DEVELOPMENT OF A COMPOSITE NOISE MUFFLER FOR SMALL GENERATING SETS

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Abstract: Sound proof generating sets are normally associated with higher power output and it is costly. This is not commonly found in small generating sets as there are often acquired by low income earners and yet they desire the some comfort. This research focuses on the development of a new composite muffler for small generating sets. The design combined the principles of reactive and active noise reduction approach. The newly designed muffler was compared with an existing design and its performance evaluated. Performance tests show an improvement in terms of insertion loss and transmission loss and a reduction in back pressure build-up in the generating set. The average overall efficiency of the existing muffler is 43.28% whereas that of the newly designed composite muffler is 55.83%.The designed composite muffler provides the gasoline generating set with an additional noise reduction (attenuation) of 17.33 dB, reduced back pressure build-up of 3.6 kPa and improvement of 12.09% overall engine efficiency.

Keywords: Gasoline, generating sets, Muffler, noise, small.

1. Introduction

Gasoline generating sets, when operational, are generally identified with developing very loud noise. Sometimes, the noise of this rather very important and useful engine could be so much that it impedes normal hearing, thus becoming environmentally harmful and unfriendly to human ears. Noise is defined as an unpleasant sound produced at different frequencies. It has irregular vibration. Thus, noise is regarded as a sound or combination of sounds of constantly varying frequency and pitch. It is a term used to signify extraneous signals which do not covey useful information for the problem at hand [1].

As with any environmental hazard, control technology should aim at reducing noise to acceptable levels by action on the environment. Reduction of the noise can be typically solved by insulation at the noise source [2]. Such action involves the implementation of any measure that will reduce the noise being generated, and/or reduce the noise transmission through the air or through the structure of the environment (workplace). Such measures include modifications of the engine, machinery, the workplace operations, and the layout of the workroom/generating room. The best approach for noise hazard control in the environment is to eliminate or reduce the hazard at its source of generation, either by direct action on the source or on its confinement.

Therefore, the need to design a system to handle the reduction of the noise level developed by generating sets becomes important since noise is one of the environmental hazards. This noise control can be achieved with a well designed and constructed quieting or muffler Sound absorbing capacity of different materials suggest the potential application in construction of walls or sound barrier [3].Electricity generating plants are normally associated with noise and vibration which are unfriendly to human health and environment.[4].Besides, it also constitute a social menace of noise and air pollution by running the generating sets[5].Noise pollution has been shown to be a global health hazard and this could be worsen by the use of noise emitting generating sets[6]. Each of its stages requires decisions about the materials of which the product can be made. Often the choice of materials in design is dictated by performance, cost and availability. But sometimes it is the other way round: the new product, or the evolution of the existing one, was suggested or made possible by the new materials.

Most existing mufflers, which are commonly available for very big and industrial generating plants, are imported, thus very expensive [6]. So there is a need to design and construct a modified muffler for small gasoline generating sets (5Kw or less).

[7] Opined that good muffler in generating sets, other than harmful sound reduction of the waste exhaust gases, also boost the engine power, durability and fuel economy of the generating plant.

In this design the active and reactive method of noise reduction was used to provide sound proof (muffler) at a low cost for small generating set - Tiger TG950 gasoline ($950VA$) and its performance was evaluated.

2.0 Materials and Methods

The steps used in this research include: design, production and testing of the performance of the newly designed muffler. The newly designed muffler was later compared with the existing muffler of Tiger TG950 generating.

2.1 Design Calculations

The design calculations were done chamber by chamber for both the reactive and active muffling chamber.

The reactive chamber is divided into two separate rectangular compartments. Equation 1 below was used in its calculation.

$$\text{Rectangular volume} = l \times b \times h \tag{1}$$

where $l\ is\ the$ length, $b\ is\ the$ breadth and $h\ is\ the$ height.

