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Computer Aided Simulation and Experimental Investigation of Absorptive-Reactive Exhaust Muffler for Transmission Loss and Back Pressure Analysis

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A B S T R A C T

Silencer or Mufflers are the device which is used to absorb the noise at certain extent which is released from the engine. The muffler used for the case study is actually been implemented in the diesel generator Manufactured by Cummins. The main purpose of the muffler is to reduce the noise and the pollutant emitting from the engine. This sound is absorbed or reduced by using the perforated materials which is called as Absorptive silencers. In the same way, if the muffler is given chambers, baffles and reflections, it is referred to as Reactive Muffler. In this project, the principle of Absorption and reflection is done to modify the baffle based reflective muffler. The drafting and prototype of the muffler is been done in PTC Creo Software. The Sound Flow Analysis is done using ANSYS. The Experimental Investigation explains the transmission, insertion and back pressure analysis for normal and modified muffler. The Decibel meter is used to measure the unwanted sound. The material for perforation is used as Glass Wool and and for reaction chamber mild steel plates and pipes are used. After the modification of Silencer, readings are taken for in simulation and experimentation. The results are achieved in the Simulation and Experimental approach. The Comparison of results are done which are obtained in both these approaches.

Keywords:Reactive Silencer, Absorptive Silencer, Transmission Loss, FEA analysis.

1. Introduction :

1.1. Mufflers :

The muffler – it's the last component of your exhaust system, yet first in the hearts of many "mod crazy" car enthusiasts. Always heard before seen (unless your muffler truly is whisper-quiet), the typical muffler does its job quietly and, quite literally, under the radar. So far under the radar, it's barely above the road.The muffler is one of the most changed, tweaked, modified, relocated, redesigned, rigged, repaired and ready-for-anything components. Experts enjoy engineering the muffler's design, and even amateurs aren't afraid of playing around with the muffler's position and performance. Muffler modifications don't involve just sound; there are certain changes that can actually increase your car's horsepower and engine efficiency, just by altering a few choice characteristics. This unsung hero – remember, it's not supposed to sing – is along for the ride for one reason: to keep your car's under-body audio hush-hush. It also has a huge responsibility. The muffler is the ultimate final filter. How important is the muffler? Well, consider its position in the grand scheme of things. It's the last component before all of your cars "input" becomes "output."

The main Functions of Muffler are -

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- Mufflers serve to keep the exhaust quiet to acceptable levels.
- Bear in mind that the combustion process is a series of explosions that produces allot of noise.
- Most mufflers use baffles to bounce the exhaust around sending off the energy and quieting the noise.
- Some mufflers also use fiberglass packing that absorbs the sound energy as the gases flow through.

1.2. Types of Muffler :

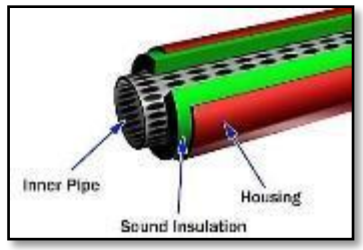

Figure 1: Absorptive Muffler

The first type is frequently chosen because of its low cost and because it causes a lower back pressure. It uses the absorption to reduce the sound energy. Sound waves are reduced as their energy is converted into heat in the absorptive material. In the absorptive muffler the exhaust noise is passed from straight pipe which are perforated and absorptive materials like glass fibres, steel wool are used to absorb the noise.Sound-absorbing materials absorb most of the sound energy striking them and reflect very little. Therefore, sound absorbing materials have been found to be very useful for the control of noise. They are used in a variety of locations: close to sources of noise (close to sources in electric motors, for example), in various paths (above barriers), and sometimes close to a receiver (inside earmuffs). A wide range of sound-absorbing materials exist; they provide absorption properties dependent upon frequency, composition, thickness, surface finish, and method of mounting. However, materials that have a high value of sound absorption coefficient are usually porous. A porous absorbing material is a solid that contains cavities, channels or interstices so that sound waves are able to enter through them. Porous absorbing materials can be classified as cellular, fibrous, or granular; on the basis of their microscopic configurations. Open-celled polyurethane and foams are examples of cellular materials. Fibrous materials generally consist of natural and synthetic fibers such as glass fibers and minerals and they also can be sometimes granular. Granular absorbing materials include some kinds of asphalt, porous concrete, granular clays, sands, gravel, and soils.

