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Experimental Investigation for the effect of Inlet & Outlet Pipe Lengths on Noise Attenuation in a Muffler

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Abstract

With the increase use of large industrial machinery (such as huge generators) and the increase in public awareness and concern for noise control the desire to be able to properly design a silencer for specific application is increasing. A test rig is built for a reactive muffler. The object is to minimize the noise level using different pipe lengths for inlet and outlet (discharge) tubes are studied. The major conclusion was that the taller outlets pipe the higher noise attenuation will be obtained.

دراسة عملية لتأثير اطوال أنابيب الإدخال والإخراج على تخفيض الصوت في كاتم

الملخص

مع تزايد استخدامات المكائن الصناعية الكبيرة (كالمولدات الكهربائية الضخمة) وكذلك مع تزايد القلق العام والاهتمام بالسيطرة على التلوث الصوتي، لذا تولدت الحاجة لتصميم كواتم ذات المواصفات الخاصة. تم بناء نموذج كاتم من النوع التفاعلي وتم استخدام أطوال مختلفة لأنابيب الإدخال والإخراج للكاتم لغرض دراسة تأثيرها في تخفيض مستوى الصوت وكان من اهم الاستنتاجات ان زيادة طول انبوب الاخراج يؤدي إلى زيادة في تخفيض (كتم)الصوت.

1. Introduction:

Traffic noise is a form of environmental pollution, and is the collective sound energy emanating from vehicles such as cars, trucks and motorcycles. As the population grows, there is increasing levels of traffic noise and greater exposure to it. This has been profound in public health implications. The World Health Organization has documented seven categories of adverse health effects of environmental noise pollution on humans. It has become a recognized health issue in society. This is because traffic noise is the largest form of environmental noise pollution. It poses the largest threat to one’s health in terms of the adverse effect of pollution [1].Engine exhaust noise is controlled through the use of silencers and mufflers. Industrial mufflers, (and mufflers in general), attenuate noise by two fundamentally different methods. The first method, called reactive attenuation - reflects the sound energy back towards the noise source. The second method is absorptive attenuation which absorbs sound by converting sound energy into small amounts of heat. There are three basic industrial muffler types which use these methods to attenuate facility noise. These are reactive silencers, absorptive silencers and anyone or both of them combined with resonator.

Internal combustion engine is a major source of noise pollution. These engines are used for various purposes such as, in power plants, automobiles, locomotives, and in various manufacturing machineries. The noise is caused either by pulses which created when an exhaust valve opens and a burst of high pressure gas suddenly enters the exhaust system or by the friction of various parts of the engine. The exhaust noise is the most dominant. The limitation of the noise is caused by the exhaust system which is accomplished by the use of silencers and mufflers.

Pulses are released by the exhaust are the cause of engine noise. When the expansion stroke of the engine comes near the end, the outlet valve opens and the remaining pressure in the cylinder discharges exhaust gases as a pulse into the exhaust system. These pulses are between 0.1 and 0.4 atmosphere in amplitude, with pulse duration between 2 and 5 milliseconds. The frequency spectrum is directly correlated with the pulse duration. The cut-off frequency lies between 200 and 500 Hz. Generally, engines produce noise of 100 to 130 dB depending on the size and the type of the engine.

In general, sound waves propagating along a pipe can be attenuated using either a dissipative or a reactive muffler. A dissipative muffler uses sound absorbing material to take energy out of the acoustic motion in the wave, as it propagates through the muffler. Reactive silencers, which are commonly used in automotive applications, reflect sound waves back towards the source and prevent sound from being transmitted along the pipe. Reactive silencer design is based on either the principle of a Helmholtz resonator or an expansion chamber, and requires the use of acoustic transmission line theory.

Two typical reactive muffler designs are considered. The first in Figure (1), is frequently chosen because of its low cost and because it causes a lower back pressure. The second design is shown in Figure (2), provides more attenuation and is typical of the design recommended by muffler manufacturers. However there is no direction connection between the inlet and the outlet so, back pressure is generated that can affect engine performance. This is sometimes referred to as a baffled muffler design.

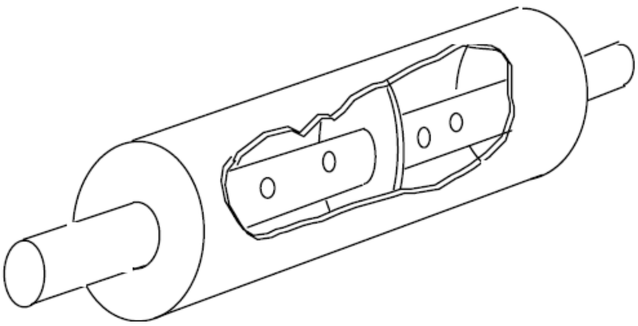


Figure (1): Schematic diagram of a reactive muffler with two cavities and no flow restriction