Volumetric dimensions of each compartment $= (100 \times 100 \times 50)\mathrm{mm}^3$
$= 5.0 \times 10^{-5}\ \mathrm{m}^3$

Total reactive muffling chamber volume $= 2 \times 5.0 \times 10^{-5}\mathrm{m}^3$
$= 10.0 \times 10^{-5}\ \mathrm{m}^3$
$= 10^{-6}\ m^3$

This active muffler chamber is made up of the following components namely:

(i) Three bowel-shaped perforated pipes arranged in parallel but flow connections in series. Equation 2 presents the formula for determining the cross-sectional area of the pipe

$$\text{Cross-sectional area of pipe} = {}^{\pi \mathrm{d}^2}\!/_{4} \tag{2}$$

where $d\ is\ the$ pipe diameter (mm) and d= 12.7
Cross-sectional area of each pipe:$= 1.2669 \times 10^{-4}\mathrm{m}^2$

Active pipe length put together (for three pipes) $= 3 \times 60.0\ \mathrm{mm}$
$= 1.8 \times 10^{-1}\mathrm{m}$
Total active chamber volume $= 1.2669 \times 10^{-4}\ \times 1.8 \times 10^{-1}$
$= 2.2804 \times 10^{-5}\mathrm{m}^3$

Slotted cover box $= 200 \times 60 \times 50\mathrm{mm}^3$
$= 6.0 \times 10^{-5} \pm 0.002\ \mathrm{m}^3$

The energy loss due to friction as a result of pipe internal surface roughness was calculated using Darcy-Weisbach formula ([8] and [9] as given in Equation 3

$$h_f = {}^{4fLV^2}\!/_{2dg} \tag{3}$$

where, h_f $is\ the$ energy loss due to friction, f $is\ the$ coefficient of friction (a function of Reynolds number,Re), L $is\ the$ total length of pipe, V $is\ the$ mean velocity of flow, d $is\ the$ diameter of pipe and g $is\ the$ gravitational acceleration.

Meanwhile, the coefficient of friction was determined by the Reynolds relation presented in Equation 4 [10] and [9],

$$f = \frac{16}{Re} \text{ for } Re < 2000 \text{ or } f = \frac{0.0791}{Re^{1/4}} \text{ for } Re \text{ varying from } 4000 \text{ to } 10^6 \qquad (4)$$

For $Re < 2000$, the flow is laminar and or viscous and for Re varying from 4000 to 10^6, the flow is turbulence. However, for this study, laminar flow was used to minimize vibration that can increase the noise level.

To determine the velocity of gas flow, the flow rate or discharge formula was applied [11] and [12] as presented in Equation 5.

$$Q = AV(m^3/s) \qquad (5)$$

where, Q = flow rate or discharge, A = cross-sectional area and V = velocity of gas flow

$$Q = 3.3x10^{-3}\ m^3/s\ , = 1.266x10^{-4}\ m^2\ , \text{ therefore, } h_f = 1.65 \times 10^{-2}$$

Detailed sectional drawing of the composite muffler is shown in Figure. 1.

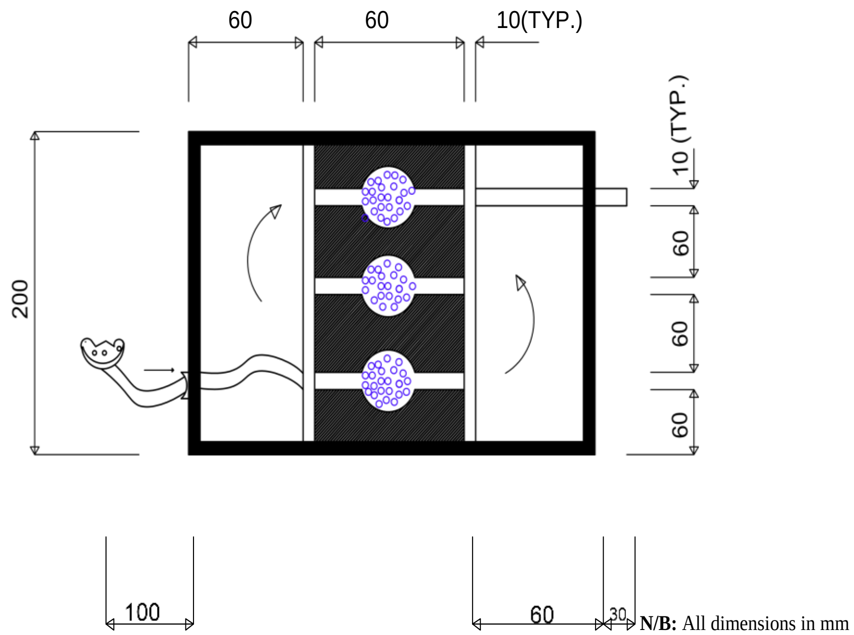

Figure. 1 Section of the designed composite muffler.