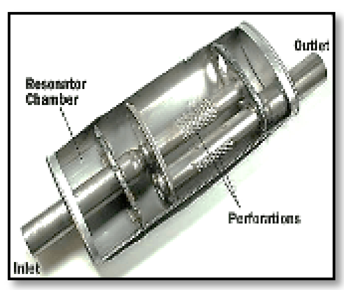

Figure 2: Reactive Mufflers

The second type of mufflers provides more attenuation referred as reactive muffler. The engine noise is reduced by the passing the exhaust from the various chambers in case of a reactive muffler. It generally consists of a series of a resonating and expansion chambers that are designed to reduce sound pressure level at certain frequencies.This type of muffler design uses only absorption of the sound wave to reduce the noise level without messing with the exhaust gas pressure. Ti is known as glass pack muffler and it reduces backpressure but producing higher noise. The sound produced by this type of muffler is much higher compared to the other type of mufflers.

Table 1 : Grades of Muffler for Absorption

No.	Grade	Transmission Loss (dB)	Body Diameter (Inch)	Body Length (Inch)
1	Commercial	15 to 25	2 to 2.5	5 to 6.5
2	Residential	20 to 30	3 to 4	6 to 10
3	Critical	25 to 35	4.5	8 to 12
4	Super Critical	35 to 45	4 to 5.5	10 to 16

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2. Problem Definition :

2.1. Losses In Muffler:

1. Transmission loss :

Transmission loss is a key quantification of the effectiveness of muffler for engineering application. Transmission loss indicates how much sound energy is prevented from travelling through a muffler. Transmission loss is the difference in the sound power level between the incident wave entering and the transmitted wave exiting the muffler when the muffler termination is anechoic. The transmission loss is a property of the muffler only. Calculation methods able to predict the transmission loss and the back pressure for a muffler with complex interior perforated ducts and baffles.

2. Insertion loss :

The insertion loss is the sound pressure level difference at a point, usually outside the system, without and with the muffler present. Though the insertion loss is very useful to industry, it is not so easy to calculate since it depends not only on the muffler geometry itself but also on the source impedance and the radiation impedance.

3. Backpressure :

Back pressure caused by the exhaust system muffler of an automotive four-stroke engine has a negative effect on engine efficiency resulting in a decrease of power output that must be compensated by increasing fuel consumption.

2.2. Problem Statements:

In industrial applications, such as Generators, compressors etc. engine operates at very high loads. Due to this loud noises are created which leads to noise pollution and several losses in the system.

- To avoid loud noises several types of mufflers are used.
- But due too much load the regular mufflers can't be that effective.
- The size of the muffler should be optimum so that it can be easily mounted upon the machine.
- The noise produced is to be minimized as much as possible.

2.3. Objectives:

- The objective of this project is to reduce the exhaust gas noise level.
- The performance of the muffler is assessed by analyzing exhaust gas flow pattern, length of expansion chamber.
- This project helps improve reduce the noise level and environmental noise pollution.

2.4. Methodology:

a. Study of Existing Muffler
b. Testing Existing Muffler
c. Study of Absorptive Principle
d. Study of Reflective Principle
e. Modification of Muffler
f. Simulation of Absorptive-Reflective Muffler
g. Experimentation of Modified Muffler
h. Experimental validation

3. Fabrication Of Muffler :

Figure 3: Three Different Views of Chamber

Chamber 1: It is reflective portion which is attached to the exit of Gen-set. It is the first portion where the Sound Enters. The Pipe is made of Galvanised material. The Pipe is enclosed with two round plates which are made of Mild Steel.
Chamber 2: It is the free space between the reflective and absorptive chamber. The chamber is followed by the absorptive chamber. The Main part of reflective chamber is pipes and Round Plate. It consists of Three pipes made of Mild Steel.
Chamber 3: It is absorptive chamber. It consists of the Perforation of internal diameter. The sheet is enrolled with thick covering of glass wool. The Absorptive section comes at the exit side of the muffler. The Perforated sheet is made of material sheet metal mild steel.

4. Experimental Setup :

In order to complete up the trail for Silencer, A prototype of model is prepared. The prototype is prepared by reducing the dimensions obtained in the design process by 1:2. Each and every dimension is reduced by half scale.

