4000 |
| **Total** | | 2.5058 | 3.3142 | 4.1699 |

Conceptual design 3 obtained the highest score of 4.1699, whereby, ranking the highest in terms of noise cancellation, durability, integrated design, and weather resistant. The design features several noise cancellation methods, including vibrational isolation, an exhaust silencer and bends within the intake duct. The use of rubber and steel constructive material owes to its weather resistance and durability. The perforation design was driven by acoustic theory of Helmholtz resonators and focuses on improving the efficiency of the generator engine through optimal thermal regulation.

## 4 Performance analysis

The effectiveness of the exhaust silencer, the required ventilation and the sound absorption due to the porous absorber are assessed, to determine the overall performance of the sound box.

### 4.1 Muffler effectiveness

Transmission loss can be used to determine the effectiveness of a muffler and can be described as the difference between the inlet sound intensity and the outlet sound intensity and is described by Equation 1 [17].

$$TL=10log_{10}\,(W_i\,/\,W_t) \tag{1}$$

Whereby the $TL$ is the transmission loss (db), $W_i$ is the incident sound intensity (W), and $W_t$ is the transmitted intensity (W). Provided that the maximum input sound power is 90db, for an output sound power of 45db and 55db, the transmission loss was determined to be 45db and 35db respectively.

### 4.2 Sound box effectiveness

The noise reduction of mineral wool porous absorbers can be determined using Equation 2 [19].

$$db = -20log_{10}{}^{(1-c)} \tag{2}$$

Whereby $db$ is the absorbed noise, and $c$ is the noise reduction coefficient, which is approximately 0.8 for mineral wool. Therefore, the determined noise cancellation for each porous absorber membrane is 13.98db, which implies that a generator noise of 90db is reduced to 76.02db.

### 4.3 Ventilation efficiency of the fan

Thermal regulation of the noise reduction mechanism is achieved using a fan, which produces an inflow of cool air into the enclosed box. Small petrol generators produce 5kW of power, and roughly 2/3 of the power generates heat, which equates to 3.33kW. The heat lost through the exhaust end is 60% of the generator heat, which is roughly 2.0kW, and the remaining 1.3kW is heat generated elsewhere in the generator [20]. The maximum temperature which the generator can withstand is 90˚C [21].

According to the energy balance equation of the generator, the mass flow rate produced by the generator can be determined using Equation 3 [20].

$$m = Q/ (C_p \Delta T) \quad (3)$$

Whereby, $m$ is the mass flow rate (kg/s), $Q$ is the heat produced by the generator (W), excluding the exhaust heat, $C_p$ is the specific heat of air at constant pressure (J/kg˚C), and $\Delta T$ is the temperature difference between the maximum generator temperature and ambient conditions (˚C). The calculated mass flow of the generator conditions during operation is 0.02 kg/s.

The volumetric air flow thus required to maintain the temperature within the box is given by Equation 4 [20].

$$V = m/\rho_a \quad (4)$$

Whereby $V$ is the volumetric flow of air ($m^3$/s), $m$ is the mass flow rate (kg/s) and $\rho_a$ is the density of air (kg/$m^3$). The volumetric flow of air required for optimal cooling of the generator is 0.016 $m^3$/s.

## 5 Detailed design

Several steps were taken to ensure that the noise reduction mechanism was optimally designed, which includes material selection, detailed design analysis and modelling.

### 5.1 Material selection

The final design is a multi-layered, full enclosure, which has an outer steel casing, and air gap, a layer of porous absorber and finally a perforated metal sheet. The base of the mechanism is rubber, to ensure ergonomics and provide vibration dissipation during generator operation. Table 5 depicts the selected material for each component, and the reason for its selection.