Aluminized steel sheet was chosen and used for casing and baffle walls, galvanized steel tubes used for inlet and outlet pipes and galvanized pipes for hanger to provide support between the muffler and the generating set. The materials were also easy to process by folding, welding, drilling and grinding operations.

The conducting pipes of different sizes in the muffler through which the hot waste exhaust gases enter and exit the exhaust muffler are made of aluminized steel tube. However, the portion of the pipe inside the muffler used was perforated tube having holes punched around the pipe to further help in attenuating the noise of the exhaust system.

Similarly, Figure. 2 shows the internals of the newly designed composite muffler

Figure.2 Transverse view of the internals of the newly designed composite muffler

The composite muffler is a combination of both the reactive and the active components as shown in the working drawings in Figure 3.

The reactive part is divided into two sections with an active component at the middle in between them. The reactive part has two pipes (inlet and outlet) and an air space, (also termed volume or capacity). Each capacity measures: $100\ \mathrm{mm}$ by$100\ \mathrm{mm}$ by $50\ \mathrm{mm}$ giving, a total capacity of $10^6\mathrm{mm}^3$.

It consists of the three under listed components:

(i) Three perforated pipes, each with a bowel-shaped design at its middle length and two throats, one as inlet pipe and the other as outlet pipe.
(ii) Sound absorbent (glass wool)
(iii) Slotted cover box

[13] and [14] asserted that though an exhaust pipe is a simple means of distributing the exhaust gases from the engine to an exit point (to the atmosphere), it also functions to support the muffler and the catalytic converter. Therefore, the galvanized steel pipe was used to provide support between the designed muffler and the generating set.

Glass fiber or glass wool is the sound absorbent and was used for sound insulation in the muffler.

A detailed part list of the newly designed composite muffler is shown in Table 1

Table 1: Part list

Part No.	Part Description	Part Off
1	Frame ($3\ \mathrm{mm}$ gauge)	1
2.	Exhaust pipes $\theta 18\ \mathrm{mm}$ (inlet), $\theta 20\mathrm{mm}$ (outlet), $1\ \mathrm{m}$ long each	1
3.	Baffle walls	3
4.	Hanger $\theta 10\mathrm{mm}$, $0.5\mathrm{m}$ long	1
5.	Glass fiber (Kg)	1
6.	M12 bolt	4
7.	M12Nut	5
8.	Washer	5
9.	Spacer	1
10.	Gasket	2

The existing Tiger TG950 generator muffler was opened transversely to expose the internals. Then, the arrangements of the internals of the newly designed muffler were designed, to overcome the shortcomings of the former. Whereas the existing Tiger TG950 generating set muffler is a reactive type, the newly designed muffler is a composite type; that is, a combination of reactive type and an active type. The muffler was produced using the materials detailed in Table 1. The sound pressure level of the exhaust gas and the gas flow rate were measured using sound level meter and flow meter respectively. The performance and efficiency tests were carried out in terms of the following:

(i) Insertion Loss (IL)
(ii) Transmission Loss (TL)
(iii) Back Pressure (BP)

[15] and [16]assert that insertion loss is defined as the difference between the acoustic powers radiated without and with a muffler fitted.

Before switching on the generating set, the microphone of the sound level meter was fixed properly, then mounted to a stand and kept at a distance of $1\ \mathrm{m}$ from the generating set whose sound pressure level was to be measured such that the microphone aligned with the exit pipe of the exhaust system of the generating set before being switched on. The background sound pressure level of the environment was first measured and recorded. Thereafter, the generating set was switched on and the sound pressure level of the exhaust gases produced by the generating set was measured and recorded in intervals of $10\ s$, starting from 0 to $90s$. In each case, three readings were taken, and the average calculated and recorded. A total of 10 readings were recorded.

Therefore, the sound pressure level with the muffler fixed, SPL_{wt} and the sound pressure level without the muffler fixed, SPL_{wo} were measured and recorded for the existing muffler. The same process was repeated for the newly designed composite muffler.

The insertion loss is given in Equation 6.

$$\mathrm{IL} = \mathrm{SPL_{wo}} - \mathrm{SPL_{wt}} \qquad (6)$$

where IL *is the* insertion loss, $\mathrm{SPL_{wo}}$ *is the* sound pressure level without muffler fitted, $\mathrm{SPL_{wt}}$ *is the* sound pressure level with muffler fitted.