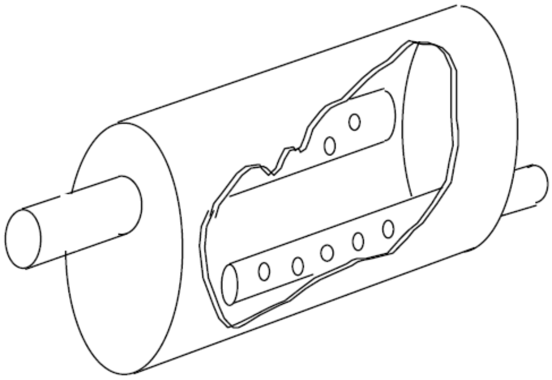


Figure (2): Schematic diagram of a typical reactive muffler in which there is no direct passage between the inlet and the exit

An investigation of most effective means for reducing noise by changing the design of muffler is held in **[2]**. But, muffler requires specific design and construction considering various noise parameters produced by the engine. The conventional design does not include much of a parametric noise analysis or other engine characteristics. A muffler for stationary petrol engine has been designed and manufactured. The performance characteristics, i.e. noise reduction capability of the muffler, has been tested and compared with that of the conventional muffler. The result has been found to be quite satisfactory.

The acoustic performance of a reactive silencer using Boundary Element Method analysis and experimental techniques has been investigated **[3]**. This analysis addresses a research topic of major interest today on how to reduce noise pollution due to vehicles, or pressure vessels of various machinery and equipment involving air ejection as a result of various processes or urban expansion.

Modeling procedures for accurate performance prediction had led to the envelopment of new methods for practical muffler components in design. The transmission loss (TL) is the more widely can be easily computed with a Boundary Element Method analysis. **Ovidiu** present an overview of the principles of Boundary Element Method for predicting the transmission loss (TL) of a muffler with two expansion chamber, the pressure distribution on surfaces of muffler and compared with the acoustic performances of the experimental set up. The predicted results agreed in some limits with the experimental data.

A broadband feed forward Active Noise Control (ANC) system that has a reference sensor has been studied **[4]**. single secondary source, and single error sensor. The main reason is related to the adaptation algorithms to the active noise control for small-diameter exhaust system. A modification of the well-known LMS algorithm, the filtered-X LMS algorithm, is presented. Contrasts between passive and active noise control are described.

A test rig for a reactive muffler has been built by **Muthana Al-Doory, Muna Kassim and Ehsan Al-Ameen [1]**. Different orifice shapes are used with the same area to study the effect of the orifice shape on noise reduction. Also the effect of the number of orifices in one plate and multi plate is discussed.

In all muffler designs the tail pipe length can have an important effect. The tailpipe itself acts as a resonant cavity that couples with the muffler cavity. The attenuation characteristics of a muffler are modified if the design tailpipe is not used. Also, the effect of exhaust gas flow speed has a detrimental effect on the muffler performance. In this paper, In order to minimize the noise level, different pipe lengths of inlet and outlet (discharge) tubes are studied with a specific diameter.

2. Theoretical Calculations:

Sound speed which is the speed of propagation sound wave through the given medium is calculated as follows:-

$C = \sqrt{(\gamma p/\rho)}$ ....(1)

$\gamma = C_p/C_v$: the ratio of air density at constant pressure to constant volume.

"for air γ=1.4"

ρ =density (kg/m^3) =1.21 kg/m^3 for air

C=sound speed=343 (m/sec) at 20 °C at Atmospheric pressure.

In general the diameter of the inlet pipe is taken same as the diameter of the exhaust port of the engine. The length of the inlet pipe is taken as small as possible so that muffler will occupy less space. There is no specific procedure for designing inlet pipe of the muffler. The outlet pipe (also termed as tail pipe) dimensions are same as that of the inlet pipe.

With regard to expansion chamber which is of reactive type. It is most effective at low frequencies. i.e. less than 500 c/s with a ratio of expansion chamber area to inlet pipe area m=10 [5] where

$$m = \frac{area\ of\ expansion\ chamber}{area\ of\ inlet\ pipe}$$

$$m = \frac{\frac{\pi}{4} D^2}{\frac{\pi}{4} d^2} = \frac{D^2}{d^2} \text{..........} (2)$$

D=Diameter of the expansion chamber (15.3 cm)
d=Diameter of the inlet pipe (4.7 cm)

with regard to wave in pipe and assuming that at some point x=0 along pipe the acoustic impedance changes from ρ c/s to $Z_o$if a wave travels in the positive x direction then the pressure and peak particle velocity are represented by Ford [6] and Lawrence [8]:

$$P_i = A\, e^{j(wt-kx)} \text{ ....} (3a)$$

$$U_i = P_i / \rho c/s$$

Is incident at this point, a reflected wave

$$P_r = B e^{j(wt+kx)} \text{ ....} (3b)$$

$$U_r = -P_r / \rho c/s$$

Traveling in the negative x direction will be produced given the impedance Z observed at x=0, we can solve for the power reflection and transmission efficient. Since the acoustic impedance Z at any point in the tube is given by Lawrence [8] as inequation (4).