**Table 5.** Selected material for major components.

| Component | Selected material | Reason for selection |
|---|---|---|
| **Rigid outer casing** | AISI 304 stainless steel | • Weather resistant and durable<br>• High melting point<br>• High strength |
| **Porous absorber** | Rockwool ProRox SL 960 | • Good sound absorption<br>• Can withstand humid conditions<br>• Manufactured from recycled materials |
| **Perforated metal sheet** | AISI 304 stainless steel | • Can withstand humid environments<br>• High melting temperature |
| **Sound box rubber base** | Black natural rubber | • Weather resistant<br>• Anti-slip properties<br>• Good shock absorption<br>• Vibration dampening properties |

Based on the selected materials available dimensions and quantity, the size of each component within the noise reduction mechanism can be determined.

### 5.2 Detailed design analysis

Several assumptions were made when analysing the noise reduction mechanism, which includes scaling the mechanism to suit different size generator models, the rubber base is vibrationally isolated from the side panels, a minimum safety factor of 3 is required.

When designing the mechanism, the Mac Africa 8.75 kVA generator, with dimensions of 700×900×580 [22]. These dimensions were the basis for the internal space of the mechanism; whereby additional space was included for maintenance and easy of installation. The final internal dimensions of the generator were chosen to be 1500×1000×800.

The volumetric air flow required is equivalent to 99.87 CFM, and as a result a standard fan from Sunon, which operates with 230V and has 117 CFM was selected for the final design [23]. The internal perforated metal sheet was customized, with a porosity not exceeding 30%. The optimal diameter and centre-to-centre distance between the perforations was determined using Equation 5 [15].

$$\varepsilon = \pi a^2/D^2 \quad (5)$$

Whereby, $\varepsilon$ is the porosity, $a$ is the perforation diameter (mm) and $D$ is the centre-to-centre distance between the perforations (mm). The optimal diameter is selected to be 10mm, and the centre-to-centre distance is 16mm, for ease of manufacturing.

The thickness of the rockwool porous absorber is determined by Equation 6 [15].

$$d = \Delta P/U\sigma \quad (6)$$

Whereby, $d$ is the thickness of the porous absorber (mm), $\Delta P$ is the change in pressure (db), $U$ is the flow velocity ($m^2$/s) and $\sigma$ is the flow resistivity (Pa s/$m^2$).

For a pressure drop of 35db, a Rockwool flow resistivity of 50 000 Pa s/$m^2$ and a flow velocity of 0.02 $m^2$/s, the calculated thickness is 33.33mm. However, due to availability of Rockwool resources, a thickness of 50mm is selected. Finally, the outermost steel casing is selected to be 1.5mm thick and the metal perforated sheet is 1.2mm thick, due to material availability. The dimensions of each of the materials are kept constant for the absorptive muffler, which is 0.3m for optimal length and sound absorption. The final model of the noise reduction mechanism can be seen in Figure 6 and Figure 7.