Transmission loss is defined as the difference (in decibels) between the sound powers incident at the entry to the muffler to that transmitted out by the muffler [16] with the same set-up for insertion loss, but here the sound level meter adjusted to read wave intensity of the exhaust gases. The power of the incident waves just at the point of entering the muffler W_i was measured and recorded. Ten readings were recorded, in interval of $10\ s$, starting from $0 - 90\ s$. In each case three readings were taken, and then the average calculated and recorded. The same process was repeated for the waves transmitted out of (just leaving) the muffler, W_t. These processes were carried out for both the existing and the newly designed composite muffler.

Mathematically, transmission loss, is given by [17] and [16] in Equation 7.

$$\mathrm{TL} = 10 \log_{10} \left| \frac{\mathrm{W_i}}{\mathrm{W_t}} \right| \qquad (7)$$

where, TL *is the* transmission loss (dB), $\mathrm{W_i}$ *is the* the power of incident wave coming towards the muffler's inlet pipe($\mathrm{W/m^2}$) and $\mathrm{W_t}$ *is the* the power of transmitted wave leaving the muffler's exit pipe ($\mathrm{W/m^2}$).

The efficiencies of the two mufflers were calculated in terms of insertion loss, transmission loss and the overall efficiency.

(i) Insertion Loss Efficiency (η_{IL})
The insertion loss efficiency was calculated for both the existing and newly designed mufflers was calculated using Equation 8

$$\eta_{\mathrm{IL}} = \frac{\mathrm{SPL_{wo}} - \mathrm{SPL_{wt}}}{\mathrm{SPL_{wo}}} \times 100\% \qquad (8)$$

Similarly, Equation 9 presents the formula for calculating transmission loss for both the existing and newly designed muffler.

(ii) Transmission Loss Efficiency (η_{TL})

$$\eta_{TL} = \frac{W_i - W_t}{W_i} \times 100\% \quad (9)$$

The overall efficiency was obtained using Equation 10

$$\eta = \frac{\eta_{IL} + \eta_{TL}}{2} \quad (10)$$

where, (η_{IL}) and (η_{TL}) are insertion and the transmission loss efficiencies.

[18] and [16] maintain that back pressure represents the extra static pressure exerted by the muffling system on the engine through the restriction in flow of exhaust gases. The back pressure was measured in terms of mass flow rate of the exhaust gases. The flow meter was coupled in the first set-up to the exhaust manifold and in the second set-up to the exit pipe of the exhaust muffler using metal tubing. With the flow meter coupled, the generating set was switched on and the gas flow rate measured and recorded for the two set-ups, each for intervals of $20\ s$. Five readings were recorded for each set-up. In each case, three readings were taken, and then the average calculated and recorded. The measurement was taken for both the existing and the newly designed composite muffler.

To find out the engine exhaust back pressure the Equation 11 was used: [19], [20] and [16]:

$$\mathrm{BP} = (\mathrm{L} \times \varrho \times \mathrm{Q}^2 \times 3.6 \times 10^6)/(\mathrm{d}^5) + \mathrm{P_r} \quad (11)$$

where, BP *is the* back pressure (kPa), L is the length of pipe (m), ϱ is the density of gas ($\mathrm{Kg/m^3}$), Q is the exhaust gas flow rate ($\mathrm{m^3/s}$), d is the inside diameter of muffler pipe (m) and $\mathrm{P_r}$ is the muffler resistance (kPa).

2.2 Performance Tests

The following performance tests were performed according to standards:

(i) Actual sound pressure level (SPL) is measured sound pressure level minus background sound pressure level.
(ii) The distance between the noise source and the sound measuring instrument (sound level meter) was kept constant at one (1) meter throughout the experiments.
(iii) Muffler resistance was determined in terms of volume flow rate of exhaust gas into and out of the muffling systems.
(iv) The efficiency of the generating set (new) - (Tiger$TG950$) used for conducting the performance tests was assumed to be 100%.
(v) Frequency values were obtained from the inverse relation with time.

Figure. 3 shows the experimental set-up to determine the noise from generating set with existing and newly designed composite muffler.