$$Z = \frac{P_i + P_r}{U_i + U_r} = \frac{\rho C}{S} * \frac{A e^{-jkx} + B\, e^{jkx}}{A e^{-jkx} - B\, e^{jkx}} \text{..........} (4)$$

So, at x=0

$$Z_o = \frac{\rho C}{S} * \frac{A+B}{A-B} \text{ ....} (5)$$

Solving for the ratio B/A, equation (6) is obtained

$$\frac{B}{A} = \frac{Z_0 - \rho C/S}{Z_0 + \rho C/S} \quad \text{.......... (6)}$$

For example, applying these equations to plane wave in a pipe of cross section area S_1as it enter a second pipe of area S_2, as shown in figure (3).The second pipe is either of infinite length or so terminated that no reflected wave is returned from its far end. when the wave length is large compared to the diameters of the pipes, it may assumed that the spatial extent (along the axis of the pipe) of the complicated flow that accompanies the adjustment of the wave from one cross sectional to the other is small compared to a wave length so that the acoustic impedance seen by the wave incident on the junction is $Z_o=\rho c/s_2$, the acoustic impedance of plane wave in the second pipe. By substituting this expression into the general equation (6) then equation (7) is obtained.

$$\frac{B}{A} = \frac{\rho c/s_2 - \rho c/s_1}{\rho c/s_2 + \rho c/s_1} = \frac{s_1 - s_2}{s_1 + s_2} \quad \text{...................... (7)}$$

The power reflection coefficient is

$$\alpha_r = \frac{W_r}{W_i} = \frac{|B|^2 / 2\rho c/s_1}{|A|^2 / 2\rho c/s_1} = \left|\frac{B}{A}\right|^2 \quad \text{........................ (8)}$$

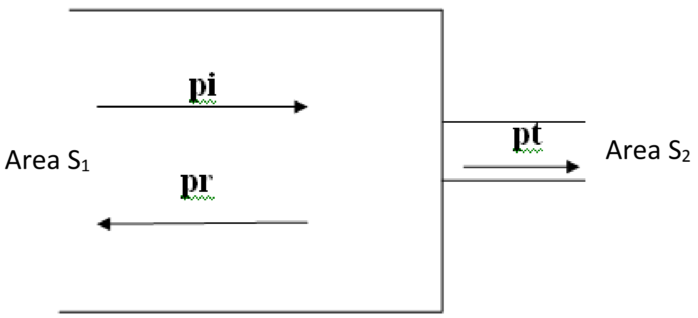


Figure (3): Two connected pipes with cross section area S_1 and S_2.

$$\alpha_r = \frac{(s_1 - s_2)^2}{(s_1 + s_2)^2}$$

$$T_c = 1 - \alpha_r$$

The Transmission Losses (TL) calculated as in references [5 & 7]

$$TL = log_{10}\left[1 + 0.25 * \left(m - \frac{1}{m}\right)^2 sin^2 kl\right] \ldots\ldots\ldots.(9)$$

Where

(ω) is angular velocity $\omega = 2\pi f$

(k) is number of waves$K = \frac{\omega}{c}$

(L) Length of expansion chamber (24cm)

(C) Sound speed (343 m/s)

Also transmission coefficient (Tc) derived in equation (10) by William [7].

$$Tc = \frac{4}{[4\cos^2 kl + (m + \frac{1}{m})^2 \sin^2 kl]} \ldots\ldots\ldots\ldots\ldots\ldots.(10)$$

With regards to theoretical results, table (1) shows the theoretical calculation for transmission losses and transmission coefficient for frequency ranged (50- 500 step 50).

Table (1) Theoretical results

Hz	KL	TL	TC
50	0.219	3.635	0.94
100	0.439	7.7732	0.8
150	0.659	10.545	0.65
200	0.879	12.39	0.51
250	1.099	13.589	0.4
300	1.319	14.286	0.32
350	1.538	14.55	0.26
400	1.758	14.450	0.21
450	1.978	13.84	0.33
500	2.198	12.798	0.15

3. Experiment Parts arrangement and Procedure:

The experimental rig shown in figure (4) contains:

1- A Hewlett Packard function generator (figure 5) to generate sound signal with different frequencies (0-1000) Hz for three types of functions.
2- Signal amplifier
3- Loud speaker. (8 inch in size)
4- Box: contains the loud speaker, with insulated inner surface to prevent the sound reflection.
5- Cone: to connect the box with the pipes and force the sound to pass in one passage.
6- Pipes with different lengths (10cm, 20cm, and 30cm) (figure7) to be used as:
    a. Inlet pipes to connect the speaker box with the silencer.
    b. outlet pipes to connect the silencer with the sound level meter.
7- The reactive silencer (muffler) (Figure 8).
8- Sound level meter placed at the output pipe end to measure the amount of (SPL) (figure9).