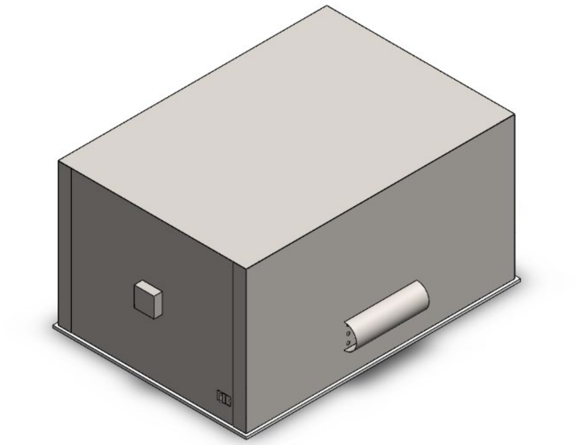


**Fig. 6.** Isometric view of noise reduction mechanism.

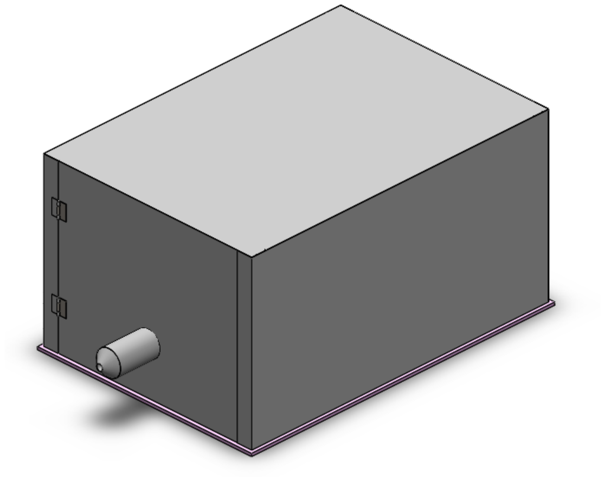


**Fig. 7.** Reverse isometric view of noise reduction mechanism

As seen in Figure 7, the front panel is attached to the right-side panel by means of two standard AISI 304 80mm hinges, which allows for the mechanism to be easily opened during use. The left side panel is also equipped with small electric wire cover, which allows for extension cables to be easily connected inside the box and fed through its connection point.

To reduce the complexity and number of components in the design, minimal fasteners were used, and the side panels simply slot into designated gaps in the front and back panel, and the top panel is simply slot in-between the four walls.

## 6 Numerical modelling

CFD analysis was conducted, whereby flow simulating software embedded in SolidWorks was used, to determine the realistic noise cancellation and temperature regulation properties of the noise reduction mechanism, when placed in an outdoor environment during use.

### 6.1 Flow simulation aim

The aim of the numerical modelling and analysis is to determine whether the passive and active ventilation features are able to optimize the temperature within the sound box, whereby not exceeding 90˚C. Furthermore, the noise cancellation of the entire mechanism is to be assessed to ensure that the legally acceptable limit of 45db is achieved.

### 6.2 Geometry

The final noise reduction mechanism was assessed during the flow simulation, as seen in Figure 8.

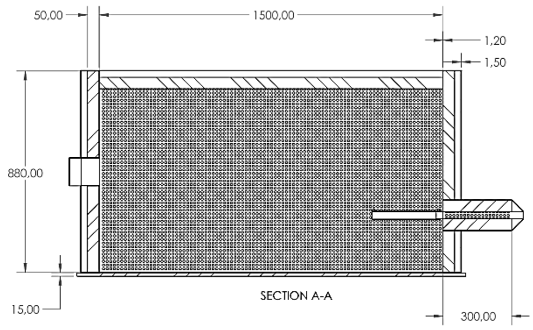


**Fig. 8.** Dimensioned sectional view of noise reduction mechanism model.

Flow simulation parameters and analysis was applied to the entire internal region of the mechanism, whereby bound by the rigid 1.5mm thick AISI 304 steel casing.

### 6.3 Flow simulation parameters

Several fluid flow parameters were defined for the internal analysis of the mechanism, whereby the fluid was considered to be air, and the impacts of humidity, gravity, solar radiation, radiation and conduction were taken into account. Table 6 depicts the various fluid parameters and their corresponding values.

**Table 6.** Flow simulation parameters.

| Parameter | Description |
|---|---|
| Analysis type | Internal analysis |
| Fluid type | Air (both turbulent and laminar); humidity considered |
| Physical features | Conduction, radiation, solar radiation and gravity |
| Atmospheric pressure | 101 325 Pa |
| Atmospheric temperature | 293.2 K |
| Gravity | -9.81 m/s (in the negative y- direction) |

These parameters were applied to the entire computational domain and remained constant for each flow analysis conducted on the mechanism.

## 6.4 Boundary conditions and load applications

For realistic modelling of the mechanism, several boundary conditions and features were applied to the mechanism, as depicted in Table 7.