Figure 4 Prototype Trail Testing Generator

Table 1 Specification of trial gen-set:

Parameter	Specifications
Frequency (Hz)	50
Rated Output (VA)	2100 VA
Maximum Output (VA)	2400 VA
DC Output	Yes
Dry Weight (Kg)	94 Kg
L x W x H (mm)	985 x 471 x 723
Ignition System	TCI
Starting System	Recoil Starter
Fuel Tank Capacity (L)	15.5

5. Experimental Investigation for Transmission Loss :

Figure 5 Experimental Investigations for Transmission Loss

Transmission loss (TL) (more specifically in duct acoustics) is defined as the difference between the sound entering on a duct acoustic device (muffler) and that sound at the exit or transmitted downstream into an anechoic termination. The procedure and connection of experimentation for determining the transmission loss is described as below.

- Without application of Muffler (Normal Sound)
- Implementation of Absorptive Muffler.
- Implementation of Absorptive and Reflective Muffler.

Table 2 Experimental Readings of sound in dB

Trail No.	Normal Sound (dB)	Use of Absorptive Muffler (dB)	Use of Modified Muffler (dB)
1.	75.5	69.4	65.3
2.	75.6	68.9	63.4
3.	76.1	70.1	64.3
4.	77.4	69.5	65.5
5.	75.3	69.2	65.1
6.	75.9	68.8	64.9
7.	76.8	68.6	65.6
8.	75.8	69.5	64.9
9.	75.3	69.4	65.5
10.	76.4	69.4	65.9

Mathematically, Transmission Loss can be given as,
$TL = 10 \times Log_{10} [W_i/W_t]$
Where,
TL = Transmission Loss in dB
W_i = Sound Leaving the Engine in dB
W_t= Sound at the exit of Muffler.in dB

6. Experimental Setup for Back Pressure Measurement and Insertion Loss :

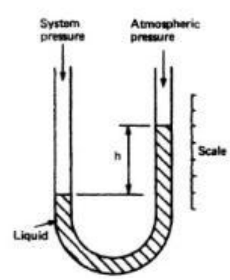

Figure 6 Experimental Setup forVertical U-Tube Manometers

The pressure difference in a vertical U-Tube manometer can be expressed as
$p = \rho g H$
Where,
P= pressure Developed in N/m^2 or Pa.
H = pressure Head
ρ_m = density of monomeric fluid of water = 1000 (kg/m^3)
ρ_a= Density of Working Fluid Air = 1.225 (kg/m^3)
g = acceleration of gravity (9.81 m/s^2)
x = Difference in the liquid height (m) = $h_1 - h_2$
h_1 = Height of Liquid in Left Limb
h_2 = Height of Liquid in Right Limb

Insertion loss (IL):

Insertion loss is defined as the difference between sound pressure levels of a silenced system and some reference system. The reference system is usually just a straight pipe of the diameter that is typical to the system in place of the muffler. This pipe should also be the same length of the muffler being tested. Insertion loss is calculated by Equation, Mathematically, Insertion Loss can be given as,
$IL = 20 \times Log[P_m/P_i]$
TL = Insertion Loss in dB
P_m = Sound Pressure at the Muffler
P_i = Sound Pressure at the insert of Muffler

Observations for Manometer Reading:

Table 3 Manometric Readings

Trail No.	Reading at Inlet (P_i)				Reading at Muffler(P_m)			
	h_1 (m)	h_2 (m)	x_i (h_1 - h_2) (m)	Eq. Height H_i	h_1 (mm)	h_2 (mm)	x_m (h_1 - h_2) (m)	Eq. Height H_m
1.	0.05	0.25	0.02	16.30	0.01	0.72	0.071	57.88
2.	0.03	0.32	0.029	23.64	0.02	0.69	0.067	54.62
3.	0.06	0.34	0.028	22.82	0.015	0.78	0.0765	62.37
4.	0.09	0.29	0.02	16.30	0.027	0.79	0.0763	62.20
5.	0.075	0.34	0.0265	21.60	0.021	0.81	0.0789	64.32
6.	0.08	0.36	0.028	22.82	0.022	0.77	0.0748	60.98
7.	0.1	0.3	0.02	16.30	0.029	0.8	0.0771	62.86
8.	0.085	0.28	0.0195	15.89	0.019	0.72	0.0701	57.15
9.	0.095	0.27	0.0175	14.26	0.02	0.76	0.074	60.33
10.	0.1	0.33	0.023	18.75	0.018	0.77	0.0752	61.31

7. Computational Fluid Dynamics :

Simulation approach involves the construction of an artificial environment within which relevant information and data can be generated. Simulation Stands for Computer Prototyping of the component. The purpose of the Simulation research strategy is to establish the existence of a cause- and- effect relationship between two parameters that is the experimentation and the objectives.