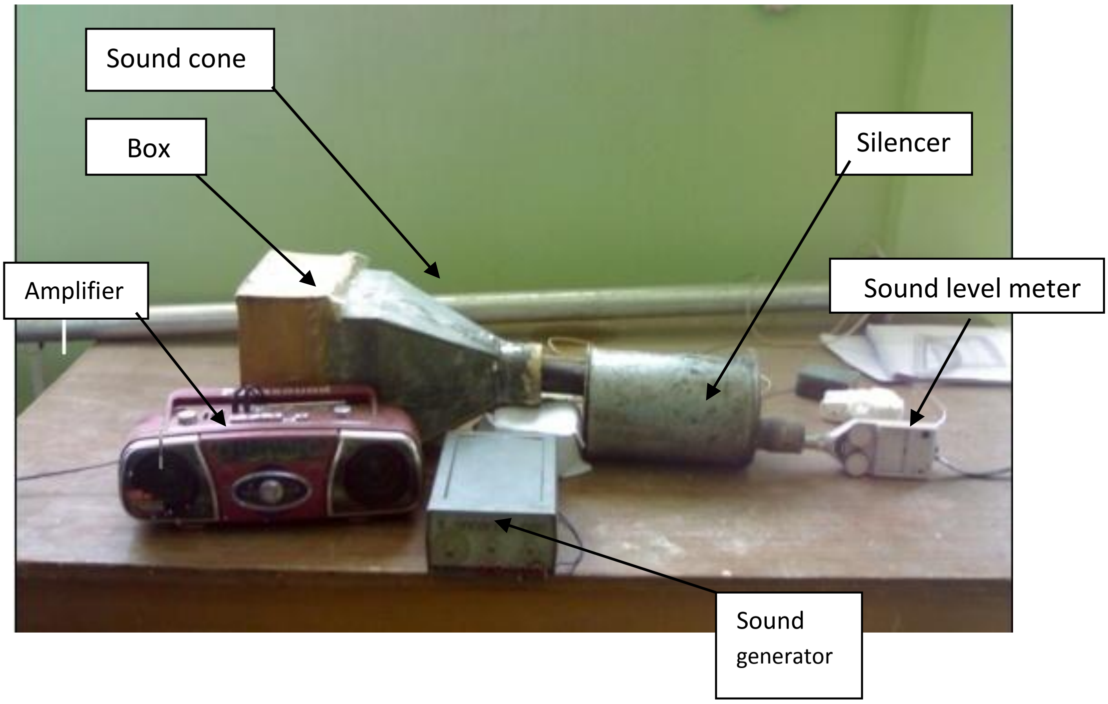


Figure (4): Arrangement of the test parts

Figure (5): Function generator

Figure (6): The Box and Cone

Figure (7): inlet and outlet pipes

Figure (8): The silencer

Figure (9): Sound level meter

The function generator (which generates the sound) is connected to the amplifier to amplify the waves to the speaker (the sound output). Then it is connected to the insulated box then the cone .The reactive silencer attached to the cone end by the sample pipes and the sound level meter is placed at the end of the outlet sample pipe. The (SPL) for each sample is measured. The signal generator turned on to give input signal with frequency range from (50 to 500) Hz and measure the SPL for each frequency.

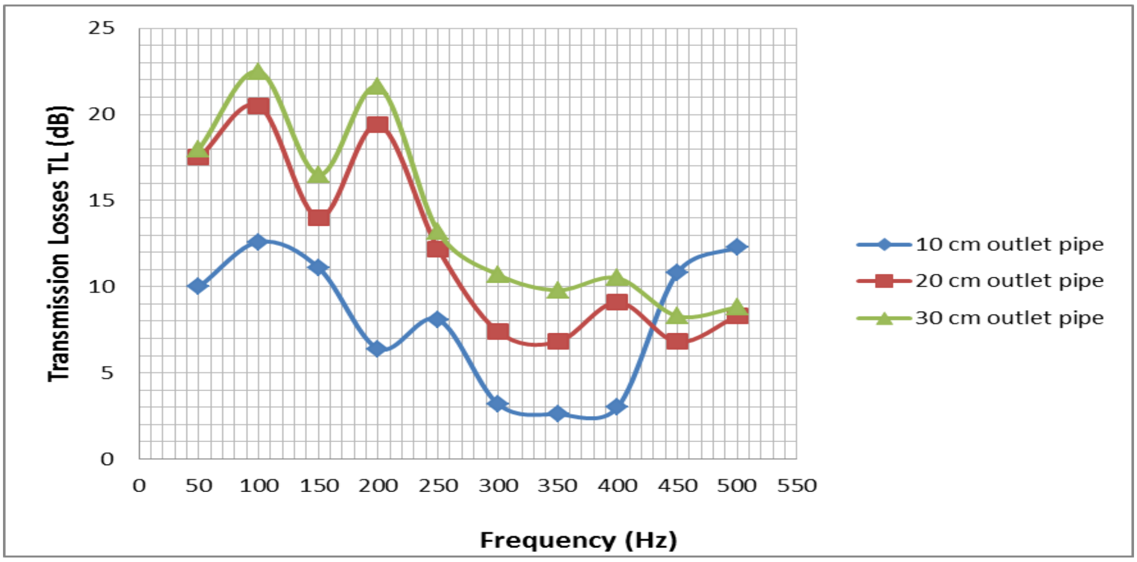
4. Experimental Results

The experimental results are the recorded values of transmission losses (TL) which equal the difference between SPL_1 (sound pressure level) and SPL_2 at inlet and outlet ends respectively, and to find values of transmission coefficient (Tc) which is equal to $(\frac{SPL_2}{SPL_1})$. these values are illustrated as charts to specify the maximum values for different pipe lengths. These charts are shown in figures 10 to 15 as follows

Figure(10) shows the TL results for the case of inlet pipe length = 10 cm and outlet pipe =10, 20 and 30 cm.