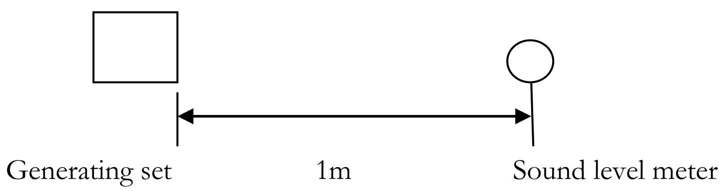

Figure3 : Experimental set-up to measure noise from the generating set

3.0 Results and Discussion

3.1 Results

Table 2 and Table 3 show the results of the insertion loss for both the existing muffler and newly designed composite muffler. The insertion loss was calculated using Equation 6.

Table 2: Insertion loss test for Tiger TG950 existing muffler

S/N	Time t (s)	Frequency f (Hz) $\times 10^{-4}$	Sound Pressure Level Without Muffler SPL_{wo} (dB)	Sound Pressure Level With Muffler SPL_{wt} (dB)	Insertion Loss IL (dB)
1.	0.0	0.0	30.0	30.0	0.0
2.	10.0	1000.0	106.4	71.3	35.1
3.	20.0	500.0	108.5	74.3	34.2
4.	30.0	333.3	109.0	71.6	37.4
5.	40.0	250.0	109.8	74.9	34.9
6.	50.0	200.0	110.7	79.0	31.7
7.	60.0	166.7	107.3	72.3	35.0
8.	70.0	142.9	108.5	73.0	35.5
9.	80.0	125.0	110.4	71.8	38.6
10.	90.0	111.1	108.9	74.6	34.3
$\sum_{1}^{10} / n$			100.95	69.28	31.67

Table 3: Insertion loss test for the newly designed composite muffler

S/N	Time □ (□)	Frequency □ (Hz) $\times 10^{-4}$	Sound Pressure Level Without Muffler SPL_{wo} (dB)	Sound Pressure Level With Muffler SPL_{wt} (dB)	Insertion Loss IL (dB)
1.	0.0	0.0	30.0	30.0	0.0
2.	10.0	1000.0	105.8	52.4	53.4
3.	20.0	500.0	109.3	53.3	56.0
4.	30.0	333.3	108.9	56.2	52.7
5.	40.0	250.0	110.3	54.2	56.1
6.	50.0	200.0	111.0	58.7	52.3
7.	60.0	166.7	109.4	53.0	56.4
8.	70.0	142.9	110.7	54.7	56.0
9.	80.0	125.0	109.1	54.6	54.5
10.	90.0	111.1	108.3	55.7	52.6
$\sum_{1}^{10} / n$			101.28	52.28	49.00

Table 4 and Table 5 show the transmission loss test for both the existing muffler and the designed composite muffler for Tiger TG950 generating set. The transmission loss was calculated using Equation 7.

Table 4: Transmission loss test for the existing muffler

S/N Time Frequency The Power of The Power of Transmission

	t (s)	f (Hz) $\times 10^{-4}$	Incident Wave Entering the Muffler W_i (W/m^2)	Transmitted Wave Leaving the Muffler W_t $\times 10^{-1}$ (W/m^2)	Loss TL (dB)
1.	0.0	0.0	30.0	30.0	0.0
2.	10.0	1000.0	113.3	48.5	36.8
3.	20.0	500.0	112.9	46.9	38.2
4.	30.0	333.3	111.2	50.1	34.6
5.	40.0	250.0	114.2	49.2	36.6
6.	50.0	200.0	115.4	47.6	38.5
7.	60.0	166.7	113.8	51.0	34.9
8.	70.0	142.9	114.1	50.7	35.2
9.	80.0	125.0	110.7	45.8	38.3
10.	90.0	111.1	111.0	49.3	35.2
$\sum_{1}^{10} / n$			104.66	46.91	32.83

Table 5: Transmission loss test for the newly designed composite muffler

S/N	Time t (s)	Frequency f (Hz) $\times 10^{-4}$	The Power of Incident Wave Entering the Muffling System W_i (W/m^2)	The Power of Transmitted Wave Leaving the Muffling System W_t $\times 10^{-1}$ (W/m^2)	Transmission Loss TL (dB)
1.	0.0	0.0	30.0	30.0	0.0
2.	10.0	1000.0	117.7	41.5	45.3
3.	20.0	500.0	121.6	40.2	48.1
4.	30.0	333.3	120.1	44.1	43.5
5.	40.0	250.0	115.9	46.2	39.9
6.	50.0	200.0	118.3	41.7	45.3
7.	60.0	166.7	119.7	39.5	48.2
8.	70.0	142.9	116.8	38.8	47.9
9.	80.0	125.0	122.1	40.3	48.1
10.	90.0	111.1	120.2	42.6	45.1
$\sum_{1}^{10} / n$			110.24	40.49	41.14

The results of back pressure for both the existing muffler and the newly designed composite muffler are shown on Table 6. This was determined using Equation 11.