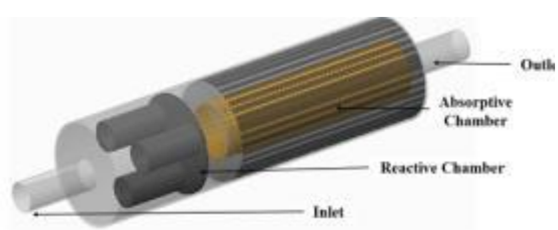

Figure 7: Prototype Model of Muffler

Experimental Investigation is the procedure carried out to support or validates a Problem statement, whereas simulation approach gives the other theoretical parameters which cannot be determined in the experimental approach or carry a costliest process for determining.From all the Dimensions that are determined in the Design Section, a prototype is prepared using the software Creo 2.0. The aim of simulation is to analyse the model or the component under actual experimental conditions on the basis of assumptions and the design parameters.

Computational Fluid Dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problem that involves fluid flow. CFD modelling is based on fundamental governing equations of fluid dynamics i.e. the conservation of mass, momentum, and energy. CFD helps to predict the fluid flow behaviour based on the mathematical modelling using software tools. It is now widely used and is acceptable as a valid engineering tool in the industry. For example; we are performing CFD for determining the back pressure and velocity of flow in the muffler. With the help of Computational Fluid Dynamics, it is very easy to use numerical methods to solve fundamental nonlinear differential equations that describe fluid flow for predefined geometries and boundary conditions. The result is a wealth of predictions for flow, velocity, temperature, density, and chemical concentrations for any region where flow occurs.

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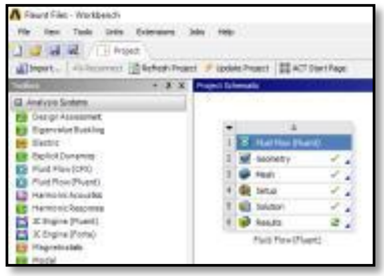


Figure 8 Ansys Fluent Section for CFX Analysis

As the Setup Proceeds towards the flow analysis, the first user interface of Setup Looks as shown in the figure above. Ansys provides general purpose, high-performance, automated, intelligent meshing software that produces the most appropriate mesh for accurate, efficient multiphysics solutions — from easy, automatic meshing to highly crafted mesh.

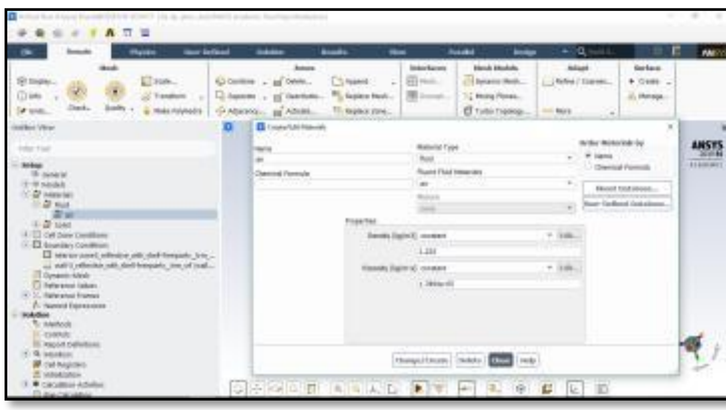


Figure 9 Properties of Flowing Material

Since ANSYS FLUENT always uses gauge pressure, you can simply set the operating pressure to zero, making gauge and absolute pressures equivalent. If the density is assumed constant or if it is derived from a profile function of temperature, the operating pressure is not used in the density calculation.

Inlet Temperature	: 581K
Air density	: 0.47 kg/m3
Specific heat at constant pressure	: 1071 J/Kg K
Kinetic viscosity	: 3.56e-6
Material	: Q235-Steel
Outlet (Relative pressure)	: 0 Pa
Wall	: No slip wall
Wall1	: Specified Shear wall with X-component