Figure(11) shows the TL results for the case of inlet pipe length = 20 cm and outlet pipe =10, 20 and 30 cm.

Figure(12) shows the TL results for the case of inlet pipe length = 30 cm and outlet pipe =10, 20 and 30 cm.
Figure(13) shows the TC results for the case of inlet pipe length = 10 cm and outlet pipe =10, 20 and 30 cm.
Figure(14) shows the TC results for the case of inlet pipe length = 20 cm and outlet pipe =10, 20 and 30 cm.
Figure(15) shows the TC results for the case of inlet pipe length = 30 cm and outlet pipe =10, 20 and 30 cm.



Figure(10):TL Vs. Frequency for 10 cm inlet pipe & different outlet pipe length

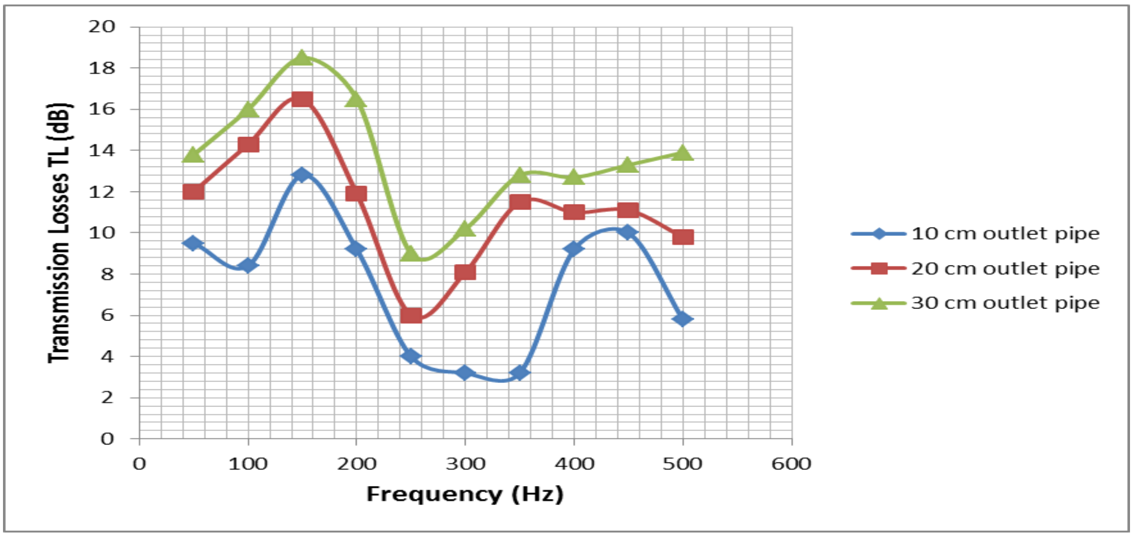


Figure (11):TL Vs. Frequency for 20 cm inlet pipe & different outlet pipe length

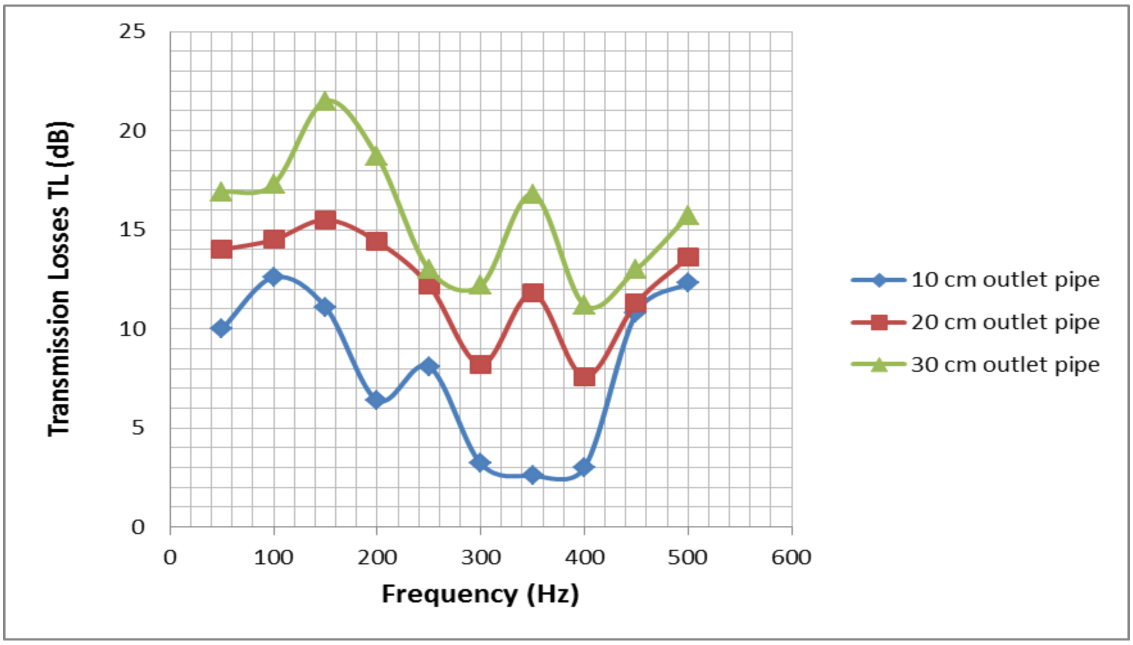


Figure (12):TL Vs. Frequency for 30 cm inlet pipe & different outlet pipe length

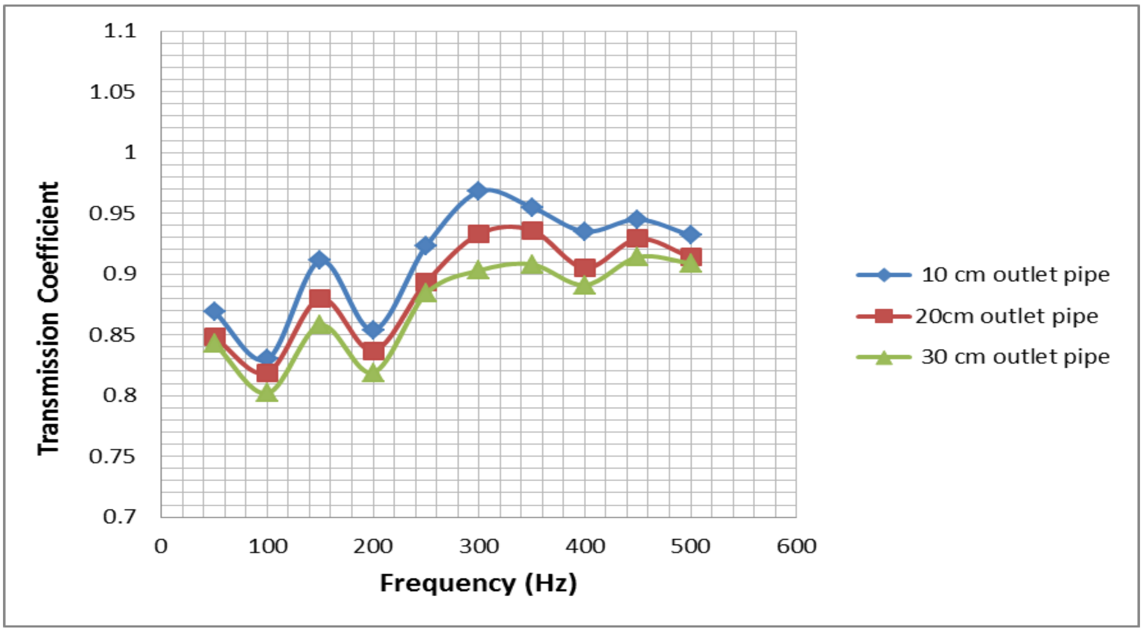


Figure (13):TC Vs. Frequency for 10 cm inlet pipe & different outlet pipe length

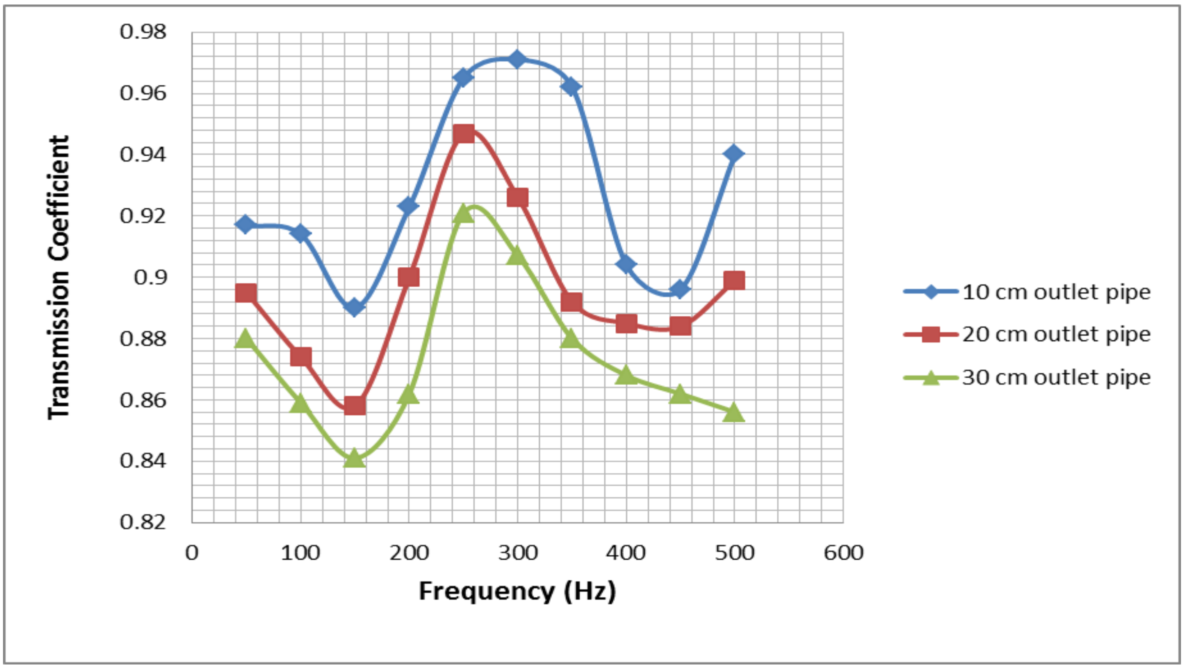