Table 6 shows the back pressure for the existing and the newly designed composite muffler

Table 6: Back pressure test for both the existing muffler and the designed composite muffler

S/N	Material Properties/ Parameters	Existing Muffler	Designed Composite Muffler
1.	Length L (m)	28.1	16.8
2.	Density ρ (Kg/m^3)	1.98	1.98
3.	Flow rate Q (m^3/s)	33.7×10^{-3}	32.4×10^{-3}
4.	Inside diameter d (m)	12.7×10^{-3}	12.7×10^{-3}
5.	Muffler resistance P_r (kPa)	12.9	10.3
	Back Pressure BP (kPa)	33.7	30.1

With an average sound pressure level without muffler SPL_{wo} =100.95db and sound pressure level with muffler =69.28db, for the existing muffler, using Equation 8 η_{IL}= 31.37%. Similarly, for the newly designed composite muffler, SPL_{wo}=101.28Db, SPL_{wt}=52.dB, $\eta_{IL} = 48.38\%$

For the existing muffler, $W_i = 104.60dB, W_t = 46.91dB$, using Equation 9, $\eta_{TL} = 55.18\%$. For the newly designed composite muffler, $W_i = 110.24dB, W_t = 40.49dB$ and $\eta_{TL} = 63.27\%$.

The overall efficiencies using Equation 10 are 43.28% for existing muffler and 55.83% for the newly designed composite muffler...

The performance and efficiency of both the existing muffler and the newly designed composite muffler for the Tiger TG950 Model generating set were fully tested in respect of the performance parameters including insertion loss, transmission loss and back pressure.

The comparison of insertion loss and Transmission loss of the existing and the newly designed composite muffler are presented in Figure.4 and Figure.5 respectively.

Figure.4 Comparison of insertion loss of the existing and the newly designed composite muffler

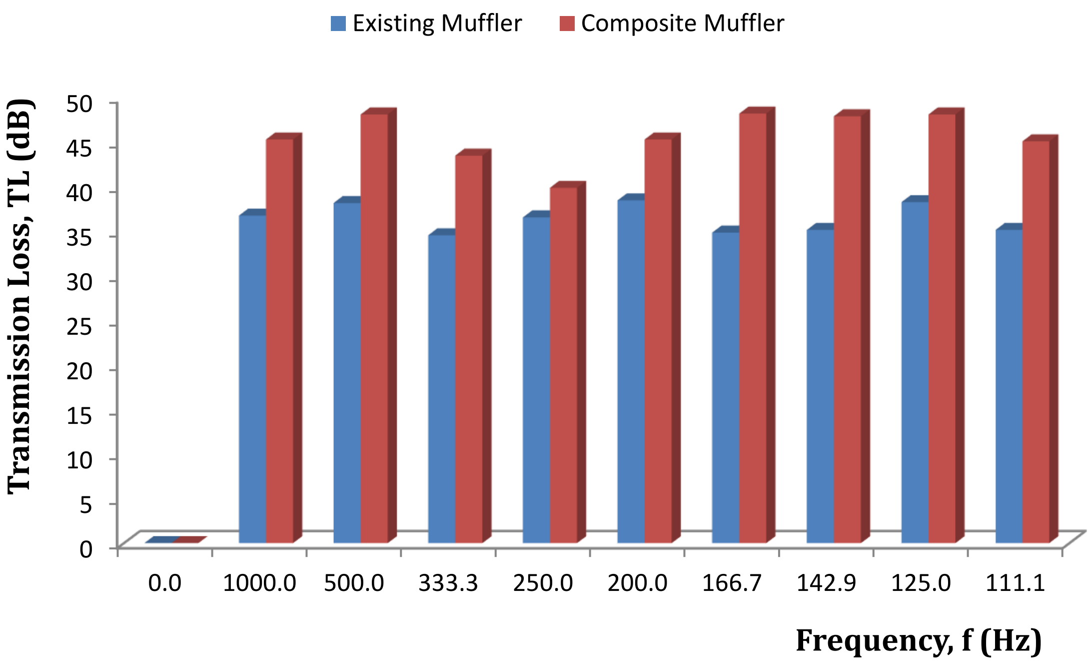

Figure. 5 Comparison of transmission loss of the existing muffler and the newly designed composite muffler

Figure.6 shows the effect of exhaust gas flow rate on back pressure of exiting and newly designed composite muffler.