**Table 7.** Boundary conditions and load applications.

| Location | Boundary condition |
|---|---|
| Inlet of fan cover | Environmental pressure (101 325 Pa) |
| Openings of passive ventilation cover | Environmental pressure (101325 Pa) |
| Axial fan | Inlet volume flow (0.06 $m^3/s$) |
| Outlet of muffler | Environmental pressure (101 325 Pa) |
| Inlet of flexible hose (into the sound box and into the muffler) | Inlet mass flow (0.02 kg/s) and heat source (260˚C) |
| Flexible stainless-steel hose | Radiative surface |
| Rockwool porous absorbing panels | Isotropic porous membrane |
| Outer rigid steel casing | Solar radiation |

These boundary conditions mimic realistic operation of the mechanism, during operation of the small petrol generator.

## 6.5 Meshing

A global mesh, as seen in Figure 9, was applied to the entire computational domain, which includes the outer surface and the internal volume of the mechanism.

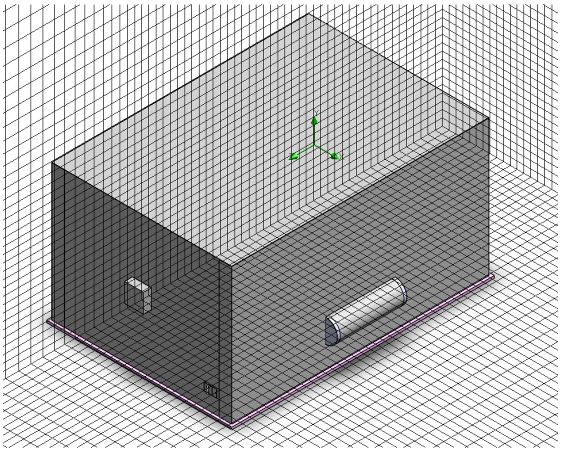


**Fig. 9.** Meshing of flow simulation model.

A fine global mesh was applied, to obtain the most accurate results for the flow simulation analysis.

## 6.6 Flow simulation results

Both the surface and the internal volume of the mechanism were analysed, to determine how temperature of the fluid is regulated within the box, and how effectively noise produced by the generator is attenuated.

The temperature analysis of the fluid within the noise reduction mechanism can be seen in Figure 10. Whereby fluid flow is affected by the axial Sunon fan, which produces an inlet of 117 CFM of air, the outlet of air by means of the passive ventilation holes on the rigid outer casing, and the outlet of hot exhaust gas through the muffler. The overall internal temperature of the sound box, excluding the muffler, is required to be a maximum of 90˚C or 363K, to ensure optimal functioning of the generator [21].

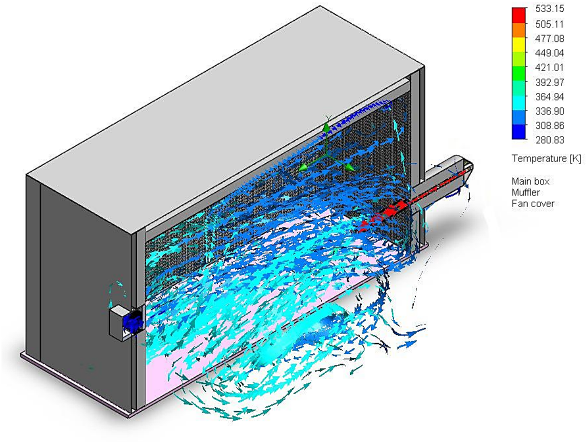


**Fig. 10.** Temperature analysis of internal fluid.

The maximum temperature occurs within the muffler, due to the outlet of hot exhaust gasses. However, the main focus is the internal volume of the mechanism, and the analysed temperature is roughly between 364.94 K and 338.90 K, which equates to between 90˚C and 66˚C. This implies that the temperature within the sound box is optimal for optimal functioning of a small petrol generator.

The acoustic power level because of several noise reducing methods, including fan and ventilation covers, rockwool porous absorber, perforated sheets and an absorptive muffler is seen in Figure 11 [24].