Figure (14):TC Vs Frequency for 20 cm inlet pipe & different outlet pipe length

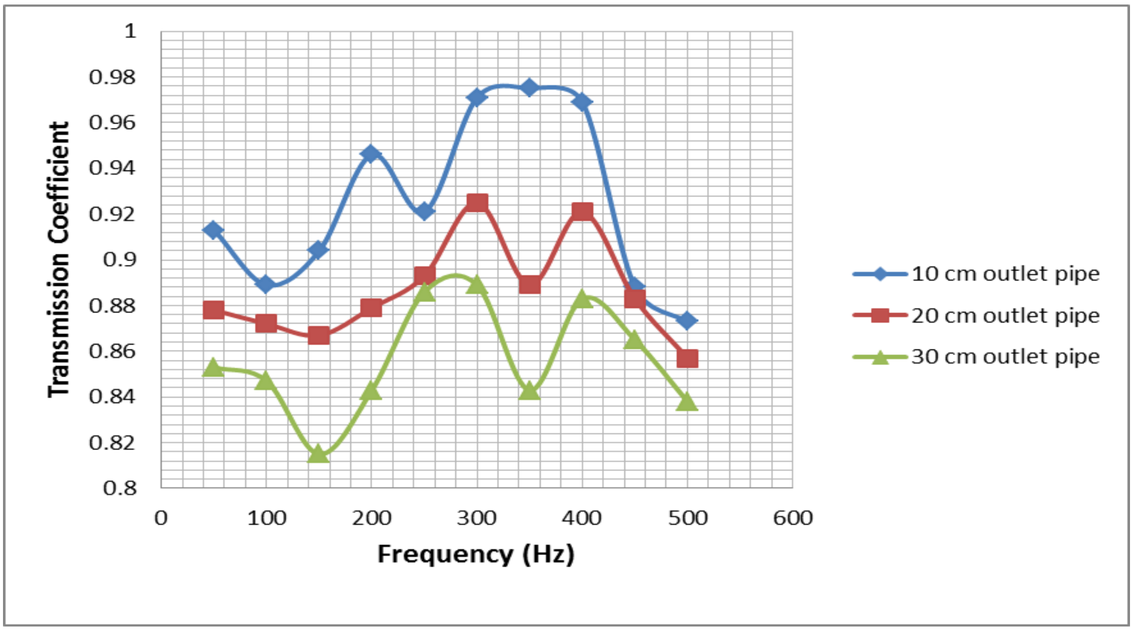


Figure (15):TC Vs Frequency for 30 cm inlet pipe & different outlet pipe length

Figures (16 & 17) show the relation between the frequency and the theoretical transmission losses, and transmission coefficient respectively. The maximum losses 14.55 dB occur at the frequency 350Hz and the minimum losses occur in frequency 50Hz is 3.635 dB. And the Maximum value of transmission coefficient at 50 Hz is 0.94 while the minimum value is 0.15 at 500Hz.