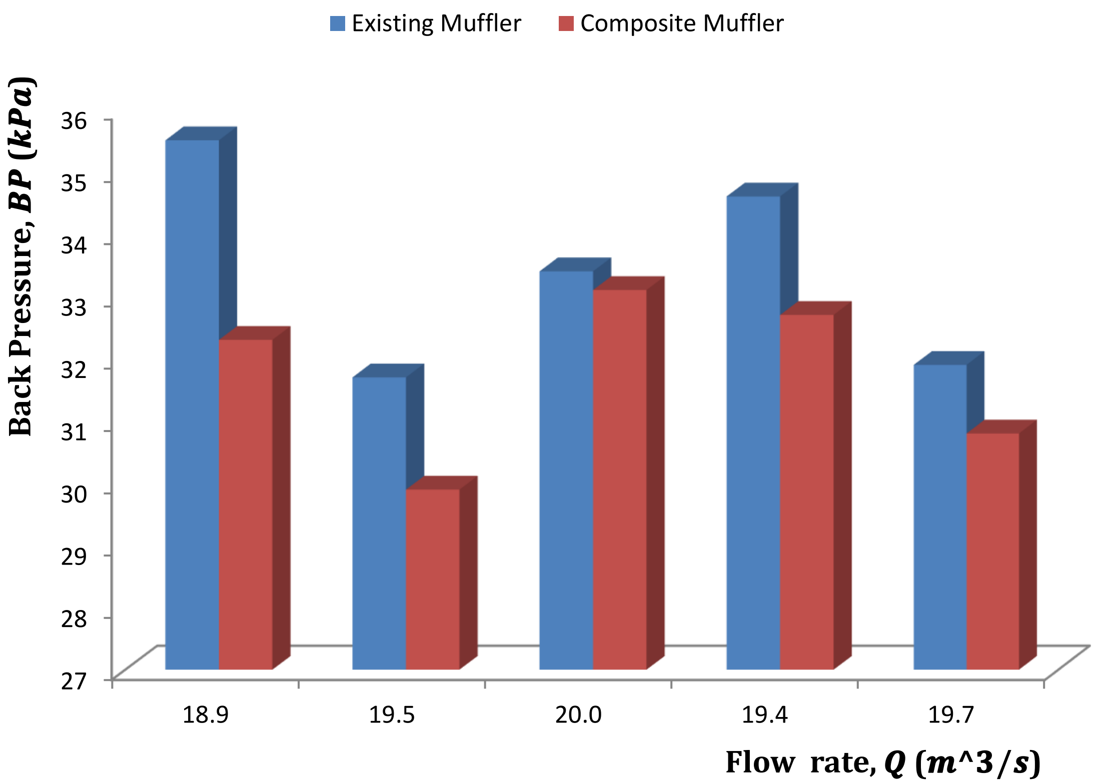

Figure.6 Effect of exhaust gas flow rate on back pressure of exiting and newly designed composite muffler

3.2 Discussion of Results

Table 2 shows the changes in insertion loss for the existing muffler, from zero time to 90 seconds. The insertion loss changed with time and gives an average of 31.67dB. When the newly designed composite muffler was fitted the insertion loss was 49.00ddB as shown in Table 3.The results obtained were compared and presented muffler in Figure.4. Table 3 and Table 4 show the transmission loss of the existing muffler and the newly designed composite muffler. The existing muffler has a transmission loss of 32.83dB, while the newly designed composite muffler has a transmission loss of 41.14dB. Figure 6 shows the comparison of the two mufflers. In both Figure.4 and Figure.5, the newly designed composite muffler performs better than the existing muffler. This implies that the newly designed muffler has further attenuated the noise of the generating set by 17.33 dB. The more the insertion loss, the more is the efficiency of the muffler.

The results in Table 6 shows that the newly designed composite muffler has a better sound attenuation power because sound attenuation in mufflers is directly proportional to transmission loss and a good muffler should have a high transmission loss [16].