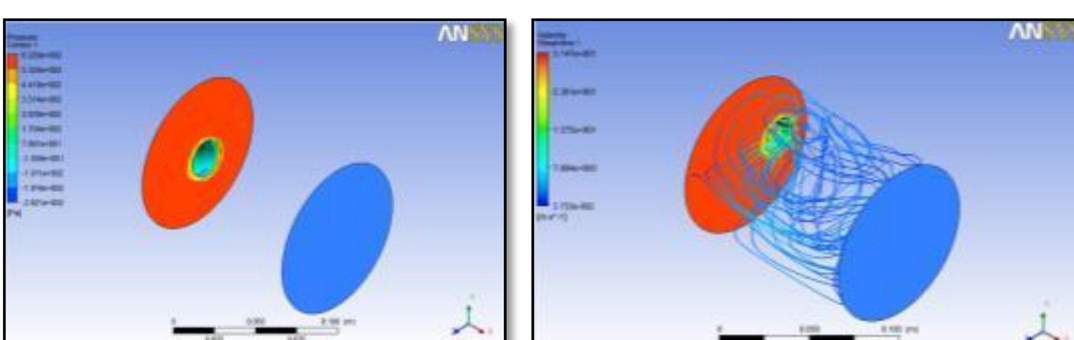


Figure 10 Pressure Distributions and Path Flow Analysis for Absorptive Chamber

The above figure shows the results for back pressure and Flow path analysis when the muffler is subjected with the Absorptive Porous Zone. The maximum Pressure to be generated is to be determined was 622 Pascal's which is also equal to 622 N/m2. The Maximum velocity of Attention is determined as 37.5 m/s

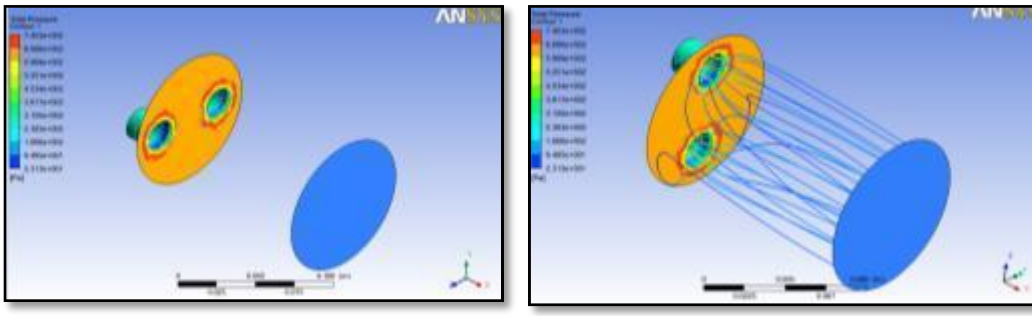


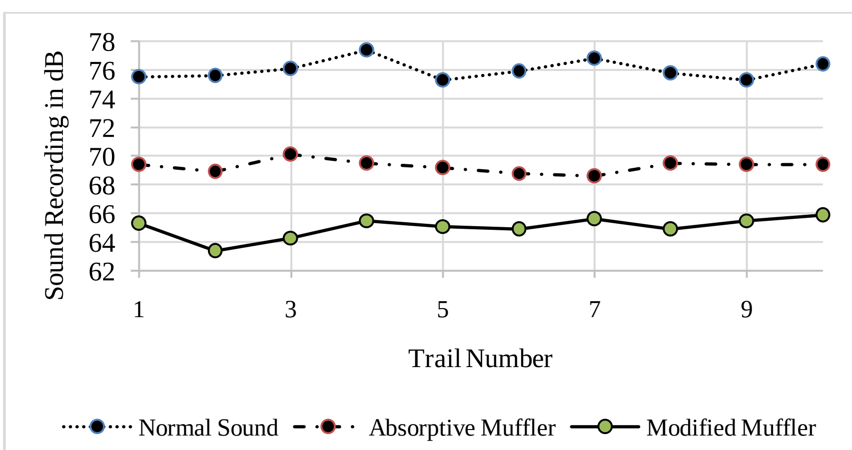
Figure 11 Pressure Distributions and Path Flow Analysis for Absorptive Chamber

The above figure shows the results for back pressure and Flow path analysis when the muffler is subjected with the Absorptive Porous Zone. The maximum Pressure to be generated is to be determined was 740 Pascal's which is also equal to 740 N/m2

8. Results and Discussion :

8.1. Noise Reduction Analysis :

We can see that, the output sound gradually goes on decreasing on the implementation of different unit of Muffler series. Hence the Mean values for all the trails can be set up as,



Graph 1 Comparison of Sound Wave Propagation for Different Mufflers

The Sound dB which results about 75db mean, reduced to 68 dB when absorptive chamber is used. Henceforth, when the modified combination of absorptive and reflective muffler is introduced the sound output decreased to 65 dB mean. The Sound is reduced upto 7 dB when implemented with Absorptive Muffler, and reduced with 11 dB with Absorptive-Reactive.