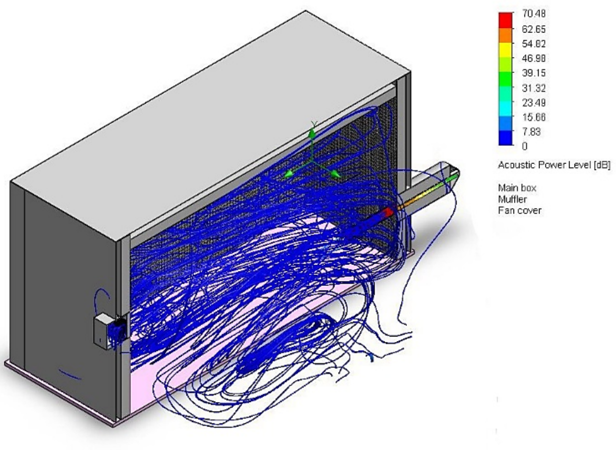


**Fig. 11.** Acoustic analysis of internal volume.

The acoustic power within the internal volume of the sound box is approximately 10db, which is well below the legally acceptable limit of 45db. This is due to majority of the noise of the generator being directed through the exhaust outlet [12].

The maximum acoustic power level occurs at the inlet of the muffler and extends along the entire length of the flexible hose. This is due to no noise cancellation or absorption occurring within the flexible hose. Once the fluid flow travels along the length of the muffler, it reduces from 70.48db to 39.15db. Figure 12 clearly depicts the flow analysis along the length of the muffler.

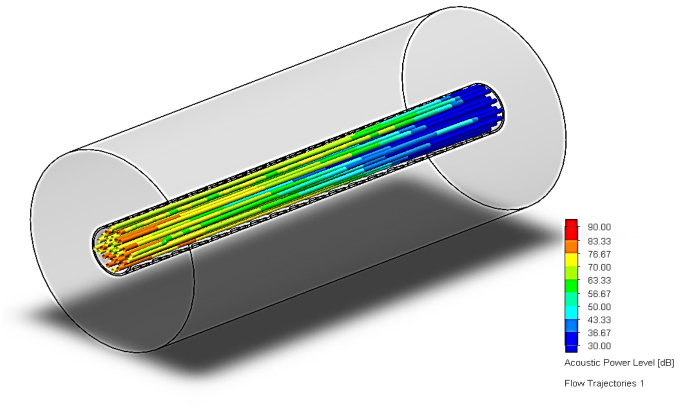


**Fig. 12.** Acoustic analysis of absorptive muffler.

The acoustic power level that enters the muffler is determined to be roughly 76db, and as the exhaust gases move along the length, it is reduced to as little as 37db, which is outlet to the environment. The reduction is noise is due to both the perforated metal tube and the rockwool porous absorber. This implies that the muffler reduces the generator noise to within a legally accepted range.

## 7 Model Validation

### 7.1 Experimental aim

The experimental project has two primary goals: first, it studies several ways for reducing generator noise and chooses the optimum strategy, and second, it designs a methodology to assess the noise reduction performance of generators while adhering to noise rules and standards. The aim is to see if the physical model actually reduces the noise

### 7.2 Apparatus

A physical model was built to validate the results of the numerical analysis was built from available materials due to the budget constraints. The dimensions of the noise insulation same to accommodate the small-scale generator. The apparatus included plywood, acoustic lining, louvered vents, axial cooling fan, Generator with 2800 W of power, a decibel meter and temperature gun. These materials were chosen because they cost less than R2 000.00 and could easily be built. The built model is presented in Figure 13.

**Fig. 13.** Enclosed noise insulator

### 7.3 Methodology

To conduct the experimental test, a systematic approach will be employed, below is a list of methods of testing to be followed:

- Take baseline noise measurements (without the enclosure).
- Enclosure installation

- Test following enclosure noise measurement (prototype testing).
- Noise loss insertion evaluation
- Vibration tests and analysis

- Conduct three iterative adjustments at various distances to achieve accurate results and a sound pressure level trend.
- Analysis of outcomes.