Back pressure is a negative property of a muffler. Good mufflers are designed such that back pressure is kept at a minimum in other to improve the efficiency of the generating set. The results from back pressure tests show that the existing muffler has an average back pressure of 33.7 kP and that of the newly designed composite muffler is 30.1 kPa .With a lower value of back pressure, it indicates that the produced muffler will make the generating set more efficient since increase in back pressure implies decrease in power output and increased fuel consumption. According to [21], back pressure is a negative characteristic of a muffler; hence, a good muffler should have very low back pressure.

In order to obtaine detailed analysis of the system performance efficiency, the calculation of the system efficiency was carried out in three perspectives namely; the insertion loss efficiency, the transmission loss efficiency and the overall system efficiency.

The results show that the existing muffler has respectively insertion loss, transmission loss and an average overall efficiency of 31.37%, 55.18%and43.28%. The corresponding values for the newly designed composite muffler are 48.38.86%, 63.27%and 55.83%. It follows that the newly designed composite muffler has 12.09% increased efficiency in noise attenuation power compared to the existing muffler. Therefore, the newly designed composite muffler desires attention.

Figure.7 shows the graphical representation of the evaluation parameters for the mufflers.

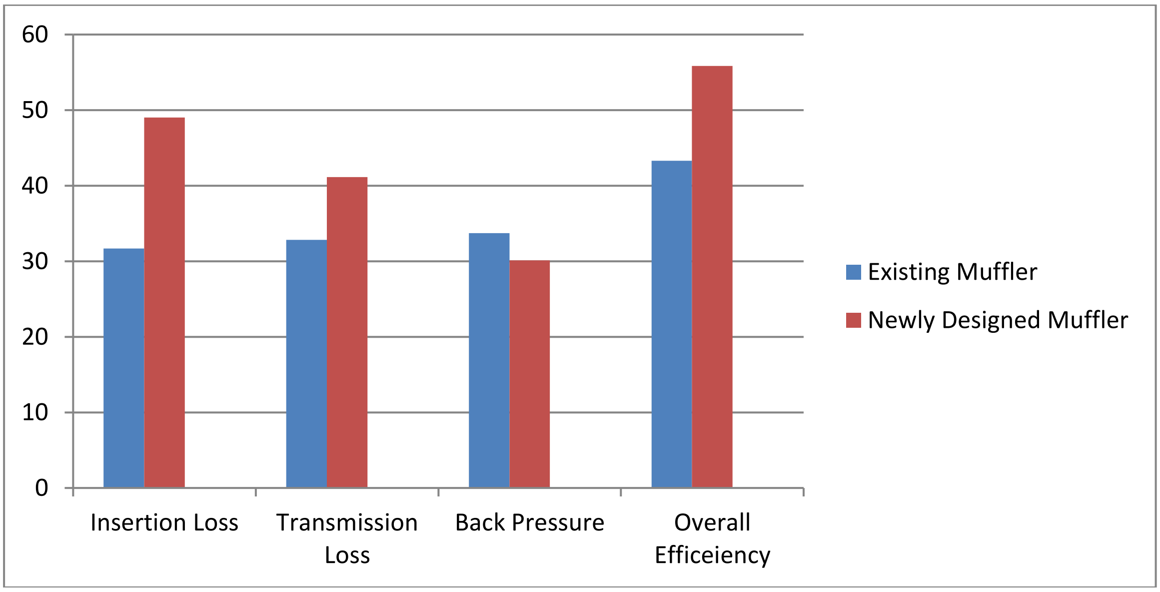

Figure.7 Graphical representation of the evaluation parameters for the mufflers

4.0 Conclusion

The conclusions made from this research are:

1. The newly designed composite muffler for the gasoline generating set has reduced the noise level by 26.4 dB.
2. The average overall efficiency of the existing muffler is 43.28% whereas that of the designed Composite muffling system is 55.83%.
3. The designed composite muffler has provided the gasoline generating set with an additional noise reduction (attenuation) of, reduced back pressure build-up of 3.6 kPa and improvement of 12.09% overall engine efficiency. Hence, with the newly designed composite muffler of the gasoline generating has an optimized overall efficiency.
4. Further research should be carried out by using new materials for the muffler that could enhance further noise reduction.

Conflicting Interest

"The authors declare no conflict of interest."

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