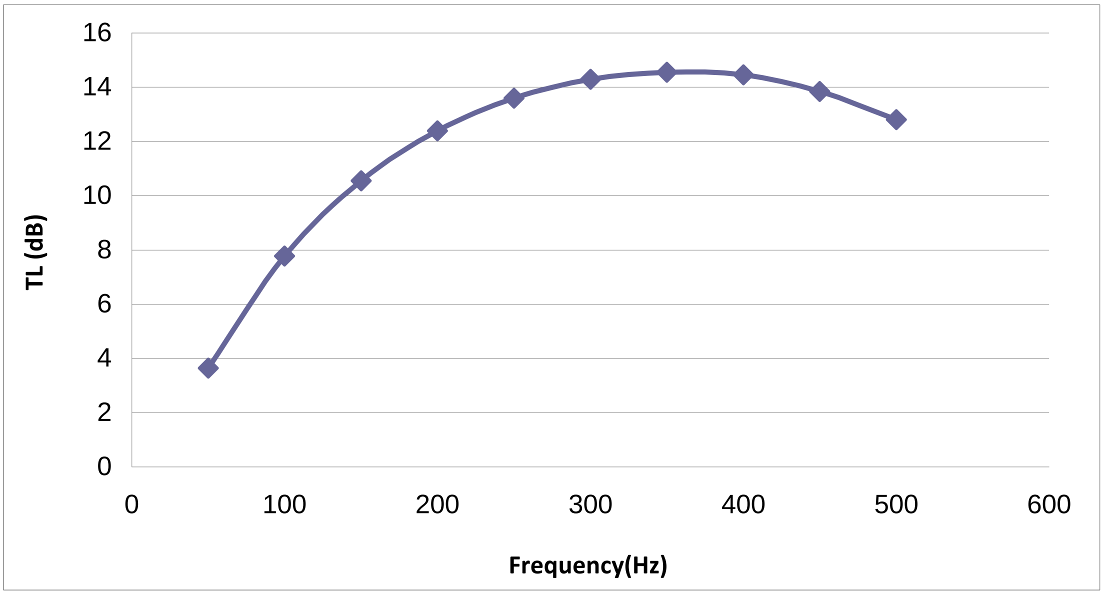


Figure (16): FrequencyVs. theoretical transmission losses

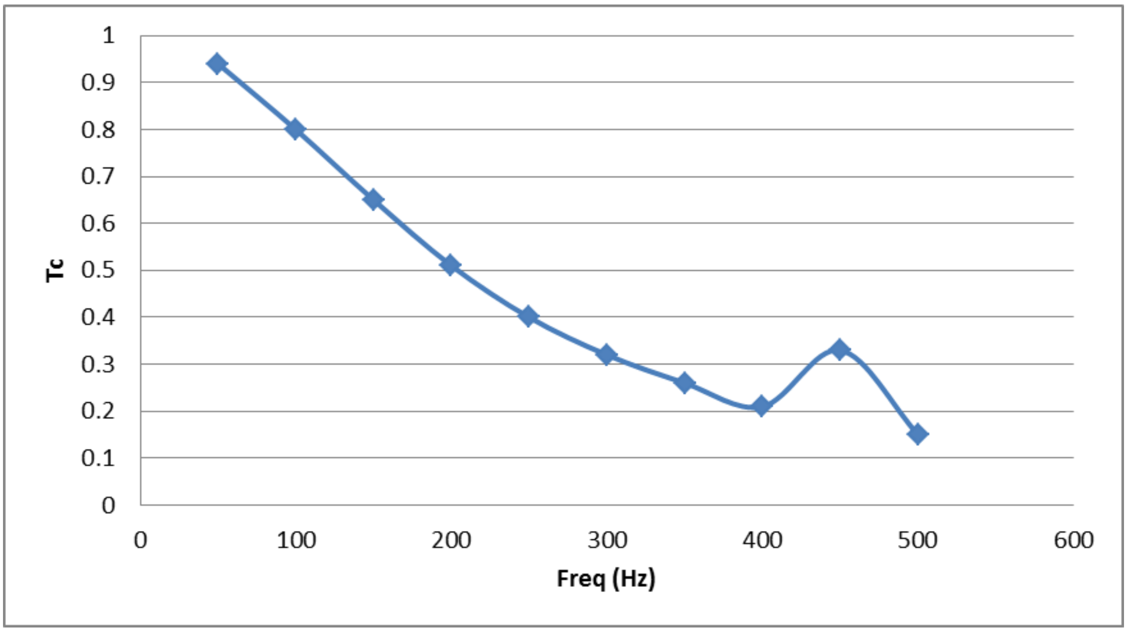


Figure (17):FrequencyVs. theoretical transmission coefficient

5. Conclusions:

From the above charts it is found that the muffler is capable of attenuating noise by about 9-18dBA in the first model and 9-19dB for the second and 11-21 dB for the third model which is the one with 30 cm inlet pipe. It is obvious that the taller outlet pipe the higher noise attenuation. When the inlet pipe length increased there is a small effect for about 2-3 dB while outlet pipe length increment from 10 to 20 to 30 give a range of 5 – 15 dB this fact realized to from charts in figures 12, 13 and 14. So it preferred to take this fact in consideration when designing the silencing system for a vehicle or I.C. Generators.

6. List of symbols:

Symbol	Definition
A & B	Real constants
C	Sound speed
D	Diameter of expansion chamber
d	Diameter of inlet pipe
k	Number of waves
L	Length of expansion chamber
m	Ratio of area of expansion chamber to area of inlet pipe
P_i	Incident pressure
P_r	Reflected wave pressure
s	Cross section area
U_i	Peak particle velocity
U_r	Reflected wave Peak particle velocity
Z	Acoustic impedance
Z_o	Acoustic impedance at x=0
α	Spatial absorption coefficient
γ	The ratio of air density at constant pressure to constant volume
ρ	Density
ω	Angular velocity

7. References:

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