### 7.4 Experimental results

The sound pressure level measurements were made at progressively increasing distances from the generator running under rated load conditions. Table 4.1 illustrates the three trials conducted for 1 m, 3 m, 5 m, 7 m, 9 m and 10 m. The average results for the generator without insulation system are presented in Table 8.

**Table 8.** No insulation results

| **Distance from insulator** | **Average noise (dBA)** | **Engine temperature (°C)** |
|---|---|---|
| 1 | 90.1 | 29.17 |
| 3 | 82.23 | 30.1 |
| 5 | 80.83 | 26.63 |
| 7 | 77.83 | 29.83 |
| 9 | 76.23 | 29.97 |
| 10 | 74.43 | 30 |

It can be observed that there is a logarithmic decrease when distance increases because the sound pressure level reached 80.3 dBA at 5 m and 74.43 dBA at 10m. The temperature of the engine averaged at 30 °C. The generator was placed inside the insulation system and the average results are presented in Table 9.

**Table 9.** Insulated generator results

| **Distance from insulator** | **Average noise (dBA)** | **Engine temperature (°C)** |
|---|---|---|
| 1 | 74.3 | 44.1 |
| 3 | 66.23 | 44.2 |
| 5 | 61.5 | 44.27 |
| 7 | 60.43 | 44.27 |
| 9 | 58.97 | 44.13 |
| 10 | 57.06 | 44.23 |

The acoustic enclosure reduced noise output significantly and consistently, as evidenced by Insertion Loss (IL) measurements. The 1m measurement position had the biggest effect, with the IL reaching 15.8 dB and dropping from 90.1 dB(A) to 74.3 dB(A). The temperature of the engine was averaging at 44 °C. The acoustic foam and plywood materials inside the enclosure inhibited natural heat dissipation via radiation and convection, resulting in higher temperatures. Due to the presence of the fan and ventilation duct, the thermal ranges remained within acceptable working parameters.

## 8 Conclusion and recommendations

Small petrol generators produce between 70 dB and 90 dB of noise, which negatively impacts both society and the environment, and which is much higher than the legally acceptable limit of 45 dB during the nighttime. However, due to ongoing power outages within South Africa, many depend on generators to maintain operation of their business and households. Therefore, a noise reduction mechanism has been designed for commercial use, whereby shown to reduce the acoustic levels of small petrol generators to roughly 37 dB at the exhaust outlet. This sound attenuation is due to the use of 50 mm thick rockwool porous absorber sheets, metal perforated sheets with a perforation diameter of 10mm and centre-to-centre distance of 16mm, along with fan and ventilation covers which reduce noise from inlet and outlet points along the mechanism.

Furthermore, extreme temperatures render a generators ability to perform and function effectively, therefore, using an axial fan which produces 117 CFM, and passive ventilation slots, the heat within the mechanism can be regulated at between 90 ˚C and 60 ˚C, which is within an acceptable temperature range.

The results from the experimental validation proved that the enclosure could reduce the noise levels. Which falls in line with the numerical model results. However, due to the budget constraints, which led to change in materials used, affected the noise level results. The muffler included in the numerical model reduced the noise level down by a further 20 dB. However, the physical model had better temperature control which kept the engine temperature below 50 °C. This could be due to weather effects and difference in materials used.

Several recommendations can be made with regards to the study which includes using more advanced flow simulating software, to effectively model time-dependent systems, and changing heat of the generator due to changing electrical loads. Finally, the flow simulation and assumptions were made for a noise reduction mechanism that is placed outdoors, and exposed to sunlight, further studies can be conducted for when the mechanism is kept indoors and not exposed to solar radiation conditions.

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