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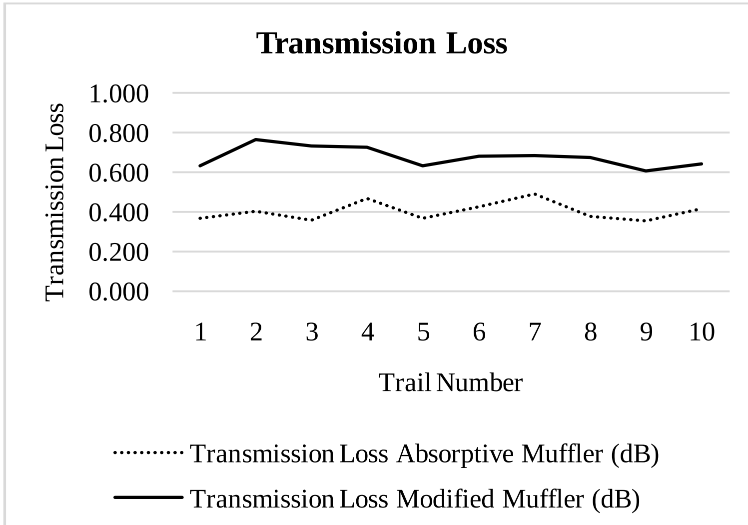
8.2. Analysis for Transmission :

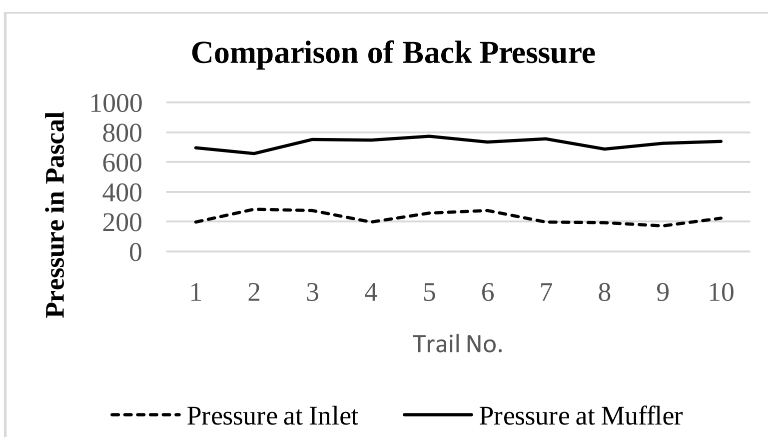


Graph 6.2 Comparison of Transmission Loss for Different Mufflers

The mean Transmission Loss in case of Absorptive Muffler is 0.4 dB whereas that in case of Modified Muffler is 0.677. Hence we can see that the transmission loss is increased up to 0.27 dB.

8.3. Back Pressure Analysis :

Back pressure (or backpressure) is a resistance or force opposing the desired flow of fluid through pipes, leading to friction loss and pressure drop.



Graph 3 Back Pressure Analysis

Engine exhaust back pressure is defined as the exhaust gas pressure that is produced by the engine to overcome the hydraulic resistance of the exhaust system in order to discharge the gases into the atmosphere. For this discussion, the exhaust back pressure is the gage pressure in the exhaust system at the outlet of the exhaust turbine in turbocharged engines or the pressure at the outlet of the exhaust manifold in naturally aspirated engines. The term back pressure can be also spelled as one word (backpressure) or using a hyphen (back-pressure).

9. Conclusions :

- The Prototype is prepared for Existing muffler and the Test has been carried out. Experimental Investigation of the transmission loss is to be done using diesel engine test rig for Calculations of Transmission loss, Muffler Volume, with respect to the experimental results.

- In this work, a case study describing the complete re-design of a muffler for a commercial gen-set has been presented.
- A preliminary prototype has been built with the aim to experimentally validate the results
- The acoustic behaviour of the existing system and of new solutions has been studied in the plane-wave sound range by means of transmission loss whose main benefits are the quick set-up and adjustment of the models and the low computational effort required to run the calculation.
- The muffler can be designed by various methods to achieve good performance. Combined muffler gives better reduction in noise compare to the single reactive muffler or absorptive muffler or combination of both.
- Noise reduction for single chamber is about 5dB whereas noise reduction for 2 Chamber is about 10 dB, therefore if number of chamber increases in muffler it gives better reduction in noise.
- More the number of chambers, more the reduction in noise. But increasing the number of chambers may also lead to the increase in the back pressure developed in chambers, which may increase the load on generator, thereby creating threat of damage to the gen-set.

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